

Exhibit C



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(54) **CMOS IMAGE SENSOR ARRANGEMENT WITH REDUCED PIXEL LIGHT SHADOWING**

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(51) **Int. Cl.**⁷ **H01L 31/062**

(52) **U.S. Cl.** **257/291; 257/184; 257/187; 257/203; 257/292; 257/293; 257/433; 257/461; 257/462; 257/929**

(58) **Field of Search** **257/184, 187, 257/203, 221, 291-293, 462, 929**

(56) **References Cited**

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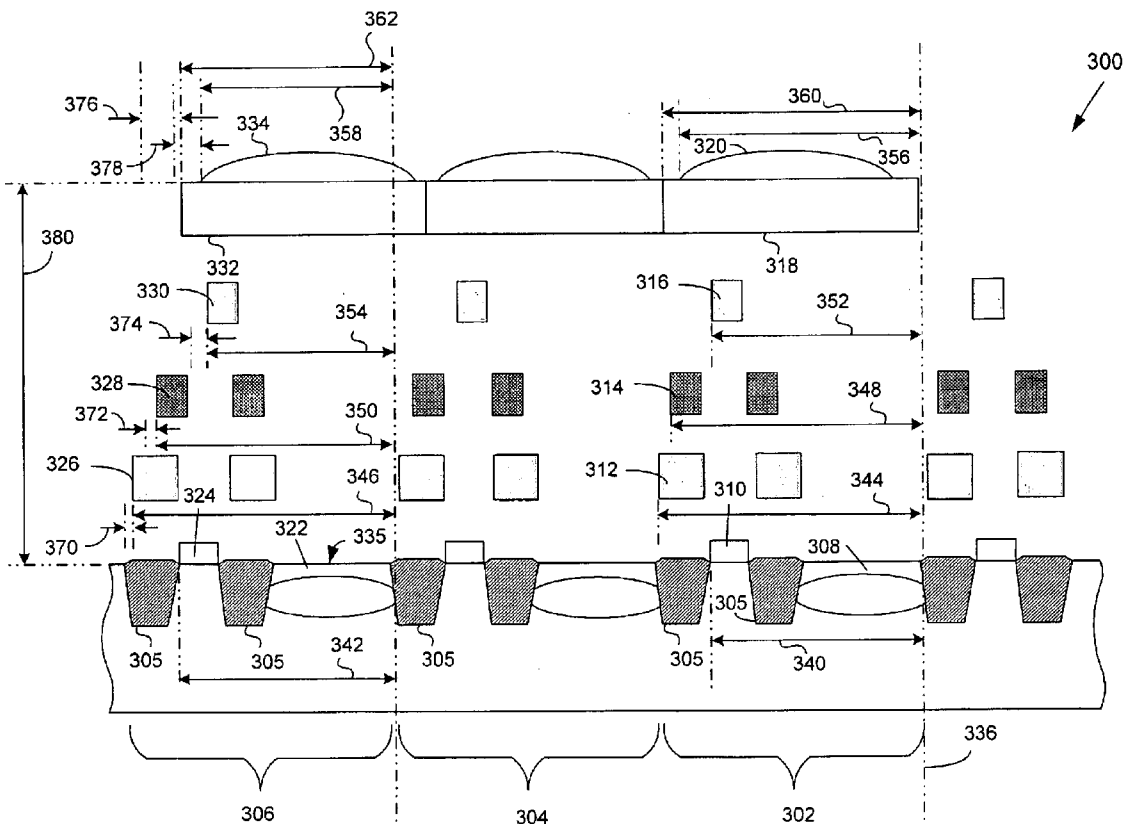
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(57) **ABSTRACT**

An exemplary CMOS image sensor comprises a plurality of pixels arranged in an array. The plurality of pixels includes a first pixel proximate an optical center of the array, and a second pixel proximate a peripheral edge of the array. The CMOS image sensor further comprises a first metal interconnect segment associated with the first pixel situated in a first metal layer, and a second metal interconnect segment associated with the second pixel situated in the first metal layer. The second metal interconnect segment is shifted closer to the optical center of the array than the first metal interconnect segment so that the second metal interconnect segment approximately aligns with a principle ray angle incident the second pixel, thereby reducing pixel light shadowing.

20 Claims, 6 Drawing Sheets



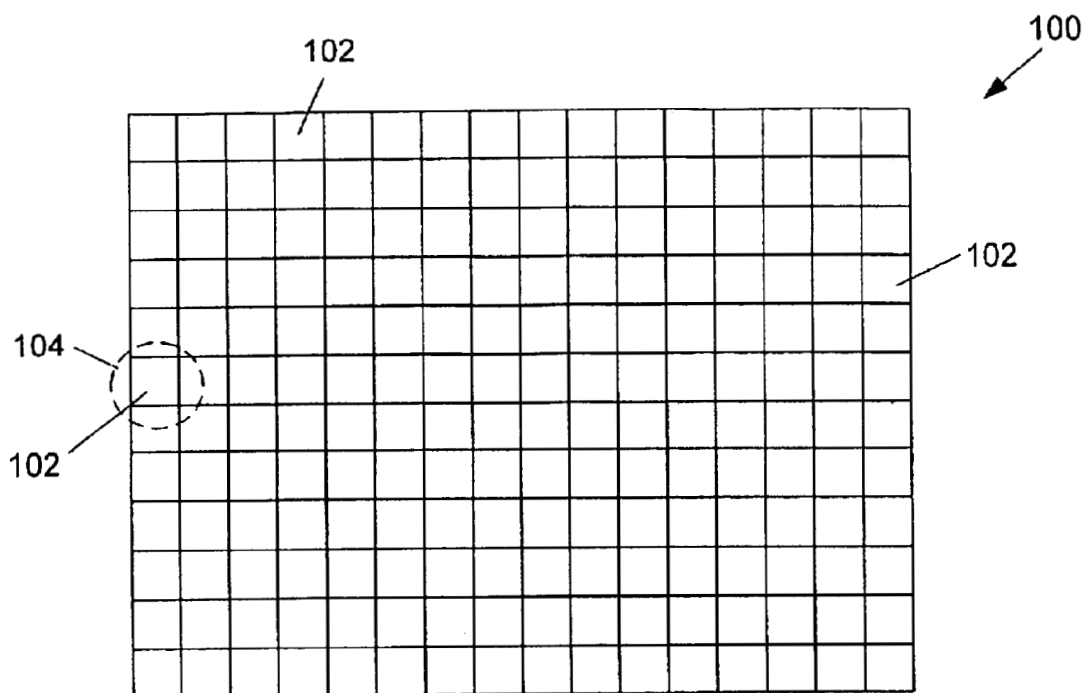


FIG. 1A

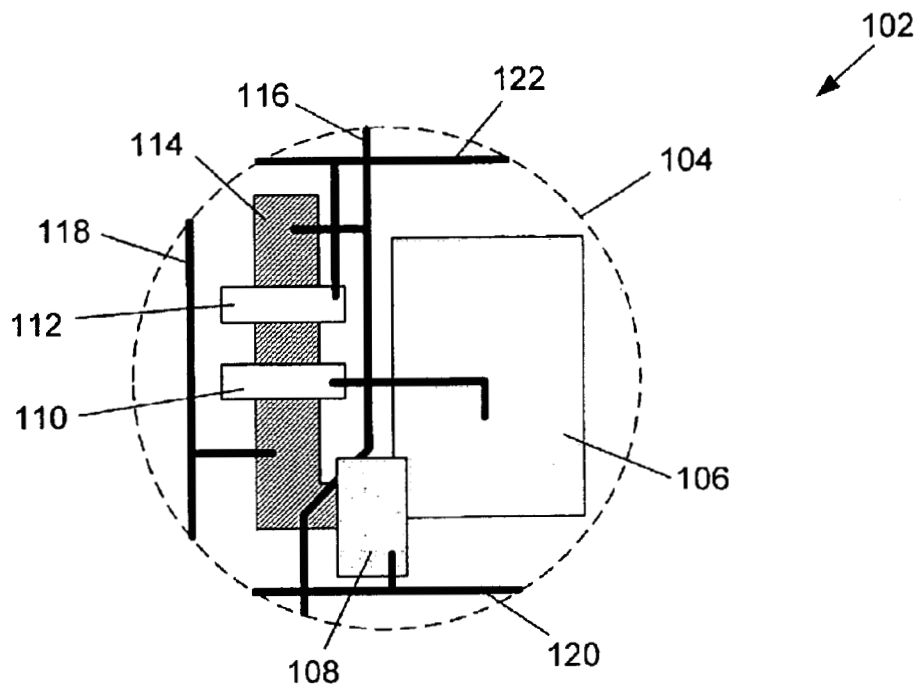


FIG. 1B

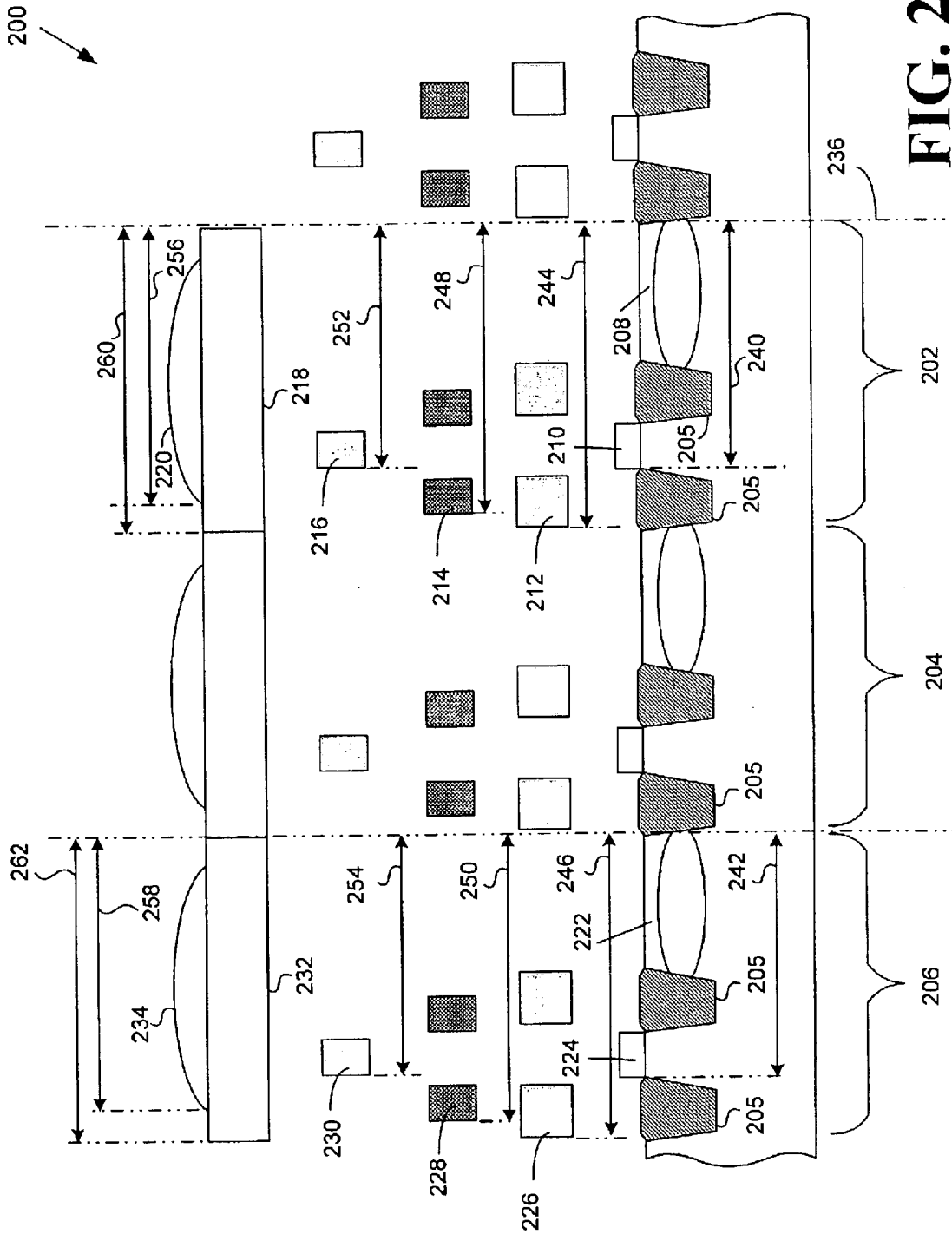


FIG. 2A

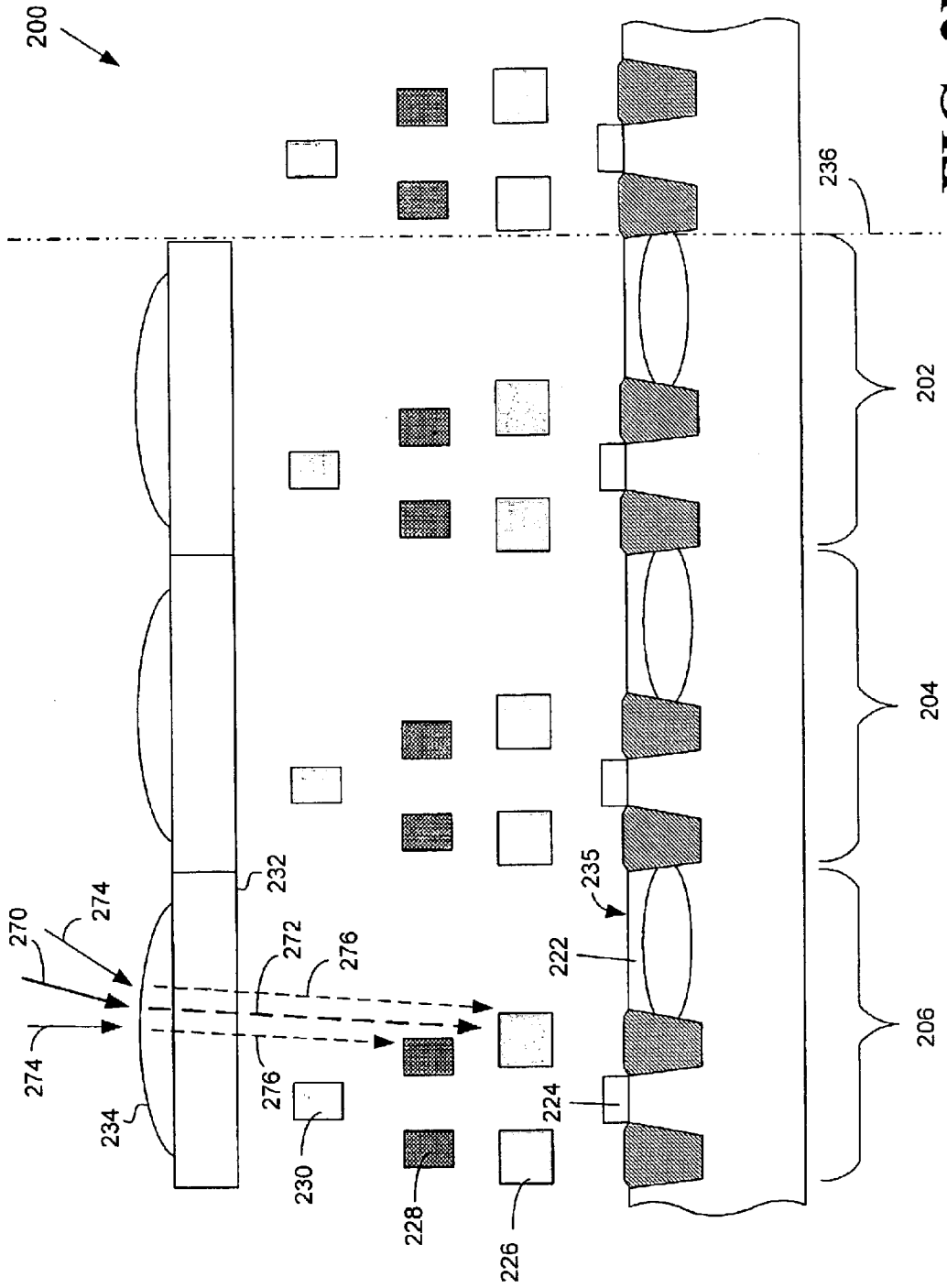


FIG. 2B

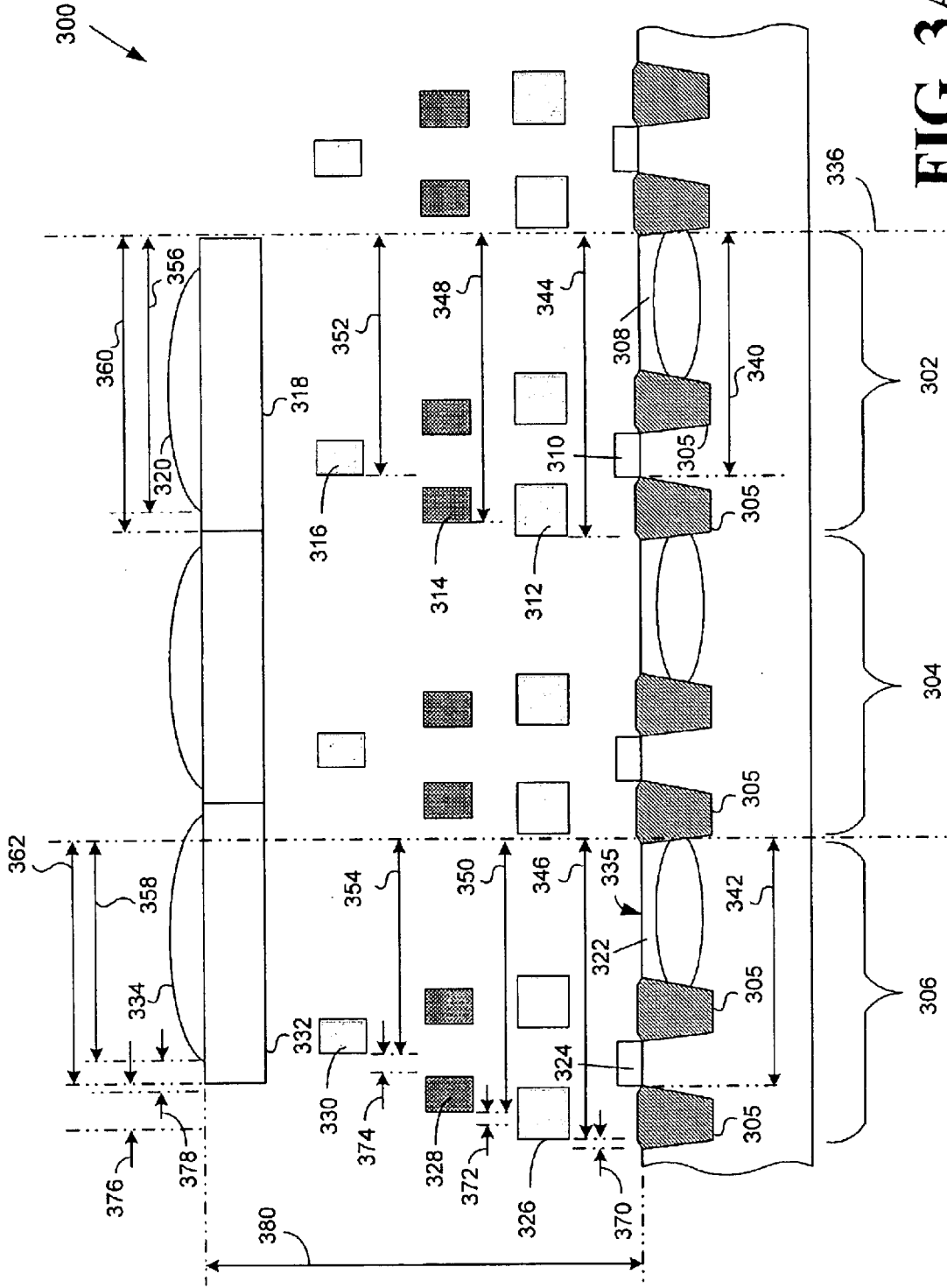


FIG. 3A

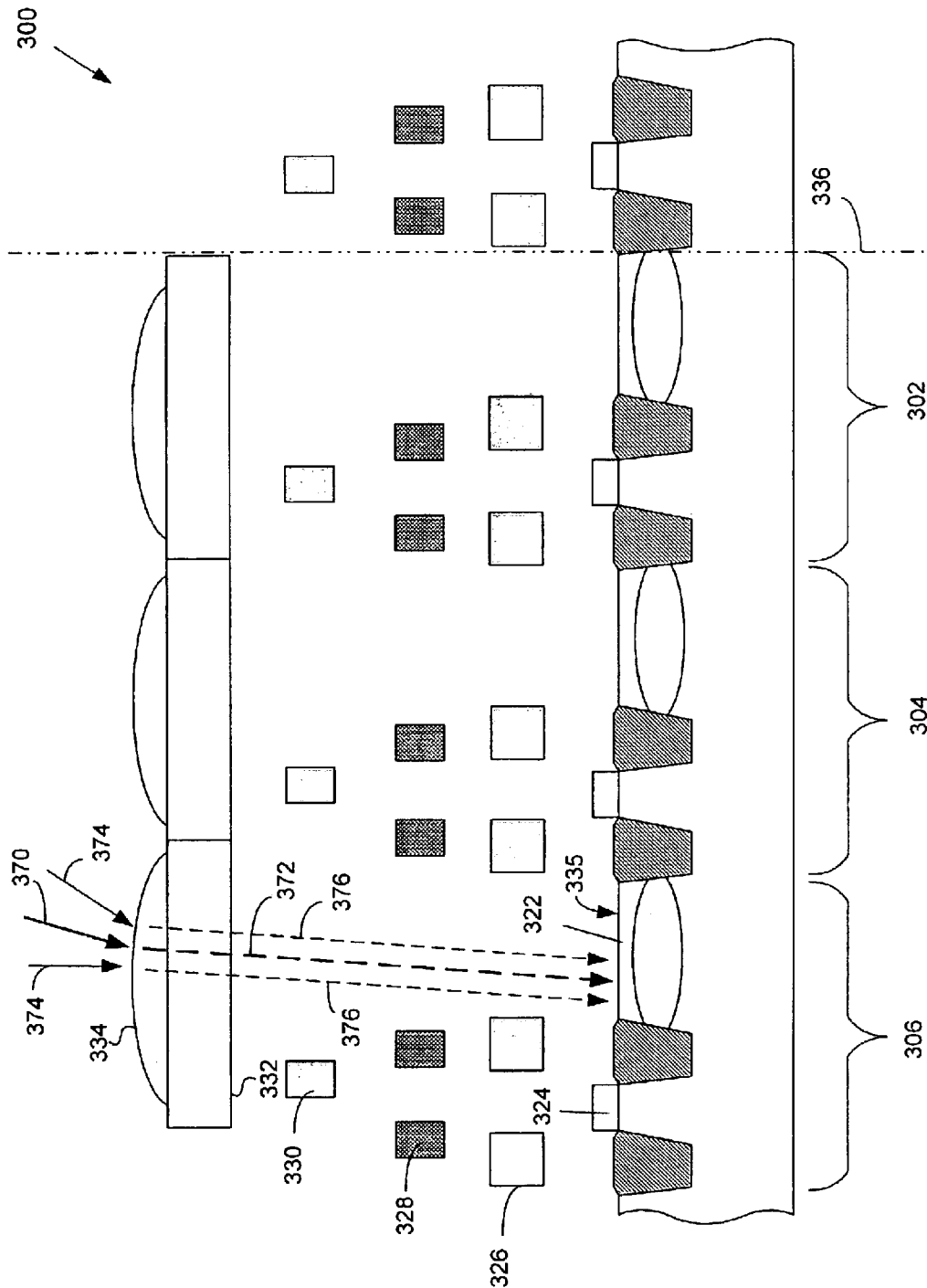


FIG. 3B

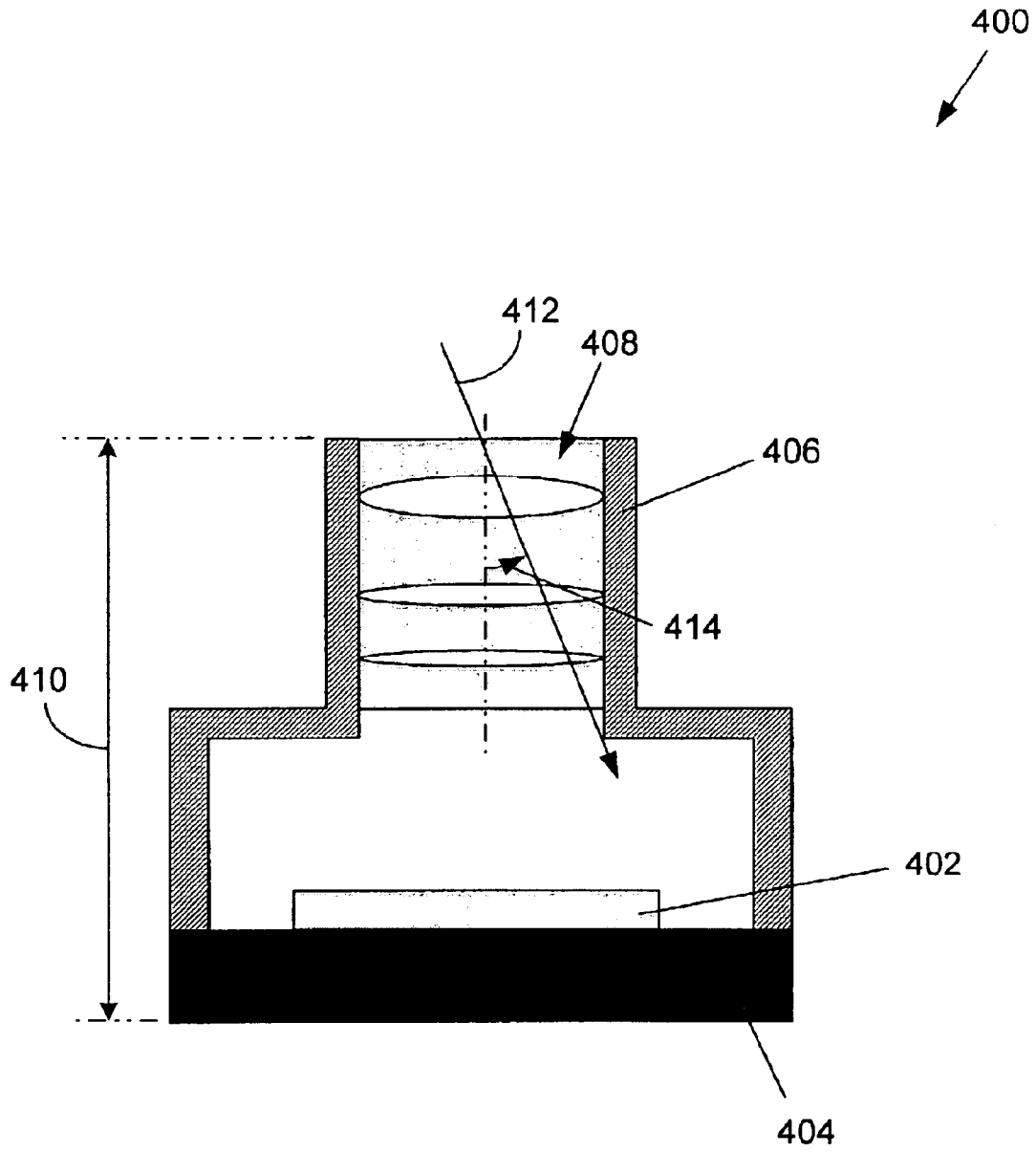


FIG. 4

CMOS IMAGE SENSOR ARRANGEMENT WITH REDUCED PIXEL LIGHT SHADOWING

RELATED APPLICATIONS

The present application claims the benefit of U.S. provisional patent application Ser. No. 60/376,750, filed on Apr. 30, 2002, the disclosure of which is hereby fully incorporated by reference in the present application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is generally in the field of solid state imaging devices. More specifically, the invention is in the field of Complementary Metal Oxide Semiconductor ("CMOS") imaging devices.

2. Related Art

Solid-state image sensors (also known as "solid-state imagers," "image sensors," and "imagers") have broad applications in many areas and in a number of fields. Solid-state image sensors convert a received image into a signal indicative of the received image. Examples of solid-state image sensors include charge coupled devices ("CCD"), photodiode arrays, charge injection devices ("CID"), hybrid focal plane arrays and CMOS imaging devices (also known as "CMOS image sensors" or "CMOS imaging arrays").

Solid-state image sensors are fabricated from semiconductor materials, such as silicon or gallium arsenide, and comprise imaging arrays of light detecting, i.e., photosensitive, elements (also known as "photodetectors" or "photoreceptors") interconnected to generate analog signals representative of an image illuminating the device. A typical imaging array comprises a number of photodetectors arranged into rows and columns, each photodetector generating photo-charges. The photo-charges are the result of photons striking the surface of the semiconductor material of the photodetector, and generating free charge carriers (electron-hole pairs) in an amount linearly proportional to the incident photon radiation. The photo-charges from each pixel are converted to a "charge signal" which is an electrical potential representative of the energy level reflected from a respective portion of the object and received by the solid-state image sensor. The resulting signal or potential is read and processed by video/image processing circuitry to create a signal representation of the image.

In recent years, CMOS image sensors have become a practical implementation option for imagers and provide cost and power advantages over other technologies such as CCD or CID. A conventional CMOS image sensor is typically structured as an imaging array of pixels, each pixel including a photodetector and a transistor region, and as discussed above, each pixel converts the incoming light into an electronic signal. In a typical three-transistor active pixel design for a CMOS image sensor, each pixel includes four wires (or "metal interconnect lines" or "metal interconnect segments") and three transistors, namely, a reset transistor, a source-follower transistor, and a select transistor. Two metal interconnect segments are disposed horizontally to provide row selection for either resetting the pixel or reading the pixel. Two other metal interconnect segments are disposed vertically (or substantially perpendicular to the first two metal interconnect segments) to provide column selection for both reading and resetting the pixel.

In conventional CMOS image sensors, the arrangement of the pixel's structures, including the relative positioning of

the photodetector, the transistor region, and the metal interconnect segments, as well other structural elements, has presented problems. A major problem which conventional CMOS image sensors exhibit is pixel light shadowing (also referred to as "geometric shadowing"). Pixel light shadowing is caused when the average ray or principal ray striking the pixel deviates significantly from normal (or perpendicular to the imaging array plane). Under these conditions, one or more of the pixel elements situated over the photodetector may block a significant amount of light from being directed at the photodetector. As a result, the brightness of the resulting image is significantly reduced, resulting in poor image quality. Moreover, the pixels situated at the periphery of the imaging array are significantly more susceptible to pixel light shadowing. As a result, the resulting images have significant and undesirable brightness falls off at the edges of the field of view. This problem is further exacerbated due to the loss of brightness at the edge of field of view common to most lens systems due to 1/Cosine effects. Consequently, the resulting image exhibits unacceptable signal-to-noise (SNR), particularly at the corners of the images. These problems are further aggravated under low light conditions.

Accordingly, there is a strong need in the art for a CMOS image sensor arrangement and method for arranging image sensor elements, which significantly reduces pixel light shadowing.

SUMMARY OF THE INVENTION

The present invention is directed to a CMOS image sensor arrangement and method for arranging image sensor elements which significantly reduce pixel light shadowing. In one exemplary embodiment, the CMOS image sensor comprises a plurality of pixels arranged in an array. The plurality of pixels includes a first pixel proximate an optical center of the array, and a second pixel proximate a peripheral edge of the array. The CMOS image sensor further comprises a first metal interconnect segment associated with the first pixel situated in a first metal layer, and a second metal interconnect segment associated with the second pixel situated in the first metal layer. In accordance with the present invention, the second metal interconnect segment is shifted closer to the optical center of the array than the first metal interconnect segment so that the second metal interconnect segment approximately aligns with a principle ray angle incident the second pixel. The photodiode elements and transistor elements of the pixels of the array remain on a fixed pitch. However, the metal interconnect segments and other pixel elements associated with the pixels of the array are positioned on a variable pitch such that these metal interconnect segments and pixel elements are shifted towards the optical center in proportion to the distance of the metal interconnect segment or associated pixel element from the optical center and in proportion to the distance of the metal interconnect segment or pixel element from the surface of the photodiode.

Thus metal interconnect segments and pixel elements can be positioned at a designated offset position so that the shifts of the metal interconnect segments and pixel elements approximately align to the principle ray angle of the lens incident to the pixel in each location in the array, thereby substantially reducing pixel light shadowing. Proximate the optical center where the principle ray angle is aligned substantially perpendicular to the wafer, the metal interconnect segments are all aligned above the transistor and isolation regions of the pixel leaving the photodiode unobscured to collecting light. In comparison, proximate the corners of the array or proximate the periphery of the array, the metal interconnect segments associated with those pixels

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are shifted so as to appear to be “tilted” towards the optical center of the array to thereby align the light collection path with the principle ray angle incident the respective pixels. Such tilts can be typically in the range of 15 to 25 degrees for certain lenses.

This offset positioning (or shift) of the interconnect elements and other pixel elements towards the optical center of the array progressively increases in small intervals at the subsequent pixel placements in proportion to the distance of the pixel from the optical center of the array. These shifts can be applied along a horizontal dimension of the array, a vertical dimension of the array, or along both a horizontal and vertical dimension of the array. With this arrangement the transistor and diode elements of the pixel are always placed in positions corresponding to a fixed pixel pitch interval.

According to another embodiment, the CMOS image sensor further comprises a third metal interconnect associated with the first pixel, and a fourth metal interconnect segment associated with the second pixel, where the third and fourth metal interconnect segment are situated in a second metal layer. In this case, the fourth metal interconnect segment is shifted closer to the optical center than the third metal interconnect segment. Where the first metal layer is situated below the second metal layer, the fourth metal interconnect segment is shifted closer to the optical center than the second metal interconnect segment. These metal interconnect elements may comprise metal lines and vertical via structures to connect the different layers of metal together. In certain embodiments, a first via is situated between the first metal interconnect segment and the third metal interconnect segment, and a second via is situated between the second metal interconnect segment and the fourth metal interconnect segment.

According to another embodiment, the CMOS image sensor further comprises a first micro lens associated with the first pixel, and a second micro lens associated with the second pixel. In this particular embodiment, a second micro lens is shifted closer to the optical center than the first micro lens.

According to another embodiment, the CMOS image sensor further comprises a first color filter associated with the first pixel and a second color filter associated with the second pixel. In this particular embodiment, a second color filter is shifted closer to the optical center than the first color filter.

In another embodiment, the invention is a method for arranging the pixel elements according to the above-described arrangement. Other features and advantages of the present invention will become more readily apparent to those of ordinary skill in the art after reviewing the following detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates a top view of a typical CMOS imaging array.

FIG. 1B illustrates an enlarged view pixel of FIG. 1A.

FIG. 2A illustrates a cross sectional-view of a known CMOS imaging array.

FIG. 2B illustrates the effect of a non-perpendicular principle ray upon a known CMOS imaging array.

FIG. 3A illustrates a cross sectional-view of a CMOS imaging array in accordance with one embodiment of the present invention.

FIG. 3B illustrates the effect of a non-perpendicular principle ray upon a CMOS imaging array according to one embodiment of the present invention.

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FIG. 4 illustrates a simplified cross-sectional view of camera system in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a CMOS image sensor arrangement and method for arranging image sensor elements. The following description contains specific information pertaining to the implementation of the present invention. One skilled in the art will recognize that the present invention may be implemented in a manner different from that specifically discussed in the present application. Moreover, some of the specific details of the invention are not discussed in order to not obscure the invention. The specific details not described in the present application are within the knowledge of a person of ordinary skill in the art.

The drawings in the present application and their accompanying detailed description are directed to merely exemplary embodiments of the invention. To maintain brevity, other embodiments of the invention which use the principles of the present invention are not specifically described in the present application and are not specifically illustrated by the present drawings. It is noted that, for ease of illustration, the various elements and dimensions shown in the drawings are not drawn to scale.

Referring first to FIG. 1A, a top view of a portion of CMOS imaging array **100** is shown including a plurality of pixels **102**, arranged into rows and columns, each pixel **102** generating photo-charges. The photo-charges generated by pixels **102** are the result of photons striking the surface of the semiconductor material of the photodetector, and generating free charge carriers (electron-hole pairs) in an amount linearly proportional to the incident photon radiation. Pixel **102** in region **104** of imaging array **100** will now be described with reference to FIG. 1B.

In FIG. 1B, region **104** and pixel **102** are shown in an enlarged view. Pixel **102** illustrates a three-transistor active pixel design including photodetector **106** (such as a photodiode), reset transistor **108**, source-follower transistor **110**, and select transistor **112**. The active area of transistors **108**, **110** and **112** is depicted as region **114** in FIG. 1B. In an effort to avoid blocking photodetector **106**, multiple layer metal construction is typically used in CMOS imaging arrays. For example, in FIG. 1B, metal interconnect segments **116** and **118** are vertically positioned and may, for example, be provided in metal layer two. Metal interconnect segments **120** and **122** are horizontally positioned and may, for example, be provided in metal layer three and metal layer one, respectively. Metal interconnect segments **116** and **118** may be used to provide column selection for both reading and resetting of photodetector **106**. Metal interconnect segment **120** may be used to provide resetting of photodetector **106**, while metal interconnect segment **122** may be used to provide reading of photodetector **106**.

Referring now to FIG. 2A, a cross sectional-view of known CMOS imaging array **200** is generally shown. Known CMOS imaging array **200** includes pixels **202**, **204** and **206**, wherein pixel **202** is situated in closer proximity to optical center axis **236** than pixel **206**. Optical center axis **236** of imaging array **200** corresponds to a reference line perpendicular to the surface plane of CMOS imaging array **200**, intersecting a center point of CMOS imaging array **200**. By way of illustration, pixel **202** may be situated adjacent or proximate to optical center axis **236**, and pixel **206** may be at or proximate the edge or periphery of known CMOS

imaging array **200**. Each pixel **202** and **206** comprises respective photodetector **208** and **224**, transistor region **210** and **224**, metal one interconnect segments **212** and **226**, metal two interconnect segments **214** and **228**, metal three interconnect segment **216** and **230**, color filter **218** and **232** and micro lens **220** and **234**.

Transistor regions **210** and **224** represent an active pixel design employing a reset transistor, a source follower transistor and a select transistor, as described above in conjunction with FIG. 1B. Respective isolation elements **205** are positioned between transistor regions and photodetectors, e.g., between transistor region **210** and photodetector **108**, and between adjacent pixels, e.g., between pixel **202** and **204**.

In known CMOS imaging array **200**, metal one interconnect segments **212** and **226**, metal two interconnect segments **214** and **228**, and metal three interconnect segments **216** and **230** are routed over respective transistor regions **210** and **224** and isolation regions **205** of pixels **202** and **206**, respectively, to provide electrical connectivity for reading and/or resetting operations involving photodetectors **208** and **222**, respectively, as discussed above.

Color filters **218** and **232** allow light of only specific wavelengths to be transmitted to respective photodetectors **208** and **222**. With the use of color filters, such as filters **218** and **232**, known CMOS imaging array **200** may be used to capture color images. Typically, such color filters are arranged in a repeating Bayer pattern of red, green, and blue filters. Micro lens **220** and **234** are typically formed of a clear polymer and are situated over respective color filters **218** and **232** to redirect light toward respective photodetectors **208** and **222**.

Known CMOS imaging array **200** is configured in a conventional arrangement where each pixel, including pixels **202**, **204** and **206**, are identical in layout and placement of its pixel elements, including corresponding metal interconnect segments, color filters and micro lenses. Stated differently, each pixel **202**, **204** and **206** and its associated pixel elements, i.e., metal interconnect segments, color filter, and micro lens, is identically arranged with a fixed pitch. Thus, dimension **240** defining the placement of the transistor region **210** of pixel **202** is the same as dimension **242** defining the placement of transistor region **224** of pixel **206**. Likewise the dimension **244** and dimension **246** (corresponding to metal one interconnect segments **212** and **226**, respectively) are the same, dimension **248** and **250** (corresponding to metal two interconnect segments **214** and **228**, respectively) are the same, dimension **252** and **254** (corresponding to metal three interconnect segments **216** and **230**, respectively) are the same, dimension **260** and **262** (corresponding to color filters **218** and **232**, respectively) are the same, and dimension **256** and **258** (corresponding to micro lenses **220** and **234**, respectively) are the same. This identical layout scheme is carried out in both the horizontal and vertical dimensions in known CMOS imaging array **200**.

This arrangement of pixel elements in known CMOS imaging array **200** results in significant pixel light shadowing in the resulting image, particularly under low light conditions. As discussed above, pixel light shadowing is caused when the average ray or principal ray striking the pixel deviates significantly from normal (or perpendicular to the imaging array plane). Referring now to FIG. 2B, principal ray **270** and ray bundle **274** are shown having incident angles significantly away from normal or away from perpendicular to imaging array surface **235** of pixel **206**. Ray

270 and ray bundle **274** are redirected by micro lens **234** and passed through color filter **232**. However, because of the initial incident angles of ray **270** and ray bundle **274**, redirected rays **272** and **276** do not strike photodetector **222** but are blocked by pixel elements situated over photodetector **222**, including one or more of metal one interconnect segments **226**, metal two interconnect segments **228** and metal three interconnect segment **230**. A significant amount of illumination will be blocked and prevented from striking photodetector **222** in this manner, resulting in significantly reduced brightness of the resulting image produced by pixel **206**.

Moreover, light incident pixels proximate optical center axis **236**, e.g., pixel **202**, strike surface **235** of those pixels at angles near normal, whereas, pixels near the edge or periphery of known CMOS imaging array **200**, i.e., near the edge of the field of view of the optical system, e.g., pixel **206**, experience an average ray angle which deviates significantly from normal. The resulting image produced by CMOS imaging array **200** thus exhibits significant pixel light shadowing as pixels proximate the edges of the field of view will produce images that have significant and undesirable brightness falls off. This problem is further exacerbated due to the loss of brightness at the edge of field of view common to most lens systems due to 1/Cosine effects. Consequently, the resulting image exhibits unacceptable signal-to-noise (SNR), particularly at the corners of the images. These problems are further aggravated under low light conditions.

Furthermore, as pixels are scaled to smaller pitches to reduced device size, pixel light shadowing becomes even more pronounced as the available area for the photodetector element is reduced. The conventional approach to addressing this problem has been to implement telecentric lenses. Telecentric lenses, however, require more optical elements, thereby increasing the height of the lens, which is undesirable in many applications, such as pocket-sized or portable electronic devices. In addition, the constraints on the optical design of telecentric lenses can result in adverse reduction in Modulation Transfer Function ("MTF"), contrast and other important image quality properties. Finally, telecentric lenses add undesirable increased costs to the camera system, rendering telecentric lenses unpractical in many applications.

Referring now to FIG. 3A, CMOS imaging array **300** which addresses and resolves pixel light shadowing in a simplified and cost-effective manner according to one embodiment of the invention is shown. Pixels **302**, **304** and **306** are shown as part of CMOS imaging array **300** for illustrative purposes, although CMOS imaging array **300** typically include a larger number of pixels. As shown in FIG. 3A, pixel **302** is situated in closer proximity to optical center axis **336** than pixel **306**. Optical center axis **336** of imaging array **300** corresponds to a reference line perpendicular to the surface plane of CMOS imaging array **300**, intersecting a center point of CMOS imaging array **300**. By way of illustration, pixel **302** may be situated adjacent or proximate to optical center axis **336**, and pixel **306** may be at or proximate the edge or periphery of CMOS imaging array **300**.

Each pixel **302** and **306** comprises respective photodetector **308** and **324**, transistor region **310** and **324**, metal one interconnect segments **312** and **326**, metal two interconnect segments **314** and **328**, metal three interconnect segment **316** and **330**, color filter **318** and **332** and micro lens **320** and **334**. As described more fully below, the particular arrangement and placement of metal one interconnect segments **312**

and **326**, metal two interconnect segments **314** and **328**, metal three interconnect segment **316** and **330**, color filters **318** and **332** and micro lenses **320** and **334** of pixels **302** and **306**, respectively, results in significantly reduced pixel light shadowing and superior resulting images.

Transistor regions **310** and **324** represent an active pixel design employing a reset transistor, a source follower transistor and a select transistor, as described above. Respective isolation elements **305** are positioned between transistor regions and photodetectors, e.g., between transistor region **310** and photodetector **308**, and between adjacent pixels, e.g., between pixel **302** and **304**. By way of illustration, isolation elements **305** may comprise shallow trench isolation regions, for example, although other isolation structures may also be used.

Metal one interconnect segments **312** and **326**, metal two interconnect segments **314** and **328**, and metal three interconnect segments **316** and **330** associated with pixels **302** and **306**, respectively, provide electrical connectivity for reading and/or resetting operations involving photodetectors **308** and **322**, respectively, as discussed above. Although not shown in FIG. 3A for ease of illustration, vias are typically positioned to provide vertical interconnections between metal levels corresponding to metal one interconnect segments **312** and **326**, metal two interconnect segments **314** and **328**, and metal three interconnect segments **316** and **330**. Also not shown in FIG. 3A for ease of illustration is a transparent dielectric that supports and encapsulates metal one interconnect segments **312** and **326**, metal two interconnect segments **314** and **328**, and metal three interconnect segments **316** and **330**.

Color filters **318** and **332** allow light of only specific wavelengths to be transmitted to respective photodetectors **318** and **332**. With the use of color filters, such as filters **318** and **332**, CMOS imaging array **300** may be used to capture color images. Typically, such color filters are arranged in a repeating Bayer pattern of red, green, and blue filters. Micro lens **320** and **334** are typically formed of a clear polymer and are situated over respective color filters **318** and **332** to redirect light toward respective photodetectors **308** and **322**.

In accordance with the present invention, the pixel elements, i.e., metal interconnect segments, color filter, micro lens, etc., associated with one or more pixels in CMOS imaging array **300** are physically shifted towards optical center axis **336** in order to approximately align with the principle ray angle incident each pixel. It is noted that the positioning and arrangement of photodetectors **308** and **322** and transistor regions **310** and **324** of pixels **302** and **306**, respectively, are identical and have a fixed pitch. Thus, dimension **340** and **342** are the same.

Referring to FIG. 4, a simplified cross-sectional view of camera system **400** is shown including image sensor **402** situated on substrate **404**, where, for example, image sensor **402** corresponds to CMOS imaging array **300** of FIG. 3A. Lens holder **406** is positioned over substrate **402** and houses lens assembly **408**. As discussed above, in pocket-sized and portable electronic devices, it is desirable to reduce height **410** of camera system **400**. Thus, maximum principal ray **412** and its incident angle **414** are dependent upon on the various physical dimensions of camera system **400** as well as the position of image sensor **402** on substrate **404**.

Continuing with FIG. 3A, the layout and design of CMOS imaging array **300** can be carried out using a computer program executed on a computer system. For example, the maximum principle ray angle for a particular lens system may be determined by modeling the optical system and pixel

performance on the computer system. Once the maximum principle ray angle is determined, the various pixel elements for one or more pixels of CMOS imaging array **300** are shifted toward optical center axis **336** to approximately align with the principle ray angle. According to one embodiment, shifts are applied by using the maximum design grid supported as described more fully below.

By way of illustration, a 22-degree maximum principle ray angle for an f2.8 lens with a +/-10-degree field of view may be defined for a particular camera system employing CMOS imaging array **300**. In accordance with invention, the vertical structure of metal interconnect segments, e.g., metal interconnect segments **312**, **314**, **316**, **326**, **328**, and **330**, and the principle ray angle are used to define a required offset or shift in the placement of each of the metal interconnect segments **312**, **314**, **316**, **326**, **328**, and **330**, as well as color filters **318** and **332** and micro lenses **320** and **334**. This shift in the metal interconnect segments **312**, **314**, **316**, **326**, **328**, and **330**, filters **318** and **332** and micro lenses **320** and **334** is directed toward optical center axis **336**, and, as shown more clearly below, results in significantly reduced blockage of incoming light from being directed at photodetectors **308** and **322**.

The amount of shift for each pixel element is dependent upon the distance of the pixel element from surface **335** of the pixel, the distance of the pixel to optical center axis **336**, and the principle ray angle. By way of example, suppose pixel **306** is situated at the extreme corner of CMOS imaging array **300**, dimension **380** defining the distance between micro lens **334** and photodetector **322** is approximately 5 microns (μm), and the camera system has a principle ray angle of 20-degrees, micro lens **334** is shifted by amount **378** towards the optical center axis **336**. Shift **378** is approximately 0.8 μm depending on the shape of the micro lens and its refractive power. The amount of offset or shift for pixel elements situated below micro lens **334**, e.g., color filter **332**, and metal interconnect segments **326**, **328** and **330**, are scaled to a lower value in proportion to the relative distance above photodetector **322**. In the above example, where pixel **306** is at the extreme corner of CMOS imaging array **300**, shift **376** for color filter **332** is approximately 0.64 μm , shift **374** for metal three interconnect segment **330** is approximately 0.48 μm , shift **372** for metal two interconnect segments **328** is approximately 0.32 μm , and shift **370** for metal one interconnect segments **326** is approximately 0.16 μm . Vias (not shown for ease of illustration) which connect metal interconnect segment are also shifted a proportional amount. Thus, any vias connecting metal three interconnect segment **300** and metal two interconnect segment **328** would be shifted by an intermediate value of 0.40 μm , and any vias connecting metal one interconnect segment **326** and metal two interconnect segment **328** would be shifted by an intermediate value of 0.24 μm . It is further noted that, contact structures of transistor regions **324** are not shifted, although the metal one interconnect segment **326** overlap of such contact structures is adjusted to provide adequate overlap between contacts structures and metal one interconnect segment **326**. Thus, transistor regions **324**, photodetector **322**, and its respective isolation regions **305** are not shifted.

According to one embodiment, shifts are applied in groups of pixels by an amount equivalent to the supported maximum design grid. For example, in 0.25 micron CMOS, the typical minimum design grid is 0.01 μm . By way of illustration, a VGA imaging array comprises 640 columns and 480 rows of pixels. The number of pixels in each shift group is determined after the maximum shift value is

determined at the edge of the field of view, i.e., for pixels situated at the edge of CMOS imaging array **300**, as described above. If, for example, the maximum shift for a pixel element at the edge or periphery of CMOS imaging array **300** is determined to be $0.8\ \mu\text{m}$, smaller shifts will be applied in increments of $0.01\ \mu\text{m}$ based upon the radial distance from optical center axis **336**. In the horizontal dimension, for example, there will be 80 groups of shifts, each group including 6 columns (or 6 pixels), each group further away from optical center axis **336** being shifted 0.01 closer to optical center axis **336**. Shifts to the pixel elements are also applied in the vertical dimension of CMOS imaging array **300** in the manner described above.

In general, shifts are applied in greater magnitudes to pixels elements situated further away from optical center axis **336** than pixels structures situated closer to optical center axis **336**. Thus, larger shifts will be applied to metal interconnect segments **326**, **328** and **330** of pixel **306** than metal interconnect segments **312**, **314** and **316** of pixel **302**. Likewise, larger shifts will be applied to color filter **332** and micro lens **334** of pixel **306** than color filter **318** and micro lens **320** of pixel **302**. Referring to metal one segment **326** of pixel **306**, for example, shift **370** indicates that that metal one segment **326** is shifted closer to optical center axis **336** relative to pixel **306** than metal one segment **312** relative to pixel **302**. Thus, dimension **344** of pixel **302** is greater than dimension **346** of pixel **306** by shift amount **370**. Likewise, shift **372** indicates that metal two segment **328** of pixel **306** is shifted closer to optical center axis **336** than metal two segment **314** of pixel **302**, and shift **374** indicates that metal three segment **330** of pixel **306** is shifted closer to optical center axis **336** than metal three segment **316** of pixel **302**. Furthermore, shift **376** indicates that color filter **332** of pixel **306** is shifted closer to optical center axis **336** than color filter **318** of pixel **302**, and shift **378** indicates that micro lens **334** of pixel **306** is shifted closer to optical center axis **336** than micro lens **320** of pixel **302**. It is noted that exceptions to this difference in shift amounts between pixels **302** and **306** arise when pixel elements of pixel **302** and **306** are in the same "shift group," in which case those pixel elements in the same shift group are shifted by the same amount, as noted above.

Also as discussed above, pixel elements situated further above pixel surface **335** are shifted by a greater amount in order to properly align the pixel elements with the principle ray angle. Thus, shift amount **378** is greater than shift amount **376**. Shift amount **378** is in turn greater than shift amount **374**; shift amount **374** is greater than shift amount **372**; and shift amount **372** is greater than shift amount **370**.

Referring to FIG. **3B**, principal ray **370** and ray bundle **374** are shown having incident angles significantly away from normal or away from perpendicular to imaging array surface **335** of pixel **306**. Ray **370** and ray bundle **374** are redirected by micro lens **334** and passed through color filter **332**. Due to the particular arrangement of CMOS imaging array **300**, redirected rays **372** and **376** of principal ray **370** and ray bundle **374** strike photodetector **322** but are not blocked by metal interconnect segment **326**, **328** and **330** because each of metal interconnect segments **326**, **328** and **330**, color filter **332**, and micro lens **334** have been shifted toward optical center axis **336** to approximately align with principle ray **370**, as described above. As a result, camera performance is significantly increased, resulting in significant or complete elimination of pixel light shadowing at the edges of CMOS imaging array **300**. According to one embodiment, 25%–50% increases in light collection at the edges of CMOS imaging array **300** is achieved. These

benefits are achieved without resort to use of telecentric lenses and its associated disadvantages. Thus, lens size can be reduced, and lens performance is increased. Moreover, since the dimensional tolerance of the manufacturing process is several times greater than a minimum design grid, these small shift or offsets will not interfere with the normal wafer manufacturing process.

From the above description of exemplary embodiments of the invention it is manifest that various techniques can be used for implementing the concepts of the present invention without departing from its scope. Moreover, while the invention has been described with specific reference to certain embodiments, a person of ordinary skill in the art would recognize that changes could be made in form and detail without departing from the spirit and the scope of the invention. For example, it is manifest that the shift amount values and the number of metal interconnect segments described above are merely exemplary and may be modified without departing from the scope and spirit of the invention. The described exemplary embodiments are to be considered in all respects as illustrative and not restrictive. It should also be understood that the invention is not limited to the particular exemplary embodiments described herein, but is capable of many rearrangements, modifications, and substitutions without departing from the scope of the invention.

Thus, a CMOS image sensor arrangement and method for arranging image sensor elements with reduced pixel light shadowing has been described.

What is claimed is:

1. A CMOS image sensor comprising:

a plurality of pixels arranged in an array;

said plurality of pixels including a first pixel proximate an optical center of said array, and a second pixel proximate a peripheral edge of said array;

a first metal interconnect segment associated with said first pixel; and

a second metal interconnect segment associated with said second pixel, wherein said first metal interconnect segment and second metal interconnect segment are situated in a first metal layer, wherein said second metal interconnect segment is shifted closer to said optical center than said first metal interconnect segment so that said second metal interconnect segment approximately aligns with a principal ray angle incident said second pixel.

2. The CMOS image sensor of claim **1**, wherein said second metal interconnect segment is shifted along a horizontal dimension of said array.

3. The CMOS image sensor of claim **1**, wherein said second metal interconnect segment is shifted along a vertical dimension of said array.

4. The CMOS image sensor of claim **1**, wherein said second metal interconnect segment is shifted along both a horizontal and a vertical dimension of said array.

5. The CMOS image sensor of claim **1**, further comprising:

a third metal interconnect segment associated with said first pixel;

a fourth metal interconnect segment associated with said second pixel, wherein said third metal interconnect segment and said fourth metal interconnect segment are situated in second metal layer, wherein said fourth metal interconnect segment is shifted closer to said optical center than said third metal interconnect segment so that said fourth metal interconnect segment approximately aligns with said principal ray striking said second pixel.

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6. The CMOS image sensor of claim 5, wherein said first metal layer is situated below said second metal layer, and wherein said fourth metal interconnect segment is shifted closer to said optical center than second metal interconnect segment.

7. The CMOS image sensor of claim 5, further comprising a first via situated between said first metal interconnect segment and said third metal interconnect segment.

8. The CMOS image sensor of claim 7, further comprising a second via situated between said second metal interconnect segment and said fourth metal interconnect segment.

9. The CMOS image sensor of claim 1, further comprising:

a first micro lens situated associated with said first pixel; and

a second micro lens associated with said second pixel, wherein said second micro lens is shifted closer to said optical center than said first micro lens.

10. The CMOS image sensor of claim 1, further comprising:

a first color filter associated with said first pixel; and

a second color filter associated with said second pixel, wherein said second color filter is shifted closer to said optical center than said first color filter.

11. A CMOS imaging array comprising:

a plurality of pixels arranged in rows and columns, each said pixel including a photodetector;

said plurality of pixels including a first pixel proximate an optical center of said CMOS imaging array, and a second pixel proximate a peripheral edge of said array;

a first metal interconnect segment associated with said first pixel; and

a second metal interconnect segment associated with said second pixel, wherein said first metal interconnect segment and second metal interconnect segment are situated in a first metal layer, wherein said second metal interconnect segment is shifted closer to said optical center than said first metal interconnect segment so that said second metal interconnect segment approximately aligns with a principal ray angle incident a photodetector of second pixel.

12. The CMOS imaging array of claim 11, wherein each of said first and second transistor regions comprises a respective reset transistor, a respective source-follower transistor, and a respective select transistor.

13. The CMOS imaging array of claim 11, wherein said photodetector is a photodiode.

14. The CMOS imaging array of claim 11, wherein said second metal interconnect segment is shifted along at least one of a horizontal or a vertical dimension of said array.

15. A CMOS imaging array of a lens system having a principle ray angle, said CMOS imaging array comprising:

a plurality of pixels including a first pixel, said first pixel having a photodetector;

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at least a first micro lens element associated with said first pixel, said first micro lens element having a first offset position;

wherein said first pixel is situated at a periphery of said imaging array, and wherein said first micro lens element is fabricated at said first offset position so that said micro lens element approximately aligns with said principle ray angle incident said first pixel.

16. The CMOS imaging array of claim 15 further comprising:

a first color filter associated with said first pixel, said first color filter having a second offset position;

wherein said second offset position is derived by proportionally scaling said first offset position according to a distance of said first color filter above said photodetector relative to a distance of said first micro lens element above said photodetector;

wherein said first color filter is fabricated over said photodetector at said second offset position, and said first micro lens is fabricated over said first color filter.

17. The CMOS imaging array of claim 15 further comprising:

a first metal interconnect segment associated with said first pixel, said first metal interconnect segment having a second offset position;

wherein said second offset position is derived by proportionally scaling said first offset position according to a distance of said first metal interconnect segment above said photodetector relative to a distance of said first micro lens element above said photodetector;

wherein said first metal interconnect segment is fabricated over said photodetector at said second offset position.

18. The CMOS imaging array of claim 17, further comprising:

a second metal interconnect segment associated with said first pixel, said second metal interconnect segment having a third offset position;

wherein said third offset position is derived by proportionally scaling said first offset position according to a distance of said second metal interconnect segment above said photodetector relative to a distance of said first micro lens element above said photodetector.

19. The CMOS imaging array of claim 18, wherein said second metal interconnect segments is fabricated above said first metal interconnect segment, said third offset position in closer proximity to an optical center axis of said imaging array than said second offset position.

20. The CMOS imaging array of claim 19 further comprising:

a via fabricated between said first metal interconnect segment and said second metal interconnect segment, said via having a fourth offset position having an intermediate position between said second offset position and said third offset position.

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