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[11] **3,778,657**

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[54] **TARGET HAVING A MOSAIC MADE UP OF A PLURALITY OF P-N JUNCTION ELEMENTS**

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[21] Appl. No.: **224,991**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 859,448, Sept. 16, 1969, abandoned.

[52] **U.S. Cl.** .... **313/65 A,** 313/66

[51] **Int. Cl.** **H01j 31/28**

[58] **Field of Search** .... 313/65 A, 66

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[57] **ABSTRACT**

An image pick-up device has a target arranged to be scanned by an electron beam in a scanning direction and comprising a semiconductor of P- or N- type substrate, and a plurality of semiconductive regions of N- or P-type on the substrate and forming P-N junction elements spaced from and isolated from each other, which elements are so arranged that at least one axis defined by a line connecting the centres of successive most closely adjacent elements is oblique relative to the scanning direction.

2 Claims, 8 Drawing Figures

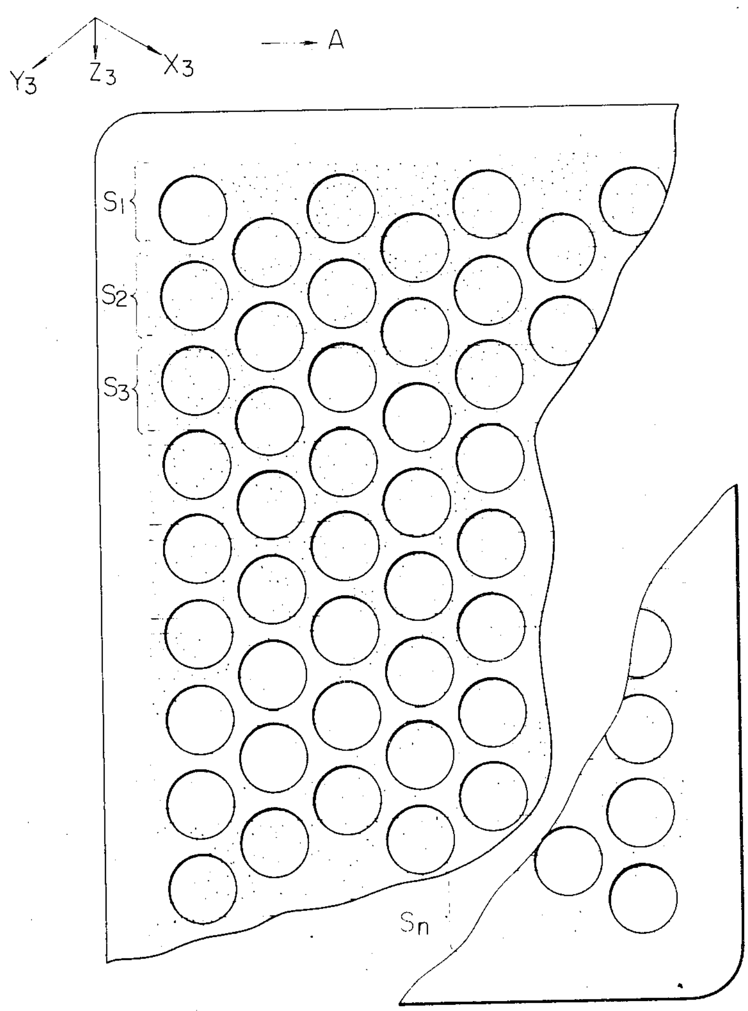

Fig. 1

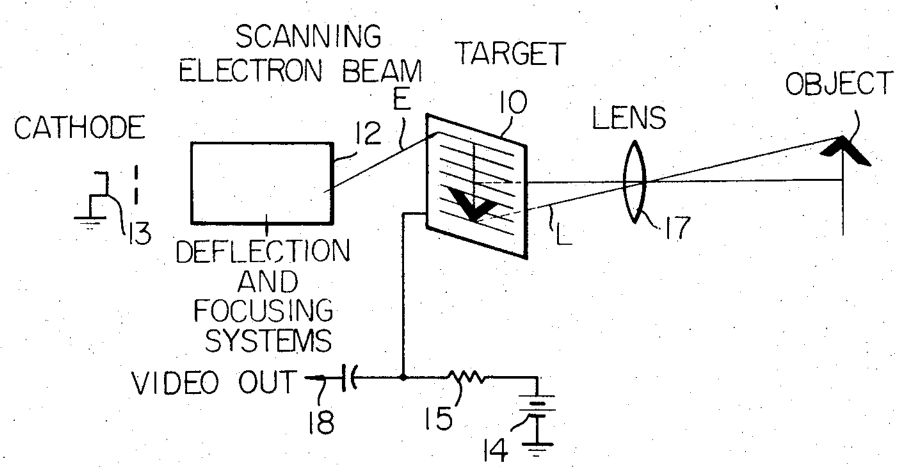

Fig. 2

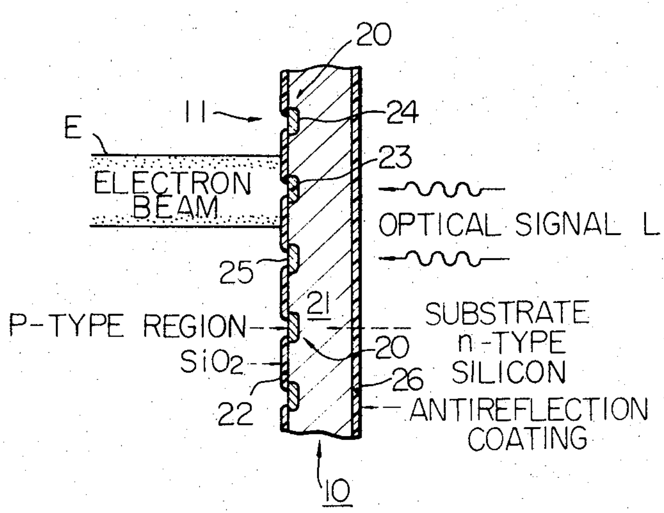

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Fig. 3

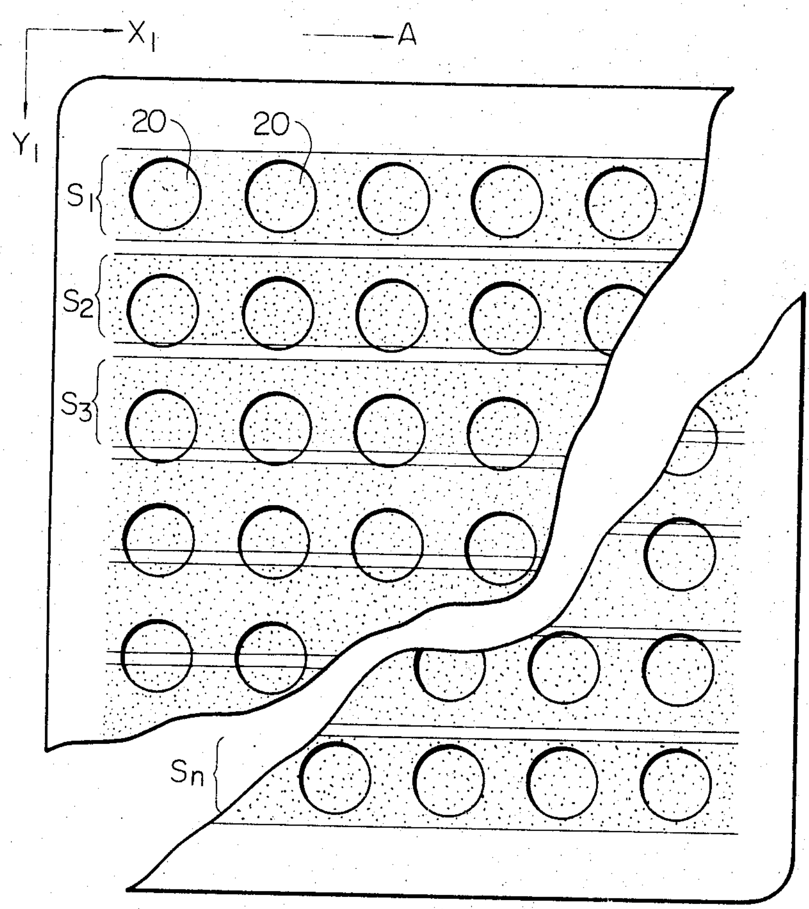

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Fig. 4a

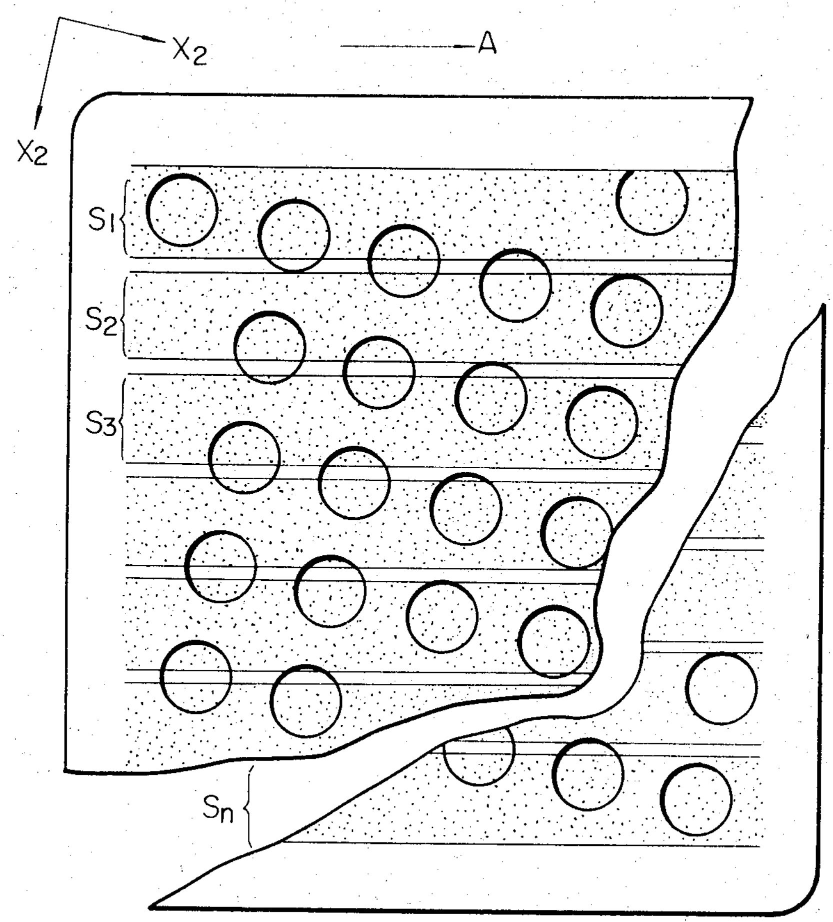

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Fig. 4b

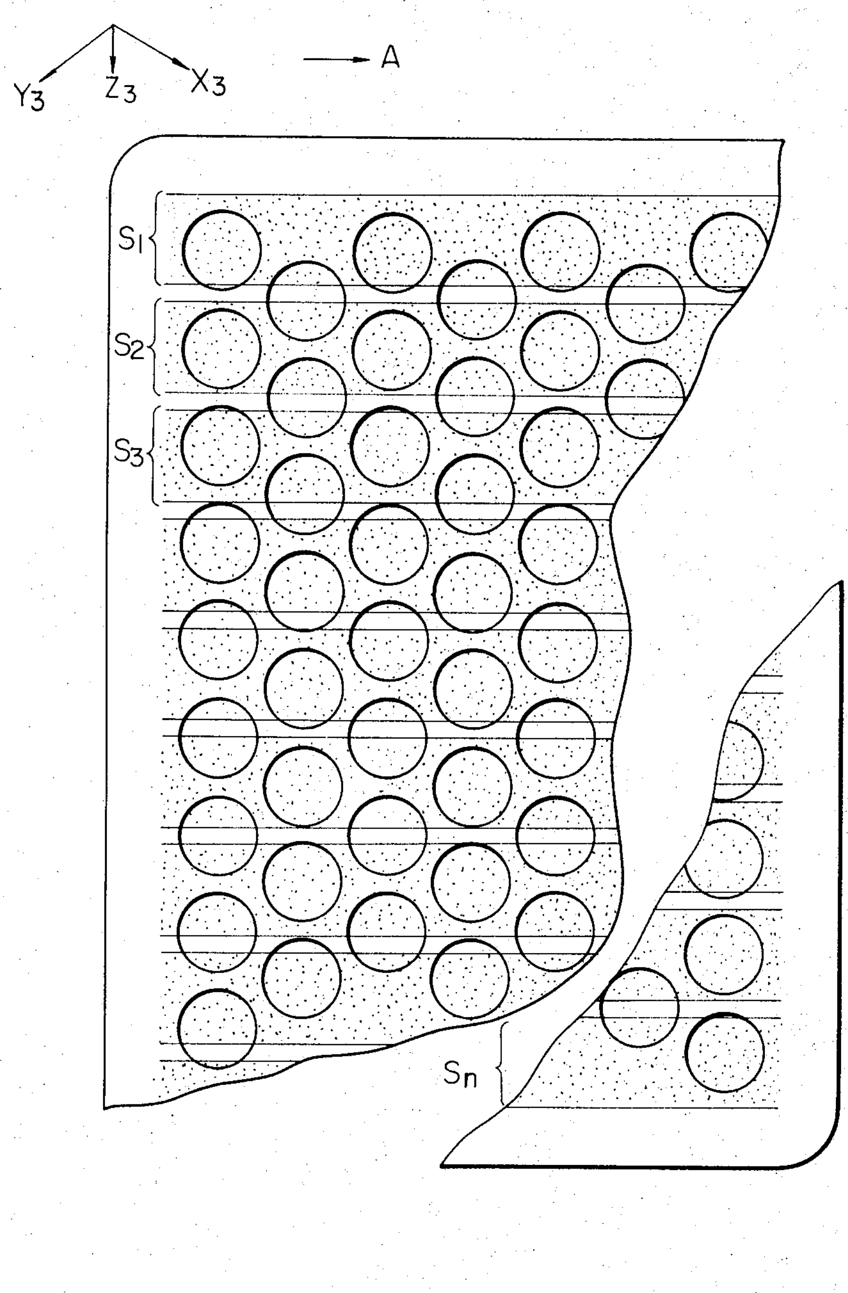

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Fig. 5

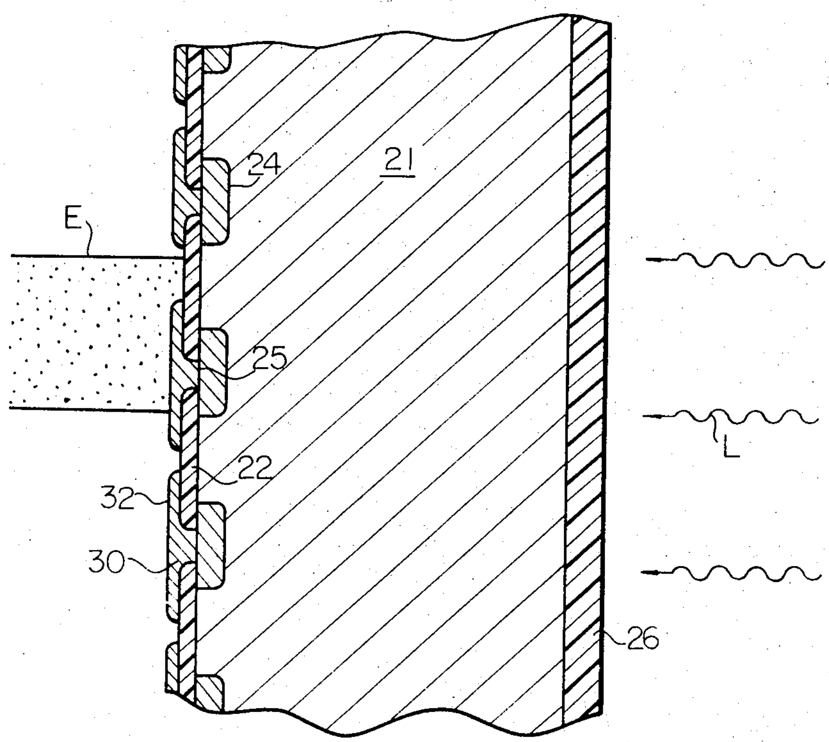

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Fig. 6a

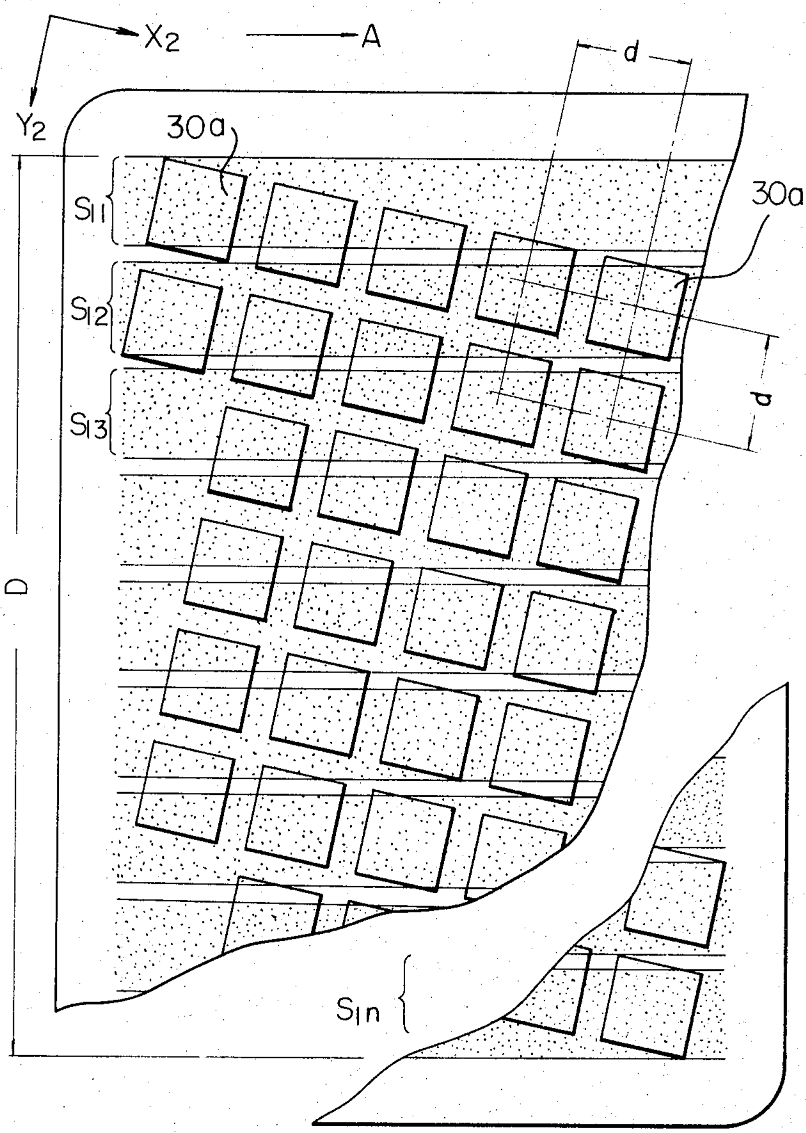

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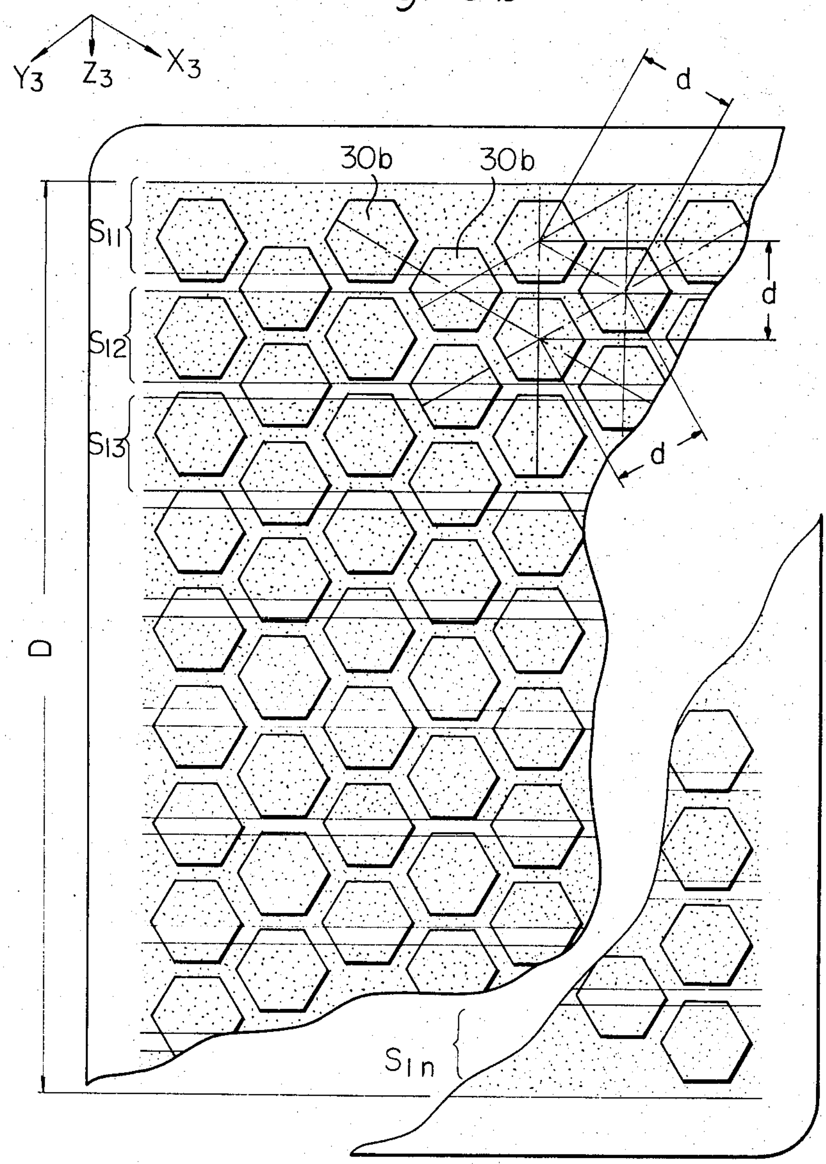
Fig. 6b



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TARGET HAVING A MOSAIC MADE UP OF A PLURALITY OF P-N JUNCTION ELEMENTS

This application is a continuation-in-part of the application Ser. No. 859,448, filed on Sept. 19, 1969, and now abandoned.

This invention relates to light sensitive storage devices and more particularly to photoconductive storage type targets suitable for use as the targets of image pick-up tubes.

One of the most common forms of high speed access to stored information involves the use of either light beams or electron beams both to write in and read out the information. These forms are usually combined with each other in such devices as the image Orthicon, Vidicon picture tube and barrier grid tube, all of which have targets providing, at least, photosensitivity and storage effect.

The conductivity transition region between two contiguous zones of opposite conductivity type is known as a P-N junction. It is known that P-N junctions are photosensitive. That is, the current flow across the P-N junction can be altered if light is incident thereon. Also it has been generally recognized in the art that a capacitive type effect is exhibited at any P-N junction. Therefore, such P-N junctions can be utilized in a target for use, for example, in a Vidicon type television camera or in a storage tube similar to a barrier grid storage type tube.

In such devices the P-N junctions have a permanent voltage in the form of a bias applied thereto: when they are reverse-biased then a certain length of time is required before the voltage across the P-N junctions returns to zero. Since the P-N junctions are photosensitive, the length of time can be substantially affected by the quantity of illumination incident on said junctions. While a mosaic of the P-N junction elements forming a target in an image pick-up tube is scanned by an electron beam, photons incident on said junctions produce minority carriers which aid in the charge decay across said junction. Therefore, the amount of charge lost in a scanning time, which is short compared to the dark decay time, is proportional to the incident illumination integrated over the scanning time.

A mosaic of the P-N junction elements forming a target in a cathode-ray tube can also be utilized as a storage mechanism where only temporary storage is required. In the following, however, not all of the possible uses and particular arrangements of a target in an image pick-up tube will be discussed.

In general, such mosaics are formed by photochemical etching utilizing a photoconductive resin which has a definite depth and homogenity, whereby the fineness of the pattern is limited. The surface of the pattern is usually covered with an oxide layer mainly for protection thereof. However, this oxide layer is liable to be charged thereupon with undesired electrons and the electrons stored around the P-N junctions increase as the regions of the P-N junctions relative to the area of the oxide layer is increased to improve the resolution of the target depending upon the number of the junction elements per unit area of the pattern. Thus, the noise resulting from the stored electrons degrades the sensitivity of the target as the resolution of the target increases.

In the prior art systems, the individual P-N junction elements are usually arranged in the same spacing along the direction of either column or row of the P-N junction elements. The signal thereby produced varies depending on the probability of the presence of the junction elements that are scanned by the electron beam and flicker noise appears in the output signals. This noise again impairs the quality of images picked up in the image pick-up tubes.

It is accordignly an object of the present invention to provide a new and improved target adapted for use in an image pick-up device.

It is another object of the invention to provide a target where the noises which may result from the stored electrons and from the same spatial phase arrangement of the P-N junction elements does not impair the sensitivity of the target.

It is still another object of the invention to increase the resolution of the target through a plurality of closely spaced discrete P-N junction elements, each of which has a metal foil electrode.

According to the invention, we provide an image pick-up device having a target arranged to be scanned by an electron beam or a scanning direction and comprising an N-type semiconductor substrate and a plurality of P-type semiconductive regions on the substrate and forming P-N junction elements spaced from and insulated from each other, which elements are so arranged that at least one axis defined by a line connecting the centres of successive most closely adjacent elements is oblique relative to the scanning directions. Preferably the P-N junction elements are provided with metal foil electrodes at the closest possible spacing. The electrodes are preferably hexagonal.

The resolution of the target provided with hexagon-shaped electrodes on the P-N junction elements is essentially improved about 56 percent in comparison with the conventional target having a matrix mosaic, if the same photoconductive material, which limits the fineness of the mosaic, is used.

The invention will become more apparent by reference to the following description of the invention taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic diagram of an image pick-up system, simply illustrating the principle of operation;

FIG. 2 is an enlarged sectional view of a conventional target in an image pick-up tube;

FIG. 3 is a plan view of the mosaic surface of the target shown in FIG. 2;

FIGS. 4*a* and 4*b* are plan views of the mosaic surface of the target in accordance with the invention;

FIG. 5 is an enlarged cross section of a target embodying the invention; and

FIGS. 6*a* and 6*b* are plan views of mosaic surfaces with metal foil electrodes in accordance with the invention.

The target of the invention can be used in an image pick-up tube shown in FIG. 1. In the image pick-up tube as shown, a mosaic surface of the target **10** is scanned by an electron beam E emitted from the cathode **13** through a deflection and focussing means **12**, while a plurality of P-N junction elements defining the mosaic are reverse-biased by a voltage source **14** through an impedance **15**. When the other side of the target is irradiated by an optical signal L from an object **16** through a lens means **17**, the optical energy of the signal L is absorbed in the N-type conductivity regions of the P-N junction elements and thereby generates holes, some of which diffuse to the P-N junctions and reduce the negative charge on the P-type conductivity regions. The scanning electron beam E returning to the site of the P-N junction deposits more negative charge of an amount proportional to the intensity of the optical signal L. The recharging current constitutes the video signal at the output terminal **18.** According to this principle, an optical image signal incident on the target can be converted into an electrical signal by scanning the electron beam on the mosaic surface of the target.

A portion of the target **10** is shown in FIG. **2,** which comprises P-N junction elements **20** on the mosaic side **11** of the target. The P-N junction elements **20** are formed by the usual planar technique. Referring to FIG. **2,** there is shown an N-type silicon substrate **21,** one side of which is covered with an oxide layer **22** of SiO_2, through which a plurality of pits are etched by photo-etching technique. Each of the etched pits extending to the substrate **21** is filled with a P-Type conductivity region **23** by diffusing a P-type conductivity impurity whereby a P-N junction **24** is formed between the substrate **21** and the P-type conductivity region **23.** The region **23** has an outer surface **25** which is to be scanned by the electron beam. An anti-reflection coacting may be coated on the surface of the substrate **21** whereon the optical signal impinges without reflection.

The conventional target **10** has a mosaic with a plurality of arrays of the P-N junction elements **20** as shown in FIG. **3,** which elements are arranged to form a matrix pattern wherein the axes of the arrays as defined by lines connecting the centres the most adjacent elements, in the present case rows and columns, are parallel to axes X_1 and Y_1, respectively. When the mosaic is scanned by the electron beam in the direction A parallel to the axis X_1 of the arrays, flicker noise appears in the time-sequential output signal for reproducing the optical signal, because the diameter of the electron beam is not large compared to the space between adjacent arrays. This noise degrades the quality of the image reproduced from the output signal. This results from the fact that a trace S_1 of scanning electron beam has a probability that the electron beam exists on the P-N junction elements during the time interval of scanning over the trace S_1. Such probability is higher than the probabilities of traces S_2 and S_3, and the output signals vary periodically for several scans, even if the incident optical signal is uniform over the entire surface of the target.

In accordance with the invention, this flicker noise can easily be eliminated by changing the directions of the axes X_1 and Y_1 of the P-N junction arrays with respect to the direction A of electron beam scanning as shown in FIG. **4***a*, wherein the mosaic has the same pattern as that shown in FIG. **3,** but the directions of the axes X_1 and Y_1 of the arrays are rotated by such an angle with respect of the direction A that both of the directions of the axes X_2 and Y_2 are different from the scanning direction A. It is apparent in FIG. **4***a* that the traces S_1 through S_n of electron beam scanning have substantially constant probabilities with respect to each other, whereby the above-mentioned flicker noise can be reduced compared to the output signal. Thus, the noise accompanied with the output signal can be reduced by providing a pattern of the mosaic wherein the directions of the axes of the P-N junction arrays are different from the scanning direction of electron beam.

In the pattern shown in FIG. **4***a*, the axis X_2 makes an angle with the scanning direction A and a right angle with the axis Y_2, but both angles may be arbitrarily selected within the scope of the invention. It will be expected that there are optimum values of these angles in that the above-mentioned probabilities are constant for the traces of the electron beams, though it is difficult to find such optimum values, in general. A pattern as shown in FIG. **4***b* is more preferable arrangement in the sense of such optimum values of the angles. In this pattern, if the centres of the most clearly adjacent elements are joined by lines, three axes X_3, Y_3 and Z_3 are obtained. The axis X_3 makes an angle of 30° to the direction A of electron beam scanning and an angle of 120° to the axis Y_3, whereas the axis Z_3 is perpendicular to the scanning direction. Thus, the P-N junction elements are distributed closely over the substrate in such a manner that centres of three P-N junction elements which are adjacent to one another form vertexes of an equilateral triangle in any portion on the substrate.

Since the substrate **21** is biased positive with respect to the electron beam potential, the P-N junction **24** behaves as a capacitor which is charged with electrons each time the electron beam impinges on the P-N junction element **20,** while electrons are also stored on the oxide layer **22** concentrated mainly around the P-N junction elements **20** through the oxide layer **22** serves to protect the edges of the junction element **20** and to keep the electron beam from landing on the substrate **21** between the P-N junction elements **20** so as to reduce the surface leakage. These stored electrons act to reduce the electrons arriving at the P-type conductivity region **23** and to degrade the efficiency of charging at the P-N junction **24**; the storage effect of the oxide layer becomes a more serious problem as the area of the P-N junction **24** relatively decreases compared to the area of the oxide layer in order to increase the resolution of the target.

This undesirable effect can be reduced by providing a metal foil electrode **30** on the outer surface of each of the P-N junction elements as shown in FIG. **5.** The metal foil electrode **30** may be formed by photochemical etching using a photomask. The photomask, usually made of glass, has a plurality of holes with a shape identical to the desired shape of the metal foil electrode outer surface **32** facing the electron beam source (not shown) in the deflection and focussing means. The holes in the photomask are, of course, distributed in the same pattern as that of the P-N junction elements **20** forming the mosaic. After a metal film is evaporated over the surface of the mosaic **11** as shown in FIG. **2,** the metal film surface is coated with a photoconductive resin and masked thereon by the photomask which is placed so that each of holes may be coincident with the corresponding P-type conductivity region **23.** Thereafter, this masked surface is photochemically etched through the photomask and chemically treated to form a plurality of metal foil electrodes **30** filling the respective etched pits and extending over the area of the oxide layer **22** around the etched pit so that the area of the outer surface **32** of the metal foil electrode will be larger than that of the outer surface **25.** This metal foil island **30** is electrically connected to the outer surface **25** of the respective P-type conductivity region **23** and electrically isolated from each other. It follows that the P-type conductivity region **23** has an electrode provided with an enlarged area of metal to be irradiated by the electron beam, so that the capacitance between the oxide layer **22** and the P-type conductivity **23** will be reduced, and thereby the storage effect of the oxide layer **22** can be eliminated.

When each of the P-N junction elements has the above-mentioned metal foil electrode arranged in the same pattern as that shown in FIGS. **4***a* and **4***b*, the noises in the output signal are reduced more effectively than expected by mere addition of the flicker noise elimination and the reduction in the undesirable storage effect. FIGS. **6***a* and **6***b* show embodiments of the target in accordance with the invention, wherein metal foil electrodes **30***a* and **30***b* are provided on the respective outer surfaces of the P-type conductivity regions. These targets in FIGS. **6***a* and **6***b* have a plurality of arrays of reverse-biased P-N junction elements distributed in respective patterns according corresponding to FIGS. **4***a* and **4***b* and the substrates are N-type silicon of 50 × 50 mm^2 and self-supporting. The P-type conductivity regions of both targets are formed by diffusing a P-type conductivity impurity through 22.6-micron diameter holes in the SiO_2 film, the centre-to-centre spacing between holes being 40 microns. These arrangements provide P-N junction capacitances sufficient to integrate the junction photoresponse over the time interval of electron beam scanning in the usual image pick-up tube.

The P-N junction element in FIG. **6***a* is provided with a square metal foil electrode **30***a* facing the electron beam source. The distance between the squares of the metal foil electrodes **30***a* may be 5.3 microns in consideration of limitations owing to dispersion of light partly due to the definite depth of a photoconductive resin used, partly to the irregularity of the deflection index of a photoresist, and owing to the precision of manufacturing the photomask.

The P-N junction elements are distributed in the same pattern as that in FIG. **4***a*, wherein X_2 and Y_2 designate the axes of the arrays of junctions, respectively, and S_{11} to S_{1n} are the traces of the electron beam that are parallel to each other. Since both the axes X_2 and Y_2 are different from those of the traces S_{11} to S_{1n}, the signal-to-noise ratio of the output signal is improved by the reduction in the noises due to both the flicker noise and the effect of electrons stored on the oxide layer.

In order to increase the resolution of the target, another preferred pattern of metal foil electrode arrangement is provided as shown in FIG. **6***b*, wherein the metal foil electrode **30***b* has a hexagon-shaped outer surface facing the electron beam source and the electrodes are distributed in a closest-spaced distribution that is the same pattern as that in FIG. **4***b*. In this pattern, X_3, Y_3 and Z_3 also designate the axes of the arrays of the metal foil electrodes **30***b* and S_{11} to S_{1n}, respectively, are the traces of the electron beams, which are parallel to each other. Either the axis X_3 or Y_3 may be at an angle of 30° with respect to the traces S_{11} to S_{1n}, and preferably be parallel to one side of each hexagons of the metal foil electrodes **30***b*. The distance between the hexagons of the metal foil electrodes **30***b* may be also 5.3 microns for the same reason as above mentioned. This pattern and the provision of the metal foil electrodes **30***b* also improves the signal-to-noise ratio of the output signal, and essentially increases the resolution of the target about 56 percent in comparison with the target in FIG. **6***a*. This improvement can easily be ascertained from a simple calculation as follows:

When the target is used for picking up television images, both targets in FIGS. **6***a* and **6***b* have the effective areas of $D \times (4/3)D$ over which is scanned by the electron beams, where D represents the vertical length of the effective areas in the targets that are, of course, horizontally scanned by the electron beam. The vertical and horizontal resolutions R_{v1}, R_{v2} and R_{h1}, R_{h2} can be obtained as the expressions

$$R_{v1} = (1/\sqrt{2}) \cdot (D/d),$$
$$R_{h1} = (4/3\sqrt{2}) \cdot (D/d),$$
$$R_{v2} = D/D,$$
$$R_{h2} = (8/3\sqrt{3}) \cdot (D/d),$$

where the suffixes 1 and 2 are added to the quantities associated with the targets in FIGS. **6***a* and **6***b*, respectively, and d is the center-to-center spacing between the adjacent P-N junction elements. Since the total resolutions R_1 and R_2 are defined and calculated as the expressions

$$R_1 = \sqrt{(R_{v1})^2 + (R_{h1})^2} = 1.17 \times D/d,$$
$$R_2 = \sqrt{(R_{v2})^2 + (R_{h2})^2} = 1.83 \times D/d.$$

Therefore, the resolution R_2 is larger than the resolution R_1 whereby the resolution of the target in FIG. **6***b* is improved about 56 percent in comparison with that in FIG. **6***a*. Furthermore, the intrinsic shape of the electrode **30***b* is advantageous in that the electric field concentration at the edges of the hexagon-shaped electrode **30***b* is smaller than those of the square-shaped electrode **30***a* as shown in FIG. **6***a*, because the former is an obtuse angle of 120° and the latter is a right angle.

The embodiments described are intended to be merely illustrative. Various other modifications and embodiments can be made without departing from the spirits and scope of the invention.

We claim:

1. An image pick-up tube comprising:

a. an evacuated envelope;

b. an electron gun at one end thereof for emitting an electron beam; and

c. a target assembly at the other end thereof adapted to be scanned by said electron beam in a given direction, comprising: a semiconductor substrate element of one of P- and N- type conductivity, a plurality of semiconductive regions of opposite polarity arranged thereon, each of said regions being arranged in equilateral-triangle relation with any adjacent two regions and arranged in directions being skewed with respect to said given direction.

2. An image pick-up tube according to claim **1**, wherein each of said semiconductive regions is provided with a metal foil electrode having a hexagon-shaped outer surface.

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