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Wilson et al.

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[54] **METHOD AND APPARATUS FOR STORING AND READING OUT CHARGE IN AN INSULATING LAYER**

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[51] **Int. Cl.** ... **G11c 5/02,** G11c 11/34, G11c 13/04

[58] **Field of Search** .... 340/173 LS, 173 CR; 317/235 NA; 313/65 A, 65 T, 89, 65 AB

[56] **References Cited**

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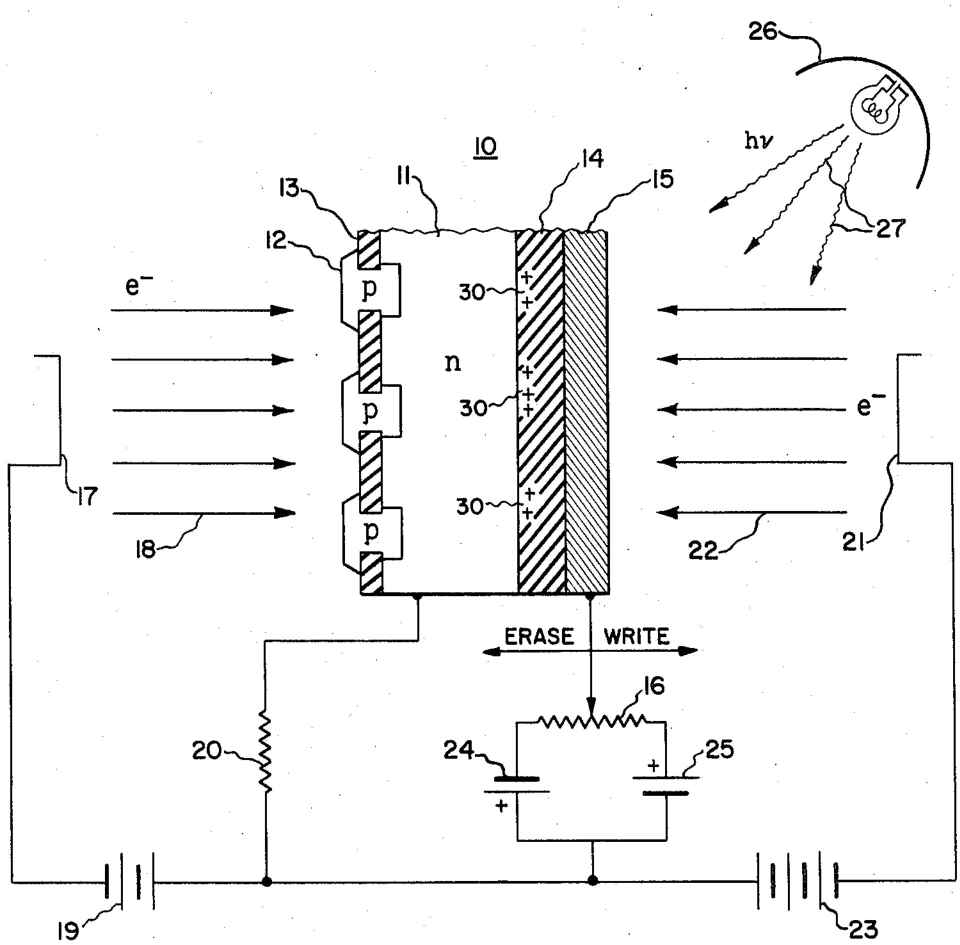
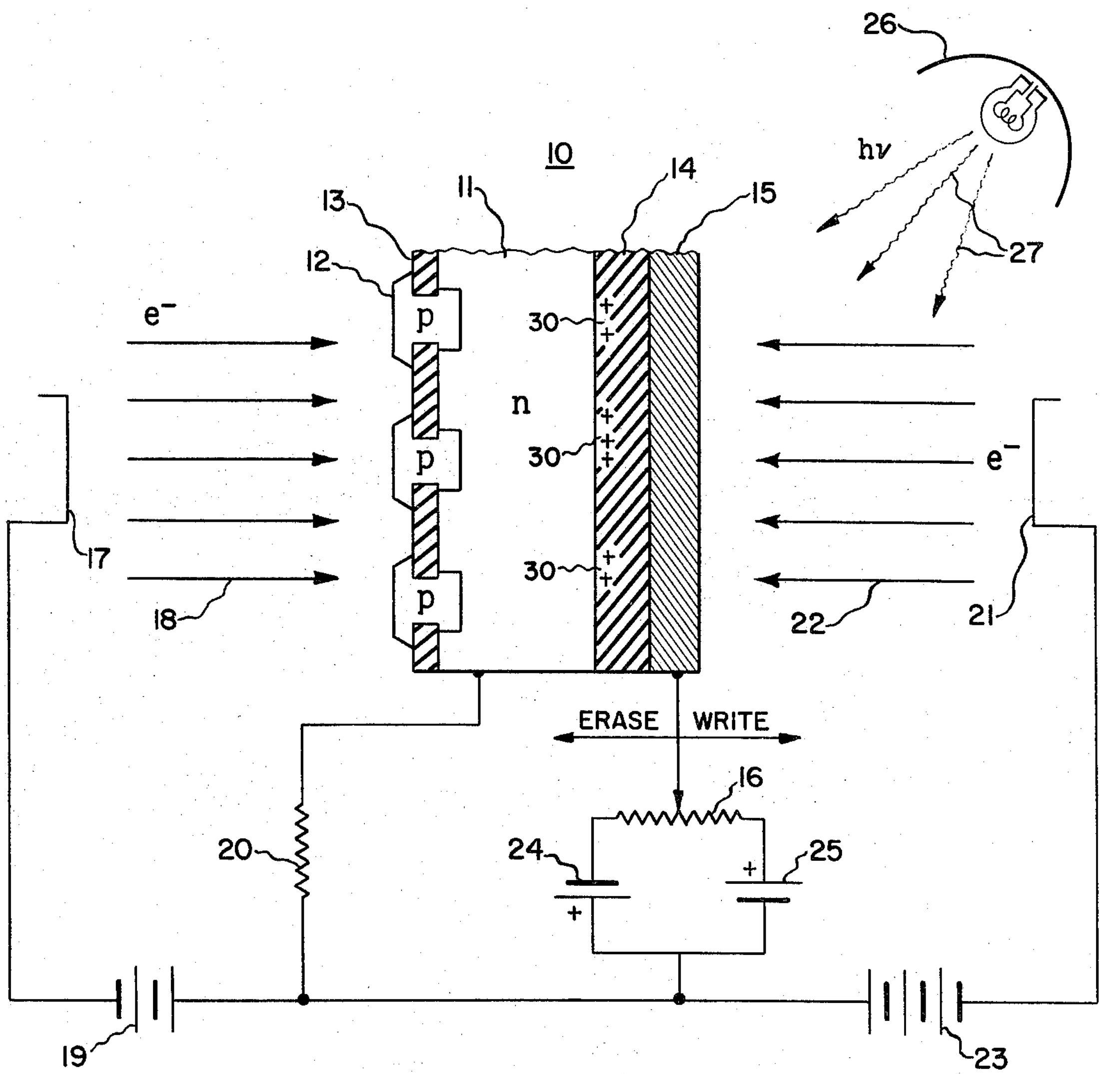
[57] **ABSTRACT**

A diode storage array, including a diode array on one face of a semiconductor wafer, an insulating layer overlying the opposite face of said wafer and a conductive layer overlying the insulating layer, is written upon by irradiating the conductive layer side of said wafer to induce charge storage in the insulating layer. The radiation may be high energy photons, a scanned electron beam or electrons from a photo-emitter. Readout is accomplished by irradiating the target with lower energy radiation to form electron-hole pairs in the wafer. The holes are selectively driven to the diode side of the wafer under the control of the stored charge where selected, reverse biased, diodes are discharged. Subsequent scanning of the diode array by an electron beam produces a variable output signal, indicative of the information stored. Since the charge on the insulating layer is not dissipated, the information can be read as often as desired.

10 Claims, 1 Drawing Figure

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METHOD AND APPARATUS FOR STORING AND READING OUT CHARGE IN AN INSULATING LAYER

This invention relates to diode array storage targets and, in particular, to a method for writing and reading with such targets.

In the prior art, diode array targets are used for a variety of functions, such as imaging devices and scan converters. In such applications attempts at providing storage capability in excess of the typical 1/30 second, the approximate time needed for scanning the entire target once, have resulted in "storage" times on the order of a few seconds. Longer storage times have been obtained by mechanisms that, in effect, interfere with the operation of the target, thereby slowing the response of the target. For example, a semi-insulating layer has been interposed between the diode array and the electron beam to reduce recharging effects of the electron beam during readout, thereby retaining some charge indicative of the information stored. However, storage targets of this type that have an appreciable storage time generally require a longer time for reading.

Alternatively, it has been proposed to store charge on the oxide on the diode side of the target. This, however, can compromise the operating characteristics of the target; e.g., charge build-up on the oxide layer during non-storing operation. Some diode array targets utilize one or more protective layers to prevent charge build-up on the oxide. However, to provide storage capability, these protective layers cannot be used.

In addition, the information stored is destructively read out in many of the systems of the prior art, i.e., the charge representing the information stored is utilized directly in the read operation and is partially or totally dissipated. Further, many systems of the prior art are not capable of carrying out the read and write functions simultaneously.

Thus, there is a need in the art for a method of writing and reading in diode array targets that provides long term, i.e., virtually indefinite, erasable storage while also providing non-destructive readout, simultaneous read and write capability, and read times comparable to non-storing targets.

In view of the foregoing, it is therefore an object of the present invention to provide a method for writing information in a diode array memory so that the information is erasable but can be stored for as long as desired.

Another object of the present invention is to provide a method for writing and reading diode array targets producing long term storage and non-destructive readout.

A further object of the present invention is to provide long term storage and rapid readout of diode array memories.

Another object of the present invention is to provide a writing and reading method for diode array storage targets in which the information stored is not directly utilized in reading.

A further object of the present invention is to provide a writing and reading method for diode array storage targets in which the electrical effect of charge representing stored information is utilized for reading.

Another object of the present invention is to provide a diode array storage target in which the reading and writing operations can be performed simultaneously.

The foregoing objects are achieved in the present invention wherein information is stored as an electric charge in an insulating layer overlying one surface of a semiconductor wafer. Reading is accomplished by inducing electron-hole pairs in the semiconductor and allowing the holes to diffuse through the wafer to the opposite surface, which contains the p-n junction array. At the p-n junction surface the holes recombine with electrons previously deposited by an electron beam to reverse bias the diodes. During a subsequent scan of the array by the electron beam, variations in the current required to restore the diodes to a reverse biased condition are indicative of the information stored.

Since the charge is stored in the insulator, it is not dissipated. By inducing the electron-hole pairs from an external source, the information can be read as often as desired or continuously. The information stored can be erased or changed as desired by suitably irradiating the insulating layer with the more energetic radiation.

A more complete understanding of the present invention can be obtained by considering the following detailed description in conjunction with the accompanying drawings, in which:

The FIGURE illustrates a diode array target system suitable for use in the present invention.

The FIGURE illustrates a preferred embodiment of the present invention wherein a diode array camera tube target is modified by the application of charge storage layers to the substrate on the opposite side of the diode array. The net result is a combination that provides a unique cooperation between the charge stored and diode array elements so as to provide a storage camera tube target that is extremely flexible in operation.

Specifically, target **10** comprises substrate **11** comprising an n-type semiconductor material onto which p-type conductivity regions **12** are grown through a plurality of apertures in apertured insulating layer **13.** Coupled to n-type conductivity substrate **11** is output resistor **20,** across which the video output signal is obtained. Connected to output resistor **20** is a source of potential **19** for suitably biasing the target relative to cathode **17.**

The target as thus described is similar to a target described by William E. Engeler in application Ser. No. 60,767, filed Aug. 3, 1970 and assigned to the same assignee as the present invention. While this particular form of diode array is shown and described it should be understood that any suitable diode array target may be utilized in carrying out the present invention. However, this particular diode array does not require the protective layers noted above.

The face of substrate **11** opposite the face in which p-type conductivity regions **12** are formed is covered by insulating layer **14,** which may conveniently comprise an oxide of substrate **11.** Layer **14** in turn is covered by a transparent conductive layer **15.** Layer **15** is connected to sources of operating potential **24** and **25** by way of potentiometer **16,** for example. Sources of operating potential **24** and **25** are further connected to a common point comprising the junction of potential source **19** and output resistor **20.** Cathode **21** is biased realtive to the target by way of bias means **23** which is also connected to the common point. Also illustrated in the FIGURE, is a source of light **26** producing photon energy illustrated by rays **27.**

The overall operation of the present invention shall be described in three parts. The first relating to the diode array, left-hand portion of the target illustrated in the FIGURE, the second relating to the operation of the right-hand portion of the target as illustrated in the FIGURE, and finally the cooperation of these two sections together.

Ignoring for the moment the presence of layers **14** and **15**, the operation of a diode array target is relatively well known and may be summarized as follows: As an initial step, the diode array is scanned by electrons **18** eminating from cathode **17.** This scan negatively charges p-type conductivity regions **12** relative to substrate **11.** Input information, generally an optical image, applied to the opposite face of the substrate **11** forms a pattern of electron hole pairs, the holes of which diffuse to the diodes and discharge the diodes in proportion to the intensity of the light absorbed in that area of the substrate. As the electron beam rescans the diode side of the substrate, the current necessary to recharge the p-type conductivity regions is proportional to the amount by which the p-type conductivity regions were discharged. This current flows in a circuit comprising cathode **17,** electron beam **18,** target **10** and output resistor **20.** Thus, the current flowing through output resistor **20** provides a video signal corresponding to the pattern of light incident upon the substrate. It may be noted that the operation of this type of target requires the continuous application of input information on the opposite face of the substrate. The storage time of the diode portion of the target is dependent upon the time it takes the dark current to completely discharge the diodes.

The right-hand side of target **10** as illustrated in the FIGURE operates to store charge in proportion to input information in insulating layer **14** for relatively long periods of time, e.g., several tens of hours. The storage of charge in insulator **14** is not permanent, i.e., the information can be readily erased.

The charge in insulating layer **14** can be created by a variety of means, such as a scanned electron beam, electrons from a photoemitter, or high energy photons. For the preferred embodiment of the present invention, it will be assumed that the pattern of charge is to be obtained from an electron beam.

Electron beam **22** emanating from cathode **21** is directed so as to write the information in a predetermined pattern as charge in insulating layer **14.** This is accomplished by utilizing a high energy electron beam, for example, 10 kilovolts. During the writing operation, transparent conductive layer **15** is biased positively with respect to n-type conductivity substrate **11.** In so doing, mobile electrons induced in insulating layer **14** by electron beam **22** are drawn off through transparent conductive layer **15.** Electron beam **22** is then terminated and a pattern of positive charges **30** is stored in insulating layer **14.**

The charge stored in insulating layer **14** can be removed in the same way it was created, except that transparent conductive layer **15** is biased negatively or not at all with respect to substrate **11.** Thus, the changeover from one mode of operation to another is very simply and easily accomplished. After all or part of the information is erased, a subsequent writing operation is performed to store new information in the erased areas.

The pattern of positive charges **30** is retained by insulating layer **14** for a relatively long time. As will be apparent from the following description of the operation of the two halves of the target together, the charge stored in insulating layer **14** is not used directly in the read out of the pattern of charged storage. Further, it should be noted that the writing operation and the reading operation are independent so that no restriction is placed on the operation of either half of target **10.**

During readout, the storage face of target **10** is illuminated by light from source **26.** Since the energy contained in a photon is proportional to the frequency (ν) of the photon it is preferable to illuminate the target with light of frequency in the range of visible light so that the positive charge pattern **30** is not changed during the reading operation, regardless of the setting of potentiometer **16.**

The incident photons penetrate into n-type conductivity substrate **11** thereby forming electron-hole pairs. Due to the storage of positive charge, the holes of the electron-hole pairs are repelled away from the storage side of target **10** to the diode side of target **10** where they discharge those diodes approximately opposite the location of the stored positive charge. In the absence of stored charge the electron-hole pairs diffuse to the interface between substrate **11** and insulator **14** where they recombine and are lost. For a silicon wafer, blue light is preferred so that the holes are created near the storage layer thereby increasing the modulation efficiency of the stored charge pattern. Thus, the pattern of charge storage is transferred from the right-hand side of target **10** as illustrated in the FIGURE to the left-hand side of target **10.** Readout of the diode array is then accomplished as described above, wherein the diodes are scanned by an electron beam and the amount of charge necessary to restore the charged condition is monitored across output resistor **20.**

As noted above, the readout and charge storage operations are completely independent since the stored charge is only used indirectly in discharging the diodes. This enables what may be generally described as special effects to be performed with the stored information. For example, the storage of information and the scanning by electron beam **18** can occur at different rates. Also, the pattern of scanning need not be the same for both the storage of information and the reading of information. For example, apparent motion can be obtained in an image by modifying the location of the starting point of the scan by electron beam **18.**

It should be emphasized that radiation in the visible region incident upon the storage side of target **10** has no effect on the stored charge regardless of the setting of potentiometer **16.** Information is written only with higher energy radiation when transparent conductive layer **15** is biased positively relative to substrate **11.** Erasure of the entire stored charge is carried out by negatively biasing transparent conductive layer **15** during higher energy irradiation, as by electron beam **22.** In this case, mobile electrons are induced and recombine with the positive charge stored in layer **14** to bring the net charge on insulating layer **14** to zero. Obviously, erasure can be either partial (one area or only part of the charge) or total (all of layer **14** or all of the charge). It should be further noted that no structure is required on the storage side of target **10**, thereby enabling a maximum of resolution to be obtained. The storage side of target **10** operates by controlling the recombination of induced electron-hole pairs by repelling the holes from the storage side of the target so that they diffuse to the diode side of the target where they discharge the diodes in the same pattern as the stored charge.

Target **10** can be fabricated in any suitable fashion, as, for example, set forth in the above-noted application of William E. Engeler, with the addition of layers **14** and **15**. Substrate **11** can be a silicon wafer on the order of 15 μ thick and the apertures through which p-type conductivity regions **12** are grown can be on the order of 8 μ in diameter. Insulating layer **14**, which may comprise several layers of insulating material, can be on the order of 5,000A. thick, necessitating a write/erase beam in excess of about 5kV. The intensity of the illumination from blue light source **26** can be on the order of $(10)^{-6}$ watts per square cm. The bias voltage on transparent conductive layer **15** can be ±50 volts. It is to be understood that the foregoing values are exemplary only and not limiting.

Having thus described the invention it will be apparent to those skilled in the art that various modifications can be made without departing from the spirit and scope of the present invention. For example, as previously noted, p-type conductivity regions **12** need not be epitaxially grown but may be formed simply as diffused regions. The source of bias potential for transparent conductive layer need not be as shown but may employ other, more elaborate sources, such as pulses for selecting write, neutral and erase in synchronism with the deflection of beam **22**. Also, any suitable deflecting means may be employed.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. An information storage target comprising:

a substrate of a first type conductivity semiconductor having first and second opposite sides;

a diode array formed on said first side;

an insulating layer, overlying said second side, for storing information in the form of electric charge; and

a conductive layer, overlying said insulating layer, for controlling the writing and erasing of information in said insulating layer.

2. The method of writing, storing, reading and erasing information in a diode array target, containing a diode array on one face of a semiconductor wafer, an insulating layer overlying the opposite face of said wafer, and a transparent, conductive layer overlying the insulating layer, comprising the steps of:

selectively irradiating the insulating layer to induce mobile electrons therein;

drawing off said mobile electrons to selectively charge said insulating layer by biasing said conductive layer to one polarity;

inducing electron-hole pairs in said wafer;

preventing recombination of said pairs and allowing at least one of said electrons and holes to diffuse to the diode side of said wafer; and

scanning the diode side of said wafer with an electron beam to read out said stored information.

3. The method as set forth in claim **2** and further comprising the steps of:

biasing said conductive layer to a second, opposite polarity; and

irradiating the insulating layer to induce mobile electrons in said insulator for neutralizing the charge on said insulating layer.

4. The method as set forth in claim **2** wherein said inducing step comprises:

irradiating said target with photons of light.

5. The method as set forth in claim **2** wherein the step of selectively irradiating comprises:

selectively irradiating the insulating layer with an electron beam penetrating said conductive layer to induce mobile electrons in said insulating layer.

6. An information storage system comprising

a semiconductor diode array target comprising a planar semiconductor substrate having a diode array on one side and an insulating layer covering the opposite side;

means for storing information in the form of electric charge in said insulating layer;

means for irradiating said opposite side of said target for inducing electron-hole pairs in said substrate, said stored charge preventing recombination of said pairs to allow diffusion of at least one of said electrons and holes toward the diode array side of said target, thereby transferring the information from one side of the target to the other; and

means for reading said information from said diode array.

7. The information storage system as recited in claim **6** wherein said target further comprises a transparent, conductive layer overlying said insulating layer and said means for storing information comprises:

a source of electron beam for irradiating selected portions of said insulating layer; and

bias means coupled to said transparent, conductive layer and said substrate for biasing said conductive layer relative to said substrate.

8. The information storage system as set forth in claim **6** wherein said means for reading said information comprises:

a source of an electron beam for irradiating selected portions of said diode array.

9. The information storage system as set forth in claim **6** wherein said means for irradiating said target comprises a source of light.

10. The information storage system as set forth in claim **9** wherein said light is blue.

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