SOLID-STATE IMAGING ELEMENT AND IMAGING DEVICE

BACKGROUND

A solid-state imaging element in which a photoelectric conversion element is provided on a semiconductor substrate is used for a charge-coupled device (CCD) image sensor, a complementary metal-oxide semiconductor (CMOS) image sensor, or the like. For example, the solid-state imaging element is provided in an imaging device such as a camera module.

An imaging device includes a lens which is provided between a subject and a solid-state imaging element. Light is incident on the subject, the light which is reflected by the subject is incident on the solid-state imaging element by the lens, and thereby an image is formed. Optical characteristics of an image are determined by the characteristics of the solid-state imaging element and the lens. In the solid-state imaging element, miniaturization of a pixel has been processing for an increase of the number of pixels, and sensitivity improvement based on the characteristics of the solid-state imaging element and the lens is desired.

DETAILED DESCRIPTION

Hereinafter, each embodiment of the invention will be described with reference to the drawings.

The drawings are schematic or conceptual. A relationship between a thickness and a width of each portion, a ratio of magnitude between the portions, or the like is not necessarily the same as actuality. In addition, even in a case of showing the same portion, there is a case in which a dimension and a ratio is differently shown from each other by the drawings.

In the specification and each figure, the same symbols or reference numerals will be attached to the same elements as those previously described with regard to a figure thereinabove, and description thereof will be appropriately omitted.

First Embodiment

FIG. 1 is a schematic view showing an imaging device according to a first embodiment.

FIG. 2A and FIG. 2B are schematic views showing a portion of the imaging device according to the first embodiment.

FIG. 1 shows how an imaging device 120 receives light from a subject 130 and forms an image. FIG. 2A shows an upper surface perspective view of a sensor section 100. FIG. 2B shows a cross-sectional diagram of a line 2B-2B of FIG. 2A.

As shown in FIG. 1, the imaging device 120 includes a lens 110 and the sensor section 100. The imaging device 120 is mounted in an electronic apparatus such as a digital camera, a camera phone, and a smart phone. The imaging device 120 is, for example, a camera module.

According to a distance from the imaging device 120 to a position of the subject 130, the imaging device 120 acquires an image of a region of another position of the subject 130 as a plurality of unit images. For example, the imaging device 120 acquires an image of a positional point 130a as a unit image, in the positional point 130a which is positioned in the subject 130. A unit image can be acquired by aligning at least one of light intensity, amplitude, and a phase using a point spread function (PSF). The point spread function is a function which shows a shape of the focused light beam of diffracted light from the lens 110. In addition, the unit image may be acquired by focusing the diffracted light from the lens 110 and aligning a plane wave. The unit image may be acquired based on the subject 130.

The lens 110 is provided between the sensor section 100 and a subject 130. The lens 110 receives light L1 from the subject 130, and forms an image using diffracted light L2 from the subject 130. As shown in Fig. 1, a position of the lens 110 is set in such a manner that an image forming plane of the lens 110 is positioned on the sensor section 100 (microlens 40). The position of the lens 110 may be set in such a manner that the image forming plane of the lens 110 is positioned between the lens 110 and the sensor section 100.

The sensor section 100 is a solid-state imaging element such as a CCD image sensor or a CMOS image sensor. The sensor section 100 converts the light which is incident on a light receiving plane by the microlens 40 into an electrical signal and outputs the electrical signal. That is, light receiving elements in the sensor section 100, each corresponding to a pixel are disposed side by side on the light receiving plane in a matrix form. Light is converted into an electrical signal of each pixel by each photoelectric conversion of the light receiving element, and is output.

As shown in FIG. 2A and FIG. 2B, a plurality of light receiving elements 101 is provided in the sensor section 100. A semiconductor layer 10, an intermediate film 20, color filters 30, microlenses 40, and a wiring layer 50 are provided in the plurality of light receiving elements 101. The semiconductor layer 10 includes a first surface 10a and a second surface 10b. The first surface 10a is a surface opposite to the second surface 10b.

The intermediate film 20 is, for example, a planarization film. The planarization film is a film which planarizes a surface on which the color filters 30 are formed. In addition, the intermediate film 20 may be an oxide film or an antireflection film. The oxide film is a film which includes a silicon oxide such as silicon dioxide (SiO2). The antireflection film is a film which includes a silicon oxide such as silicon dioxide (SiO2). If the antireflection is provided, an amount of light which is incident on the semiconductor layer 10 is increased. If an amount of light which is incident on the semiconductor layer 10 is increased, sensitivity of a pixel can be increased. The intermediate film 20 may be a stack film which includes at least one of the oxide film, the antireflection film, and the planarization film.

Lights with wavelength ranges different from each other respectively pass through the color filters 30. The color filters 30 are provided on the intermediate film 20. The color filters 30 include, for example, an R color filter through which the light with a red wavelength range passes, and a B color filter through which the light with a blue wavelength range passes. As shown in FIG. 2A, the color filters 30 are disposed in parallel to each other in a matrix form.

The microlens 40 focuses light which is emitted from a light source and is incident on the sensor section 100, and guides the light on the second surface 10b side of the semiconductor layer 10. The microlens 40 is provided on the color filter 30.

The wiring layer 50 is provided on the first surface 10a of the semiconductor 10. The wiring layer 50 includes multilayer wires 51, and an interlayer insulating layer 52. The multilayer wires 51 are formed in the inside of the interlayer insulating layer 52. A supporting substrate may be provided on a surface on a side opposite to a surface of the wiring layer 50 on which the semiconductor layer 10 is formed.

The semiconductor layer 10 is an epitaxial layer which is formed on a semiconductor substrate such as a silicon substrate. The semiconductor layer 10 includes an n-type diffusion layer 10n and a p-type region 10p.

In addition, a transmission transistor 11 and a transistor group 12 are provided in the periphery of a boundary between the semiconductor layer 10 and the wiring layer 70. The transistor group 12 includes, for example, an amplification transistor, a reset transistor, and an address transistor.

A p-n junction is formed by the n-type diffusion layer 10n and the p-type region 10p. If a predetermined reverse direction bias is applied to the p-n junction, a depletion layer is formed. The light is absorbed into the semiconductor layer 10 and a pair of a free electron and a free hole is formed. When the absorption of the light occurs in the depletion region of the p-n junction or occurs within a range of a diffusion distance of a carrier from the depletion layer, the carrier generated by the absorption of the light moves by means of an electric field, and thereby a photocurrent is generated. Thus, the depletion region that is formed by the p-n junction which is formed by the n-type diffusion layer 10n and the p-type diffusion layer 10p, and a region in the range of the diffusion distance from the depletion region correspond to a light receiving section 10r. That is, the light receiving section 10r is a section in which the light is absorbed and the photocurrent is generated, or is a section in which a photoelectric conversion is performed. That is, the light which is incident on the semiconductor layer 10 from the microlens 40 is converted into a signal by the light receiving section 10r and charges are stored. The n-type diffusion layer 10n stores signal electrons which are generated by the photoelectric conversion. The transmission transistor 11 makes the signal electrons which are stored in the n-type diffusion layer 10n move to a diffusion layer or the like. The amplification transistor which is connected to the diffusion layer or the like amplifies the signal electrons and outputs the signal electrons to the multilayer wire 51. The address transistor controls timing in which the amplification transistor outputs the signal electrons. The reset transistor controls the amplification transistor so as to be in an initial state.

An electrical signal of each pixel which is output by each photoelectric conversion of the light receiving sections 10r is signal-processed by a signal processing circuit which is embedded in an electronic apparatus, and then, is converted into image data. The image data is displayed on a monitor of the electronic apparatus, or the like.

FIG. 3 is a diagram which describes optical characteristics of an image which is formed on the sensor section.

FIG. 4 is a diagram showing the image which is formed on the sensor section.

FIG. 5 is a graph diagram showing the optical characteristics of the image which is formed on the sensor section.

FIG. 6 is another diagram which describes the optical characteristics of the image which is formed on the sensor section.

As shown in FIG. 3, a positional point 130b is a point or a portion which is positioned on the subject 130, and a point or a portion which is separated by a distance I from an optical axis A1. The positional point 130b on the subject 130 forms an image point 100b on an image surface 100a on the sensor section 100 by means of the lens 110. The image point 100b is a point in a position which is separated by a height X from the optical axis A1, in an opposite direction to the positional point 130b by using the optical axis A1 as a center.

The height X is a distance (hereinafter, there is a case of being referred to as image height) between an image point 100c which is an intersection point of the optical axis A1 on the image surface 100a and the height X, and the image point 100b. Here, an image height (IH) is a numerical value in which a distance from a central pixel of an image surface to each pixel on a two-dimensional array plane is represented by percentage, when a distance from the central pixel of the image surface to a pixel of a diagonal end is set to 100%.

An angle q1 is an angle (hereinafter, there is a case of being referred to as a chief ray angle) of a main optical line A2 which passes through the center of light flux. Here, the main optical line A2 passes through the center 110c of the lens which is the center of an image of an aperture from the positional point 130b, and is a line that is a reference for determining an image height and a position with regard to the image point. In addition, a chief ray angle (CRA) is an angle for defining a screen range. That is, the chief ray angle on the image point 100c is zero degree.

In FIG. 4, in a case in which a plurality of positional points different to each other is formed, an image point which is represented on the image surface 100a of the sensor section 100 is shown. The image height of the image point 100c is 0%, and the chief ray angle of the image point 100c is 0 degree. The image height of the image point 100d is 50%, and the chief ray angle of the image point 100d is 25 degrees. The image height of the image point 100e is 100%, and the chief ray angle of the image point 100e is 50 degrees. In addition, the image point 100c is positioned in the center of the light receiving surface of the sensor section 100. For example, in a case in which the image surface 100a is a rectangular shape, the center of the light receiving surface of the sensor section 100 is an intersection point of two diagonal lines.

As shown in FIG. 5, as the chief ray angle is increased, the image height is increased. A vertical axis shows the image height IH (%). A horizontal axis shows the chief ray angel CRA (degree). The image height and the chief ray angle are shown by a non-linear graph.

In addition, as shown in FIG. 6, if a diameter (lens diameter) of the lens is referred to as D, a distance (a focal distance of the lens) between the center of the lens and an intersection point of the optical axis on the image surface is referred to as f, a distance corresponding to the image height is referred to as x, and the chief ray angle is referred to as q, the following relational expressions (1) and (2) are satisfied.

F=f/D×××(1)

tan q=x/f×××(2)

F is a characteristic value with regard to a brightness of the lens, and is a value related to a magnitude of a point spread function. In addition, for example, the diameter D, the distance f, and the chief ray angle q are the diameter D1, the distance f1, and the chief ray angle q1 which are shown in FIG. 3. The distance x is a distance corresponding to the image height X shown in FIG. 3. For example, the diameter D of the lens is not less than 1 mm and is not more than 10 mm.

In addition, if a wavelength of light is referred to as l, the point spread function PSF and the distance x corresponding to the image height X are satisfied by the following relational expression (3). l is a wavelength of light in the center of the light receiving element 101, for example, the color filter 30.

PSF(x)=1.22´=1.22´=1.22×××(3)

Thus, a relationship between the chief ray angle and the image height is determined by the characteristics of the lens 110 and the sensor section 100 from FIG. 5. In addition, it can be seen from FIG. 6 and the relational expression (3) that as the value (distance corresponding to image height) of the image height is increased, the value of the point spread function is increased.

For example, an incident angle of the incident light which uses an axis perpendicular to the two-dimensional array plane as a reference is approximately 0 degree, in the center of a screen, and the incident light is perpendicularly incident. In this case, the center of the lens 110 is identical to the centers of the color filter 30 and the light receiving elements 101 such as the microlens 40. Meanwhile, as shown in FIG. 3, in portions other than the center of the screen, like as an end portion of the screen, the incident light which is incident on the light receiving element 101 via the lens 110 is incident with a predetermined incident angle. For this reason, the value of the point spread function PSF is increased as the value of the image height IH is increased.

FIG. 7 is a diagram showing an image which is formed on the sensor section.

FIG. 8A and FIG. 8B are schematic views showing a portion of the sensor section.

FIG. 9 is a diagram showing another image which is formed on the sensor section.

FIG. 10 is a schematic view showing another portion of the sensor section.

In FIG. 7 and FIG. 9, in a case in which a plurality of positional points different to each other is formed, an image point which is represented on the image surface 100a of the sensor section 100 is shown. In FIG. 8A, FIG. 8B, and FIG. 10, upper surface diagrams of the sensor sections 100 are shown. In the sensor section 100, the light receiving elements 101 which respectively correspond to the pixels are disposed in parallel to each other in a matrix form on the light receiving surface. For example, FIG. 8A, FIG. 8B, and FIG. 10 correspond to an portion of FIG. 2A showing a plurality of pixels.

As illustrated in FIG. 7, a region 100R1 and a region 100R2 are regions on the image surface 100a of the sensor section 100. An image point 100f to an image point 100i are points or portions in the inside of the region 100R1. An image point 100j to an image point 100m are points or portions in the inside of the region 100R2. Since the image point 100c is an intersection point of the optical axis A1 on the image surface 100a, a direction d1 and a direction d2 are arrangement directions of the pixels, and show directions in which an image height is increased.

FIG. 8A shows that as the image height is increased, the size of a pixel area (size of the light receiving section 10r) is increased, in the region 100R1 of FIG. 7. An image point 100f to an image point 100i of the region 100R1 correspond to four points or portions in the plurality of pixels. For example, in the region 100R1, in a case in which the image heights of the image point 100f and the image point 100i are 25%, and the image heights of the image point 100g and the image point 100h are 60%, a pixel area corresponding to the image point 100g and the image point 100h is larger than a pixel area corresponding to the image point 100f and the image point 100i.

FIG. 8B shows that as the image height is increased, the size of a pixel area (size of the light receiving section 10r) is increased, in the region 100R2 of FIG. 7. An image point 100j to an image point 100m of the region 100R2 correspond to four points or portions in the plurality of pixels. For example, in the region 100R2, in a case in which the image heights of the image point 100j and the image point 100m are 25%, and the image heights of the image point 100k and the image point 100l are 60%, a pixel area corresponding to the image point 100k and the image point 100l is larger than a pixel area corresponding to the image point 100j and the image point 100m.

Change examples of the pixel areas (size of the light receiving section 10r) of FIG. 8A and FIG. 8B are respectively examples. A plurality of pixels can be provided in the sensor section 100 in such a manner that, as the image height is increased, the pixel area is increased. For example, as shown in FIG. 9 and FIG. 10, the outer periphery of the image surface 100a in the inside of a region 100R3 is a portion in which an image height is high, and thus a plurality of pixels can be provided in the sensor section 100 in such a manner that the pixel area in the outer periphery is larger than that in an inner periphery. If the length of one side of a unit pixel in the inner periphery is referred to as y, the length of one side of a unit pixel in the outer periphery is represented by 1.5´y. A length of a diagonal line of a unit pixel in the outer periphery is represented by 2.1´y. That is, a plurality of pixel can be provided in the sensor section 100, in such a manner that a size of the pixel in the outer periphery is 1.5 times the size of the pixel in the inner periphery.

In the examples shown in FIG.9 and FIG. 10, a plurality of the light receiving elements 101 includes a light receiving element (first light receiving element) which is disposed in an inner periphery of the image surface 100a, and a light receiving element (second light receiving element) which is disposed in an outer periphery of the image surface 100a. Furthermore, a pixel area (second pixel area) of the light receiving element of the outer periphery is larger than a pixel area (first pixel area) of the light receiving element of the inner periphery.

In addition, based on the above-described relational expression (3) of the point spread function and the image height, a plurality of pixels may be provided in the sensor section 100 in such a manner that the pixel area is changed in proportional to the following numerical value (1) with respect to the distance x corresponding to the image height X and the wavelength l.

()2×××(1)

As described above, a plurality of pixels can be provided in the sensor section 100, in such a manner that, as the image height is increased, the pixel area is increased. In addition, a plurality of pixels can be provided in the sensor section 100, in such a manner that the pixel area is changed with respect to the image height and the wavelength of light.

As a result, the size of the light receiving section 10r can be increased as the image height is increased. In addition, the size of the light receiving section 10r can be changed based on the image height and the wavelength of light. In this way, if the light receiving section 10r is provided in the sensor section 100, spectral quantum efficiency is increased and sensitivity is increased, based on the characteristics of the sensor section 100 and the lens 110.

In the sensor section 100 of the embodiment, a plurality of pixels is provided, in such a manner that the pixel area (size of the light receiving section 10r) is changed with respect to the image height and the wavelength of light. In this way, if a plurality of pixels is provided in the sensor section 100, the spectral quantum efficiency can be increased, based on the characteristics of the sensor section 100 and the lens 110. As a result, it is possible to provide a solid-state imaging element and an imaging device in which the sensitivity is further increased.

Hereinafter, review results based on the finding of the conditions described above will be described.

FIG. 11 is a graph diagram showing a relationship between the point spread and the chief ray angle.

FIG. 12A to FIG. 12G are diagrams showing a relationship between the point spread and the chief ray angle.

FIG. 13A to FIG. 13G are diagrams showing a relationship between the point spread and the chief ray angle.

In FIG. 11, a relationship between a diameter of the point spread function of each wavelength range and the chief ray angle is shown by a curved line CL1 to a curved line CL3. A vertical axis denotes a diameter (micrometer) of the point spread function PSF. A horizontal axis denotes the chief ray angle (degree). The diameter of the point spread function is a diameter of a shape of a light beam represented by the point spread function. A lens in which an F value is 2.0 is used.

The curved line CL1 shows a relationship between the diameter of the point spread function and the chief ray angle, in a case in which the wavelength l is 480 nanometers. The curved line CL2 shows a relationship between the diameter of the point spread function and the chief ray angle, n a case in which the wavelength l is 520 nanometer. The curved line CL3 shows a relationship between the diameter of the point spread function and the chief ray angle, in a case in which the wavelength l is 620 nanometers. The curved line CL1 is a blue wavelength region, the curved line CL2 is a green wavelength region, and then the curved line CL3 is a red wavelength region.

In a case in which the chief ray angle of the curved line CL1 is 0 degree, the diameter of the point spread function is 1.17 micrometers. In a case in which the chief ray angle of the curved line CL1 is 50 degrees, the diameter of the point spread function is 1.82 micrometers.

In a case in which the chief ray angle of the curved line CL2 is 0 degree, the diameter of the point spread function is 1.27 micrometers. In a case in which the chief ray angle of the curved line CL2 is 50 degrees, the diameter of the point spread function is 1.97 micrometers.

In a case in which the chief ray angle of the curved line CL3 is 0 degree, the diameter of the point spread function is 1.51 micrometers. In a case in which the chief ray angle of the curved line CL3 is 50 degrees, the diameter of the point spread function is 2.35 micrometers.

It can be seen that, if the chief ray angle is increased from 0 degree to 50 degrees, also in all of the curved line CL1 to the curved line CL3, the diameter of the point spread function can be increased by approximately 1.5 degrees. As a result, it can be seen that, if the chief ray angle is increased, the diameter of the PSF is increased also in all of the blue, green, and red wavelength ranges.

In FIGS. 12A to 12G, and FIGS. 13A to 13G, shape changes of the point spread function of a predetermined image height are shown, in a case in which the wavelength is changed. In FIGS. 12A to 12G, and FIGS. 13A to 13G, the shape changes of the point spread function are represented by shades of monotone color. In this case, dark portions show the shapes of the point spread function. In FIGS. 12A to 12G, the wavelength l is changed from 0.40 micrometers to 0.70 micrometers, in a case in which the image height is 0%. In FIGS. 13A to 13G, the wavelength l is changed from 0.40 micrometers to 0.70 micrometers, in a case in which the image height is 80%. The shape of the point spread function is a shape of a light beam which is represented by the point spread function. A lens is used, in which the wavelength of one side of a unit pixel is 1.12 micrometers, and the F value is 2.0.

FIG. 12A and FIG. 13A show the shapes of the point spread function in a case in which the wavelength l is 0.40 micrometers. FIG. 12B FIG. 13B show the shapes of the point spread function in a case in which the wavelength l is 0.45 micrometers. FIG. 12C and FIG. 13C show the shapes of the point spread function in a case in which the wavelength l is 0.50 micrometers.

FIG. 12D and FIG. 13D show the shapes of the point spread function in a case in which the wavelength l is 0.55 micrometers. FIG. 12E and FIG. 13E show the shapes of the point spread function in a case in which the wavelength l is 0.60 micrometers. FIG. 12F and FIG. 13F show the shapes of the point spread function in a case in which the wavelength l is 0.65 micrometers. FIG. 12G and FIG. 13G show the shapes of the point spread function in a case in which the wavelength l is 0.70 micrometers.

It can be seen from FIG. 12B, FIG. 12C, FIG. 13B,and FIG. 13C that the shapes of the point spread function are thin in the blue wavelength range, when the image height is also 0% and 80%, compared to other shape diagrams. It can be seen from FIG. 12D, FIG. 12E, FIG. 13D,and FIG. 13E that the shapes of the point spread function are intermediate in the green wavelength range, when the image height is also 0% and 80%, compared to other shape diagrams.

It can be seen from FIG. 12F, FIG. 12G, FIG. 13F,and FIG. 13G that the shapes of the point spread function are thick in the red wavelength range, when the image height is also 0% and 80%, compared to other shape diagrams. That is, it can be seen that, as the wavelength is increased, the shape of the point spread function becomes thick. In addition, it can be seen that, if the image height is increased, the shape of the point spread function is obliquely distorted, when FIGS. 12A to 12G, and FIGS. 13A to 13G are compared to each other.

FIG. 14 is a graph diagram showing a relationship between light absorptance and a wavelength.

FIG. 15 is a diagram showing a relationship between sensitivity and a lens.

FIG. 16 is a diagram showing a relationship between quantum efficiency and a wavelength.

FIG. 17 is a diagram showing a relationship between an amount of received light and a pixel area (size of the light receiving section 10r).

In FIG. 14, in a case in which lens characteristics are changed, absorptances of color filters in each wavelength range are represented by a cured line CL4 to a curved line CL6. A vertical axis denotes absorptance of a color filter. If the color filter absorbs all the light, the absorptance is 1.0. A horizontal axis denotes a wavelength l (micrometer).

The curved line CL4 shows the absorptance of a color filter in each wavelength range, in a case in which a lens in which the F value is an arbitrary value is used. The curved line CL5 and the curved lint CL6 show the absorptances of the color filters in each wavelength range, in a case in which a lens in which the F value is 2.05 is used.

In addition, the curved line CL5 shows the absorptance of the color filter, in a case in which the diffracted light from the lens 110 is focused and a plane wave is aligned. The curved line CL6 shows the absorptance of the color filter in a case of being aligned by light intensity, using the point spread function.

A region a which is surrounded by a solid line is a region in which the shape of the point spread function is changed. For example, the shape of the point spread function of the region a corresponds to the shape of the point spread function shown in FIG. 12A and FIG. 13A. A region b which is surrounded by a solid line is a region in which the shape of the point spread function is thin. For example, the shape of the point spread function of the region b corresponds to the shape of the point spread function shown in FIG. 12B, FIG, 12C, FIG, 13B, and FIG. 13C.

A region c which is surrounded by a solid line is a region in which the shape of the point spread function is intermediate. For example, the shape of the point spread function of the region c corresponds to the shape of the point spread function shown in FIG. 12D, FIG, 12E, FIG, 13D, and FIG. 13E. A region d which is surrounded by a solid line is a region in which the shape of the point spread function is thick. For example, the shape of the point spread function of the region d corresponds to the shape of the point spread function shown in FIG. 12F, FIG, 12G, FIG, 13F, and FIG. 13G.

It can be seen that the absorptance of the color filter is decreased in the region b, compared the region d with the region b. In addition, it can be seen that a change of the absorptance of the color filter is decreased in the region c. It can be seen that the absorptance of the color filter is increased in the region d.

As a result, it can be seen that the region b in which the absorptance of the color filter is decreased is a region in which the shape of the point spread function is thin. It can be seen that the region c in which the change of the absorptance of the color filter is decreased is a region in which the shape of the point spread function is intermediate. It can be seen that the region d in which the absorptance of the color filter is increased is a region in which the shape of the point spread function is thick.

In FIG. 15, with regard to pixels with areas different from each other, sensitivity in a case in which the F value of the lens is changed is shown. A vertical axis denotes sensitivity S. A horizontal axis denotes an F value of a lens. In addition, a straight line SL1 shows a relationship between the sensitivity S of a pixel with relatively large area and the F value of the lens. A straight line SL2 shows a relationship between the sensitivity S of a pixel with relatively small area and the F value of the lens. An aperture ratio of the pixel of the straight line SL1 is high, compared to that of the pixel of the straight line SL2.

It can be seen that, if the F value is increased, the sensitivity S is decreased, also in both the straight line SL1 and the straight line SL2. In addition, it can be seen that a reduction rate of the sensitivity S in a case in which the F value is increased is increased, in the straight line SL2. As a result, it can be seen that, if the pixel is miniaturized by reducing an area of a unit pixel, a reduction rate of the sensitivity S in a case in which the F value is increased is increased is increased.

In FIG. 16, in a case in which the lens characteristics are changed, quantum efficiency of each wavelength range is shown by a curved line CL7 to a curved line CL12. A vertical axis denotes the quantum efficiency QE. A horizontal axis denotes the wavelength l (micrometer).

The curved line CL7 to the curved line CL9 show the quantum efficiency QE of a blue wavelength region, a green wavelength region, and a red wavelength region, in a case in which a lens in which the F value is an arbitrary value is used. The curved line CL10 to the curved line CL12 show the quantum efficiency QE of a blue wavelength region, a green wavelength region, and a red wavelength region, in a case in which a lens in which the F value is 2.05 is used. In addition, the curved line CL10 to the curved line CL12 show the quantum efficiency QE in a case in which light intensity is aligned using the point spread function. One side of the unit pixel is 1.12 micrometers, also in all of the curved line CL7 to the curved line CL12.

It can be seen from the curved line CL7 and the curved line CL10, and the curved line CL8 and the curved line CL11 that the quantum efficiency QE is increased in the blue wavelength range and the green wavelength range. The blue wavelength range and the green wavelength range are ranges in which the shape of the point spread function is thin, compared to the red wavelength range. As a result, it can be seen that, if the shape of the point spread function is thin, the sensitivity is relatively increased, with respect to the size (size of the light receiving section 10r) of a pixel. That is, it can be seen that, if the shape of the pixel is determined based on the shape of the point spread function, the sensitivity is relatively increased.

In FIG. 17, in a case in which an area of a unit pixel is changed, an amount of received light of a predetermined chief ray angle is shown by a plot. A vertical axis denotes an amount of received light at the time in which an amount of incident light is set to 1. A horizontal axis denotes a pixel area (mm2). The wavelength l of light is 550 nanometers. The F value of the lens is 0.9. In addition, FIG. 17 shows an amount of received light in a case in which light intensity is aligned using the point spread function, and illustrates a simulation result.

A rectangular plot shows an amount of received light with respect to the pixel area (size of the light receiving section 10r), in a case in which the chief ray angle is 30 degrees. A plot of diamond shows an amount of received light with respect to the pixel area, in a case in which the chief ray angle is 0 degree. If the rectangular plot is compared to the plot of diamond, an amount of received light in which the chief ray angle is 30 degrees is 0.64, and an amount of received light in which the chief ray angle is 0 degree is 0.8, in a case in which the pixel area is 1 mm2. In a case in which the pixel area is 1.7 mm2, an amount of received light in which the chief ray angle is 30 degree sis 0.8. As a result, it can be seen that it is necessary to increase the pixel area to approximately 70%, in order to obtain the same amount of received light in the chief ray angel of 30 degrees as that in the chief ray angel of 0 degree. That is, it can be seen that, in order to obtain the same amount of received light as that of the image height of 0%, it is necessary to increase the pixel area to 70%.

As described above, there is a case in which spectral quantum efficiency is decreased according to the characteristics of the lens, in the solid-state imaging element. As a main cause, the pixel area does not match the shape of the point spread function in which the spectral quantum efficiency is increased, because the size of the pixel of the solid-state imaging element is uniform regardless of the image height.

In the embodiment, a plurality of pixels is provided in the sensor section 100 in such a manner that the pixel area is changed with respect to the image height and the wavelength of light. If the plurality of pixels is provided in the sensor section 100 in this way, the spectral quantum efficiency can be increased based on the characteristics of the sensor section 100 and the lens 110.

According to the embodiment, it is possible to provide a solid-state imaging element and an imaging device in which sensitivity is further increased.

Second Embodiment

FIG. 18 is a diagram showing an image which is formed on a sensor section according to a second embodiment.

FIG. 19 is a schematic view showing a portion the sensor section according to the second embodiment.

In FIG. 18, an image point which is represented on an image surface 100a of a sensor section 100 is shown, in a case in which points different from each other are formed. In FIG. 19, an upper surface diagram of the sensor section 100 is shown. In the sensor section 100, light receiving elements 101 which respectively correspond to pixels are disposed in parallel to each other on a light receiving surface in a matrix form. For example, FIG. 19 corresponds to a portion of FIG. 2A showing the plurality of pixels.

As shown in FIG. 18, a region 100R4 is a region on the image surface 100a of the sensor section 100. FIG. 19 shows that a pixel area (size of the light receiving section 10r) becomes large in an outer periphery of the image surface 100a in the area 100R4. For example, since the outer periphery of the image surface 100a is a portion in which an image height is high, a plurality of pixels can be provided in the sensor section 100 in such a manner that the pixel area in the outer periphery is larger than that in an inner periphery. If a length of one side of a unit pixel in the inner periphery is referred to as y, a length of a diagonal line of the unit pixel in the inner periphery is represented by 1.4´y. A length of a long side of the unit pixel in the inner periphery is represented by 2.0´y.

In addition, if a direction toward a diagonal line end from the center of the image surface 100a is referred to as d3, the plurality of pixels is provided in the sensor section 100 so as to disposed in parallel along the direction d3. That is, in the embodiment, the plurality of pixels is disposed in parallel so as to rotate by approximately 45 degrees with respect to arrangement directions d1 and d2 of the pixels in FIG. 8 and FIG. 10. The arrangement example of the pixels in FIG. 19 is an example, and for example, the pixels may be disposed in parallel so as to rotate by a predetermined angle with respect to the arrangement directions d1 and d2 of the pixels in FIG. 8 and FIG. 10. In addition, a plurality of pixels can be provided in the sensor section 100 in such a manner that, as the image height is increased, the pixel area is increased.

In addition, it is preferable that, in a case in which the pixels are disposed in parallel, the green pixels are disposed so as to be adjacent to each other, and the red pixels and the blue pixels are disposed so as to be adjacent to each other. For example, the pixels are disposed in such a manner that the green pixels are adjacent to each other with respect to a travel direction of a main light beam, and the red pixels and the blue pixels are disposed so as to be adjacent to each other. Since a red wavelength and a blue wavelength are wavelength range separated from each other, it is possible to reduce color mixing caused by adjacent pixels.

In the embodiment, a plurality of pixels is provided in the sensor section 100 in such a manner that the pixel area is changed with respect to the image height and the wavelength of light. If the plurality of pixels is provided in the sensor section 100 in this way, the spectral quantum efficiency can be increased based on the characteristics of the sensor section 100 and the lens 110.

In addition, the plurality of pixels is provided in the sensor section 100 so as to be disposed in parallel along the direction d3 toward the diagonal line end from the center of the image surface 100a. If the plurality of pixels is provided in the sensor section 100 in this way, a boundary between the pixels adjacent to each other is reduced by the shape of the pixel based on the shape of the point spread function, and thereby sensitivity can be increased.

According to the embodiment, it is possible to provide a solid-state imaging element and an imaging device in which sensitivity is further increased.

What is claimed is:

1. A solid-state imaging element comprising:

a plurality of light receiving elements that respectively includes a light receiving section which performs a photoelectric conversion of light from a subject,

in which a size of each of the plurality of light receiving sections is set based on a distance from a center of a light receiving surface of the solid-state imaging element to each light receiving element, and a wavelength of light of a center of each of the plurality of light receiving elements.

2. The element according to Claim 1, wherein a pixel area that is determined by each of the plurality of light receiving elements is set based on the distance from the center of the light receiving surface of the solid-state imaging element to each of the light receiving elements, and a wavelength of light of the center of each of the plurality of light receiving elements.

1. The element according to Claim 2, wherein as the distance is increased, the pixel area is increased.
2. The element according to Claim 3, wherein a ratio in which the pixel area is increased becomes different according to the wavelength of light.
3. The element according to Claim 4, wherein as the wavelength of light is increased, a ratio in which the pixel area is increased is increased.
4. The element according to Claim 2, wherein the plurality of light receiving elements includes a first light receiving element which is disposed in an inner periphery of the light receiving surface and has a first pixel area, and a second light receiving element which is disposed in an outer periphery of the light receiving surface and has a second pixel area larger than the first pixel area.
5. The element according to Claim 2, wherein the pixels are disposed in parallel along a direction toward a diagonal line end from the center of the light receiving surface.
6. The element according to Claim 2, wherein pixels corresponding to green are disposed so as to be adjacent to each other, with respect to a travel direction of a main light beam.
7. The element according to Claim 2, wherein pixels corresponding to red and pixels corresponding to blue are disposed so as to be adjacent to each other, with respect to a travel direction of a main light beam.
8. An imaging device comprising:

a solid-state imaging element having a plurality of light receiving elements that respectively includes a light receiving section which performs a photoelectric conversion of light from a subject; and

a lens that is provided between the subject and the solid-state imaging element,

in which a size of each of the plurality of light receiving sections is set based on a distance from a center of a light receiving surface of the solid-state imaging element to the light receiving element, and a wavelength of light of a center of each of the plurality of light receiving elements.

1. The device according to Claim 10, wherein in a case in which a diameter of the lens is referred to as D, a focal distance of the lens is referred to as f, the distance is referred to as x, and the wavelength of light is referred to as l, the following expression is satisfied,

()2

1. The device according to Claim 10, wherein a pixel area that is determined by each of the plurality of light receiving elements is set based on the distance from the center of the light receiving surface of the solid-state imaging element to each of the light receiving elements, and a wavelength of light of the center of each of the plurality of light receiving elements.
2. The device according to Claim 12, wherein in a case in which a diameter of the lens is referred to as D, a focal distance of the lens is referred to as f, the distance is referred to as x, and the wavelength of light is referred to as l, the pixel area is changed in proportion to the following expression,

()2

1. The device according to Claim 12, wherein as the distance is increased, the pixel area is increased.
2. The device according to Claim 14, wherein a ratio in which the pixel area is increased becomes different according to the wavelength of light.
3. The device according to Claim 15, wherein as the wavelength of light is increased, a ratio in which the pixel area is increased is increased.
4. The device according to Claim 12, wherein the plurality of light receiving elements includes a first light receiving element which is disposed in an inner periphery of the light receiving surface and has a first pixel area, and a second light receiving element which is disposed in an outer periphery of the light receiving surface and has a second pixel area larger than the first pixel area.
5. The device according to Claim 12, wherein the pixels are disposed in parallel along a direction toward a diagonal line end from the center of the light receiving surface.
6. The device according to Claim 12, wherein pixels corresponding to green are disposed so as to be adjacent to each other, with respect to a travel direction of a main light beam.
7. The device according to Claim 12, wherein pixels corresponding to red and pixels corresponding to blue are disposed so as to be adjacent to each other, with respect to a travel direction of a main light beam.

Drawings

FIG. 5

CRA(degree)

FIG. 11

DIAMETER OF PSF(mm)

CRA(degree)

FIG. 14

ABSORPTANCE

FIG. 17

AN AMOUNT OF RECEIVED LIGHT

PIXEL AREA(mm2)