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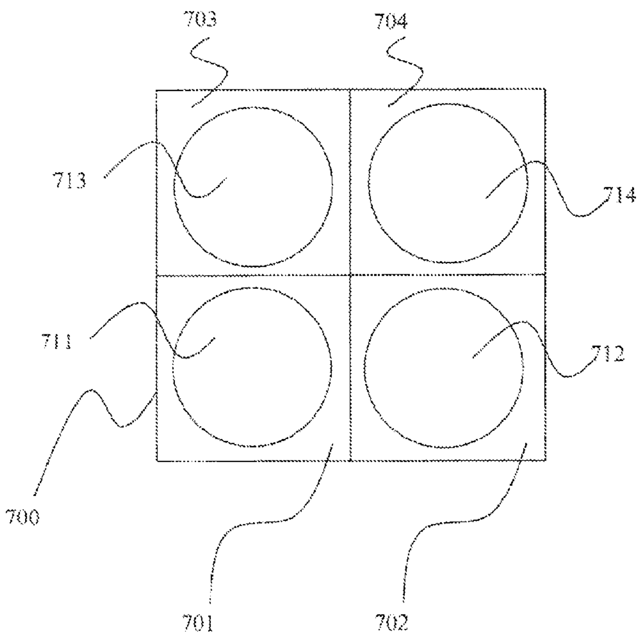
(54) **Title**: SYSTEM AND METHOD FOR IMAGING USING MULTI APERTURE CAMERA

Figure 7



(57) **Abstract**: The present invention relates to a system and method for improving the spatial resolution of digital cameras that consist of multiple imaging lens assemblies (hereinafter: imaging channels) and at least one sensor that can be divided in to two or more regions. The imaging lenses are designed to have the same field of view but different modulation transfer function as a function of field of view. The final processed image is composed of details obtained by different imaging channels. Each imaging channel provides luminance details for different areas of the final image while all imaging channels provide chrominance (color details) of the complete scene. As a result of the modulation transfer function variation, each channel has an area where the modulation of some areas in the scene is higher. The present invention relates generally to a system and method for capturing an image, and more particularly to an advanced imaging systems having more than one aperture.

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SYSTEM AND METHOD FOR IMAGING USING MULTI APERTURE CAMERA

The present invention relates to a system and method for improving the spatial resolution of digital cameras that consist of multiple imaging lens assemblies (hereinafter: imaging channels) and at least one sensor that can be divided in to two or more regions. The imaging lenses are designed to have the same field of view but different modulation transfer function as a function of field of view. The final processed image is composed of details obtained by different imaging channels. Each imaging channel provides luminance details for different areas of the final image while all imaging channels provide chrominance (color details) of the complete scene. As a result of the modulation transfer function variation, each channel has an area where the modulation of some areas in the scene is higher. The present invention relates generally to a system and method for capturing an image, and more particularly to an advanced imaging systems having more than one aperture.

BACKGROUND OF THE INVENTION

US 2001/0134282 relates to an imaging device, comprising: a lens array including a plurality of lenses facing a subject; an image sensor obtaining a compound-eye image including single-eye images of the subject formed by the lenses; and a computing unit processing the compound-eye image obtained by the image sensor, wherein the lenses have different radii of curvature and substantially a same back focal length; and the computing unit extracts an in-focus image from the compound-eye image. The imaging unit also includes light-shielding walls for preventing crosstalk between light beams passing through adjacent lens sets of the lens array. The imaging unit also includes an image sensor such as a CMOS sensor that converts optical images of the subject formed by the lens sets of the lens array into an image signal (data), wherein the image sensor is mounted on a substrate. Lens surfaces of the lens sets of the lens array have different radii of curvature so that the lens sets focus at different subject distances. In addition to setting the radii of curvature as described above, the lens sets are configured to have substantially the same back focal length.

International application WO 2009/151903 relates to camera array fabricated on a semiconductor substrate to include a plurality of sensor elements, comprising: a first imager fabricated at a first location of the semiconductor substrate, the first imager including at least two first image sensor elements; and a second imager fabricated on a second location of the semiconductor substrate, the second imager including at least two second image sensor elements not overlapping with first image sensor elements. International application WO 2009/151903 relates to using a distributed approach to capturing images using a plurality of imagers of different imaging characteristics wherein each imager may be spatially shifted from another imager in such a manner that an imager captures an image that us shifted by a sub-pixel amount with respect to another imager captured by another imager. Each imager may also include separate optics with different filters and operate with different operating parameters (e.g., exposure time). Distinct images generated by the imagers are processed to obtain an enhanced image. Each imager may be associated with an optical element fabricated using wafer level optics (WLO) technology.

US 2011/0080487 relates to an imaging device comprising at least one imager array, and each imager in the array comprises a plurality of light sensing elements and a lens stack including at least one lens surface, where the lens stack is configured to form an image on the light sensing elements, wherein a spectral filter is provided within each imager and is configured to pass a specific spectral band of light; and spectral filters that pass different spectral bands are provided within at least two of the imagers. In addition, US 2011/0080487 also discloses that at least one lens surface in the optical stack of an imager differs based upon the specific spectral band of light passed by the spectral filter within the imager; and each lens surface is selected from the group consisting of diffractive, Fresnel, refractive and combinations thereof, wherein each of the imagers is optically separated from the other imagers by at least two opaque surfaces located in front of the light sensing elements and having openings arranged in axial alignment with the lens stack of the imager.

US 2005/0225654 relates to a color camera, including at least three sub-cameras, each sub-camera having an imaging lens, a color filter, and an array of detectors, wherein filters associated with a color set are substantially the same. The color camera combines images from the at least three sub-cameras to form a composite multi-color image, at least two of the at least three sub-cameras each generate an image for a substantially same color spectra, the at least two images for the substantially same color spectra having a variation there between to provide a resolution of a composite image for the substantially same color spectra which is higher than that of an individual sub-camera, a resolution of a color image not having the substantially same color spectra being less than the resolution of the composite image.

JP2011109484 relates to a multiple-lens camera apparatus with which several image area, the color filter of each color positioned for this every imaging region, and the lens array to which it corresponded for this every imaging region wherein the multiple-lens camera apparatus with which the focal distances with respect to this imaging region of at least two sub lenses of this lens array mutually differ.

An imaging system typically consists of an imaging lens and a detecting sensor. An imaging lens collects light emitted or reflected from objects in a scene and images this light onto a detector. A detector is a photosensitive device, which converts light in to electronic signal later forming a digital image. To photograph a color image a color filter must be used to separate between different spectral regions of the total spectrum that is being imaged.

A common filter that is used is called a Bayer mask which is a mask that is positioned on top of the detecting surface and allows different spectra (colors) to reach different pixels on the detector, for example a Bayer filter is composed of one green pixel mask followed by a red pixel mask followed on the row below by a blue pixel mask and finally another green pixel mask. Using a color mask such as a Bayer mask requires the use of a standard single lens having sufficient resolution and performance at all 3 colors used by the color mask (Red Green and Blue in the case of a Bayer mask but other color combinations can be used having different spectrum filters placed in different pixel location).

A phenomena caused by the use of color mask is the appearance of color artifacts also caused by the spatial disposition of the different colors. For example imaging a white line on black background having spatial resolution of Nyquist meaning 1 rows of pixels is white and the adjacent row is black will appear as different color lines depending on the position of the lines on the sensor. Given the sensors active area dimension (also known as format) and the desired field of view, the focal length of the lens can be calculated. The size of the aperture of the lens which determines the lens ability to collect light is also set according to sensors photo sensitivity, exposure time and acceptance of noise levels in the captured images. The focal length divided by the aperture’s size is called F-Number and indicates the lens ability to collect light from a scene. The lower the F-Number is the more light the lens will be able to deliver to the sensor plane.

An object of the present invention is to overcome the loss of effective resolution originating from the partial use of the sensor active area by each imaging.

Another object of the present invention is to provide improve low light performance by making smart use of the multiple imaging channels.

The present invention relates generally to a system and method for capturing an image, and more particularly to an advanced system employing a multi aperture camera. More in detail the present invention relates to a system for improving image spatial resolution using a multi aperture digital camera having at least two different modulation transfer functions, as a function of field, of lenses of the different imaging channels.

The term multi aperture digital camera as referred to means a camera that consists of more than one imaging lenses each having its aperture and lens elements. The term at least two different modulation transfer functions, as a function of field, as referred to means modulation as a function of field of view will be different in one or more spatial frequencies. The term lenses of the different imaging channels as referred to means any imaging lens that may consist of one or more optical surfaces having an optical power that is different than zero. The term image spatial resolution as referred to means the ability of lens to create an image which can resolve details that have a size of 1/f in which f is the spatial resolution.

The present inventors found that the image spatial resolution can by improved by using a multi aperture camera as recited in the appended claims and sub claims. In an aspect of the disclosure there is provided a system for imaging including a one or more imaging sensors; two or more lenses, each lens forms an initial image at a different location on the sensor or on the different sensors in the case of multiple sensors. According to an embodiment at least two of the apertures have the same field of view of the different imaging channels.

According to another embodiment of the present system the different modulation transfer functions as a function of field are designed such to improve spatial resolution of different parts of the image at each imaging channel. In an embodiment the different modulation transfer functions are achieved by means of different optical properties of the lens elements in the different imaging channels, in which the different optical properties include lens shapes, lens thicknesses, air space thicknesses, lens materials and apertures dimensions.

According to another embodiment the different modulation transfer functions are achieved by introducing field curvature to two or more lenses of the imaging channels and different focusing of the said lenses. The benefit of introducing field curvature and different focusing can be seen in the aspect of increasing modulation at different parts of the image by using two or more lenses that share the same design except for the back focus.

The system may include one or more color filters integrated to the system. The system may include one or more polarized filters integrated to the system. The system may include one or more neutral density filters integrated to the system. In an embodiment of the invention at least one of the imaging channels includes a filter as mentioned before. In an embodiment of the present system the imaging channels form an image on a single imaging detector. Two or more initial images may have lower light intensity signal as compare to the other initial images. Two or more initial images may have higher light intensity signal as compare to the other initial images. In an embodiment of the present invention the at least two of the imaging channels include a chromatic filter and in which at least one additional imaging channel has a broader spectral transmission than the said chromatic filter. This will result in the ability to create a color or monochrome image having special characteristics.

The system may include an algorithm for adding initial images to form a final image having higher dynamic range. The system may include at least two lenses which have a different F-Number. The system may also include least two lenses are focused to the same distance or two lenses which are focused to a different distance.

According to the present invention there is provided a method for imaging which includes the steps of transmitting reflected or emitted light collected from a scene to a detector via at least two lenses, forming at least two images on different locations of the detector and processing at least two images received on the detector to form a complete image.

The method may also include additional step of filtering the collected light so as to receive a colored image, the filtering may be color filtering, polarized filtering or neutral density filtering.

According to the present invention there is also provided a method for improving image spatial resolution using the present system, which method comprises the following steps:

A1. Selecting the area of interest from each imaging channel.

B1. Combining the thus selected areas into a final image.

By using such a method it is possible to create a final image with higher resolution than the single images of the different imaging channels. More in detail step A1 relates to selecting the areas in which the modulation is higher, and step B1 relates to forming a final image with higher modulation across the whole field of view.

According to another embodiment of the present invention for improving image spatial resolution using the present system, the method comprises the following steps:

A2. Selecting the area of interest from at least two images.

B2. Combining the thus selected areas into a composed luminance of the final image.

C2. Combining the chrominance of the final image from at least two differently chromatically filtered images.

D2. Combining the luminance of step B2 and chrominance of step C2 into a final color image.

By using such a method it is possible to create a final color image with higher resolution than the single images of the different imaging channels. More in detail step A2 relates to selecting the areas in which the modulation is higher, step B2 relates to combining the said areas in to one luminance matrix having high modulation across the whole field of view, step C2 relates to creating chrominance information for all positions in the final image, and step D2 relates to combining the said chrominance matrix with the said luminance matrix into a color image having any known format.

In the aforementioned methods it is preferred that the area of interest is of higher modulation. This will result in a combined luminance matrix that has higher modulation across the whole field of view.

According to an embodiment of the present methods it is optional to carry out an additional step of upscaling, i.e. in which before the step of combining the images of the different imaging channels the images of the different imaging channels are upscaled. According to a preferred embodiment the step of upscaling takes place in the direction x and y in which the scaling factor in x and in y may be of different magnitude. The effect of this will result in a final image with higher resolution the resolution of the single imaging channels.

Another object of the present invention is to provide a method for improving low light performance using the present system, which method comprises the following steps:

A3. Using the one or more images of said broader spectral chromatically filtered imaging channels to create the luminance of the final image.

B3. Combining the chrominance of the final image from at least two differently chromatically filtered images.

C3. Combining the luminance of step A3 and chrominance of step B3 into a final color image.

The effect of these steps A3, B3 and C3 is that final image will demonstrate a higher signal to noise ratio.

Another object of the present invention is to provide a method for selecting luminance for the final image using the present system, which method comprises the following steps:

A4. Determining the amount of light in a scene.

B4. Selecting the source of luminance for the final image according to the said amount of light.

C4. Applying the method according to the aforementioned method regarding improving spatial resolution or improving low light performance according to the selection of step B4.

By using such a method it is possible to increase the signal to noise ration of the final image in low light conditions and increase the resolution of the final image in normal lighting conditions. More in detail step A4 relates to relates to calculation the amount of light in a scene by using the exposure time and the pixels signal values in one or more of the imaging channels, and step B4 relates to making a selection between the broader spectrally filtered imaging which may be corrected for distortion and the chromatically filtered images which may be corrected for distortion, and step C4 relates to using the source of luminance to create a final image, respectively.

In another embodiment of the present invention the method for selecting luminance for the final image using the present comprises the following steps:

A5. Determining the amount of signal levels is an area of the image with the size of at least one pixel.

B5. Selecting the source of luminance for the said area in the final image according to the said signal level of step A5.

C5. Applying the method according the aforementioned method regarding improving spatial resolution or improving low light performance according to the selection of step B5 at a said area of step A5.

By using such a method it is possible to dynamically select the source of the luminance and as such improve the signal to noise ratio of the final image in low lighting conditions. More in detail step A5 relates to calculation the amount of light in a scene by using the exposure time and the pixels signal values in one or more of the imaging channels, and step B5 relates selecting the source of luminance at each area that can be one or more pixels in size by choosing the between the broader spectrum channel and the , and step C5 relates to relates to creating a final image that consists of luminance and chrominance in which he luminance has higher effective resolution or higher signal to noise ratio in the case of low amount of light in the scene, respectively.

When using multi aperture digital cameras, each lens forms an image that is smaller than the size of the sensor or total size of sensors. The resulting products of such a multi aperture digital camera are multiple images that have lower effective resolution, lower than an image captured by a single aperture lens using the same sensor or a single sensor having a pixel count that is equal to the sum of the plurality of sensors. This reduction of resolution can be compensated by use of more pixels but this solution leads to higher price and larger dimensions, which is undesirable in most cases.

In an embodiment of the present system the optical element comprises an integrated optical barrier for blocking light. Such a barrier can be created using a dicing technique, powder blasting, etching, scoring techniques. According to another embodiment canals are created in an optical element using dicing techniques. Preferably, the barriers are created within or on top of a sensor cover substrate.

According to wafer optics manufacturing processes a wafer having multiple integrated barriers or canals can be used. Such a wafer has multiple canals wherein the canals are filled with optical absorbing material. According to another embodiment the wafer has multiple canals wherein the canals surfaces are coated with absorbing coating. It is also possible to coat with different optical coatings in different locations on the wafer surface, wherein the coatings at each location transmits a different light spectrum, especially wherein each said location on said wafer is associated with the arrangement of sub images.

According to another embodiment of the present invention the system comprises two or more lenses wherein each lens comprises one or more optical elements where some or all have a non circular aperture allowing a decrease in distances between the lenses. The largest lens element in each lens has a footprint which is smaller than the size of the detector area that is used to collect the light passing through the same lens.

In addition some optical elements have a non circular aperture and others have a circular aperture.

The present invention further relates to a micro lens for a usage in a multi lens camera for increasing the light collection efficiency of the pixels having more than one center of symmetry. It is preferred that in such a micro lens the number of said centers of symmetry depends on the number of lenses. Each center of symmetry is preferably created opposite a center of an opposite lens, the lens is associated with a sub image which includes the corresponding center of symmetry. In an embodiment the arrangement of said micro lens array is associated with the arrangement of sub images.
The following invention proposes an alternative solution that allows increasing the effective resolution of a multi aperture camera without the need of using a sensor with more pixels.

The present invention thus relates to the use of a multi aperture digital camera having at least two different transfer functions, as a function of field, of lenses of the different imaging channels for improving image spatial resolution.

According to another embodiment the present invention relates to the use of a multi aperture digital camera having at least two different transfer functions, as a function of field, of lenses of the different imaging channels for improving low light imaging performance.

SUMMARY OF THE INVENTION

In an imaging system containing multi apertures as described above we will address herein after each lens and the area of the sensor in which the lens forms an image on as an imaging channel.

The digital camera is composed of two or more imaging channels where the imaging lens of each channel can be different than the imaging lens of other channels.
The focal length of a lens is defined by the distance in which the lens will form an image of an object that is positioned at infinity.

The lens F-Number is defined as the focal length divided by the entrance pupil diameter which is set by the lens aperture.

The maximal achievable modulation transfer function of a lens with a given F-Number is limited by the diffraction effect.

An ideal lens would have the maximal possible modulation transfer function all across its field of view but an actual lens typically does not reach this limit and typically demonstrates a higher modulation transfer function in the center of the field of view. In a system containing multi lenses for imaging the same scene on to a sensor or sensors using different chromatic filtering or with no chromatic filtering, it is proposed to use lenses with different modulation as a function of field of view. Each lens will be designed to have a higher modulation transfer function at a different region of the scene. Using a special algorithm for combining the details captured by all or some of the lenses and their corresponding areas on the sensor will result in a digital image of the complete scene with high modulation transfer function over the complete field of view.

It is also proposed to use lenses that have varying F-Number across the field of view in which for each lens the area that has higher modulation has also a lower F-Number and therefore the limitation of the modulation is higher

Using the proposed method above results in a high-resolution image that was composed by extracting specific areas from different channels. The high-resolution image that was composed can be a monochrome image. Converting this image into a color image requires extraction of the color information for each pixel or pixel groups from some or all of images.

Dividing an image into color data also known as chrominance and intensity data also known as luminance is achieved using the stitched monochrome image as the luminance source for each pixel and using information from images from 3 or more different channels.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to a system and method which may be applied to a variety of imaging systems. This system and method provide high quality imaging while considerably reducing the length of the camera as compared to other systems and methods.

Specifically, the object of the present invention is to provide a system and a method to improve image capturing devices while maintaining the same filed of view. This is accomplished by using a 2 or more lenses. Each lens forms a small image of the scene. Each lens transfers light emitted or reflected from objects in the scenery onto a proportional area in the detector. The optical track of each lens is proportional to the segment of the detector which the emitted or reflected light is projected on. Therefore, when using smaller lenses, the area of the detector which the emitted or reflected light is projected on, referred hereinafter as the active area of the detector, is smaller. When the detector is active for each lens separately, each initial image formed is significantly smaller as compare to using one lens which forms an entire image. One lens camera transfers emitter or reflected light onto the entire detector area.

Therefore instead of using a single lens to form a large image covering the complete sensor active area, we propose to use two or more lenses where each form a small image covering only a part of the sensor's active area.

The sensor that will be used will not have any color mask on its active area and instead each lens will have a color filter integrated within the optical barrel or in front of the lens (between the lens and the scene) or between the lens and the sensor or placed on top of the sensor part that is used with the specific lens.

The invention will be more clearly understood by reference to the following description of preferred embodiments thereof read in conjunction with the figures attached hereto. In the figures, identical structures, elements or parts which appear in more than one figure are labeled with the same numeral in all the figures in which they appear. Dimensions of components and features shown in the figures are chosen for convenience and clarity of presentation and are not necessarily shown to scale. The figures are listed below.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a side view of a single lens camera.

Figure 2 illustrates a sensor array (201) having multiple pixels.

Figure 3 illustrates a side view of a three lens camera having one sensor and three lenses.

Figure 4 illustrates an example of a scene as projected on to the sensor.

Figure 5 illustrates a front view of a three lens camera using one rectangular sensor divided in to three regions.

Figure 6 illustrates a front view of a three lens camera having one sensor, one large lens and two smaller lenses.

Figure 7 illustrates a front view of a four lens camera having a one sensor (700) and four lenses.

Figure 8 illustrates a 16 lens camera having four regions, each containing four lenses as illustrated in figure 7.

Figure 9 illustrates a graph of modulation versus field of view at a specific spatial frequency.

Figure 10 illustrates a graph of modulation versus field of view at a specific spatial frequency.

Figure 11 schematically shows an embodiment of a section of multi aperture digital camera.

Figure 12 schematically shows an exploded view of the individual parts shown in Figure 11.

Figure 13A schematically shows individual lens elements in a 2x2 array.

Figure 13B schematically shows a top view of the 2x2 array shown in Figure 13A.

Figure 14A schematically shows one lens element in a 2x2 integrated lens element.

Figure 14B schematically shows a top view of the integrated 2x2 array shown in Figure 14A.

Figures 15A, 16A, and 17A, 18, 19 schematically show a construction of different sizes of lenses in a lens array.

Figures 15B, 16B, and 17B schematically show the sensors to be used in connection with the lenses shown in figures 15A, 16A, and 17A, respectively.

Figures 20, 21, 22, and 23 schematically show different embodiments of a section of multi aperture digital camera.

Figure 1 illustrates a side view of a single lens camera having a single lens (102) that can comprise one or more elements and a single sensor (101).

Figure 2 illustrates a sensor array (201) having multiple pixels where the position of the green filter, red filter and blue filter are marked by (202), (203) and (204) respectively. The image that will be taken using this configuration needs to be processed in order to separate the green, red and blue images.

Figure 3 illustrates a side view of a three lens camera having one sensor (310) and three lenses (301), (302) and (303). Each one of the said lens will project the image of the same scene on to segments of the sensor marked by (311), (312), and (313) respectively. Each one of the three lenses will have different color filters integrated within the lens, in front of it or between the lens and sensor (310). Using the described configuration the image acquired by the sensor will be composed of two or more smaller images, each imaging information from the scene at different spectrums.

Figure 4 illustrates an example of a scene as projected on to the sensor (401), in each region of the sensor (402), (403) and (404) the same scene is projected but each region will contain information for light at different wavelengths representing different colors according to the filters integrated within the lens that forms the image on each region.

The described configuration does not require the use of a color mask and therefore the maximal spatial frequency that can be resolved by the sensor is higher, on the other hand using smaller lens and smaller active area per channel necessarily means that the focal length of the lens is smaller and therefore the spatial resolution in objects space is decreased. Overall the maximal resolvable resolution for each color remains same.

The image acquired by the sensor is composed of two or smaller images, each containing information of the same scene but in different colors. The complete image is then processed and separated in to 3 or more smaller images and combined together to one large color image.

The described method of imaging has many advantages:

1. Shorter lens track (height) as each one of the lens used is smaller in size than the single lens covering the same field of view, the total track (height) of each lens is smaller allowing the camera to be smaller in height, an important factor for mobile phone cameras, notebook cameras and other applications requiring short optical track.
2. Reduced Color artifacts- Since each color is captured separately, artifacts originating from spatial dependency of each color in a color mask will not appear.
3. Lens requirements: each lens does not have to be optimal for all spectrums used but only for one spectrum, allowing simplifying the lens design and possibly decreasing the amount of elements used in each lens as no color correction is needed.
4. Larger Depth of Focus: the depth of focus of a system depends on its focal length. Since we use smaller lenses with smaller focal lengths, we increase the depth of focus by the scale factor squared.
5. Elimination of focus mechanism: focus mechanisms change the distance between the lens and the sensor to compensate for the change in object distance and to assure that the desired distance is in focus during the exposure time. Such a mechanism is costly and has many other disadvantages such as:
    a. Size
    b. Power consumption
    c. Shutter lag

d. Reliability
e. price

Using a fourth lens in addition to the three used for each color red, green and blue (or other colors) with a broad spectral transmission can allow extension of the sensor's dynamic range and improve the signal-to-noise performance of the camera in low light conditions.

All configuration described above using a fourth lens element can be applied on other configurations having two or more lenses.

Another configuration that is proposed is using two or more lenses with one sensor having a color mask integrated or on top of the sensor such as a Bayer mask. In such a configuration no color filter will be integrated in to each lens channel and all lenses will create a color image on the sensor region corresponding to the specific lens. The resulting image will be processed to form one large image combining the two or more color images that are projected on to the sensor.

Three lens camera:

Dividing the sensor's active area in to 3 areas, one for each color Red, Green and Blue (or other colors) can be achieved by placing 3 lens one beside the other as described in the drawing below: The resulting image will consist of 3 small images were each contains information of the same scene in different color. Such a configuration will comprise of 3 lenses where the focal length of each lens is 4/9 of an equivalent single lens camera that uses a color filter array, these values assume a 4:3 aspect ratio sensor.

Figure 5 illustrates a front view of a three lens camera using one rectangular sensor (500) divided in to three regions (501), (502) and (503). The three lenses (511), (512) and (513) each having different color filters integrated within the lens, in front of the lens or between the lens and the sensor are used to form an image of the same scene but in different colors. In This example each region of the sensor (501), (502) and (503) are rectangular having the longer dimension of the rectangle perpendicular to the long dimension of the complete sensor.

Other three lens configuration can be used, such as using a larger green filtered lens and two smaller lenses for blue and red, such a configuration will results in higher spatial resolution in the green channel since more pixels are being used.

Figure 6 illustrates a front view of a three lens camera having one sensor (600), one large lens (613) and two smaller lenses (611) and (612). The large lens (613) is used to form an image on the sensor segment marked (603) while the two smaller lenses form an image on the sensor's segments marked with (601) and (602) respectively. The larger lens (613) can use a green color filter while the two smaller lenses (611) and (612) can use a blue and red filter respectively. Other color filters could be used for each lens.

Four lens camera:

A four lens camera will comprise of 4 lenses each having different color filter integrated within the lens, before the lens or between the lens and the sensor region corresponding to the said lens. The color filters use for each lens can be partially repeated meaning a specific color filter can appear twice causing 2 of the 4 lens to image the same scene and at the same spectrum.

Figure 2 illustrates a front view of 4 lens camera having one sensor (200), four lenses (211-214) while each lens form an image on a corresponding segment of the sensor marked by (201-204) respectively.

Figure 7 illustrates a front view of a four lens camera having a one sensor (700) and four lenses (711), (712), (713) and (714). Each lens forms an image on the corresponding sensor region marked with (701), (702), (703) and (704) respectively. Each one of the lenses will be integrated with a color filter in side the lens, in front of the lens or between the lens and the sensor. All four lenses could be integrated with different color filter or alternatively two of the four lenses could have the same color filter integrated in side the lens, in front of the lens or between the lens and the sensor. For example using two green filters one blue filter and one red filter will allow more light collection in the green spectrum.

MxN lens camera:

Using M and /or N larger than 2 allows higher shortening factor and higher increase in depth of focus.

Figure 8 illustrates a 16 lens camera having 4 regions (801), (802), (803) and (804) each containing four lenses as illustrated in figure 7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

In a first embodiment a system with 3 (three) imaging channels each having a different color filter integrated within the imaging channel with transmission of Red, Green and Blue. All imaging channels have the same diagonal field of view. In this embodiment the lenses of the imaging channels were designed to have higher modulation at different area of the image. The higher modulation is introduced by allowing the modulation of the other areas of the image to decrease. Fig 9 illustrates a graph of modulation versus field of view at a specific spatial frequency which is Nyquist in this case but can be any other frequency, in which the modulation of each imaging channels is higher at a part of the field of view.

The imaging channel (channel 1 in figure 9) including a Green color filter demonstrates higher modulation at the center of the field of view, The imaging channel (channel 2 in figure 9) including a Red color filter demonstrates higher modulation between the central area of the field of view and up to an area close to the corner of the field of view. The imaging channel (channel 3 in figure 9) including a Blue color filter demonstrates higher modulation at the corner of the field of view.

Figure 9 illustrates the modulation variation as a function of field of view for the three lenses of the first embodiment. As seen in the graph at any given field of view at least one imaging channel images the scene with a higher modulation.

After capturing of the images or during the readout a luminance matrix is created according to one of the two methods:

1. At each area of the final image that can be one or more pixels in size, the source of luminance is chosen from one of the three imaging channels according to predefined table that for each area selects the source of luminance according to the imaging channel having the highest modulation in the said area.
2. By comparing sharpness of each area or detail in the three imaging channels and choosing the sharpest one as the source of luminance.

In both cases a chrominance matrix is also created using the images of the three imaging channels.

The luminance and chrominance matrix contain sufficient information as a color image. Converting the luminance and chrominance in to other image formats such as RGB, YUV or any other known format is not described here but is a well known procedure.

Second Embodiment:

In a second embodiment a system with 4 (four) imaging channels each having a different color filters integrated within the imaging channel with transmission of Red, Green and Blue and White, in which the later is a filter having wider spectral transmission compared to the Red, Green and Blue. All imaging channels have the same diagonal field of view. In this embodiment the lenses of the imaging channels that include the Red, Green and Blue were designed to have higher modulation at different area of the image. The higher modulation is introduced by allowing the modulation of the other areas of the image to decrease. Fig 9 illustrates a graph of modulation versus field of view at a specific spatial frequency which is Nyquist in this case but can be any other frequency, in which the modulation of each imaging channels is higher at a part of the field of view.

The White channel has a near uniform modulation as a function of field of view. The imaging channel (channel 1 in figure 9) including a Green color filter demonstrates higher modulation at the center of the field of view, The imaging channel (channel 2 in figure 9) including a Red color filter demonstrates higher modulation between the central area of the field of view and the up to an area close to the corner of the field of view. The imaging channel (channel 3 in figure 9) including a Blue color filter demonstrates higher modulation at the corner of the field of view.

Figure 9 illustrates the modulation variation as a function of field of view for the three lenses of the first embodiment. As seen in the graph at any given field of view at least one imaging channel images the scene with a higher modulation.

After capturing of the images or during the readout a luminance matrix is created according to one of the three methods:

1. At each area of the final image that can be one or more pixels in size, the source of luminance is chosen from one of the three imaging channels according to predefined table that for each area selects the source of luminance according to the imaging channel having the highest modulation in the said area.
2. By comparing sharpness of each area or detail in the three imaging channels and choosing the sharpest one as the source of luminance.
3. By using the image of the imaging channel that includes a white channel.

A smart algorithm can choose to use one of the above three methods for computing the luminance matrix by determining the amount of light in a scene. The amount of light can be estimated by the exposure time and the signals or average signal in the image of one or more imaging channels.

In case of low lighting conditions it is preferred to use the third method of creating the luminance matrix using the white channel only as this channel will demonstrate a higher signal-to-noise ratio which leads to lower noise in the final image.

The decision can be done on a global level or on a pixel or area level allowing the use of information from all four imaging channels for creating the luminance matrix. In this case the luminance of bright areas in the scene will be created using one of the three color channels and luminance at darker areas will be created using information from the white channel. In both cases a chrominance matrix is also created using the images of the three imaging channels or using the four channels. The luminance and chrominance matrix contain sufficient information as a color image. Converting the luminance and chrominance in to other image formats such as RGB, YUV or any other known format is not described here but is a well known procedure.

Third Embodiment:

In a third embodiment a system with 2 (two) imaging channels both using the same spectrum. One of the imaging channels was designed to have higher modulation at the central area of the image and the other imaging channel was designed to have higher modulation at the peripheral area on the image. The higher modulation is introduced by allowing the modulation of the other areas of the image to decrease.

Figure 10 illustrates a graph of modulation versus field of view at a specific spatial frequency which is Nyquist in this case but can be any other frequency, in which the modulation of each imaging channels is higher at a part of the field of view.

After capturing of the images or during the readout, a combined image is created according to one of the two methods:

1. At each area of the final image that can be one or more pixels in size, the source image is chosen from one of the two imaging channels according to predefined table that for each area selects the source image according to the imaging channel having the highest modulation in the said area.
2. By comparing sharpness of each area or detail in the two imaging channels and choosing the sharpest one as the source.

Figure 11 schematically shows an embodiment of a section of multi aperture digital camera, i.e. a lens package 1100. The lens package 1100 comprises an image capturing element 1101, e.g. a Charge Coupled imaging Device (CCD) or a CMOS imaging device. In general such an image capturing element 1101 is referred to as a solid-state image sensor (SSIS). The image capturing element 1101 converts optical images of the subject formed by the lens elements of the lens array 1103 into an image signal (data). The image capturing element 1101 is mounted on a substrate (not shown) and comprises a cover 1102 for protecting the sensor against the environment. The lens array 1103 is housed in a lens holder 104, and the lens holder 1104 is provided with a cover plate 1105. The lens holder 1104 has the function of a spacer as well, because the lens array 1103 is supported by the lens holder 1104. The height of this support determines for a dominant part the distance between the lens array 1103 and the sensor 1101. The cover plate may include optionally baffle. Light falls into the cover plate 1105 and travels through the lens array 1103 to the sensor 1101. The individual parts may be bonded by an adhesive layer (not shown). Preferably, the one or more adhesive layers are rim-shaped, the adhesive material being present outside an area coinciding with the projection of the circumference of the lens elements present in the lens array.

Figure 12 schematically shows an exploded view of the individual parts shown in Figure 11.

Figure 13A schematically shows individual lens elements 1106 in a 2x2 array placed on a sensor 1101.

Figure 13B schematically shows a top view of the 2x2 array shown in Figure 13A.

Figure 14A schematically shows one lens element 1107 in a 2x2 array, i.e. a 2x2 integrated lens element placed on a sensor.

Figure 14B schematically shows a top view of the integrated 2x2 array shown in Figure 14A.

The present invention is not restricted to a 2x2 array construction but other configuration are possible as well, like (please mention the types of arrays).

Figures 15A, 16A, and 17A, 18, 19 schematically show a construction of different sizes of the lenses 1106 in a lens array.

Figures 15B, 16B, and 17B schematically show the sensors 1101 to be used in connection with the lenses shown in figures 15A, 16A, and 17A, respectively. Although Fig Z relates to individual lens elements in a 2x2 array, other configurations, e.g. integrated constructions, are possible as well, like nxm array, wherein n and m are integers. In addition different sizes and shapes of the lenses are possible.

Figure 20 schematically shows another embodiment of a section of multi aperture digital camera, i.e. a lens package 1200. Individual arrays 1201, 1202 comprising lens elements are positioned within a housing 1203, and spacers 1204, 1205, 1206, 1207 are located on the sensor cover 1208 mounted on sensor 1209. The bonding between the spacers 1204, 1205, 1206, 1207 and the sensor cover 1208 is through an adhesive. An adhesive is also present between the spacers 1204, 1205, 1206, 1207 and the respective arrays 1201, 1202. (Remark: spacer 1204 and 1205 are same spacer, also same is valid for 1206 and 1207)

Figure 21 schematically shows another embodiment of a section of multi aperture digital camera, i.e. a lens package 1300. Individual arrays 1301, 1302 comprising lens elements are positioned within a housing 1303, and spacers 1304, 1305, 1306 are located on the sensor cover 1307 being mounted on sensor 1308. The bonding between the spacers 1304, 1305, 1306 and the sensor cover 1307 is through an adhesive. An adhesive is also present between the spacers 1304, 1305, 1306 and the arrays 1301, 1302. The polymer based lens elements are provided on transparent substrates 1309, 1310 via replication technology. Examples of transparent substrates are glass, polymers, quartz, ceramics, sapphire, crystalline alumina, Yttria, yttrium aluminium garnet (YAG). The lens package 1300 also includes light-shielding walls for preventing crosstalk between light beams passing through adjacent lens elements of the lens array 1301, 1302. The replicated lenses may be provided with one ore more additional layers, such as color filters, diaphragms, infra red reflecting layer, anti reflection layer (not shown). These additional layers can be present between the substrates 1309, 1310 and the lens element replicated thereon. The lens elements of the lens array 1301, 1302 can have different shapes, thicknesses, air space thicknesses, polymer materials and aperture dimensions.

Figure 22 schematically shows another embodiment of a section of multi aperture digital camera, i.e. a lens package 1400. Array 1401 comprising lens elements is positioned within a housing 1402, and spacers 1403, 1404, 1405 are located on the sensor cover 1406 being mounted on sensor 1407. The bonding between the spacers 1403, 1404, 1405 and the sensor cover 1406 is through an adhesive. An adhesive is also present between the spacers 1403, 1404, 1405 and the array 1401.

Figure 23 schematically shows another embodiment of a section of multi aperture digital camera, i.e. a lens package 1500. Array 1501 comprising lens elements is positioned within a housing 1502, and spacers 1503, 1504, 1505 are located on the sensor cover 1506 being mounted on sensor 1507. The bonding between the spacers 1503, 1504, 1505 and the sensor cover 1506 is through an adhesive. An adhesive is also present between the spacers 1503, 1504, 1505 and the array 1501. The polymer based lens elements are provided on transparent substrates 1508, 1509 via replication technology. Examples of transparent substrates are glass, polymers, quartz, ceramics. sapphire, crystalline alumina, Yttria, yttrium aluminium garnet (YAG).

Suitable wafer level optics technologies are disclosed in WO2004027880A2 which may be considered to be fully incorporated herein. Suitable replication technologies are disclosed in U.S. patents Nos. 6,773,638 and 4,890,905, which may be considered to be fully incorporated herein. The replica layer used in the present optical system is preferably composed of a UV curable polymer, selected from the group of polycarbonates, polystyrenes, poly(meth)acrylates, polyurethanes, polyamids, polyimids, polyethers, polyepoxides and polyesters. A replica layer is obtained by using a replication method in which use is made of a mould having a precisely defined surface, for example an aspherical surface, wherein a small amount of a radiation-curable resin, for example a UV curable resin, is applied to the mould surface. Subsequently, the resin is spread over the mould surface, so that the cavities present in the mould are filled with the resin, whereupon the whole is subsequently irradiated for curing the resin and the thus cured product is removed from the mould. The cured product is a negative of the mould surface. An advantage of the replication process is that lenses having an intricate refractive surface, such as an aspherical surface, can be produced in simple manner, without complicated processes of grinding and polishing the lens body being required. In addition to that, the replica layer is durably joined to the surface to which the replica layer is applied, without adhesives being used. In addition, there is no occurrence of so-called "air gaps", which lead to large refractive index transitions between the surface and the air layer that is present.

Suitable UV curable compositions are: polycarbonates, including diethylene glycolbis-(allyl)carbonate, polystyrenes, including polychlorine styrene, polyacrylates, such as poly(trifluoroethyl methacrylate), poly(isobutyl methacrylate), poly(methylacrylate), poly(methyl methacrylate), poly(alphamethyl bromium acrylate), poly(methacrylic acid)-2,3-dibromium propylpoly(phenyl methacrylate poly(pentachlorine phenyl-methacrylate polymer), polyester compounds such as diallylphthalate, poly(vinyl-benzoate), poly(vinylnaphthalene), poly(vinylcarbazole) and silicones in the form of various types of resin materials, as well as acrylic resin, urethane resin, epoxy resin, enthiol resin or thiourethane resin or photopolymer.

Exposure preferably takes place with an intensity of between 100 en 2000 W/cm<2>, in particular 700 W/cm<2>, and a dose of 1 - 15 J/cm<2>, in particular 7 J/cm<2>, a wavelength in the 320-400 nm range and an exposure time of 1-60 seconds, in particular 10 seconds.

Suitable UV curable adhesive compositions include GAFGARD233 (marketed by DuPont, type vinylpyrrolidone), Norland Inc. NOA-61 , NOA-63, NOA-65, Three bond AVR-100 and Sony Chemical UV-1003, possibly provided with the usual additives such as initiators, reactive or nonreactive dilutants, crosslinking agents, fillers, pigments and anti-shrinkage agents.

Spacers mentioned in the Figures are made of a rigid material, for example glass, silicon or a composite material such as FR4. In an embodiment the spacer plate is so configured that it will not interfere with the light path through the two separate lens elements, The spacer plate comprises an opening which is positioned coaxially with a main optical axis of the lens element in question, whilst in a special embodiment the side of said opening is provided with an anti-reflective coating.

The color filters, Infrared blocking filters, apertures and antireflection coatings on the substrates or lens surfaces can be manufactured according to well known industrial processes, like coating processes chemical vapor deposition, physical vapor deposition.

Suitable technologies regarding a multi- aperture camera through assembling discrete optical elements, lens housing and optical blocking structures are disclosed in US2010/0127157, and US2010/0039713. These documents are incorporated here by reference. The optical elements can be manufactured through injection molding or glass molding of a thermoplast or pressing a glass preshape in a single cavity or plural cavity mold.

Suitable technologies for manufacturing present coverplate and present lens holder for wafer level optics camera are disclosed in US2010/0052192, US2009/0321861 and US2010/0117176. These documents are incorporated here by reference.

Alternatively lens holder, coverplate can be provided through assembling injection molded, ceramic or metal housing. Sumitomo Bakelite: X83563- ,X84179,G750L-B

Typical sizes for the present camera module height is about 4-10mm, for camera module foot print; 4x4mm to 20x20 mm. The dimension is not necessarily square, but in special embodiments also constructions of different sizes are possible, e.g. 4x10mm.

according to an embodiment the image sensor package is within the range of 0.4 - 0,8mm. Dimensions of lens diameters are within a range of 2-4 mm, glas substrates within a range of 0.200-1mm. For the replicated lenses one may apply a sag height in a range of 20 μ – 250μ, or even in a range of 500 -1000 μ. Typical dimensions for a buffer layer are 30 μ – 100μ.

CLAIMS

1. A system for improving image spatial resolution using a multi aperturedigital camera having at least two different modulation transfer functions as a function of field, of lenses of the different imaging channels.

2. The system of claim 1 in which at least two of the apertures have the same field of view of the different imaging channels.

3. The system according to any one or more of the preceeding claims in which the different modulation transfer functions as a function of field are designed to improve spatial resolution of different parts of the image at each imaging channel.

4. The system according to any one or more of the preceeding claims in which the different modulation transfer functions is achieved by means of different optical properties of the lens elements in the different imaging channels.

5. The system of claim 4 in which the different optical properties include lens shapes, lens thicknesses, air space thicknesses, lens materials and apertures dimensions.

6. The system according to any one or more of the preceeding claims 1-3 in which the different modulation transfer functions are achieved by introducing field curvature to two or more lenses of the imaging channels and different focusing of the said lenses.

7. The system according to any one or more of the preceeding claims in which at least one of the imaging channels includes a neutral density filter.

8. The system according to any one or more of the preceeding claims in which at least one of the imaging channels includes a chromatic filter.

9. The system according to any one or more of the preceeding claims in which at least one of the imaging channels includes a polarizing filter.

10. The system according to any one or more of the preceeding claims in which the imaging channels form an image on a single imaging detector.

11. The system according to any one or more of the preceeding claims in which the at least two of the imaging channels include a chromatic filter and in which at least one additional imaging channel has a broader spectral transmission than the said chromatic filter.

12. A method for improving image spatial resolution using the system according to claims 1-11 comprising the following steps:

A1. Selecting the area of interest from each imaging channel.

B1. Combining the thus selected areas into a final image.

13. A method for improving image spatial resolution using the system according to claims 1-11 in comprising the following steps:

A2. Selecting the area of interest from at least two images.

B2. Combining the thus selected areas into a composed luminance of the final image.

C2. Combining the chrominance of the final image from at least two differently chromatically filtered images.

D2. Combining the luminance of step B2 and chrominance of step C2 into a final color image.

14. A method according to claim 12 and 13 in which the area of interest is of higher modulation transfer function.

15. A method according to claim 12 and 13 in which before the step of combining the images of the different imaging channels the images are upscaled.

16. A method according to claim 15 in which upscaling takes place in the direction x and y in which the scaling factor in x and in y maybe different.

17. A method for improving low light performance using the system according to any one or more of the claims 1-11 comprising the following steps:

A3. Using the one or more images of said broader spectral chromatically filtered imaging channels to create the luminance of the final image.

B3. Combining the chrominance of the final image from at least two differently chromatically filtered images.

C3. Combining the luminance of step A3 and chrominance of step B3 into a final color image.

18. A method for selecting luminance for the final image using the system according to any one or more of the claims 1-11 comprising the following steps:

A4. Determining the amount of light in a scene.

B4. Selecting the source of luminance for the final image according to the said amount of light.

C4. Applying the method according to claim 13 or 17 according to the selection of step B.

19. A method for selecting luminance for the final image using the system according to any one or more of the claims 1-11 comprising the following steps:

A5. Determining the amount of signal levels is an area of the image with the size of at least one pixel.

B5. Selecting the source of luminance for the said area in the final image according to the said signal level of step A5.

C5. Applying the method according to claim 13 or 17 according to the selection of step B at a said area of step A.

20. The use of a multi aperturedigital camera having at least two different modulation transfer functions as a function of field, of lenses of the different imaging channels according to anyone or more of the claims 1-11 for improving image spatial resolution.

21. The use of a multi aperturedigital camera having at least two different modulation transfer functions as a function of field, of lenses of the different imaging channels according to anyone or more of the claims 1-11 for improving low light imaging performance.

Figure 1

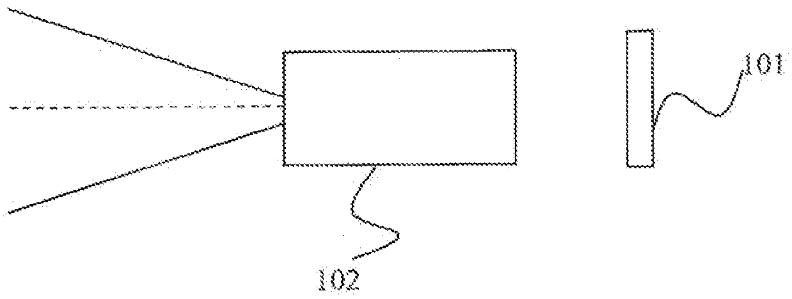


Figure 2

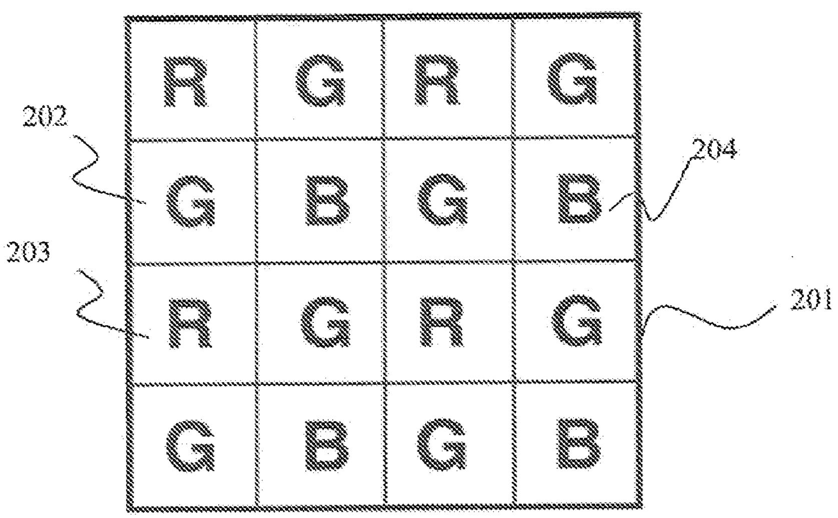


Figure 3

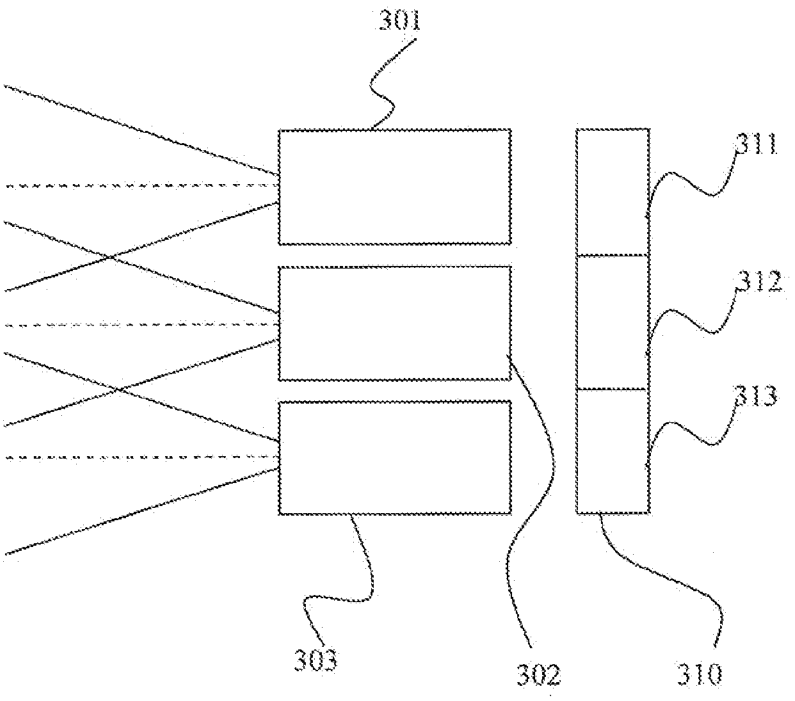


Figure 4

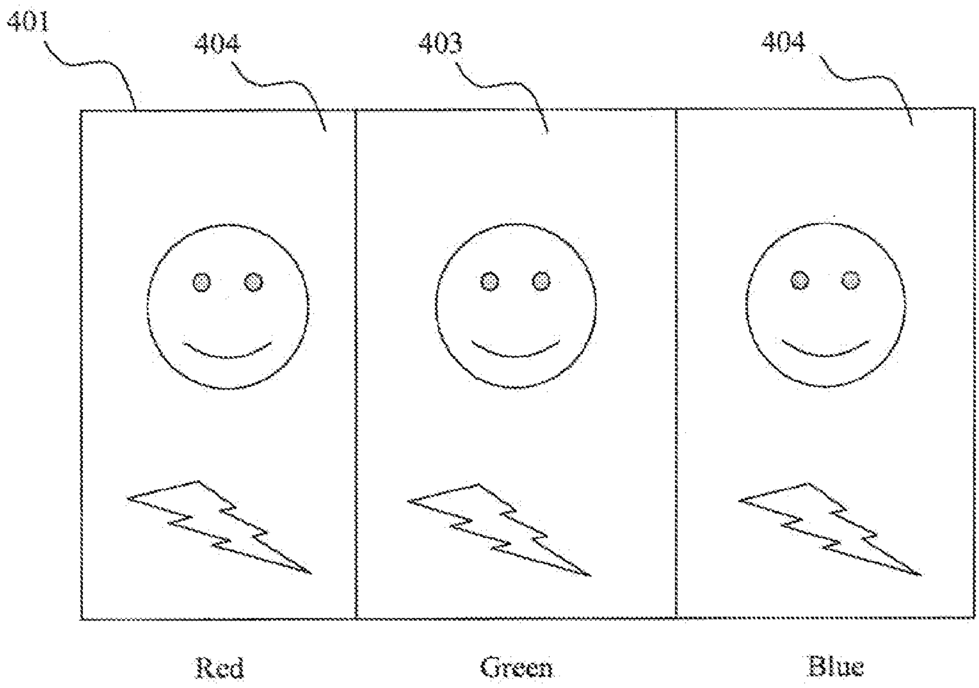


Figure 5

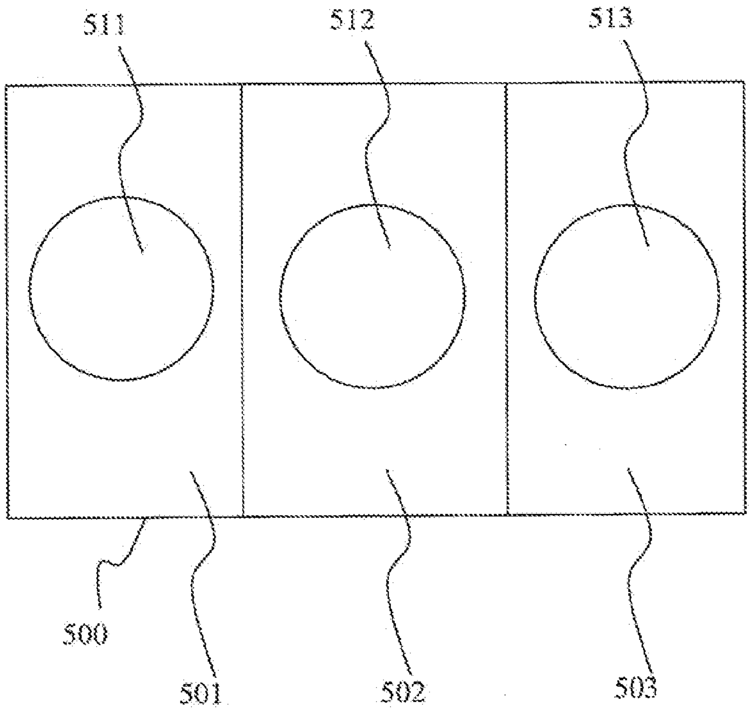


Figure 6

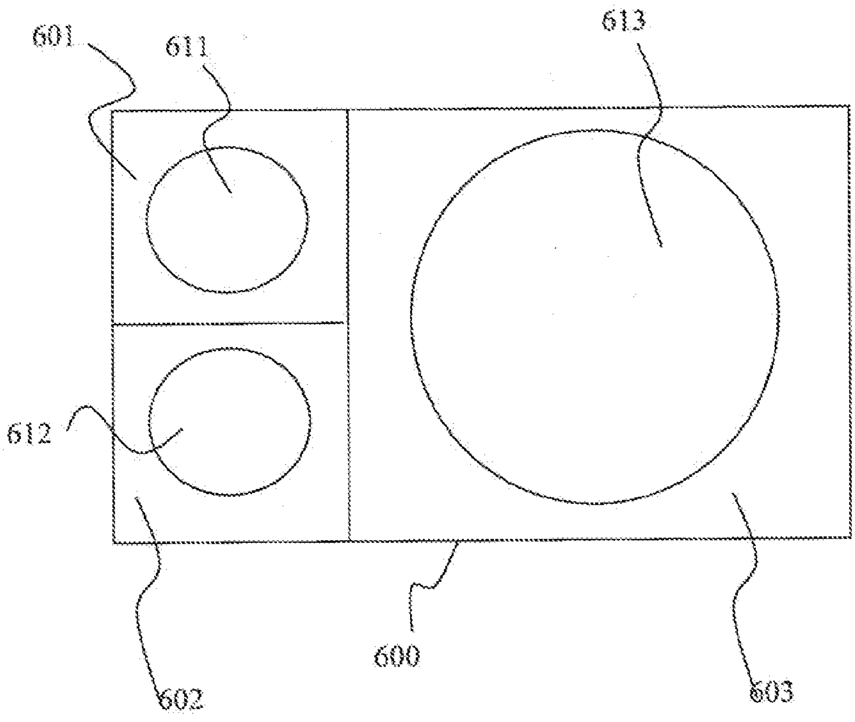


Figure 7

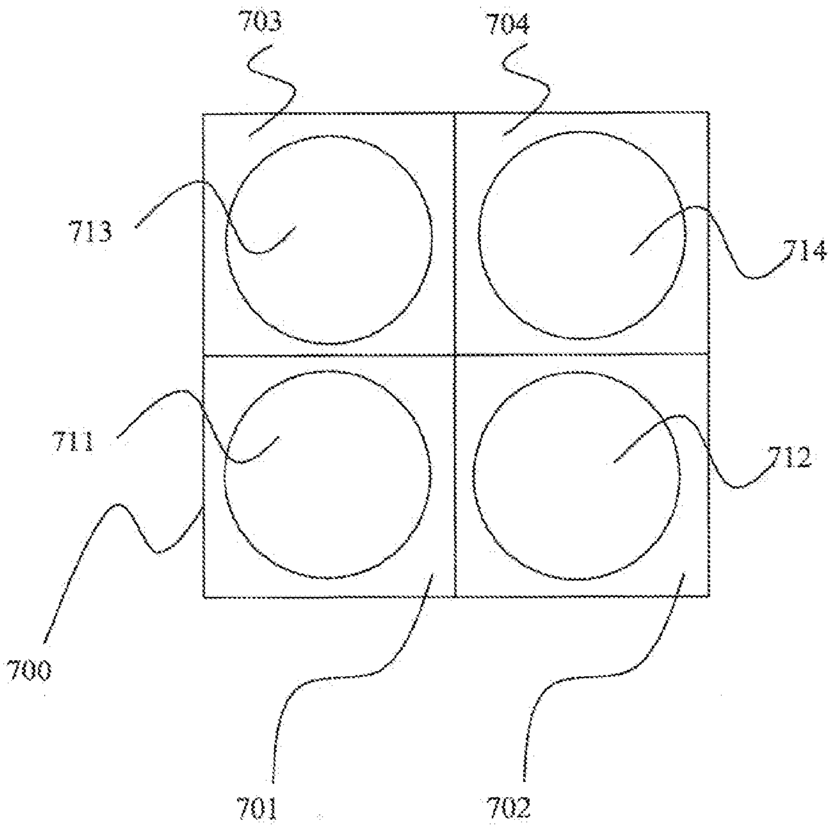


Figure 8

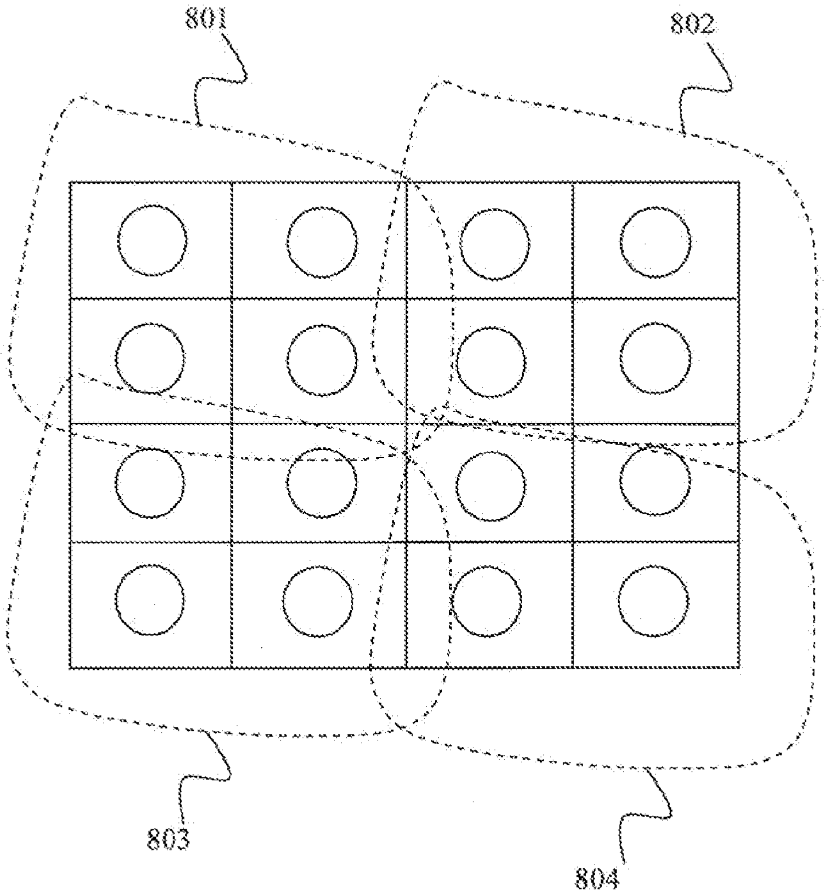


Figure 9

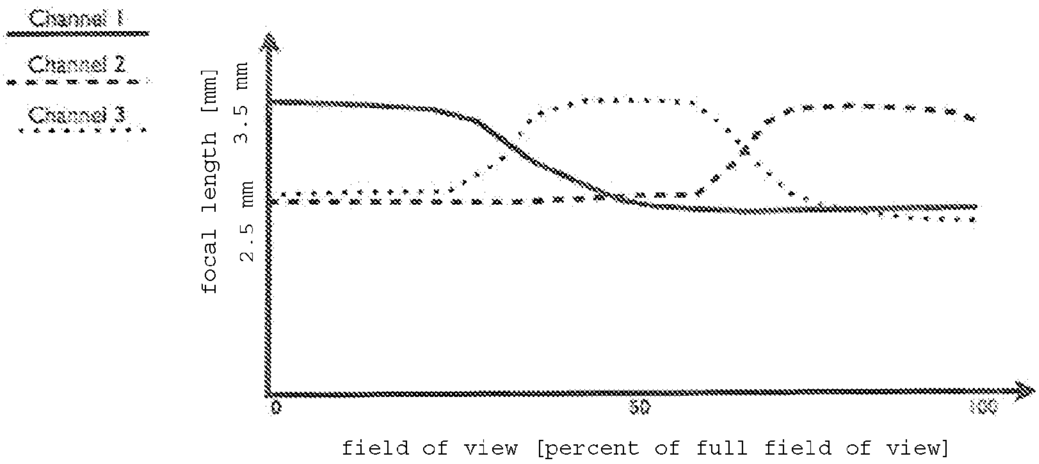
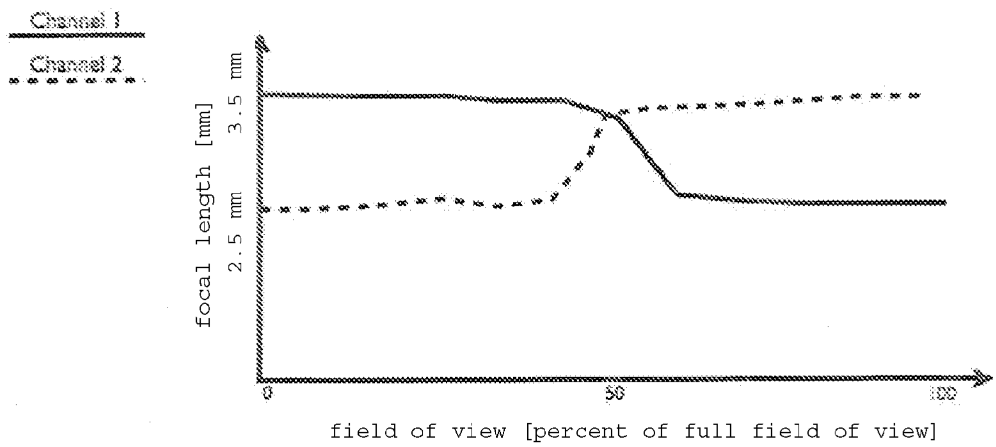


Figure 10



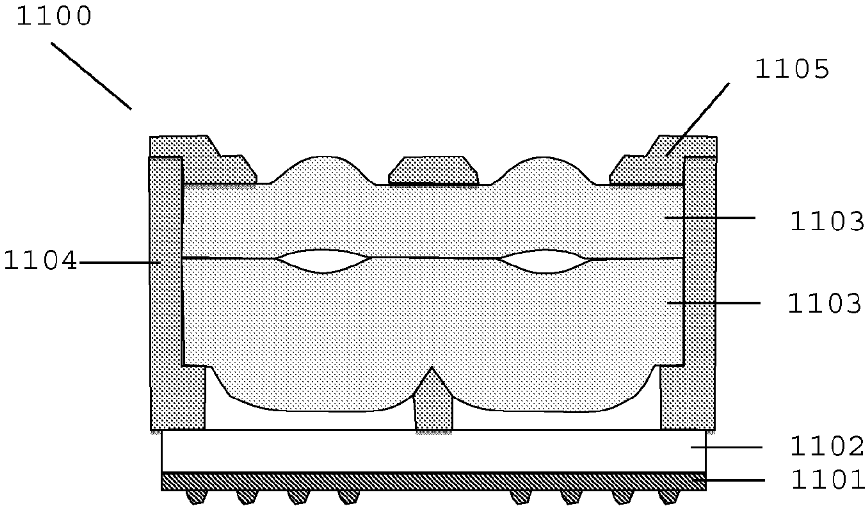


Fig. 11

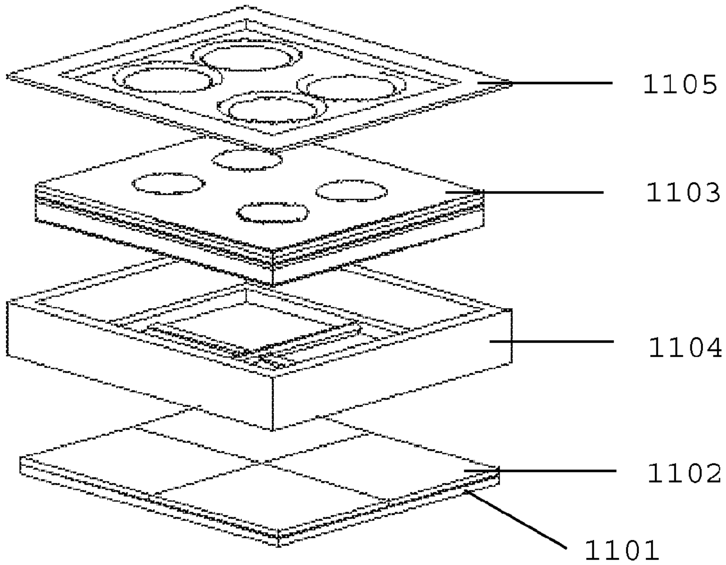


Fig. 12

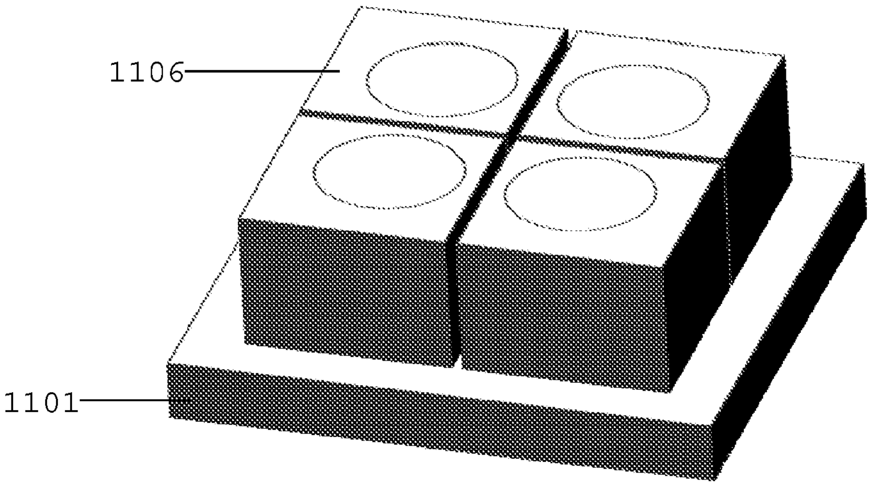


Fig. 13 A

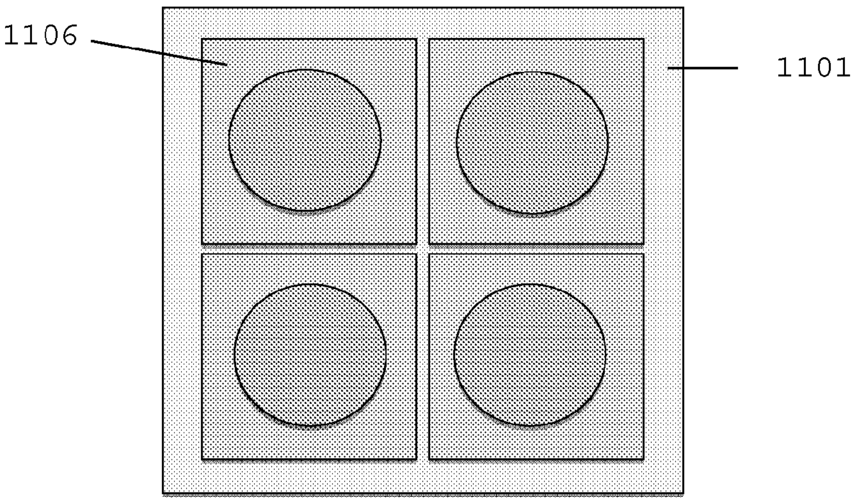


Fig. 13 B

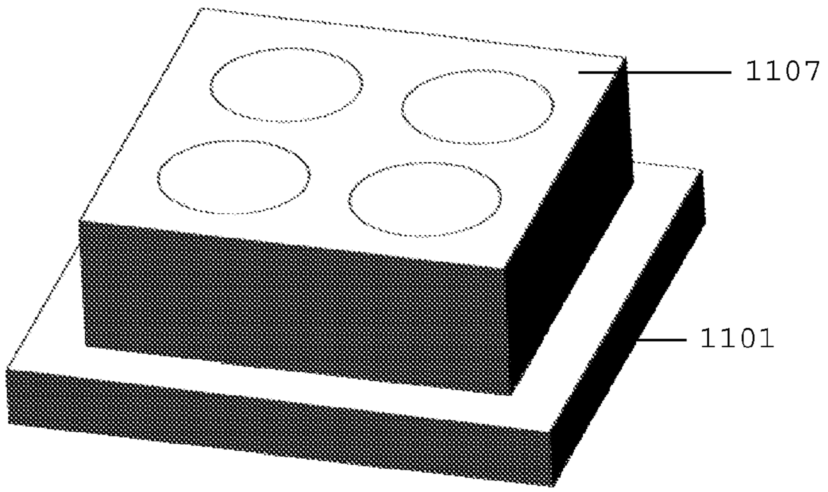


Fig. 14 A

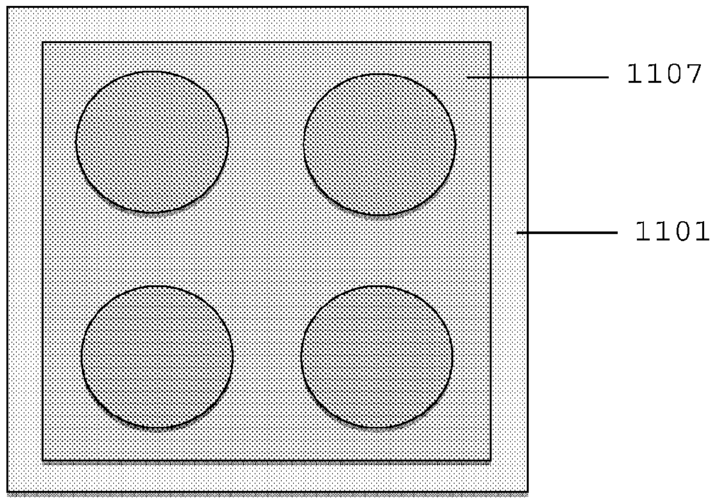


Fig. 14 B

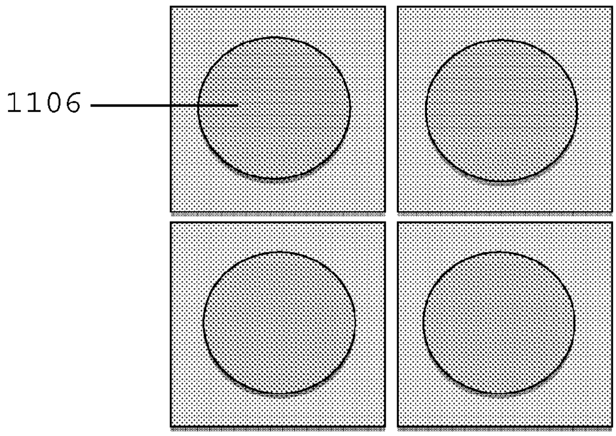


Fig. 15 A

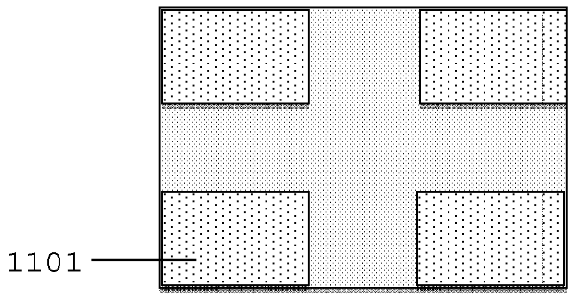


Fig. 15 B

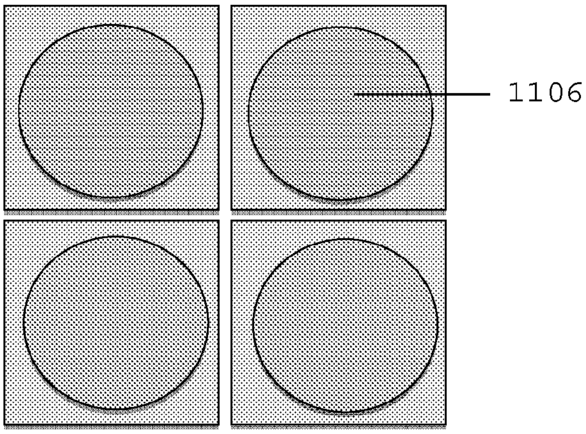


Fig. 16 A

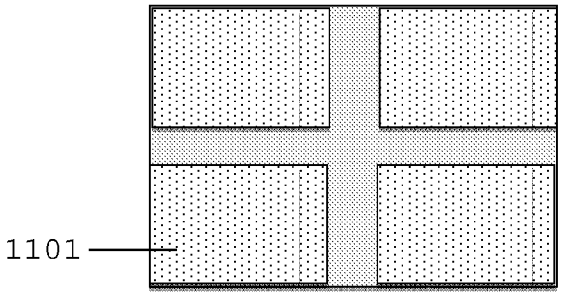


Fig. 16 B

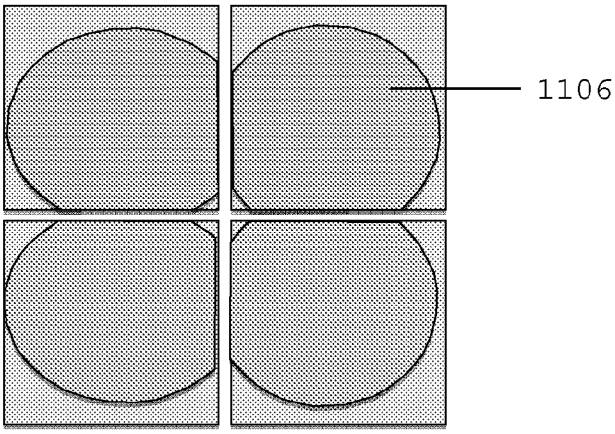


Fig. 17 A

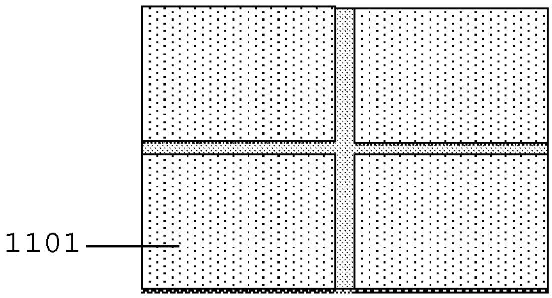


Fig. 17 B

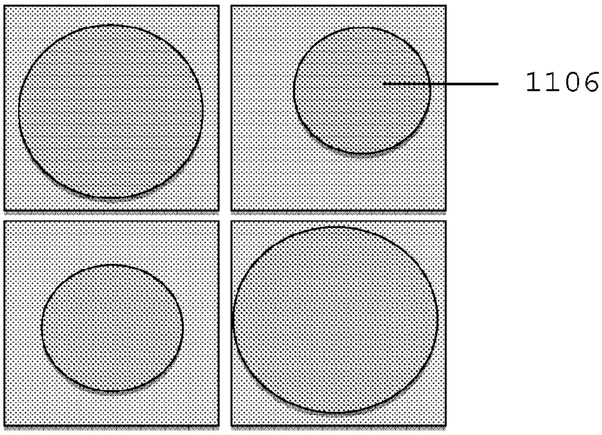


Fig. 18

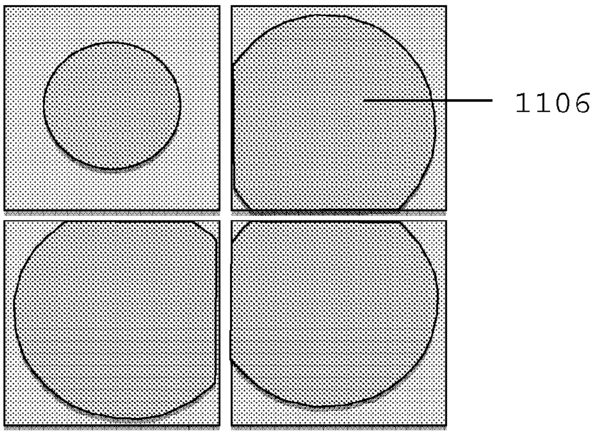


Fig. 19

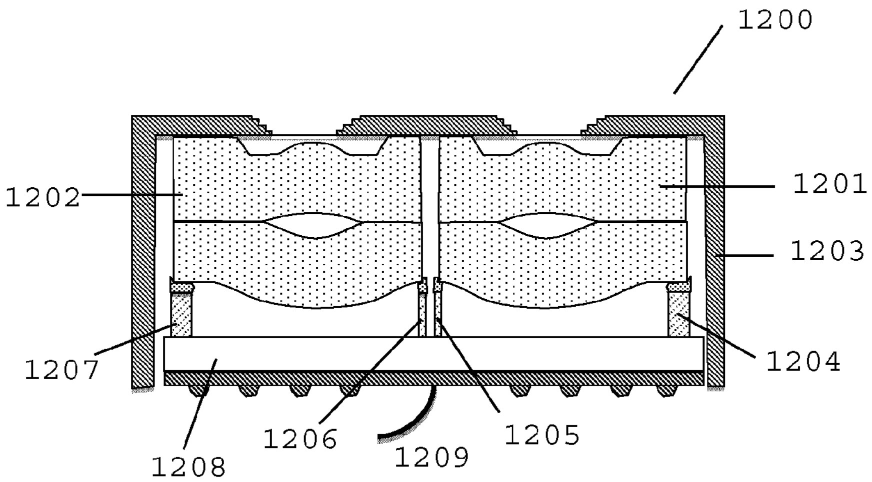

1200
1202
1201
1203
1207
1204
1208
1206
1209
1205

Fig. 20

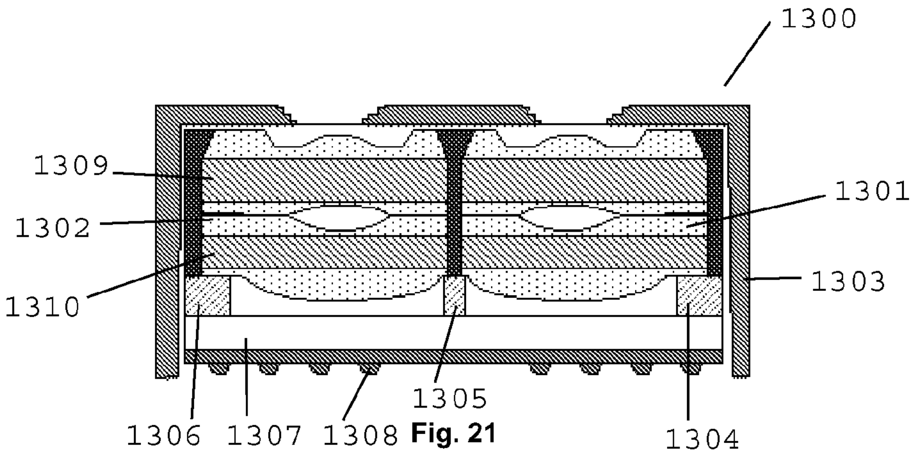

1300
1309
1301
1302
1303
1310
1305
1306
1307
1308
1304

Fig. 21

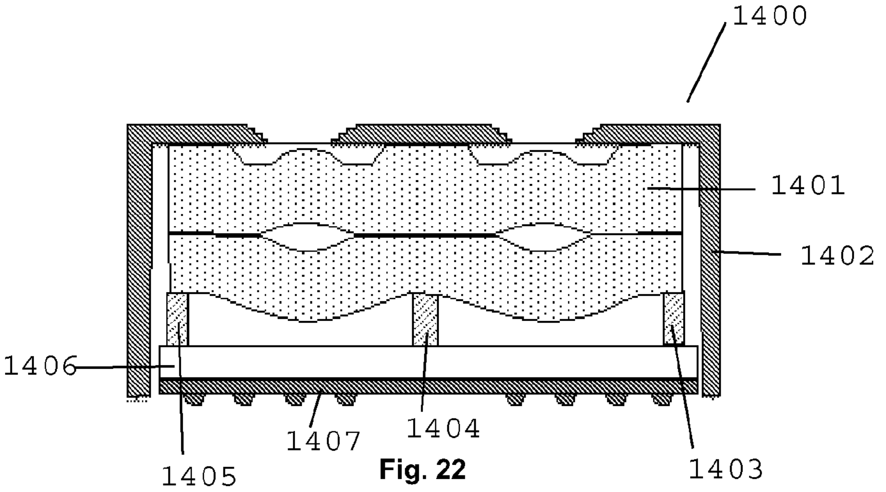

1400
1401
1402
1406
1407
1404
1405
1403

Fig. 22

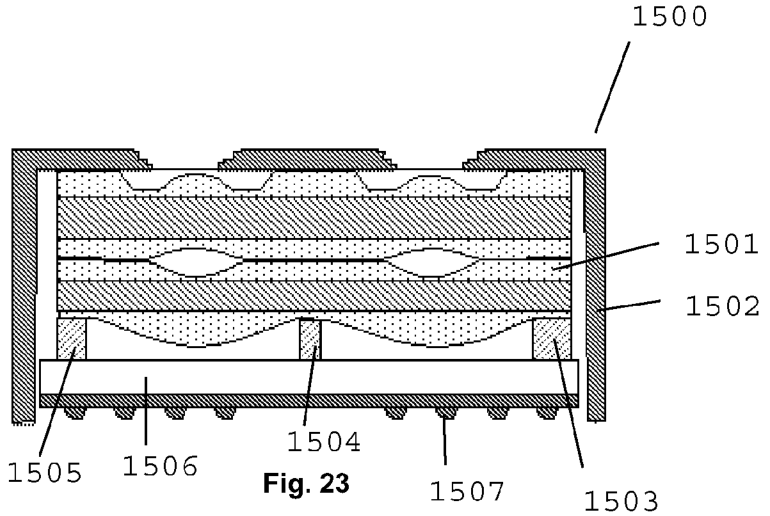

1500
1501
1502
1505
1506
1504
1507
1503

Fig. 23

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2011/050722

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N5/225 H04N9/04 H04N5/232
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04N G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	M. MIROTZNIK ET AL: "A practical enhanced-resolution integrated optical-digital imaging camera (PERIODIC)", PROCEEDINGS OF SPIE, vol. 7348, 1 January 2009 (2009-01-01), pages 734806-734806-9, XP55015831, ISSN: 0277-786X, DOI: 10.1117/12.819484	1-4,6,7, 9,10,20, 21
Y	paragraph [0001] - paragraph [0004] figures 1-7	5,8,11

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 April 2012	16/04/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Potin, Delphine

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2011/050722

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ROARKE HORSTMEYER ET AL: "Flexible multimodal camera using a light field architecture", 2009 IEEE INTERNATIONAL CONFERENCE ON COMPUTATIONAL PHOTOGRAPHY (ICCP 2009), IEEE, US, 16 April 2009 (2009-04-16), pages 1-8, XP031740275, ISBN: 978-1-4244-4534-9 paragraph [0005]; figure 5	8,11
X,P	EP 2 336 816 A2 (RICOH CO LTD [JP]) 22 June 2011 (2011-06-22) paragraph [0014] - paragraph [0027] figures 1-16	1-4,6, 10,20
X	US 2007/177004 A1 (KOLEHMAINEN TIMO [FI] ET AL) 2 August 2007 (2007-08-02)	1-3,8-21
Y	paragraph [0020] - paragraph [0063] figures 1-5	5
X	RYOICHI HORISAKI ET AL: "A compound-eye imaging system with irregular lens-array arrangement", PROCEEDINGS OF SPIE, vol. 7072, 1 January 2008 (2008-01-01), pages 70720G-70720G-9, XP55015828, ISSN: 0277-786X, DOI: 10.1117/12.796698	1-3,10, 20
A	paragraph [0001] - paragraph [0005] figure 2	6
X	US 2007/211164 A1 (OLSEN RICHARD I [US] ET AL) 13 September 2007 (2007-09-13) paragraph [0099] - paragraph [0118] paragraph [0133] - paragraph [0135] figures 22-23D,27A	1-3,7-9, 20
A	US 2008/278610 A1 (BOETTIGER ULRICH C [US]) 13 November 2008 (2008-11-13) paragraph [0019] - paragraph [0020] paragraphs [0026] - [0027] paragraphs [0033] - [0037] paragraphs [0051] - [0053] figures 1-3,6,10	17-19
A	JP 2005 303694 A (KONICA MINOLTA HOLDINGS INC) 27 October 2005 (2005-10-27) paragraph [0009] - paragraph [0025] figures 1-3	12-16

-/--

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2008/085679 A1 (RAYTHEON CO [US]; SILVER ALAN G [US]; MENEFEE MICHAEL C [US]) 17 July 2008 (2008-07-17) page 7, line 1 - line 32 page 8, line 30 - page 9, line 27 figures 1-3 -----	12-14,17
A	WO 2009/123278 A1 (SHARP KK [JP]; TANAKA SEIICHI) 8 October 2009 (2009-10-08) & US 2011/025905 A1 (TANAKA SEIICHI [JP]) 3 February 2011 (2011-02-03) used as a translation paragraph [0059] - paragraph [0090] figures 1-12 -----	15,16
A	US 2004/047518 A1 (TIANA CARLO [US]) 11 March 2004 (2004-03-11) paragraph [0031] - paragraph [0088] figures 1-15 -----	12-19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NL2011/050722

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2011/050722

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2336816 A2	22-06-2011	EP 2336816 A2	22-06-2011
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		US 2011134282 A1	09-06-2011
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		WO 2009123278 A1	08-10-2009
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		EP 1540575 A1	15-06-2005
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		JP 4261480 B2	30-04-2009
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		US 2004047518 A1	11-03-2004
		WO 2004021264 A1	11-03-2004

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-11, 20, 21

   A multi aperture camera having different optical properties for the optical parts in the different imaging channel.

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2. claims: 12-16(completely); 18, 19(partially)

   A method for improving spatial resolution by combining selected areas of the different imaging channel into a final color image.

   ---

3. claim: 17

   A method for reconstructing a color image with a higher dynamic range by combining low resolution images with different spectral contents.
