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(54) IMPROVEMENTS IN OR RELATING TO IMAGE PICK-UP DEVICES

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195, Broadway, New York City, New York State, United States of America, a Corporation organised and existing under the laws of the State of New York, 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:—

This invention relates to image pick-up devices.

There is currently a widespread attempt to develop area and line imaging devices which are all "solid state" to replace present devices employing a scanning electron beam. Recently, a new form of semiconductor information storage device has been proposed which in one embodiment would permit economical manufacture of such imaging devices—see copending application No. 21832/71 (Serial No. 1,340,619).

Such devices have come to be known as charge coupled devices—see, for example, Tompsett et al, "Charge Coupled 8-Bit Shift Register", Applied Physics Letters, Vol. 17, No. 3, pp. 111—115. Briefly, in these devices information in the form of charge carriers may be moved through a semiconductor material by successively biasing a row of electrodes comprising MIS devices. Charge transfer is thus realized by successively creating in the semi-conductor material potential wells (e.g., depletion regions) into which the charge carrier will be attracted. The charge carriers may be generated in many ways. One method is to generate hole-electron pairs in the material by photon absorption. Minority carriers will then be swept into the potential wells formed under the biased electrodes.

It has therefore been suggested that the charge coupled device concept may be used in an imaging device comprising basically an array of MIS devices wherein minority

carriers are formed in proportion to incident light, and read-out merely by sequentially biasing the metal electrodes—see the above-mentioned patent application.

One of the difficulties associated with the device as proposed is a lack of sharp resolution. Because light is continually incident on the MIS array, minority carriers will be swept into the potential wells formed under the electrodes during readout, thus causing a smearing of the image.

According to this invention an image pick-up device includes a charge storage medium, first and second arrays of electrodes adjacent to and insulated from a surface of said medium, means for projecting an image onto a surface of said medium to form charge carriers therein, means for shielding the region of said medium beneath said second array from incident radiation, and means for biasing said first array of electrodes to collect charge carriers representative of the projected image in the region of said medium beneath said first array, for transferring charge carriers from the region of said medium beneath said first array to the region of said medium beneath said second array, and for reading out charge carriers stored in the region of said medium beneath said second array.

In one embodiment said first array may comprise a row of interconnected electrodes, and said second array may comprise another row of interconnected electrodes parallel and adjacent to said row to form columns of electrodes therewith, and a row of readout electrodes parallel and adjacent to said other row, said biasing, transferring and reading means being adapted to bias said readout electrodes sequentially.

In another embodiment said first array may comprise a plurality of electrodes arranged in rows and columns the electrodes in each row being interconnected, and said second array may comprise a second plurality of electrodes arranged in rows parallel to

the rows of said first array and in columns extending the columns of said first array the electrodes in each row of said second array being interconnected, and a row of readout electrodes parallel and adjacent to the final interconnected row in said second array, said

Where the storage medium is a body of semiconductor material there is preferably provided means for isolating charge carriers in the region of said medium beneath each of said columns of electrodes from charge carriers in the region of said medium beneath the adjacent column or columns of said electrodes. The isolating means may include means for forming depletion regions in said medium between adjacent columns of electrodes. Preferably there is also provided means for forming a depletion region in said medium in the area around said arrays to inhibit semiconductor-insulator interface charge recombination.

The invention will now be described by way of example with reference to the accompanying drawing in which:

Figs. 1A—1C are schematic views of an area imaging device in accordance with the invention and are provided to demonstrate the device operation;

Fig. 2 is a schematic plan view of the device shown in Fig. 1;

Fig. 3 is a cross-sectional view taken along line 3—3' of Fig. 2; and

Fig. 4 is a plan schematic view of a line imaging device in accordance with the invention.

Figs. 1A—1C and Fig. 2 show, for the purpose of simplicity, an area imaging device with a sensing array of just four elements by six elements. Clearly the present invention also finds application in much larger arrays.

Referring now to Fig. 1A, the device includes a semiconductor bulk portion 10 which, illustratively, may be n-type silicon. Overlying the surface of the bulk is a dielectric layer, 11, which may be, for example, silicon dioxide. Situated on top of this dielectric layer is a series of metal electrodes 12a—d, 13a—d, 14a—d and 15. In the view shown in Fig. 1A these electrodes form one column of MIS devices in the area imaging device.

The image of an object, such as 30, is projected on the surface of the semiconductor bulk opposite the electrodes by means of a light source 16 and a lens 29. One portion of this surface is shielded from the light by some means such as an opaque field stop 17. The actual means employed for this shielding purpose is unimportant. The device may therefore be considered divided into two portions. The first six electrodes form one column of the area sensing array, while the

last seven electrodes form one column of the area storage and readout array, as will be described in more detail below. It should be noted that the image may also be projected on the electrode side of the semiconductor bulk if transparent electrodes are provided.

In the sensing portion, electrodes 12a and 12b are coupled to a conduction path A_1 , electrodes 13a and 13b are coupled to a path A_2 and electrodes 14a and 14b are coupled to a path A_3 to define a three-phase charge coupled system. Likewise, every third electrode of the storage and readout portion is coupled to one of the conduction paths B_1 , B_2 or B_3 with the exception of electrode 15 which is coupled to a conductor path C_1 . Clock pulses are supplied to each of these conduction paths in order to sequentially bias the electrodes as will be explained below. Means are provided for allowing the corresponding electrodes of the two portions (e.g., 12a, 12b, 12c and 12d) to be pulsed simultaneously at certain points in time. These means are illustrated schematically as switches 18, 19 and 20. In order to read out the charge information, means are also provided for coupling conduction path C_1 to path B_1 , again illustrated as a switch 21.

The operation of the device may be seen by first referring to the sequence of steps illustrated in Figs. 1A—1C. In Fig. 1A, a pulse has been applied to electrodes 13a and 13b from conduction path A_2 to form potential wells in the semiconductor material, 10, beneath the electrodes. The light incident on the material generates hole-electron pairs therein and minority carriers then diffuse to the nearest potential minimum (as described in the above-mentioned copending application). The minority carriers, represented by "+" in the figure, which have been swept into each potential well, are therefore representative of the light intensity on the semiconductor surface over the area covered by each set of three electrodes (12a, 13a, 14a, and 12b, 13b, 14b, respectively).

These "packets" of charge may be moved through the semiconductor by sequentially pulsing the electrodes and therefore forming successive potential wells into which the charge will flow. Thus, the corresponding conduction paths of the sensing portion and the storage-readout portion of the device are coupled together and a pulse sequentially applied to A_1 , A_2 and A_3 at a rapid rate to move the charge quickly out of the sensing portion into the storage-readout portion. At the stage shown in Fig. 1B, the charge "packets" now reside under electrodes 13c and 13d where they are held. The rapid transfer has prevented any significant smearing effects and since the storage-readout portion is shielded from the light, the charge may now be read out at a slower rate without any additional collection of minority carriers.

In order to read out the information from the storage-readout portion, the conduction paths of the two portions are decoupled. This permits conduction paths B_1 , B_2 and B_3 to be pulsed while conduction path A_2 remains pulsed such that the information in the storage-readout section is read out while the sensing section continues to integrate. In the readout operation, conduction path C_1 must be coupled to B_1 by closing switch 21 so that charge may be transferred to the area below the last electrode. At the stage shown in Fig. 1C, the conduction paths have been pulsed in the sequence B_3 — B_1 — B_2 so that the first "packet" of charge has been transferred to the area below electrode 15, while the second "packet" is held under 13d. The first "packet" can now be read out in a direction out of or into the page since electrode 15 represents one electrode in a serial readout array. This is described below with reference to Fig. 2. The second "packet" can subsequently be transferred to electrode 15 by the same sequence of pulses and readout. In the meantime the sensing array continues to collect charge under electrodes 13a and 13b and the process of transfer and readout is repeated.

Fig. 2 illustrates the full area array formed by four columns of devices shown in Figs. 1A—1C. Thus, each electrode of Figs. 1A—1C forms part of a row of four elements which are coupled in common to one of the conduction paths. In the view shown, the interconnections between electrodes in a row have been partially cut away to illustrate the basic structure of the device. When conduction path A_2 is pulsed, charge will collect beneath the electrodes in the second and fifth rows of the sensing array. Then, by pulsing the electrodes in the manner previously described, the charge is transferred to the area beneath the rows of storage electrodes coupled to path B_2 and subsequently read out a line at a time. The readout operation is performed by the electrodes 22 of which electrode 15 already mentioned is a part. A row of charge "packets" is transferred into the area beneath this last row by pulsing the conduction paths B_1 , B_2 and B_3 while conduction path C_1 is coupled to B_1 through switch 21. After decoupling C_1 , the conduction paths of the last row are pulsed in the sequence C_2 — C_3 — C_1 to move the charge laterally into some output stage such as a region of diffused p-type semiconductor material, 23, where the charge can be detected by a variety of methods known in the art. The operation of the device may therefore be described in general as a parallel transfer of charge to a serial readout.

Since charge is being transferred through the semiconductor a row at a time, it is desirable to provide some means of preventing coupling of charge from one column of

electrodes to the next while forming the array of electrodes as densely packed as possible. In Fig. 2 this is accomplished by providing strips of metal, 24, overlying the dielectric material at the edges of the device and in the area between the columns of electrodes.

This structure can be more easily appreciated with reference to Fig. 3 which is a cross-sectional view along line 3—3' of Fig. 2. The row of electrodes in Fig. 3 has been pulsed "on" and minority carriers transferred to the area of the bulk underneath. The metal strips 24 are maintained at a constant negative bias to form depletion regions in the bulk material which are much shallower than those formed by the pulsed electrodes. This creates potential barriers between the packets of charge residing under each electrode in the row which prevent charge from moving into an adjacent column.

The biased metal strips perform the further function of maintaining transfer efficiency. In actual practice, it is desirable to apply a uniform bias to all electrodes so as to maintain shallow depletion regions in the bulk when the electrodes are not pulsed. This is done to prevent recombination of charge which has been trapped at the bulk-dielectric interface. Recombination would still occur, however, in the areas just beyond the edge of each electrode since the depletion regions formed at resting potential are essentially confined to the areas just beneath the electrodes. In the imaging device described, this would give rise to poor transfer efficiency and charge loss which would become significant for small area electrodes. The depletion regions formed in these edge areas by the metal strips, however, eliminate this undesired recombination.

Fig. 3 also illustrates one technique for forming a row of electrodes in the imaging device. After the metal strips 24 are formed on the dielectric surface, a dielectric material 25 is deposited on the strips. A metal can then be deposited over the resulting structure to form the electrodes such as 13c and the interconnections thereto so that the row of electrodes may be coupled to one of the conduction paths (in the row shown in Fig. 3, to B_2).

It should be clear from the description of the area imaging device above that a great many modifications are feasible. While the device has been described in terms of a three-phase charge coupled system, a four-phase or two-phase system may be employed. (For an example of the latter, see copending application No. 21833/71 (Serial No. 1,340,620). Several other means are also available to prevent cross-coupling. For example, in the case of n-type silicon described, a diffusion of n+ conductivity-type material into the bulk between the columns should provide adequate shielding. In addition, the

device may be designed so that the first row of charge "packets" is transferred from the sensing array directly into the last row of electrodes (22 in Fig. 2) for serial readout thereby keeping the number of rows of electrodes to a minimum.

Referring now to Fig. 4 a line imaging device, shown in plan view, has a sensing array which consists of a single row of electrodes 26 which are coupled to a conduction path D_1 . Interconnections have been omitted in this view for the sake of clarity. As before, supplying a bias to this row of electrodes forms minority carriers in the semiconductor bulk in proportion to incident light. The second and third row of electrodes are shielded from the light and may be considered the transfer and readout array. These rows are coupled to conduction paths D_2 and E_1 , respectively. Once again, metal strips 27 are provided to prevent cross-coupling between adjacent columns and maintain transfer efficiency. In operation, the "packets" of charge are transferred out of the area under the first row of electrodes into the area beneath the third row by pulsing the conduction paths in the sequence $D_2-E_1-D_1$. D_1 is then held at a pulsed "on" condition so that the first row integrates while the "packets" in the third row are read out. As in the area imaging device, the row of charge packets is read out serially by sequentially pulsing conduction paths E_1 , E_2 and E_3 until all the charge is transferred to an output stage such as a diffusion 28 where the signal is detected. Once again it should be clear that the array shown in Fig. 4 is illustrative only, and in actual practice a row would comprise many more electrodes. In such case, signal degeneration may arise due to the large number of transfers necessary in the serial readout operation. To avoid this problem, several readout diffusions 28 may be interspersed in the last row and the signals subsequently combined.

It should be noted that while the invention has been described with a semiconductor material as the charge storage medium, it has been previously found that the charge coupled device concept is equally applicable to materials normally considered insulating or semi-insulating. The use of these materials is described fully in copending application No. 21832/71 (Serial No. 1,340,619), and the present invention may be performed with them.

Various logic circuits may be employed to pulse the electrodes of the area and line imaging devices in the manner described and can readily be devised by those skilled in the art. Consequently, a description of these circuits has been omitted.

WHAT WE CLAIM IS:—

1. An image pick-up device including a charge storage medium, first and second arrays of electrodes adjacent to and insulated from a surface of said medium, means for projecting an image onto a surface of said medium to form charge carriers therein, means for shielding the region of said medium beneath said second array from incident radiation, and means for biasing said first array of electrodes to collect charge carriers representative of the projected image in the region of said medium beneath said first array, for transferring charge carriers from the region of said medium beneath said first array to the region of said medium beneath said second array, and for reading out charge carriers stored in the region of said medium beneath said second array.

2. A device as claimed in claim 1 wherein said first array comprises a row of interconnected electrodes, and said second array comprises another row of interconnected electrodes parallel and adjacent to said row to form columns of electrodes therewith, and a row of readout electrodes parallel and adjacent to said other row, said biasing, transferring and reading means being adapted to bias said readout electrodes sequentially.

3. A device as claimed in claim 1 wherein said first array comprises a plurality of electrodes arranged in rows and columns the electrodes in each row being interconnected, and said second array comprises a second plurality of electrodes arranged in rows parallel to the rows of said first array and in columns extending the columns of said first array the electrodes in each row of said second array being interconnected, and a row of readout electrodes parallel and adjacent to the final interconnected row in said second array, said biasing, transferring and reading means being adapted to bias said readout electrodes sequentially.

4. A device as claimed in any one preceding claim wherein said medium is a body of semiconductor material.

5. A device as claimed in claim 4 when appended to claim 2 or 3 including means for isolating charge carriers in the region of said medium beneath each of said columns of electrodes from charge carriers in the region of said medium beneath the adjacent column or columns of said electrodes.

6. A device as claimed in claim 5 wherein said isolating means includes means for forming depletion regions in said medium between adjacent columns of electrodes.

7. A device as claimed in claim 6 including means for forming a depletion region in said medium in the area around said arrays

device may be designed so that the first row of charge "packets" is transferred from the sensing array directly into the last row of electrodes (22 in Fig. 2) for serial readout thereby keeping the number of rows of electrodes to a minimum.

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2. A device as claimed in claim 1 wherein said first array comprises a row of interconnected electrodes, and said second array comprises another row of interconnected electrodes parallel and adjacent to said row to form columns of electrodes therewith, and a row of readout electrodes parallel and adjacent to said other row, said biasing, transferring and reading means being adapted to bias said readout electrodes sequentially.

3. A device as claimed in claim 1 wherein said first array comprises a plurality of electrodes arranged in rows and columns the electrodes in each row being interconnected, and said second array comprises a second plurality of electrodes arranged in rows parallel to the rows of said first array and in columns extending the columns of said first array the electrodes in each row of said second array being interconnected, and a row of readout electrodes parallel and adjacent to the final interconnected row in said second array, said biasing, transferring and reading means being adapted to bias said readout electrodes sequentially.

4. A device as claimed in any one preceding claim wherein said medium is a body of semiconductor material.

5. A device as claimed in claim 4 when appended to claim 2 or 3 including means for isolating charge carriers in the region of said medium beneath each of said columns of electrodes from charge carriers in the region of said medium beneath the adjacent column or columns of said electrodes.

6. A device as claimed in claim 5 wherein said isolating means includes means for forming depletion regions in said medium between adjacent columns of electrodes.

7. A device as claimed in claim 6 including means for forming a depletion region in said medium in the area around said arrays



to inhibit semiconductor-insulator interface charge recombination.

- 5 8. An image pick-up device arranged and adapted to operate substantially as herein described with reference to the accompanying drawing.

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