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Inventor(s)

CHAJI; Gholamreza et al.

CIRCUIT AND SYSTEM INTEGRATION ONTO A MICRODEVICE SUBSTRATE

Abstract

An integrated optical display system includes a backplane with appropriate electronics, and an array of micro-devices. A touch sensing structure may be integrated into the system. In one embodiment, an integrated circuit and system is integrated on top of micro-devices transferred to a substrate. Openings in a planarization layer (or layers) may be provided to connect the micro-devices with electrodes and other circuitry. Light reflectors may be used to redirect the light, and color conversion layers or color filters may be integrated before the micro-devices or on the substrate surface opposite to the surface of micro-devices.

Inventors: CHAJI; Gholamreza (Kitchener, CA), FATHI; Ehsanollah (Waterloo, CA), SADEGHIMAKKI; Bahareh (Kitchener, CA), SIBONI; Hossein Zamani (Waterloo, CA)

Applicant: VueReal Inc. (Waterloo, CA)

Family ID: 1000008589286

Assignee: VueReal Inc. (Waterloo, ON)

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application is a division of U.S. patent application Ser. No. 16/542,026, filed on Aug. 15, 2019, now allowed, which claims priority to and the benefit of U.S. Provisional Patent Application Nos. 62/746,300, filed on Oct. 16, 2018, 62/768,812, filed on Nov. 16, 2018, and 62/808,578, filed on Feb. 21, 2019, and which is a continuation-in-part of U.S. patent application Ser. No. 15/892,523, filed on Feb. 9, 2018, abandoned, which claims priority to and the benefit of U.S. Provisional Patent Application Nos. 62/456,739, filed on Feb. 9, 2017, and 62/482,939, filed on Apr. 7, 2017, each of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present disclosure relates to the integration of circuits and systems into a microdevice substrate. Few embodiments of the present disclosure also relates to the integration of color conversion layer(s) into the micro device substrate. Some embodiments of the present disclosure also relates to expanding an area of micro devices or a bonding area of micro devices.

BACKGROUND

[0003] One method to improve the system performance is to integrate microdevices into a system substrate. The challenge is transferring millions of these devices and integrating them with circuits for every pixel with proper yield.

[0004] An objective of the present invention is to overcome the shortcomings of prior art by providing microdevices integrated with circuits.

SUMMARY

[0005] A few embodiments of this description are related to integration of circuits and systems in microdevice substrate. The microdevice substrate may comprise micro light emitting diodes (LEDs), organic LEDs, sensors, solid state devices, integrated circuits, MEMS (microelectromechanical systems), and/or other electronic components.

[0006] One embodiment includes light sources sandwiched between two reflective layers with at least one patterned reflective layer. The patterned reflective layer may have a profiled pattern to improve the light output uniformity. There may be other layers between the device and reflective layers.

[0007] The receiving substrate may be, but is not no limited to, a printed circuit board (PCB), thin film transistor (TFT) backplane, integrated circuit substrate, or, in one case of optical micro devices

such as LEDs, a component of a display, for example a driving circuitry backplane. The micro device donor substrate and receiver substrate patterning may be used in combination with different transfer technologies, including but not limited to pick and place with different mechanisms, e.g. electrostatic transfer head and elastomer transfer head, or direct transfer mechanisms, such as dual function pads and more.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention will be described in greater detail with reference to the accompanying drawings which represent preferred embodiments thereof, wherein:

[0009] FIG. 1 is a schematic cross-sectional diagram illustrating a system based on integration of circuit to a receiver substrate with integrated micro devices, in accordance with an embodiment of the invention.

[0010] FIG. 2A shows a top view of the receiver substrate with openings to the micro devices, in accordance with an embodiment of the invention.

[0011] FIG. 2B shows a receiver substrate with micro devices and integrated circuits, in accordance with an embodiment of the invention.

[0012] FIG. 3 shows another exemplary structure of integrating circuits into the receiver substrate with micro devices, in accordance with an embodiment of the invention.

[0013] FIG. 4A shows an exemplary structure of connecting devices in a localized integration area to a circuit in an opening, in accordance with an embodiment of the invention.

[0014] FIG. 4B shows an exemplary structure of connecting devices in a localized integration area to a circuit in an opening which incorporates a reflective layer, in accordance with an embodiment of the invention.

[0015] FIG. 4C is a schematic cross-sectional diagram illustrating micro devices and reflective layers, in accordance with an embodiment of the invention.

[0016] FIG. 4D is a schematic cross-sectional diagram illustrating micro devices and reflective layers, in accordance with an embodiment of the invention.

[0017] FIG. 4E shows another example with a balanced optical structure, in accordance with an embodiment of the invention.

[0018] FIG. 5A-5D show cross section of a top structure integrated to the receiver substrate with the microdevices, in accordance with an embodiment of the invention.

[0019] FIG. 6A shows a floor plan of a local array and global array with connections for microdevices that have connections on one side, in accordance with an embodiment of the invention.

[0020] FIG. 6B-6D show another floor plans of a local array and global array with connections and common electrode for microdevices that have connections on one side, in accordance with an embodiment of the invention.

[0021] FIG. 7A shows a pad floor plan for a microdevice with two pads, in accordance with an embodiment of the invention.

[0022] FIG. 7B shows a top view of a pad floor plan for a microdevice with two pads, in accordance with an embodiment of the invention.

[0023] FIG. 8A shows a light guide based on two reflective layers with one that is patterned.

[0024] FIG. 8B shows a patterned reflective layer with a gradient profile, in accordance with an embodiment of the invention.

[0025] FIG. 9A shows a light source sandwiched between two reflective layers with at least one that is patterned, in accordance with an embodiment of the invention.

[0026] FIG. 9B shows exemplary ray tracing of the light source output in the structure of FIG. 9A,

in accordance with an embodiment of the invention.

[0027] FIG. 9C shows some of the critical parameters of the structure in FIG. 9A, in accordance with an embodiment of the invention.

[0028] FIG. 10A-B show cross for light source sandwiched between reflective layers to create uniform surface emitting light source, in accordance with an embodiment of the invention.

[0029] FIG. 11A-C show other embodiments for light source sandwiched between reflective layers to create uniform surface emitting light source, in accordance with an embodiment of the invention.

[0030] FIG. 12A is a schematic cross-sectional diagram illustrating a system based on integration of a buffer layer to a receiver substrate, in accordance with an embodiment of the invention.

[0031] FIG. 12B is a schematic cross-sectional diagram illustrating the system based on integration of micro devices to the receiver substrate, in accordance with an embodiment of the invention.

[0032] FIG. 12C is a schematic cross-sectional diagram illustrating the system with integrated micro devices and planarization layers, in accordance with an embodiment of the invention.

[0033] FIG. 12D is a schematic cross-sectional diagram illustrating the system with integrated micro devices and a plurality of other planarizing layers, in accordance with an embodiment of the invention.

[0034] FIG. 12E is a schematic cross-sectional diagram illustrating the system with integrated micro devices and vias in the planarization layers, in accordance with an embodiment of the invention.

[0035] FIG. 12F is a schematic cross-sectional diagram illustrating integration of micro devices and a backplane, in accordance with an embodiment of the invention.

[0036] FIG. 12G is a schematic cross-sectional diagram illustrating the system integration with micro devices and different top layers, in accordance with an embodiment of the invention.

[0037] FIG. 12H is a schematic cross-sectional diagram illustrating the system integration with micro devices and another substrate on a top surface of the passivation layer, in accordance with an embodiment of the invention.

[0038] FIG. 12I is a schematic cross-sectional diagram illustrating the system integration with micro devices and removing the first substrate, in accordance with an embodiment of the invention.

[0039] FIG. 12J is a schematic cross-sectional diagram illustrating the system integration with micro devices and the optical layers covering the buffer layer, in accordance with an embodiment of the invention.

[0040] FIG. 13A-13F is a schematic cross-sectional diagram illustrating the system integration with micro devices with openings in the planarization layers, in accordance with an embodiment of the invention.

[0041] FIG. 14A shows a top view of integration of backplane with the micro devices through openings, in accordance with an embodiment of the invention.

[0042] FIG. 14B shows another top view of integration of backplane with the micro devices through openings, in accordance with an embodiment of the invention.

[0043] FIG. 15A is a schematic cross-sectional diagram illustrating the system integration with micro devices having planarization and dielectric layers, in accordance with an embodiment of the invention.

[0044] FIG. 15B is a schematic cross-sectional diagram illustrating the system integration with micro devices and metallization, in accordance with an embodiment of the invention.

[0045] FIG. 15C is a schematic cross-sectional diagram illustrating the system integration with micro devices, in accordance with an embodiment of the invention.

[0046] FIG. 16A-16C is a schematic cross-sectional diagram illustrating a backplane arrangement including integrated circuits thereon, in accordance with an embodiment of the invention.

[0047] FIG. 17A is a schematic cross-sectional diagram illustrating a micro device integrated with different layers, in accordance with an embodiment of the invention.

[0048] FIG. 17B shows a top view of FIG. 17A, in accordance with an embodiment of the

invention.

[0049] FIG. **17C** is a schematic cross-sectional diagram illustrating micro devices integration with a backplane, in accordance with an embodiment of the invention.

[0050] FIG. **17D** is a schematic cross-sectional diagram illustrating micro devices integrated on a substrate with trenches in the passivation layers, in accordance with an embodiment of the invention.

[0051] FIG. **18A-18C** shows some exemplary combination of the micro device and backplane compensation on top of the micro devices, in accordance with an embodiment of the invention.

[0052] FIG. **19A** is a schematic cross-sectional diagram illustrating a micro device integrated with different top layers and a backplane, in accordance with an embodiment of the invention.

[0053] FIG. **19B** is a schematic cross-sectional diagram illustrating the micro device integrated with different the top layers, the backplane, and color conversion layers, in accordance with an embodiment of the invention.

[0054] FIG. **19C** is a schematic cross-sectional diagram illustrating the micro device integrated with different top layers, the backplane, the color conversion layers, and removal of the substrate, in accordance with an embodiment of the invention.

[0055] FIG. **19D** is a schematic cross-sectional diagram illustrating the micro device integrated with different top layers, the backplane, the color conversion layers, and removal of the buffer layer, in accordance with an embodiment of the invention.

[0056] FIG. **20A** is a schematic cross-sectional diagram illustrating a micro device integrated with different top layers, a backplane, and a contact on a top surface of the micro device, in accordance with an embodiment of the invention.

[0057] FIG. **20B** is a schematic cross-sectional diagram illustrating the micro device integrated with different top layers, the backplane, the color conversion layers, and the contact on a top surface of the micro device, in accordance with an embodiment of the invention.

[0058] FIG. **20C** is a schematic cross-sectional diagram illustrating the micro device integrated with different top layers, the backplane, the color conversion layers, the contact on a top surface of the micro device, and removal of the substrate, in accordance with an embodiment of the invention.

[0059] FIG. **20D** is a schematic cross-sectional diagram illustrating the micro device integrated with different top layers, the backplane, the color conversion layers, the contact on a top surface of the micro device through a via in the planarization layer, and removal of the buffer layer, in accordance with an embodiment of the invention.

[0060] FIGS. **21A-21D** are schematic cross-sectional diagrams illustrating a micro device having reflector on sidewalls of the micro device, in accordance with an embodiment of the invention.

[0061] FIG. **22** is a schematic cross-sectional diagram illustrating a micro device integrated with color conversion layers on a buffer layer, in accordance with an embodiment of the invention.

[0062] FIGS. **23A-23B** are schematic cross-sectional diagrams illustrating a display system, in accordance with an embodiment of the invention.

[0063] FIG. **24** is a schematic cross-sectional diagram illustrating a device substrate with a stack of layers deposited thereon, in accordance with an embodiment of the invention.

[0064] FIG. **25A** shows a structure where extension layers are added to the device, in accordance with an embodiment of the invention.

[0065] FIG. **25B** shows an exemplary top view of the device of the structure in FIG. **25A**, in accordance with an embodiment of the invention.

[0066] FIG. **26A** shows a device where the extension layers are used as planarization layers, in accordance with an embodiment of the invention.

[0067] FIG. **26B** shows an exemplary top view of the structure in FIG. **26A**, in accordance with an embodiment of the invention.

[0068] FIG. **27A** is a schematic cross-sectional diagram illustrating the extension layers are used as planarization as well, in accordance with an embodiment of the invention.

[0069] FIG. 27B shows an exemplary top view of the structure in FIG. 27A, in accordance with an embodiment of the invention.

[0070] FIG. 28A is a schematic cross-sectional diagram illustrating a top contact is extended to a bottom side of the microdevice, in accordance with an embodiment of the invention.

[0071] FIG. 28B is a schematic cross-sectional diagram illustrating a pad is extended to the extension layers, in accordance with an embodiment of the invention.

[0072] FIG. 29 is a schematic cross-sectional diagram illustrating a device substrate in accordance with an embodiment, in accordance with an embodiment of the invention.

[0073] Use of the same reference numbers in different figures indicate similar or identical elements.

[0074] While the present disclosure is susceptible to various modifications and alternative forms, specific embodiments or implementations have been shown by way of example in the drawings and will be described in detail herein. It should be understood, however, that the disclosure is not intended to be limited to the particular forms disclosed. Rather, the disclosure is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

[0075] While the present teachings are described in conjunction with various embodiments and examples, it is not intended that the present teachings be limited to such embodiments. On the contrary, the present teachings encompass various alternatives and equivalents, as will be appreciated by those of skill in the art.

[0076] In this disclosure, pads in a receiver substrate may refer to a designated area in a receiver substrate where a microdevice is transferred to. The pads may be conductive to prepare a connection between the microdevice and the pixel circuits or connections where the pixel circuits may be underneath the pad or on the side of the pad. The pad may have some form of bonding materials to hold the micro device permanently. The pad may be stack of multiple layers to offer a more mechanically stable structure and also better functionality, such as bonding and conductivity capability.

[0077] The pads in this description may provide an electrical connection, a mechanical connection, or just a defined area to transfer microdevices. The shape of the pads used in the embodiments are for illustration purpose and may have any arbitrary shape. The position of pads in respect to the pixels may be changed without any effect on the embodiments. The orientation of the group of pads in the pixel may be changed. For example, they may be rotated, shifted or moved to a different position. The pads may have a complex structure comprising different conductive, semiconductor, and/or dielectric layers. The pads may be positioned on top of other structures, such as transistors, in the receiver substrate. Also, the pads may be beside other structures on the receiver substrates.

[0078] The shape of light sources used in the embodiments are illustration purposes and devices may have different shapes. The light source devices may have one or more pads on side that will contact the receiver substrate. The pads may be mechanical, electrical, or a combination of both. The one or more pads may be connected to a common electrode or row/column electrodes. The electrodes may be transparent or opaque. The light sources may have different layers. The light sources may be comprised of different materials such as organic, inorganic, or a combination of them.

[0079] With reference to FIG. 1, an embodiment of the present invention comprises a substrate **100**, a bottom electrode **104**, microdevices **106**, top electrodes **112**, and an integrated circuit layer **114**. A buffer layer **102** may be deposited between the substrate **100** and the bottom electrode **104**. The buffer layer(s) **104** may be used as delamination layer, as well as to separate the fully integrated system from the substrate **100**. The buffer layer **102** may be eliminated, especially when the stacked microdevices **106** and the circuit layer structure **114** remain on the substrate **100**. The bottom electrode **104** may be deposited on the substrate **100**, and may be patterned for individual

microdevices **106** or be used as a common electrode for all of the micro-devices **106**. Some extra layers may be deposited on top of the bottom electrode **104** to create bonding places for the microdevices **106**. Prior to the microdevices **106** being transferred onto the substrate **100**, a planarizing layer **108** is developed over the bottom electrode **104**, and over and around the microdevices **106**. It is possible that the planarizing layer **108** is comprised of a few different layers and materials, e.g. a dielectric layer. Openings **110** are then formed, e.g. etched, into the planarizing layer **108** down to each microdevice **106**. The backplane may then be mounted on the microdevice structure by first disposing or forming top electrodes **112** in the openings **110**, whereby the top electrodes **112** may be connected to the micro device **106**. The top electrodes **112** may then be used to connect the micro device **106** to an integrated circuit layer **114** interconnecting each of the micro devices **106**, via the top electrodes **112**, to external power and control systems. The integrated circuit layer **114** may be either TFTs, CMOS chiplet, or another type of integrated circuit. The common electrode **104** may be ignored, if there is no connection for the microdevice **106** to a common voltage level. Before or after depositing buffer layer **102**, a touch sensing structure may be placed over the micro-devices **106**. The touch sensing structure may be separated from the microdevices **106** and/or their electrode(s) **112** by a dielectric layer. The touch structure may be in the same plane as the micro devices **106**. The touch structure may comprise any type, such as capacitive, resistive, pressure, optical, or a combination thereof.

[0080] FIG. 2A illustrates a top view of the planarizing layer **108**. The openings **110** that extend through the planarizing layer **108** may be used to receive the top electrodes **112** to connect to the microdevices **106** to the integrated circuit layer **114**. The number of openings **110** for each microdevice **106** depends on the number of connections required between the microdevice **106** and the integrated circuit layer **114**.

[0081] FIG. 2B illustrates connection between the backplane, i.e. the integrated circuit layer **114**, and the microdevices **106**. Trace circuits **122** extend from the top electrodes **112** in the openings **110** to a pad **116** in the integrated circuit layer **114**. There may be common electrodes, e.g. electrodes **120** and **118**. The common electrodes **118** and **120** may be directly connected to the top electrodes **112** or the circuit may extend through the trace circuits **122** to avoid any short in the crossing. The integrated circuit layer **114**, e.g. the backplane, may be fabricated after the planarizing layer **108**, and the backplane may be comprised of a TFT layer.

[0082] In alternative embodiments, other layers, such as color conversion, color filter, or other devices may be included, e.g. deposited, between the substrate **100** and the micro device **106**. In another embodiment, light distribution layers may be integrated between the micro-devices **106** and the other layers, e.g. integrated circuit layer **114**, on top of the micro-devices **106**. In another embodiment, other structures, such as a color conversion layer, color filter or other devices may be placed on the underside of substrate **100**, opposite to the side where the micro-devices **106** are located. In another embodiment, the bottom electrode **104** may be a distribution layer.

[0083] With reference to FIG. 3, a receiver structure **108** includes a plurality of the micro devices **106** formed into an array of rows and columns, which are connected with row electrodes **118a** to **118f** and column electrodes **120a** to **120e**. The driving and controlling integrated circuit **114** is connected to the columns **120a** to **120e** and rows **118a** to **118f** to drive the micro devices **106**. The connection is made down through connection via openings **110a** in the planarizing layer **108**. There may also be general column electrodes **120** and row electrodes **118** for the driving integrated circuit layer **114**.

[0084] FIG. 4A illustrates a floor plan to integrate microdevices **106** into a backplane integrated circuit layer **114**, and to provide access to a controllable electrode for the micro devices **106**. The floor plan includes an integration area **420** which can include pads, a landing area, and other structures, and at least one controllable electrode **422**. In one embodiment, the controllable electrode **422** and the integration area **420** are transparent to enable light to pass through them for use in particular optoelectronic devices. In another embodiment, for certain optoelectronic devices,

the controllable electrode **422** is extended between two columns (rows or adjacent micro devices **106**) to an open area **424**, where a driver may be integrated. Here, the controllable electrode **422** may be reflective to direct light toward and through the bottom layers, e.g. transparent bottom electrode **104**. Although this structure is useful for some applications, such as integrating microLED for lighting, it may be a challenge due to structural non-uniformity for applications, such as backlight units for display applications. FIG. **4B** illustrates a structure including an additional continuous reflector layer **426** on top of the integrated circuit layer **114**, and a patterned transparent integration area **422**. The continuous reflector layer **426** enables more uniform light extraction.

[0085] FIG. **4C** illustrates a cross sectional view of one exemplary embodiment of FIGS. **4A-4B**. The reflective layer **426** may be deposited or transferred onto the substrate **100** and then the buffer (or dielectric) layer **102** may be deposited on top of the reflective layer **426**. Another buffer layer(s) or other structures may be deposited before the reflective layer **426**. In the exemplary embodiment of FIG. **4D**, the reflective layer **426** may be deposited on the other side of the substrate **100**, i.e. opposite the bottom electrodes **104** and microdevices **106**. In the illustrated embodiments of FIGures. **4C** and **4D**, the bottom electrodes **104** are patterned for each microdevice **106**, while the top electrode **416** is a single common electrode, either of which may be transparent or reflective. On both the structures of FIGS. **4C** and **4D**, other layers may be deposited after the micro device **106** integration, such as the filler or planarizing layer **108** around the microdevices **108**, and the top electrode **416**. Other layers may be included in the top electrode layer **416**, such as color conversion. In an exemplary structure, illustrated in FIG. **4E**, the integration area **420** and the electrodes **422** are shaped the same across all areas. Here, the electrodes **422** are extended across the active area and to avoid shorting the devices **106**, some electrode have at least one opening **422-c** to disintegrate the active **422-a** part of the electrode from the inactive part **422-b**, which is there for uniformity. Accordingly, active and inactive electrodes **422-a** and **422-b**, respectively, are used to balance the optical uniformity of the local array and control electrode structure.

[0086] A challenge for a low cost application is the integration of other structures, such as top electrodes **112**, into the receiver substrate **100** with integrated micro devices **106**. One method of integration is the deposition process as shown in FIG. **5A**, as hereinbefore discussed with reference to FIGS. **1** and **4**. However, this process may be expensive and require expensive and large equipment. Another method is printing. FIG. **5B** illustrates a structure to laminate the top structure **516** including the top electrodes **112**. Here, the top structure **516** is fabricated separately with different methods. The receiver substrate **100** with integrated micro devices **106** may be insulated with a filler layer **108**, but the filler layer **108** does not cover the microdevices **106**, so the exposed microdevices extend upwards from the filler layer **108**, eliminating the need for openings **110**, and enabling connection to the top electrodes **112**. The top structure **516** may then be laminated to the receiver substrate **100**. The pads **520** on the receiver substrate **100** or the top structure **516** have layers to provide electrical contact due to pressure and temperature applied during lamination. The materials may be alloyed or annealed to create the electrical conduction pads **520**. In another embodiment, further annealing steps may be used after the lamination process. The filler layer **108** may be either deposited or printed onto the receiver substrate **100**. In another exemplary structure, demonstrated in FIG. **5C**, individual spacers **508** are used on the receiver substrate **100** between micro devices **106**, instead of a full filler layer **108**. The spacers **508** may include a dielectric or insulating material, thereby eliminating the possibility of shorting the structures on the top structure **516** to unwanted areas on the receiver substrate **100**. As illustrated in FIG. **5D**, the spacers **508** may extend to the same height of the micro devices **106**, e.g. the same height as the bottom electrode **104** and the micro-devices combined, whereby the spacers **508** extend upwardly from the substrate **100** substantially the same distance as the micro-devices **106**, so that the spacers **508** may also support the top structure **516**. Here, the position of top structure **516** and bottom substrate **100** may be changed without affecting the performance.

[0087] In a structure with micro devices **106** that have a contact on one side, a local and/or global array structure needs to include connections to both electrodes. Here, in a local array, the micro devices **106** may be connected in series or parallel. FIG. **6A** illustrates a structure in which the local array is located in an integration area **420**. The microdevices **106** are formed in a series structure in the form of rows (or columns) and then connected together to form a parallel structure in the form of columns (or rows). The microdevices **106** may be connected together in series with series electrodes **422c** extending therebetween, and they may be connected to a driver through common first and second electrodes **422a** and **422b** at opposite ends of the arrays of microdevices **106**. One of the first and second electrodes **422a** or **422b** may be a common electrode to multiple integration areas **420** of micro-devices **106**, e.g. multiple pixels, as shown in FIG. **6B**, to reduce the number of traces connected to a driver. In another embodiment, the first electrode **422a** may be on a different side of the integration areas **420** in columns (or rows) to enable sharing the common electrodes **422a** between two adjacent columns (or rows). FIG. **6C** illustrates another exemplary embodiment to connect the microdevices **106** into parallel and series configuration, in which an array of microdevices **106**, i.e. a plurality of rows and columns, in an integration area **420** and interconnected by series electrodes **422c**, are connected to a single second electrode **422b**. A plurality of integration areas **420** are then connected to a single common first electrode **422a**. FIG. **6D** illustrates a full parallel structure for a localized array **420**. Here, the micro devices **106** in the localized array **420** may be connected to the electrodes **422c** to be in parallel. The microdevice/electrode structures in FIGS. **6A-6D** may be fabricated in one conductive layer on the substrate **100** to form all possible electrodes and result in very low cost process. It is possible to use single microdevices **106** for each localized array **420** as well.

[0088] FIG. **7A** illustrates an embodiment in which multiple electrodes **104** and pads **105** are disposed on the receiver substrate **100** based on a two pad microdevice **106**. The size of the electrode **104** is $X4\ 756$ and a distance between two electrodes in $X3\ 754$. Similar structures may be used for multiple pads **105**, each with a pad size of $X1\ 750$. The distance between the two pad locations on the receiver substrate **100** should be smaller than $X2-2Dx-2Bx$, where $X2\ 752$ is the distance between the electrode pads **105** of the micro devices **106**, Dx is the transfer alignment accuracy of the microdevice **106**, and Bx is the minimum size required for a proper bonding between pads **105** on the receiver substrate **100** and on the micro device **106**.

[0089] FIG. **7B** illustrates a top view of the embodiment of FIG. **7A**. The size of the receiver pad **105** in the X direction is larger than $X1+2Dx-Db$. Here, the size of the receiver pad **105** in the Y direction is different from the X direction, i.e. should be larger than $Y1+2Dy-Db$, where $Y1\ 758-1$ is the size of the micro device pad **105** in the Y direction, Dy is the transfer alignment accuracy in the Y direction and Db is the minimum bonding overlap. The size of the bottom electrode **104** in the Y direction is $Y2\ 758$.

[0090] According to an embodiment for a pad design on the receiver substrate **100**, the pad size is larger than the “pad size of micro devices+2x transfer alignment accuracy–minimum bonding overlap”.

[0091] According to another embodiment for a pad design on the receiver substrate **100**, the distance between the pads on the receiver substrate **100** is smaller than the “distance between pads of a micro device–2x transfer alignment accuracy–pad size of micro device+minimum bonding overlap”.

[0092] The localized arrays **420** are then connected through the common electrodes **422a** to form the global array. Each localized array **420** may be controlled separately through the second controllable electrode **422b**.

[0093] An embodiment of a light guide plate (LGP) **800** utilizing the integrated system in accordance with the present invention, illustrated in FIGS. **8A** and **8B**, comprises a backlight plate structure in which the light from one or more light sources **820** is directed in a substrate **822**, which may include one or more of the following: the substrate **100**, the planarization layer **108**, the

bottom electrode **104**, the top electrode **112**, and the integrated circuit layer **114**. The structure is developed by depositing (or another form of forming) a reflective layer **824** on one side of the substrate **822** and an array of reflective patterns **826**, e.g. circles or another suitable shape, on the other, e.g. opposite, side of the substrate **822** as shown in FIG. **8A**. The pattern also may also be a negative image of what is shown in FIG. **8A**, i.e. circular or other suitably shaped openings in FIG. **8B**. In one case, the patterned reflective layer **826** may be deposited on separate substrate and laminated to the first substrate **822**. This structure may be used for other embodiments described here as well.

[0094] In order to manipulate the angle of light beams inside the substrate **822**, the top and/or bottom sides of the substrate **822** before and/or after the metal deposition of layers **824** and **826** may be textured using mechanical or chemical methods. The textures may have a random texture or they may have certain patterns engineered to increase the efficiency of the backlight plate. The array of reflective patterns **826** may be uniform or the array of reflective patterns **826** may have a gradient depending on the position, number, or distribution of the light sources, e.g. spaced farther apart when proximate to the light source **820** and spaced closer together when remote from the light sources **820**, as shown in FIG. **8C**. In one embodiment, the light sources **820** may be LEDs installed in one side edge of the substrate **822**. In addition, the substrate **822** may have any thickness independent of the height of the light source **820**. Optical means may be used to prevent the escape of light beams when the height of the light source **820** is larger than the thickness of the substrate **822**. In one case, the substrate **822** may be comprised of a flexible PEN plastic and the metallic layers **824** and **826** may be comprised of one or more of aluminum and silver layers deposited using sputtering or printed using screen printing systems.

[0095] According to another embodiment of the present invention, an LGP **900** illustrated in FIGS. **9A** to **9C**, includes light sources **920**, which may be distributed on one side of a substrate **922**, with the fully reflective layer **924** on one side of the substrate **922**, and a partially patterned reflective layer **926** on the opposite side of the substrate **922**, as shown in FIG. **9A**. In this case, the light sources **920** may or may not be aligned with the reflective patterns **926** on the other side of the substrate **922**. The substrate **922** may be a filling layer, e.g. dielectric, or just an air gap with spacers between the two reflective layers **924** and **926**. The substrate **922** may include one or more of the following: the substrate **100**, the planarization layer **108**, the bottom electrode **104**, the top electrode **112**, and the integrated circuit layer **114**. Any of the previous methods may be used here for spacer or passivation layers. There may be another substrate on either side of the reflective layers **924** and **926**. Either of the reflective layers **924** and **926** may be part of either electrode for the sources **920** as well. Using this scheme, one can increase the light extraction efficiencies by distributing the light sources **920** on the surface of substrate **922** of the reflective layer **924**, instead of using an edge-lit scheme.

[0096] FIG. **9B** illustrates an example of beam ray propagation of the aforementioned embodiment. The patterned reflective layers **926** may be a negative image of what is shown, i.e. with a reflective sheet with transparent openings, instead of transparent spaces between reflective shapes. Also, the patterns **926** may have a different profile, such as gradient around the light source **920**, to compensate for the light non-uniformity caused by individual point source devices. On top of the LGP **900**, e.g. any layer **924** or **926**, there may be other structures, such as a color conversion layer deposit, laminated or stacked thereon. In one embodiment, a color conversion layer may be disposed on each light source **920**. As an example, assuming smooth surfaces and interfaces, positioning of the metallic patterns **926** may be optimized for 1) maximum extraction of the lights from the individual light sources **920** and 2) propagation of the light across the substrate **922** for uniform illumination.

[0097] In an example calculation, both top and bottom surfaces/interfaces of the substrate **922** are assumed to be smooth. Depending on a dimension “a” **928** of a shape in the reflective pattern **926**, a dimension “b” **930** of a transparent opening in the reflective pattern **926**, and a light beam angle α

932, beams with angles larger than minimum angle $\alpha_{\text{sub.1}}$ to avoid the closest reflective pattern, but less than a critical angle $\alpha_{\text{sub.c}}$ of light exiting light source **920**, will exit the light guide plate (LGP) **900** from the nearest opening **934**.

[0098] Accordingly, the critical distance for escaping light $x = dx \tan(\alpha_{\text{sub.c}}) - (a/2)$ OR $\tan(\alpha_{\text{sub.c}}) = (a/2 + x)/d$.

[0099] The minimum angle for escaping light is defined by $\tan(\alpha_{\text{sub.1}}) = (a/2)/d$ and the beam angle relating to the critical distance **934** is the critical angle minus the minimum angle or $\alpha_{\text{sub.x}} = \alpha_{\text{sub.c}} - \alpha_{\text{sub.1}}$. If $x > b$ the beam angle relating to escaping light will be less than the critical distance x , whereby the escaping angle will be $\alpha_{\text{sub.x}} = \tan^{-1}((a/2 + b)/d) - \alpha_{\text{sub.1}}$.

[0100] In an ideal case, any beam with angles greater than the critical angle $\alpha_{\text{sub.c}}$ or the escape angle $\alpha_{\text{sub.x}}$ when $x > b$, will be trapped inside the LGP **900**, e.g. beam 3 in FIG. **9C**. Beams with angles less than $\alpha_{\text{sub.c}}$ will exit the LGP **900** either through the nearest opening **934** or the subsequent openings depending on the launch angles, the reflective pattern dimension “a” **928**, and the gap dimension “b” **930**.

[0101] Texturizing the bottom reflective surface and/or the top surface of the substrate **922** optimizes the propagation of light, and results in a uniform light beam extraction in the areas between two adjacent light sources **920**. In another embodiment, instead of texturing the top surface of the substrate **922** of the LGP **900** (shown in FIG. **5**) before pattern deposition, this process may be performed after pattern formation. Consequently, only areas denoted by “b” are texturized. In another embodiment, the top surface of the substrate **922** may be texturized after pattern deposition of the patterned reflective layer **926**, and the bottom surface of the substrate **922** may be textured before metal blanket deposition of the reflective layer **924**.

[0102] In another embodiment, as shown in FIG. **10A**, an LGP **1000** includes light sources **1020**, which may be positioned on a top surface of a substrate **1022**, underneath reflective patterns **1026** and on an opposite side to the reflective layer **1024**.

[0103] In another embodiment, shown in FIG. **10B**, an LGP **1050** includes a height, which is the same as the height of the light sources **1020**, or the light sources **1020** are installed in holes embedded into the substrate **1022**, which may include one or more of the following: the substrate **100**, the planarization layer **108**, the bottom electrode **104**, the top electrode **112**, and the integrated circuit layer **114**. In this scheme, the light beams come from the side of the light source **1020**. For LED light sources, the top and bottom reflector layers **1026** and **1024** may be part of the electrodes for the LED contacts as well. Similar to other embodiments, top and bottom surfaces of the substrate **1022** may be texturized before or after metal deposition of the reflective layers **1024** and **1026**. In this example a dent (or a hole) is made in the substrate **1022** and after placing LEDs **1020**, they are secured in place by epoxy or other means of curable materials.

[0104] In another embodiment the top surface of a substrate **1122** may have concave or convex mirror structures to further enhance the uniform light extraction from an LGP unit **1100**. As shown in FIG. **11A**, each LED **1120** is placed between the focal point (F) of a concave structure **1126-1** and the mirror **1124-1**. The concave structures **1124-B** additionally facilitate the light propagation along the LGP **1100**. In this case, the LEDs **1120** may be on top or bottom side of the substrate **1122**, i.e. proximate to either reflective layer **1124** or **1126**, depending on the light source height and the overall thickness of the LGP **1100**.

[0105] In another embodiment, illustrated in FIG. **11B**, the height of the light source **1120** is comparable with that of the LGP **1150**, i.e. substantially the same as the substrate **1122**, whereby pyramid concave mirrors **1124-2** may be provided in the top or bottom reflective layers **1124** or **1126** to guide side-illuminating light toward the bottom or top perforated plate (FIG. **11B**).

[0106] FIG. **11C** illustrates another embodiment, in which an LGP **1175** includes light source **1120** embedded inside the substrate **1122**, which has been modified for receiving convex mirror structures **1126-2**. The substrate **1122** may include one or more of the following, the substrate **100**,

the planarization layer **108**, the bottom electrode **104**, the top electrode **112**, and the integrated circuit layer **114**. The convex structures **1126-2** may decrease the total number of light sources **1120** required in the backlight units, while maintaining a particular uniform light intensity. In all of the above-mentioned examples, careful calculations will be done to find the optimum curvature of the convex or concave mirrors **1124-1** and **1124-2** for uniform light radiation from the backlight unit. In addition, optical micro lenses may be provided between two adjacent top reflectors to further enhance the light propagation.

[0107] In the embodiments of FIGS. **9A-9C**, **10A-10B**, and **11A-10C**, either of the reflective layers **924/926**, **1024/1026**, **1124/1126** may be part of the electrode for the light sources **920**, **1020**, **1120**. A transparent electrode may be deposited on or before the patterned reflective layer **926**, **1026**, **1126**. In the embodiments of FIGS. **9A-C**, **10A-B**, and **11A-C**, substrates with other structure, such as electrodes, color conversion layers, and other layers may be provided before or after any of reflective layers. In the embodiments of **9A-C**, FIG. **10A-B**, and FIG. **10A-C**, the substrate **922**, **1022**, **1122** may be a filler layer, or just space between the two reflective layers. The filler may have particles with reflective characteristics to improve the light output uniformity. In the embodiments of **9A-C**, FIG. **10A-B**, and FIG. **10A-C**, the patterned reflective layers may have a profile, such as a gradient around the point light source to create uniform light output with fewer light sources.

[0108] In the embodiment of FIG. **9A-9C**, the light sources **920** may or may not be aligned with the reflective patterns **926** on the other side of the substrate **922**. The substrate **922** may be a filler layer or just a space between two reflective layers **924**, **926**. Any of previous methods may be used for the spacer or passivation layers. There may be another substrate on either side of the reflective layers **924**, **926**. Either of reflective layers **924**, **926** may be part of either electrode for the source.

Microdevice and Backplane Integration

[0109] Some embodiments of the present disclosure relates to the post processing steps for enhancing the performance of micro devices after transferring into a receiver substrate.

[0110] One method to improve the system performance is to integrate microdevices into a system substrate. The challenge is to transferring millions of these micro devices and integrate them with circuits for every pixel with proper yield. The system substrate can be uneven due to other components in the system substrate prior to the transfer of the micro devices. Although planarization may work, but it may interfere with the transfer process due to limitation for processing parameters such as pressure, temperature and etc. Another challenge is that bonding the micro devices into an electrode in the system substrate is a time consuming process and generally it is done for each transfer step. Therefore, if a system requires few hundred transfer steps (cycles), it will take several hours to finish the process due to the timing required for bonding. Moreover, the bonding repeatability and reliability at such small pad size are major concerns affecting yield and lifetime of the system.

[0111] In one embodiment, a method to integrate one or more microdevices to a system substrate is provided. The method comprising transferring the one or more microdevices to the system substrate, forming a protective layer to cover the one or more microdevices, patterning the protective layer to receive conductive electrodes and connecting backplane elements to the one or more microdevices through the conductive electrodes.

[0112] Various embodiments in accordance with the present structures and processes provided are described below in detail.

[0113] In addition, these embodiments exemplarily illustrate with one or more micro light-emitting devices, but the invention is not limited thereto. The number of micro light-emitting devices may be changed according to actual requirements.

[0114] In this description, the terms “system substrate”, “receiver substrate” and “display substrate” are used interchangeably. However, it is clear to one skilled in the art that the embodiments described herein are independent of substrate type.

[0115] Here, micro devices (e.g., GaN LEDs) are fabricated by depositing a stack of material on a sapphire substrate. The micro devices structure may be in the form of one of: a cylindrical structure, a mesa structure, a flip-chip structure, or a vertical structure.

[0116] FIG. 12A shows a cross section of a system based on integration of a buffer layer to a receiver substrate. FIG. 12A shows a system substrate **1202**. A buffer layer **1204** may be formed on a top surface of the substrate **1202**. The buffer layer(s) **1204** may be used as a delamination layer as well as a separate layer that can separate the fully integrated system from the substrate **1202**. It is possible to eliminate the buffer layer **1204** specially when the stacked microdevice and circuit structure is staying on the substrate **1202**. The buffer layer **1204** can also include an electrode that can be patterned or be used as common electrode. Some extra layers can be deposited on top of the electrode to create bonding places for micro devices. The buffer layer is formed before transferring the micro devices to the system substrate **1202**. The buffer layer is formed between the microdevices and the substrate surface.

[0117] FIG. 12B shows a plurality of microdevices **1206** transferred over the system substrate **1202**. In one case, the micro-devices can be micro light emitting devices. In another case, the micro devices may be any micro device that may typically be manufactured in planar batches, including but not limited to LEDs, OLEDs, inorganic LEDs, sensors, solid state devices, integrated circuits, MEMS, and/or other electronic components.

[0118] FIG. 12C shows a cross section of a system with integrated micro devices and planarization layers. A protective layer **1208** may be formed to cover the micro devices **1206** bonded to the substrate **1202**. The protective layer can be a planarizing layer. It is possible that the protective layer **1208** is made of few different layers and materials, e.g. dielectric layer. In one case, the protective layer **1208** can be extended beyond the microdevice edges. In one embodiment, another passivation layers can be used to cover the micro devices.

[0119] FIG. 12D shows a cross section of an embodiment with integrated micro devices and a plurality of another planarizing layers. A plurality of another planarizing layers **1210** may be formed over the protective layer **1212** covering the micro devices **1206**. The other planarizing layers **1210** can be any other layer such as the extension of the protective layer **1208**, a passivation layer, a protective layer or any other separate layer. In one case, color conversion layer can be integrated prior to the planarization layer. In another case, the color conversion layer can be integrated after the protective layer (passivation layer) and can be covered by another passivation layer. In one embodiment, color conversion layer can be the passivation layer.

[0120] If the planarization layer covering the micro devices, vias can be formed in the planarization layers to provide access to the micro devices.

[0121] FIG. 12E shows a cross section of an embodiment with integrated micro devices and vias in the passivation layers. A plurality of vias **1214** can be made e.g. etched, in the planarizing layers **1210** down to each micro device **1206**. These vias **1214** can be used to connect the micro devices **1206** to backplane elements. The top conductive electrodes **1212** are then formed in the openings **1214**, whereby the top conductive electrodes **1230** may be connected to the micro devices **1206**. The top conductive electrodes **1230** may then be used to connect the micro devices **1206** to the integrated circuit layer **1216**.

[0122] The integrated circuit layer may be either a backplane, thin film transistors, CMOS chiplet, or other type of integrated circuit. The openings **1214** extending through the planarizing layer **1210** may be used to receive conductive electrodes for connecting to the microdevices **1206** to the backplane elements. In one case, the openings **1214** are formed before the formation of conductive electrodes that connects the microdevice to the backplane elements. The number of vias **1214** for each microdevice **1206** depends on the number of connections required between the microdevice **106** and the backplane elements and coupling method. The integrated circuit layer, e.g. the backplane, may be fabricated after the planarizing layer **1210**, and the backplane may be comprised of a thin film transistor (TFT) layer.

[0123] FIG. **12F** shows a cross section of a system with integrated micro devices and a backplane. A backplane **1216** can be coupled to the micro device structure by disposing or forming conductive electrodes **1230** in the vias **1214**. The backplane **1216** can be connected to the micro devices **1206** through the vias **1214**. The conductive electrodes **1230** may be connected to the micro devices **1206**. The top conductive electrodes may then be used to connect the micro device **106** to an integrated circuit layer that interconnects each of the micro devices **1206**, via the electrodes, to power supplies or control systems. The integrated circuit layer may be either thin film transistors, CMOS chiplet, or other type of integrated circuit.

[0124] FIG. **12G** shows a cross section of an embodiment with integrated micro devices and different top layers. A plurality of additional layers may be formed on top of the microdevices **1206** and the backplane **1216**. The additional layers **1218** may comprises optical layers, passivation layer, a color conversion layer, a color filter, an optical enhancement layer, a touch sensing electrode, or a common electrode. The touch sensing structure can be separated from micro-devices and or their electrode(s) by a dielectric layer. The touch structure can be in the same plane as the micro devices. The touch structure can be of different types such as capacitive, resistive, pressure, optical or combination thereof. An electrode may be deposited and can be patterned or be used as common electrode. Some extra layers can be deposited on top of this electrode for optical properties.

[0125] In one embodiment, the first substrate (e.g., in this case, the receiver substrate **1202**) can be removed to enable flexible system or post processing steps performed on the side of the system facing the first substrate. In one case, there is no need for supportive layer/protective layer or substrate and the stacked layers on the system can handle the separation process. In another embodiment, another supportive or permanent substrate is added to the other side of the system different from the side on the first substrate.

[0126] FIG. **12H** shows a cross section of an embodiment with integrated micro devices and a second substrate **1220** on a surface of the system. The system can be separated from the first substrate while supported by the second substrate **1220**.

[0127] FIG. **12I** shows a cross section of an embodiment with integrated micro devices and removing the first substrate. The first substrate can be removed after integration of the secondary substrate **1220**. The separation is done by modifying the buffer layer **1204**. The post processing steps may be performed on the surface of the layers separated from the first substrate. Here, the buffer layer can include a protective layer to protect the devices (e.g. micro devices, the backplane components, and other conductive layers) from any side effect during the separation process. In one case, the protective layer can absorb the excess emission from the laser used to separate the system from the first substrate. In one embodiment, the protective layer can be removed after the separation process. The other post processing steps can include at least one of: forming one or more vias (openings) in a single or plurality of layers, removing one or more of the plurality of layers, forming different electrodes, forming optical layers, forming color conversion/filter layers, or forming passivation layer.

[0128] FIG. **12J** shows a cross section of an embodiment with integrated micro devices and other layers covering the buffer layer. After the removal of the first substrate, the other layers **1222** that may comprise one of a passivation layer, a color conversion layer, a color filter, an optical enhancement layer, a touch sensing electrode, or a common electrode can be formed over the buffer layer. In one case, other layers such as color conversion layer, color filter or other devices can be placed on the side of substrate which is opposite to the side where micro-devices are located. Here, plurality of vias **104** can be formed in the one or more layers to provide coupling options to the micro devices or the backplane. Various embodiments related to FIG. **12J** has been described in the disclosure.

[0129] In some embodiments, the planarization layer can have vias at different locations to micro devices to make connections with backplane. These embodiments exemplarily illustrate with one

micro light-emitting device, but the invention is not limited thereto. The number of micro light-emitting devices may be changed according to actual requirements.

[0130] After all the microdevices transferred to a system substrate, to make connections with backplane, pre-processing steps can be done on the transferred microdevices. Here, the microdevice has contacts on one side. The contacts need to get exposed to have connections with backplane. The connections can be provided by vias opened at different locations of microdevice contacts. The different locations can be p-type ohmic contact and n-type ohmic contact of the microdevice. The number of openings for each microdevice depends on the number of connections required between the microdevice and the backplane. The surface of system substrate can be leveled by using planarization layer.

[0131] FIG. **13A** shows a cross section of a system with integrated micro devices having vias to make connections with a backplane, according to some embodiments. A passivation layer/planarization layer **1308** may be deposited over a top surface of the micro device **1310**. A plurality of vias/openings (**1306**, **1312**) can be made to connect the micro device **1302** to the backplane. The plurality of openings can be made through the passivation layer/planarization layer **1308** deposited over the micro devices. A planarization layer **1308** formed over micro devices, and openings are formed to expose the backplane working circuitry. The micro device can have multiple layers stacked together.

[0132] FIG. **13B** shows cross section of a system with integrated micro devices having openings to make connections with the backplane according to some embodiments. After all the microdevices transferred to a system substrate, the surface can be leveled by using planarization layer. A passivation layer/planarization layer **1308** may be deposited over a top surface of the micro device **1310**. In one case, an opening **1306** can be made to connect the micro device **1302** to the backplane. In another case, a common electrode/metal layer **1314** can be deposited on a surface of the microdevice **1310** to connect to the backplane. The common electrode can be shared with other microdevices. There can be more than one planarization layers. Each planarization layer can have a plurality of vias or a direct metal layer. One planarization step can cover or extend to one of the surfaces and the other planarization layer can extend to a surface or cover a surface higher than the first surface. There can be vias between planarization layer to connect the connections at different planarization layers together.

[0133] FIG. **13C** shows another exemplary system with combination of connections and vias at different surfaces of a micro device. A metallization (conductive) layer **1336** may be deposited over the first surface of the micro device **1310**. The metallization layer can be a common electrode for all the microdevices. A plurality of vias/openings can be made to connect the connection of the micro devices **1310** to a backplane located at surface of the micro device that is different from the first surface. Here, the micro device can have two or more different surfaces at different heights. One planarization step can cover or extend to one of the surfaces and the other planarization layer can extend to a surface or cover a surface higher than the first surface. One of an opening **1314-1** of the plurality of openings can be made through the passivation layer **1308** deposited over the micro devices. A planarization layer **1308** may be formed over micro devices, and openings are formed to expose the backplane working circuitry.

[0134] FIG. **13D** shows cross section of an exemplary system with combination of connections and vias at different surfaces of a micro device. A plurality of vias can be made to connect the micro devices **1310** to a backplane. The planarization layer **1308** can have a plurality of vias. As shown in FIG. **13D**, an opening **1306** can be made through passivation/planarization layer **208** deposited over the micro device wherein another opening **1318** can be made through a buffer layer **1320**.

[0135] FIG. **13E** shows cross section of a system with integrated micro devices having openings to make connections with a backplane according to some embodiments. A plurality of openings can be made to connect the micro devices **1310** to a backplane. A metallization layer **1334** may be deposited over one of the planarization surface coupling to the micro devices and an opening **1318**

can be made via a buffer layer **1320** at a bottom surface of the micro device.

[0136] FIG. **13F** shows cross section of a system with integrated micro devices having openings to make connections with a backplane according to some embodiments. An opening (**1306**) can be made to micro device **1310** for connections to a backplane through the passivation/planarization layer **1308**. A metallization layer **1344** may be deposited over one of the planarization surfaces opposite to the surface of the micro devices **1310**.

[0137] FIG. **14A** shows a top view of backplane according to one embodiment. Here, the micro device **1410** are covered by plurality of layers. The plurality of layers may comprise a passivation/planarization layer **1414** surrounding the micro device **1410**. A plurality of vias/openings (**1418**, **1412**) can be made to connect the micro device **1410** to the backplane components **1402**. The backplane components **1402** can be connected to the micro device through conductive layers **1406**, **1408** and vias **1412**, **1418**. The backplane can include multiple conductive traces **1406**, **1404**, **1408**, **1416**. These traces can be in one layer or separate layers. Other separate layers such as a passivation layer, a color conversion layer, an optical enhancement layer, a touch sensing electrode, or a common electrode may also be deposited over the micro-devices. The backplane component can be a transistor, capacitor, a signal source, a power source, etc.

[0138] FIG. **14B** shows another exemplary top view of the system with a backplane. Here, the micro device **1410** are covered by plurality of layers. The plurality of layers may comprise a passivation/planarization layer **1414** surrounding the micro device **1410**. A backplane components **1402** can be connected to the micro device **1410** through conductive layers **1406**, **1408** and vias **1412**, **1418**. The backplane can include multiple conductive traces **1406**, **1404**, **1408**. In one case, a metalization layer **1422** can be used to connect the microdevice to a component in the backplane or a power/signal source. Another common conductive layer **1420** can be used to connect another connection of the micro device. In a case, there can be a dielectric layer between the other conductive layer **1420** and the metalization layer **1422**. The dielectric layer is formed between the metalization layer and another conductive layer connecting to the one or more microdevices can be used to avoid shorting between electrodes.

[0139] Some embodiments of the present disclosure show integration of microdevices with backplane with plurality of vias at different locations of microdevices. Here, a reflective layer can be integrated over the microdevices to confine the light with the active area of the microdevice. The reflective layer can be a common electrode or a patterned electrode.

[0140] FIG. **15A** shows a cross section of an embodiment with integrated micro devices having planarization and dielectric layers. FIG. **15A** shows a substrate **1506**. A buffer layer **1508** can be deposited on top of the substrate **1506**. The buffer layer (or layers) can be used as delamination layer as well as a separate layer that is separating the fully integrated system from the substrate **1506**. It may be possible to eliminate this layer **1508** especially when the stacked micro-device and circuit structure is staying on the substrate **1506**. Micro-devices **1512** are transferred into the substrate **1506**. Here, the micro device can have two or more different surfaces at different heights. One planarization step can cover or extend to one of the surfaces and the other planarization layer can extend to a surface or cover a surface higher than the first surface. Thus, the system can include multiple step planarization layer. A planarizing layer **1514** may be formed over the micro device **1512**. It is possible that the planarizing layer **1514** is made of few different layers. A planarizing layer can be a passivation layer. Vias **1518-1** can be made in the planarizing layer **1514** to connect the micro device **1512** to a backplane **1502** located at surface of the micro device **1512** that is different from the first surface. The vias **1518-1** may be used to provide conductive electrode **1520** to connect the micro device **1512** to the backplane **1502**. The backplane can be either thin film transistors, CMOS chiplet, or other type of integrated circuit. A dielectric layer **1510** can be formed over the electrode **1520** and a reflective layer/reflector **1516** can be formed over the dielectric layer **1510** through a via **1518-2** in the dielectric layer. The planarization layer **1514** can be extended over the substrate to provide connections to the backplane **1502**. It is noted that any of the layers

can be eliminated. In one case, the surface of the transferred device is planarized first. Then, vias can be opened to create contact to the backplane. This contact can be at the edge or in the middle of the arrays. The conductive electrode **1520** includes the reflective material **1516** for directing light from the micro device. The dielectric layer **1510** includes openings therethrough to enable light to travel through to the electrode **1520**.

[0141] FIG. **15B** shows a cross section of an embodiment with integrated micro devices and backplane. Here, micro devices **1512** are transferred into the substrate **1506** having a buffer layer **1508** at top of the substrate **1506**. Here, the system can include multiple step planarization layer. Each planarization layer can have a plurality of vias. The planarizing layer/passivation layer **1522** may be deposited over the micro devices **1512** having two or more different surfaces at different heights. The planarization layer **1522** can be extended over the substrate **1506** to provide connections to the backplane **1502**. The openings **1518-1**, **1518-2** are extending through the planarizing layer **1522** may be used to receive conductive electrodes **1520** for connecting to the micro devices **1512** to the backplane elements **1502**.

[0142] FIG. **15C** shows a cross section of an embodiment with micro devices. Here, a buffer layer **1508** can be deposited on top of the substrate **1506**. Micro devices **1530** are transferred into the substrate **1506**. A planarizing layer **1514** is formed over the micro device **1530**. Vias **1518** can be made in the planarizing layer **1514**. These vias can be opened to create contact to the backplane **1502**. This contact can be at the edge or in the middle of the arrays. A reflective layer **1516** can be deposited for directing light from the micro device. The dielectric layer **1510** includes openings therethrough to enable light to travel. Here, an opening **1532** has been provided through the buffer layer **1508** and the planarization layer **1504** can be extended over the substrate **1506** to provide connections to the backplane **1502** through openings (**1518**, **1532**).

[0143] FIG. **16A** is a cross section illustrating a backplane arrangement including integrated circuits thereon according to some embodiments of the present invention. Here, the micro device can have two or more different surfaces at different heights. One planarization step can cover or extend to one of the surfaces and the other planarization layer can extend to a surface or cover a surface higher than the first surface. For example, a metallization layer **1616** may be deposited over one of the planarization surface coupling to the micro devices. There can be vias between planarization layer to connect the connections at different planarization layer together. A metalization layer **1616** may be directly deposited over a top surface of the micro devices or an opening **1604** can be made to the dielectric layer **1606** to connect the micro devices **1614** to a backplane **1602**. A reflective layer **1608** can be deposited for directing light from the micro device.

[0144] FIG. **16B** is a cross section illustrating a backplane arrangement including integrated circuits thereon according to some embodiments of the present invention. Here, a plurality of opening have been provided to connect the micro device **1614** to the integrated circuit layer **1602** and system. The circuit can be either thin film transistors, CMOS chiplet, or other type of integrated circuit. An opening **1604** can be formed through the planarization layer/passivation layer **1606** and other opening **1622** can be formed through the buffer layer **1610**. A reflective layer **1608** can be deposited for directing light from the micro device **1614**.

[0145] FIG. **16C** is a cross section illustrating a backplane arrangement including integrated circuits thereon according to some embodiments of the present invention. Here, openings **1604** may be provided through the planarization layer/passivation layer **1642** to the micro device **1614** on a substrate **1612** having a buffer layer **1610**. The planarization layer **1642** can be extended over the substrate to provide connections to the backplane **1602**.

[0146] In all embodiments demonstrated in FIG. **15A-C** and FIG. **16A-C**, the backplane component can be on top of the planarization or micro device.

[0147] FIG. **17A** shows a cross section of a micro device integrated with plurality of layers according to some embodiments of the present invention. In some embodiments, optical layers, such as color conversion **1722**, color filter **1726**, passivation layer and/or an electrode (blocking

layer) or other devices may be included, e.g. deposited, on a buffer layer **1710** and the micro device **1720**. In this case, other structures, such as a color conversion layer, color filter or other devices may be placed on the underside opposite to the side where the micro-devices are located. Other layers such as planarization/passivation layer **1702** and a reflector/reflective layer **1724** may be deposited at a top surface of the micro device. Post processing steps for additional structure such as reflective layers, fillers, black matrix or other layers may be used to improve the out coupling or confining of the generated LED light. In another example, color conversion layers are integrated into the system substrate to create different output from the micro devices. A color filter mounted on the buffer layer may be used for receiving light from the light emitting micro device. To reduce the direct light intensity, a blocking layer **1704** is deposited covering part of the micro device surface. In one case, the blocking layer can be the micro device electrode or another functional electrode such as touch screen electrode. The micro device light is get reflected back to the color conversion layer in combination by the blocking layer and the reflector layer. After or before the color conversion layer, there can be a passivation layer **1706** to protect the color conversion materials. A color filter can be added to the stack allowing the only the output of the color conversion layer to pass through. A passivation layer can be added after the color conversion layer. [0148] FIG. **17B** shows a top view of microdevice integrated with separate layers according to some embodiments of the present invention. FIG. **17B** shows a top view of FIG. **17A**, where separate layers such as color conversion layers **1722**, reflective layers **1724**, passivation/planarization layers **1728**, color filters **1726** or other separate layers are deposited over the micro device **1720**.

[0149] FIG. **17C** shows a cross section view of micro device integrated with optical layers and a backplane. In some embodiments, optical layers, such as color conversion **1722**, color filter **1726**, passivation layer **1706** and/or an electrode (blocking layer) **1704** or other devices may be included, e.g. deposited, at a bottom surface of the buffer layer **1710** and the micro device **1720**. In this case, optical structures, such as a color conversion layer, color filter or other devices may be placed on the underside opposite to the side where the micro-devices are located. Other layers such as planarization/passivation layer **1728** and a reflective layer/reflector **1724** may be deposited at a top surface of the micro device **1720**. A top planarization layer/passivation layer **1730** can be deposited over the reflective layer. The integrated circuit layer, e.g. the backplane, may be fabricated after the planarizing layer, and the backplane **1708** may be comprised of a thin film transistor (TFT) layer. Other optional passivation/planarization layers may be deposited over the backplane. The backplane component can be on top of the micro device structure layer.

[0150] FIG. **17D** shows a cross section of a system with micro devices integrated on a substrate with trenches in the passivation layers. A plurality of micro devices (e.g. **1702**, **1704**) are provided over the buffer layer **1710**. A plurality of passivation layers can be deposited over the substrate to enable implementation or fabrication of backplane into the system with the micro device. The planarization layer can be a continuous film or can be patterned to create reflective optical structure. A planarization or protective layer **1706a** can be deposited covering the backplane and micro devices. This passivation can act as a support structure for the system as well. Another passivation/planarization layer **1706b** can be deposited on the other side of the system. This layer **1706b** can act as a support for the system as well. A plurality of trenches (**1708a** and **1708b**) can be formed in the passivation layers (passivation layer **1706a** & passivation layer **1708b**) deposited at top and bottom surfaces. Components of the backplane can be on top of the micro devices as well. The plurality of trenches

[0151] FIG. **18A-18C** shows some exemplary combination of the micro device and backplane compensation on top of the micro devices.

[0152] FIG. **18A** shows a cross section view of micro devices integrated with plurality of passivation layers integrated with backplane components. In one case, a plurality of micro devices **1802** may be formed over a buffer layer **1806**. The buffer layer can be a passivation layer. Another

passivation layer/planarization layer **1808** may be formed over the micro device and can be patterned to create connections with the backplane components **1804**.

[0153] FIG. **18B** shows a cross section view of micro devices integrated with plurality of passivation layers integrated with backplane components. In one case, a plurality of micro devices **1802** may be formed over a buffer layer **1806**. The buffer layer can be a passivation layer. Another passivation layer/planarization layer **1808** may be formed over the micro device and can be patterned to create connections with the backplane components **1804**. A reflective layer/reflector **1810** can be formed over the planarization/passivation layer for directing light from the micro device.

[0154] FIG. **18C** shows another cross section view of micro devices **1802** integrated with plurality of passivation layers integrated with backplane components wherein a dielectric layer **1812** may be formed over the reflective layer/reflector **1810** to enable light to travel through to a top electrode or backplane components **1804**.

Color Conversion Layer Integration With Micro Device Substrate

[0155] Some embodiments of the present disclosure relate to the integration of color conversion layer(s) into a micro device substrate.

[0156] According to one embodiment, a display system may be provided. The display system may comprise a substrate, a buffer layer deposited over the substrate, a bonding pad formed on a top surface of the buffer layer, at least one micro device transferred on top of the bonding pad, and one or more color conversion layers disposed on the substrate surface or buffer layer surface opposite to the surface of the micro device.

[0157] According to another embodiment, a method of manufacturing a display system may be provided. The method may comprising providing a substrate, depositing a buffer layer over the substrate, forming a bonding pad on a top surface of the buffer layer, transferring at least one micro device on top of the bonding pad, and disposing one or more color conversion layers on the substrate surface or buffer layer surface opposite to the surface of the micro device.

[0158] According to some embodiments, a display system may be provided. The display system may comprising: a substrate, one or more planarization layers formed over the substrate; a bonding pad formed on a top surface of the one or more planarization layers, at least one micro device transferred on top of the bonding pad, and one or more color conversion layers disposed on or over the micro device.

[0159] This disclosure is related to the integration of color conversion layer(s) in a micro device substrate. The micro device substrate may comprise micro light emitting diodes (LEDs), organic LEDs, sensors, solid state devices, integrated circuits, MEMS, and/or other electronic components. The color conversion layers may include phosphor or quantum dots (QD).

[0160] In one embodiment, the color conversion layers may integrate on the micro device substrate surface opposite to a surface of the micro device.

[0161] In another embodiment, the color conversion layers may integrate on a buffer layer.

[0162] In yet another embodiment, the substrate may be removed and color conversion layer(s) may be directly formed on a surface of the buffer layer.

[0163] In some embodiments, the color conversion layer(s) may be formed after the buffer layer, wherein the buffer layer may be removed and color conversion layer(s) may be directly formed on the surface of the micro device.

[0164] In another embodiment, the buffer layer is the substrate.

[0165] In further embodiments, a bonding pad is formed on top of the buffer layer.

[0166] In another embodiment, one or more planarization layers may be formed on or over the at least one micro device.

[0167] In another embodiment, a reflector/blocking layer may be formed over the buffer layer before the bonding pad.

[0168] In yet another embodiment, the bonding pad may be transparent to allow light to get inside

or outside of the micro device.

[0169] In some embodiments, a black matrix may be deposited between the color conversion patterns to reduce ambient reflection and color mixing of the micro device.

[0170] In yet another embodiment, a bank layer may be formed for the color conversion layers to separate different color conversion layers.

[0171] In another embodiment, at least one contact deposited over the micro device, through a via in the one or more planarization layers, to provide an electrode to connect the micro device to the backplane.

[0172] In another embodiment, the bonding pad comprises a light distribution pad/structure and a bonding layer. The bonding pad may be used to improve the surface profile for bonding.

[0173] In another embodiment, the light distribution pad/structure can be formed before the bonding layer. The light distribution structure enhances the light extraction from the micro device. A light distribution layer may be provided in the light distribution structure. The light distribution layer and the light distribution structure may be the same. In another case, a height of the light distribution layer can be adjusted to compensate for the depth of the bank layer. The light distribution layer can be on part of the bank layer with reflector layer, or fill the entire bank layer.

[0174] In some embodiments, the planarization layer may be formed around the micro device and a second reflective structure may cover the patterned planarization layer.

[0175] In another embodiment, a similar or a different planarization layer(s) may be used to level at least some of the areas around the micro device.

[0176] In another embodiment, a backplane may be formed and extended over the micro device. The micro device may have at least one contact to the backplane through an electrode. The electrode may be the same or part of the second reflector.

[0177] FIG. **19A** shows a cross section of a micro device integrated with a plurality of layers according to some embodiments of the present invention. FIG. **19A** shows a substrate **1902**. A buffer layer **1906** may be deposited on a top surface of the substrate **1902**. The buffer layer (or layers) can be used as a delamination layer as well separating the fully integrated system from the substrate **1902**. It is possible to eliminate the buffer layer **1906** especially when the stacked micro device and circuit structure are staying on the substrate **1902**. A bonding pad **1908** may be formed on a top surface of the buffer layer **1906**. The bonding pad **1908** and the buffer layer **106** may be the same or different layers. In one embodiment, a reflector/blocking layer **1912** may be formed over the buffer layer before the bonding pad **1908**. A micro device **1904** may be transferred into the substrate **1902** on top of the bonding pad **1908**. The bonding pad **1908** may be transparent to allow light to get inside or outside of the micro device. The blocking layer **1912** can be a micro device electrode or another functional electrode such as a touchscreen electrode. Other layers such as a planarization layer **1910** may be formed on or over the micro device. It is possible that the planarizing layer **1910** may be made of a few different layers. The planarizing layer **1910** can be a passivation layer. A second reflector/reflective layer **1920** may cover the patterned planarization layer **1910**. Another similar or different planarization layer **1918** may be formed over the reflective layer **1920** to level out the areas around the micro device **1904**.

[0178] In one embodiment, vias may be made in the planarization layer **1918** to connect the micro device **1904** to a backplane **1914**. The vias may be used to provide conductive electrode to connect the micro device **1904** to the backplane. The backplane may be extended over the micro device **1904**. The backplane can be either thin film transistors, CMOS chiplet, or another type of integrated circuit. Post processing steps for additional structure such as reflective layers or other layers may be used to improve the outcoupling or confinement of the generated LED light. The planarization layer **1918** can be extended over the substrate to provide connections to the backplane **1914**. It is noted that any of the layers can be eliminated. In one case, the surface of the transferred device is planarized first. Then, vias can be opened to create contact to the backplane. This contact can be at the edge or in the middle of the arrays. In one case, the conductive electrode may include

the second reflector to direct light from the micro device.

[0179] FIG. **19B** shows a cross section illustrating a micro device integrated with different top layers, a backplane, and color conversion layers. In this case, other structures, such as a color conversion layer(s) **1922**, color filter, or other devices may be placed on the underside of the substrate **1902** opposite to the side where the micro device **1904** is located. In another example, color conversion layer(s) **1922** are integrated into the micro device substrate **1902** to create different output from the micro device. Color conversion layers may comprise color filter layers mounted on the buffer layer **1906** to receive light from the light emitting micro device **1904**. The micro device light is reflected back to the color conversion layer(s) **1922** in combination by the blocking layer and the reflector layer **1920**. In one case, a black matrix **1924** may be deposited between the color conversions patterns to reduce ambient reflection and color mixing of the micro device **1904**. In one example, the black matrix may be a layer of resins such as polyimide or polyacrylic in which particles of black pigment such as carbon black have been dispersed. In another aspect, color filters may be deposited on the color conversion layers. One can use a planarization layer and/or bank layer after the color conversion layer before depositing the color filter layers. The bank layer can separate different color conversion layers.

[0180] After or before the color conversion, there may be a passivation layer to protect the color conversion materials. A color filter may be added to the stack to allow only the output of the color conversion layer to pass through. A passivation layer can be added after the color conversion layer.

[0181] FIG. **19C** shows a cross section illustrating a micro device integrated with different top layers, a backplane, color conversion layers, and removal of the substrate. In this case, the substrate may be removed to enable a flexible system or color conversion layer(s) may be directly formed on the surface of the buffer layer. The system can be separated from the substrate while supported by the backplane **1914**. This separation may be done by modifying the buffer layer **1906**. The post processing steps may be performed on the surface of the layers separated from the substrate. Here, the buffer layer may include a protective layer to protect the devices (e.g., micro devices, the backplane components, and other conductive layers) from any side effect during the separation process. In one case, the protective layer can absorb the excess emission from laser that was used to separate the system from the substrate. In one embodiment, the protective layer can be removed after the separation process.

[0182] FIG. **19D** shows a cross section illustrating a micro device integrated with different top layers, a backplane, color conversion layers, and removal of the buffer layer. After the removal of the substrate, the buffer layer **1906** may be removed and the color conversion layer(s) may be formed on the surface. Here, a plurality of vias can be formed in the one or more layers to provide coupling options to the micro devices or the backplane.

[0183] FIG. **20A** shows a cross section of an embodiment with micro devices. Here, a buffer layer **2006** may be deposited on top of the substrate **2002**. Micro device **2004** is transferred into the substrate **2002**. A planarizing layer **2010** is formed over the micro device **2004**. Vias **2016** can be made in the planarizing layer. These vias can be opened to create contact **2030** to the backplane **2014**. This contact **2030** can be at the edge or in the middle of the micro device. A reflective layer **2020** can be deposited to direct light from the micro device. Another planarization layer **2018** can be extended over the substrate to provide connections to the backplane through openings. A bonding pad **2008** can couple to the device through at least one of the contacts (e.g., the contact at the top side). In one case, a layer that can be dielectric is covering the part of the device surface that is not covered by the contact. There can be side surfaces which can have different functions such as a passivation layer, optical enhancement layer, or encapsulation layer.

[0184] FIG. **20B** shows a cross section illustrating a micro device integrated with different top layers, a backplane, color conversion layers, and a contact on a top surface of the micro device through a via in the planarization layer **2016**. These vias can be opened to create contact **2030** to the backplane **2014**. This contact **2030** can be at an edge or in the middle of the micro device. In

one case, other structures, such as a color conversion layer(s), color filter or other devices may be placed on the underside opposite to the side where the micro device is located. In another example, color conversion layer(s) **2036** are integrated into the micro device **2004** substrate to create different output from the micro device. A color filter may be mounted on the buffer layer to receive light from the light emitting micro device. In one case, a black matrix **2032** may be deposited between the color conversions patterns to reduce ambient reflection and color mixing of the micro device.

[0185] One may use a planarization layer and/or bank layer after or before the color conversion layer before depositing the color filter layers. The bank layer can separate different color conversion layers. A bank layer may be formed for the color conversion layers to separate different color conversion layers.

[0186] FIG. **20C** shows a cross section illustrating a micro device integrated with different top layers, a backplane, color conversion layers, a contact on a top surface of the micro device through a via in the planarization layer and removal of the substrate. In this case, the substrate **2002** as shown in FIG. **20B** may be removed to enable a flexible system or post processing steps performed on the side of the system facing the substrate. The system can be separated from the substrate **2002** while supported by the backplane **2014**. This separation may be done by modifying the buffer layer **2006**.

[0187] FIG. **20D** shows a cross section illustrating a micro device integrated with different top layers, a backplane, color conversion layers, a contact on a top surface of the micro device through a via in the planarization layer, and removal of the buffer layer. After the removal of the substrate as shown in FIG. **20C**, the buffer layer **2006** may be removed. Here, a plurality of vias can be formed in the one or more layers to provide coupling options to the micro devices or the backplane **2014**.

[0188] FIGS. **21A-21D** shows cross section views illustrating a micro device having reflector on sidewalls of the micro device according to embodiments of the present disclosure. Here, a buffer layer **2106** deposited on top of the substrate **2102**. The micro device **2104** is transferred into the substrate **2102**. A reflective layer **2118** may be deposited on the sidewalls of the micro device **2104** to direct light from the micro device. A planarizing layer **2110** may be formed over the micro device. A via **2120** may be made in the planarizing layer **2110** to create contact **2130** to the backplane **2114**. This contact **2130** can be at an edge or in the middle of the micro device. A bonding pad **2108** may couple to the device through at least one of the contacts (e.g., the contact at the top side).

[0189] FIG. **21B** shows the integration of color conversion layer(s) into the micro device substrate **2102** on the underside opposite to the side where the micro device **2104** is located to create different output from the micro device. In one case, a black matrix **2132** may be deposited on the sidewalls of the color conversion layers **2136** to reduce an ambient reflection of the micro device **2104**.

[0190] FIG. **21C** shows a cross section illustrating a micro device integrated with a contact on a top surface of the micro device, and removal of the substrate. In this case, the substrate **2102** as shown in FIG. **21B** may be removed to enable a flexible system or post processing steps performed on the side of the system facing the substrate. The system can be separated from the substrate **2102** while supported by the backplane **2114**. The separation may be done by modifying the buffer layer **2106**.

[0191] FIG. **21D** shows that after the removal of the substrate as shown in FIG. **21C**, the buffer layer **2106** may be removed. Here, a plurality of vias can be formed in the one or more layers to provide coupling options to the micro devices or the backplane **2114**.

[0192] FIG. **22** shows a cross section illustrating a micro device integrated with different layers and a backplane. In this case, a buffer layer **2206-1** may be formed on the substrate **2240** followed by formation of color conversion layer(s) **2236** over the buffer layer **2206-1**.

[0193] FIGS. **23A-23B** show a cross section of a display system. In FIG. **23A**, a substrate **2308**

may be provided. A plurality of planarization layers **2314** may be formed over the substrate. A backplane may also be formed over the planarization layers. A bonding pad may be formed on a top surface of the planarization layer(s) **2314**. The bonding pad comprises a light distribution pad **2312** and a bonding layer **2304**. The light distribution pad **2312** and the bonding layer **2304** may be the same or different. In one embodiment, a reflector layer/blocking layer **2310** may be formed over the planarization layer(s) before the bonding pad. The reflector (or the blocking layer) **2310** is mounted on one or more sides of the light distribution pad to reflect light back through the light distribution structure and color conversion layer(s). A micro device **2302** may be transferred into the substrate **2308** on top of the bonding pad. The bonding pad may be transparent to allow light to get inside or outside of the micro device. The bonding pad may be provided to improve the surface profile for bonding. The reflector layer **2310** coupled to the micro device may direct the light through the light distribution pad. There may be a filler around the micro device. The filler may be a color conversion layer(s) **2306**. In another case, color conversion may be on top of a filler layer. [0194] The light distribution pad **2312** distributes the light before reaching the color conversion layer(s) **2306**. In one structure, the light is distributed and directed away from the substrate where the color conversion layer **2306** is located. The light distribution pad can be a thick transparent layer. In one example, this layer is more than 3 μm . In another example, the side of the transparent layer is blocked by opaque or reflective layer(s) **2310** for each pixel or sub-pixel. In another example, there can be a reflective layer behind or on top of the micro device.

[0195] With reference to FIG. **23B**, a substrate **2308** may be provided. A plurality of planarization layers **2314** may be formed over the substrate. A buffer layer may also be formed over the substrate. A backplane may also be formed over the substrate. Here, a transparent bonding pad may be formed inside a reflector structure **2310**. The bonding pad comprises a light distribution pad **2312** and a bonding layer **2304**. The reflector **2310** is transparent and as such the light from the micro device can be directed into the reflector. In one case, the reflector can also direct the light to the micro device in case the micro device is a sensor. A bank layer **2320** or other planarization layers may be deposited over the reflective layer. There may be a filler around the micro device. The filler may be a color conversion layer(s) **2306**. In another case, color conversion may be on top of a filler layer.

[0196] In another embodiment, the light distribution pad/structure **2312** can be formed before the bonding layer **2304**. The light distribution structure **2312** enhances the light extraction from the micro device. In another case, a height of the light distribution layer can be adjusted to compensate for the depth of the bank layer **2320**. The light distribution layer can be on part of the bank layer with reflector layer or fill the entire bank layer.

Expanding the Size of Micro-Device for a Better Integration

[0197] Some embodiments of the present disclosure relate to methods and structures for enhancing the bonding process of micro devices into a substrate (e.g. system substrate).

[0198] Development of micro-devices consists of few major steps such as epitaxial growth of multiple layers, patterning and passivation of the layers, and lift off process. These steps can be costly and therefore, there is a significant desire to reduce the size of micro devices to produce more of them in one wafer substrate. This way, the cost per micro-device can be reduced. However, handling and bonding of such a device can be challenging. For example, for sub **10** micrometer device, the pads can be as small as a couple of micrometers. Bonding such small pads to a substrate requires significant alignment as the quality of the bonding will be affected significantly by the overlap. Moreover, the property of such bonding can be compromised due to the small surface area of the bond pads. There remains a need for expanding the device area or bonding area of micro devices.

[0199] Some embodiments of the present disclosure relate to expanding the device area or bonding area of micro devices. Herein described, an optoelectronic device comprising one or more extension layers formed around the optoelectronic device and at least one contact layer extended to

the extension layers.

[0200] Various embodiments in accordance with the present structures and processes provided are described below in detail.

[0201] FIG. **24** shows an optoelectronic device substrate **2402**, wherein different conductive layers **2404** and active layers **2406** are deposited on top of the device substrate **2402** followed by other conductive layers **2408**. The device comprising a plurality of semiconductor layers disposed on the device substrate **2402** forming a top surface and a bottom surface, wherein the plurality of semiconductor layers are isolated into smaller areas forming at least one side surface and at least one conductive pad is formed that is coupled to the optoelectronic device on either the top or the bottom surface. The conductive layers **2404** may comprises buffer layers, p-type doped layers, n-type doped layers, charge blocking layers, and electrode. The active layers **2406** may comprise multi quantum well (MQW) layer, and other conductive layers **2408**. The MQW layer may include a plurality of single quantum layers in a stack. The conductive layers can be transparent or opaque. The examples of a transparent conductive layer are thin Ni/Au or ITO that can be formed on the p-doped semiconductor layer (e.g. GaN or GaAs) for a better lateral current conduction. The conductive layer can have a stack of different layers. For example, the p-type electrode such as Pd/Au, Pt or Ni/Au is then formed on the transparent conductive layer. Here, the ohmic contact **2412** is surrounded by a dielectric layer **2410**. A bonding pad **2414** can be deposited over the ohmic contact **2412** and can be extended over the dielectric layer. The dielectric layer can avoid unwanted short/coupling between the device and the ohmic contact.

[0202] However, for small devices or devices with multiple pads, the area may not be sufficient to make the pads large.

[0203] FIG. **25A** shows the microdevice **2406** formed on the substrate **2402** wherein a plurality of extension layers **2510** are added to the device **2406**. Here, the one or more extension layers are formed around the optoelectronic device **2406** at the side surface and at least one bonding pad e.g., **2414** may extended to the one or more extension layers **2510**. Some of these extension layers **2510** can have other functions such as reflection, color conversion, and etc. The dielectric layer **2410** can be extended over the extension layers **2510**. The bonding pad **2414** can extend over the extension layers **2510** as well. The extension layers **2510** can be also optimized to enhance the light extraction by using different reflection indices. In one case, the extension layers **2510** can be formed on a buffer layer deposited on the substrate **2402**.

[0204] In one case, at least one of the one or more extension layers is a polymer and a width of the at least one of the one or more extension layers is between 100 nm to a few micrometers.

[0205] FIG. **25B** shows an exemplary top view of the device as shown in FIG. **25A**. Here, the extension layers **2522** covers at least one side of the micro device **2524** and the pad **2520** connected to the contact/via **2412** extends to at least a part of the extension layers **2522** in one direction.

[0206] FIG. **26A** shows a device where the extension layers **2522** are used as planarization layers as well. Here, the device **2602** has more than one contact (**2606**, **2604**) and there is an opening in the extension layers **2522** to provide access to at least one of the contacts (**2606**, **2604**). The extension layers **2522** can include the dielectric layer as well. The micro device **2602** can have p or n type bonding pads. One of the bonding pads (P, N) at least cover a part of the extension layers **2522**. A trench **2610** is made through the extension layer **2522** to a lower level contact **2604**

[0207] FIG. **26B** shows an exemplary top view of the structure in FIG. **26A**. Here, the extension layers **2522** cover at least one side of a trench **2610** to a lower level contact **2606**. The bonding pad **2612** for that connection **2604** can extend to at least one area of the extension layer **2522**. The other contact **2606** on the other side of the device **2602** is connected to the another bonding pad **2614** that can be extended to at least another area of the extension layers **2522**.

[0208] FIG. **27A** shows another device embodiment where the extension layers **2522** are used as planarization layers as well. Here, the device has more than one contact (**2704**, **2706**) and there is an opening in the extension layers to provide access to at least one of the contacts (**2704**, **2706**).

The extension layers **2522** can include the dielectric layer as well. One of the pads (P, N) at least cover part of the extension area. A gate contact **2710** can also be provided to the extension layers **2522** connected to gate metal.

[0209] FIG. **27B** shows an exemplary top view of the structure in FIG. **27A**. Here, the extension layers **2522** cover at least one side of the trench **2710** to the lower level contact **2708**. The pad **2706** for that connection extends to at least one area of the extension layer **2522**. Here, other contacts **2712**, **2714** are connected to the device **2708** through other contact pads **2720**, **2740**. The other contact **2714** on the other side of the device **2708** is connected to another pad **2740** that is extended to at least another area of the extension layers **2522**.

[0210] FIG. **28A** shows an embodiment where the top contact **2802** is extended to the bottom side of the device **2824**. The traces of the bonding pad **2804** is covered by the extension layers **2522**. After that a via through the extension layers **2522** or part of device area provide access to the device from the other side of the device. The top contact **2802** may be connected to the trace through the via.

[0211] FIG. **28B** shows an embodiment wherein the top contact **2816** can be extended to the other side of the microdevice through a trace **2818**. The trace **2818** is covered by the extension layers **2522**. The extension layers **2522** can be the planarization layers. A temporary substrate **2820** can be bonded on a top surface of the micro device. The extension layers **2522** can be formed on a buffer layer **2822** deposited on the substrate **2820**. In one case, there can be an intermediate layer **2806** that get connected to the pad **2814** through a via **2830**. In another case, it can be connected to the pad **2814** directly. The pad **2814** can be extended to the extension layers **2522**.

[0212] FIG. **29** shows an embodiment having plurality of micro devices connected to a driver substrate according to one embodiment of the invention. The driver substrate can include pixel circuits **2918**. The micro devices **2910** coupled to the pixel circuits either through bonding pads **2908** or through traces **2904** deposited to cover at least one contact point in the device and one contact point in the driver substrate coupled to the pixel circuit. The driver substrate can have contact pads **2940** on a side different from the side where the microdevices **2910** are located. These contact pads **2940** are either coupled to the pixel circuits **2918** or to the microdevices through a via **2920** in the substrate. There can be a polarization/dielectric layer **2916** between a part of microdevice and part of the driver substrate. There can be further planarization/encapsulation layer **2912** after the microdevices **2910** are integrated in the driver substrate. The driver substrate is then coupled to the system substrate either through the bonding pads **2940** on the driver substrate and the pads **2902** on system substrate **2900** or through traces **2922** deposited to cover at least one contact point in the driver substrate and one contact point in the system substrate **2900**. The system substrate **2900**, can have extra circuitry or contact layers **2946** that enable accessing the driver substrate. The bonding agent **2942** provide mechanical reliability and can also be used as a coupling agent as well. In one case, the bonding agent **2942** can be patterned to be only in selected areas. There can be planarization and bonding agent **2940** between system substrate **2900** and driver substrate. Here, a plurality of micro devices **2910** such as red, green and blue can be provided. The plurality of micro devices can be connected together to a driver substrate forming a cell.

[0213] According to one embodiment, a method to integrate one or more microdevices to a system substrate is provided. The method comprising transferring the one or more microdevices to the system substrate, forming a protective layer to cover the one or more microdevices, extended beyond the edges of the one or more microdevices, patterning the protective layer to receive conductive electrodes and connecting backplane elements to the one or more microdevices through the conductive electrodes. The conductive electrodes include individual electrodes for each micro device.

[0214] According to another embodiment, the protective layer comprises a planarization layer, wherein the planarization layer is one of: a continuous planarization layer or a patterned

planarization layer.

[0215] According to yet other embodiments, the method may further comprising forming a plurality of another planarizing layers over the protective layer covering each micro device. The plurality of another planarizing layers is one of: an extension of the protective layer, a passivation layer, another protective layer or any other separate layer. The protective layer is removed before formation of the conductive electrodes that connects the one or more microdevices to the backplane elements.

[0216] According to some embodiment, patterning the protective layer comprising forming a plurality of vias in the protective layer before the formation of the conductive electrodes that connects the one or more microdevices to the backplane elements. The plurality of vias are provided at different locations of the microdevices to provide connection to the backplane elements and a metallization layer or a common electrode is directly deposited to the one or more microdevices.

[0217] According to further embodiments, the method may further comprising forming a buffer layer between the one or more microdevices and the system substrate, forming a plurality of other layers on top of the backplane elements, wherein the plurality of other layers comprises one of: a passivation layer, a color conversion layer, an optical enhancement layer, a touch electrode, or a common electrode, performing post processing steps on a surface of the plurality of other layers separated from the system substrate, wherein the post processing steps include at least one of: opening of one or more of the plurality of other layers, removing one or more of the plurality of other layers, forming different electrodes, forming optical layers, forming color conversion/filter layers, or forming passivation layer, integrating a secondary system substrate to the plurality of other layers; and removing the system substrate after integration of the secondary system substrate.

[0218] According to some embodiments, the buffer layer comprises another protective layer to protect the micro devices during separation process and a plurality of another vias are formed in the buffer layer to a side opposite to a first side of microdevices to provide coupling options to the micro devices.

[0219] According to further embodiments, the method may further comprising providing one or more color conversion layers disposed on the substrate surface or buffer layer surface opposite to the surface of the micro device and providing one or more additional layers on the color conversion layers underside the microdevices, wherein the additional layers comprise one of: a color filter, a black matrix, a bank layer, a blocking layer, a reflective layer, a passivation layer and a planarization layer. The planarization layer is a support layer comprises one of: a continuous planarization layer or a patterned planarization layers, and wherein another patterned planarization layer is provided over the microdevices and backplane.

[0220] According to another embodiment, a display system is provided. The display system comprising: a substrate, a buffer layer deposited over the substrate, a bonding pad formed on a top surface of the buffer layer, at least one micro device transferred on top of the bonding pad; and one or more color conversion layers disposed on the substrate surface or buffer layer surface opposite to the surface of the micro device. The buffer layer is modified to separate the substrate from the display system, wherein the buffer layer is thinned or removed.

[0221] According to one embodiment, the display may further comprising: a first reflective layer formed over the buffer layer before the bonding pad, one or more planarization layers formed on or over the at least one microdevice, a second reflective layer that covers the one or more planarization layers; and a backplane formed and extended over the one or more planarization layers. the bonding pad is transparent to allow light gets inside or outside of the micro device.

[0222] According to another embodiment, the display may further comprising: a black matrix deposited between the color conversion layers, opposite to the surface of the micro device, to reduce ambient reflection and color mixing of the micro device; and a bank layer formed for the color conversion layers to separate different color conversion layers.

[0223] According to some embodiments, the display may further comprising at least one contact deposited over the micro device, through a via in the one or more planarization layers, to provide an electrode to connect the micro device to the backplane.

[0224] According to another embodiment, a method of manufacturing a display system may be provided. The method may comprising providing a substrate, depositing a buffer layer over the substrate, forming a bonding pad on a top surface of the buffer layer, transferring at least one micro device on top of the bonding pad; disposing one or more color conversion layers on the substrate surface opposite to the surface of the micro device, and forming a reflective layer over the buffer layer on the surface of the bonding pad opposite to the micro device.

[0225] According to one embodiment, a display system may be provided. The display system may comprising: a substrate, one or more planarization layers formed over the substrate, a bonding pad formed on a top surface of the one or more planarization layers, at least one micro device transferred on top of the bonding pad; and one or more color conversion layers disposed on or over the micro device. The bonding pad comprises a light distribution structure and a bonding layer, the light distribution structure is one of: a part of the bank layer with a reflective layer or fills the entire bank layer and the reflective layer is formed over the planarization layer before the bonding pad to direct light through the light distribution pad.

[0226] According to some embodiments, an optoelectronic device may be provided. The optoelectronic device may comprising a plurality of semiconductor layers, disposed on a substrate, forming a top surface and a bottom surface, wherein the plurality of semiconductor layers having isolated areas forming at least one side surface, at least one conductive pad coupled to the optoelectronic device on at least one of the top or the bottom surface; and one or more extension layers formed around the optoelectronic device at the at least one side surface, wherein the at least one conductive pad is extended to the one or more extension layers. The one or more extension layers covers at least one side of the optoelectronic device and the at least one contact layer provided through an opening in the one or more extension layers.

[0227] According to another embodiment, the one or more extension layers covers at least one side of the optoelectronic device and the at least one contact layer provided through an opening in the one or more extension layers.

[0228] According to one embodiment, the device may further comprising a dielectric layer formed around the at least one contact and extended over the one or more extension layers. The at least one conductive pad deposited over the at least one contact layer and extended over the dielectric layer. The one or more extension layers comprises at least one of: another dielectric layer, a reflective layer and a color conversion layer. The one or more extension layers formed on a buffer layer. The one or more extension layers expand an area of the optoelectronic device, where at least one of the one or more extension layers is a polymer. Also, the width of the at least one of the one or more extension layers is between 100 nm to a few micrometers.

[0229] In summary, the present disclosure relates to the integration of circuits and systems into a microdevice substrate by providing protective layers on the donor substrate, integrating color conversion layer(s) into the micro device substrate opposite to a surface of microdevices. Some embodiments of the present disclosure also relate to expanding an area of micro devices or a bonding area of micro devices.

[0230] The foregoing description of one or more embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

Claims

- 1.** A method to integrate one or more microdevices to a system substrate, the method comprising: transferring the one or more microdevices to the system substrate; forming a protective layer to cover the one or more microdevices, extended beyond the edges of the one or more microdevices. patterning the protective layer to receive conductive electrodes; and connecting backplane elements to the one or more microdevices through the conductive electrodes, wherein the conductive electrodes include individual electrodes for each micro device.
 - 2.** The method of claim 1, wherein the protective layer comprises a planarization layer, wherein the planarization layer is one of: a continuous planarization layer or a patterned planarization layer.
 - 3.** The method of claim 1, further comprising: forming a plurality of another planarizing layers over the protective layer covering each micro device, wherein the plurality of another planarizing layers comprises one of: an extension of the protective layer, a passivation layer, a dielectric layer, another protective layer, a color conversion layer, a reflective layer and a separate layer.
 - 4.** The method of claim 1, wherein patterning the protective layer comprising: forming a plurality of vias in the protective layer before the formation of the conductive electrodes that connects the one or more microdevices to the backplane elements.
 - 5.** The method of claim 1, wherein the plurality of vias is provided at different locations of the microdevices to provide connection to the backplane elements.
 - 6.** The method of claim 1, wherein a metallization layer or a common electrode is directly deposited to the one or more microdevices.
 - 7.** The method of claim 1, wherein the protective layer is removed before formation of the conductive electrodes that connects the one or more microdevices to the backplane elements.
 - 8.** The method of claim 1, further comprising: forming a buffer layer between the one or more microdevices and the system substrate.
 - 9.** The method of claim 1, further comprising: forming a plurality of other layers on top of the backplane elements, wherein the plurality of other layers comprises one of: a passivation layer, a color conversion layer, an optical enhancement layer, a touch electrode, or a common electrode.
 - 10.** The method of claim 9, further comprising: performing post processing steps on a surface of the plurality of other layers separated from the system substrate, wherein the post processing steps include at least one of: opening of one or more of the plurality of other layers, removing one or more of the plurality of other layers, forming different electrodes, forming optical layers, forming color conversion/filter layers, or forming passivation layer.
 - 11.** The method of claim 9, further comprising: integrating a secondary system substrate to the plurality of other layers; and removing the system substrate after integration of the secondary system substrate.
 - 12.** The method of claim 8, wherein the buffer layer comprises another protective layer to protect the micro devices during separation process.
 - 13.** The method of claim 8, wherein a plurality of another vias is formed in the buffer layer to a side opposite to a first side of microdevices to provide coupling options to the micro devices.
 - 14.** The method of claim 9, further comprising providing one or more color conversion layers disposed on the substrate surface or buffer layer surface opposite to the surface of the micro device.
 - 15.** The method of claim 14, further comprising providing one or more additional layers on the color conversion layers underside the microdevices, wherein the additional layers comprise one of: a color filter, a black matrix, a bank layer, a blocking layer, a reflective layer, a passivation layer and a planarization layer.
 - 16.** The method of claim 15, wherein the planarization layer is a support layer that comprises one of: a continuous planarization layer or a patterned planarization layer, and wherein another patterned planarization layer is provided over the microdevices and backplane.
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