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(54) COLOUR IMAGE SENSING DEVICE

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America of 343 State Street, Rochester, New York 14650, United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates in general to image sensing devices, and in particular to solid state colour image sensing devices.

U.S. Patent 3,985,449 discloses a solid-state colour image sensing device which utilizes an array of semiconductor photoelements with each element detecting a range of wavelengths which is dependent on the bias voltages applied to the element. Sensing of the primary colours can be accomplished by using the same element successively at three differing bias voltages, or by using a group of three elements, each biased at a different voltage. U.S. Patent 3,985,449 also discloses that it is advantageous to use a group of three elements, so that the colour information can be obtained substantially simultaneously.

However, an array of groups of three elements, as disclosed in U.S. Patent 3,985,449 does not function as well as would be desired. Because three image sites (pixels) are used to obtain information for a single area, the resolution is only one-third of that which could be obtained if only one image site (pixel) was used. Furthermore, such an arrangement is inefficient because only a portion of the light falling on a particular photoelement is used to produce an electrical signal, the remainder of the light falling on such a photoelement being wasted. The device is therefore not as sensitive as if all the light falling on each photoelement were used to produce an electrical signal.

According to the present invention, there is provided a colour image sensing device comprising a chip of semiconductor material having a radiation receiving surface and wherein the chip has alternate layers of opposite conductivity silicon forming superimposed multiple buried channels at different distances from the radiation receiving surface, each channel being sensitive to radiation of a bandwidth dependant on the distance from the image receiving surface.

Because the channels are superimposed, the resolution is the same as for a monochrome image sensing device which uses a single image site. Furthermore, because any light which is not absorbed in one channel, to produce image signal, is absorbed in another, all of the light impinging in the element is used to produce image signal, the sensitivity of the device is high.

Reference should be made to U.S. Patent 3,792,322, for a more detailed discussion of buried channel devices generally, and of buried channel charge coupled devices in particular.

In the present invention, a buried channel charge coupled device (bccd) employs typically three channels, formed by six silicon semiconductor layers of alternately different dopant types. By so setting the thicknesses of the first and second layers that radiation of a first colour, because of differential absorption, is prevented from appreciably entering the third and subsequent layers— and by so setting the thicknesses of the first through fourth layers that radiation of a second colour, because of absorption, is prevented from appreciably entering the fifth and sixth layers—a three channel colour sensitive bccd is provided. Assuming the first, third

and fifth layers are p-doped (acceptor doped), and the second, fourth and sixth layers (the sixth layer may comprise the semiconductor substrate) are n-doped (donor doped), a first signal channel extends from the surface of the device to somewhere within the n-doped seconds layer, although the p-doped first layer carries signal charges, if any; similarly, a second signal channel extends from somewhere within the n-doped second layer to somewhere within the n-doped fourth layer, the sandwiched p-doped third layer, however, being a second signal-carrying layer; and, finally, a third signal channel extends from somewhere within the n-doped fourth layer to the n-doped sixth layer, the sandwiched p-doped fifth layer being a third signal-carrying layer. Although each of the three signal channel has a width that includes adjacent non-signal-carrying layers, photo-generated signal carriers which occur within the non-signal-carrying layers selectively drift to, and are processed by, respective signal-carrying layers.

Assuming, for example, the first, second, and third colours are respectively blue, green, and red, all photon-generated carriers produced within the first channel by blue, green, and red radiation drift to the first layer for processing by gate electrodes on the surface of the device. Similarly, all photon-generated carriers produced within the second channel by green and red radiation drift to the third layer for processing by the gate electrodes. And all photon-generated carriers produced within the third channel by red radiation drift to the fifth layer for processing by the gate electrodes. Thus, the gate electrodes of the bccd are common to all three channels (i.e., triads comprise superpositioned—as opposed to side-by-side—regions of the device) and simultaneously process all three colour signals in proper phase with each other.

The present invention will now be described by way of example, with reference to the accompanying drawings in which:—

Figs. 1*a* and 1*b* are diagrams useful in describing the present invention;

Fig. 2 is a plan view of an embodiment of a colour image sensing device in accordance with the present invention;

Fig. 3 is a generally schematic elevational view of the embodiment of the present invention shown in Fig. 2;

Fig. 4 is a cross-sectional view of the embodiment of Fig. 2 taken along lines 4—4 thereof; and

Fig. 5 is a schematic showing of an area array of colour image sensing devices according to the present invention.

Construction of a colour image sensing device in accordance with the present invention will now be described with reference to Figure 1*a*, which depicts an energy band diagram. Starting with an original wafer or substrate (6th layer) that may contain for example, 2×10^{14} n-type donor impurities per cm^3, a p-doped (boron) region of, for example, 1 μm thickness, (5th layer) is ion-implanted into the wafer, the dopant level of the p-doped region being, for example, 0.6×10^{16} impurities per cm^3. An n-doped epitaxial layer of, for example, 2 μm thickness is then grown atop the p-doped region (5th layer) by heating the wafer in an atmosphere of arsenic-doped silane. The dopant level of the epigrown layer is, for example, 0.8×10^{16} impurities per cm^3. Then, a p-doped (boron) region of, for example, 1 μm thickness and having a dopant level of 1×10^{16} impurities per cm^3, is ion-implanted into the epigrown n-doped layer to form two layers, which, for example may be each 1 μm thick, i.e. the third and fourth layers. Again, an n-doped layer is epitaxially grown atop the p-doped third layer by heating the wafer in an atmosphere of arsenic-doped silane, this epigrown layer being, for example, 1.3 μm in thickness. By ion-implanting to a depth of, for example, 0.3 μm (3.5×10^{16} boron impurities per cm^3) into the epigrown layer, such layer is converted into a pair of layers, one of, for example 0.3 μm thickness and one of, for example, 1 μm thickness (i.e., the first and second layers of the device). A gate oxide layer 10 is then grown or deposited atop the device, after which a transparent conductive gate electrode(s) 12 is applied over the oxide layer.

The fabrication of the gate oxide layer and conductive gate structure is determined in the type of charge coupled device (CCD), i.e., two phase, three phase, four phase, or interline transfer. This aspect of the structure is well known in the art.

Suitable electrical contact must be established with the layers. This is accomplished away from the area of the gate electrodes by a charge draining electrode, at the input or output end of each line of photoelements or gate electrodes. With electrical contact so made, the p-doped first, third and fifth layers are reverse-biased with respect to the second and fourth layers and substrate. The substrate, second and fourth layers are held at, for example, ground potential and the first, third and fifth layers are held at negative voltage with respect to the second and fourth layers and substrate. The unbiased energy band diagram is shown in Fig. 1*b*. Application of reverse bias causes all mobile charges to be drained from the layers, resulting in the energy band profile

shown in Fig. 1*a*. The exact shape of the energy band diagram depends critically upon the doping levels of the various layers, the substrate doping, the thickness of the gate oxide layer and the voltage applied to the charge draining electrodes. Once these parameters are known, the energy band diagram may be obtained by methods well known in the art.

The thicknesses of the layers and the doping levels of Fig. 1*a*, with a gate oxide layer thickness of 0.2 μm, and with small negative "biasing" voltage, produce relative minima in the energy band diagram at approximately 0.7 μm and 2.6 μm below the gate oxide layer 10. The first photosensitive channel is approximately 0.7 μm wide being bounded by the interface of the gate oxide layer 10 and the first energy band minimum, i.e., the minimum nearest the gate oxide layer. The second photosensitive channel is approximately 1.9 μm wide being bounded by the first energy band minimum and the second energy band minimum. The third photosensitive channel is more than 10 μm wide being bounded, in Fig. 1*a*, on the left by the second energy band minimum and on the right the boundary is several microns into the substrate, the depth of the boundary depending mostly on the minority carrier diffusion length.

The image sensing device formed by the above described bccd is irradiated from the gate side. Both the gate oxide layer 10, which is an insulator, and the gate electrode 12 are virtually transparent to visible radiation. Photons in the visible spectrum will be essentially completely absorbed in the layered structure since the penetration depth lies between 0.2 μm and 5 μm for the wavelength range 0.4 μm to 0.7 μm. Blue radiation (0.40—0.49 μm) is substantially absorbed within the 0.7 μm wide photosensitive channel nearest the gate oxide layer 10. Green radiation is substantially absorbed within the two channels at 2.6 μm, and is therefore absorbed within the third channel.

For a p-channel device, an absorption event generates a hole as the signal charge. The hole is produced at the depth or location in the semiconductor at which the absorption event occurs. If a signal hole 14 is created in the first photosensitive channel (by a red, green or blue photon), it drifts to a potential well (for holes) 16 of the first channel. Similarly, a signal hole 18 created in the second photosensitive channel, by a green or red photon, drifts to a potential well 20 of the second channel, and a signal hole 22 created in the third photosensitive channel (by a red photon) drifts to a potential well 24 of the third channel. The signal charge accumulates in the channels according to the radiation exposure incident upon that area under the gate electrode.

The electrostatic potential of the three potential wells in which the signal charge accumulates may be manipulated by controlling the voltage on the gate electrode 12. It should be appreciated that the potential wells associated with all three colour channels are controlled by a single gate voltage, and therefore the signal holes are manipulated simultaneously. For example, such holes may be transferred from the region beneath one gate to the region beneath an adjacent gate, just as for a conventional charge coupled device, as is well known in the art.

Referring now to Figs. 2—4 an embodiment of a three phase linear bccd imaging device according to the present invention comprises an n-doped silicon wafer, into which a p-doped layer 28 is ion-implanted. An epigrown n-doped layer 30, formed over the layer 28, thereby forming an n-doped layer 26, has a p-doped layer 32 ion-implanted into it; and an n-doped layer 34, which is epigrown on layer 32, has a p-doped layer 36 ion-implanted into it. As described in connection with Fig. 1*a*, the layers 28, 32 and 36 are, for example, 1μm, 1 μm, and 0.3 μm thick, respectively, and the epigrown layers 30 and 34 are 2 μm thick.

The face of the resultant chip of semiconductor material, which forms the radiation receiving surface of the chip is covered with a transparent oxide layer 38 of SiO_2 thereby forming the gate oxide layer, which in turn is overlaid with a linear array of transparent gate electrode(s) 40 appropriately interconnected for purposes of charge transfer.

The layers 36 and 38 are "U-shaped", the layer 36 extending to the side X of the device and the layer 28 extending to the side Y of the device as shown in Figure 2. The layer 32 extends to almost the complete length of that device between the extremities Z—Z, as shown in Figure 2.

Heavily p-doped diffusions 42, 44 and 46, which serve as conductors, extend from windows in the nonconductive oxide layer 38 to, respectively, the p-doped layers 28, 32, and 36. Ohmic metal contacts 48, 50, and 52 are made, respectively, to the diffusions 42, 44 and 46. A channel stop diffusion 47, shown only in Fig. 2, confines photon-generated charges to processing by the gate electrode(s) 40.

A typical application of the device shown in Figs. 2—4 would be in the line scanning of images. In operation, the device would have reverse-biasing negative voltages applied to the contacts (terminals) 48, 50, and 52. Such voltages would deplete mobile carriers from the signal handling channels formed by layers 28, 32, 36, and create an

energy band profile similar to that shown in Fig. 1*a*. After a period during which photon-produced holes have collected in the channels formed by layers 28, 32, and 36, for example under the gate electrode 40A (to which, nominally, a zero voltage is applied), a negative voltage would be applied to the electrode 40A, while the electrode 40B is caused to go to (or remain at) zero volts. This would cause the signal holes in each of the channels formed by layers 28, 32, and 36 to shift simultaneously from under the gate electrode 40A to under gate electrode 40B. Further processing would be in accordance with techniques known in the art.

An image sensing device of the type disclosed offers many improvements over previous solid state colour image sensing devices, namely, improved spatial resolution, and higher effective quantum efficiency.

As the time "superposed" colour signals simultaneously leave the device they are applied to a matrixing circuit encompassing appropriate coefficients for the discrete colours, as is known in the art. One such matrixing circuit is indicated in Fig. 2.

The invention has been described in detail with particular reference to a preferred embodiment thereof, but it will be understood that variations and modifications can be effected with the scope of the present invention. For example, while a linear image sensing device is depicted in Figs. 2—4, the concepts of the present invention may be incorporated into an area image sensing array, for example in the manner depicted in Fig. 5. While a p-channel device has been discussed in connection with Figs. 1—4, an n-channel device according to the present invention would be the same as that shown in Figs. 1—4, except that all impurity types noted in Figs. 1—4 would be reversed, and gate and bias voltages would become positive. Also, while a three channel device has been described, a similar device having any number of channels would be within the scope of the invention, provided that the channels are selective of colour. Further, if desired, filters may be applied over the device to limit the response of the device, for example, to the visible spectrum. Furthermore, although a three phase device is shown in Figs. 2—4, both two or four phase configurations, as well as the interline transfer type image sensing device may incorporate the present invention.

WHAT WE CLAIM IS:—

1. A colour image sensing device comprising a chip of semiconductor material having a radiation receiving surface and wherein the chip has alternate layers of opposite conductivity silicon forming superimposed multiple buried channels at different distances from the radiation receiving surface, each channel being sensitive to radiation of a bandwidth dependent on the distance from the image receiving surface.

2. A colour image sensing device according to Claim 1 wherein the chip of semiconductor material has three buried channels, the channel closest to the radiation receiving surface being sensitive to red, green and blue radiation, the channel farthest from the radiation receiving surface being sensitive only to red radiation, and the intermediate channel being sensitive to only red and green radiation.

3. A colour image sensing device according to Claim 1 or Claim 2 wherein the chip of semiconductor material comprises six layers of alternate conductivity silicon, the first layer, which is closest to the radiation receiving surface, having a thickness of less than 0.7 μm, the first, second and third layers having a combined thickness of less than 2.6 μm, and the first, second, third and fourth layers having a combined thickness greater than 2.6 μm.

4. A colour image sensing device substantially as hereinbefore described with reference to Figures 1—4 of the accompanying drawings.

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