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IMAGE SENSOR DEVICE.

The invention relates to an image sensor device for collecting a radiation image and converting it into an electrical signal which device comprises at least one semiconductor body in which at a major surface a plurality of mutually separated substantially parallel charge transport channels are defined, the semiconductor body being provided at the same major surface with an insulating layer on which for the charge transport an electrode system is disposed which extends above the charge transport channels, windows being provided in the electrode system whereby radiation, in particular short-wave light, can penetrate through the windows into the semiconductor body to produce charge carriers therein, which electrode system comprises a first group of electrodes which extend in a direction transverse to the charge transport channels.

In such a device, which is known from Dutch Patent Application No. 8000999 laid open for public inspection on 16th September 1981, there is produced in the radiation-sensitive part a pattern of charge packets which corresponds to the radiation or exposure pattern and which after the termination of the integration period can be transferred to a storage register (frame/field-transfer). The charge stored in the storage register is then shifted line by line into a shift register, from which it can be read for further processing.

By means of the electrode system, depletion regions can be induced in the underlying semiconductor body, in or near which regions charge carriers can be produced by absorption of radiation. These charge carriers can then be stored in the depletion regions below the electrode system in the form of the aforementioned charge packets.

The embodiment of the said Dutch Patent Application shows an image sensor device which is provided in the radiation-sensitive part with windows which are bounded transversely to the direction of transport by the first group of electrodes and in the direction of transport by parts of an electrode which mainly extend above the transport channels. In this manner, an image sensor device is

obtained comprising an electrode system which is suitable to shift the charge packets produced in the radiation-sensitive part into a storage register by means of a three-phase clock system. In order to obtain a shorter response time and a high speed of transport, the electrode elements parallel to the direction of transport may be interconnected, if desired, by means of transverse connections. Such a structure of the electrodes provides a very high sensitivity especially to blue light for said image sensor device.

For further processing, the stored charge, which corresponds to a sensed image, is generally converted into a signal for a television receiver. It is then usual to activate alternately the even-numbered and the odd-numbered lines of the image screen. It is therefore desirable for this so-called interlacing that within one line period (1/30 - 1/25 second) a transfer from the radiation-sensitive part to a storage register is effected twice, whereby the charge storage takes place alternately in different parts of the radiation-sensitive part. For this purpose, the charge packets are alternately collected in said image sensor device within one image period at different areas, i.e. alternately below the two electrodes of the first group and below the electrode parts limiting the windows in the direction of transport.

However, problems arise with this method of interlacing. One problem consists in that, in order to obtain a high radiation-sensitivity in the relevant image sensor device, the parts located between the windows of the electrodes parallel to the direction of transport have a length exceeding their width. The width of these electrode parts will generally be the minimum track width of the conductor tracks used so as to minimize the surface area to be utilized. In order to obtain a high radiation-sensitivity, the length of these parts is chosen a few times larger, in a typical embodiment, for example 14μm with a (minimum) track width of 3.6μm. When charge is collected under this electrode, the associated depletion region therefore has a surface area of approximately $50\mu m^2$. At the same time, the integration regions are accurately defined due to the fact that the

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relative distance of the electrodes is not excessively large (approximately 5μm) so that electrons produced between the transport channels are distributed over these adjacent transport channels.

In the device shown in the said Dutch Patent Application, in which the channel stopper regions extend under the electrodes of the first group and moreover limit directly the transport channel, during a second integration period charge is collected within the same image period under the electrodes which are located at right angles to the charge transport channel and overlap each other in part. With the same (minimum) track width, in this case the depletion region would occupy at most a surface area of approximately $12\mu m^2$. Moreover, the depletion region thus produced adjoins the surrounding radiation-transparent windows only at the corners. This means that the charge carriers, especially when they are produced at the centre of such a window, have to cover an additionally long path to the depletion region as compared with the situation during the aforementioned first integration period. This effect is increased further by the aforementioned fact that, in the direction of transport, the windows have a larger dimension than in the transverse direction.

In order to avoid this effect, the signals produced could be amplified to a different extent, but this leads to the use of additional control electronics.

The enlargement of the depletion region under the first electrodes by choosing narrower channel stopper regions under these electrodes, is also only partly effective. In fact it has been found that especially due to the large distance from the electrode part parallel to the direction of transport the effective sensitivity of adjacent integration regions can vary considerably owing to process variations and deviations in the geometry of the electrodes due to the fact that owing to the said variations the barrier under these electrode parts is poorly defined. This could possibly be improved slightly by electronic means in that the average value of two image signals is utilized in signal

processing.

The invention has for its object to provide a charge-coupled image sensor device in which these disadvantages can be obviated for the major part by being less sensitive to such process variations and mask deviations.

A further object is to provide such a device in which the charge packets for even- and odd-numbered image lines may be collected in substantially the same manner.

The invention is based on the recognition of the fact that this can be achieved by the use of an electrode structure in which one continuous electrode structure is formed in the radiation-sensitive part of the device above the transport channels so that no loss of transport efficiency occurs, but that this continuous electrode structure can be achieved by means of a second and third group of electrodes which define completely or in part the edges of the windows and are arranged transverse to the direction of transport.

Such a charge-coupled image sensor device according to the invention is therefore characterised in that the radiation-transparent windows, viewed at right angles to the surface, are bounded at least in part by both a second and a third group of electrodes, in that the second group of electrodes are electrically insulated from the first group of electrodes and are part of a second layer of conductive material, in that the third group of electrodes are electrically insulated from the first and second groups of electrodes and are part of a third layer of conductive material, in that the electrodes of the second and third groups extend mainly in a direction transverse to the charge transport channels, and in that the electrodes of the third group overlap in part the electrodes of the second group at least at the area of the charge transport channels.

As a result, a higher steadiness of the windows can be obtained. They may be bounded in the direction of transport by electrodes of the first group provided in one processing step and are bounded in the transverse direction by parts of the electrodes

of the second or third group. Furthermore the electrodes of the second and third groups can take the same form. Possible relative displacements of the second and third groups of electrodes are now substantially equal throughout the semiconductor device and do not influence the size of the windows.

The parts of the electrode above the transport channels, such as described for the image sensor device in Dutch Patent Application No. 8000999, are now effectively subdivided into two groups. This provides the possibility of collecting charge alternately under electrode parts of one of the two groups, these electrode parts being located directly beside the radiation-transparent windows. By means of a four-phase clock system, interlacing can be achieved by collecting charge twice within one image period practically in an identical way from substantially adjacent accurately defined parts of the radiation-sensitive part of the device.

At the expense of a certain amount of space, the relative variation of the size of windows defined in different semiconductor bodies can be reduced even further by causing the windows to be entirely bounded by the electrodes of the second and third groups. Consequently, possible variations in sensitivity to blue light due to alignment tolerances during the manufacture of the first group of electrodes are avoided.

In one preferred embodiment of an image sensor device in accordance with the invention, the electrodes of the first group are alternately coupled to an electrode of the second and of the third group in such a manner that the coupling, at least in the operative condition, introduces a potential difference between the electrodes of the first group and between the electrodes of the second and of the third group, respectively. Such a device is particularly suitable for charge transport by means of a two-phase clock system.

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

Figure 1 shows schematically a circuit arrangement of a

charge-coupled image sensor device to which the invention relates;

Figure 2 shows diagrammatically in plan view a part of the radiation-sensitive part of such an image sensor device in accordance with the invention;

Figure 3 shows diagrammatically in cross-section the image sensor device taken on the line III-III in Figure 2;

Figure 4 shows diagrammatically in cross-section the image sensor device taken on the line IV-IV in Figure 2;

Figure 5 shows diagrammatically in cross-section the image sensor device taken on the line V-V in Figure 2;

Figure 6 shows diagrammatically in plan view a part of the radiation-sensitive part of another image sensor device in acccrdance with the invention;

Figure 7 shows diagrammatically in cross-section the image sensor device taken on the line VII-VII in Figure 6, and

Figure 8 shows diagrammatically in cross-section the image sensor device taken on the line VIII-VIII in Figure 6.

The Figures are schematic and not drawn to scale, whilst for the sake of clarity in the cross-sections in particular the dimensions in the direction of thickness are strongly exaggerated. Semiconductor zones of the same conductivity type are generally cross-hatched in the same direction; in the various embodiments, corresponding parts are generally designated by like reference numerals.

Figure 1 shows a circuit schematic of a charge-coupled image sensor device 1 of the so-called frame/field-transfer type. Such an image sensor device comprises a radiation-sensitive sensor part 2 in which a pattern of electric charge carriers corresponding to the radiation image is formed during a given exposure period. After the exposure period, the pattern of electric charge carriers is stored temporarily in the storage part 3 from which the pattern is read sequentially by means of the shift register 4. This reading can be effected by means of techniques known per se. If desired, the signals obtained may be amplified before further processing by means of the amplifier 22 shown diagrammatically.

The image sensor device (Figures 2 - 5) comprises a semiconductor body 5 which is composed, for example, of a silicon substrate 6 of the n-type having a resistivity of approximately 10Ω.cm (approximately 5.10^{14} donor atoms/cm^3) and a p-type region deposited thereon and having a doping of approximately 3.10^{15} acceptor atoms/cm^3. The p-type region 7 may be deposited, for example, by means of epitaxial growth. At the major surface 8 of the semiconductor body 5, there are defined a plurality of mutually separated substantially parallel charge transport channels (in Figure 1 designated by reference numeral 9), in which charge transport can take place, as indicated diagrammatically in Figure 1 by means of arrows 10. In the present case, the charge transport device is constituted by a charge-coupled device (ccd) with bulk transport (pccd or bccd). The charge transport channels are constituted by n-type regions 11 which are mutually separated by p-type regions 12. The n-type regions in this example have an average impurity concentration of approximately 10^{16} atoms/cm^3 and have a depth of approximately 1μm, while their width amounts to approximately 3.5μm. The p-type regions 12 have at the surface a concentration of approximately 10^{18} atoms/cm^3, while the width of these regions at the surface is approximately 5μm and these regions penetrate to a depth of approximately 0.5μm into the semiconductor body 5.

The major surface 8 is coated with a layer 13 of insulating material, for example, silicon oxide. On this insulating layer 13 is disposed a first set of electrodes, by means of which potential wells can be produced in the semiconductor material for charge storage and charge transport.

This first set of electrodes 15, 16 is mutually insulated and extends in a direction at right angles to the direction of the charge transport channels at intervals of approximately 4μm along the channels.

As a material for the electrodes, for example, polycrystalline silicon may be chosen. Since polycrystalline silicon is comparatively poorly transparent to short-wave (blue) light, the

electrode system is provided with windows 14 through which blue light in particular can penetrate into the semiconductor body 5 and can produce charge carriers therein.

In accordance with the invention, the electrode system therefore comprises a second set of electrodes 17 and a third set of electrodes 18; these are located mainly transverse to the transport channels 11 and have projecting parts 19,20 which extend above these channels 11 in a direction parallel to the charge transport direction. The electrodes 17,18 and the electrodes 15,16 limit the radiation-transparent windows 14 in the transverse direction of the channels 11, while the projecting parts 19,20 of the electrodes 17,18 limit the windows 14 in the longitudinal direction of the channels 11. Above the channel 11 the individual electrodes 18 overlap in part projecting parts 19 of an electrode 17, while projecting parts 20 of the electrodes 18 overlap in part a next electrode 17 located on the other side of the electrode 18. Due to the fact that the charge transport channels 11 are thus covered entirely by the electrode system, no loss of transport efficiency occurs when charge is transported under these electrodes. Above the channels 11 the electrodes 17 and 18 in this embodiment constitute together with the electrodes 15 and 16 an electrode system for a four-phase clock system.

In this configuration, charge carriers produced by radiation can now be alternately integrated in a similar manner in adjacent regions. For this purpose, the relevant charge packets are alternately collected under the projecting parts 19 and 20 of the electrodes 17 and 18, respectively. Upon exposure of the radiation-sensitive part 2 of the image sensor device, charge carriers are produced. Blue light produces charge carriers substantially only to a depth of approximately 0.1µm, in particular in the p-type region 12, which is left free by the windows 14. The holes produced due to this radiation stay in the p-type region 12, while the electrons produced are distributed over the adjacent charge transport channels 11 due to the fact that such a voltage is applied to the electrodes 17 or 18 that potential wells for

electrons are obtained in the charge transport channels under the electrodes 17 or 18.

Light of a greater wave-length can reach the surface 8 also outside the windows 14 and produce charge carriers down to a much larger depth. The electrons flow to the nearest potential wells in the channel regions 11, while the holes are drained through the p-type regions 12 or the p-type substrate 7.

Within one image period, for example, during the first half such a voltage is first applied to the electrodes 17 that under the projecting parts 19 in the channel regions 11 potential wells are formed in which charge packets (electrons) are collected in the manner described above. The projecting parts 19 may have, for example, a length of 5μm and a width of 3.6μm and a mutual spacing of 5μm.

Subsequently, the charge packets are transported to the storage part 3 with the aid of a suitably chosen clock voltage variation at the electrodes 15, 16, 17 and 19 for further processing.

During the second half of the period, potential wells are first formed under the projecting parts 20 of the electrodes 18 which have the same dimensions as the parts 19. Thus, it is achieved that in both halves of one period charge is collected in substantially the same manner in two rows of image elements. After the charge packets have been collected, they are transported to the storage part 3. The clock signals required for the electrodes 15,16,17 and 18 may be used, if desired, to transfer the information still stored from the first half of the image sensing period to an output register 4 for further processing.

An even more favourable method of interlacing can be used in which charge is continuously collected under the electrode parts 19 and 20 of the electrodes 17 and 18. After the integration periods, during the first half of an image period, for example, the charge packets collected under the electrode parts 19 are added to those collected under the electrode parts 20, while during the second half the charge packets collected under the electrode parts 20 are

added to those collected under the parts 19. The adding process is effected such that the charge transport takes place in the direction of the arrows 10.

The storage part 3 need not collect radiation and consequently need not be provided with windows so that as a whole it can be realized on a considerably smaller surface area than the radiation-sensitive part 2.

The required clock signals for the charge transport both in the sensor part 2 and in the storage part 3 can be obtained, like the clock signals for the shift register 4, in a well known manner, for example, by means of shift registers not shown further in Figure 1.

The device can be manufactured in a usual manner. After a p-type epitaxial layer 7 has been grown onto the n-type substrate 6, n-type channels 11 are formed in this layer by means of implantation or diffusion. On the surface 8 is deposited a thin oxide layer and on this layer are formed in a well known manner the electrodes 15, 16, preferably from polycrystalline silicon. After an oxidation step for electrically insulating the electrodes 15,16 the electrodes 17,19 are formed, likewise from polycrystalline silicon. After these electrodes have been electrically insulated again by an oxidation step, the electrodes 18,20 are formed. After the electrode system has been finished in this manner, the regions 12 are formed by means of an implantation step.

The device shown in Figures 1 to 5 can in a simple manner be rendered suitable for a two-phase clock system, i.e. by applying a potential difference between the electrodes 17 and 18 and the electrodes 15 and 16 so that asymmetrical potential wells are obtained. The potential difference, which is indicated diagrammatically in Figure 2 by the voltage source 21, may be applied, for example, by means of a voltage divider, as described in Dutch Patent Application No. 7,200,519 laid open for public inspection, or by means of a capacitive coupling, as described in Dutch Patent Application No. 7,114,859 laid open for public inspection. An additional advantage of this configuration is the

low relative capacitance between the two clock phases because these phases overlap each other over a very small part.

In the device shown in Figures 6 to 8, the electrodes 17,18 are constructed so that they fully define the windows 14. Although this is at the expense of a certain amount of surface area, all the windows 14 are now fully identical; this can be achieved simply in that the same mask is used in the manufacture of the relatively shifted electrodes 17 and 18. Due to the fact that the electrodes 15,16 now do not participate in the definition of the windows 14, mutual tolerances between these electrodes and the electrodes 17,18 no longer influence the size of the windows.

The charge packets are now alternately collected mainly under the connecting parts 19,20 or in the other interlacing method are collected simultaneously under the parts 19 and 20. Otherwise, the reference numerals have the same meaning as in the preceding embodiment.

Of course, the invention is not limited to the embodiments described above, but various modifications are possible for those skilled in the art without departing from the scope of the invention. For example, in a manner analogous to Figures 6 to 8, electrodes 17,18 may be constructed as long strips with openings without fully defining the windows, for example, when the distance between the electrodes 15,16 is smaller than the dimensions of the openings in the transport device. Furthermore, other kinds of transport devices may be used, such as, for example, bucket brigade registers and surface ccd's.

CLAIMS:

1. An image sensor device for collecting a radiation image and converting it into an electrical signal, which device comprises at least one semiconductor body in which at a major surface a plurality of mutually separated substantially parallel charge transport channels are defined, the semiconductor body being provided at the same major surface with an insulating layer on which for the charge transport an electrode system is disposed which extends above the charge transport channels, windows being provided in the electrode system whereby radiation can penetrate into the semiconductor body to produce charge carriers therein, which electrode system comprises a first group of electrodes which extend in a direction transverse to the charge transport channels, characterised in that the radiation-transparent windows, viewed at right angles to the surface, are bounded at least in part by both a second group and a third group of electrodes, in that the second group of electrodes are electrically insulated from the first group of electrodes and are part of a second layer of conductive material, in that the third group of electrodes are electrically insulated from the first and second groups of electrodes and are part of a third layer of conductive material, in that the electrodes of the second and third groups mainly extend in a direction transverse to the charge transport channels, and in that at least at the area of the charge transport channels the electrodes of the third group overlap in part the electrodes of the second group.

2. An image sensor device as claimed in Claim 1, characterised in that the electrodes of the second and third groups are comb-shaped in plan view, the teeth of the comb extending above the charge transport channels.

3. An image sensor device as claimed in Claim 1, characterised in that the radiation-sensitive windows are constituted by openings in the electrodes of the second and third groups.

4. An image sensor device as claimed in any one of Claims 2

and 3, characterised in that the outline of the electrodes of the second and third groups are substantially identical at least in plan view.

5. An image sensor device as claimed in any one of the preceding Claims, characterised in that the electrode system comprises an electrode structure for four-phase charge transport.

6. An image sensor device as claimed in any one of Claims 1 to 4, characterised in that the electrodes of the first group are alternately coupled electrically to an electrode of the second group and to an electrode of the third group in such a manner that at least in the operative condition the coupling introduces a potential difference between the electrodes of the first group and the electrodes of the second and third groups, respectively.

7. An image sensor device as claimed in Claim 6, characterised in that the electrode system comprises an electrode structure for two-phase charge transport.

8. An image sensor device as claimed in any one of the preceding Claims, characterised in that the device is further provided with a control circuit and with at least one circuit for further processing the electrical signal.

9. An image sensor device as claimed in Claim 8, characterised in that the control circuit and the circuit for further processing the electrical signal are realized at least in part in the semiconductor body.

10. An image sensor device substantially as described with reference to Figures 2 to 5 or to Figures 6 to 8 of the accompanying drawings.