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(54) **Title**: IMAGE SENSORS HAVING GRATINGS FOR COLOR SEPARATION

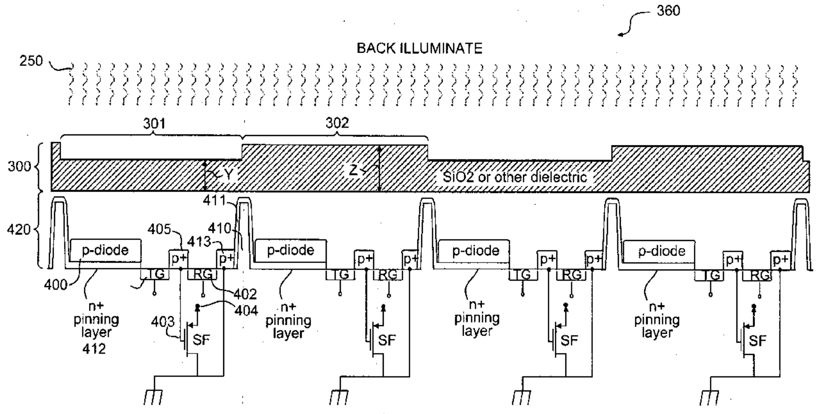


FIG. 7

(57) **Abstract**: An image sensor includes an array of pixels comprising a plurality of kernels that repeat periodically and each kernel includes n photosensitive regions (400) for collecting charge in response to light, n is equal to or greater than 2; and a transparent layer (300) spanning the photosensitive regions having n optical paths, at least two of which are different, wherein each optical path directs light of a predetermined spectral band into specific photosensitive regions.

IMAGE SENSORS HAVING GRATINGS FOR COLOR SEPARATION

FIELD OF THE INVENTION

The present invention generally relates to image sensors having an array of pixels subdivided into kernel of pixels, and more particularly to such image sensors having different optical paths for pixels in the kernel for improving color separation and increasing quantum efficiency.

BACKGROUND OF THE INVENTION

In general, as pixels made using CMOS processes for image sensors scale to smaller dimensions, several performance properties of the imagers using these pixels degrade. One performance property in particular, quantum efficiency (QE), degrades quickly. The loss in performance is confounded with the addition of a color-filter-array (CFA) on top of the pixel array. The purpose of the CFA is to allow for color separation of the incoming light for providing the ability to reconstruct color images. However, for a given wavelength, most of the filters are absorbing. Therefore, any given wavelength effectively sees a series of small apertures above the pixel array. As the pixel pitch shrinks, the size of this effective aperture in the CFA pattern becomes comparable to the wavelength of visible light. Light diffraction diverts light onto adjacent pixels and reduces the effective QE of the targeted color pixel. Consider FIG. 1a for example. For incoming red light, the blue and green CFA of the blue **103** and green pixels **101, 104** are effectively blocking. For a Bayer pattern **105**, FIG. 1b illustrates this creates a small aperture **112** above the red pixel **102** for red light. Especially below 2 μm pixel pitches, diffraction spreads the incoming red light into the adjacent blue and green pixels since the CFA is positioned a finite distance above the active layer of the image sensor where the photons are converted to charge carriers. Diffraction corrupts the effectiveness of the CFA to separate colors, increasing color crosstalk. It also effectively reduces the QE of the red pixel.

FIG. 2 shows prior art for the cross-section of four pmos pixels through the red and green CFA of a back illuminated image sensor. This will also be used as a reference point for describing the present invention in the Detailed Description of the Invention.

Still referring to FIG. 2, there is shown a photodiode **200** where photo-generated charge carriers are collected. For readout the charge carriers are electrically transferred to a floating diffusion **205** by adjusting the voltage on a transfer gate **201**. The floating diffusion signal feeds the input of the source-follow transistor **203**. The low-impedance output of the source-follower **203** drives the output line **204**. After readout the signal in the floating diffusion **205** is emptied into the reset drain **213** by controlling the voltage on the reset gate **202**. Sidewall isolation **210** between the photodiodes directs photo-generated charge carriers into the nearest photodiode **200** reducing color crosstalk within the device layer. To reduce dark current there is a thin pinning layer **212** at the surface between the silicon and dielectric near the photodiode **200**. To also reduce dark current, there is a thin n-doping layer **211** along the sidewall isolation **210**. Incoming light **250** first passes through the color filter array layer **230**, then an antireflection coating layer **222**, then a spacer layer that is typically silicon dioxide **221** before reaching the active device layer **220**. However, the optical stack **221, 222,** and **230** can consist of more or fewer layers depending on application, and often includes a micro-lens array for the top layer. FIG. 3 provides a single pixel schematic for this non-shared pinned photodiode structure of FIG. 2.

FIG. 4 shows simulation results for QE for a prior art 1.1 μm pixel array with a Bayer pattern. The peak QE for the blue response curve **503** associated with the blue pixel **103** is 40%. The peak QE for the green response curves **501, 504** associated with the green pixels **101, 104** is 35%. The peak QE for the red response curve **502** associated with the red pixel **102** is 23%. For these simulations the thickness of the dielectric spacer **221** layer is 0.5 μm. Increasing the dielectric spacer thickness **221** degrades performance resulting in lower peak QE and increased color crosstalk.

Although the presently known and utilized image sensor is satisfactory, there is a need to address the above-described drawback.

SUMMARY OF THE INVENTION

It is an object of the present invention to improve color crosstalk between adjacent pixels and increase QE by replacing the CFA with a binary optical path grating. Effective QE can be greater than 100%.

This object is achieved by adjusting optical path differences for each pixel in a color kernel such that for a specific wavelength the light intensity falling onto the image sensor interferes constructively near the surface of one pixel and destructively for the other pixels within the color kernel. For another specific wavelength, light interferes constructively near the surface of a second pixel and destructively for the other pixels within the color kernel.

These and other objects, features, and advantages of the present invention will become apparent to those skilled in the art upon a reading of the following detailed description when taken in conjunction with the drawings wherein there is shown and described an illustrative embodiment of the invention.

Advantageous Effect of the Invention

The present invention has the advantage of improving color crosstalk between adjacent pixels and increasing QE.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter of the present invention, it is believed that the invention will be better understood from the following description when taken in conjunction with the accompanying drawings, wherein:

FIGS. 1a-1b show prior art of a Bayer color filter array pattern;

FIG. 2 shows prior art of a cross-section of four pixels of a backside illuminated image sensor cut through the red and green portion of the Bayer CFA pattern. Pixel circuitry is for a pmos image sensor;

FIG. 3 shows prior art of a pmos non-shared pixel schematic;

FIG. 4 is a plot of wavelength versus QE of a Bayer color filter array;

FIG. 5 illustrates the first embodiment of this invention. The plan view shows a pixel array with an optical path grating. W, X, Y, and Z represent different thickness of the transparent layer above each pixel within the color kernel;

FIG. 6 shows a plan view of the color kernel with the optical path grating (W, X, Y, and Z), and more detail of the pixel device structure;

FIG. 7 shows a cross-section of four pixels of a backside illuminated image sensor cut through the red and green portion of the color kernel of the optical path grating (Y and Z);

FIG. 8 is a simulated plot of QE versus wavelength for each pixel in the color kernel of FIG. 4 for 1.1 μm pixel;

FIGS. 9a-9d illustrate how constructive and destructive interference is used to improve color crosstalk and result in QE values for a given pixel at a given wavelength of greater than 100%. Shown are intensity plots of light just above the silicon surface for four different wavelengths for the color kernel of FIG. 4. The plots are plan view and the light normal incident. For the four plots the wavelengths are 420 nm, 470 nm, 590 nm, and 650 nm;

FIG. 10 illustrates the beginning of one method to fabricate the optical path grating. Shown are two cross-sections, each of four pixels. One cross-section is cut through pixels **303** and **304** of FIG.7. The other cross-section is cut through pixels **301** and **303** of FIG. 7;

FIG. 11 is a 3D view of an optical path grating with microlenses;

FIGS. 12a-12b illustrate a method of placing microlenses on the transparent layer;

FIGS. 13a-13b illustrate a method of transferring the microlens pattern to the transparent layer;

FIGS. 14a-14b illustrate a method for performing a first etch;

FIGS. 15a-15b illustrate a method of fabricating the optical path grating after the second resist is patterned;

FIGS. 16a-16b illustrate the final optical path grating after the second etch step;

FIG. 17 is a 3D view of an optical path grating using two materials with different index of refraction and a microlens array;

FIG. 18 is a 3D view of an optical path grating using two materials with different index of refraction and a microlens array where a single microlens is placed over four pixels; and

FIG. 19 is an imaging device having the image sensor array of FIG. 7.

DETAILED DESCRIPTION OF THE INVENTION

An optical path as defined herein is:

$$\text{optical path} = n \times d, \qquad \text{(Eq. 1)}$$

where n is the index of refraction and d is the thickness of the material through which the light is passing.

Turning now to FIG. 7, there is shown a portion of an image sensor array 401 of an image sensor of the first embodiment of the present invention. It is noted that, although the cross section only shows four pixels for simplicity, the image sensor array **401** typically includes thousands or millions of pixels. It is further noted that the image sensor array **401** is typically a part of an active pixel sensor as will be discussed in FIG. 19. Referring back to FIG. 7, the image sensor array **401** includes a plurality of pixels **301** and **302** disposed in an active layer **420**. The pixels **301** and **302** are preferably grouped together in a 2x2 array, hereinafter a color kernel, that repeats over the array as will be described in detail hereinbelow. Although a 2x2 array is preferred, other color kernel sizes may also be used. Each pixel **301** and **302** includes a charge collection region, preferably a pinned photodiode **400**, disposed slightly away from the surface of the active layer that receives the incident light **250**. The configuration of polysilicon gates **401, 402, 403**, and metal wires **404** opposite the illuminated side of the active layer **420** is called backside illumination. The pinned photodiode **400** collects charge in response to the incident light. The pinned photodiode **400** includes a pinning layer **412** beneath a doped region of opposite conductivity type disposed thereon. Although a pinned photodiode **400** and backside illumination are used for the preferred embodiment, a photodiode may also be used as the charge collection region and front illumination be used as charge collection region, both of which are well known and will not be discussed herein.

When activated, a transfer gate **401** passes charge from the pinned photodiode **400** to a charge-to-voltage conversion region **405**, preferably a floating diffusion, which converts charge to a voltage signal. An amplifier or buffer **403**, preferably a source follower amplifier, passes the voltage onto an output line for further processing. A reset gate **402** is activated for resetting the floating diffusion **405** to a predetermined signal level.

A transparent grating layer **300** with a varying thickness is disposed spanning the pixels **301** and **302** (and the pixels not shown in the drawing) for directing the incident light **250** into the active layer **420** as will be described in detail hereinbelow. The transparent layer may be made of either silicon dioxide, silicon nitride or a transparent organic material.

Referring to the plan view of the image sensor array **401** (commonly referred to as pixel array) in FIG. 5, there is shown the 2x2 color kernel **310** having the transparent layer overlaid thereon. The thickness of the transparent layer **300** (see FIG. 7) over each pixel **301, 302, 303**, and **304** (see FIGS. 5 and 6 for all four pixels) in the color kernel **310** is different (Y, Z, W, and X). This creates four optical paths. Although the present invention in its preferred embodiment uses thickness to create the different optical paths, materials having different index of refractions may be used to create the different optical paths. In the example, the thickness of the silicon dioxide transparent layer **300** for Y, Z, W, and X are 2.5 μm, 3.0 μm, 1.5 μm, and 2.0 μm, respectively. Consequently, there are four optical paths created. Blue light constructively interferes just above pixel **303** and is effectively directed into this pixel. Likewise, green-blue light is directed into pixel **301**, green-red light is directed into pixel **304**, and red light is directed into pixel **302**. It is noted that the repeating pattern of the transparent layer **300** is repeated for each kernel of pixels.

FIG. 6 shows a more detailed plan view of the four pixels **301, 302, 303**, and **304** within a color kernel **310** and the device components buried beneath the imager surface. These components include the photodiode **400**, transfer gate **401**, reset gate **402**, source-follower **403**, source-follower output **404**, floating-diffusion **405**, sidewall isolation **410**, reset drain **413**, and contacts **350** from the metal lines (not shown) to the gates **401, 402, 403**, and source/drain implant regions **405, 413, 404**. These device components are also illustrated in the cross-section of FIG. 7. The optical stack is simply a transparent layer **300**. Through this cross-section in FIG. 7 there are only two heights Y and Z.

FIG. 8 shows simulation results for QE for a 1.1 μm pixel array using the first embodiment of the present invention as describe by FIGS. 5-7. The peak QE for the blue response curve **603** associated with the blue pixel **303** is 120%. The peak QE for the green/blue response curve **601** associated with the green/blue pixel **301** is 116%. The peak QE for the green/red response curve **604** associated with the green/red pixel **304** is 105%. The peak QE for the red response curve **604** associated with the red pixel **302** is 86%. The QE for a given wavelength can be greater than 100% for a given pixel because the optical paths are adjusted in such a way to take advantage of constructive and destructive interference.

FIGS. 9a-9d illustrate how constructive and destructive interference leads to QE curves with peaks greater than 100%. Shown are four plan view plots of the light intensity just above the silicon active layer **420** on the illuminated side for different wavelengths. For blue light (420 nm) most of the light intensity **703** is above pixel **303**. Likewise, for green/blue light (470 nm) most of the light intensity

701 is above pixel **301**. Likewise again, for green/red light (590 nm) most of the light intensity **704** is above pixel **304**. Finally, for red light (650 nm) most of the light intensity **702** is above pixel **302**.

To help visualize the optical path grating, FIG. 10 shows a 4x4 pixel cutaway of FIGS. 5-7. Clearly visible is the optical stack **300** on top of the active layer **420**. The four pixels (**301**, **302**, **303**, and **304**) within a single color kernel are identified, along with the Δ height differences **1050** between the four transparent pillars.

As shown in FIG. 8, the peak QE for the blue, green/blue, green/red, and red response curves (**603**, **601**, **604**, and **602**) are at wavelengths of 440 nm, 485 nm, 585 nm, and 645 nm respectively. This is for normal incidence. Unfortunately, tilting the angle of the incoming light away from normal incidence increases the optical path differences for the different pixels. This changes the details of the constructive and destructive interference and results in slight differences for the wavelength at which the QE is a peak for the different response curves. The differences in peak position increase further with increasing tilt angle. When this imager is placed into a camera system, the chief ray at the center of the pixel array is normal incidence; however, the chief ray angle for pixels near the edge of the array can exceed 30 degrees. Since the response curves depend on tilt angle, this leads to color shifts (hue shifts) across the image that are not always easy to correct.

There are several ways to minimize hue shifts associated with changes in tilt angle of the incident light. One method is to refine the binary optical path grating with more height differences, and optimize this refined system. This involves more etches to provide more possible heights in the transparent layer. This refinement also involves breaking the pixel into sub-pixel regions. For example, consider the case where there are eight possible heights and each pixel is broken up into sixteen-square subregions. With four pixels, this gives 512 degrees of freedom for the optical stack. Using numerical simulation, all cases can be modeled for a range of wavelengths, and the system optimized in such a way that there is good color separation for the four pixels, and the hue shifts are minimal. However, forcing the system to minimize the hue shift is the same as forcing the optical path above each pixel to be the same. The solution to this problem is something that looks like a microlens with a focal point just above the silicon surface. So instead of creating a microlens-like structure using binary optical techniques, it is easier to simply create a series of continuous microlenses.

FIG. 11 shows an optical path grating similar to the optical path grating of FIG. 11 where the optical path difference between pixels is Δ **1250** but there is also a microlens above each pixel **1210**. This new structure will have better hue shift performance with changing tilt angle.

FIGS. 12-16 illustrate a method for fabricating an optical path grating with curved surfaces in the shape of a microlens as in FIG. 11. It is noted that FIGS. 12-16 describe Δ changes referenced by numerals not directly shown in FIGS. 12-16 but are shown in FIGS. 10, 11, 17 and/or 18. The following described procedure requires fewer lithography steps than that of a Bayer CFA. FIGS. 12a-12b show two cross-sections of four pixels each, one through pixels **303** and **304** of the color kernel, the other through pixels **301** and **302** of the color kernel. Fabrication of the devices within the active layer **420** is complete, and the back illuminated imager thinned. Silicon dioxide or some other transparent layer **300** of thickness greater than **D** has been grown or deposited on the illuminated side of the active layer **420**. One top of the layer **300** is a patterned microlens array **1025**. There are numbers of methods for fabricating this microlens array including microgap patterning and reflow and gray scale photolithography.

FIGS. 13a-13b show the silicon dioxide layer **300** after a 1:1 directional etch that transfers the microlens surface into the transparent layer material. The thickness of layer **300** at the edge of the microlens is D. A resist layer **1020** is applied to a portion of the image array and patterned so that pixels **301** and **302** are covered with resist **1020**, and the pattern leaves exposed the transparent layer **300** within pixels **303** and **304**. The exposed transparent layer **300** is etched a thickness of 2Δ **1030**.

FIGS. 14a-14b show both cross-sections after a thickness of 2Δ **1030** of the transparent layer is etched and removed as discussed in the previous paragraph. The resist **1020** is then removed.

FIGS. 15a-15b illustrate the next step in the process after the patterned resist **1020** for the first etch is removed as discussed in the previous paragraph. A second resist layer **1040** is applied to the image array and patterned. This pattern exposes the transparent layer **300** within pixels **301, 303** and covers the transparent layer **300** within pixels **302** and **304**. The exposed transparent layer **300** is etched and removed.

FIGS. 16a-16b show both cross-sections after a thickness of Δ **1050** of the transparent layer is etched and removed as discussed in the preceding paragraph. The resist **1040** (of FIG. 15b) is removed. The final thicknesses of the transparent layer **300** are D, D-Δ, D-2Δ, and D-3Δ for pixels **302, 301, 304**, and **303** respectively.

The optical path grating in FIG. 11 will have superior hue shift performance to the optical path grating in FIG 10, however, for steeper and steeper angles, the highest pillar of transparent material (pixel **302**) casts shadows on the shorter pillars (pixels **301, 304**, and **303**) since the material is not 100% transparent. This shadowing leads to hue shifts, the root cause of which is not variations in optical path length, but instead a reduction in light intensity over the shorter pixels.

FIG. 17 illustrates a way to minimize the hue shifts due to shadowing and optical path length differences. A second transparent material **1320** is inserted between the original optical path grating **300** and the microlens **1430.** To maintain an optical path difference between the different pixels within the color kernel, the index of refraction of the two materials (**300** and **1320**) must be different. The microlens array **1430** is placed on top of the planer surface of layer **1320.** The planar microlens array eliminates problems due to shadowing.

Finally, FIG. 18 shows a structure similar to FIG. 17 except the size of the microlens **1530** equals the size of the color kernel and not the individual pixel (**301, 302, 303**, and **304**). This has the advantage of focusing the light bundle from each microlens **1530** through each optical grating block (**301, 302, 303**, and **304**) reducing hue shift even more.

FIG. 19 is a block diagram of an imaging system that can be used with the image sensor array **401** of present the invention. Imaging system **1200** includes digital camera phone **1202** and computing device **1204**. Digital camera phone **1202** is an example of an image capture device that can use an image sensor incorporating the present invention. Other types of image capture devices can also be used with the present invention, such as, for example, digital still cameras and digital video camcorders.

Digital camera phone **1202** is a portable, handheld, battery-operated device in an embodiment in accordance with the invention. Digital camera phone **1202** produces digital images that are stored in memory **1206**, which can be, for example, an internal Flash EPROM memory or a removable memory card. Other types of digital image storage media, such as magnetic hard drives, magnetic tape, or optical disks, can alternatively be used to implement memory **1206**.

Digital camera phone **1202** uses lens **1208** to focus light from a scene (not shown) onto image sensor array **401** of active pixel sensor **1212**. Image sensor array **401** provides color image information using the Bayer color filter pattern in an embodiment in accordance with the invention. Image sensor array **401** is controlled by timing generator **1214**, which also controls flash **1216** in order to illuminate the scene when the ambient illumination is low.

The analog output signals output from the image sensor array **410** are amplified and converted to digital data by analog-to-digital (A/D) converter circuit **1218**. The digital data are stored in buffer memory **1220** and subsequently processed by digital processor **1222**. Digital processor **1222** is controlled by the firmware stored in firmware memory **1224**, which can be flash EPROM memory. Digital processor **1222** includes real-time clock **1226**, which keeps the date and time even when digital camera phone **1202** and digital processor **1222** are in a low power state. The processed digital image files are stored in memory **1206**. Memory **1206** can also store other types of data, such as, for example, music files (e.g. MP3 files), ring tones, phone numbers, calendars, and to-do lists.

In one embodiment in accordance with the invention, digital camera phone **1202** captures still images. Digital processor **1222** performs color interpolation followed by color and tone correction, in order to produce rendered sRGB image data. The rendered sRGB image data are then compressed and stored as an image file in memory **1206**. By way of example only, the image data can be compressed pursuant to the JPEG format, which uses the known "Exif" image format. This format includes an Exif application segment that stores particular image metadata using various TIFF tags. Separate TIFF tags can be used, for example, to store the date and time the picture was captured, the lens f/number and other camera settings, and to store image captions.

Digital processor **1222** produces different image sizes that are selected by the user in an embodiment in accordance with the invention. One such size is the low-resolution "thumbnail" size image. Generating thumbnail-size images is described in commonly assigned U.S. Patent No. 5,164,831, entitled "Electronic Still Camera Providing Multi-Format Storage Of Full And Reduced Resolution Images" to Kuchta, et al. The thumbnail image is stored in RAM memory **1228** and supplied to display **1230**, which can be, for example, an active matrix LCD or organic light emitting diode (OLED). Generating thumbnail size images allows the captured images to be reviewed quickly on color display **1230**.

In another embodiment in accordance with the invention, digital camera phone **1202** also produces and stores video clips. A video clip is produced by summing multiple pixels of image sensor array **410** together (e.g. summing pixels of the same color within each 4 column x 4 row area of the image sensor array **410**) to create a lower resolution video image frame. The video image frames are read from image sensor array **410** at regular intervals, for example, using a 15 frame per second readout rate.

Audio codec **1232** is connected to digital processor **1222** and receives an audio signal from microphone (Mic) **1234**. Audio codec **1232** also provides an audio signal to speaker **1236**. These components are used both for telephone conversations and to record and playback an audio track, along with a video sequence or still image.

Speaker **1236** is also used to inform the user of an incoming phone call in an embodiment in accordance with the invention. This can be done using a standard ring tone stored in firmware memory **1224**, or by using a custom ring-tone downloaded from mobile phone network **1238** and stored in memory **1206**. In addition, a vibration device (not shown) can be used to provide a silent (e.g. non-audible) notification of an incoming phone call.

Digital processor **1222** is connected to wireless modem **1240**, which enables digital camera phone **1202** to transmit and receive information via radio frequency (RF) channel **1242**. Wireless modem **1240** communicates with mobile phone network **1238** using another RF link (not shown), such as a 3GSM network. Mobile phone network **1238** communicates with photo service provider **1244**, which stores digital images uploaded from digital camera phone **1202**. Other devices, including computing device **1204**, access these images via the Internet **1246**. Mobile phone network **1238** also connects to a standard telephone network (not shown) in order to provide normal telephone service in an embodiment in accordance with the invention.

A graphical user interface (not shown) is displayed on display **1230** and controlled by user controls **1248**. User controls **1248** include dedicated push buttons (e.g. a telephone keypad) to dial a phone number, a control to set the mode (e.g. "phone" mode, "calendar" mode" "camera" mode), a joystick controller that includes 4-way control (up, down, left, right) and a push-button center "OK" or "select" switch, in embodiments in accordance with the invention.

Dock **1251** recharges the batteries (not shown) in digital camera phone **1202**. Dock **1251** connects digital camera phone **1202** to computing device **1204** via dock interface **1252**. Dock interface **1252** is implemented as wired interface, such as a USB interface, in an embodiment in accordance with the invention. Alternatively, in other embodiments in accordance with the invention, dock interface **1252** is implemented as a wireless interface, such as a Bluetooth or an IEEE 802.11b wireless interface. Dock interface **1252** is used to download images from memory **1206** to computing device **1204**. Dock interface **1252** is also used to transfer calendar information from computing device **1204** to memory **1206** in digital camera phone 1202.

PARTS LIST

100	Bayer CFA pattern
101	Green color filter
102	Red color filter
103	Blue color filter
104	Green color filter
105	Bayer color kernel
112	Effective aperture for red light
200	Photodiode implant
201	Transfer gate
202	Reset gate
203	Source/Follower transistor
204	Output
205	Floating diffusion
210	Sidewall isolation
211	N-doping layer
212	Pinning implant
213	Reset Drain
220	Active layer
221	Dielectric layer
222	Anti-reflection layer
230	CFA layer
250	Normal incident light
300	Transparent layer
301	Green/Blue pixel
302	Red pixel
303	Blue pixel
304	Green/Red pixel
310	Color kernel
350	Contacts
400	pinned photodiode
401	Image sensor array
401	Transfer gate
402	Red response curve

402	Reset gate
403	polysilicon gate
403	Blue response curve
403	Buffer
404	Source-follower output
404	metal wires
404	Implant region
404	Green response curve
405	Implant region
405	Conversion region
405	Floating diffusion
410	Sidewall isolation
412	Pinning layer
413	Implant region
413	Reset drain
420	Active layer
501	Green response curve
502	Red response curve
503	Blue response curve
504	Green response curve
601	Green/blue response curve
602	Red response curve
603	Blue response curve
604	Green/red response curve
701	Intensity peak region for 470 nm light
702	Intensity peak region for 650 nm light
703	Intensity peak region for 420 nm light
704	Intensity peak region for 590 nm light
1010	Cross-section through pixels 303 and 304
1011	Cross-section through pixels 301 and 302
1020	Patterned resist layer
1025	Patterned microlens array
1030	Etched amount of transparent layer
1040	Second patterned resist layer

1050	Etched amount of transparent layer
1200	Imaging system
1202	Imaging Device
1204	Computing device
1206	Memory
1208	Lens
1210	Microlens
1212	Active Pixel Sensor
1214	Timing Generator
1216	Flash
1218	Analog/digital converter
1220	Buffer Memory
1222	Processor
1224	Firmware
1226	Clock
1228	RAM
1230	Display
1232	Audio Codec
1234	Microphone
1236	Speaker
1238	Network
1240	Wireless Modem
1242	Connection
1244	Service provider
1246	Internet
1248	User Controls
1250	Difference in transparent layer thickness between pixels
1251	Dock
1252	Interface
1320	Second transparent material layer
1430	Microlens
1530	Microlens

CLAIMS:

1. An image sensor comprising:

(a) an array of pixels comprising a plurality of kernels that repeat periodically and each kernel includes n photosensitive regions for collecting charge in response to light, n is equal to or greater than 2; and

(b) a transparent layer spanning the photosensitive regions having n optical paths, at least two of which are different, wherein each optical path directs light of a predetermined spectral band into specific photosensitive regions.

2. The image sensor as in claim 1, wherein differences in the optical paths are created by different thicknesses of the transparent material.

3. The image sensor as in claim 1, wherein differences in the optical paths are created by different index of refractions.

4. The image sensor as in claim 3, wherein the transparent layer is either silicon dioxide, silicon nitride, or a transparent organic material.

5. The image sensor of claim 1, wherein the optical paths are different from each other.

6. The image sensor as in claim 2, wherein the transparent material includes a curved surface.

7. The image sensor as in claim 1 further comprising a second layer disposed spanning the transparent layer, and the second layer includes a planar or substantially planar surface on a surface opposite a surface of the second layer contacting the transparent layer.

8. The image sensor as in claim 7 further comprising a plurality of microlenses disposed spanning the second layer.

9. The image sensor as in claim 1, wherein each microlens spans an individual pixel.

10. The image sensor as in claim 9, wherein each microlens spans a kernel of pixels.

11. A method for manufacturing an image sensor, the method comprising the steps of:

(a) providing an active layer having a plurality of photodiodes each for collecting charge in response to light;

(b) providing a dielectric spanning the active layer;

(c) providing a plurality of microlenses spanning the dielectric;

(d) etching the microlenses for transferring a shape of the microlenses to the dielectric;

(e) patterning resist over a portion of the dielectric for forming exposed and unexposed dielectric;

(g) etching the exposed dielectric;

(h) removing the resist; and

(i) repeating steps (e) through (h).

12. An imaging device comprising:

an image sensor comprising:

(a) an array of pixels comprising a plurality of kernels that repeat periodically and each kernel includes n photosensitive regions for collecting charge in response to light, n is equal to or greater than 2; and

(b) a transparent layer spanning the photosensitive regions having n optical paths, at least two of which are different, wherein each optical path directs light of a predetermined spectral band into specific photosensitive regions.

13. The imaging device as in claim 12, wherein differences in the optical paths are created by different thicknesses of the transparent material.

14. The imaging device as in claim 12, wherein differences in the optical paths are created by different index of refractions.

15. The imaging device as in claim 14, wherein the transparent layer is either silicon dioxide, silicon nitride, or a transparent organic material.

16. The imaging device as in claim 12, wherein the optical paths are different from each other.

17. The imaging device sensor as in claim 13, wherein the transparent material includes a curved surface.

18. The imaging device as in claim 12 further comprising a second layer disposed spanning the transparent layer, and the second layer includes a planar or substantially planar surface on a surface opposite a surface of the second layer contacting the transparent layer.

19. The imaging device as in claim 18 further comprising a plurality of microlenses disposed spanning the second layer.

20. The imaging device as in claim 12, wherein each microlens spans an individual pixel.

21. The imaging device as in claim 12, wherein each microlens spans a kernel of pixels.

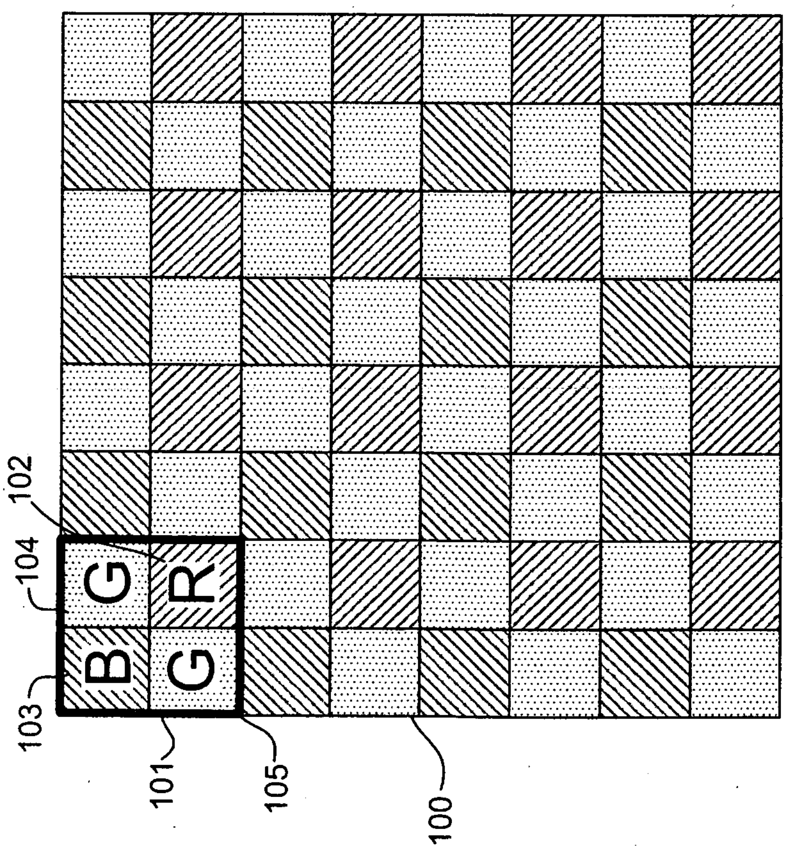


FIG. 1a

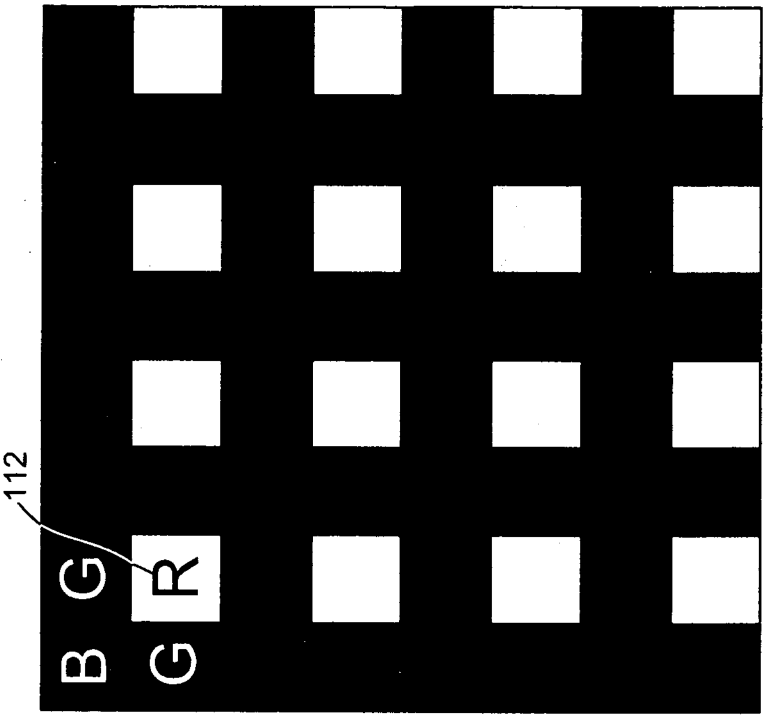


FIG. 1b

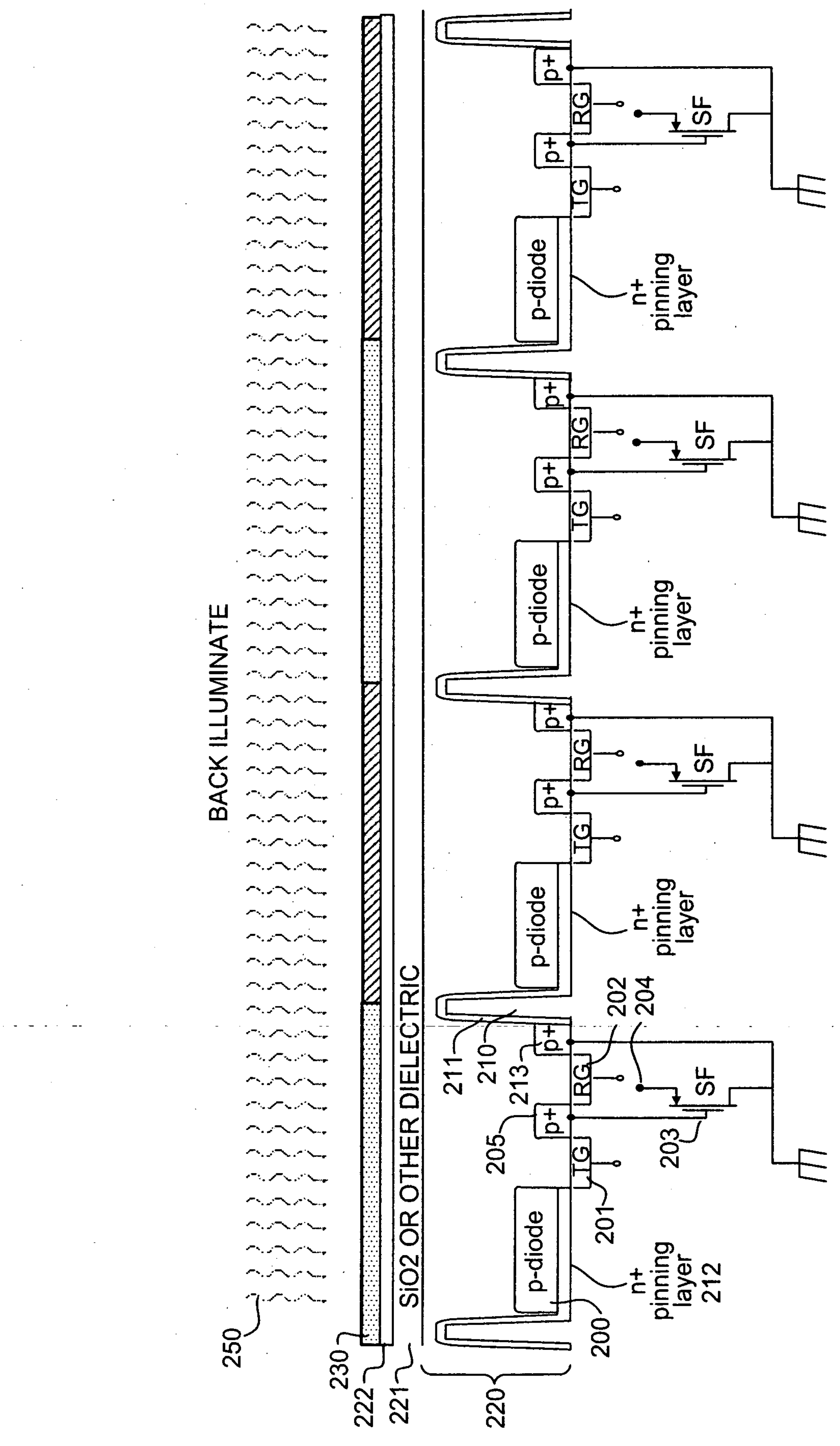

BACK ILLUMINATE
SiO2 OR OTHER DIELECTRIC
p-diode
n+ pinning layer
n+ pinning layer 212
TG
RG
p+
SF
250
230
222
221
220
200
201
205
203
213
210
211
202
204

FIG. 2

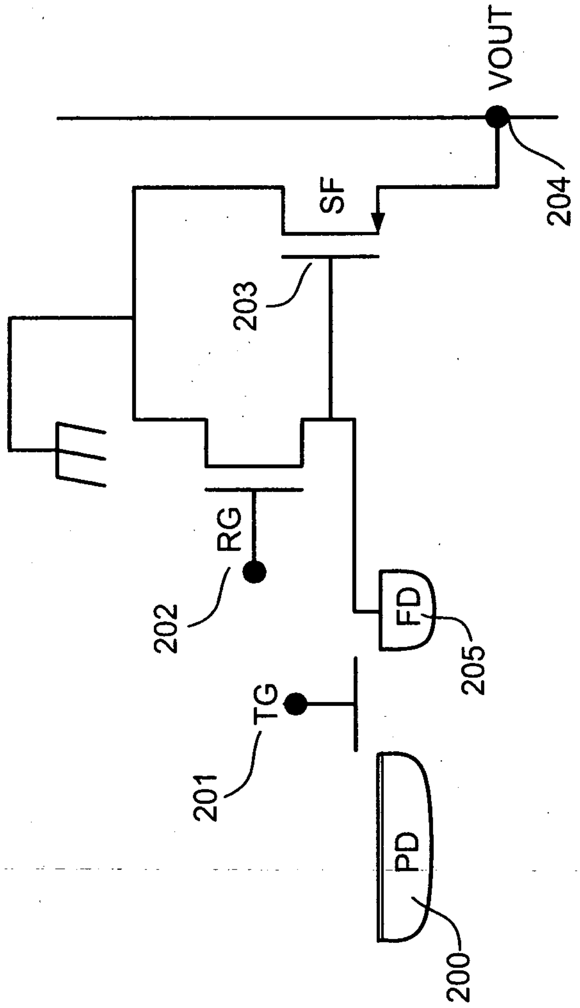


FIG. 3

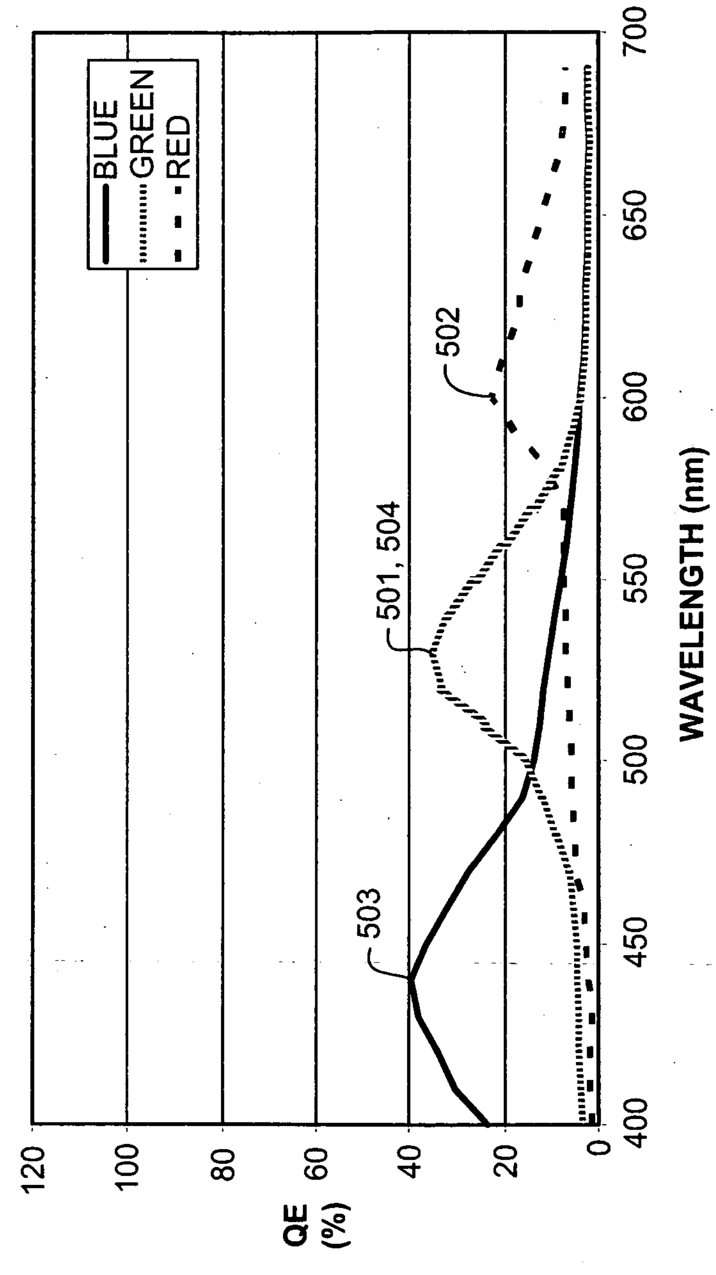

QE (%)
120
100
80
60
40
20
0
400
450
500
550
600
650
700
WAVELENGTH (nm)
BLUE
GREEN
RED
503
501, 504
502

FIG. 4

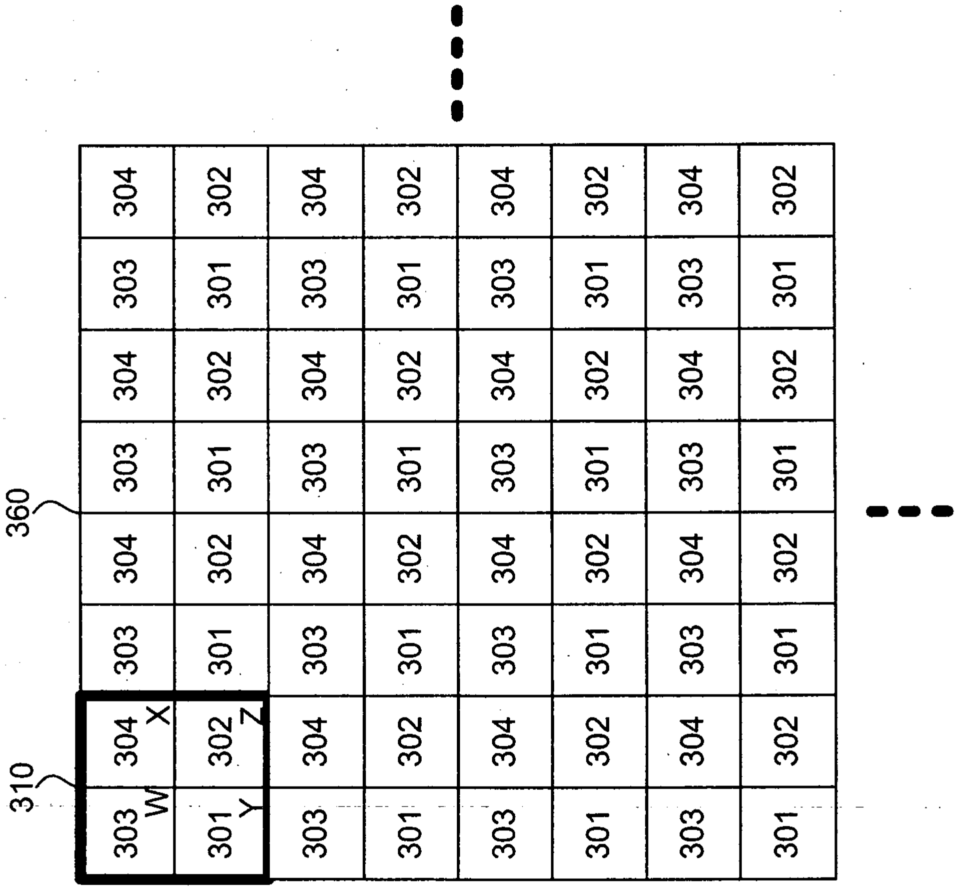

360
310
W
X
Y
Z
303 304 303 304 303 304 303 304
301 302 301 302 301 302 301 302
303 304 303 304 303 304 303 304
301 302 301 302 301 302 301 302
303 304 303 304 303 304 303 304
301 302 301 302 301 302 301 302
303 304 303 304 303 304 303 304
301 302 301 302 301 302 301 302

FIG. 5

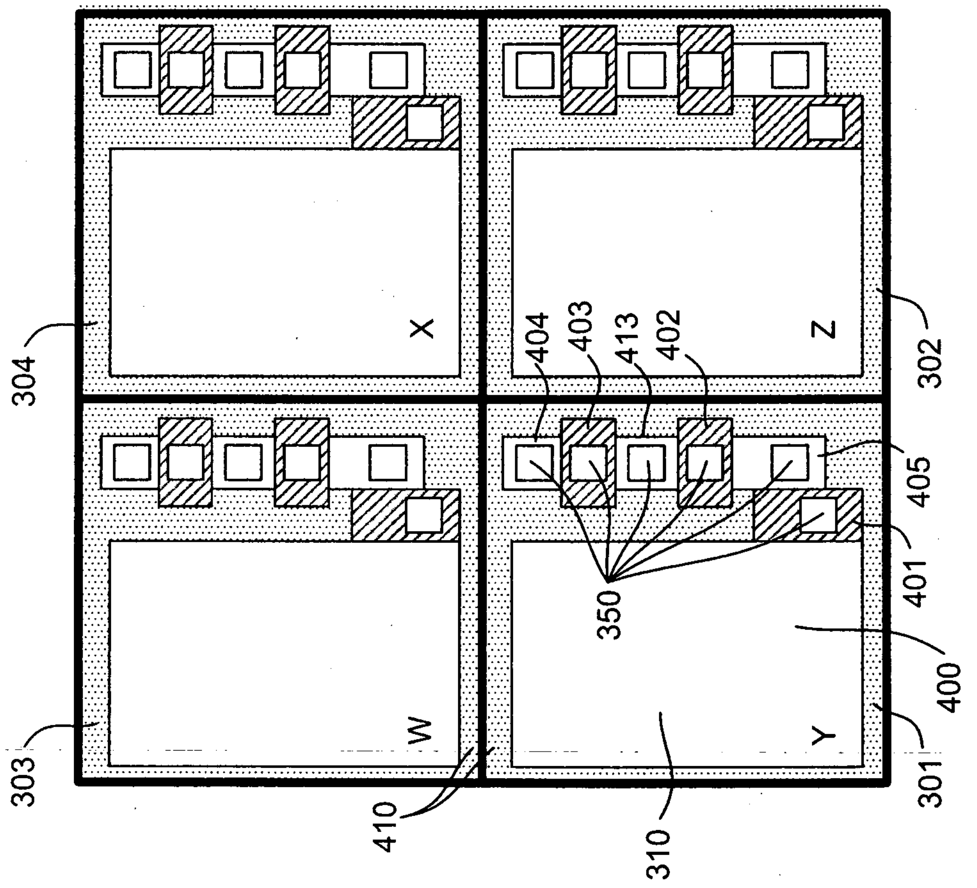


FIG. 6

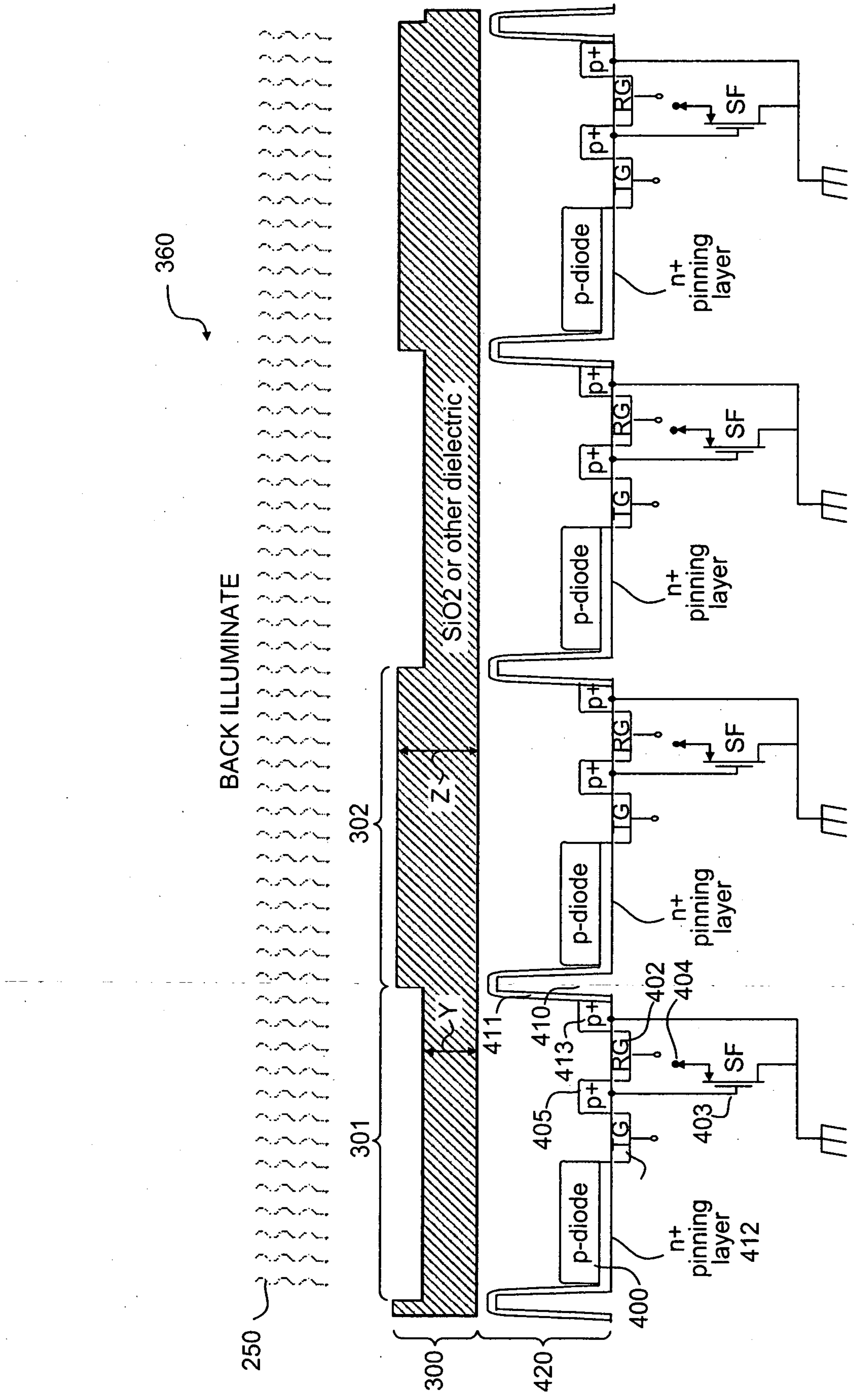

360
BACK ILLUMINATE
250
300
420
301
302
Y
Z
SiO2 or other dielectric
p-diode
n+ pinning layer 412
n+ pinning layer
TG
RG
p+
SF
400
402
403
404
405
410
411
413

FIG. 7

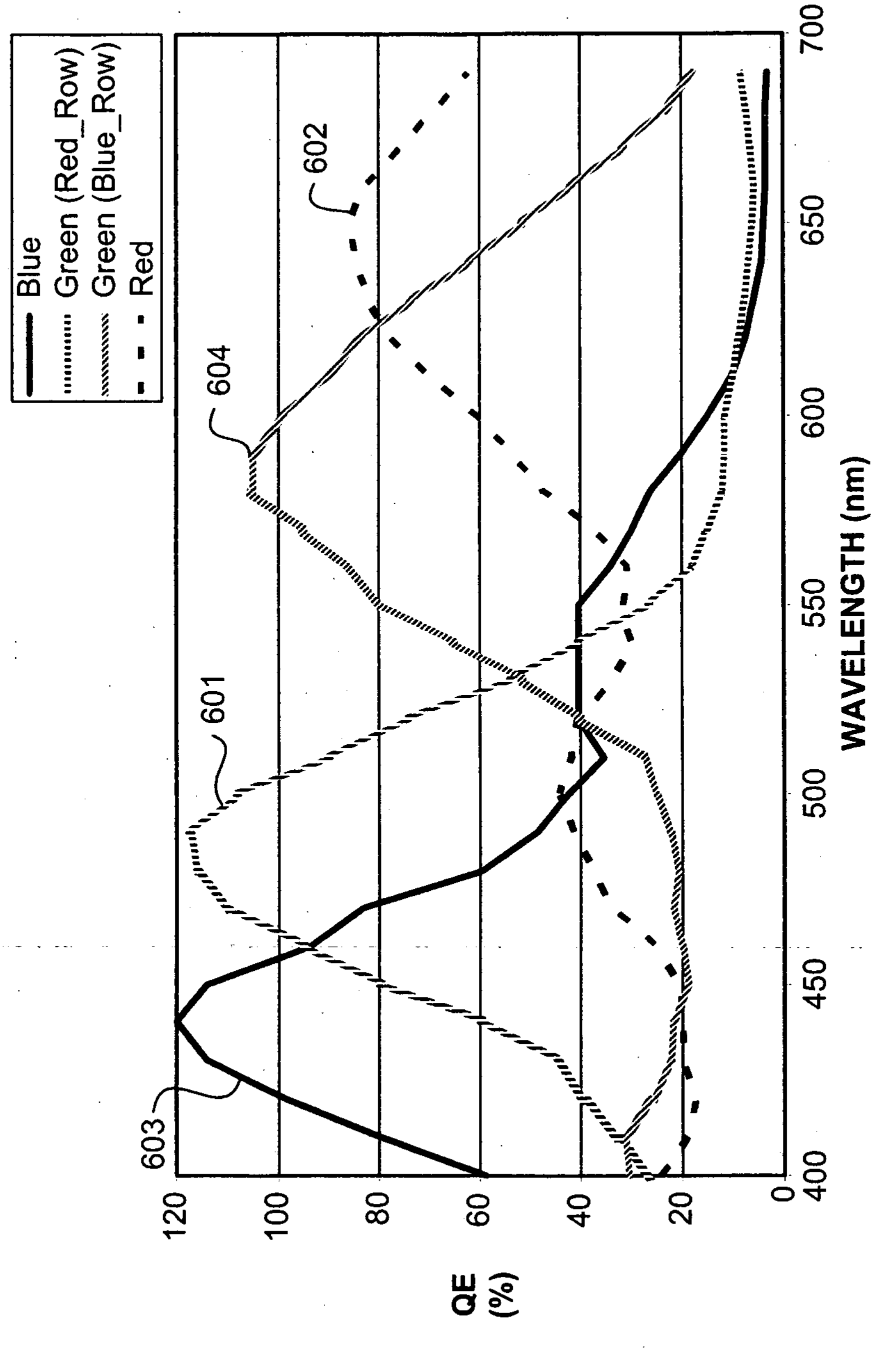
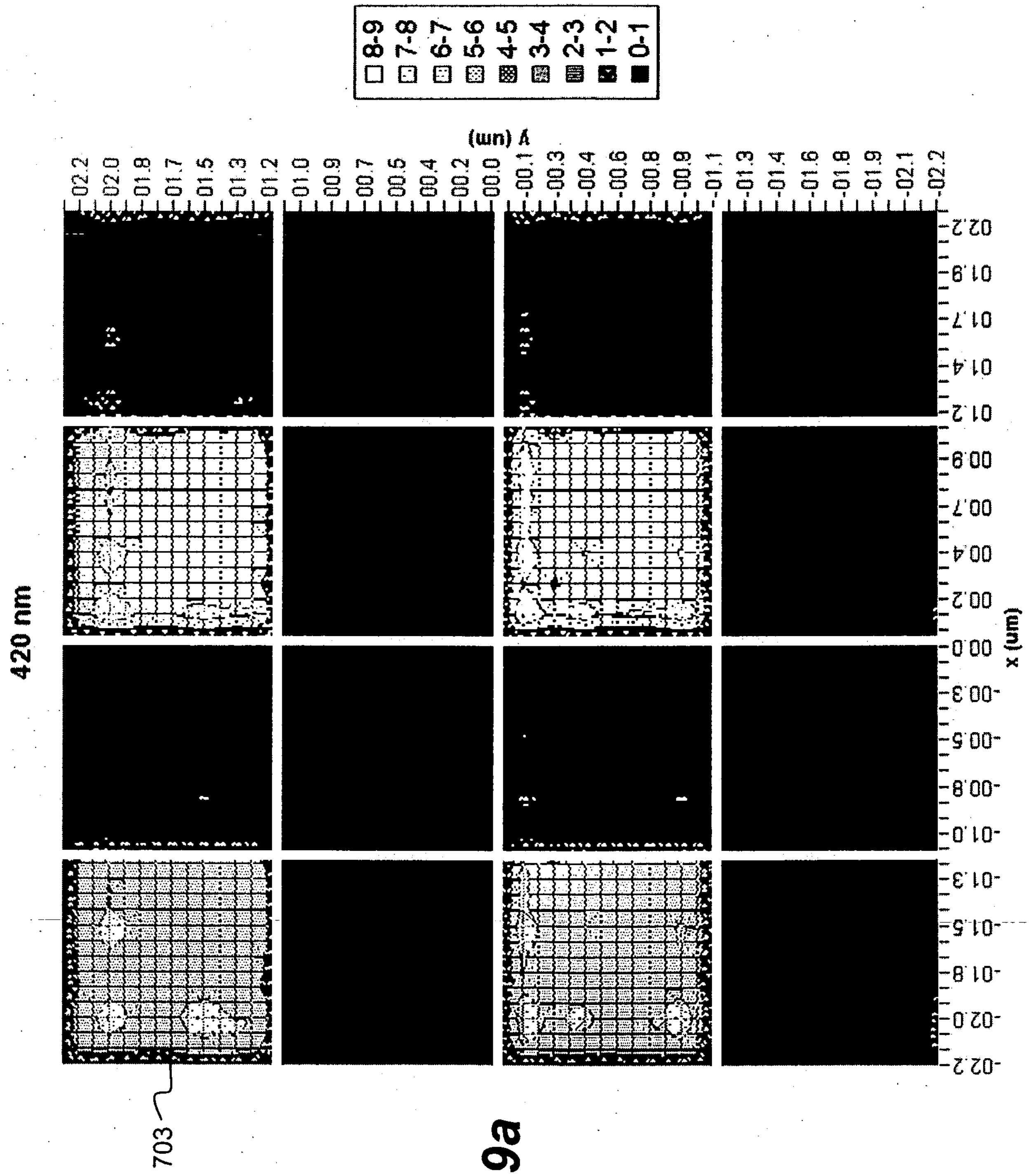

Blue
Green (Red_Row)
Green (Blue_Row)
Red
601
602
603
604
QE (%)
120
100
80
60
40
20
0
400
450
500
550
600
650
700
WAVELENGTH (nm)

FIG. 8



420 nm
8-9
7-8
6-7
5-6
4-5
3-4
2-3
1-2
0-1
y (um)
02.2
02.0
01.8
01.7
01.5
01.3
01.2
01.0
00.9
00.7
00.5
00.4
00.2
00.0
-00.1
-00.3
-00.4
-00.6
-00.8
-00.9
-01.1
-01.3
-01.4
-01.6
-01.8
-01.9
-02.1
-02.2
x (um)
02.2
01.9
01.7
01.4
01.2
00.9
00.7
00.4
00.2
00.0
-00.3
-00.5
-00.8
-01.0
-01.3
-01.5
-01.8
-02.0
-02.2
703

FIG. 9a

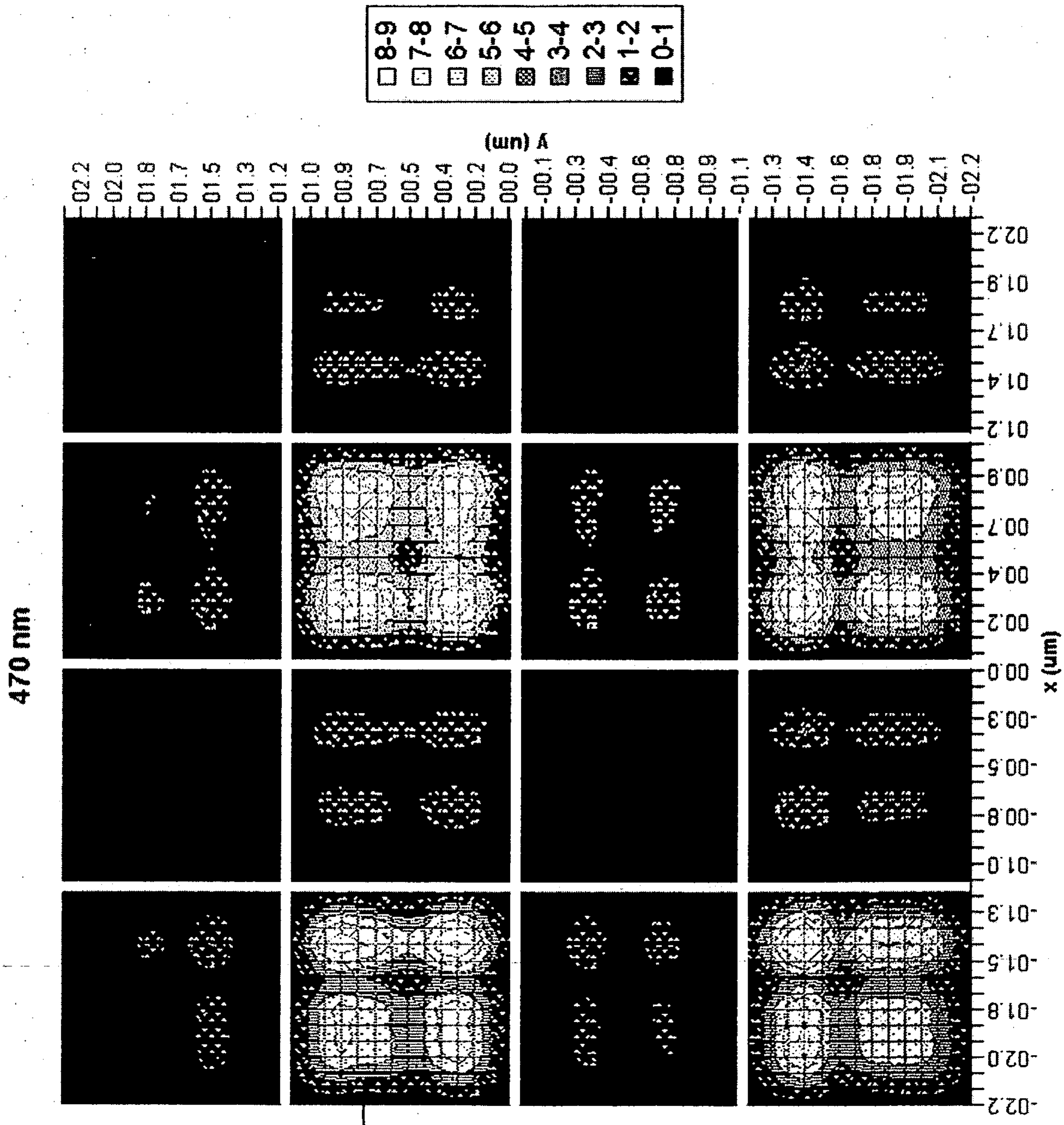

8-9
7-8
6-7
5-6
4-5
3-4
2-3
1-2
0-1
y (um)
02.2
02.0
01.8
01.7
01.5
01.3
01.2
01.0
00.9
00.7
00.5
00.4
00.2
00.0
-00.1
-00.3
-00.4
-00.6
-00.8
-00.9
-01.1
-01.3
-01.4
-01.6
-01.8
-01.9
-02.1
-02.2
x (um)
02.2
01.9
01.7
01.4
01.2
00.9
00.7
00.4
00.2
00.0
-00.3
-00.5
-00.8
-01.0
-01.3
-01.5
-01.8
-02.0
-02.2
470 nm
701

FIG. 9b

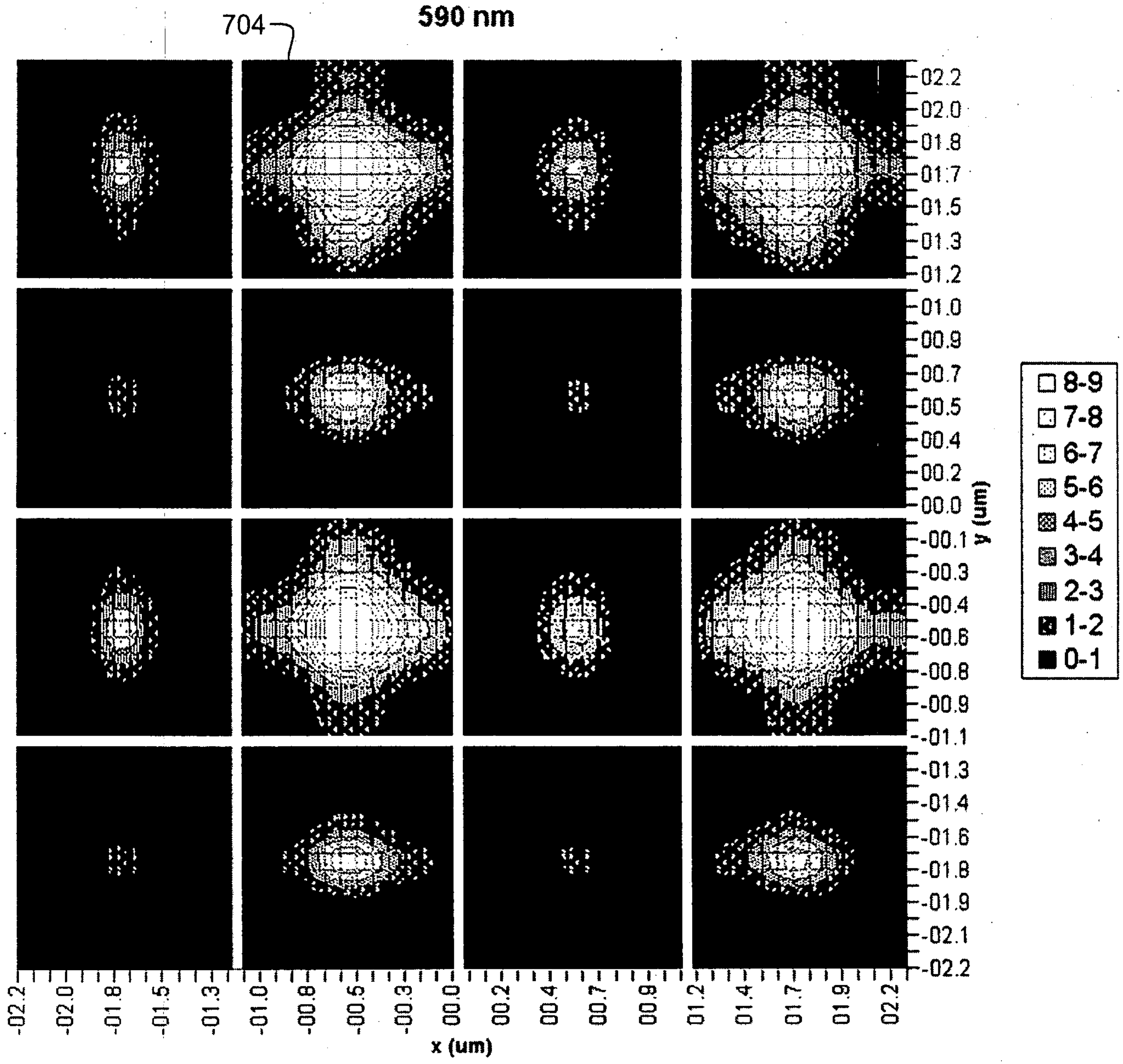

704
590 nm
02.2
02.0
01.8
01.7
01.5
01.3
01.2
01.0
00.9
00.7
00.5
00.4
00.2
00.0
-00.1
-00.3
-00.4
-00.6
-00.8
-00.9
-01.1
-01.3
-01.4
-01.6
-01.8
-01.9
-02.1
-02.2
y (um)
-02.2
-02.0
-01.8
-01.5
-01.3
-01.0
-00.8
-00.5
-00.3
00.0
00.2
00.4
00.7
00.9
01.2
01.4
01.7
01.9
02.2
x (um)
□ 8-9
□ 7-8
□ 6-7
▨ 5-6
▨ 4-5
▨ 3-4
▨ 2-3
▨ 1-2
■ 0-1

FIG. 9c

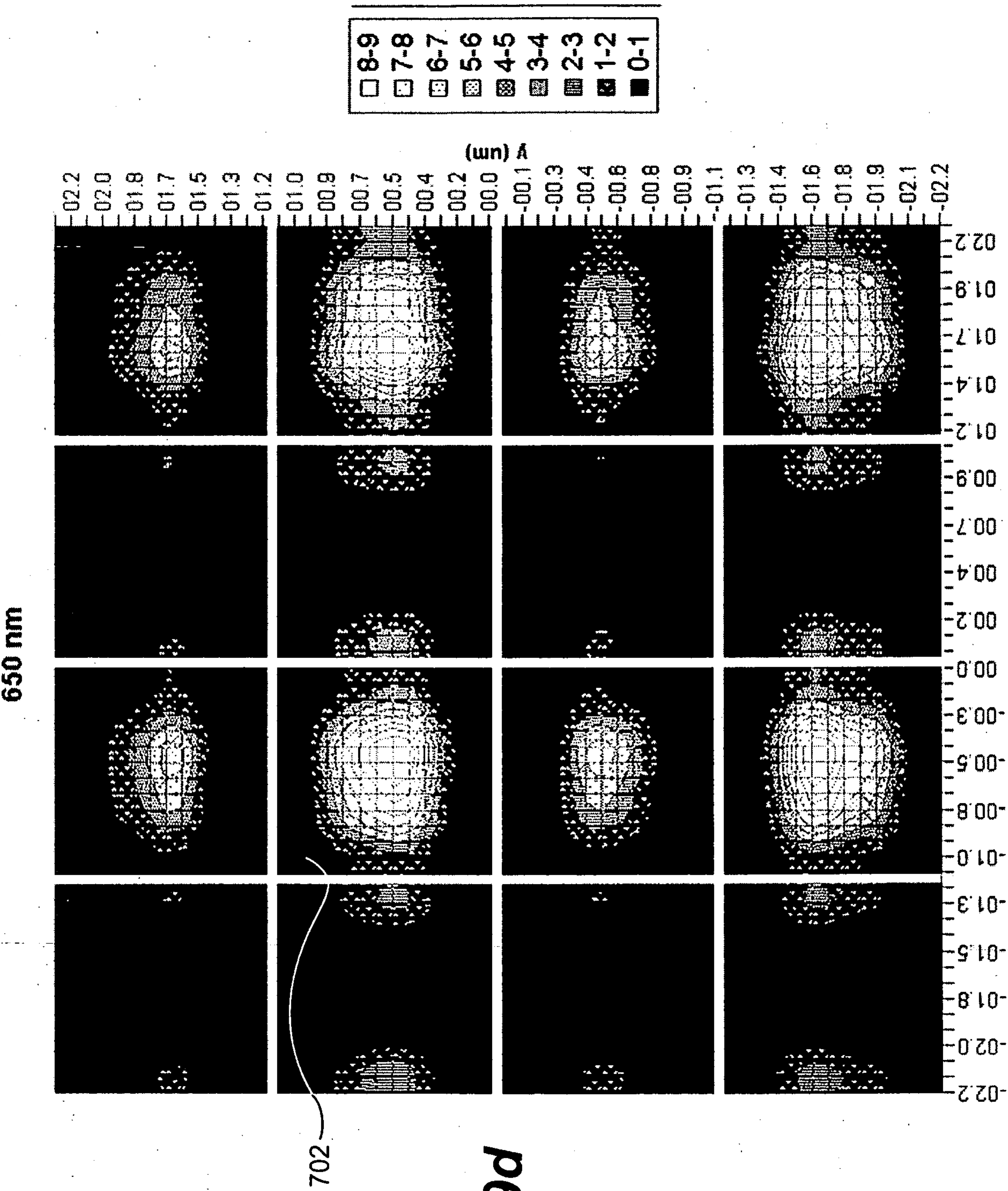

650 nm
8-9
7-8
6-7
5-6
4-5
3-4
2-3
1-2
0-1
y (um)
02.2
02.0
01.8
01.7
01.5
01.3
01.2
01.0
00.9
00.7
00.5
00.4
00.2
00.0
-00.1
-00.3
-00.4
-00.6
-00.8
-00.9
-01.1
-01.3
-01.4
-01.6
-01.8
-01.9
-02.1
-02.2
x (um)
02.2
01.9
01.7
01.4
01.2
00.9
00.7
00.4
00.2
00.0
-00.3
-00.5
-00.8
-01.0
-01.3
-01.5
-01.8
-02.0
-02.2
702

FIG. 9d

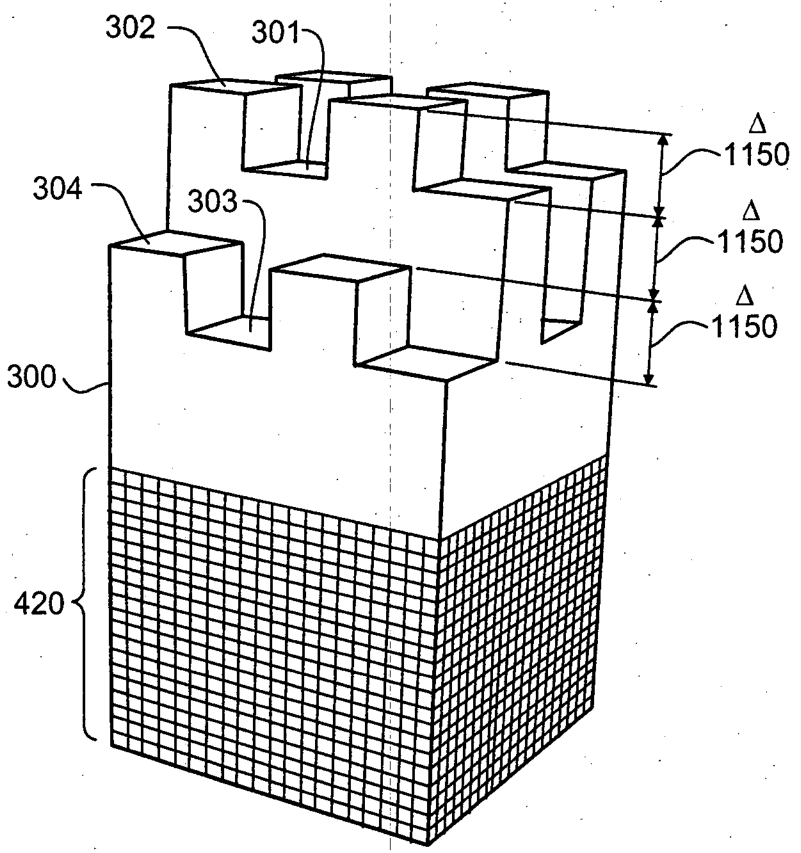

302
301
304
303
Δ
1150
Δ
1150
Δ
1150
300
420

FIG. 10

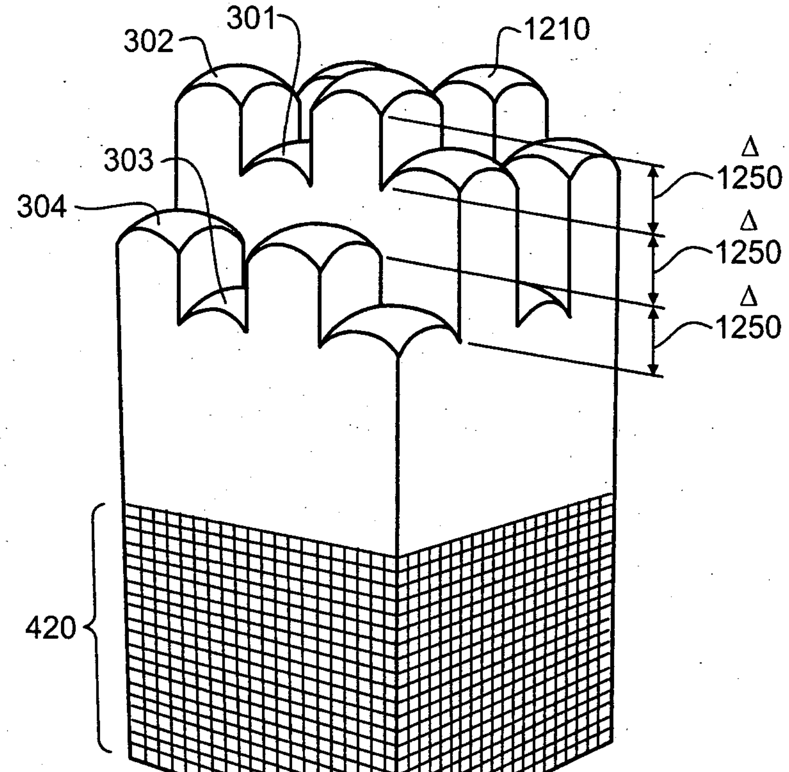

302
301
1210
303
304
Δ
1250
Δ
1250
Δ
1250
420

FIG. 11

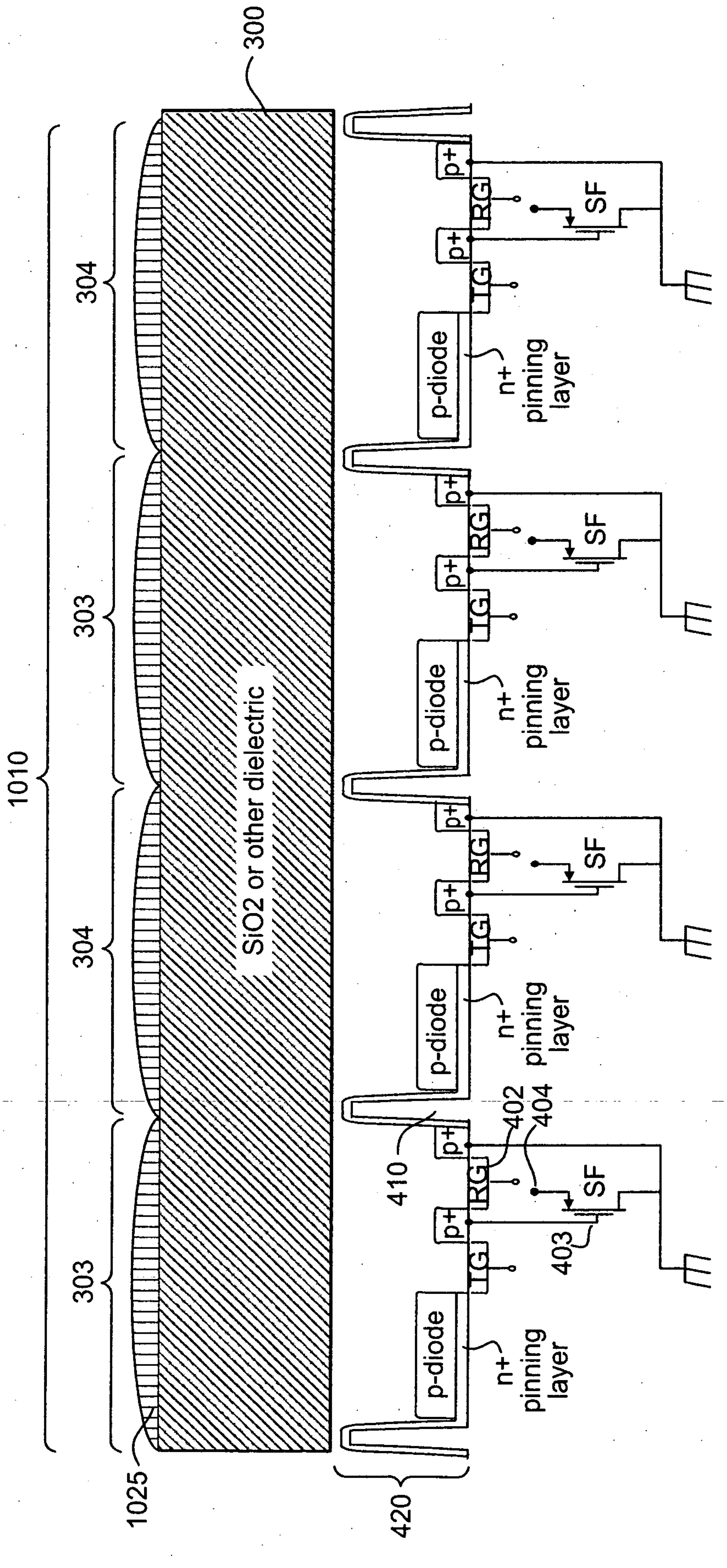

300
1010
304
303
304
303
SiO2 or other dielectric
p-diode
n+ pinning layer
TG
p+
RG
SF
410
402
404
403
1025
420

FIG. 12a

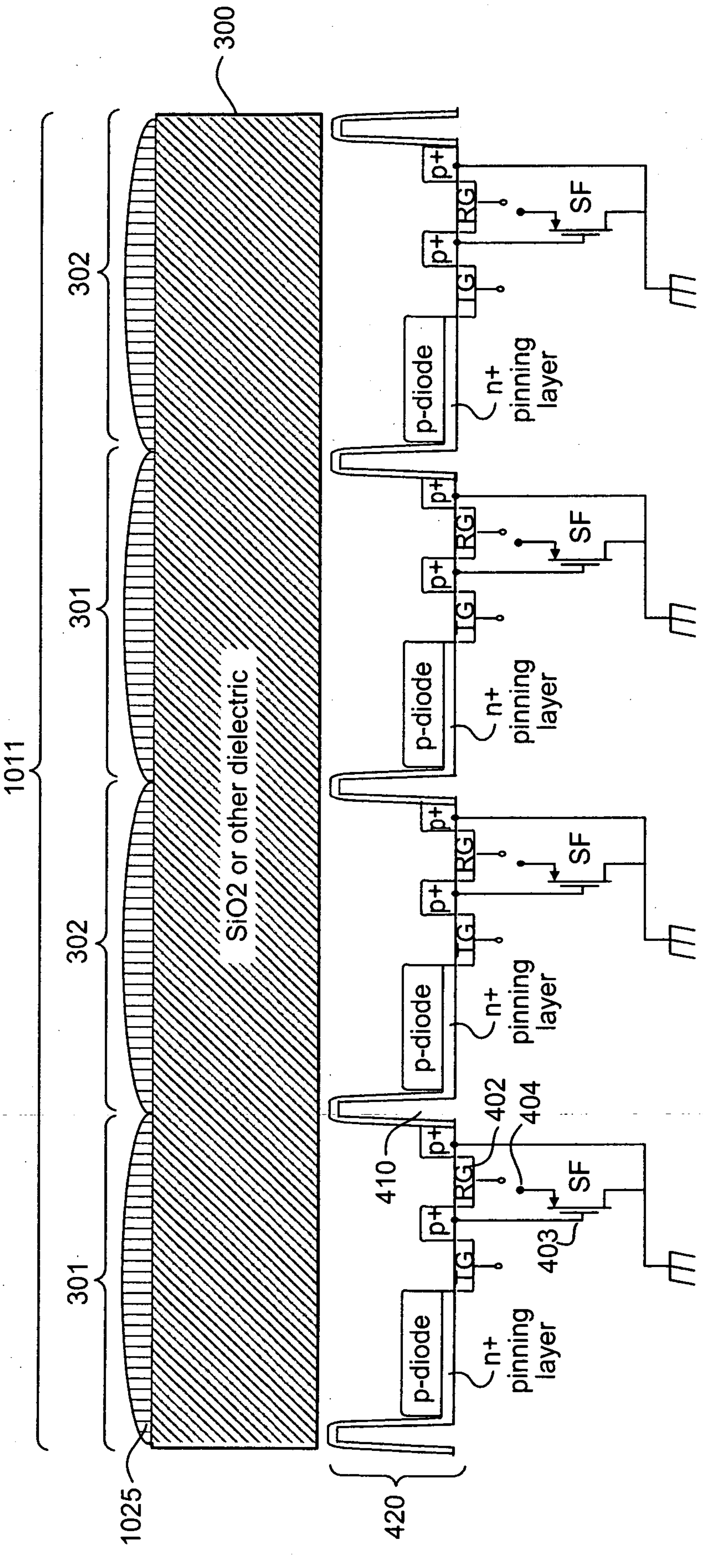

300
1011
302
301
302
301
SiO2 or other dielectric
p-diode
n+ pinning layer
LG
p+
RG
p+
SF
402
404
403
410
1025
420

FIG. 12b

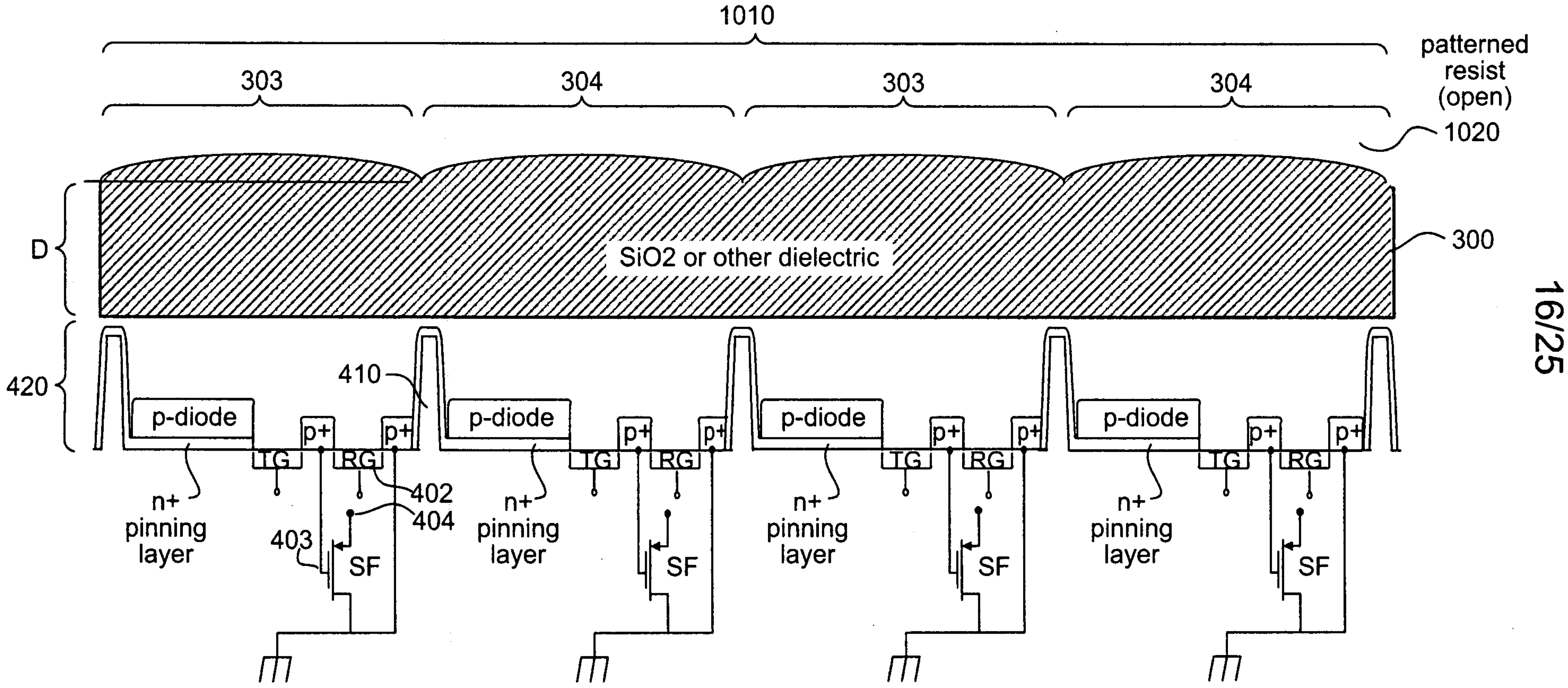

1010
303
304
303
304
patterned
resist
(open)
1020
D
SiO2 or other dielectric
300
420
410
p-diode
p+
TG
RG
402
404
403
n+
pinning
layer
SF

FIG. 13a

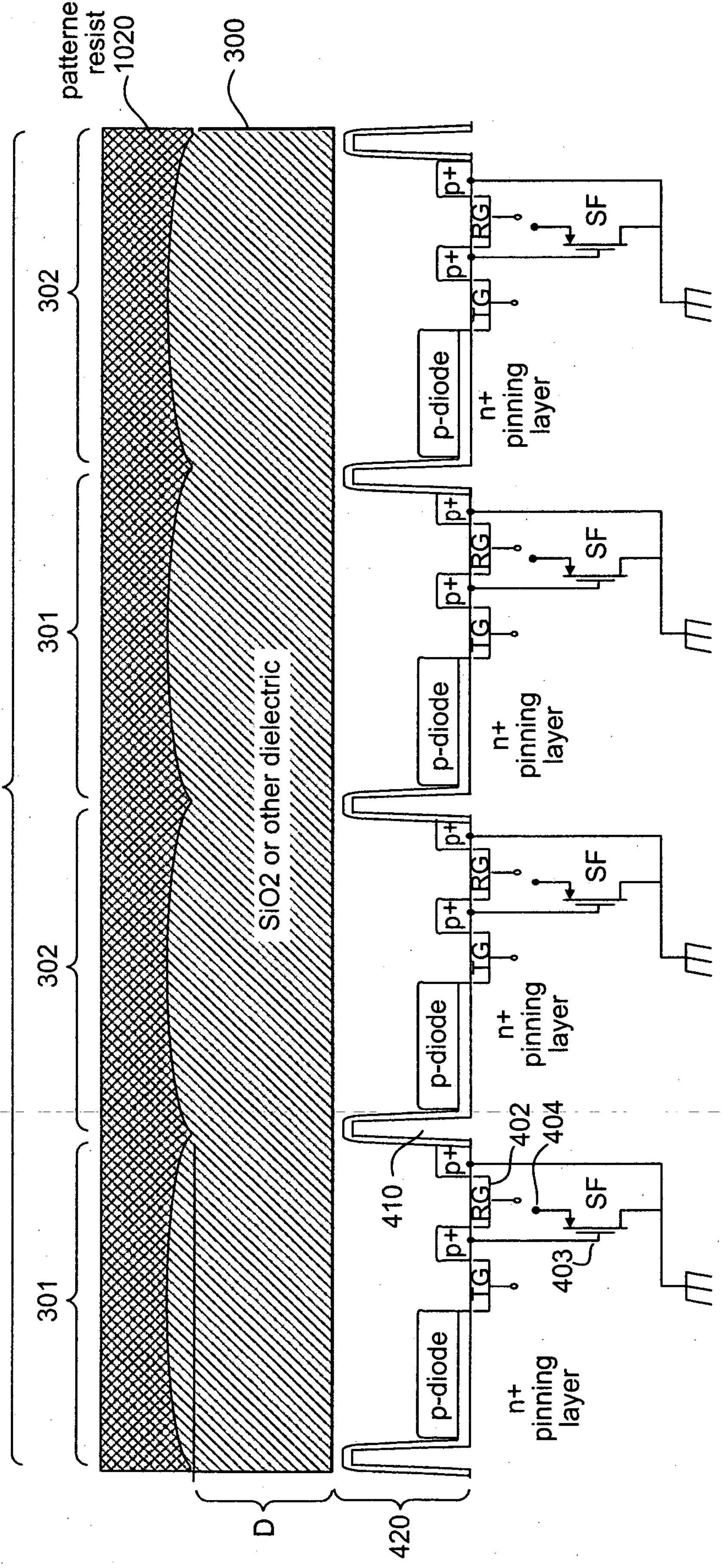

patterned resist 1020
300
302
301
302
301
1011
SiO2 or other dielectric
p+
RG
SF
p+
TG
p-diode
n+ pinning layer
410
402
404
403
D
420

FIG. 13b

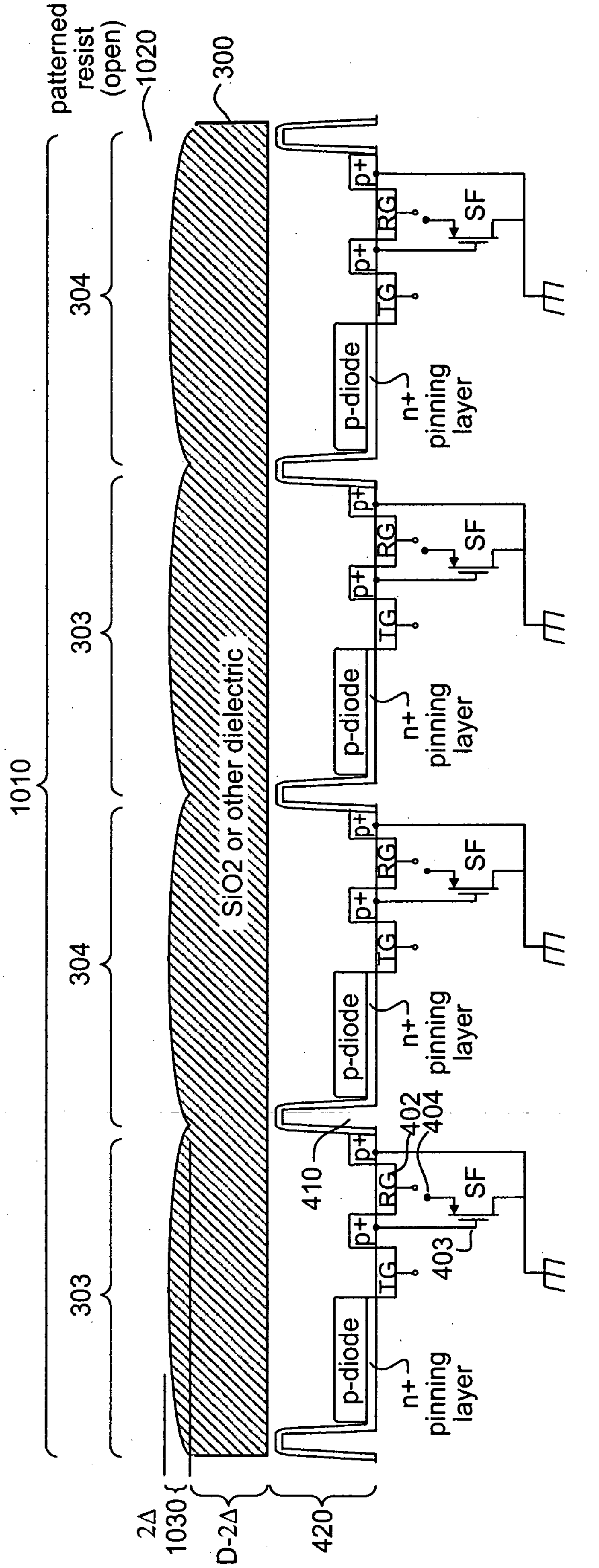

patterned resist (open)
1020
300
1010
304
303
304
303
SiO2 or other dielectric
p-diode
n+ pinning layer
TG
p+
RG
SF
402
404
410
403
2Δ
1030
D-2Δ
420

FIG. 14a

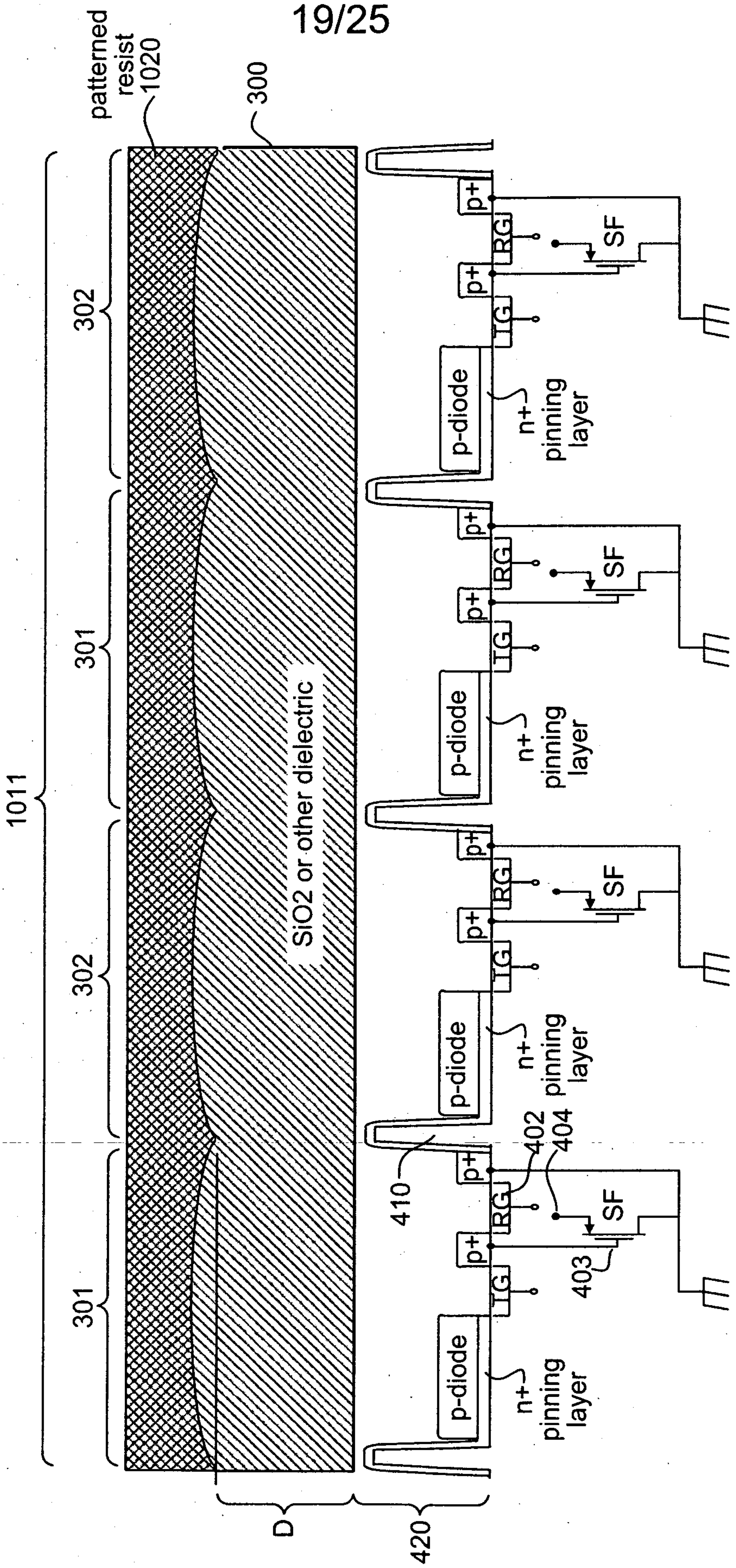

patterned resist 1020
300
1011
301
302
301
302
SiO2 or other dielectric
D
420
410
p-diode
n+ pinning layer
TG
p+
RG
SF
402
404
403

FIG. 14b

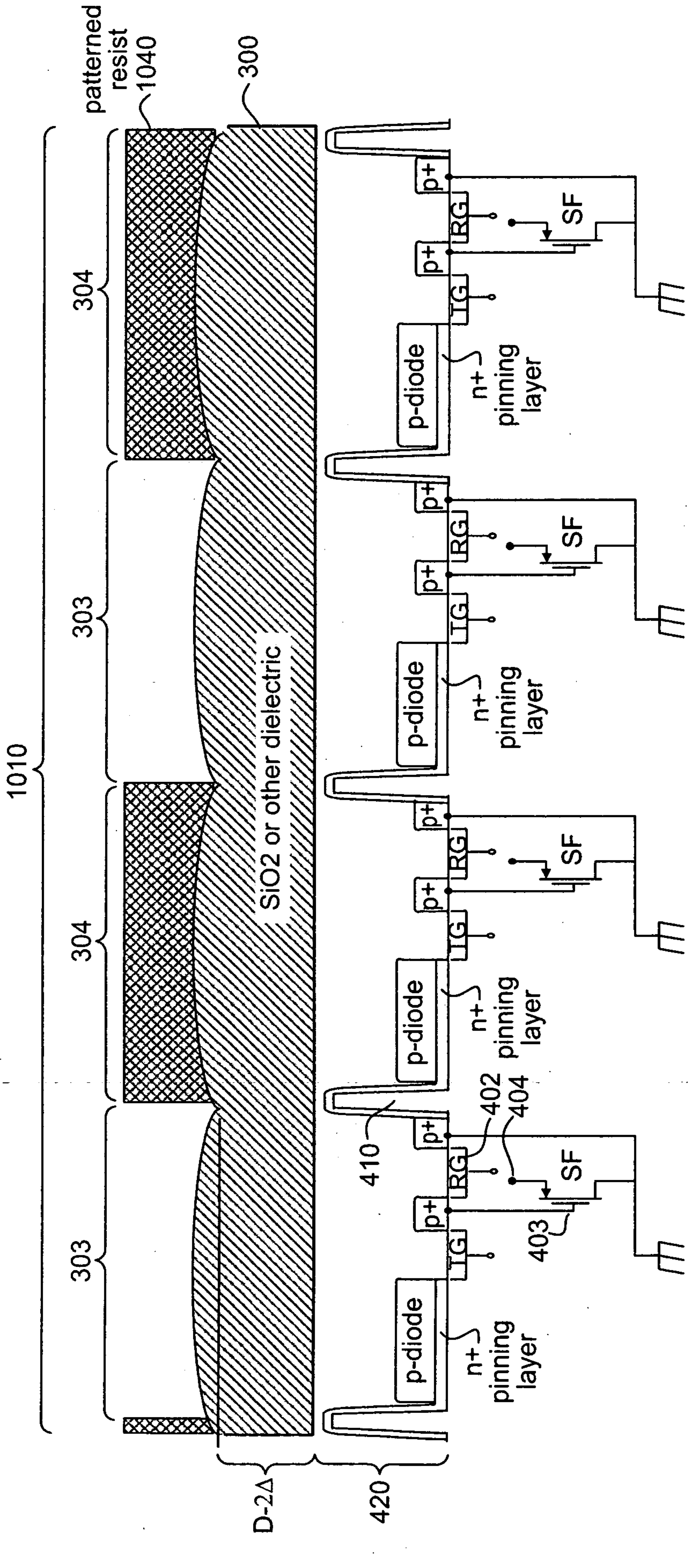

patterned resist
1040
300
1010
304
303
304
303
SiO2 or other dielectric
p+
RG
p+
TG
SF
p-diode
n+
pinning layer
402
404
403
410
D-2Δ
420

FIG. 15a

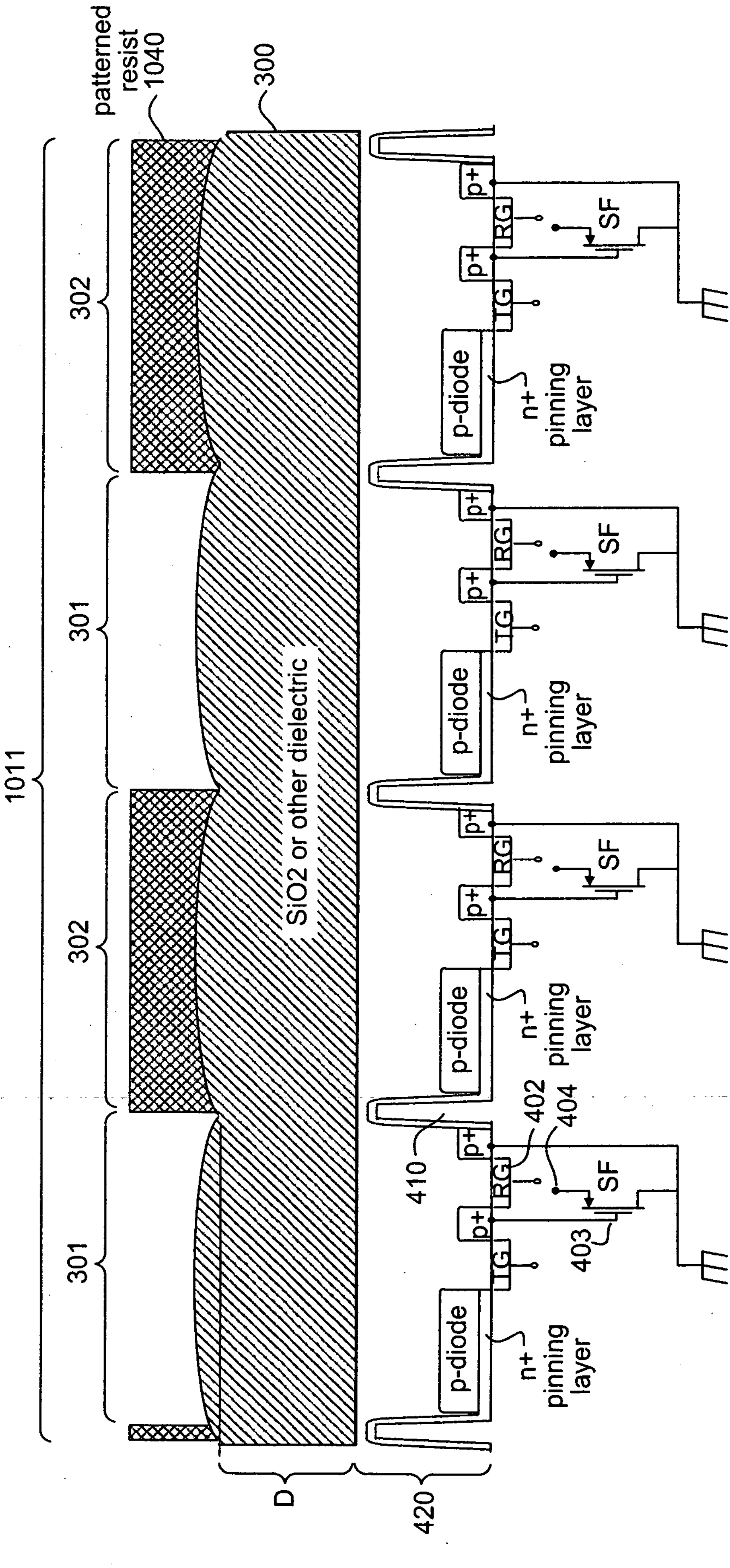

patterned resist 1040
300
302
301
302
301
1011
SiO2 or other dielectric
p-diode
n+ pinning layer
TG
p+
RG
p+
SF
410
402
404
403
D
420

FIG. 15b

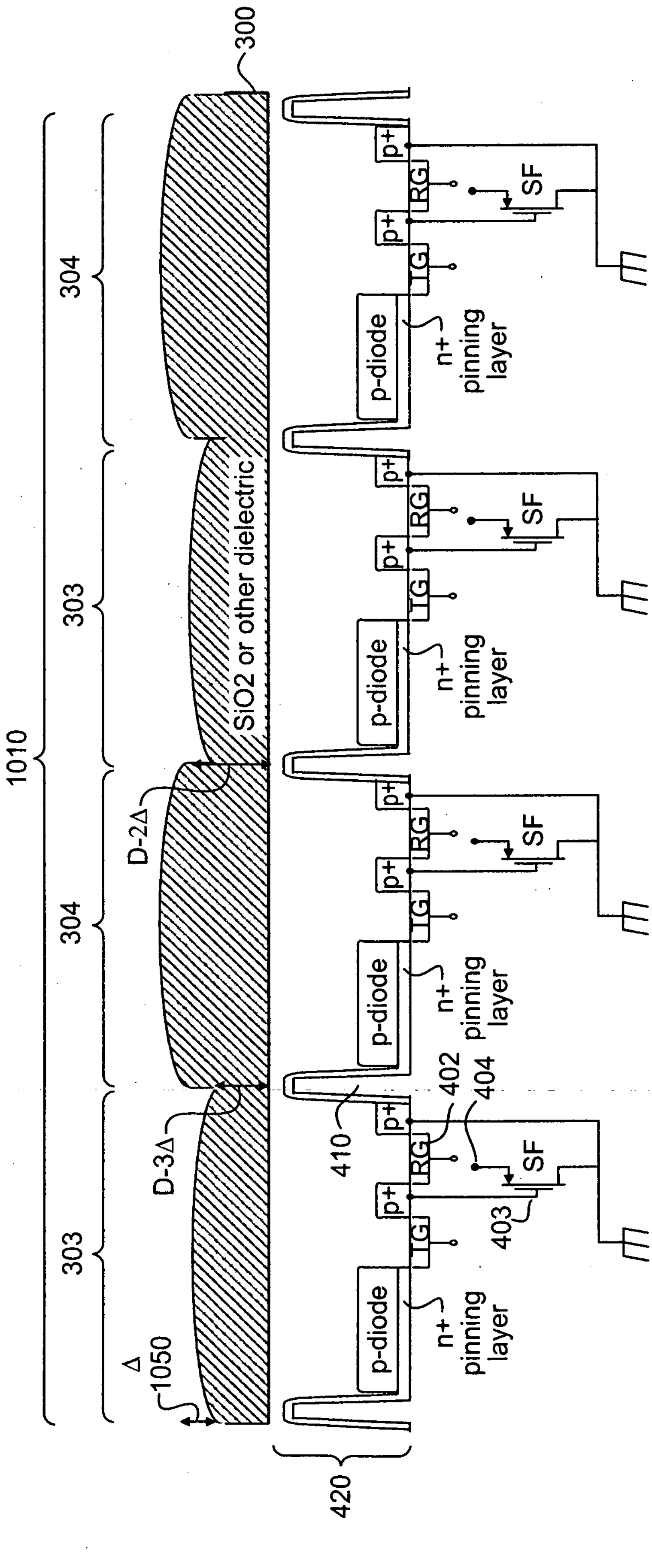

300
1010
304
303
304
303
SiO2 or other dielectric
D-2Δ
D-3Δ
Δ
1050
420
p-diode
n+
pinning
layer
TG
p+
RG
SF
410
402
404
403

FIG. 16a

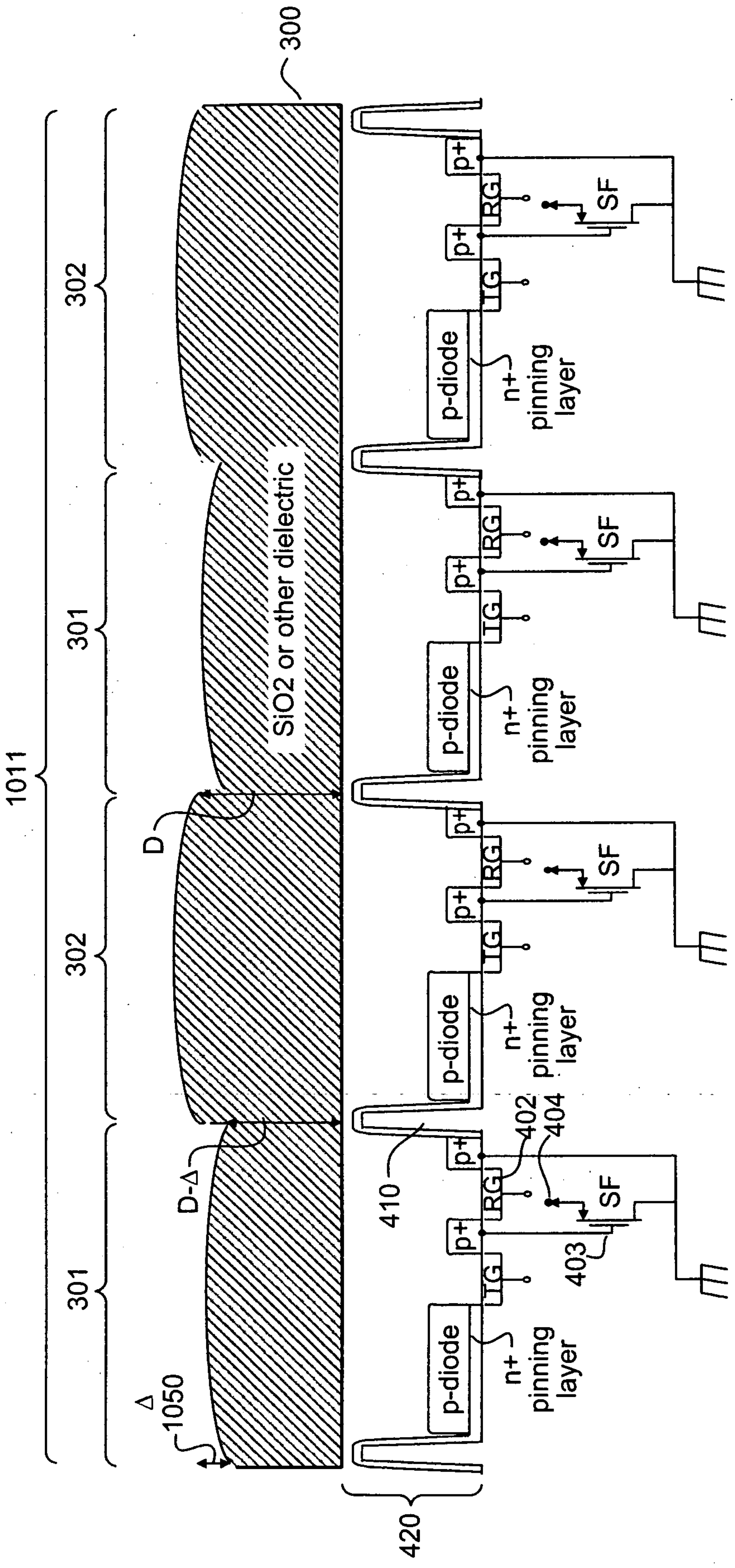

300
302
301
302
301
1011
SiO2 or other dielectric
D
D-Δ
Δ
1050
420
410
402
404
403
p-diode
n+ pinning layer
TG
p+
RG
SF

FIG. 16b

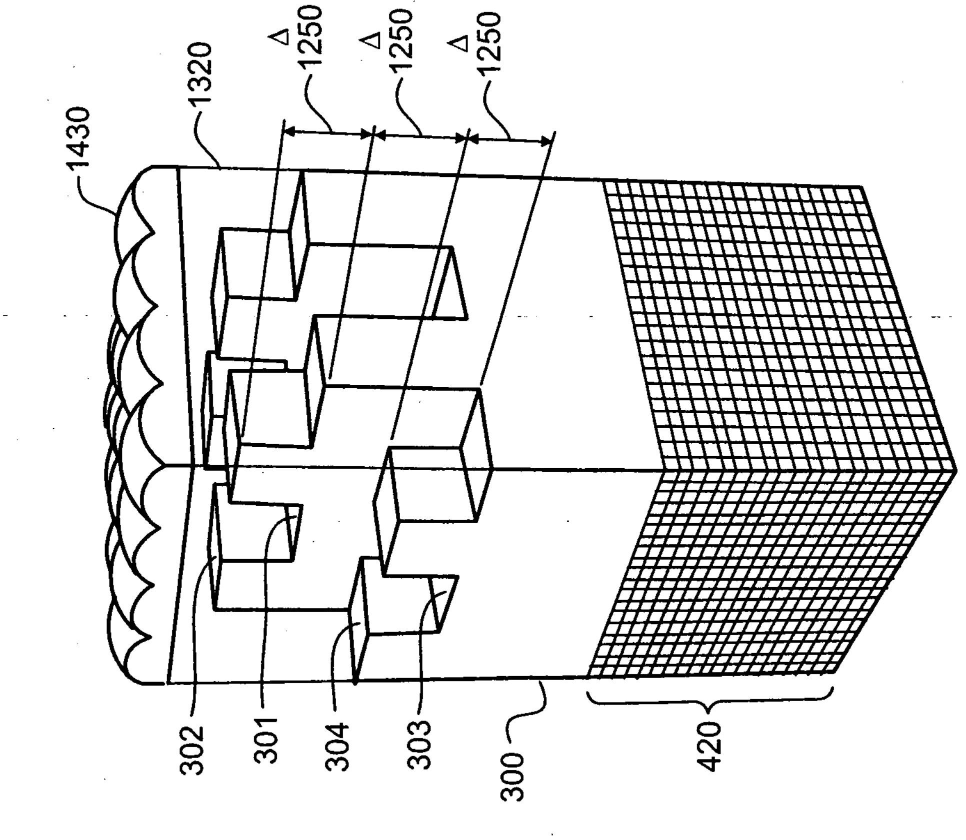

1430
1320
1250
Δ
1250
Δ
1250
Δ
302
301
304
303
300
420

FIG. 17

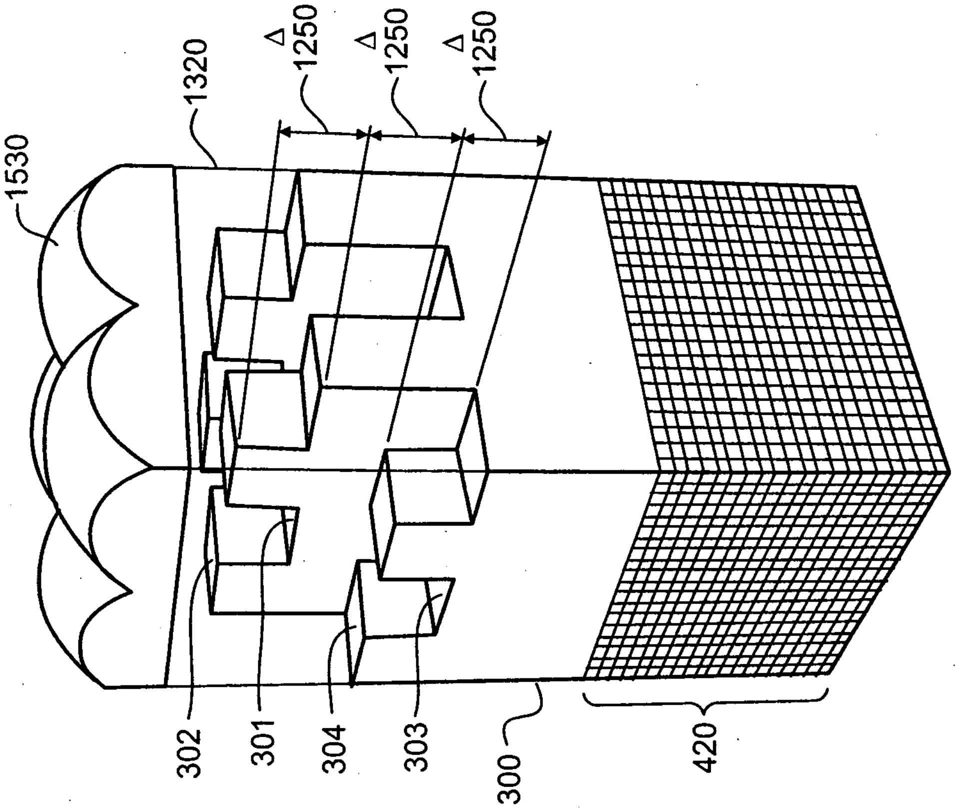

1530
1320
1250
Δ
1250
Δ
1250
Δ
302
301
304
303
300
420

FIG. 18

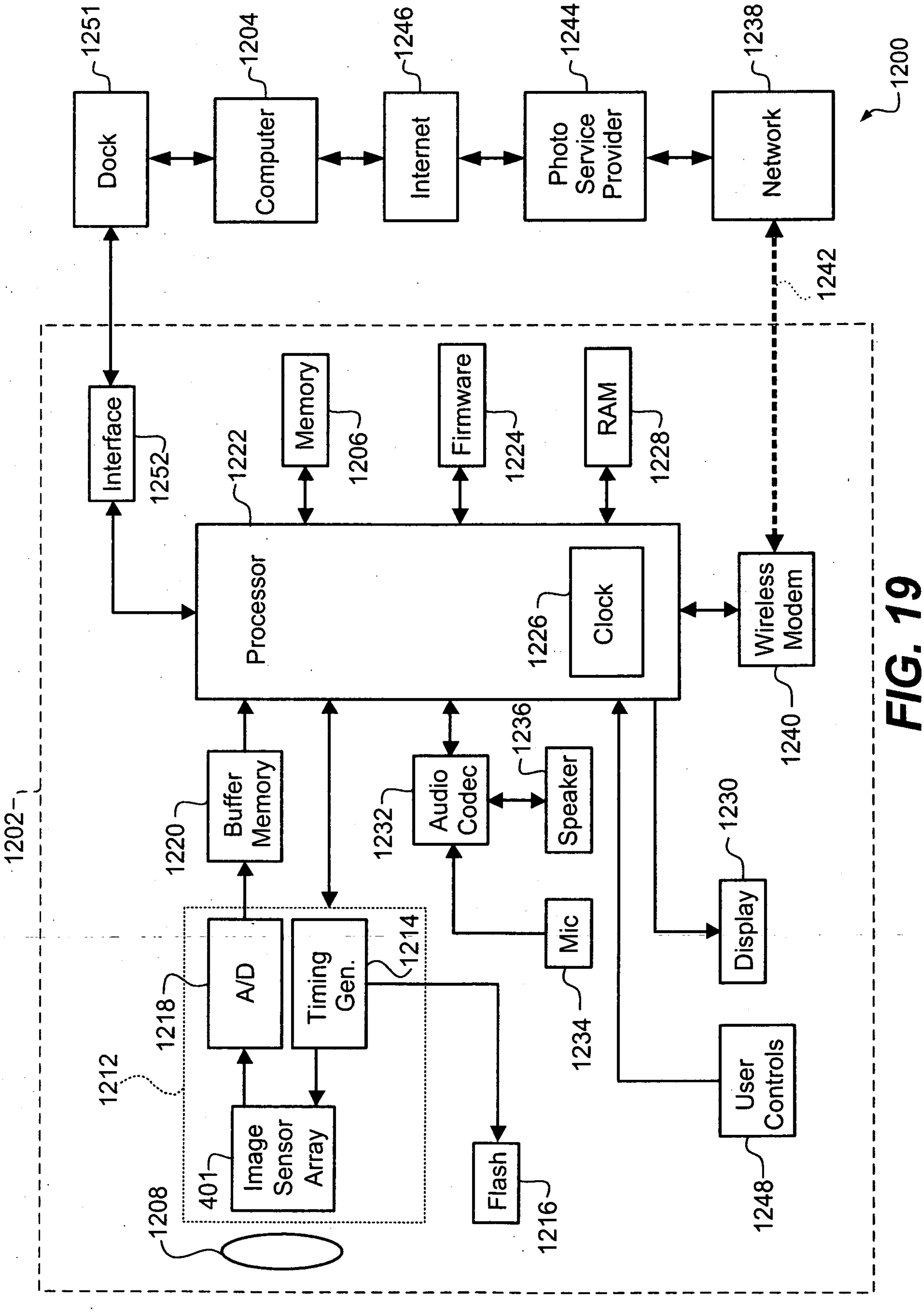

Dock
1251
Computer
1204
Internet
1246
Photo Service Provider
1244
Network
1238
1200
1242
1202
Interface
1252
Processor
1222
Memory
1206
Firmware
1224
RAM
1228
Clock
1226
Wireless Modem
1240
Buffer Memory
1220
Audio Codec
1232
Speaker
1236
Display
1230
A/D
1218
Timing Gen.
1214
Mic
1234
User Controls
1248
1212
Image Sensor Array
401
1208
Flash
1216

FIG. 19

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/005915

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L27/146

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)
H01L

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	US 2006/145223 A1 (RYU SANG-WOOK [KR]) 6 July 2006 (2006-07-06) paragraphs [0039] - [0041], [0050] - [0063] figures 6, 7 8a-8c -----	1-5,7-9, 12-16, 18-20
X	US 4 506 949 A (KNOP KARL H [CH]) 26 March 1985 (1985-03-26) column 3, lines 7-21 column 4, lines 18-34, 55-59 figures 1,3 -----	1-5, 12-16,21
X	EP 1 592 067 A1 (MATSUSHITA ELECTRIC IND CO LTD [JP]) 2 November 2005 (2005-11-02) paragraphs [0054] - [0056] figure 3 ----- -/--	1-6,8-9, 12-17,20

☒ Further documents are listed in the continuation of Box C.

☒ 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 25 January 2010	Date of mailing of the international search report 02/02/2010
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Markmann, Markus

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/017490 A2 (OPSOLUTION NANOPHOTONICS GMBH [DE]; OPSOLUTION GMBH [DE]; HILLMER HART) 14 February 2008 (2008-02-14) page 7, line 9 - page 10, line 5 page 14, line 34 - page 15, line 24 figures 6a-6c	1-5,9, 12-17,20
X	WO 2008/012235 A1 (COMMISSARIAT ENERGIE ATOMIQUE [FR]; GIDON PIERRE [FR]; GRAND GILLES [F) 31 January 2008 (2008-01-31) page 13, line 17 - page 15, line 18 figures 6a, 6b, 8	1-2,4-5, 7-9, 12-13, 15-16, 18-20
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