United States Patent Application Publication	20250264728
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	LI; Qiming et al.

DISPLAY PANELS WITH AN INTEGRATED OFF-AXIS MICRO-LENS ARRAY

Abstract

A light emitting structure array system with a micro-lens array structure includes a first light emitting mesa, which includes a light emitting layer, a bottom bonding layer, a top electrode layer, and an insulation layer. The bottom bonding layer is at a bottom of the light emitting layer and bonded with the semiconductor substrate. The top electrode layer covers the first light emitting mesa and electrically connected with a reflective cup surrounding the first light emitting mesa. The reflective cup is electrically connected with a semiconductor substrate. The insulation layer covers a side wall of the light emitting layer. The light emitting structure array system with a micro-lens array structure further includes a first micro-lens formed above the light emitting mesa. A central axis of the first micro-lens is coaxially aligned with a central axis of the first light emitting mesa.

Inventors: **LI; Qiming (Albuquerque, NM), ZHU; Yuankun (Shanghai, CN), ZHAO; Shuang (Shanghai, CN)**

Applicant: **Jade Bird Display (Shanghai) Limited** (Shanghai, CN)

Family ID: **1000008578009**

Appl. No.: **19/190474**

Filed: **April 25, 2025**

Related U.S. Application Data

parent US continuation 18740686 20240612 PENDING child US 19190474
parent US continuation 17486113 20210927 parent-grant-document US 12038590 child US 18740686
us-provisional-application US 63083972 20200927

Publication Classification

Int. Cl.: **G02B27/09** (20060101)

U.S. Cl.:

CPC **G02B27/0961** (20130101); **G02B27/0922** (20130101);

Background/Summary

RELATED APPLICATION [0001] This application is a continuation application of U.S. patent application Ser. No. 18/740,686, filed on Jun. 12, 2024, entitled “DISPLAY PANELS WITH AN INTEGRATED OFF-AXIS MICRO-LENS ARRAY,” which claims priority to U.S. patent application Ser. No. 17/486,113, filed on Sep. 27, 2021, entitled “DISPLAY PANELS WITH AN INTEGRATED OFF-AXIS MICRO-LENS ARRAY,” which claims priority to U.S. Provisional Patent Application No. 63/083,972, filed Sep. 27, 2020, entitled “DISPLAY PANELS WITH AN INTEGRATED OFF-AXIS MICRO-LENS ARRAY.” The contents of the above patent applications are incorporated herein in their entirety by reference.

TECHNICAL FIELD
[0002] The present disclosure relates generally to display devices, and more particularly, to systems and fabrication methods for display panels integrated with an off-axis micro-lens array.
BACKGROUND
[0003] Display technologies are becoming increasingly important in today's commercial electronic devices. These display panels are widely used in stationary large screens such as liquid crystal display televisions (LCD TVs) and organic light emitting diode televisions (OLED TVs) as well as portable electronic devices such as laptop personal computers, smartphones, tablets and wearable electronic devices. Much of development for the stationary large screens is directed to achieve a high viewing angle in order to accommodate and enable multiple audiences to see the screen from various angles. For example, various liquid crystal materials such as super twisted nematic (STN) and film compensated super twisted nematic (FSTN) have been developed to achieve a large viewing angle of each and every pixel light source in a display panel.
[0004] However, most of the portable electronic devices are designed mainly for single users, and screen orientation of these portable devices should be adjusted to be the best viewing angle for the corresponding users instead of a large viewing angle to accommodate multiple audiences. For example, a suitable viewing angle for a user may be perpendicular to the screen surface. In this case, compared with stationary large screens, light emitted at a large viewing angle is mostly wasted. Additionally, large viewing angles raise privacy concerns for portable electronic devices used in public areas.
[0005] In addition, in a conventional projection system based on a passive imager device, such as liquid crystal display (LCD), digital mirror devices (DM D), and liquid crystal on silicon (LCOS), the passive imager device itself does not emit light. Specifically, the conventional projection system projects images by optically modulating collimated light emitted from a light source, i.e., by either transmitting, e.g., by an LCD panel, or reflecting, e.g., by a DM D panel, part of the light at the pixel level. However, the part of the light that is not transmitted or reflected is lost, which reduces the efficiency of the projection system. Furthermore, to provide the collimated light, complex illumination optics are used to collect divergent light emitted from the light source. The illumination optics not only cause the system to be bulky but also introduce additional optical loss into the system, which further impacts the performance of the system. In a conventional projection system, typically less than 10% of the illumination light generated by the light source is used to form the projection image.

[0006] Light emitting diode (LED) having the advantages of long service life, low energy consumption and others, is widely used in various fields. As the next generation's optical source, they are being used as the back light unit for mobile phones, digital devices, liquid crystal displays etc., and also as lightings for dashboards and tail lights of vehicles, traffic lights, and other general lightings. They are widely used in display fields including interior and exterior electric signs as well as in bio and environmental fields including water contamination and oxygen concentration in blood. The application range of LEDs continues to extend every year due to improvement of product performance and drop in production cost. To satisfy these needs, various researches are in progress. There are two main methods: enhancing internal quantum efficiency and enhancing external extraction efficiency. The internal quantum efficiency can be enhanced by increasing the recombination rate of electron-hole pairs, which emits lights in the active layer of LEDs, and decreasing the recombination rate of that, which does not emit lights. However, this method has some limit in its technology. On the other hand, active researches are going on now regarding the increase in external extraction efficiency. In order to overcome this problem, the micro-lens array is used to reduce one or more of scattering, internal reflection, wave guiding, absorption and the like.
[0007] LEDs made of semiconductor materials can be used in mono-color or full-color displays. In current displays that employs LEDs, the LEDs are usually used as the light source to provide the light to be optically modulated by, e.g., the LCD or the DM D panel. That is, the light emitted by the LEDs does not form images by itself. LED displays using LED panels including a plurality of LED dies as the imager devices have also been studied. In such an LED display, the LED panel is a self-emissive imager device, where each pixel can include one LED die (mono-color display) or a plurality of LED dies each of which represents one of primary colors (full-color display).
[0008] However, the light emitted by the LED dies is generated from spontaneous emission and is thus not directional, resulting in a large divergence angle. The large divergence angle can cause various problems in an LED display. For example, due to the large divergence angle, the light emitted by the LED dies can be more easily scattered and/or reflected in the LED display. The scattered/reflected light can illuminate other pixels, resulting in light crosstalk between pixels, loss of sharpness, and loss of contrast.
[0009] Furthermore, the direction of the light emitted out of every micro-lens in the conventional LED is same, thereby the lights can only focus on a plane and not on a single point, which limits the application fields of the LEDs. In addition, extra refraction optical structures are needed to be applied in the LED, causing light crosstalk between pixels, loss of sharpness and loss of contrast.

SUMMARY

[0010] There is a need for improved display designs that improve upon, and help to address the shortcomings of conventional display systems, such as those described above. In particular, there is a need for display panels with reduced viewing angle for better protection for user's privacy, better directional focus, or/and reduced light waste for reduced power consumption and reduced light interference between pixels with better images.
[0011] Various embodiments include a display panel with integrated micro-lens array. The display panel typically includes an array of pixel light sources (e.g., LEDs, OLEDs) electrically coupled to corresponding pixel driver circuits (e.g., FETs). The array of micro-lenses is aligned to the pixel light sources and positioned to reduce the divergence of light produced by the pixel light sources. The display panel may also include an integrated optical spacer to maintain the positioning between the micro-lenses and pixel driver circuits.
[0012] The micro-lens array reduces the divergence angle of light produced by the pixel light sources and the useable viewing angle of the display panel. This, in turn, reduces power waste, increases brightness and/or better protects user privacy in public areas.
[0013] A display panel with integrated micro-lens array can be fabricated using a variety of manufacturing methods, resulting in a variety of device designs. In one aspect, the micro-lens array is fabricated directly as mesas or protrusions of the substrate with the pixel light sources. In some

aspects, self-assembly, high temperature reflow, grayscale mask photolithography, molding/imprinting/stamping, and dry etching pattern transfer are techniques that can be used to fabricate micro-lens arrays.

[0014] Other aspects include components, devices, systems, improvements, methods and processes including manufacturing methods, applications, and other technologies related to any of the above.

[0015] The present disclosure provides a light emitting structure with an off-axis micro-lens, thereby the direction of the light out of the micro-lens can be changed without extra optical structures.

[0016] In some embodiments, the light emitting display with an off-axis micro-lens array, can control the light direction of every micro-lens, and light from different micro-lenses of the micro-lens array can focus on one point.

[0017] The present disclosure also provides a light detective device with an off-axis micro-lens array, and the light detective device can receive the light from a point. Furthermore, the non-parallel light from the point can be changed to parallel light through the micro-lens array. The parallel light can then enter into the sensor or another light detection unit.

[0018] In some embodiments, the present disclosure provides a light emitting structure comprising three micro-lenses. Thereby the brightness and/or sharpness of the light emitting display using the light emitting structure can be adjusted, and the useable viewing angle can be decreased.

[0019] Some exemplary embodiments of the present disclosure include a light emitting structure comprising three micro-lenses. For example, a first micro-lens may be formed above a first light emitting mesa, and a central axis of the first micro-lens is not coaxially aligned with a central axis of the first light emitting mesa. One part of the light emitted from the first light emitting area can directly arrive at and pass through the first micro-lens. A second micro-lens may be positioned on the second light emitting mesa and a third micro-lens may be positioned on the second micro-lens. One part of the light emitted from the second light emitting mesa can directly arrive at and pass through the second micro-lens. One part of the light passing through the second micro-lens may further arrive at and pass through the third micro-lens. As a consequence, the light path can be adjusted upon the relative position of the three micro-lenses. Therefore, the divergence can be reduced and the useable viewing angle can be decreased to the extent that displays and panels using LED devices may be seen by a user's view perpendicular to surfaces of the displays and panels. This, in turn, can reduce power waste and increase brightness and/or better protect user privacy in public areas.

[0020] In another example, the light emitting structure may further comprise one or more reflective cups, and the first light emitting mesa and the second light emitting mesa may be surrounded by the one or more reflective cups. One part of the light emitted from the first and second light emitting mesas can directly arrive at and pass through one or more of the three micro-lenses. Another part of the light emitted from the first and second light emitting mesas can arrive at and be reflected by the one or more reflective cups and then arrive at and pass through one or more of the three micro-lenses. As a result, more light emitted from the first and second light emitting mesas can be utilized, compared to the light emitting structure without any reflective cup. Therefore, the divergence can be reduced and the useable viewing angle can be decreased to the extent that displays and panels using the LED devices may be seen by several users. This can also reduce power waste, increase brightness and/properly protect user privacy in public areas.

[0021] In some embodiments, a light emitting structure includes a diffraction lens, thereby the brightness and/or sharpness of the light emitting display can be adjusted. Selective wavelength of the light may also be reflected by or pass through the diffraction lens.

[0022] Some exemplary embodiments of the present disclosure include a light emitting structure comprising a micro-lens formed on a light emitting mesa and a diffraction lens covering the micro-lens. The micro-lens may be aligned to the light emitting mesa and covered by the diffraction lens to reduce the divergence of the light emitting from the light emitting mesa. For example, the micro-

lens may be co-axially aligned to the light emitting mesa and covered by the diffraction lens. One part of the light emitted from the light emitting area can directly arrive at and pass through the micro-lens, and then selectively pass through the diffraction lens. Another part of the light emitted from the light emitting mesa may directly arrive at and selectively pass through the diffraction lens. One advantage of the disclosed light emitting structure is to enhance the brightness of the light emitting structure. Another advantage is to increase the contrast of the light emitting structure. Therefore, the divergence can be reduced and the useable viewing angle can be decreased to the extent that displays and panels using LED devices may be seen by a user's view perpendicular to surfaces of the displays and panels. This, in turn, can reduce power waste and increase brightness and/or better protects user privacy in public areas.
[0023] In another example, the micro-lens may be co-axially aligned to the light emitting area, positioned on the light emitting mesa, covered by the diffraction lens and surrounded by a reflective cup. Part of the light emitted from the light emitting area can directly arrive at and pass through the micro-lens and/or the diffraction lens. Another part of the light emitted from the light emitting center can arrive at and be reflected by the reflective cup and then arrive at and pass through the micro-lens and/or the diffraction lens. As a result, more light emitted from the light emitting mesa can be utilized, compared to the light emitting structure without the reflective cup. Therefore, the divergence can be reduced and the useable viewing angle can be decreased to the extent that displays and panels using the LED devices may be seen by several users. This can also reduce power waste, increase brightness and/properly protect user privacy in public areas.
[0024] The present disclosure thus includes, without limitation, the following exemplary embodiments.
[0025] Some exemplary embodiments of the present disclosure include a light emitting structure array system with an off-axis micro-lens array structure comprising: at least one light emitting mesa; and at least one micro-lens, formed above the light emitting mesa, wherein a central axis of the at least one micro-lens is not coaxially aligned with a central axis of the at least one light emitting mesa.
[0026] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the relative position of each micro-lens relative to a corresponding light emitting mesa in the light emitting structure array system are the same.
[0027] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure array system further includes a sensor, and emitting light rays from the at least one light emitting mesa through the at least one micro-lens is converted together into the sensor.
[0028] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the sensor is arranged at a central axis of the light emitting structure array system.
[0029] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, a respective offset distance of a central axis of a respective micro-lens relative to a central axis of a respective light emitting mesa becomes larger from the center of the light emitting structure array system to either edge of the light emitting structure array system.
[0030] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the sensor is not arranged at a central axis of the light emitting structure array system.
[0031] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, an offset distance of a central axis of a respective micro-lens relative to a central axis of a respective light emitting mesa becomes larger from a central axis of the sensor to either edge of the light emitting structure array system.
[0032] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, an angle of light emitted out of a respective micro-lens

becomes larger from a central axis of the sensor to either edge of the light emitting structure array system.

[0033] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the offset range of the central axis of the at least one micro-lens from the central axis of the at least one light emitting mesa is not more than 4.5 μm.

[0034] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the offset distance between an edge of a bottom surface of the at least one light emitting mesa and an edge of a bottom surface of the at least one micro-lens is within 30% of a diameter of the bottom surface of the at least one micro-lens.

[0035] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the material of the at least one micro-lens is silicon oxide or organic materials.

[0036] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the bottom surface of the at least one micro-lens intersects with the central axis of the at least one light emitting mesa.

[0037] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure array system further includes a semiconductor substrate and a reflective cup, and the at least one light emitting mesa is formed on the semiconductor substrate, and the at least one light emitting mesa is surrounded by the reflective cup.

[0038] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the inside wall of the reflective cup is stair-shaped.

[0039] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the at least one light emitting mesa includes: a light emitting layer, a bottom bonding layer, at the bottom of the light emitting layer and bonded with the semiconductor substrate, and a top electrode layer, covering the at least one light emitting mesa and electrically connected with the reflective cup. In some embodiments, the reflective cup is electrically connected with the semiconductor substrate.

[0040] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure array system further includes a spacer, formed between the at least one light emitting mesa and the at least one micro-lens.

[0041] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the height of the spacer is less than the height of the at least one micro-lens.

[0042] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure array system, the semiconductor substrate is an IC substrate.

[0043] Some exemplary embodiments of the present disclosure include a light emitting structure with at least one off-axis micro-lens that includes: a light emitting mesa; a first micro-lens, formed on the light emitting mesa; and, a second micro-lens, formed on the light emitting mesa and covering the first micro-lens.

[0044] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the diameter of the second micro-lens is larger than the diameter of the first micro-lens.

[0045] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, a central axis of the first micro-lens is coaxially aligned with a central axis of the light emitting mesa, and a central axis of the second micro-lens is not coaxially aligned with the central axis of the light emitting mesa.

[0046] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, a central axis of the second micro-lens is coaxially aligned with a central axis of the light emitting mesa, and a central axis of the first micro-lens is not coaxially aligned with the central axis of the light emitting mesa.

[0047] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, a central axis of the first micro-lens is not coaxially aligned with a central axis of the light emitting mesa, a central axis of the second micro-lens is not coaxially aligned with the central axis of the light emitting mesa, and, the central axis of the first micro-lens is not coaxially aligned with the central axis of the second micro-lens.
[0048] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the light emitting structure includes more than one set of light emitting mesa, first micro-lens and second micro-lens. In some embodiments, the position of a respective first micro-lens relative to a respective second micro-lens on the light emitting structure within a respective set is different.
[0049] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the offset distance between the central axis of the second micro-lens and the central axis of the light emitting mesa is not more than 12 μm.
[0050] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the offset distance between the central axis of the first micro-lens and the central axis of the light emitting mesa is not more than 1.5 μm.
[0051] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the offset distance between the central axis of the first micro-lens and the central axis of the second micro-lens is not more than 6 μm and is not less than 4.5 μm.
[0052] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the bottom surface of the second micro-lens intersects with the central axis of the light emitting mesa.
[0053] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the bottom surface of the first micro-lens intersects with the central axis of the light emitting mesa.
[0054] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the material of the first micro-lens is as same as the material of the second micro-lens.
[0055] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with at least one off-axis micro-lens further includes a semiconductor substrate and a reflective cup. In some embodiments, the light emitting mesa is formed on the semiconductor substrate, and the light emitting mesa is surrounded by the reflective cup.
[0056] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the inside wall of the reflective cup is stair-shaped.
[0057] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the light emitting mesa includes: a light emitting layer; a bottom bonding layer, at the bottom of the light emitting layer and bonded with the semiconductor substrate; and a top electrode layer, covering the light emitting mesa and electrically connected with the reflective cup, wherein the reflective cup is electrically connected with the semiconductor substrate.
[0058] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with at least one off-axis micro-lens further includes a spacer, formed between the light emitting mesa and the first micro-lens.
[0059] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the height of the spacer is less than that of the first micro-lens.
[0060] In some exemplary embodiments or any combination of exemplary embodiments of the

light emitting structure with at least one off-axis micro-lens, the semiconductor substrate is an IC substrate.
[0061] Some exemplary embodiments of the present disclosure include a light emitting structure with at least one off-axis micro-lens, comprising: a light emitting mesa; a first micro-lens, formed on the light emitting mesa; and, a second micro-lens, formed on the first micro-lens.
[0062] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the diameter of the second micro-lens is less than the diameter of the first micro-lens.
[0063] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, a central axis of the first micro-lens is coaxially aligned with a central axis of the light emitting mesa, and a central axis of the second micro-lens is not coaxially aligned with the central axis of the light emitting mesa.
[0064] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the light emitting structure includes more than one set of light emitting mesa, first micro-lens and second micro-lens. In some embodiments, a position of a respective first micro-lens relative to a respective second micro-lens on the light emitting structure within a respective set is different.
[0065] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the offset distance between the central axis of the second micro-lens and the central axis of the light emitting mesa is not more than 1.5 μm.
[0066] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the bottom surface of the first micro-lens intersects with the central axis of the light emitting mesa.
[0067] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the bottom surface of the second micro-lens does not intersect with the central axis of the light emitting mesa.
[0068] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the material of the first micro-lens is the same as the material of the second micro-lens.
[0069] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with at least one off-axis micro-lens further includes a semiconductor substrate and a reflective cup, wherein the light emitting mesa is formed on the semiconductor substrate, and the light emitting mesa is surrounded by the reflective cup.
[0070] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the inside wall of the reflective cup is stair-shaped.
[0071] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the light emitting mesa includes: a light emitting layer; a bottom bonding layer, at the bottom of the light emitting layer and bonded with the semiconductor substrate; and, a top electrode layer, covering the light emitting mesa and electrically connected with the reflective cup, wherein the reflective cup is electrically connected with the semiconductor substrate.
[0072] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with at least one off-axis micro-lens further includes a spacer, formed between the light emitting mesa and the first micro-lens.
[0073] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with at least one off-axis micro-lens, the height of the spacer is less than height of the first micro-lens.
[0074] In some exemplary embodiments or any combination of exemplary embodiments of the

light emitting structure with at least one off-axis micro-lens, the semiconductor substrate is an IC substrate.
[0075] Some exemplary embodiments of the present disclosure include a light emitting structure with an off-axis micro-lens structure, comprising: a first light emitting mesa; at least a first micro-lens, formed above the first light emitting mesa, wherein a central axis of the first micro-lens is not coaxially aligned with a central axis of the first light emitting mesa; a second light emitting mesa; at least a second micro-lens, formed above the second light emitting mesa; and at least a third micro-lens, formed on the second light emitting mesa.
[0076] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the third micro-lens covers and contacts a whole top surface of the second micro-lens.
[0077] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset range of the central axis of the first micro-lens from the central axis of the first light emitting mesa is not more than 4.5 μm.
[0078] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between an edge of the bottom surface of the first light emitting mesa and an edge of the bottom surface of the first micro-lens is within 30% of a diameter of the bottom surface of the first micro-lens.
[0079] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the material of the first micro-lens is silicon oxide or organic materials.
[0080] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the bottom surface of the first micro-lens intersects with the central axis of the first light emitting mesa.
[0081] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a semiconductor substrate and at least two reflective cups, wherein the first light emitting mesa, the second light emitting mesa are formed on the semiconductor substrate, and the first light emitting mesa and the second light emitting mesa are surrounded by a respective reflective cup of the two reflective cups.
[0082] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the inside walls of the reflective cups are stair-shaped.
[0083] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the first light emitting mesa includes: a first light emitting layer; a first bottom bonding layer, at a bottom of the first light emitting layer and bonded with the semiconductor substrate, and; a top electrode layer, at a top surface the first light emitting mesa and electrically connected with a first reflective cup of the two reflective cups. In some embodiments, the second light emitting mesa includes: a second light emitting layer; a second bottom bonding layer, at a bottom of the second light emitting layer and bonded with the semiconductor substrate; and the top electrode layer, also at a top surface of the second light emitting mesa and electrically connected with a second reflective cup of the two reflective cups, wherein the first and the second reflective cups are electrically connected with the semiconductor substrate.
[0084] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a spacer, covering the first light emitting mesa and the second light emitting mesa, wherein the spacer is formed between the first light emitting mesa and the first micro-lens, and the spacer is also formed between the second light emitting mesa and the second micro-lens.
[0085] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the height of the spacer is less than height of the first micro-lens.
[0086] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, diameter of the third micro-lens is larger than diameter of the second micro-lens.

[0087] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, a central axis of the second micro-lens is coaxially aligned with a central axis of the second light emitting mesa, and a central axis of the third micro-lens is not coaxially aligned with the central axis of the second light emitting mesa.
[0088] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, a central axis of the third micro-lens is coaxially aligned with a central axis of the second light emitting mesa, and a central axis of the second micro-lens is not coaxially aligned with the central axis of the second light emitting mesa.
[0089] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, a central axis of the second micro-lens is not coaxially aligned with a central axis of the second light emitting mesa, a central axis of the third micro-lens is not coaxially aligned with the central axis of the second light emitting mesa, and, the central axis of the second micro-lens is not coaxially aligned with the central axis of the third micro-lens.
[0090] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the light emitting structure includes more than one set of light emitting mesa, first micro-lens, second micro-lens, and third micro-lens. In some embodiments, a position of a respective second micro-lens relative to a respective third micro-lens on the light emitting structure within a respective set is different.
[0091] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between the central axis of the third micro-lens and the central axis of the second light emitting mesa is not more than 12 μm.
[0092] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between the central axis of the second micro-lens and the central axis of the second light emitting mesa is not more than 1.5 μm.
[0093] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between the central axis of the second micro-lens and the central axis of the third micro-lens is not more than 6 μm and is not less than 4.5 μm.
[0094] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the bottom surface of the third micro-lens intersects with a central axis of the second light emitting mesa.
[0095] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the bottom surface of the second micro-lens does not intersect with a central axis of the second light emitting mesa.
[0096] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the material of the second micro-lens is the same as the material of the third micro-lens, and, the material of the first micro-lens is the same as the material of the third micro-lens.
[0097] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between the central axis of the first micro-lens and the central axis of the first light emitting mesa is less than an offset distance between a central axis of the third micro-lens and a central axis of the second light emitting mesa.
[0098] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the semiconductor substrate is an IC substrate.
[0099] Some exemplary embodiments of the present disclosure include a light emitting structure, comprising: a first light emitting mesa; a first micro-lens, formed above the first light emitting mesa, wherein a central axis of the first micro-lens is not coaxially aligned with a central axis of the first light emitting mesa; a second light emitting mesa; a second micro-lens, formed above the second light emitting mesa; and a third micro-lens, formed on the second micro-lens, wherein the third micro-lens does not cover a whole top surface of the second micro-lens.
[0100] In some exemplary embodiments or any combination of exemplary embodiments of the

light emitting structure, the offset distance between the central axis of the first micro-lens and the central axis of the first light emitting mesa is not more than 4.5 μm.
[0101] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between an edge of a bottom surface of the first light emitting mesa and an edge of a bottom surface of the first micro-lens is within 30% of a diameter of the bottom surface of the first micro-lens.
[0102] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the material of the first micro-lens is silicon oxide or organic materials.
[0103] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the bottom surface of the first micro-lens intersects with the central axis of the first light emitting mesa.
[0104] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a semiconductor substrate and reflective cups, wherein the first light emitting mesa and the second light emitting mesa are formed on the semiconductor substrate, and wherein the first light emitting mesa and the second light emitting mesa are surrounded by a respective reflective cup.
[0105] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the inside wall of each of the reflective cups is stair-shaped.
[0106] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the first light emitting mesa includes: a first light emitting layer; a first bottom bonding layer, formed at a bottom of the first light emitting layer and bonded with the semiconductor substrate; a top electrode layer, covering the first light emitting layer and electrically connected with a first reflective cup of the reflective cups. In some embodiments, the second light emitting mesa includes: a second light emitting layer; a second bottom bonding layer, formed at a bottom of the second light emitting layer and bonded with the semiconductor substrate; the top electrode layer, also covering the second light emitting layer and electrically connected with a second reflective cup of the reflective cups, wherein the reflective cups are electrically connected with the semiconductor substrate.
[0107] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a spacer covering the first light emitting mesa and the second light emitting mesa, wherein the spacer is formed between the first light emitting mesa and the first micro-lens, and the spacer is also formed between the second light emitting mesa and the second micro-lens.
[0108] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the height of the spacer is less than the height of the first micro-lens.
[0109] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the horizontal dimension of the third micro-lens is less than the horizontal dimension of a bottom surface of the second micro-lens.
[0110] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, a central axis of the second micro-lens is coaxially aligned with a central axis of the second light emitting mesa, and a vertical axis of the third micro-lens is not coaxially aligned with the central axis of the second light emitting mesa, the vertical axis passing a center point of the third micro-lens when the third micro-lens is a complete shape.
[0111] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the light emitting structure includes more than one set of light emitting mesa, first micro-lens and second micro-lens. In some embodiments, a position of a respective first micro-lens relative to a respective second micro-lens on the light emitting structure within a respective set is different.
[0112] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between the vertical axis of the third micro-lens and the

central axis of the second light emitting mesa is not more than 1.5 μm.

[0113] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the bottom surface of the second micro-lens intersects with the central axis of the second light emitting mesa

[0114] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the bottom surface of the first micro-lens does not intersect with the central axis of the first light emitting mesa.

[0115] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the material of the second micro-lens is the same as the material of the third micro-lens, and the material of the first micro-lens is the same as the material of the second micro-lens.

[0116] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the offset distance between the central axis of the first micro-lens and the central axis of the first light emitting mesa is larger than the offset distance between the vertical axis of the third micro-lens and the central axis of the second light emitting mesa.

[0117] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the semiconductor substrate is an IC substrate.

[0118] Some exemplary embodiments of the present disclosure include a light emitting structure with coaxial micro-lenses, comprising: a light emitting mesa; a first micro-lens, formed on the light emitting mesa; and, a second micro-lens, covering and contacting the first micro-lens.

[0119] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the refractive index of the first micro-lens is higher than the refractive index of the second micro-lens.

[0120] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the material of the second micro-lens is different from the material of the first micro-lens.

[0121] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the first micro-lens has a hemisphere structure, and the second micro-lens has a polygon structure without carve-out of the first micro-lens or composite structure without carve-out of the first micro-lens.

[0122] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the composite structure is a combination of a hemisphere structure and a trapezoid structure or a hemisphere structure and a triangle structure.

[0123] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the trapezoid structure is formed at a bottom of the hemisphere structure, or, the triangle structure is formed at the bottom of the hemisphere structure.

[0124] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the polygon structure is a trapezoid structure having an inclined top surface relative to a bottom surface of the trapezoid structure.

[0125] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, a central axis of the first micro-lens and a central axis of the second micro-lens is coaxially aligned with a central axis of the light emitting mesa.

[0126] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with coaxial micro-lenses further includes a semiconductor substrate and a reflective cup, wherein the light emitting mesa is formed on the semiconductor substrate, and the light emitting mesa is surrounded by the reflective cup.

[0127] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the inside wall of the reflective cup is stair-shaped.

[0128] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the light emitting mesa includes: a light emitting layer; a bottom bonding layer, at the bottom of the light emitting layer and bonded with the semiconductor substrate, and; a top electrode layer, covering the light emitting mesa and electrically connected with the reflective cup, wherein the reflective cup is electrically connected with the semiconductor substrate.
[0129] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with coaxial micro-lenses further includes a spacer, formed above the light emitting mesa.
[0130] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the height of the spacer is less than the height of the first micro-lens or height of the second micro-lens.
[0131] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with coaxial micro-lenses, the semiconductor substrate is an IC substrate.
[0132] Some exemplary embodiments of the present disclosure include a light emitting structure with an elliptical micro-lens structure, comprising: a light emitting mesa; at least an elliptical micro-lens, formed above the light emitting mesa, wherein a central axis of the elliptical micro-lens is not coaxially aligned with a central axis of the light emitting mesa.
[0133] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the elliptical micro-lens is formed by a quarter of sphere combined with a quarter of ellipsoid.
[0134] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, a radius of the sphere is not more than 9 μm, and a long radius of the ellipsoid is not more than 18 μm.
[0135] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, an offset distance of a center of the elliptical micro-lens from a center of the light emitting mesa in the horizontal level is not more than 4.5 μm.
[0136] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the material of the elliptical micro-lens is silicon oxide or organic materials.
[0137] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the bottom surface of the elliptical micro-lens intersects with the central axis of the light emitting mesa.
[0138] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a semiconductor substrate and a reflective cup, wherein the light emitting mesa is formed on the semiconductor substrate, and the light emitting mesa is surrounded by the reflective cup.
[0139] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the inside wall of the reflective cup is stair-shaped.
[0140] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the light emitting mesa includes: a light emitting layer; a bottom bonding layer, at a bottom of the light emitting layer and bonded with the semiconductor substrate; and a top electrode layer, covering the light emitting mesa and electrically connected with the reflective cup, wherein the reflective cup is electrically connected with the semiconductor substrate.
[0141] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a spacer, formed between the light emitting mesa and the elliptical micro-lens.
[0142] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the height of the spacer is less than the height of the elliptical micro-lens.
[0143] In some exemplary embodiments or any combination of exemplary embodiments of the

light emitting structure, the height of the spacer is less than 5 μm.
[0144] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the semiconductor substrate is an IC substrate.
[0145] Some exemplary embodiments of the present disclosure include a light emitting structure with a micro-lens composite structure, comprising: a light emitting mesa; and a micro-lens composite structure. In some embodiments, micro-lens composite structure includes: at least a micro-lens, formed above the light emitting mesa; and, a reflective part, formed on one side of the micro-lens.
[0146] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the micro-lens is a sphere with a breach at a surface of the micro-lens.
[0147] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the reflective part is formed on a surface of the breach.
[0148] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the breach has an inclined surface relative to a bottom surface of the micro-lens, and, the reflective part is a plane structure attached on the inclined surface.
[0149] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the breach is a depression, and, the reflective part is attached to a surface of the depression.
[0150] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the material of the micro-lens is silicon oxide or organic materials.
[0151] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the bottom surface of the micro-lens intersects with a central axis of the light emitting mesa.
[0152] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with a micro-lens composite structure further includes a semiconductor substrate and a reflective cup, wherein the light emitting mesa is formed on the semiconductor substrate and the light emitting mesa is surrounded by the reflective cup.
[0153] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the inside wall of the reflective cup is stair-shaped.
[0154] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the light emitting mesa includes: a light emitting layer; a bottom bonding layer, at the bottom of the light emitting layer and bonded with the semiconductor substrate; and a top electrode layer, covering the light emitting mesa and electrically connected with the reflective cup, wherein the reflective cup is electrically connected with the semiconductor substrate.
[0155] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with a micro-lens composite structure further includes a spacer, formed between the light emitting mesa and the micro-lens.
[0156] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the height of the spacer is less than height of the micro-lens.
[0157] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with a micro-lens composite structure, the semiconductor substrate is an IC substrate.
[0158] Some exemplary embodiments of the present disclosure include a light emitting structure,

comprising: a light emitting mesa; a micro-lens formed on the light emitting mesa; and a diffraction lens covering the micro-lens.
[0159] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the material of the micro-lens is different from material of the diffraction lens.
[0160] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the diffraction lens is a Bragg mirror.
[0161] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the center point of a top surface of the diffraction lens is on the central axis of the micro-lens.
[0162] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, a central axis of the diffraction lens is inclined relative to a vertical axis perpendicular to a substrate of the light emitting structure and the central axis of the micro-lens is vertical relative to the vertical axis perpendicular to the substrate of the light emitting structure.
[0163] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the micro-lens has a hemisphere structure, and the diffraction lens has a polygon structure or a composite structure.
[0164] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the composite structure comprises a combination of a hemisphere structure and a trapezoid structure or a combination of a hemisphere structure and a triangle structure.
[0165] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the trapezoid structure is formed at a bottom of the hemisphere structure, or the triangle structure is formed at the bottom of the hemisphere structure.
[0166] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the polygon structure is a trapezoid structure comprising an inclined top surface relative to a bottom surface of the trapezoid structure.
[0167] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, a central axis of the micro-lens and an axis passing through a center point of a top surface of the diffraction lens are coaxially aligned with a central axis of the light emitting mesa.
[0168] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a semiconductor substrate and at least one reflective cup, wherein the light emitting mesa is formed on the semiconductor substrate, and the light emitting mesa is surrounded by the at least one reflective cup.
[0169] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the inside wall of the reflective cup is stair-shaped.
[0170] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the light emitting mesa includes: a light emitting layer; a bottom bonding layer at the bottom of the light emitting layer and bonded with the semiconductor substrate; and a top electrode layer, covering the light emitting mesa and electrically connected with the at least one reflective cup, and wherein the at least one reflective cup is electrically connected with the semiconductor substrate.
[0171] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure further includes a spacer covering the light emitting mesa.
[0172] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the height of the spacer is less than the height of the micro-lens.
[0173] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure, the semiconductor substrate is an IC substrate.
[0174] Some exemplary embodiments of the present disclosure include a light emitting structure with an off-axis micro-lens structure, comprising: a light emitting mesa; and at least a micro-lens,

formed above the light emitting mesa, wherein a central axis of the micro-lens is not coaxially aligned with a central axis of the light emitting mesa.
[0175] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the offset distance of the central axis of the micro-lens from the central axis of the light emitting mesa is not more than 4.5 μm.
[0176] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the offset distance between an edge of a bottom surface of the light emitting mesa and an edge of a bottom surface of the micro-lens is within 30% of a diameter of the bottom surface of the first micro-lens.
[0177] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the material of the micro-lens is silicon oxide or organic materials.
[0178] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the bottom surface of the micro-lens intersects with the central axis of the light emitting mesa.
[0179] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with an off-axis micro-lens structure further includes a semiconductor substrate and a reflective cup, wherein the light emitting mesa is formed on the semiconductor substrate, and the light emitting mesa is surrounded by the reflective cup.
[0180] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the inside wall of the reflective cup is stair-shaped.
[0181] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the light emitting mesa includes: a light emitting layer; a bottom bonding layer, at a bottom of the light emitting layer and bonded with the semiconductor substrate; and a top electrode layer, covering the light emitting mesa and electrically connected with the reflective cup, wherein the reflective cup is electrically connected with the semiconductor substrate.
[0182] In some exemplary embodiments or any combination of exemplary embodiments, the light emitting structure with an off-axis micro-lens structure further includes a spacer, formed between the light emitting mesa and the micro-lens.
[0183] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the height of the spacer is less than the height of the micro-lens.
[0184] In some exemplary embodiments or any combination of exemplary embodiments of the light emitting structure with an off-axis micro-lens structure, the semiconductor substrate is an IC substrate.
[0185] The design of the display devices and systems disclosed herein results in reduced viewing angle and reduced light interference that improve the light emission efficiency, resolution, and overall performance of the display systems. Thus, implementation of the display systems with micro-lens arrays can better satisfy the display requirements for Augmented Reality (AR) and Virtual Reality (VR), heads-up displays (HUD), mobile device displays, wearable device displays, high definition projectors, and automotive displays as compared with the use of conventional displays.
[0186] Note that the various embodiments described above can be combined with any other embodiments described herein. The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and

instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0187] So that the present disclosure can be understood in greater detail, a more particular description may be had by reference to the features of various embodiments, some of which are illustrated in the appended drawings. The appended drawings, however, merely illustrate pertinent features of the present disclosure and are therefore not to be considered limiting, for the description may admit to other effective features.

[0188] For convenience, “up” is used to mean away from the substrate of a light emitting structure, “down” means toward the substrate, and other directional terms such as top, bottom, above, below, under, beneath, etc. are interpreted accordingly.

[0189] FIG. **1**A illustrates a cross-sectional view of an exemplary light emitting structure, according to some embodiments.

[0190] FIG. **1**B illustrates a fabrication method to form a display panel integrated with a micro-lens array using top down pattern transfer, according to some embodiments.

[0191] FIG. **1**C illustrates a fabrication method to form a display panel integrated with a micro-lens array using top down pattern transfer, according to some embodiments.

[0192] FIGS. **2**A-**2**C each illustrate a cross-sectional view of some exemplary embodiments of the reflective cups, according to some embodiments.

[0193] FIG. **3** illustrates a cross-sectional view of an exemplary structure of the light emitting mesa on the substrate in FIG. **1**A, in accordance with some embodiments.

[0194] FIG. **4** illustrates a cross-sectional view of an exemplary light emitting structure with an array of micro-lenses and light emitting mesas, according to some embodiments.

[0195] FIG. **5** is a top view of a light emitting structure array system of off-axially arranged light emitting mesas and micro-lenses, according to some embodiments.

[0196] FIG. **6** illustrates a cross-sectional view of a light emitting structure array system with a sensor located at a center position above the light emitting structure array system, according to some embodiments.

[0197] FIG. **7** illustrates a cross-sectional view of a light emitting structure array system with a sensor located at a side or non-central position above the light emitting structure array system, according to some embodiments.

[0198] FIG. **8** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0199] FIGS. **9**A-**9**D illustrate some exemplary simulation results for the light exiting from the big micro-lens from the light emitting structure shown in FIG. **8**, according to some embodiments.

[0200] FIG. **10** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0201] FIGS. **11**A-**11**E illustrate some exemplary simulation results for the light exiting from the big micro-lens from the light emitting structure shown in FIG. **10**, according to some embodiments.

[0202] FIG. **12** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0203] FIG. **13** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0204] FIGS. **14**A-**14**B illustrate some exemplary simulation results for the light exiting from the big micro-lens from the light emitting structure shown in FIG. **13**, according to some embodiments.

[0205] FIG. **15** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0206] FIG. **16** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0207] FIG. **17** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0208] FIG. **18** illustrates a cross-sectional view of an exemplary light emitting structure having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0209] FIG. **19** illustrates a cross-sectional view of an exemplary light emitting structure having at least two micro-lens and light emitting mesa pairs, and at least one of the pairs has a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0210] FIG. **20** illustrates a cross-sectional view of an exemplary light emitting structure having at least two micro-lens and light emitting mesa pairs, and at least one of the pairs has a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments.

[0211] FIG. **21** illustrates a cross-sectional view of an exemplary light emitting structure having at least one micro-lens group and light emitting mesa pair, according to some embodiments.

[0212] FIG. **22** illustrates a cross-sectional view of an exemplary light emitting structure having at least one micro-lens group and light emitting mesa pair, according to some embodiments.

[0213] FIG. **23** illustrates a cross-sectional view of an exemplary light emitting structure having at least one micro-lens group and light emitting mesa pair, according to some embodiments.

[0214] FIG. **24** illustrates a cross-sectional view of an exemplary light emitting structure having at least one micro-lens group and light emitting mesa pair, according to some embodiments.

[0215] FIG. **25** illustrates a cross-sectional view of an exemplary light emitting structure having at least one micro-lens group and light emitting mesa pair, according to some embodiments.

[0216] FIG. **26** illustrates a cross-sectional view of an exemplary light emitting structure having at least one micro-lens and light emitting mesa pair, according to some embodiments.

[0217] FIG. **27** illustrates a cross-sectional view of an exemplary light emitting structure having at least two micro-lens and light emitting mesa pairs, and at least one of the micro-lenses has a breach portion covered by a reflective part, according to some embodiments.

[0218] FIG. **28** is a top view of a micro LED display panel, in accordance with some embodiments.

[0219] In accordance with common practice, the various features illustrated in the drawings may not be drawn to scale. Accordingly, the dimensions of the various features may be arbitrarily expanded or reduced for clarity. In addition, some of the drawings may not depict all of the components of a given system, method or device. Finally, like reference numerals may be used to denote like features throughout the specification and figures.

DETAILED DESCRIPTION

[0220] Numerous details are described herein in order to provide a thorough understanding of the example embodiments illustrated in the accompanying drawings. However, some embodiments may be practiced without many of the specific details, and the scope of the claims is only limited by those features and aspects specifically recited in the claims. Furthermore, well-known processes, components, and materials have not been described in exhaustive detail so as not to unnecessarily obscure pertinent aspects of the embodiments described herein.

[0221] As discussed above, in some examples, LED dies have a large divergence angle, which can cause various problems such as those discussed in the Background section. Moreover, in a projection system employing an LED array having a plurality of LED dies as a self-emissive imager device, a projection lens or a projection lens set is needed to project the image generated by the LED array, and the projection lens may have a limited numerical aperture. Thus, due to the large divergence angle of the LED dies, only a portion of the light emitted by the LED dies can be collected by the projection lens. This reduces the brightness of the LED-based projection system and/or increases the power consumption.

[0222] Embodiments consistent with the disclosure include an integrated display panel as a self-emissive imager device, including a substrate with an array of pixel driver circuits, an array of mesas which can include, for example, LED dies, formed over the substrate, and an array of micro-lens formed over the array of mesas, and methods of making the display panel. The display panel and projection systems based on the display panel combine the light source, the image forming function, and the light beam collimation function into a single monolithic device and are capable of overcoming the drawbacks of conventional projection systems. Furthermore, direction and focus of the light from the LEDs can be adjusted individually on each of the micro-lens group and light emitting mesa pairs formed on the display panel.

[0223] FIG. **1**A illustrates a cross-sectional view of an exemplary light emitting structure **100**, according to some embodiments. For convenience, “up” is used to mean away from the substrate **110**, “down” means toward the substrate **110**, and other directional terms such as top, bottom, above, below, under, beneath, etc. are interpreted accordingly. The light emitting structure **100** comprises a light emitting mesa **101**, as shown in FIG. **1**A within the dashed line rectangle. In some embodiments, the light emitting mesa **101** includes at least one single pixel light emitting device, such as an LED or a micro-LED, or an OLED, and light is emitted from the light emitting mesa **101**. The light emitting mesa **101** has a top surface and a bottom surface. In some embodiments, the diameter or width of the top surface of the light emitting mesa **101** is in the range of 1 μm-8 μm, and the diameter or width of the bottom surface of the light emitting mesa **101** is in the range of 3 μm-10 μm. In some embodiments, the diameter or width of the top surface of the light emitting mesa **101** is in the range of 8 μm-25 μm, and the diameter or width of the bottom surface of the light emitting mesa **101** is in the range of 10 μm-35 μm. In some embodiments, the height of the light emitting mesa **101** is in the range of 1-10 μm. In some embodiments, the height of the light emitting mesa **101** is about 1.3 μm. In some embodiments, the diameter or width of the top surface of the light emitting mesa **101** is equal or more than the diameter or width of the bottom surface of the light emitting mesa **101**.

[0224] In some embodiments, a display panel includes an array of single pixel light emitting devices, such as the light emitting mesa **101**. In some embodiments, the distance between center axes of the two adjacent light emitting mesas is in the range of 1 μm-10 μm. In some embodiments, the distance between center axes of the two adjacent light emitting mesas may vary from about 40 μm, to about 20 μm, to about 10 μm, and/or to about 5 μm or below. In some embodiments, sizes of the mesas and distances between the light emitting mesas may depend on the resolution of the display. For example, for a display panel with 5000 Pixels Per Inch (PPI), the diameter or width of the top surface of the light emitting mesa **101** is 1.5 μm and the diameter or width of the bottom surface of the light emitting mesa **101** is 2.7 μm. In some embodiments, the distance between the closest bottom edges of two adjacent light emitting mesas may be in the range of 1 μm-10 μm. In some embodiments, the distance between the closest bottom edges of two adjacent light emitting mesas is 2.3 μm.

[0225] In some exemplary embodiments, the light emitting structure **100** further comprises a micro-lens. As shown in FIG. **1**A, the light emitting structure **100** may comprise a micro-lens **102** formed above the light emitting mesa **101**. In some embodiments, the micro-lens **102** is positioned relative to the light emitting mesa **101**, and to reduce the divergence of the light emitting from the light emitting mesa **101** and decrease usable viewing angle from the single pixel LED device. As shown in FIG. **1**A, the micro-lens **102** has a vertical central axis A-A′, and the light emitting mesa **101** has a vertical central axis B-B′. The vertical central axis is perpendicular to the surface of the substrate **110**. The central axis may refer to a straight line passing any two center points of a figure. For example, the central axis of the micro-lens **102** (i.e., the central axis A-A′) passes through the center point of the top surface of the micro-lens **102** and the center point of the bottom surface of the micro-lens **102**.

[0226] In some embodiments, the micro-lens **102** is off-axially stacked on the light emitting mesa **101**, i.e., the central axis A-A′ of the micro-lens **102** is not coaxially aligned with, does not overlap or coincide with the central axis B-B′ of the light emitting mesa **101**. In some embodiments, the horizontal distance between the central axis A-A′ of the micro-lens **102** and central axis B-B′ of the light emitting mesa **101** is at least 1 μm, 2 μm, 5 μm or 10 μm. In some embodiments, the horizontal distance between the central axis A-A′ of the micro-lens **102** and central axis B-B′ of the light emitting mesa **101** is no more than 4.5 μm. In some instances, the horizontal offset distance may be less than half of the diameter of the bottom surface of the light emitting mesa **101**, less than a quarter of the diameter of the bottom surface of the light emitting mesa **101**. Therefore, the divergence can be reduced and the usable viewing angle can be decreased to the extent that displays and panels using the single pixel LED devices may be seen by several users. This can also reduce power waste, increase brightness and/properly protect user privacy in public areas.

[0227] In some other embodiments (not shown in FIG. **1**A), micro-lens **102** is co-axially aligned to the light emitting mesa **101** along the A-A′ direction, and the horizontal distance between the central axis A-A′ of the micro-lens **102** and central axis B-B′ of the light emitting mesa **101** is 0. All of the light emitted from the light emitting mesa **101** can directly arrive at and pass through the micro-lens **102**. Therefore, the divergence can be reduced and the useable viewing angle can be decreased to the extent that displays and panels using the single pixel LED devices may be seen by a user's view perpendicular to surfaces of the displays and panels when the central axis A-A′ of the micro-lens **102** and central axis B-B′ of the light emitting mesa **101** are the same. This, in turn, can reduce power waste and increase brightness and/or better protect user privacy in public areas. In another example, a part of the light emitted from the light emitting mesa **101** can directly arrive at and pass through the micro-lens **102**, and another part of the light emitted from the light emitting center can pass around or bypass the micro-lens **102**. Thus, the brightness of the light emitting structure can be adjusted.

[0228] In some embodiments, the structure of the micro-lens may include one element with one plane surface and one convex surface. For example, as shown in FIG. **1**A, the structure of the micro-lens **102** may be hemisphere. The structure of the micro-lens **102** may also be semi-ellipsoid, semi-oval, or other single element with one plane surface and one convex surface. In some embodiments, the structure of the micro-lens **102** may also be a polygon structure or a composite structure. For example, the composite structure may comprise a hemisphere and a cylinder positioned under the plane surface of the hemisphere. For another example, the composite structure may be formed by a quarter of sphere combined with a quarter of ellipsoid. In this example, the radius of the sphere may not be more than 9 μm and the long radius of the ellipsoid may not be more than 18 μm. Yet in some embodiments, the micro-lens may have a triangular or rectangular footprint while having a curved surface.

[0229] In some embodiments, the micro-lens may further include a reflective part which can adjust the light path. For example, the micro-lens **102** may include an inclined surface formed on one side of the surface of the micro-lens **101** and the reflective part may be formed on the inclined surface. In one example, the reflective part may be a plane attached to the inclined surface. In another example, the reflective part may be a curved or wavy surface.

[0230] In some embodiments, the material of the micro-lens may comprise inorganic or plastic (organic) materials that are transparent to the light emitted from the light emitting structure **100**. For example, the preferred material of the micro-lens **102** may be silicon oxide. In some embodiments, the inorganic materials include silicon oxide, silicon nitride, silicon carbide, titanium oxide, zirconium oxide, aluminum oxide, Phosphosilicate glass (PSG), or Borophosphosilicate glass (B PSG), or any combination thereof. In some embodiments, the plastic materials include polymers such as SU-8, PermiNex, Benzocyclobutene (BCB), or transparent plastic (resin) including spin-on glass (SOG), or bonding adhesive Micro Resist BCL-1200, or any combination thereof.

[0231] In some embodiments, micro-lenses composed of inorganic or organic materials are formed by patterning with a mask, a photolithography process, and then etching. In some embodiments, micro-lenses composed of organic materials are formed by patterning with a mask, a photolithography process, and then a reflow process at a high temperature.

[0232] In some embodiments, a first method for fabricating a micro-lens includes a step of depositing a micro-lens material layer directly on at least the top of the pixel light source and in direct physical contact with the pixel light source. In some embodiments, the shape of the micro-lens material layer is conformed to the shape of the pixel light source and forms a hemisphere on the pixel light source. In some embodiments, the top of the pixel light source is generally flat and the shape of the formed micro-lens **102** is generally hemispheric. In some embodiments, the micro-lens material layer is deposited on the surface of the pixel light source, such as the planarized surface of the single pixel tri-color LED device, directly by chemical vapor deposition (CV D) technology. In some embodiments, the deposition parameters for the CV D process are: the power is about 0 W to about 1000 W, the pressure is about 100 milli-torr to about 2000 milli-torr, the temperature is around 23° C. to around 500° C., the gas flow is about 0 to about 3000 sccm (standard cubic centimeters per minute), and the time is about 1 hour to about 3 hours. In some embodiments, the material of the micro-lens material layer is a dielectric material such as silicon dioxide.

[0233] In some embodiments, the first method for fabricating a micro-lens further includes a step of patterning the micro-lens material layer to expose the electrode area of the substrate. In some embodiments, the step of patterning the micro-lens material layer includes an etching step. In some embodiments, the etching step includes a step of forming a mask on the surface of the micro-lens material. The etching step also includes a step of patterning the mask via a photolithography process, thereby forming openings in the mask and exposing the micro-lens material layer above the electrode area of the pixel light source. The etching step further includes a step of etching the portions of the micro-lens material layer exposed by the openings with the mask protection in place. In some embodiments, the exposed micro-lens material layer is etched by a wet etching method.

[0234] In some embodiments, a second method for fabricating a micro-lens also includes an optional step of forming a mark layer with marks for aligning to the micro-lens material layer deposited in later steps. For example, the mark layer is formed to align the units of the light emitting pixels to the micro-lens material layer in order to form the micro-lens at the center of the pixel light source. In some embodiments, the mark layer is formed to align the pixel light source to the layers above it especially the micro-lens material layer in order to form the micro-lens on the top of the pixel light source.

[0235] The second method for fabricating a micro-lens further includes a step of depositing a micro-lens material layer directly on at least the top of one pixel light source. FIGS. **1**B-**1**C further show a fabrication method to form a display panel integrated with a micro-lens array using top down pattern transfer, according to some embodiments. In some embodiments, the micro-lens material layer **1145** covers the top of the pixel light source **1106**M as shown in FIG. **1**B and the top surface of the micro-lens material layer **1145** is flat. In some embodiments, the micro-lens material layer **1145** is deposited on the top of the pixel light source array **1106** by spin coating. In some embodiments, the material of the micro-lens material layer **1145** is photoresist. In some embodiments, the material of the micro-lens material layer **1145** is dielectric material such as silicon oxide.

[0236] The second method for fabricating a micro-lens further includes a step of patterning the micro-lens material layer from the top down, thereby forming at least a hemisphere in the micro-lens material layer as shown in FIGS. **1**B-**1**C. In some embodiments, the patterning is carried out without passing through or etching to the bottom of the micro-lens material layer **1145**. In some embodiments, the hemisphere of the micro-lens **1120** is placed above at least one pixel light source **1106**M.

[0237] In some embodiments, the step of patterning the micro-lens material layer from the top down further includes a first step of depositing a mask layer **1130** on the surface of the micro-lens material layer **1145** as shown in FIG. **1**B.

[0238] The step of patterning the micro-lens material layer from the top down also includes a second step of patterning the mask layer **1130** to form a hemisphere pattern in the mask layer **1130**. In some examples, the mask layer **1130** is patterned by a photolithography process firstly and then a reflowing process. In some embodiments, the photo-sensitive polymer mask layer **1130** is patterned into isolated cells **1140**, as shown in FIG. **1**B in dotted rectangle cells, to prepare for the formation of the hemisphere pattern. As one example, the isolated cells **1140** are patterned and formed via a photo-lithography process. The patterned photo-sensitive polymer mask layer **1150** with the isolated cells **1140** is then shaped into hemisphere pattern **1160** using high temperature reflow process. In one approach, the isolated cells **1140** are formed into isolated hemisphere pattern **1160** via high temperature reflow. In some embodiments, the isolated hemisphere pattern **1160** of one pixel is not in direct physical contact with a hemisphere pattern of an adjacent pixel. In some embodiments, the hemisphere pattern **1160** of one pixel only contacts with a hemisphere pattern of an adjacent pixel at the bottom of the hemisphere pattern **1160**. The patterned photo-sensitive polymer mask layer **1150** is heated to a temperature above the melting point of the polymer material for a certain time. After the polymer material melts into a liquefied state, the surface tension of the liquefied material will render it into a shape with a smooth curvature surface. For a cell with a round base of a radius R when the height of the cell is 2R/3, a hemispherical shape/pattern will be formed after the reflow process. FIG. **1**B shows a display panel integrated with the array of hemisphere patterns **1160** after the high temperature reflow process is finished. In some embodiments, the hemisphere pattern in the mask layer can be formed by other fabrication method including the fabrication method for the micro-lens described in the first method for fabricating a micro-lens. In some other embodiments, the hemisphere pattern in the mask layer can be formed using grayscale mask photolithography exposure. In some other embodiments, the hemisphere pattern in the mask layer can be formed via a mold/imprinting process.

[0239] The step of patterning the micro-lens material layer from the top down further includes a third step of using the hemisphere pattern **1160** as a mask, etching the micro-lens material layer **1145** to form the hemisphere in the micro-lens material layer **1145**. In some examples, etching the micro-lens material layer **1145** is by a photolithography process. In some examples, etching the micro-lens material layer **1145** is by a dry etching such as plasma etching process **1135** as shown in

FIG. **1**B. In some embodiments, after the micro-lens material layer **1145** is etched, the micro-lens material layer **1145** is not etched through to expose the top surface of the pixel light source **1106**M as shown in FIGS. **1**B-**1**C, thereby a spacer **1170** is formed on the top of the pixel light source **1106**M or covering the top of the pixel light source **1106**M as shown in FIG. **1**C.

[0240] The second method for fabricating a micro-lens further includes a step of patterning the micro-lens material layer to expose the electrode area (not shown in FIG. **1**C) of the substrate. In some embodiments, the step of patterning the micro-lens material layer includes an etching step. In some embodiments, the etching step includes a step of forming a mask on the surface of the micro-lens material. The etching step also includes a step of patterning the mask via a photolithography process, thereby forming openings in the mask and exposing the micro-lens material layer above the electrode area of the pixel light source. The etching step further includes a step of etching the exposed micro-lens material layer with the mask protection. In some embodiments, the exposed micro-lens material layer is etched by a wet etching method. In some embodiments, the opening for an electrode is positioned outside the display array area.

[0241] As described above, FIGS. **1**B to **1**C show various fabrication methods to form a display panel integrated with a micro-lens array. It should be understood that these are merely examples, and other fabrication techniques can also be used.

[0242] Although the detailed description contains many specifics, these should not be construed as limiting the scope of the invention but merely as illustrating different examples and aspects of the invention. It should be appreciated that the scope of the invention includes other embodiments not discussed in detail above. For example, micro-lenses with different shape bases may also be used, such as square base or other polygon base.

[0243] In some exemplary embodiments, the light emitting structure **100** may further comprise a spacer covering the light emitting mesa. For example, as shown in FIG. **1**A, the light emitting structure **100** may comprise a spacer **108** covering the light emitting mesa **101**. The spacer **108** may be an optically transparent layer formed to provide a proper spacing between the micro-lens **102** and the light emitting mesa **101**. Thus, the light emitted from the light emitting mesa **101** can pass through the spacer **108** and then arrive at the micro-lens **102**. In some embodiments, the spacer **108** may also fill up the area surrounding the light emitting mesa **101** and increase the refractive index of the medium surrounding the light emitting mesa **101**. Therefore, the spacer **108** may change the optical path of the light emitted from the light emitting mesa **101**. In some embodiments, the spacer **108** may be positioned between the light emitting mesa **101** and the micro-lens **102**. In some embodiments, a top surface of the spacer **108** may be planarized. In some embodiments, the spacer **108** may be formed directly on the surface of a planarized insulation layer **109**, as shown in FIG. **1**A. In some embodiments, the spacer **108** may cover and be in contact with the exposed top surface of a conductive layer, such as the conductive layer **115** as shown in FIG. **1**A. In some embodiments, the spacer **108** may be integrated with the micro-lens **102**. In some embodiments, the spacer **108** may be the same as or part of the planarized insulation layer **109** and integrated with the planarized insulation layer **109**.

[0244] In some embodiments, the spacer **108** extends the light path emitted from the light emitting mesa **101**. In some embodiments, the spacer **108** changes the light path emitted from the single pixel LED device by making the light emitted from the LED device more focused or more divergent according to the design needs.

[0245] In some embodiments, the dimension of the bottom surface of the micro-lens **102** may be smaller than the dimension of the bottom surface of the light emitting mesa **101**. In some embodiments, the dimension of the bottom surface of the micro-lens **102** may be the same or greater than the dimension of the bottom surface of the light emitting mesa **101**, as shown in FIG. **1**A.

[0246] In some embodiments, the spacer **108** can be made from a variety of materials that are transparent at the wavelengths emitted from the light emitting mesa **101**. Example transparent materials for the spacer **108** include polymers, dielectrics and semiconductors. In some embodiments, the spacer **108** may comprise one or more dielectric materials. In some embodiments, the dielectric materials include one or more materials, such as silicon oxide, silicon nitride, silicon carbide, titanium oxide, zirconium oxide, aluminum oxide. In some embodiments, the spacer **108** is made of photoresist. In some embodiments, the spacer **108** and the micro-lens **102** have the same material. In some embodiments, the spacer **108** and the micro-lens **102** have different materials.

[0247] In some exemplary embodiments, the height of the spacer may be less than the height of the micro-lens. For example, as shown in FIG. **1**A, the height of the spacer **108** may be less than the height of the micro-lens **102**. In some exemplary embodiments, the height of the spacer **108** may be equal to or more than the height of the micro-lens **102**. In some embodiments, the height of the spacer formed between the one light emitting mesa and one micro-lens may not be equal to the height of the spacer formed between another light emitting mesa and another micro-lens within the same display panel. In other embodiments, the height of the spacer formed between one light emitting mesa and one micro-lens may not be even. For example, as for the height of the spacer formed between the light emitting mesa **101** and the first micro-lens **102**, the height of the spacer at the central axis A-A′ may be smaller than the height of the space at the central axis B-B′.

[0248] In some exemplary embodiments, the light emitting structure **100** may further comprise a semiconductor substrate and at least one reflective cup. The light emitting mesa may be formed on the semiconductor substrate, and the edges/edge surfaces of the light emitting mesa may be surrounded by the at least one reflective cup. A reflective cup is a structure that is located relative to the light emitting mesa **101** in order to reflect light emitted from the light emitting mesa **101** in a substantially upward direction. In some embodiments, a reflective cup forms a round sidewall around the light emitting mesa **101** and includes multiple parts such as reflective cup parts **111** and **112**. For example, as shown in FIG. **1**A, the light emitting structure **100** may comprise a semiconductor substrate **110** and reflective cup parts **111** and **112**. The light emitting mesa **101** may be formed on the semiconductor substrate **110**, and surrounded by the reflective cup parts **111** and **112**. The reflective cup parts **111** and **112** may be formed on the semiconductor substrate **110**.

[0249] In some exemplary embodiments, the semiconductor substrate **110** may be an integrated circuitry (IC) substrate. The light emitting mesa may be driven by the IC individually or collectively. In some embodiments, the semiconductor substrate **110** may be another electric conductive substrate.

[0250] In some embodiments, the reflective cup parts **111** and **112** can isolate at least some of the light or substantially all the light emitted from the light emitting mesa **101**. For example, as shown in FIG. **1**A, when the heights of the reflective cup parts **111** and **112** are higher than the height of the light emitting mesa **101**, the reflective cup parts **111** and **112** can prevent some or substantially all the light emitted from adjacent light emitting mesas around the light emitting mesa **101** from interfering the light emitted from the light emitting mesa **101**. Therefore, the reflective cup parts **111** and **112** can suppress the inter-pixel light crosstalk and improve the overall contrast of LED displays using the light emitting structure **100**. In some embodiments, reflection from the reflective cups can also increase the light emitting efficiency and brightness by focusing the light emission into a certain direction. For example, some of the light emitted from the light emitting mesa **101** may arrive at and be reflected upward by the reflective cup parts **111** and **112**.

[0251] In some embodiments, the heights of the reflective cup parts **111** and **112** may be larger than the height of the light emitting mesa **101**. In some embodiments, the heights of the reflective cup parts **111** and **112** may be equal to or lower than the height of the light emitting mesa **101**. In some embodiments, the heights of the reflective cup parts **111** and **112** may be between 0.5 micron to 50 microns. In some embodiments, the heights of the reflective cup parts **111** and **112** may be between 1 micron to 20 microns. In some embodiments, the heights of the reflective cup parts **111** and **112** may be between 2 microns to 10 microns. In a preferred embodiment, the heights of the reflective cup parts **111** and **112** is about 2.5 microns while the height of the light emitting mesa **101** is about 1.9 microns. In some embodiments, the heights of the reflective cups may vary. For example, the height of the reflective cup part **111** may be different than the height of the reflective cup part **112**.

[0252] In some embodiments, the top surface of the spacer **108** may be above top surfaces of the reflective cup parts **111** and **112**. In some embodiments, the top surface of the spacer **108** may be at the same height as or below the top surfaces of the reflective cup parts **111** and **112**. In some embodiments, the top surface of the spacer **108** may be at the same height as or below the top surfaces of the reflective cup part **111** but higher that the top surface of the reflective cup part **112**.

[0253] An inside wall of the reflective cup may refer to the surface facing the light emitting mesa. For example, as shown in FIG. **1**A, the inside wall **113** of the reflective cup **111** part and the inside wall **114** of the reflective cup part **112** may face the light emitting mesa **101**. Shapes of the inside wall of the reflective cup may be various. In some embodiments, the inside wall of the reflective cup may be straight, such as the inside walls **113** and **114** as shown in FIG. **1**A. In some embodiments, steepness of the inside walls of the reflective cup parts **111** and **112** may be designed to decrease the divergence of the light emitted from the light emitting mesa **101**. For example, the angle of the inside wall of the reflective cup **111** relative to a vertical axis perpendicular to the semiconductor substrate **110** may be from at least 5 degrees to at most 75 degrees. In another example, the angle of the inside wall of the reflective cup **111** relative to a vertical axis perpendicular to the semiconductor substrate **110** may be from at least 10 degrees to at most 50 degrees.

[0254] In some embodiments, the inside wall of the reflective cup may be curved, wavy, multiline or a combination thereof. Detailed structures of the inside wall of the reflective cup would be further described below with some exemplary embodiments in FIGS. **2**A-**2**C.

[0255] In some embodiments, the reflective cup may comprise metal. In some embodiments, the reflective cup may comprise dielectric material such as silicon oxide. In some embodiments, the reflective cup may comprise photosensitive dielectric material. In some embodiments, the photosensitive dielectric material may comprise SU-8, photosensitive polyimide (PSPI), or Benzocyclobutene (BCB). In other embodiments, the reflective cup may comprise photoresist material.

[0256] In some exemplary embodiments, a light emitting mesa **101** may include a conductive electrode layer **115** as a covering layer at the top of the light emitting mesa **101**. In some embodiments, a light emitting mesa **101** includes a light emitting layer **120**. In general, an LED light emitting layer includes a PN junction/diode with a p-type region/layer and an n-type region/layer, and an active layer between the p-type region/layer and n-type region/layer.

[0257] The conductive electrode layer may be electrically connected with the reflective cup including reflective cup parts **111** and **112**, and may further electrically connected with the light emitting layer, such as light emitting layer **120** of the light emitting mesa **101**. In one example, as shown in FIG. **1**A, the conductive electrode layer **115** may be electrically connected to the reflective cup parts **111** and **112** at the bottom of each of the reflective cup parts **111** and **112** respectively. In another example, not shown in FIG. **1**A, the conductive electrode layer **115** may be electrically connected to the reflective cup parts **111** and **112** at the top of each of the reflective cup parts **111** and **112** respectively. The conductive electrode layer may cover the light emitting layer **120** and further be electrically connected with the light emitting layer **120** at the top thereof. In another example, the conductive electrode layer **115** may be electrically connected to the reflective cup parts **111** and **112** at the inside walls, such as **113** and **114**, of each of the reflective cup parts **111** and **112** respectively. In some embodiments, the conductive electrode layer **115** may be formed between the light emitting layer **120** and the micro-lens **102**. In some embodiments, the conductive electrode layer **115** may be formed between the spacer **108** and the light emitting layer **120**. In some embodiments, the conductive electrode layer **115** may be made of materials such as graphene, Indium Tin Oxide (ITO), Aluminum-Doped Zinc Oxide (AZO), or Fluorine doped Tin Oxide

(FTO), or any combinations thereof. In some embodiments, the conductive electrode layer **115** may be transparent and some of the light emitted from the light emitting layer **120** may pass through the conductive electrode layer **115**.

[0258] In some exemplary embodiment, the light emitting mesa **101** may further comprise one or more metal bonding layer (e.g., metal bonding layer **116**) formed on the semiconductor substrate **110**. The metal bonding layer may be electrically connected with the light emitting mesa **101**. For example, as shown in FIG. **1**A, the light emitting mesa **101** may comprise the metal bonding layer **116** at the bottom of the light emitting mesa **101**. The metal bonding layer **116** may be formed on the semiconductor substrate **110**. The metal bonding layer **116** may be further formed at the bottom of the light emitting mesa **101** and electrically connected with the light emitting layer **120**. In some embodiments, the metal bonding layer **116** has an oblique side surface. The oblique side surface may enhance easy connections for different connectors to the LED light emitting layers, prevent disconnections of those connectors because of sharp angles, and enhance the overall stability of the device. In some embodiments, the metal bonding layer **116** can also be used as a reflector to reflect light emitted from the LED layers above.

[0259] In some embodiments, the metal bonding layer **116** is electrically connected to both a driver circuit on the semiconductor substrate **110** and the light emitting layer **120** above the metal bonding layer **116**, acting like a P-electrode. In some embodiments, the thickness of the metal bonding layer **116** is about 0.1 micron to about 3 microns. In other embodiments, the thickness of a metal bonding layer **116** is about 0.3 μm. The metal bonding layer **116** may include ohmic contact layers, and metal bonding layers. In some embodiments, two metal layers may be included in the metal bonding layer **116**. One of the metal layers may be deposited the layer above the metal bonding layer within the light emitting structure **100**. A counterpart bonding metal layer may be also deposited on the semiconductor substrate **110**.

[0260] In some embodiments, compositions for the metal bonding layer **116** include Au—Au bonding, Au—Sn bonding, Au—In bonding, Ti—Ti bonding, Cu—Cu bonding, or a mixture thereof. For example, if Au—Au bonding is selected, the two layers of Au respectively need a Cr coating as an adhesive layer, and Pt coating as an anti-diffusion layer. And the Pt coating is between the Au layer and the Cr layer. The Cr and Pt layers are positioned on the top and bottom of the two bonded Au layers. In some embodiments, when the thicknesses of the two Au layers are about the same, under a high pressure and a high temperature, the mutual diffusion of Au on both layers bond the two layers together. Eutectic bonding, thermal compression bonding, and transient liquid phase (TLP) bonding are example techniques that may be used.

[0261] In some exemplary embodiments, the light emitting structure **100** may further include some isolation structures such as **118** between the light emitting mesas, such as the light emitting mesa **101**, on the substrate **110**. The isolation structure **118** is formed on the substrate **110**. In some embodiments, the isolation structure **118** is thinner than the bonding layer **116**. In some embodiments, the isolation structure **118** is made of dielectric materials, such as SiO2. In some embodiments, the dielectric materials of the isolation structure **118** can be inorganic or organic materials.

[0262] In some exemplary embodiments, the light emitting structure **100** may further include an insulation layer **117** on the surface of the light emitting layer **120**, and on the surfaces of the isolation structures **118** and the bonding layer **116**. In some embodiments, the conductive electrode layer **115** is then formed on the surface of the insulation layer **117**. In some embodiments, the insulation layer **117** is made of dielectric materials, such as SiO2. In some embodiments, the dielectric materials of the insulation layer **117** can be inorganic or organic materials.

[0263] FIGS. **2**A-**2**C each illustrate a cross-sectional view of some exemplary embodiments of the reflective cups, which may correspond to the reflective cup parts **111** and/or **112** in FIG. **1**A, according to some embodiments. In some embodiments, as shown in FIG. **2**A, the reflective cup **201** may comprise an inside wall **201***a* facing the light emitting mesa **101**. The inside wall **201***a* may be curved so as to reflect some of the light emitted from the light emitting mesa **101** upwardly. In some embodiments, as shown in FIG. **2**B, the inside wall of the reflective cup **202** may be multiline which includes the sub-inside walls **202**A, **202**B and **202**C. The sub-inside walls **202**A, **202**B and **202**C face towards the light emitting mesa **101** so that some of the light emitted from the light emitting mesa may be reflected by the sub-inside walls **202**A, **202**B and **202**C upwardly. Each of the sub-inside walls may also adjust the focus for the light emitted (especially horizontally) in a different pattern. In some embodiments, steepness (the angle of the inside wall of the reflective cup relative to a vertical axis perpendicular to the semiconductor substrate **110**) of each of the sub-inside walls (relative to the bottom of the reflective cup **202**) from bottom to top of the reflective cup **202** may become greater. In other embodiments, the steepness of each of the sub-inside walls (relative to the bottom of the reflective cup **202**) from bottom to top of the reflective cup **202** may become smaller. In other embodiments, steepness of each of the sub-inside walls (relative to the bottom of the reflective cup **202**) from bottom to top of the reflective cup **202** may be randomly selected.

[0264] Y et in some embodiments, as shown in FIG. **2**C, the inside wall of the reflective cup **203** may be stair-shaped. The reflective cup **203** may include one or more stair structures (e.g., stair structures **203-1**, **203-2** and **203-3**). Each of the one or more stair structures may comprise a sub-inside wall (e.g., sub-inside walls **203***a*, **203***b* and **203***c*, respectively). Similar to the reflective cup **202** mentioned above, the reflective cup **203** can also reflect some of the light emitted from the light emitting mesa upwardly, and adjust the focus for the light emitted (especially horizontally) in a different pattern, for example, by changing each of the sub-inside walls' steepness and height.

[0265] In some embodiments, the reflective cup can be fabricated by a combination of deposition, photo-lithography and etching processes. In some embodiments, the reflective cup may be fabricated by other suitable methods. In one example, the reflective cup may be fabricated by the steps: 1) PSPI is formed into the reflective cup shape by photolithography process; 2) a metal layer with high reflectivity (Pt, Rh, Al, Au, Ag), TiO2/SiO2 stacked layer (Distributed Bragg Reflector (DBR)), or any other layer with total reflection property (ODR) is deposited on the whole surface by vapor deposition; and 3) the reflective layer is shaded by a photoresist while the reflective layer on the other region is etched, whereby the light emitting area is exposed into air. In another example, the reflective cup may be fabricated by the steps: 1) an isolation layer (SiO2, SiN or SU8) which is thicker than the light emitting structure is deposited or spinned on the light emitting structure; 2) using the photoresist as a mask, the reflective cup shape is etched in the isolation layer; 3) a metal layer with high reflectivity (Pt, Rh, Al, Au, Ag), TiO2/SiO2 stacked layer (DBR), or any other layer with total reflection property (ODR) is deposited on the whole surface by vapor deposition; and 4) the reflective layer is shaded by a photoresist while the reflective layer on the other region is etched, whereby the light emitting area is exposed.

[0266] In some embodiments, the reflective cup may further include one or more reflective coatings. The one or more reflective coatings may be disposed on one or more inside walls of the reflective cup, e.g., the inside walls **113**, **114**, and **201***a*, the sub-inside walls **202**A, **202**B and **202**C, and the sub-inside walls **203***a*, **203***b* and **203***c*. The bottom of each of the one or more reflective coatings does not contact the light emitting mesa, e.g., the light emitting mesa **101** as described in FIG. **1**A (not shown in FIG. **2**). The one or more reflective coatings can reflect light emitted from the light emitting mesa and therefore enhance the brightness and luminous efficacy of micro-LED panels or displays. For example, the light emitted from the light emitting mesa may arrive at the one or more reflective coatings and may be reflected upward by the one or more reflective coatings.

[0267] In some embodiments, the one or more reflective coatings, together with the reflective cup, can utilize reflection direction and/or reflection intensity of the light emitted from the light emitting mesa. For example, the sub-inside walls **203***a*, **203***b* and **203***c* may be inclined at a certain angle, and therefore the one or more reflective coatings disposed on the sub-inside walls **203***a*, **203***b* and

203*c* are inclined at the same angle as the sub-inside walls **203***a*, **203***b* and **203***c*. When the light emitted from the light emitting mesa arrives at the one or more reflective coatings, the light emitted from the light emitting mesa would be reflected by the one or more reflective coatings in accordance with the angle of the sub-inside walls **203***a*, **203***b* and **203***c*.

[0268] Materials of the one or more reflective coatings may be highly reflective with a reflectivity greater than 60%, 70% or 80%, and therefore most of the light emitted from the light emitting mesa can be reflected. In some embodiments, the one or more reflective coatings may comprise one or more metallic conductive materials with high reflectivity. In these embodiments, the one or more metallic conductive materials may comprise one or more of aluminum, gold or silver. In other some embodiments, the one or more reflective coatings can be multi-layered. To be more specific, the one or more reflective coatings may comprise a stack of one or more reflective material layers and one or more dielectric material layers. For example, the one or more reflective coatings may comprise one reflective material layer and one dielectric material layer. In some other embodiments, the one or more reflective coatings may comprise two reflective material layers and one dielectric material layer positioned between the two reflective material layers. Y et in some other embodiments, the one or more reflective coatings may comprise two dielectric material layers and one reflective material layer positioned between the two dielectric material layers. In some embodiments, the multi-layered structure may comprise two or more metal layers, which may comprise one or more of TiAu, CrAl or TiWAg.

[0269] In some embodiments, the one or more reflective coatings may be multi-layered Omni-Directional Reflector (ODR), which comprises a metal layer and a Transparent and Conductive Oxides (TCO) layer. For example, the multilayered structure may comprise a dielectric material layer, a metal layer and a TCO layer. In some embodiments, the one or more reflective coatings may comprise two or more dielectric material layers, which are disposed alternately to form a DBR. For example, the one or more reflective coatings may comprise a dielectric material layer, a metal layer and a transparent dielectric layer. The transparent dielectric layer may comprise one or more of SiO.sub.2, Si.sub.3N.sub.4, Al.sub.2O.sub.3, or TiO.sub.2. The one or more reflective coatings may further comprise a dielectric material layer, a TCO and a DBR. In other embodiments, the one or more reflective coatings may comprise one or more metallic conductive materials with high reflection. In these embodiments, the one or more metallic conductive materials may comprise one or more of aluminum, gold or silver.

[0270] In some embodiments, the one or more reflective coatings can be conductive, and then the one or more reflective coatings may also perform functions as electrical contacts to the light emitting structure **100**. For example, the light emitting mesa **101** may be electrically connected with the one or more reflective coatings. The one or more reflective coatings may be patterned to not block light emitted from the light emitting mesa. The one or more reflective coatings may then also function as the common electrode for the LED device and/or the LEDs on a display panel.

[0271] FIG. **3** illustrates a cross-sectional view **300** of an exemplary structure of the light emitting mesa **101** on the substrate **110** in FIG. **1**A, in accordance with some embodiments. As described in FIG. **1**A, the light emitting mesa **101** may include at least one light emitting layer (e.g., light emitting layer **120**), a bottom bonding layer (e.g., bottom bonding layer **116**) at the bottom of the light emitting layer **120** and bonded with the semiconductor substrate **110**. In some embodiments, the light emitting mesa **101** includes a top electrode layer (e.g., top electrode layer **115**) covering the light emitting layer **120** and electrically connected with the at least one reflective cup (e.g., the reflective cup parts **111** and/or **112**) as described in FIG. **1**A. In some embodiments, the at least one reflective cup (e.g., the reflective cup parts **111** or **112**) may be electrically connected with the semiconductor substrate **110**. For example, as shown in FIG. **3**, the light emitting mesa **101** may include the light emitting layer **120**, the bottom bonding layer **116** at a bottom of the light emitting layer **120** and bonded with the semiconductor substrate **110**, and the top electrode layer **115** covering the light emitting layer **120** and electrically connected with the at least one reflective cup

111 and/or **112** (as described in FIGS. **1-2**, not shown in FIG. **3**).

[0272] In some embodiments, the light emitting layer **120** may emit green, blue or red light. The light emitted from the light emitting layer **120** may pass through and/or around the top electrode layer **115** and arrive at the micro-lens **102** (as described in FIG. **1**A, not shown in FIG. **3**). The light emitted from the light emitting layer **120** may also arrive at the at least one reflective cup **111** and/or **112** and be reflected upwardly to the micro-lens **102** or/and another lens (not shown in FIG. **3**). In some embodiments, the light emitting mesa **101** may comprises two or more light emitting layers emitting distinct colors. The two or more light emitting layers may be stacked vertically or arranged in parallel in the same level. For example, the light emitting layer emitting green light may be disposed on the light emitting layer emitting red light; or the light emitting layer emitting green light may be arranged parallel to the light emitting layer emitting red light in the horizontal direction. In some embodiments, the light emitting structure **100** may include two or more light emitting mesas. In some embodiments, each of the light emitting mesas may include at least a light emitting layer that emits a distinct color. When two light emitting mesas are within the light emitting structure **100**, two colors and the combinations of the two colors can be emitted from the light emitting structure **100**. When three light emitting mesas are within the light emitting structure **100**, three colors and the combinations of the three colors can be emitted from the light emitting structure **100**.

[0273] In some embodiments, the light emitting layer such as **301** may include many epitaxial sub-layers with different compositions. Examples of the LED epitaxial layers may include III-V nitride, III-V arsenide, III-V phosphide, and III-V antimonide epitaxial structures. Examples of micro-LEDs may include GaN based UV/blue/green micro LEDs, AlInGaP based red/orange micro LEDs, and GaAs or InP based infrared (IR) micro LEDs.

[0274] In some embodiments, the bottom bonding layer **116** can be a metal layer or a conductive transparent layer, such as an ITO layer, which is formed at the bottom of the light emitting layer **120** to improve conductivity and transparency. In some embodiments, when there are more than one light emitting layers within the light emitting mesa, the light emitting layers are bonded together by a respective bonding layer in between. The light emitted from the light emitting layers may pass through the bonding layers above the current light emitting layer and be reflected by the bonding layers beneath the current light emitting layer. In some embodiments, the bottom bonding layer **116** is bonded with the semiconductor substrate **110**.

[0275] In some embodiments, the top electrode layer **115** can be a metal layer or a conductive transparent layer, such as an ITO layer, that is formed on the light emitting layer **120** to improve conductivity and transparency. In addition, in some embodiments, there are additional conductive layers at the bottom and top of each of the light emitting layer, such as conductive layer **302** at the bottom of the light emitting layer **120**, and conductive layer **303** at the top of the light emitting layer **120**. Each of the conductive layers are electrically connected with either the top electrode layer or the IC circuit within the substrate. The top electrode layer **115** may be electrically connected with another circuit or component. In some embodiments, there may be a contact pad **304**, as shown in FIG. **3**, positioned between the top electrode layer **115** and the conductive layer **303**. The contact pad **304** may be made of materials such as graphene, ITO, TCO, AZO, or FTO, or any combinations thereof. In some embodiments, the conductive layer **303** may be electrically connected with the at least one reflective cup via the conductive electrode layer **115** (as described in FIG. **1**A).

[0276] In some embodiments, a reflective layer, such as reflective layer **301**, may be positioned above the bottom bonding layer **116** and at bottom of each light emitting layer, such as light emitting layer **120**. In some embodiments, a reflective layer, such as reflective layer **301**, may be positioned below the conductive layer, such as conductive layer **302**, at the bottom of each light emitting layer, such as light emitting layer **120**. The reflective layer may improve light transmission efficiency. For example, the light emitted from the light emitting layer **120** may be reflected by the

reflective layer **301**. In some embodiments, the materials of the reflective layer may have a high reflectivity, especially to the light emitted by the light emitting layer(s) above the current reflective layer. For example, the reflectivity of the reflective layer is above 60%. In another example, the reflectivity of the reflective layer is above 70%. In yet another example, the reflectivity of the reflective layer is above 80%. In some embodiments, the material of the reflective layer may be metal selected from one or more of Rh, Al, Ag, and Au. In some embodiments, the reflective layer may include at least two sublayers with different refractive index. Each of the sublayers also has a high reflectivity such as above 60%, 70% or 80%. In some embodiments, the reflective layer may include a DBR structure. For example, the reflective layer may be formed from multiple layers of alternating or different materials with varying refractive index. In some instances, each layer boundary of the DBR structure causes a partial reflection of an optical wave. The reflective layer can be used to reflect some selected wavelengths. In some embodiments, the reflective layer may be made of multiple layers, e.g., at least two layers, of SiO_2 and Ti_3O_5, respectively. By varying the thicknesses and numbers of layers of SiO_2 and Ti_3O_5 respectively, selective reflection or transmission of light at different wavelengths can be formed.
[0277] In some embodiments, the at least one reflective cup may be electrically connected with the semiconductor substrate. For example, through a top electrode layer.
[0278] FIG. **4** illustrates a cross-sectional view of an exemplary light emitting structure **400** with an array of micro-lenses and light emitting mesas, according to some embodiments. In some exemplary embodiments, a light emitting structure comprises a first light emitting mesa. For example, the light emitting structure **400** comprises a first light emitting mesa **401**, as shown in FIG. **4**. In some embodiments, the first light emitting mesa **401** has the same or similar dimension, shape, structure, composition, positioning and fabrication (including the reflective cup and other related structures, such as an optional spacer) as the light emitting mesa **101** and related structures described in FIG. **1**A. The first light emitting mesa **401** may include an LED or a micro-LED and light may be emitted from the first light emitting mesa **401**. The first light emitting mesa **401** may have a top surface and a bottom surface. In some embodiments, the diameter or width of the top surface of the first light emitting mesa **401** and the diameter or width of the bottom surface of the first light emitting mesa **401** may be in the range similar as described above with reference to FIG. **1**A.
[0279] In some exemplary embodiments, the light emitting structure **400** further comprises a first micro-lens. As shown in FIG. **4**, the light emitting structure **400** comprises a first micro-lens **402** formed on the first light emitting mesa **401**. In some embodiments, the first micro-lens **402** may have the same or similar dimension, shape, structure, composition, positioning and fabrication as the micro-lens **102** described in FIG. **1**A. In some embodiments, the first micro-lens **402** may be co-axially aligned to the first light emitting mesa **401** along the C-C′ direction (not shown in FIG. **4**), and be positioned above the first light emitting mesa **401**. The axis C-C′ as shown in FIG. **4** refers to the central axis of the first light emitting mesa **401**, and the axis D-D′ as shown in FIG. **4** refers to the central axis of the first micro-lens **402**. In these embodiments with co-axially aligned center axes (not shown in FIG. **4**), all of the light emitted from the first light emitting mesa **401** can directly arrive at and pass through the first micro-lens **402**. Therefore, the divergence can be reduced and the useable viewing angle can be decreased to the extent that displays and panels using the single pixel LED devices may be seen by a user's view perpendicular to surfaces of the displays and panels. This, in turn, can reduce power waste and increase brightness and/or better protect user privacy in public areas. In another example, a part of the light emitted from the first light emitting mesa **401** can directly arrive at and pass through the first micro-lens **402**, and another part of the light emitted from the light emitting center can pass around or bypass the micro-lens **402**. Thus, the brightness from the first light emitting mesa **401** can be adjusted.
[0280] Y et in another example, the central axis of the first micro-lens **402** is off-axially stacked on the central axis of the first light emitting mesa **401** as shown in FIG. **4**. In other words, the central

axis D-D′ of the first micro-lens **402** is not coaxially aligned with, does not overlap or coincide with the central axis C-C′ of the first light emitting mesa **401**, as shown in FIG. **4**. In some embodiments, an offset distance between the central axis D-D′ of the first micro-lens **402** and the central axis C-C′ of the first light emitting mesa **401** is not more than 4.5 μm. In this example, the vertical light array **440** from the center of the light emitting mesa **401** is redirected by the micro-lens as the light array **442** which is at an angle to the vertical light array **440**. The light array **444** from the edge of the light emitting mesa **401** toward the center of the micro-lens **402** is redirected by the micro-lens as the light array **446** which is at a greater angle to the axis perpendicular to the substrate **410** relative to that of the light array **444**. In this embodiment, the divergence can be reduced and the usable viewing angle can be decreased to the extent that displays and panels using the single pixel LED devices may be seen by a user's view at only certain degrees to surfaces of the displays and panels. This can also reduce power waste, increase brightness and/properly protect user privacy in public areas.

[0281] In FIG. **4**, the light emitting structure includes multiple light emitting mesas distributed in an array. For example, FIG. **5** is a top view of a light emitting structure array system **500** of off-axially arranged light emitting mesas and micro-lenses, according to some embodiments. The shape of the array can be a matrix, a circle, a rectangle, a square, a hexagon, or another shape. In the array, one micro-lens is arranged above each of the light emitting mesas respectively. A light emitting mesa **501**, and a micro-lens **502** on top of the light emitting mesa **501** are included in the array of off-axially arranged light emitting mesas and micro-lenses. In some embodiments, an edge of the first light emitting mesa is near an edge of the first micro-lens, for example, an offset distance between an edge of a bottom surface of the first light emitting mesa and an edge of a bottom surface of the first micro-lens is within 30% of a diameter of the bottom surface of the first micro-lens. For example, as shown in FIG. **4**, the line E-E′ refers to the vertical line passing through the farthest point of the edge of the bottom surface of the first light emitting mesa **401** (farthest point **504** of the first light emitting mesa **501** in the cross-sectional view along G-G′ in FIG. **5**). Analogously, the line F-F′ refers to the vertical line passing through the farthest point of the edge of the bottom surface of the first micro-lens **402** (farthest point **506** of the first micro-lens **502** in the cross-sectional view along G-G′ in FIG. **5**). The offset distance between the edge of the bottom surface of the first light emitting mesa **401** and the edge of the bottom surface of the first micro-lens **402** refers to the offset distance between the line E-E′ and the line F-F′. In some embodiments, as shown in FIG. **5**, the offset distance between the edge of the bottom surface of the first light emitting mesa **401** and the edge of the bottom surface of the first micro-lens **402** is zero, for example **504** and **506** are the same point. In some embodiments, as shown in FIG. **4**, the offset distance between the edge **504** of the bottom surface of the first light emitting mesa **401**/**501** and the edge **506** of the bottom surface of the first micro-lens **402**/**502** is very small, for example, the offset distance between the line E-E′ and the line F-F′ may be within 30% of the diameter of the bottom surface of the first micro-lens **402**. In some embodiments, the offset distance between the line E-E′ and the line F-F′ may be more than 30% but less than 50% of the diameter of the bottom surface of the first micro-lens **402**. In some embodiments, the offset distance between the line E-E′ and the line F-F′ may be more than 50% of the diameter of the bottom surface of the first micro-lens **402**.

[0282] In some embodiments, the bottom surface of the first micro-lens **402** covers a position of the central axis C-C′ of the first light emitting mesa **401**. In other words, the central axis C-C′ of the first light emitting mesa **401** intersects with the bottom surface of the first micro-lens **402**, as shown in FIG. **4**.

[0283] In some embodiments, the structure of the first micro-lens **402** may include one element with one plane surface and one convex surface. For example, as shown in FIG. **4**, the structure of the first micro-lens **402** may be hemisphere. Other structures of the first micro-lens **402** may also be other structures/shapes similar as described above with the reference to FIG. **1**A. In some embodiments, the first micro-lens **402** may further include a reflective part which can adjust the light path. The reflective part may be similar to the reflective part as explained above.

[0284] In some embodiments, the material of the first micro-lens **402** comprises inorganic or organic materials. For example, the material of the first micro-lens **402** may comprise silicon oxide. Other materials of the first micro-lens **402** and methods of manufacturing may be the same or similar to the materials and manufacturing of the micro-lens **102** as explained above with reference to FIG. **1**A.

[0285] In some embodiments, the light emitting structure **400** further comprises a second light emitting mesa, and a second micro-lens formed above the second light emitting mesa. For example, as shown in FIG. **4**, the light emitting mesa **400** comprises a second light emitting mesa **403** and a second micro-lens **404** formed above the second light emitting mesa **403**. In some embodiments, the second light emitting mesa **403** may be similar to the first light emitting mesa **401** as described above and the second micro-lens **404** may be similar to the first micro-lens **402** as described above. In some embodiments, the second light emitting mesa **403** may be adjacent to the first light emitting mesa **401**. For example, as shown in FIG. **4**, the second light emitting mesa **403** is adjacent to the first light emitting mesa **401** at the same horizontal level. In another example, the second light emitting mesa **403** may be adjacent to the first light emitting mesa **401** at a higher or lower horizontal level.

[0286] In some embodiments, the structure of the second micro-lens **404** may include one element with one plane surface and one convex surface. For example, as shown in FIG. **4**, the structure of the second micro-lens **404** may be hemisphere. Other structures of the second micro-lens **404** may also be other structures/shapes similar as described above with reference to FIG. **1**A. In some embodiments, the second micro-lens **404** may further include a reflective part which can adjust the light path. The reflective part may be similar to the reflective part as explained above.

[0287] In some embodiments, the offset between the central axis of the first micro-lens **402** to the central axis of the first light emitting mesa **401** is the same as the offset between the central axis of the second micro-lens **404** to the central axis of the second light emitting mesa **403**. In some embodiments, the offset between the central axis of the first micro-lens **402** to the central axis of the first light emitting mesa **401** is not the same as the offset between the central axis of the second micro-lens **404** to the central axis of the second light emitting mesa **403**. As shown in FIG. **5**, in some embodiments, the relative positions of each micro-lens, such as **502**, to each corresponding light emitting mesa, such as **501**, are the same within the light emitting structure array system **500**. For example, the offset distance of the central axis of a micro-lens relative to the central axis of a corresponding light emitting mesa (such as the distance between line D-D′ and line C-C′ as shown in FIG. **4**) is the same across all the light emitting mesa and micro-lens pairs on the light emitting structure array system **500**. This way, all the light emitted from the light emitting mesa and micro-lens pairs on the light emitting structure array system **500** are directed in the same angle or similar angle range toward a user or a device.

[0288] FIG. **6** illustrates a cross-sectional view of a light emitting structure array system **600** with a sensor **602** located at a center position above the light emitting structure array system **600**, according to some embodiments. The light emitting structure array system **600** includes one or more light emitting mesas, such as **604**, **608**, **612**, **616**, and **620**, and one or more micro-lenses, such as **606**, **610**, **614**, **618**, and **622**, each of which can be similar as described in any one of FIGS. **1**-**5**. In some embodiments, the emitting light rays from the one or more light emitting mesas through the one or more micro-lenses are converted together into the sensor **602**. In some embodiments, the sensor **602** (or the central axis of the sensor **602**) is arranged at a location that is at a central axis H-H′ of the light emitting structure array system **600**.

[0289] In some embodiments, the offset distances of the micro-lens relative to the corresponding light emitting mesa are different within the light emitting structure array system **600**. In some embodiments, the offset distance of the micro-lens relative to the light emitting mesa is decided by the position of the sensor and the position of the micro-lens relative to the sensor. In some embodiments, as shown in FIG. **6**, the offset distance of the central axis of a micro-lens relative to the central axis of a corresponding light emitting mesa (such as the distance between line D-D′ and line C-C′ as shown in FIG. **4**), becomes larger from the center of the light emitting structure array system where the sensor **602** is located, to the edge of the light emitting structure array system **600**. In other words, the offset distance of the central axis of a first micro-lens, such as **610**, relative to the central axis of a first light emitting mesa, such as **608**, is smaller than the offset distance of the central axis of a second micro-lens, such as **614**, relative to the central axis of the second light emitting mesa, such as **612**, when the first micro-lens and the first light emitting mesa are both closer in distance to the sensor **602** than both of the second micro-lens and the second light emitting mesa to the same sensor **602**. In some embodiments, the offset distance of the central axis of a micro-lens, such as **606**, relative to the central axis of a corresponding light emitting mesa, such as **604**, is zero, when both of the central axis micro-lens and the central axis of the light emitting mesa are coaxially aligned with the central axis of the sensor **602**. In some embodiments, the offset distance range for the micro-lens and light emitting mesa pairs on the light emitting structure array system **600** is not more than 4.5 μm.

[0290] In some embodiments, the offset distances of the central axis of a respective micro-lens relative to the central axis of a respective corresponding light emitting mesa are symmetric around the central axis of the light emitting structure array system **600**, where the sensor **602** is located. For example, the offset distance of the central axis of the micro-lens **610** relative to the central axis of a corresponding light emitting mesa **608**, and the offset distance of the central axis of the micro-lens **618** relative to the central axis of a corresponding light emitting mesa **616**, are the same. The offset distance of the central axis of the micro-lens **614** relative to the central axis of a corresponding light emitting mesa **612**, and the offset distance of the central axis of the micro-lens **622** relative to the central axis of a corresponding light emitting mesa **620**, are the same. In some embodiments, on the right of the central axis of the sensor, the micro-lens is shifted to the left relative to the corresponding light emitting mesa beneath the micro-lens (see, e.g., micro-lens **610** and **614** in FIG. **6**). In some embodiments, on the left of the central axis of the sensor, the micro-lens is shifted to the right relative to the corresponding light emitting mesa beneath the micro-lens (see, e.g., micro-lens **618** and **622** in FIG. **6**).

[0291] The light emitting structure array system **600** as shown in FIG. **6** can direct light emitted from each of the light emitting mesas toward the sensor **602** at a center location. For example, the light emitted from the light emitting mesa **604** at its central axis at the center of the light emitting structure array system **600** does not change its direction after passing through the micro-lens **606**. The light emitted from the light emitting mesa **608** at its central axis changes its direction toward the sensor **602** after passing through the micro-lens **610**. The light emitted from the light emitting mesa **612** at its central axis changes its direction toward the sensor **602** after passing through the micro-lens **614**. The angle of the light emitted from the micro-lens located toward the edge of the light emitting structure array system **600** relative to a vertical axis perpendicular to the surface of the substrate is larger than the angle of the light emitted from the micro-lens located toward the center of the light emitting structure array system **600** relative to a vertical axis perpendicular to the surface of the substrate. For example, the angle of the light emitted from the micro-lens **614** located toward the edge of the light emitting structure array system **600** relative to a vertical axis perpendicular to the surface of the substrate is larger than the angle of the light emitted from the micro-lens **610** located toward the center of the light emitting structure array system **600** relative to a vertical axis perpendicular to the surface of the substrate.

[0292] FIG. **7** illustrates a cross-sectional view of a light emitting structure array system **700** with a sensor **702** located at a side or non-central position above the light emitting structure array system **700**, according to some embodiments. The light emitting structure array system **700** includes one or more light emitting mesas, such as **704**, **708**, **712**, **716**, and **720**, and one or more micro-lenses, such as **706**, **710**, **714**, **718**, and **722**, each of which can be similar as described in any one of FIGS. **1**-**5**. In some embodiments, the emitting light rays from the one or more light emitting mesas through the one or more micro-lenses are converted together into the sensor **702**. In some embodiments, the sensor **702** (or the central axis of the sensor **702**) is arranged at a location that is not at a central axis of the light emitting structure array system **700**. For example, a central axis I-I′ of the sensor **702** is passing through a side of the light emitting structure array system **700**.

[0293] In some embodiments, the offset distances of the micro-lens relative to the corresponding light emitting mesa are different within the light emitting structure array system **700**. In some embodiments, the offset distance of the micro-lens relative to the light emitting mesa is decided by the position of the sensor and the position of the micro-lens relative to the sensor. In some embodiments, as shown in FIG. **7**, the offset distance of the central axis of a micro-lens relative to the central axis of a corresponding light emitting mesa (such as the distance between line D-D′ and line C-C′ as shown in FIG. **4**), becomes larger for each micro-lens-mesa pair as the position progresses from a central axis I-I′ of the sensor **702**, to an edge of the light emitting structure array system **700**, i.e., progressing from central axis I-I′ in a leftward horizontal direction in FIG. **7**. In other words, the offset distance of the central axis of a first micro-lens, such as **706**, relative to the central axis of a first light emitting mesa, such as **704**, is smaller than the offset distance of the central axis of a second micro-lens, such as **710**, relative to the central axis of the second light emitting mesa, such as **708**, when the first micro-lens and the first light emitting mesa are both closer in distance to the sensor **702** than both of the second micro-lens and the second light emitting mesa to the same sensor **702**. In some embodiments, not shown in FIG. **7**, the offset distance of the central axis of a micro-lens, relative to the central axis of a corresponding light emitting mesa, is zero, when both of the central axis micro-lens and the central axis of the light emitting mesa are coaxially aligned with the central axis of the sensor **702**. In some embodiments, the offset distance range for the micro-lens and light emitting mesa pairs on the light emitting structure array system **700** is not more than 4.5 μm.

[0294] In some embodiments, not shown in FIG. **7**, the offset distances of the central axis of a respective micro-lens relative to the central axis of a respective corresponding light emitting mesa are symmetric around the central axis of the sensor **702**. In some embodiments, on the right of the central axis of the sensor, the micro-lens is shifted to the left relative to the corresponding light emitting mesa beneath the micro-lens. In some embodiments, on the left of the central axis of the sensor, the micro-lens is shifted to the right relative to the corresponding light emitting mesa beneath the micro-lens.

[0295] The light emitting structure array system **700** as shown in FIG. **7** can direct light emitted from each of the light emitting mesas toward the sensor **702** at a non-central location. For example, the light emitted from the light emitting mesa **708** at its central axis changes its direction toward the sensor **702** after passing through the micro-lens **710**. The light emitted from the light emitting mesa **712** at its central axis changes its direction toward the sensor **702** after passing through the micro-lens **714**. The angle of the light emitted from the micro-lens located farther from the central axis of the sensor **702** relative to a vertical axis perpendicular to the surface of the substrate is larger than the angle of the light emitted from the micro-lens located nearer to the central axis of the sensor **702** relative to a vertical axis perpendicular to the surface of the substrate. For example, the angle of the light emitted from the micro-lens **714** located farther from the central axis of the sensor **702** relative to a vertical axis perpendicular to the surface of the substrate is larger than the angle of the light emitted from the micro-lens **710** located nearer to the central axis of the sensor **702** relative to a vertical axis perpendicular to the surface of the substrate.

[0296] When the offset distances of the micro-lens relative to the corresponding light emitting mesas are the same, the light emitted out of the micro-lens array are in parallel and forms an irradiation plane. When the offset distances of the micro-lens relative to the corresponding light emitting mesas are different, the light emitted out of the micro-lens array can focus on a point but not a plane.

[0297] FIG. **8** illustrates a cross-sectional view of an exemplary light emitting structure **800** having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **800** includes a small micro-lens, such as **806** or **808**, and a big micro-lens, such as **802** or **804**. The small micro-lens, such as **806** or **808**, is formed on the light emitting mesa, such as **401** or **403**. The big micro-lens is formed on the light emitting mesa, such as **401** or **403**, and covers the small micro-lens, such as **806** or **808**. The diameter of the big micro-lens, such as **802**, is larger than the diameter of the small micro-lens, such as **806**, so as to improve the light extraction efficiency.

[0298] In some embodiments, as shown in FIG. **8**, the central axis J-J′ of the small micro-lens **806** is shifted from the central axis K-K′ of the light emitting mesa **401** to change the light direction, while the central axis of the big micro-lens **802** is coaxially aligned with (or the same as) the central axis K-K′ of the light emitting mesa **401**. In some embodiments, the offset distance between the central axis of the small micro-lens **806** and the central axis of the light emitting mesa **401** is not more than 9 μm, preferably not more than 1.5 μm.

[0299] In some embodiments, the edge of the small micro-lens **806** does not need to cover the central axis of the light emitting mesa **401**, as shown in FIG. **8**, while the edge of the big micro-lens **802** covers the central axis of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis K-K′ of the light emitting mesa **401** does not need to intersect with the bottom surface of the small micro-lens **806**, while the central axis K-K′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **802**. In some other embodiments, not shown in FIG. **8**, both the edges of the small micro-lens **806** and big micro-lens **802** cover the central axis of the light emitting mesa **401**. In other words, the central axis K-K′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **806**, and the central axis K-K′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **802**.

[0300] In some embodiments, the light ray **840** emitted from the light emitting mesa **401** is redirected as **842** out of the big micro-lens **802**. The light ray **844** emitting from the light emitting mesa **401** is redirected as **846** while it travels through the small micro-lens **806** and as **848** out of the big micro-lens **802**. The addition of the small micro-lens within the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle. For example, in FIG. **8**, the light rays from the big micro-lens are more focused in certain directions after exiting.

[0301] FIGS. **9**A-**9**D illustrate some exemplary simulation results for the light exiting from the big micro-lens from the light emitting structure **800** shown in FIG. **8**, according to some embodiments. FIGS. **9**A-**9**D show the change of the exiting light intensity from the light emitting structure **800** as the offset distance between the central axis K-K′ of the light emitting mesa, such as **401**, and the central axis J-J′ of the small micro-lens, such as **806**, changes, while the central axis of the big micro-lens, such as **802** is coaxially aligned with (or the same as) the central axis K-K′ of the light emitting mesa, such as **401**. The exiting light intensity was measured in a vertical plane that passes the vertical central axis of the light emitting mesa, such as the central axis K-K′ of the light emitting mesa **401**. X and Y denote the offset distances in micrometers on a horizontal plane parallel to the substrate **410** in the two orthogonal directions: X direction and Y direction. In this example, the largest horizontal dimension (such as the bottom surface) of the light emitting mesa, such **401**, is 8 μm. The largest horizontal dimension (such as the bottom surface) of the small micro-lens, such as **806**, is 18 μm. The largest horizontal dimension of the big micro-lens (such as the bottom surface), such as **802**, is 36 μm. FIGS. **9**A-**9**D also show the change of the exiting light intensity from the light emitting structure **800** as the angle of the exiting light ray relative to an axis perpendicular to the substrate **410** (exiting angle θ represented in degrees) changes.

[0302] For example, in FIG. **9**A, when the offset distance between the central axis of the light emitting mesa and the central axis of the small micro-lens in the X direction is 1.5 μm, and in the Y direction is 1.5 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.3 a.u. There are two other secondary peak normalized exiting light intensities at around +30 and −30 degree exiting angles. The secondary peak intensity is about 0.15 a.u. When the absolute value of the exiting angle is larger than 30 degrees, the light intensity gradually decreases to zero as the absolute value of the exiting angle becomes bigger. When the absolute value of the exiting angle is smaller than 30 degrees, the light intensity gradually decreases as the absolute value of the exiting angle becomes smaller with a minimum intensity value at about 0.05 a.u. near 0 degree exiting angle.

[0303] For example, in FIG. **9**B, when the offset distance between the central axis of the light emitting mesa and the central axis of the small micro-lens in the X direction is 3 μm, and in the Y direction is 3 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.3 a.u. There are two other secondary peak normalized exiting light intensities at around +35 and −35 degree exiting angles. The secondary peak intensity is about 0.16 a.u. When the absolute value of the exiting angle is larger than 35 degrees, the light intensity gradually decreases to zero as the absolute value of the exiting angle becomes bigger. When the absolute value of the exiting angle is smaller than 35 degrees, the light intensity gradually decreases as the absolute value of the exiting angle becomes smaller with a minimum intensity value at about 0.05 a.u. near 0 degree exiting angle.

[0304] For example, in FIG. **9**C, when the offset distance between the central axis of the light emitting mesa and the central axis of the small micro-lens in the X direction is 4.5 μm, and in the Y direction is 4.5 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.2 a.u. There are two other secondary peak normalized exiting light intensities at around +30 and −30 degree exiting angles. The secondary peak intensity is about 0.16 a.u. When the absolute value of the exiting angle is larger than 30 degrees, the light intensity gradually decreases to zero as the absolute value of the exiting angle becomes bigger. When the absolute value of the exiting angle is smaller than 30 degrees, the light intensity gradually decreases as the absolute value of the exiting angle becomes smaller with a minimum intensity value at about 0.01 a.u. near 0 degree exiting angle.

[0305] For example, in FIG. **9**D, when the offset distance between the central axis of the light emitting mesa and the central axis of the small micro-lens in the X direction is 9 μm, and in the Y direction is 9 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.275 a.u. There are two other secondary peak normalized exiting light intensities at around +40 and −40 degree exiting angles. The secondary peak intensity is about 0.16 a.u. When the absolute value of the exiting angle is larger than 40 degrees, the light intensity gradually decreases to zero as the absolute value of the exiting angle becomes bigger. When the absolute value of the exiting angle is smaller than 40 degrees, the light intensity gradually decreases as the absolute value of the exiting angle becomes smaller with a minimum intensity value at about 0.075 a.u. near 0 degree exiting angle.

[0306] FIG. **10** illustrates a cross-sectional view of an exemplary light emitting structure **1000** having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1000** includes a small micro-lens, such as **1006** or **1008**, and a big micro-lens, such as **1002** or **1004**. The small micro-lens, such as **1006** or **1008**, is formed on the light emitting mesa, such as **401** or **403**. The big micro-lens is formed on the light emitting mesa, such as **401** or **403**, and covers the small micro-lens, such as **1006** or **1008**. The diameter of the big micro-lens, such as **1002**, is larger than the diameter of the small micro-lens, such as **1006**, so as to improve the light extraction efficiency.

[0307] In some embodiments, as shown in FIG. **10**, the central axis M-M′ of the big micro-lens **1002** is shifted from the central axis L-L′ of the light emitting mesa **401** to change the light direction, while the central axis of the small micro-lens **1006** is coaxially aligned with (or the same as) the central axis L-L′ of the light emitting mesa **401**. Preferably, the offset distance between the central axis of the big micro-lens **1002** and the central axis of the light emitting mesa **401** is not more than 12 μm, in some embodiments, is not more than 1.5 μm.

[0308] In some embodiments, the edge of the small micro-lens **1006** covers the central axis of the light emitting mesa **401**, as shown in FIG. **10**, and the edge of the big micro-lens **1002** covers the central axis of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis L-L′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **1006**, and the central axis L-L′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **1002**.

[0309] In some embodiments, the light ray **1038** emitting from the light emitting mesa **401** is redirected as **1040** while it travels through the big micro-lens **1002** and as **1042** out of the big micro-lens **1002**. The light ray **1044** emitted from the light emitting mesa **401** travels through the small micro-lens **1006** and is then redirected as **1046** out of the big micro-lens **1002**. The addition of the small micro-lens within the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle. For example, in FIG. **10**, the light rays from the big micro-lens are more focused in certain directions after exiting.

[0310] FIGS. **11**A-**11**E illustrate some exemplary simulation results for the light exiting from the big micro-lens from the light emitting structure **1000** shown in FIG. **10**, according to some embodiments. FIGS. **11**A-**11**E show the change of the exiting light intensity from the light emitting structure **1100** as the offset distance between the central axis L-L′ of the light emitting mesa, such as **401**, and the central axis J-J′ of the big micro-lens, such as **1002**, changes, while the central axis of the small micro-lens, such as **1006** is coaxially aligned with (or the same as) the central axis L-L′ of the light emitting mesa, such as **401**. The exiting light intensity was measured in a vertical plane that passes the vertical central axis of the light emitting mesa, such as the central axis L-L′ of the light emitting mesa **401**. X and Y denote the offset distances in micrometers on a horizontal plane parallel to the substrate **410** in the two orthogonal directions: X direction and Y direction. In this example, the largest horizontal dimension (such as the bottom surface) of the light emitting mesa, such **401**, is 8 μm. The largest horizontal dimension (such as the bottom surface) of the small micro-lens, such as **1006**, is 18 μm. The largest horizontal dimension of the big micro-lens (such as the bottom surface), such as **1002**, is 36 μm. FIGS. **11**A-**11**E also show the change of the exiting light intensity from the light emitting structure **1000** as the angle of the exiting light ray relative to an axis perpendicular to the substrate **410** (exiting angle θ represented in degrees) changes.

[0311] For example, in FIG. **11**A, when the offset distance between the central axis of the light emitting mesa and the central axis of the big micro-lens in the X direction is 3 μm, and in the Y direction is 3 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.28 a.u. There is one secondary peak normalized exiting light intensity at around +40 degree exiting angle and the secondary peak intensity is about 0.175 a.u. When the value of the exiting angle is larger than 40 degrees, the light intensity gradually decreases to zero as the value of the exiting angle becomes bigger. When the value of the exiting angle is smaller than 40 degrees and larger than 0 degree, the light intensity gradually decreases as the value of the existing angle becomes smaller with a minimum intensity value at about 0.05 a.u. near 0 degree exiting angle. When the value of the exiting angle is smaller than 0 degree, the light intensity stays stable till around-30 degrees, and then gradually decreases to zero as the value of the exiting angle becomes smaller.

[0312] For example, in FIG. **11**B, when the offset distance between the central axis of the light emitting mesa and the central axis of the big micro-lens in the X direction is 4.5 μm, and in the Y direction is 4.5 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.2 a.u. There is one peak normalized exiting light intensity at around +45 degree exiting angle and the peak intensity is about 0.2 a.u. When the value of the exiting angle is larger than 45 degrees, the light intensity gradually decreases to zero as the value of the exiting angle becomes bigger. When the value of the exiting angle is smaller than 45 degrees and larger than 0 degree, the light intensity gradually decreases as the value of the existing angle becomes smaller with a minimum intensity value at about 0.025 a.u. near 0 degree exiting angle. When the value of the exiting angle is smaller than 0 degree, the light intensity gradually decreases to zero as the value of the exiting angle becomes smaller.

[0313] For example, in FIG. **11**C, when the offset distance between the central axis of the light emitting mesa and the central axis of the big micro-lens in the X direction is 6 μm, and in the Y direction is 6 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.21 a.u. There is a secondary peak normalized exiting light intensity at around +50 degree exiting angle and the secondary peak intensity is about 0.18 a.u. When the value of the exiting angle is larger than 50 degrees, the light intensity gradually decreases to zero as the value of the exiting angle becomes bigger. When the value of the exiting angle is smaller than 50 degrees and larger than 0 degree, the light intensity gradually decreases as the value of the existing angle becomes smaller with a minimum intensity value at about 0.025 a.u. near 0 degree exiting angle. When the value of the exiting angle is smaller than 0 degree, the light intensity stays stable till around-20 degrees, and then gradually decreases to zero as the value of the exiting angle becomes smaller.

[0314] For example, in FIG. **11**D, when the offset distance between the central axis of the light emitting mesa and the central axis of the big micro-lens in the X direction is 9 μm, and in the Y direction is 9 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.15 a.u. There is a secondary peak normalized exiting light intensity at around +55 degree exiting angle and the secondary peak intensity is about 0.09 a.u. When the value of the exiting angle is larger than 55 degrees, the light intensity gradually decreases to zero as the value of the exiting angle becomes bigger. When the value of the exiting angle is smaller than 55 degrees and larger than 0 degree, the light intensity gradually decreases as the value of the existing angle becomes smaller with a minimum intensity value at about 0.03 a.u. near 25 degrees and the light intensity gradually increases as the value of the existing angle becomes smaller. When the value of the exiting angle is smaller than 0 degree, the light intensity stays stable till around-20 degrees, and then gradually decreases to zero as the value of the exiting angle becomes smaller.

[0315] For example, in FIG. **11**E, when the offset distance between the central axis of the light emitting mesa and the central axis of the big micro-lens in the X direction is 12 μm, and in the Y direction is 12 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.2 a.u. When the value of the exiting angle is smaller than 0 degree, the light intensity gradually decreases to zero as the value of the exiting angle becomes smaller. When the value of the exiting angle is bigger than 0 degree, the light intensity gradually decreases to zero as the value of the exiting angle becomes bigger.

[0316] FIG. **12** illustrates a cross-sectional view of an exemplary light emitting structure **1200** having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1200** includes a small micro-lens, such as **1206** or **1208**, and a big micro-lens, such as **1202** or **1204**. The small micro-lens, such as **1206** or **1208**, is formed on the light emitting mesa, such as **401** or **403**. The big micro-lens is formed on the light emitting mesa, such as **401** or **403**, and covers the small micro-lens, such as **1206** or **1208**. The diameter of the big micro-lens, such as **1202**, is larger than the diameter of the small micro-lens, such as **1206**, so as to improve the light extraction efficiency.

[0317] In some embodiments, as shown in FIG. **12**, the central axis N-N′ of the small micro-lens **1206** and the central axis of the big micro-lens **1202** shift from the central axis O-O′ of the light emitting mesa **401** to change the light direction, while the central axis of the small micro-lens **1206** is coaxially aligned with (or the same as) the central axis of the big micro-lens **1202**. Preferably, the offset distance between the central axis of the big micro-lens **1202** and the central axis of the light emitting mesa **401** is not more than 12 μm.

[0318] In some embodiments, the edge of the small micro-lens **1206** covers the central axis of the light emitting mesa **401**, as shown in FIG. **12**, and the edge of the big micro-lens **1202** covers the central axis of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis O-O′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **1206**, and the central axis O-O′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **1202**.

[0319] In some embodiments, the light ray **1236** emitting from the light emitting mesa **401** is redirected as **1238** while it travels through the small micro-lens **1206**, is then redirected as **1240** while it travels through the big micro-lens **1202** and as **1242** out of the big micro-lens **1202**. The light ray **1244** emitted from the light emitting mesa **401** travels through the small micro-lens **1206**, is then redirected as **1246** while it travels through the big micro-lens **1202**, and as **1248** out of the big micro-lens **1202**. The addition of the small micro-lens within the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle especially when the first and the big micro-lenses have different refractive indices. For example, in FIG. **12**, the light rays from the big micro-lens are more focused in certain directions around the light emitting mesa after exiting.

[0320] FIG. **13** illustrates a cross-sectional view of an exemplary light emitting structure **1300** having a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1300** includes a small micro-lens, such as **1306** or **1308**, and a big micro-lens, such as **1302** or **1304**. The small micro-lens, such as **1306** or **1308**, is formed on the light emitting mesa, such as **401** or **403**. The big micro-lens is formed on the light emitting mesa, such as **401** or **403**, and covers the small micro-lens, such as **1306** or **1308**. The diameter of the big micro-lens, such as **1302**, is larger than the diameter of the small micro-lens, such as **1306**, so as to improve the light extraction efficiency.

[0321] In some embodiments, as shown in FIG. **13**, the central axis Q-Q′ of the small micro-lens **1306** and the central axis R-R′ of the big micro-lens **1302** shift from the central axis P-P′ of the light emitting mesa **401** to change the light direction, while the central axis of the small micro-lens **1306** is not coaxially aligned with (or not the same as) the central axis of the big micro-lens **1302**.

Preferably, the offset distance between the central axis Q-Q′ of the small micro-lens **1306** and the central axis R-R′ of the big micro-lens **1302** is not more than 6 μm and is not less than 4.5 μm. In some embodiments, the central axis of the big micro-lens **1302** and the central axis of the light emitting mesa **401** is not more than 12 μm. Furthermore, the positions of the small micro-lens relative to the big micro-lens for a respective micro-lens group and light emitting mesa pair can be different within the same display panel to obtain various light directions and light angles.

[0322] In some embodiments, the edge of the small micro-lens **1306** covers the central axis P-P′ of the light emitting mesa **401**, as shown in FIG. **13**, and the edge of the big micro-lens **1302** covers the central axis P-P′ of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis P-P′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **1306**, and the central axis P-P′ of the light emitting mesa **401** intersects with the bottom surface of the second micro-lens **1302**. In another embodiments, only the edge of the small micro-lens **1306** covers the central axis P-P′ of the light emitting mesa **401**.

[0323] In some embodiments, the light ray **1338** emitting from the light emitting mesa **401** is redirected as **1340** while it travels through the big micro-lens **1302** and as **1342** out of the big micro-lens **1302**. The light ray **1344** emitted from the light emitting mesa **401** travels through the small micro-lens **1306**, is then redirected as **1346** while it travels through the big micro-lens **1302**, and as **1348** out of the big micro-lens **1302**. The addition of the small micro-lens within the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle especially when the first and the big micro-lenses have different refractive indices. For example, in FIG. **13**, the light rays from the big micro-lens are more focused in certain directions around the light emitting mesa after exiting.

[0324] FIGS. **14**A-**14**B illustrate some exemplary simulation results for the light exiting from the big micro-lens from the light emitting structure **1300** shown in FIG. **13**, according to some embodiments. FIGS. **14**A-**14**B show the change of the exiting light intensity from the light emitting structure **1300** as the offset distance between the central axis P-P′ of the light emitting mesa, such as **401**, and the central axis Q-Q′ of the small micro-lens, such as **1306**, and the offset distance between the central axis P-P′ of the light emitting mesa, such as **401**, and the central axis R-R′ of the big micro-lens, such as **1302**, both changes. The exiting light intensity was measured in a vertical plane that passes the vertical central axis of the light emitting mesa, such as the central axis P-P′ of the light emitting mesa **401**. X and Y denote the offset distances in micrometers on a horizontal plane parallel to the substrate **410** in the two orthogonal directions: X direction and Y direction. In this example, the largest horizontal dimension (such as the bottom surface) of the light emitting mesa, such **401**, is 8 μm. The largest horizontal dimension (such as the bottom surface) of the small micro-lens, such as **1306**, is 18 μm. The largest horizontal dimension of the big micro-lens (such as the bottom surface), such as **1302**, is 36 μm. FIGS. **14**A-**14**B also show the change of the exiting light intensity from the light emitting structure **1300** as the angle of the exiting light ray relative to an axis perpendicular to the substrate **410** (exiting angle θ represented in degrees) changes.

[0325] For example, in FIG. **14**A, when the offset distance between the central axis of the light emitting mesa and the central axis of the small micro-lens in the X direction is 3 μm, and in the Y direction is 3 μm, and the offset distance between the central axis of the light emitting mesa and the central axis of the big micro-lens in the X direction is 9 μm, and in the Y direction is 9 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.06 a.u. There is a peak normalized exiting light intensity at around +55 degree exiting angle and the peak intensity is about 0.095 a.u. When the value of the exiting angle is larger than +55 degrees, the light intensity gradually decreases to zero as the value of the exiting angle becomes bigger. When the value of the exiting angle is smaller than 55 degrees and larger than 0 degree, the light intensity gradually decreases as the value of the existing angle becomes smaller with a minimum intensity value at about 0.015 a.u. near 0 degree exiting angle. When the value of the exiting angle is smaller than 0 degree, the light intensity stays stable at 0.025 a.u. till around-55 degrees, and then gradually decreases to zero as the value of the exiting angle becomes smaller.

[0326] For example, in FIG. **14**B, when the offset distance between the central axis of the light emitting mesa and the central axis of the small micro-lens in the X direction is 4.5 μm, and in the Y direction is 4.5 μm, and the offset distance between the central axis of the light emitting mesa and the central axis of the big micro-lens in the X direction is 9 μm, and in the Y direction is 9 μm, the maximum normalized exiting light intensity at 0 degree exiting angle is about 0.08 a.u. There is a peak normalized exiting light intensity at around +55 degree exiting angle and the peak intensity is about 0.09 a.u. When the value of the exiting angle is larger than +55 degrees, the light intensity gradually decreases to zero as the value of the exiting angle becomes bigger. When the value of the exiting angle is smaller than +55 degrees and larger than 0 degree, the light intensity gradually decreases as the value of the existing angle becomes smaller with a minimum intensity value at about 0.015 a.u. near 0 degree exiting angle. When the value of the exiting angle is smaller than 0 degree, the light intensity stays stable at 0.025 a.u. till around-55 degrees, and then gradually decreases to zero as the value of the exiting angle becomes smaller.

[0327] In some embodiments of FIGS. **8-13**, preferably, the edge of the big micro-lens covers the central axis of the light emitting mesa, thereby avoiding the light extraction efficiency reduction. In some embodiments of FIGS. **8-13**, the material of the small micro-lens is different from the material of the big micro-lens, for example, the big micro-lens and the small micro-lens has different refractive indices with different optical properties. In some embodiments of FIGS. **8-13**, the material of the small micro-lens is the same as the material of the big micro-lens to avoid light loss at the interfaces.

[0328] FIG. **15** illustrates a cross-sectional view of an exemplary light emitting structure **1500** having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1500** includes a small micro-lens, such as **1506** or **1508**, and a big micro-lens, such as **1502** or **1504**. The big micro-lens, such as **1502** or **1504**, is formed on the light emitting mesa, such as **401** or **403**. The small micro-lens is formed above the big micro-lens, such as **1502** or **1504**, and covers a portion of the surface of the big micro-lens but does not cover the whole surface of the big micro-lens. The diameter of the big micro-lens, such as **1502**, is larger than the diameter of the small micro-lens, such as **1506**, so as to improve the light extraction efficiency. In some embodiments as shown in FIG. **15**, the small micro-lens, such as **1506** is formed directly on the big micro-lens, such as **1502**, in a way that the top surface of the big micro-lens is intact (with its original shape, such as a hemisphere) and the bottom surface of the small micro-lens conforms to the shape of the surface of the big micro-lens. In some embodiments, the overall shape of the small micro-lens is a hemisphere with the bottom surface confirms to the shape of a portion of the top surface of the big micro-lens.

[0329] In some embodiments, as shown in FIG. **15**, the central axis of the small micro-lens **1506** is defined as the axis perpendicular to the surface of the substrate **410** that passes through the center of the complete spherical shape or other shape that forms the small micro-lens (as an incomplete spherical shape or other shape). In some embodiments, the central axis J-J′ of the small micro-lens **1506** is shifted from the central axis K-K′ of the light emitting mesa **401** to change the light direction, while the central axis of the big micro-lens **1502** is coaxially aligned with (or the same as) the central axis K-K′ of the light emitting mesa **401**. In some embodiments, the offset distance between the central axis of the small micro-lens **1506** and the central axis of the light emitting mesa **401** is not more than 9 μm, preferably not more than 1.5 μm.

[0330] In some embodiments, the edge of the small micro-lens **1506** does not need to cover the central axis of the light emitting mesa **401**, as shown in FIG. **15**, while the edge of the big micro-lens **1502** covers the central axis of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis K-K′ of the light emitting mesa **401** does not need to intersect with the bottom surface of the small micro-lens **1506**, while the central axis K-K′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **1502**. In some other embodiments, not shown in FIG. **15**, both the edges of the small micro-lens **1506** and big micro-lens **1502** cover the central axis of the light emitting mesa **401**. In other words, the central axis K-K′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **1506**, and the central axis K-K′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **1502**.

[0331] In some embodiments, the light ray **1540** emitted from the light emitting mesa **401** is redirected as **1542** out of the big micro-lens **1502**. The light ray **1544** emitting from the light emitting mesa **401** is redirected as **1546** while it travels through the big micro-lens **1502**, is then redirected as **1548** while it travels through the small micro-lens **1506**, and as **1550** out of the small micro-lens **1506**. The addition of the small micro-lens above the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle. For example, in FIG. **15**, the light rays from the big micro-lens are more focused in certain directions after exiting.

[0332] In some embodiments, the simulation results for the light exiting from the big micro-lens and small micro-lens from the light emitting structure **1500** shown in FIG. **15**, are very similar to the situations as shown in FIGS. **9**A-**9**D, when the small micro-lens is within the big micro-lens embodiments as shown in FIG. **8**. For example, the exiting light intensity from the light emitting structure **1500** changes as the offset distance between the central axis K-K′ of the light emitting mesa, such as **401**, and the central axis J-J′ of the small micro-lens, such as **1506**, changes, while the central axis of the big micro-lens, such as **1502** is coaxially aligned with (or the same as) the central axis K-K′ of the light emitting mesa, such as **401**. The exiting light intensity was measured in a vertical plane that passes the vertical central axis of the light emitting mesa, such as the central axis K-K′ of the light emitting mesa **401**. X and Y denote the offset distances in micrometers on a horizontal plane parallel to the substrate **410** in the two orthogonal directions: X direction and Y direction. In this example, the largest horizontal dimension (such as the bottom surface) of the light emitting mesa, such **401**, is 8 μm. The largest horizontal dimension of the small micro-lens, such as **1506**, is 18 μm. The largest horizontal dimension of the big micro-lens (such as the bottom surface), such as **1502**, is 36 μm. The exiting light intensity from the light emitting structure **1500** also changes as the angle of the exiting light ray relative to an axis perpendicular to the substrate **410** (exiting angle θ represented in degrees) changes.

[0333] FIG. **16** illustrates a cross-sectional view of an exemplary light emitting structure **1600** having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1600** includes a small micro-lens, such as **1606** or **1608**, and a big micro-lens, such as **1602** or **1604**. The big micro-lens, such as **1602** or **1604**, is formed on the light emitting mesa, such as **401** or **403**. The small micro-lens is formed above the big micro-lens, such as **1602** or **1604**, and covers a portion of the surface of the big micro-lens but does not cover the whole surface of the big micro-lens. The diameter of the big micro-lens, such as **1602**, is larger than the diameter of the small micro-lens, such as **1606**, so as to improve the light extraction efficiency. In some embodiments as shown in FIG. **16**, the small micro-lens, such as **1606** is formed directly on the big micro-lens, such as **1602**, in a way that the top surface of the big micro-lens is intact (with its original shape, such as a hemisphere) and the bottom surface of the small micro-lens conforms to the shape of the surface of the big micro-lens. In some embodiments, the overall shape of the small micro-lens is a hemisphere with the bottom surface confirms to the shape of a portion of the top surface of the big micro-lens.

[0334] In some embodiments, as shown in FIG. **16**, the central axis of the small micro-lens **1606** is defined as the axis perpendicular to the surface of the substrate **410** that passes through the center of the complete spherical shape or other shape that forms the small micro-lens (as an incomplete spherical shape or other shape). In some embodiments, as shown in FIG. **16**, the central axis M-M′ of the big micro-lens **1602** is shifted from the central axis L-L′ of the light emitting mesa **401** to change the light direction, while the central axis of the small micro-lens **1606** is coaxially aligned with (or the same as) the central axis L-L′ of the light emitting mesa **401**. Preferably, the offset distance between the central axis of the big micro-lens **1602** and the central axis of the light emitting mesa **401** is not more than 12 μm. In some embodiments, the offset distance between the central axis of the big micro-lens **1602** and the central axis of the light emitting mesa **401** is not more than 1.5 μm.

[0335] In some embodiments, the edge of the small micro-lens **1606** covers the central axis of the light emitting mesa **401**, as shown in FIG. **16**, and the edge of the big micro-lens **1602** covers the central axis of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis L-L′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **1606**, and the central axis L-L′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **1602**.

[0336] In some embodiments, the light ray **1638** emitted from the light emitting mesa **401** is redirected as **1640** while it travels through the big micro-lens **1602**, and is then redirected as **1642** out of the big micro-lens **1602**. The light ray **1644** emitting from the light emitting mesa **401** travels through the big micro-lens **1602**, is redirected as **1646** while it travels through the small micro-lens **1606**, and is then redirected as **1648** out of the small micro-lens **1606**. The addition of the small micro-lens above the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle. For example, in FIG. **16**, the light rays from the big micro-lens are more focused in certain directions after exiting.

[0337] In some embodiments, the simulation results for the light exiting from the big micro-lens and small micro-lens from the light emitting structure **1600** shown in FIG. **16**, are very similar to the situations as shown in FIGS. **11**A-**11**E, when the small micro-lens is within the big micro-lens embodiments as shown in FIG. **10**.

[0338] FIG. **17** illustrates a cross-sectional view of an exemplary light emitting structure **1700** having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1700** includes a small micro-lens, such as **1706** or **1708**, and a big micro-lens, such as **1702** or **1704**. The big micro-lens, such as **1702** or **1704**, is formed on the light emitting mesa, such as **401** or **403**. The small micro-lens is formed above the big micro-lens, such as **1702** or **1704**, and covers a portion of the surface of the big micro-lens but does not cover the whole surface of the big micro-lens. The diameter of the big micro-lens, such as **1702**, is larger than the diameter of the small micro-lens, such as **1706**, so as to improve the light extraction efficiency. In some embodiments as shown in FIG. **17**, the small micro-lens, such as **1706** is formed directly on the big micro-lens, such as **1702**, in a way that the top surface of the big micro-lens is intact (with its original shape, such as a hemisphere) and the bottom surface of the small micro-lens conforms to the shape of the surface of the big micro-lens. In some embodiments, the overall shape of the small micro-lens is a hemisphere with the bottom surface confirms to the shape of a portion of the top surface of the big micro-lens.

[0339] In some embodiments, as shown in FIG. **17**, the central axis of the small micro-lens **1706** is defined as the axis perpendicular to the surface of the substrate **410** that passes through the center of the complete spherical shape or other shape that forms the small micro-lens (as an incomplete spherical shape or other shape). In some embodiments, as shown in FIG. **17**, the central axis N-N′ of the small micro-lens **1706** and the central axis of the big micro-lens **1702** shift from the central axis O-O′ of the light emitting mesa **401** to change the light direction, while the central axis of the small micro-lens **1706** is coaxially aligned with (or the same as) the central axis of the big micro-lens **1702**. Preferably, the offset distance between the central axis of the big micro-lens **1702** and the central axis of the light emitting mesa **401** is not more than 12 μm.

[0340] In some embodiments, the edge of the small micro-lens **1706** covers the central axis of the light emitting mesa **401**, as shown in FIG. **17**, and the edge of the big micro-lens **1702** covers the central axis of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis O-O′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **1706**, and the central axis O-O′ of the light emitting mesa **401** intersects with the bottom surface of the big micro-lens **1702**.

[0341] In some embodiments, the light ray **1738** emitting from the light emitting mesa **401** is redirected as **1740** while it travels through the big micro-lens **1702** and as **1742** out of the big micro-lens **1702**. The light ray **1744** emitted from the light emitting mesa **401** travels through the big micro-lens **1702**, is then redirected as **1746** while it travels through the small micro-lens **1706**, and as **1748** out of the small micro-lens **1706**. The addition of the small micro-lens above the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle. For example, in FIG. **17**, the light rays from the big micro-lens are more focused in certain directions around the light emitting mesa after exiting.

[0342] FIG. **18** illustrates a cross-sectional view of an exemplary light emitting structure **1800** having a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. In some embodiments, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1800** includes a small micro-lens, such as **1806** or **1808**, and a big micro-lens, such as **1802** or **1804**. The big micro-lens, such as **1802** or **1804**, is formed on the light emitting mesa, such as **401** or **403**. The small micro-lens is formed above the big micro-lens, such as **1802** or **1804**, and covers a portion of the surface of the big micro-lens but does not cover the whole surface of the big micro-lens. The diameter of the big micro-lens, such as **1802**, is larger than the diameter of the small micro-lens, such as **1806**, so as to improve the light extraction efficiency. In some embodiments as shown in FIG. **18**, the small micro-lens, such as **1806** is formed directly on the big micro-lens, such as **1802**, in a way that the top surface of the big micro-lens is intact (with its original shape, such as a hemisphere) and the bottom surface of the small micro-lens conforms to the shape of the surface of the big micro-lens. In some embodiments, the overall shape of the small micro-lens is a hemisphere with the bottom surface confirms to the shape of a portion of the top surface of the big micro-lens.

[0343] In some embodiments, as shown in FIG. **18**, the central axis of the small micro-lens **1806** is defined as the axis perpendicular to the surface of the substrate **410** that passes through the center of the complete spherical shape or other shape that forms the small micro-lens (as an incomplete spherical shape or other shape). In some embodiments, as shown in FIG. **18**, the central axis Q-Q′ of the small micro-lens **1806** and the central axis R-R′ of the big micro-lens **1802** shift from the central axis P-P′ of the light emitting mesa **401** to change the light direction, while the central axis of the small micro-lens **1806** is not coaxially aligned with (or not the same as) the central axis of the big micro-lens **1802**. Preferably, the offset distance between the central axis Q-Q′ of the small micro-lens **1806** and the central axis R-R′ of the big micro-lens **1802** is not more than 6 μm and is not less than 4.5 μm. In some embodiments, the central axis of the big micro-lens **1802** and the central axis of the light emitting mesa **401** is not more than 12 μm. Furthermore, the positions of the small micro-lens relative to the big micro-lens for a respective micro-lens group and light emitting mesa pair can be different within the same display panel to obtain various light directions and light angles.

[0344] In some embodiments, the edge of the small micro-lens **1806** covers the central axis P-P′ of the light emitting mesa **401**, as shown in FIG. **18**, and the edge of the big micro-lens **1802** covers the central axis of the light emitting mesa **401**, also as described above in FIG. **4**. In other words, the central axis P-P′ of the light emitting mesa **401** intersects with the bottom surface of the small micro-lens **1806**, and the central axis P-P′ of the light emitting mesa **401** intersects with the bottom surface of the second micro-lens **1802**. In another embodiments, only the edge of the big micro-lens **1802** covers the central axis P-P′ of the light emitting mesa **401**.

[0345] In some embodiments, the light ray **1838** emitting from the light emitting mesa **401** is redirected as **1840** while it travels through the big micro-lens **1802** and as **1842** out of the big micro-lens **1802**. The light ray **1844** emitted from the light emitting mesa **401** travels through the big micro-lens **1802**, is then redirected as **1846** while it travels through the small micro-lens **1806**, and as **1848** out of the small micro-lens **1806**. The addition of the small micro-lens above the big micro-lens can further direct and adjust the light within a certain portion of the LED pixel structure to a certain angle. For example, in FIG. **18**, the light rays from the big micro-lens are more focused in certain directions around the light emitting mesa after exiting.

[0346] In some embodiments, the simulation results for the light exiting from the big micro-lens and small micro-lens from the light emitting structure **1800** shown in FIG. **18**, are very similar to the situations as shown in FIGS. **14**A-**14**B, when the small micro-lens is within the big micro-lens embodiments as shown in FIG. **13**.

[0347] In some embodiments of FIGS. **15-18**, preferably, the edge of the big micro-lens covers the central axis of the light emitting mesa, thereby avoiding the light extraction efficiency reduction. In some preferred embodiments of FIGS. **15-18**, the material of the small micro-lens is the same as the material of the big micro-lens to avoid light loss at the interfaces. In some embodiments of FIGS. **15-18**, the material of the small micro-lens is different from the material of the big micro-lens, for example, the big micro-lens and the small micro-lens has different refractive indices with different optical properties.

[0348] FIG. **19** illustrates a cross-sectional view of an exemplary light emitting structure **1900** having at least two micro-lens and light emitting mesa pairs, and at least one of the pairs has a small micro-lens within a big micro-lens, wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **4**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. The light emitting structure **1900** includes a first pair of big micro-lens **402** and light emitting mesa **401**. The light emitting structure **1900** includes a second pair of big micro-lens **404** and light emitting mesa **403**, and a small micro-lens **1902** within the big micro-lens **404**.

[0349] Similar as shown above in any one of FIGS. **8**, **10**, **12**, and **13**, within the same micro-lens group and light emitting mesa pair, the light emitting structure **1900** includes a small micro-lens, such as **1902**, and a big micro-lens, such as **404**. The small micro-lens, such as **1902** is formed on the light emitting mesa, such as **403**, and within the big micro-lens, such as **404**. The big micro-lens, such as **404**, is formed on the light emitting mesa, such as **403**, and covers the small micro-lens, such as **1902**. The diameter of the big micro-lens, such as **404**, is larger than the diameter of the small micro-lens, such as **1902**, so as to improve the light extraction efficiency.

[0350] Within the same micro-lens group and light emitting mesa pair of the light emitting structure **1900**, the relative positions and offset distances between the central axis S-S′ of the light emitting mesa **403**, the central axis T-T′ of the small micro-lens **1902**, and the central axis U-U′ of the big micro-lens **404** is the same or similar as described in above in any one of FIGS. **8**, **10**, **12**, and **13**.

[0351] In some embodiments, in FIG. **19**, the offset distance between the central axis D-D′ of the micro-lens **402** and the central axis C-C′ of the corresponding light emitting mesa **401** is less than the offset distance between the central axis U-U′ of the big micro-lens **404** and the central axis S-S′ of the corresponding light emitting mesa **403**.

[0352] FIG. **20** illustrates a cross-sectional view of an exemplary light emitting structure **2000** having at least two micro-lens and light emitting mesa pairs, and at least one of the pairs has a small micro-lens above a big micro-lens (or the small micro-lens located farther on the light emitting path of the light emitting structure relative to the big micro-lens), wherein the lateral dimension of the small micro-lens is smaller than that of the big micro-lens, according to some embodiments. The big micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **4**. The material, shape, and fabrication of the small micro-lens is similar to the big micro-lens as described above in FIGS. **1-7**. The light emitting structure **1900** includes a first pair of big micro-lens **402** and light emitting mesa **401**. The light emitting structure **1900** includes a second pair of big micro-lens **404** and light emitting mesa **403**, and a small micro-lens **1902** above the big micro-lens **404**.

[0353] Similar as shown above in FIGS. **15-18**, within the same micro-lens group and light emitting mesa pair, the light emitting structure **2000** includes a small micro-lens, such as **2002**, and a big micro-lens, such as **404**. The big micro-lens, such as **404**, is formed on the light emitting mesa, such as **403**. The small micro-lens, such as **2002**, is formed above the big micro-lens, such as **404**, and covers a portion of the surface of the big micro-lens but does not cover the whole surface of the big micro-lens. The diameter of the big micro-lens, such as **404**, is larger than the diameter of the small micro-lens, such as **2002**, so as to improve the light extraction efficiency. In some embodiments as shown in FIG. **20**, the small micro-lens, such as **2002** is formed directly on the big micro-lens, such as **404**, in a way that the top surface of the big micro-lens is intact (with its original shape, such as a hemisphere) and the bottom surface of the small micro-lens conforms to the shape of the surface of the big micro-lens. In some embodiments, the overall shape of the small micro-lens is a hemisphere with the bottom surface confirms to the shape of a portion of the top surface of the big micro-lens.

[0354] Within the same micro-lens group and light emitting mesa pair of the light emitting structure **2000**, the relative positions and offset distances between the central axis S-S′ of the light emitting mesa **403**, the central axis T-T′ of the small micro-lens **2002**, and the central axis U-U′ of the big micro-lens **404** is the same or similar as described in above in any one of FIGS. **15-18**.

[0355] In some embodiments, in FIG. **20**, the offset distance between the central axis D-D′ of the micro-lens **402** and the central axis C-C′ of the corresponding light emitting mesa **401** is larger than the offset distance between the central axis T-T′ of the small micro-lens **2002** and the central axis S-S′ of the corresponding light emitting mesa **403**.

[0356] In some embodiments, in any one of the FIGS. **19-20**, the material of the small micro-lens, **1902** or **2002**, is the same as that of the big micro-lens **404** within the same micro-lens group and light emitting mesa pair. In some embodiments, the material of the big micro-lens **402** is the same as that of the small micro-lens, **1902** or **2002**, in another micro-lens group and light emitting mesa pair.

[0357] FIG. **21** illustrates a cross-sectional view of an exemplary light emitting structure **2100** having at least one micro-lens group and light emitting mesa pair, according to some embodiments. The micro-lens **102** and light emitting mesa **101** pair array (including related reflective cups, and optional spacers) structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **1**A. In FIG. **21**, a micro-lens **2102** is formed above the micro-lens **102**. In some embodiments, the micro-lens **2102** covers and contacts the top surface of the micro-lens **102**. The material, and fabrication of the micro-lens **2102** is similar to the micro-lens **102** as described above in FIGS. **1-7**. In some embodiments, the central axis of the micro-lens **102** and the central axis of the micro-lens **2102** are coaxially aligned or the same. In some embodiments as described above, the central axis of the micro-lens **102** is not coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In a preferred embodiment, the central axis of the micro-lens **102** is coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In some embodiments, the horizontal dimension of the micro-lens **2102** is the same or larger than the horizontal dimension of the micro-lens **102**.

[0358] In some embodiments, the material of the micro-lens **2102** is different from the material of the micro-lens **102**. In some embodiments, the refractive index of the micro-lens **102** is higher than that of the micro-lens **2102**, improving the light extraction efficiency. The light ray direction from the light emitting mesa **101** is changed via the micro-lens **102** and the micro-lens **2102**. For example, the light ray **2104** emitting from the central axis of the light emitting mesa **101** travels through the micro-lens **102** and the micro-lens **2102**, and is redirected as **2106** out of the micro-lens **2102**. The light ray **2108** emitting from the light emitting mesa **101** travels through the micro-lens **102**, is redirected as **2110** when it travels through the micro-lens **2102**, and is redirected as **2112** out of the micro-lens **2102**.

[0359] In FIG. **21**, in some embodiments, the bottom of the micro-lens **2102** conforms to the top curved surface of the micro-lens **102**. In some embodiments, the micro-lens **102** has a shape of a hemisphere. In some embodiments, the micro-lens **2102** has a cylindrical structure with a polygon shaped cross-section when the carve-out of the micro-lens **102** is not considered. When seen from a cross-sectional view without consideration of the carve-out of the micro-lens **102**, the polygon structure may be a plane figure that is described by a finite number of straight line segments connected to form a closed polygonal chain. For instance, the plain figure may be a monogon, digon, triangle, quadrilateral, pentagon, hexagon, heptagon, octagon, decagon, hendecagon, dodecagon, tridecagon, tetradecagon, pentadecagon, hexadecagon, heptadecagon, octadecagon, enneadecagon, icosagon, icositetragon, triacontagon, tetracontagon, pentacontagon, hexacontagon, heptacontagon, octacontagon, enneacontagon, hectogon or other regular or irregular shapes.

[0360] As shown in FIG. **21**, in some embodiments, the polygon shape cross-section is a trapezoid shape having an inclined top surface **2130** without consideration of the carve-out of the micro-lens **102**. In some embodiments, the inclined top surface **2130** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 10-80 degrees. In some embodiments, the inclined top surface **2130** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 30-60 degrees. In some embodiments, the inclined top surface may be curved, wavy or the combination thereof.

[0361] The addition of the micro-lens **2102** above the micro-lens **102** can further direct and adjust the light from the light emitting mesa to a certain angle. For example, in FIG. **21**, the light rays from the micro-lens **102** are more focused in certain directions around the light emitting mesa after exiting. Therefore, even when the central axis of the light emitting mesa **101** and the central axis of the micro-lens **102** are the same, the light out from the micro-lens **102** can still be redirected toward a certain angle when it travels through and out of the micro-lens **2102**. Furthermore, the light exiting angle and intensity can be further adjusted when the off-sets of the central axes of the micro-lens **102** and the micro-lens **2102** relative to the central axis of the light emitting mesa **101** are respectively changed. For example, the central axis of the micro-lens **2102** does not need to be the same as the central axis of the micro-lens **102** or the central axis of the light emitting mesa **101** and the offsets can be varied within the same display.

[0362] FIG. **22** illustrates a cross-sectional view of an exemplary light emitting structure **2200** having at least one micro-lens group and light emitting mesa pair, according to some embodiments. The micro-lens **102** and light emitting mesa **101** pair array (including related reflective cups, and optional spacers) structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **1**A. In FIG. **22**, a micro-lens **2202** is formed above the micro-lens **102**. In some embodiments, the micro-lens **2202** covers and contacts the top surface of the micro-lens **102**. The material, and fabrication of the micro-lens **2202** is similar to the micro-lens **102** as described above in FIGS. **1-7**. In some embodiments, the central axis of the micro-lens **102** and the central axis of the micro-lens **2202** are coaxially aligned or the same. In some embodiments as described above, the central axis of the micro-lens **102** is not coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In a preferred embodiment, the central axis of the micro-lens **102** is coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In some embodiments, the horizontal dimension of the micro-lens **2202** is the same or larger than the horizontal dimension of the micro-lens **102**.

[0363] In some embodiments, the material of the micro-lens **2202** is different from the material of the micro-lens **102**. In some embodiments, the refractive index of the micro-lens **102** is higher than that of the micro-lens **2202**, improving the light extraction efficiency. The light ray direction from the light emitting mesa **101** is changed via the micro-lens **102** and the micro-lens **2202**. For example, the light ray **2204** emitting from the central axis of the light emitting mesa **101** travels through the micro-lens **102** and the micro-lens **2202**, and is redirected as **2206** out of the micro-lens **2202**. The light ray **2208** emitting from the light emitting mesa **101** travels through the micro-lens **102**, is redirected as **2210** when it travels through the micro-lens **2202**, and is redirected as **2212** out of the micro-lens **2202**.

[0364] In FIG. **22**, in some embodiments, the bottom of the micro-lens **2202** conforms to the top curved surface of the micro-lens **102**. In some embodiments, the micro-lens **102** has a shape of a hemisphere. In some embodiments, the micro-lens **2202** has a cylindrical structure with a triangular shaped cross-section when the carve-out of the micro-lens **102** is not considered. As shown in FIG. **22**, in some embodiments, the micro-lens **2202** has an inclined top surface **2230**. In some embodiments, the inclined top surface **2230** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 10-80 degrees. In some embodiments, the inclined top surface **2230** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 30-60 degrees.

[0365] The addition of the micro-lens **2202** above the micro-lens **102** can further direct and adjust the light from the light emitting mesa to a certain angle. For example, in FIG. **22**, the light rays from the micro-lens **102** are more focused in certain directions around the light emitting mesa after exiting. Therefore, even when the central axis of the light emitting mesa **101** and the central axis of the micro-lens **102** are the same, the light out from the micro-lens **102** can still be redirected toward a certain angle when it travels through and out of the micro-lens **2202**. Furthermore, the light exiting angle and intensity can be further adjusted when the off-sets of the central axes of the micro-lens **102** and the micro-lens **2202** relative to the central axis of the light emitting mesa **101** are respectively changed. For example, the central axis of the micro-lens **2202** does not need to be the same as the central axis of the micro-lens **102** or the central axis of the light emitting mesa **101** and the offsets can be varied within the same display.

[0366] FIG. **23** illustrates a cross-sectional view of an exemplary light emitting structure **2300** having at least one micro-lens group and light emitting mesa pair, according to some embodiments. The micro-lens **102** and light emitting mesa **101** pair array (including related reflective cups, and optional spacers) structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **1**A. In FIG. **23**, a micro-lens **2302** is formed above the micro-lens **102**. In some embodiments, the micro-lens **2302** covers and contacts the top surface of the micro-lens **102**. The material, and fabrication of the micro-lens **2302** is similar to the micro-lens **102** as described above in FIGS. **1-7**. In some embodiments, the central axis of the micro-lens **102** and the central axis of the micro-lens **2302** are coaxially aligned or the same. In some embodiments as described above, the central axis of the micro-lens **102** is not coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In a preferred embodiment, the central axis of the micro-lens **102** is coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In some embodiments, the horizontal dimension of the micro-lens **2302** is the same or larger than the horizontal dimension of the micro-lens **102**.

[0367] In some embodiments, the material of the micro-lens **2302** is different from the material of the micro-lens **102**. In some embodiments, the refractive index of the micro-lens **102** is higher than that of the micro-lens **2302**, improving the light extraction efficiency. The light ray direction from the light emitting mesa **101** is changed via the micro-lens **102** and the micro-lens **2302**. For example, the light ray **2304** emitting from the central axis of the light emitting mesa **101** travels through the micro-lens **102** and the micro-lens **2302**, and is redirected as **2306** out of the micro-lens **2302**. The light ray **2308** emitting from the light emitting mesa **101** travels through the micro-lens **102**, is redirected as **2310** when it travels through the micro-lens **2302**, and is redirected as **2312** out of the micro-lens **2302**.

[0368] In FIG. **23**, in some embodiments, the bottom of the micro-lens **2302** conforms to the top curved surface of the micro-lens **102**. In some embodiments, the micro-lens **102** has a shape of a hemisphere. In some exemplary embodiments, a composite structure may be a combination of two or more structures. In some embodiments, the micro-lens **2302** is a composite structure with two shape components **2302-1** and **2302-2**. The micro-lens component **2302-1** is formed at the bottom of the micro-lens component **2302-2**. In some embodiments, the micro-lens component **2302-1** has a cylindrical structure with a polygon shaped cross-section when the carve-out of the micro-lens **102** is not considered. As shown in FIG. **23**, in some embodiments, the polygon shape cross-section is a trapezoid shape having an inclined top surface **2330** without consideration of the carve-out of the micro-lens **102**. As shown in FIG. **23**, in some embodiments, the micro-lens component **2302-1** has an inclined top surface **2330**. In some embodiments, the inclined top surface **2330** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 10-80 degrees. In some embodiments, the inclined top surface **2330** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 30-60 degrees. As shown in FIG. **23**, in some embodiments, the micro-lens component **2302-2** has a shape of a hemisphere with a flat bottom side surface and a convex top side surface. The flat bottom side surface of the micro-lens component **2302-2** touches and covers seamlessly with the inclined top surface **2330** of the micro-lens component **2302-1**. The flat bottom side surface of the micro-lens component **2302-2** and the inclined top surface **2330** of the micro-lens component **2302-1** have the same shape and dimension, and they both incline at the same angle relative to the axis perpendicular to the surface of the substrate **110**. The two micro-lens components **2302-1** and **2302-2** are integral portions of the micro-lens **2302** and form a composite shape of the micro-lens **2302**.

[0369] The addition of the micro-lens **2302** above the micro-lens **102** can further direct and adjust the light from the light emitting mesa to a certain angle. For example, in FIG. **23**, the light rays from the micro-lens **102** are more focused in certain directions around the light emitting mesa after exiting. Therefore, even when the central axis of the light emitting mesa **101** and the central axis of the micro-lens **102** are the same, the light out from the micro-lens **102** can still be redirected toward a certain angle when it travels through and out of the micro-lens **2302**. Furthermore, the light exiting angle and intensity can be further adjusted when the off-sets of the central axes of the micro-lens **102** and the micro-lens **2302** relative to the central axis of the light emitting mesa **101** are respectively changed. For example, the central axis of the micro-lens **2302** does not need to be the same as the central axis of the micro-lens **102** or the central axis of the light emitting mesa **101** and the offsets can be varied within the same display.

[0370] FIG. **24** illustrates a cross-sectional view of an exemplary light emitting structure **2400** having at least one micro-lens group and light emitting mesa pair, according to some embodiments. The micro-lens **102** and light emitting mesa **101** pair array (including related reflective cups, and optional spacers) structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **1**A. In FIG. **24**, a micro-lens **2402** is formed above the micro-lens **102**. In some embodiments, the micro-lens **2402** covers and contacts the top surface of the micro-lens **102**. The material, and fabrication of the micro-lens **2402** is similar to the micro-lens **102** as described above in FIGS. **1-7**. In some embodiments, the central axis of the micro-lens **102** and the central axis of the micro-lens **2402** are coaxially aligned or the same. In some embodiments as described above, the central axis of the micro-lens **102** is not coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In a preferred embodiment, the central axis of the micro-lens **102** is coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In some embodiments, the horizontal dimension of the micro-lens **2402** is the same or larger than the horizontal dimension of the micro-lens **102**.

[0371] In some embodiments, the material of the micro-lens **2402** is different from the material of the micro-lens **102**. In some embodiments, the refractive index of the micro-lens **102** is higher than that of the micro-lens **2402**, improving the light extraction efficiency. The light ray direction from the light emitting mesa **101** is changed via the micro-lens **102** and the micro-lens **2402**. For example, the light ray **2404** emitting from the central axis of the light emitting mesa **101** travels through the micro-lens **102** and the micro-lens **2402**, and is redirected as **2406** out of the micro-lens **2402**. The light ray **2408** emitting from the light emitting mesa **101** travels through the micro-lens **102**, is redirected as **2410** when it travels through the micro-lens **2402**, and is redirected as **2412** out of the micro-lens **2402**.

[0372] In FIG. **24**, in some embodiments, the bottom of the micro-lens **2402** conforms to the top curved surface of the micro-lens **102**. In some embodiments, the micro-lens **102** has a shape of a hemisphere. In some embodiments, the micro-lens **2402** is a composite structure with two shape components **2402-1** and **2402-2**. The micro-lens component **2402-1** is formed at the bottom of the micro-lens component **2402-2**. The micro-lens component **2402-1** has a cylindrical structure with a triangular shaped cross-section when the carve-out of the micro-lens **102** is not considered. As shown in FIG. **24**, in some embodiments, the micro-lens component **2402-1** has an inclined top surface **2430**. In some embodiments, the inclined top surface **2430** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 10-80 degrees. In some embodiments, the inclined top surface **2430** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 30-60 degrees. As shown in FIG. **24**, in some embodiments, the micro-lens component **2402-2** has a shape of a hemisphere with a flat bottom side surface and a convex top side surface. The flat bottom side surface of the micro-lens component **2402-2** touches and covers seamlessly with the inclined top surface **2430** of the micro-lens component **2402-1**. The flat bottom side surface of the micro-lens component **2402-2** and the inclined top surface **2430** of the micro-lens component **2402-1** have the same shape and dimension, and they both incline at the same angle relative to the axis perpendicular to the surface of the substrate **110**. The two micro-lens components **2402-1** and **2402-2** are integral portions of the micro-lens **2402** and form a composite shape of the micro-lens **2402**.

[0373] The addition of the micro-lens **2402** above the micro-lens **102** can further direct and adjust the light from the light emitting mesa to a certain angle. For example, in FIG. **24**, the light rays from the micro-lens **102** are more focused in certain directions around the light emitting mesa after exiting. Therefore, even when the central axis of the light emitting mesa **101** and the central axis of the micro-lens **102** are the same, the light out from the micro-lens **102** can still be redirected toward a certain angle when it travels through and out of the micro-lens **2402**. Furthermore, the light exiting angle and intensity can be further adjusted when the off-sets of the central axes of the micro-lens **102** and the micro-lens **2402** relative to the central axis of the light emitting mesa **101** are respectively changed. For example, the central axis of the micro-lens **2402** does not need to be the same as the central axis of the micro-lens **102** or the central axis of the light emitting mesa **101** and the offsets can be varied within the same display.

[0374] FIG. **25** illustrates a cross-sectional view of an exemplary light emitting structure **2500** having at least one micro-lens group and light emitting mesa pair, according to some embodiments. The micro-lens **102** and light emitting mesa **101** pair array (including related reflective cups, and optional spacers) structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **1**A. In FIG. **25**, a micro-lens **2502** is formed above the micro-lens **102**. In some embodiments, the micro-lens **2502** covers and contacts the top surface of the micro-lens **102**. In some embodiments, the material, and fabrication of the micro-lens **2502** is similar to the micro-lens **102** as described above in FIGS. **1-7**. In some embodiments, the micro-lens **2502** is a diffraction micro-lens. In some embodiments, the central axis of the micro-lens **102** and the center point of the top surface **2540** of the diffraction micro-lens **2502** intersects. In a preferred embodiment, the central axis of the micro-lens **102** is coaxially aligned with or the same as the central axis B-B′ of the light emitting mesa **101**. In some embodiments, the horizontal dimension of the micro-lens **2502** is the same or larger than the horizontal dimension of the micro-lens **102**.

[0375] In some embodiments, the material of the micro-lens **2502** is different from the material of the micro-lens **102**. In some embodiments, the refractive index of the micro-lens **102** is higher than that of the micro-lens **2502**, improving the light extraction efficiency. In some embodiments, the refractive index of the micro-lens **102** is smaller than that of the micro-lens **2502**. The light ray direction from the light emitting mesa **101** is changed via the micro-lens **102** and the micro-lens **2502**. For example, the light ray **2504** emitting from the central axis of the light emitting mesa **101** travels through the micro-lens **102** and the micro-lens **2502**, and is redirected as **2506** out of the micro-lens **2502**. The light ray **2508** emitting from the light emitting mesa **101** travels through the micro-lens **102**, is redirected as **2510** when it travels through the micro-lens **2502**, and is redirected as **2512** out of the micro-lens **2502**.

[0376] In FIG. **25**, in some embodiments, the bottom of the micro-lens **2502** conforms to the top curved surface of the micro-lens **102**. In some embodiments, the micro-lens **102** has a shape of a hemisphere. In some embodiments, the micro-lens **2502** is a composite structure with four shape components **2502-1**, **2502-2**, **2502-3**, and **2502-4**. In some embodiments, the micro-lens component **2502-1** has a cylindrical structure with a polygon shaped cross-section when the carve-out of the micro-lens **102** is not considered. As shown in FIG. **25**, in some embodiments, the polygon shape cross-section is a trapezoid shape having an inclined top surface **2530** without consideration of the carve-out of the micro-lens **102**. In some other embodiments, not as shown in FIG. **25**, the micro-lens component **2502-1** has a cylindrical structure with a triangular shaped cross-section when the carve-out of the micro-lens **102** is not considered, similar as the micro-lens component as described above in FIGS. **22** and **24**. The micro-lens component **2502-1** is formed at the bottom of the micro-lens components **2502-2**, **2502-3**, and **2502-4**.

[0377] As shown in FIG. **25**, in some embodiments, the micro-lens component **2502-1** has an inclined top surface **2530**. In some embodiments, the inclined top surface **2530** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 10-80 degrees. In some embodiments, the inclined top surface **2530** has an angle relative to an axis perpendicular to the surface of the substrate **110** in the range of 30-60 degrees. As shown in FIG. **25**, in some embodiments, the micro-lens component **2502-2** has a shape of a hemisphere with a flat bottom side surface and a convex top side surface. In some embodiments, the micro-lens component **2502-2** has a central axis V-V′ that passes through the center point of the top surface and the center point of the bottom surface of the hemisphere shape micro-lens component **2502-2**. In some embodiments, the center point may refer to a point that is related to a geometrical figure in such a way that for any point on the figure there is another point on the figure such that a straight line joining the two points is bisected by the original point. For example, the diffraction micro-lens **2502** may be a hemisphere structure, and therefore the center point of the top surface of the diffraction micro-lens **2502** may refer to the peak point of the top surface of the hemisphere structure.

[0378] The central axis V-V′ is inclined while the central axis of the micro-lens **102** is vertical. In some embodiments, the central axis V-V′ of the micro-lens component **2502-2** is perpendicular to the inclined top surface **2530** of the micro-lens component **2502-1**. The flat bottom side surface of the micro-lens component **2502-2** touches and covers seamlessly with a central portion of the inclined top surface **2530** of the micro-lens component **2502-1**. The flat bottom side surface of the micro-lens component **2502-2** and the inclined top surface **2530** of the micro-lens component **2502-1** contacts each other, and they both incline at the same angle relative to the axis perpendicular to the surface of the substrate **110**. In some embodiments, around the micro-lens component **2502-2**, some polygon structure is formed such as, micro-lens components **2502-3** and **2502-4** from the cross section in FIG. **25** to increase diffraction. In some embodiments, the polygon structure is similar to the stair-like structure described in FIG. **2**C. In some embodiments the stair-like structure micro-lens components **2502-3** and **2502-4** has an increased step top surface toward the edge of the micro-lens **2502**. In some embodiments, the micro-lens components **2502-3** and **2502-4** have multiple surfaces that are inclined at different angles to redirect light from the light emitting structure **2500** into different directions. The four micro-lens components **2502-1**, **2502-2**, **2502-3**, and **2502-4** are integral portions of the micro-lens **2502** and form a composite shape of the micro-lens **2502**. In some embodiments, the micro-lens **2502** has multiple surfaces that are inclined at different angles to redirect light from the light emitting structure **2500** into different directions.

[0379] The addition of the diffraction micro-lens **2502** above the micro-lens **102** can further direct and adjust the light from the light emitting mesa to a certain angle. For example, in FIG. **25**, the light rays from the micro-lens **102** are more diffracted in certain directions around the light emitting mesa after exiting. Therefore, even when the central axis of the light emitting mesa **101** and the central axis of the micro-lens **102** are the same, the light out from the micro-lens **102** can still be redirected toward a number of angles when it travels through and out of the micro-lens **2502**. Furthermore, the light exiting angle and intensity can be further adjusted when the off-sets of the central axes of the micro-lens **102** and the micro-lens **2502** relative to the central axis of the light emitting mesa **101** are respectively changed. For example, the central axis of the micro-lens **2502** does not need to be the same as the central axis of the micro-lens **102** or the central axis of the light emitting mesa **101** and the offsets can be varied within the same display.

[0380] In some embodiments, lights with certain wavelengths may be selectively passed through or reflected by the diffraction micro-lens **2502** according to the design thereof. In some embodiments, the diffraction lens may be on the micro-lens **102** and the bottom surface of the diffraction micro-lens **2502** is no larger than the bottom surface of the micro-lens **102**.

[0381] In some embodiments, the diffraction micro-lens **2502** may comprise a single slit where the diffraction effect may occur. In some embodiments, the diffraction micro-lens **2502** may comprise a double slit where the diffraction effect may occur. In some embodiments, the diffraction micro-lens **2502** may comprise one or more circular apertures where the diffraction effect may occur. In some embodiments, the diffraction micro-lens **2502** may comprise one or more periodic and/or non-periodic structures where the diffraction effect may occur.

[0382] In some exemplary embodiments, the diffraction micro-lens **2502** may be a Bragg mirror. The Bragg mirror may comprise an alternating sequence of layers of two different optical materials. For example, the Bragg mirror may be a quarter-wave mirror. Each layer of the optical materials may have a different thickness corresponding to one quarter of the wavelengths for which the Bragg mirror is designed. When the Bragg mirror is designed for larger angles of incidence, accordingly thicker layers may be needed. Therefore, selected wavelengths of the light emitted from the light emitting mesa and/or the light passing through the micro-lens can be reflected by the Bragg mirror. In some embodiments, the Bragg mirror is implemented on the top surface of the micro-lens **2502**. In some embodiments, the Bragg mirror is only implemented on the surface of micro-lens components **2502-3** and **2502-4**.

[0383] In some embodiments, a Bragg mirror for a red light LED include multiple layers of Au or/and Indium Tin Oxide (ITO).

[0384] In one example, the Bragg mirror may comprise an alternating arrangement of TiO2 and SiO2 layers. In one example, the following Distributed Bragg reflector (DBR) structure shown in Table 1 may be used to reflect green light from a green light LED:

TABLE-US-00001 TABLE 1 DBR layer structure for a green light LED reflective layer. Layer composition Layer thickness (in nanometer) SiO2 1000 TiO2 109.54 SiO2 318.48 TiO2 64.95 SiO2 106.07 TiO2 245.76 SiO2 137.08 TiO2 65.14 SiO2 106.77 TiO2 338.95 SiO2 37.27 TiO2 12.41 SiO2 352.18 TiO2 70.83 SiO2 229.25 Indium tin oxide (ITO) 20

[0385] In one example, the following DBR structure shown in Table 2 may be used to reflect blue light from a blue light LED:

TABLE-US-00002 TABLE 2 DBR layer structure for a blue light LED reflective layer. Layer composition Layer thickness (in nanometer) SiO2 1000 SiO2 183.36 TiO2 96 SiO2 84.65 TiO2 51.37 SiO2 332.37 TiO2 79.95 SiO2 423.13 TiO2 52.99 SiO2 35.87 TiO2 235.03 SiO2 253.67 TiO2 64.38 SiO2 336.08 ITO 20

[0386] The light emitting structure **2500** may use the Bragg mirror with different structures. In some embodiments, the Bragg mirror may be a dielectric mirror based on thin-film coating technology, fabricated, for example with electron beam evaporation or with ion beam sputtering. In these embodiments, the Bragg mirror may comprise amorphous materials. In some embodiments, the Bragg mirror may be fiber Bragg gratings, including long-period fiber gratings. In these embodiments, the fiber Bragg gratings can be fabricated by irradiating a fiber with spatially patterned ultraviolet light. In some embodiments, the Bragg mirror may be volume Bragg gratings which can be made in photosensitive bulk glass. In some embodiments, the Bragg mirror may be a semiconductor Bragg mirror which can be produced with lithographic methods. Other types of Bragg mirror may be used based on, e.g., corrugated waveguide structures which can be fabricated via lithography.

[0387] In some embodiments, the Bragg mirror may use other multilayer mirror designs which is different from the simple quarter-wave design. In these embodiments, the Bragg mirror may have a lower reflectance for the same number of layers, but can be optimized for example as dichroic mirrors or as dispersive chirped mirrors for dispersion compensation.

[0388] In some embodiments, as described in FIG. **1**A, the micro-lens **102** can be formed in many different shapes or composite shapes. FIG. **26** illustrates a cross-sectional view of an exemplary light emitting structure **2600** having at least one micro-lens and light emitting mesa pair, according to some embodiments. The micro-lens **2602** and light emitting mesa **2601** pair array (including related reflective cups, and optional spacers) structure, dimension, shape, fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **1**A. In some embodiments, the micro-lens **2602** is an elliptical micro-lens formed by a quarter of sphere combined with a quarter of ellipsoid. In some embodiments, not shown in FIG. **26**, other micro-lenses as described in FIGS. **8-25** can be formed above or within the micro-lens **2602**.

[0389] In a preferred embodiment, the central axis of the micro-lens **2602** (the axis that passes through the center point of the bottom surface of the micro-lens **2602** that is vertical to the surface of the substrate) is not coaxially aligned with or the same as the central axis of the light emitting mesa **2601**.

[0390] In some embodiments, the micro-lens **2602** is a composite structure with two shape components **2602-1**, and **2602-2**. In some embodiments, the micro-lens component **2602-1** is a quarter of a sphere. In some embodiments, the micro-lens component **2602-2** is a quarter of an ellipsoid. The two shape components **2602-1**, and **2602-2** form seamlessly and integrate with each other. For example, the diameter of the micro-lens component **2602-1** matches the diameter along the Z direction of the micro-lens component **2602-2** and the diameter along the direction that is perpendicular to the cross-section **2600**. The two micro-lens components **2602-1**, and **2602-2** are integral portions of the micro-lens **2602** and form a composite shape of the micro-lens **2602**

[0391] The light ray direction from the light emitting mesa **2601** is changed via the micro-lens **2602** in a different angle from different surfaces of the micro-lens **2602**. FIG. **26** shows a simulation of the light ray paths of many different light rays from the light emitting mesa **2601** into the micro-lens **2602** including the effect of diffraction and reflection. For example, the light ray **2604** emitting from the central axis of the light emitting mesa **2601** travels through the micro-lens **2602**, and is redirected as **2606** out of the micro-lens **2602**. The light ray **2608** emitting from the light emitting mesa **2601** travels through the micro-lens **2602**, is redirected as **2610** out of the micro-lens **2602**.

[0392] In some embodiments, the radius of the sphere is not more than 9 μm and the long radius of the ellipsoid is not more than 18 μm. In some embodiments, similar as in FIG. **1**A for the micro-lens **102**, in order to improve the light extraction efficiency, the offset distance of the central axis of the micro-lens **2602** from the central axis of the light emitting mesa **2601** in the horizontal level is not more than 4.5 μm. In some embodiments, similar as in FIG. **1**A for the micro-lens **102**, the edge of the micro-lens **2602** covers the central axis of the light emitting mesa **2601**.

[0393] The composite asymmetric shape of the micro-lens **2602** can further direct and adjust the light from the light emitting mesa to a certain angle. For example, in FIG. **26**, the light rays from the micro-lens **2602** are more diffracted in certain directions and more focused in other directions around the light emitting mesa after exiting. Therefore, even when the central axis of the light emitting mesa **2601** and the central axis of the micro-lens **2602** are the same, the light out from the micro-lens **2602** can still be redirected toward a number of angles when it travels through and out of the micro-lens **2602**. Furthermore, the light exiting angle and intensity can be further adjusted when the off-sets of the central axes of the micro-lens **2602** and the micro-lens above the micro-lens **2602** relative to the central axis of the light emitting mesa **2601** are respectively changed. For example, the central axis of the micro-lens above the micro-lens **2602** does not need to be the same as the central axis of the micro-lens **2602** or the central axis of the light emitting mesa **2601** and the offsets can be varied within the same display.

[0394] FIG. **27** illustrates a cross-sectional view of an exemplary light emitting structure **2700** having at least two micro-lens and light emitting mesa pairs, and at least one of the micro-lenses has a breach portion covered by a reflective part, according to some embodiments. The micro-lens and light emitting mesa pair (including related reflective cups, and optional spacers) array structure, dimension, shape (without consideration of the breach), fabrication, and material, is the same or similar to the light emitting structure described in any one of FIGS. **1-7**, especially in FIG. **4**. The light emitting structure **2700** includes a first pair of micro-lenses **2702** and light emitting mesa **401**. The light emitting structure **2700** includes a second pair of micro-lenses **2704** and light emitting mesa **403**.

[0395] In some embodiments, the micro-lens **2702** or **2704** has a carved-out portion as a breach at one side of the top surface of the micro-lens. In one example, the breach **2710** leaves an inclined flat surface on the micro-lens **2702**. In another example, the breach **2720** leaves a curved surface on the micro-lens **2704**. In some embodiments, a reflective part is formed on or attached to the surface of the breach. For example, a reflective part **2712** is formed on the surface of the breach **2710**. A reflective part **2722** is formed on the surface of the breach **2720**. The reflective part is a surface conforms to the shape of the surface of the breach on the micro-lens. For instance, the reflective part **2712** on the micro-lens **2702** is an incline flat surface layer. The reflective part **2722** on the micro-lens **2704** is a curved surface layer. The shape of the breach and reflective part is not limited to flat and curved shapes, other shapes such as a portion of the surface of a rectangle, triangle, square, polygon, and other composite shape might be possible.

[0396] In some embodiments, the reflective part **2712** or **2722** may include a reflective layer to improve light reflection within a certain portion of the micro-lens. In these embodiments, the reflective layer may have a high reflectivity. For example, the reflectivity of the reflective layer may be above 60%. In another example, the reflectivity of the reflective layer may be above 70%. In yet another example, the reflectivity of the reflective layer may be above 80%. Y et in these embodiments, the material of the reflective layer may comprise metal selected from one or more of Rh, Al, Ag, and Au, or comprise two sublayers with different refractive index. In some embodiments, the reflective layer may be a Bragg mirror as described above in FIG. **25**.

[0397] In some embodiments, the light ray direction from the light emitting mesa **401** is changed via the micro-lens **2702** and the reflective part **2712** in different angles from different surfaces of the micro-lens **2702**. For example, the light ray **2714** emitting from the light emitting mesa **401** travels through the micro-lens **2702**, is reflected as **2716** within the micro-lens **2702**, and is redirected as **2718** out of the micro-lens **2702**. In some embodiments, the light ray direction from the light emitting mesa **403** is changed via the micro-lens **2704** and the reflective part **2722** in different angles from different surfaces of the micro-lens **2704**. For example, the light ray **2724** emitting from the light emitting mesa **403** travels through the micro-lens **2704**, is reflected as **2726** within the micro-lens **2704**, and is redirected as **2728** out of the micro-lens **2704**.

[0398] The asymmetric shape of the micro-lens with a breach combined with a reflective part can further direct and adjust the light from the light emitting mesa to a certain angle. For example, in FIG. **27**, the light rays from the micro-lens **2702** or **2704** are more diffracted in certain directions and more focused in other directions around the light emitting mesa after exiting. Therefore, even when the central axis of the light emitting mesa, such as **401**, and the central axis of the micro-lens, such as **2702**, are the same, the light out from the micro-lens **2702** can still be redirected toward a number of angles when it travels through and out of the micro-lens **2702**. Furthermore, the light exiting angle and intensity can be further adjusted when the off-set of the central axis of the micro-lens, such as **2702**, relative to the central axis of the light emitting mesa, such as **401**, and the position of the breach, such as **2710**, on the micro-lens, are respectively changed. For example, the off-set of the central axis of the micro-lens and the central axis of the light emitting mesa, the position of the breach, and the shape and type of the breach can be varied within the same display.

[0399] Although the detailed description contains many specifics, these should not be construed as limiting the scope of the invention but merely as illustrating different examples and aspects of the invention. It should be appreciated that the scope of the invention includes other embodiments not discussed in detail above. For example, micro-lenses with different shape bases may also be used, such as square base or other polygon base. Various other modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus of the present invention disclosed herein without departing from the spirit and scope of the invention as defined in the appended claims. Therefore, the scope of the invention should be determined by the appended claims and their legal equivalents.

[0400] Further embodiments also include various subsets of the above embodiments including embodiments shown in FIGS. **1-27** combined or otherwise re-arranged in various other embodiments. For example, each embodiment of the micro-lens (group) and light emitting mesa pair structure described in any one of FIGS. **1-27** can be mixed with any other embodiments described in FIGS. **1-27** within the same display panel.

[0401] FIG. **28** is a top view of a micro LED display panel **2800**, in accordance with some embodiments. The display panel **2800** includes a data interface **2810**, a control module **2820** and a pixel region **2850**. The data interface **2810** receives data defining the image to be displayed. The source(s) and format of this data will vary depending on the application. The control module **2820** receives the incoming data and converts it to a form suitable to drive the pixels in the display panel. The control module **2820** may include digital logic and/or state machines to convert from the received format to one appropriate for the pixel region **2850**, shift registers or other types of buffers and memory to store and transfer the data, digital-to-analog converters and level shifters, and scan controllers including clocking circuitry.

[0402] The pixel region **2850** includes an array of mesas (not separately shown from the LED **2834** in FIG. **28**) including pixels. The pixels include micro LEDs, such as a single color or multi-color LED **2834**, integrated with pixel drivers, for example as described above. An array of micro-lens (not separately shown from the LED **2834** in FIG. **28**) covers the top of the array of mesas. In this example, the display panel **2800** is a color RGB display panel. It includes red, green and blue pixels. Within each pixel, the LED **2834** is controlled by a pixel driver. The pixel makes contact to a supply voltage (not shown) and ground via a ground pad **2836**, and also to a control signal, according to the embodiments shown previously. Although not shown in FIG. **28**, the p-electrode of the LED **2834** and the output of the driving transistor are electrically connected. The LED current driving signal connection (between p-electrode of LED and output of the pixel driver), ground connection (between n-electrode and system ground), the supply voltage V dd connection (between source of the pixel driver and system V dd), and the control signal connection to the gate of the pixel driver are made in accordance with various embodiments. Any of the micro-lens array disclosed herein can be implemented with the micro LED display panel **2800**.

[0403] FIG. **28** is merely a representative figure. Other designs will be apparent. For example, the colors do not have to be red, green and blue. They also do not have to be arranged in columns or stripes. As one example, apart from the arrangement of a square matrix of pixels shown in FIG. **28**, an arrangement of hexagonal matrix of pixels can also be used to form the display panel **2800**.

[0404] In some applications, a fully programmable rectangular array of pixels is not necessary. Other designs of display panels with a variety of shapes and displays may also be formed using the device structures described herein. One class of examples is specialty applications, including signage and automotive. For example, multiple pixels may be arranged in the shape of a star or a spiral to form a display panel, and different patterns on the display panel can be produced by turning on and off the LEDs. Another specialty example is automobile headlights and smart lighting, where certain pixels are grouped together to form various illumination shapes and each group of LED pixels can be turned on or off or otherwise adjusted by individual pixel drivers.

[0405] Even the lateral arrangement of devices within each pixel can vary. In FIG. **1**A, the LEDs and pixel drivers are arranged vertically, i.e., each LED is located on top of the corresponding pixel driver circuit. Other arrangements are possible. For example, the pixel drivers could also be located “behind”, “in front of”, or “beside” the LED.

[0406] Different types of display panels can be fabricated. For example, the resolution of a display panel can range typically from 8×8 to 3840×2160. Common display resolutions include QVGA with 320×240 resolution and an aspect ratio of 4:3, XGA with 1024×768 resolution and an aspect ratio of 4:3, D with 1280×720 resolution and an aspect ratio of 16:9, FHD with 1920×1080 resolution and an aspect ratio of 16:9, UHD with 3840×2160 resolution and an aspect ratio of 16:9, and 4K with $326×2160 resolution. There can also be a wide variety of pixel sizes, ranging from sub-micron and below to 10 mm and above. The size of the overall display region can also vary widely, ranging from diagonals as small as tens of microns or less up to hundreds of inches or more.

[0407] Different applications will also have different requirements for optical brightness and viewing angle. Example applications include direct viewing display screens, light engines for home/office projectors and portable electronics such as smart phones, laptops, wearable electronics, AR and VR glasses, and retinal projections. The power consumption can vary from as low as a few milliwatts for retinal projectors to as high as kilowatts for large screen outdoor displays, projectors, and smart automobile headlights. In terms of frame rate, due to the fast response (nanoseconds) of inorganic LEDs, the frame rate can be as high as KHz, or even M Hz for small resolutions.

[0408] Further embodiments also include various subsets of the above embodiments including embodiments as shown in FIGS. **1**-**28** combined or otherwise re-arranged in various other embodiments.

[0409] Although the detailed description contains many specifics, these should not be construed as limiting the scope of the invention but merely as illustrating different examples and aspects of the invention. It should be appreciated that the scope of the invention includes other embodiments not discussed in detail above. For example, the approaches described above can be applied to the integration of functional devices other than LEDs and OLEDs with control circuitry other than pixel drivers. Examples of non-LED devices include vertical cavity surface emitting lasers (VCSEL), photodetectors, micro-electro-mechanical system (MEMS), silicon photonic devices, power electronic devices, and distributed feedback lasers (DFB). Examples of other control circuitry include current drivers, voltage drivers, trans-impedance amplifiers, and logic circuits.

[0410] The preceding description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the embodiments described herein and variations thereof. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the subject matter disclosed herein. Thus, the present disclosure is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the following claims and the principles and novel features disclosed herein.

[0411] Features of the present invention can be implemented in, using, or with the assistance of a computer program product, such as a storage medium (media) or computer readable storage medium (media) having instructions stored thereon/in which can be used to program a processing system to perform any of the features presented herein. The storage medium can include, but is not limited to, high-speed random access memory, such as DRAM, SRAM, DDR RAM or other random access solid state memory devices, and may include non-volatile memory, such as one or more magnetic disk storage devices, optical disk storage devices, flash memory devices, or other non-volatile solid state storage devices. Memory optionally includes one or more storage devices remotely located from the CPU(s). Memory or alternatively the non-volatile memory device(s) within the memory, comprises a non-transitory computer readable storage medium.

[0412] Stored on any machine readable medium (media), features of the present invention can be incorporated in software and/or firmware for controlling the hardware of a processing system, and for enabling a processing system to interact with other mechanisms utilizing the results of the present invention. Such software or firmware may include, but is not limited to, application code, device drivers, operating systems, and execution environments/containers.

[0413] It will be understood that, although the terms "first," "second," etc. may be used herein to describe various elements or steps, these elements or steps should not be limited by these terms. These terms are only used to distinguish one element or step from another.

[0414] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the claims. As used in the description of the embodiments and

the appended claims, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.
[0415] As used herein, the term “if” may be construed to mean “when” or “upon” or “in response to determining” or “in accordance with a determination” or “in response to detecting,” that a stated condition precedent is true, depending on the context. Similarly, the phrase “if it is determined [that a stated condition precedent is true]” or “if [a stated condition precedent is true]” or “when [a stated condition precedent is true]” may be construed to mean “upon determining” or “in response to determining” or “in accordance with a determination” or “upon detecting” or “in response to detecting” that the stated condition precedent is true, depending on the context.
[0416] The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the claims to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain principles of operation and practical applications, to thereby enable others skilled in the art to best utilize the invention and the various embodiments.

Claims

1. A light emitting structure array system with a micro-lens array structure comprising: a first light emitting mesa on a semiconductor substrate, including: a light emitting layer; a bottom bonding layer, at a bottom of the light emitting layer and bonded with a semiconductor substrate; a top electrode layer, covering the first light emitting mesa and electrically connected with a reflective cup surrounding the first light emitting mesa, wherein the reflective cup is electrically connected with the semiconductor substrate; and an insulation layer covering a side wall of the light emitting layer; and a first micro-lens, formed above the first light emitting mesa, wherein a central axis of the first micro-lens is coaxially aligned with a central axis of the first light emitting mesa.
2. The light emitting structure array system according to claim 1, wherein the top electrode layer is in electrical contact with at least a portion of a top surface of the light emitting layer.
3. The light emitting structure array system according to claim 2, wherein a top surface of the insulation layer is flush with the top surface of the light emitting layer.
4. The light emitting structure array system according to claim 2, wherein a top surface of the insulation layer is higher than the top surface of the light emitting layer.
5. The light emitting structure array system according to claim 4, wherein the insulation layer covers at least a portion of the top surface of the light emitting layer.
6. The light emitting structure array system according to claim 4, wherein the insulation layer does not cover at least a portion of the top surface of the light emitting layer.
7. The light emitting structure array system according to claim 1, further comprising a sensor, wherein emitting light rays from the first light emitting mesa through the first micro-lens are converted together into the sensor.
8. The light emitting structure array system according to claim 2, wherein a sensor is arranged at a central axis of the light emitting structure array system.
9. The light emitting structure array system according to claim 2, wherein a sensor is not arranged at a central axis of the light emitting structure array system.
10. The light emitting structure array system according to claim 1, wherein a material of the first micro-lens is silicon oxide or organic materials.

11. The light emitting structure array system according to claim 1, wherein an inside wall of the reflective cup is stair-shaped.
12. The light emitting structure array system according to claim 1, wherein an inside wall of the reflective cup comprises a plurality of sidewalls at different angles.
13. The light emitting structure array system according to claim 1, further comprising a spacer, formed between the first light emitting mesa and the first micro-lens.
14. The light emitting structure array system according to claim 13, wherein a height of the spacer is less than height of the first micro-lens.
15. The light emitting structure array system according to claim 1, wherein the semiconductor substrate is an IC substrate.
16. The light emitting structure array system according to claim 1, further comprises a second light emitting mesa and a corresponding second micro-lens, wherein a relative position of the first micro-lens relative to the first light emitting mesa is different from a relative position of the second micro-lens relative to the corresponding second light emitting mesa.
17. The light emitting structure array system according to claim 16, wherein a bottom surface of the second micro-lens intersects with a central axis of the corresponding second light emitting mesa.
18. The light emitting structure array system according to claim 16, wherein material of the first micro-lens is as same as material of the second micro-lens.
19. The light emitting structure array system according to claim 1, wherein the bottom bonding layer is a metal layer.
20. The light emitting structure array system according to claim 1, wherein the top electrode layer is a conductive transparent layer.
21. The light emitting structure array system according to claim 1, wherein the insulation layer is made of dielectric materials.
22. The light emitting structure array system according to claim 13, wherein material of the spacer is as the same as material of the first micro-lens.
23. A method of fabricating a display panel integrated with a micro-lens array, comprising: providing a substrate; forming a plurality of pixel light sources including at least one mesa on the substrate; depositing a micro-lens material layer directly on the plurality of pixel light sources, wherein the micro-lens material layer covers a top of the plurality of pixel light sources and a top surface of the micro-lens material layer is flat; and performing a patterning process including patterning the micro-lens material layer from top down, thereby forming the micro-lens array including a plurality of hemispheres in the micro-lens material layer, wherein the plurality of hemispheres are placed above the plurality of pixel light sources.
24. The method of claim 23, wherein the micro-lens material layer is deposited by spin coating.
25. The method of claim 23, further comprising: after forming the plurality of pixel light sources and before depositing the micro-lens material layer, forming a mark layer with marks for aligning to the micro-lens material layer in the patterning process.
26. The method of claim 23, further comprising: patterning the micro-lens material layer to expose an electrode area of the substrate.
27. The method of claim 23, further comprising: depositing a mask layer on the top surface of the micro-lens material layer; patterning the mask layer to form a hemisphere pattern in the mask layer; and using the hemisphere pattern as a mask, etching the micro-lens material layer to form the plurality of hemispheres in the micro-lens material layer.
28. The method of claim 27, wherein, after the micro-lens material layer is etched, the micro-lens material layer is not etched through to expose a top surface of the at least one mesa, thereby a spacer is formed on the top of the at least one mesa.
29. The method of claim 27, wherein the mask layer is patterned by a photolithography process firstly and then a reflowing process.
