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[54] **QUADRANT PHOTODIODE**

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[52] **U.S. Cl.** ....**313/96,** 250/211, 250/220, 317/235 IV, 317/235 AJ

[51] **Int. Cl.** **H01j 39/06,** H01l 15/06

[58] **Field of Search** ....313/96, 94, 65 A, 101, 102, 313/65 AB; 250/211 J

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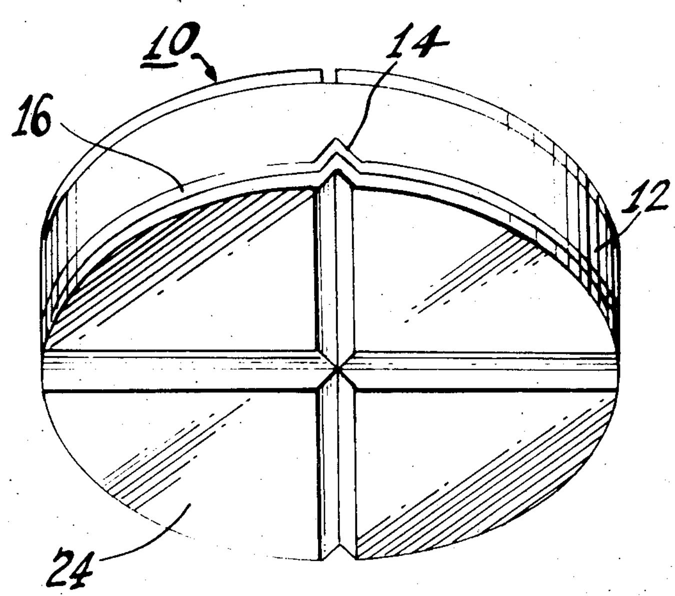
[57] **ABSTRACT**

A quadrant photodiode including a flat substrate of high resistivity semiconductor material, such as silicon, of one conductivity type having a thin region of the one conductivity type within and extending across one surface thereof and four quadrant shaped regions of the opposite conductivity type in its other surface. The quadrant shaped regions are arranged in a circle with the straight edges of adjacent quadrants being in closely spaced relation. The surface of the substrate having the one conductivity type region therein is provided with V-shaped grooves which are directly opposed to and extend along the spaces between the edges of the quadrant-shaped regions. The surfaces of the grooves serve to refract the light which is incident on the surface toward the quadrant-shaped regions so as to prevent optical cross-talk between the quadrant-shaped regions.

7 Claims, 6 Drawing Figures



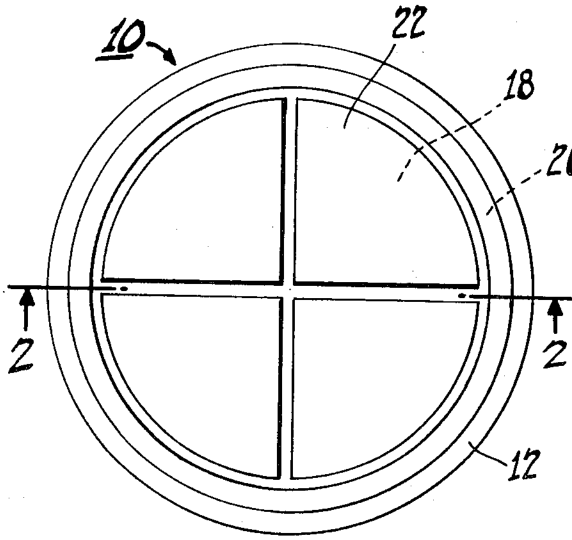


Fig. 1.

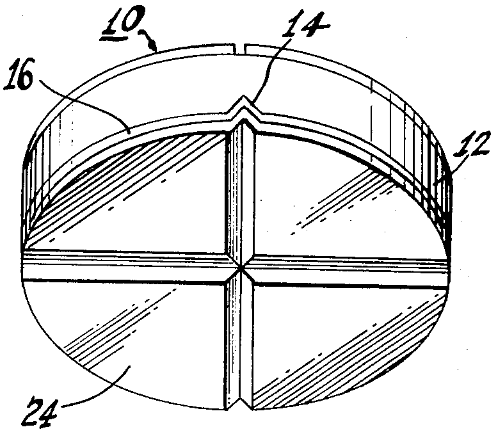


Fig. 3.

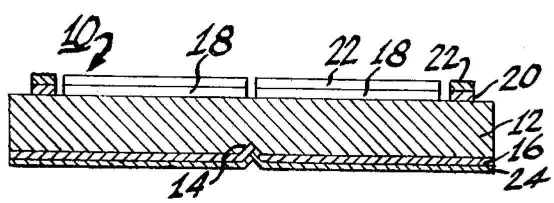


Fig. 2.

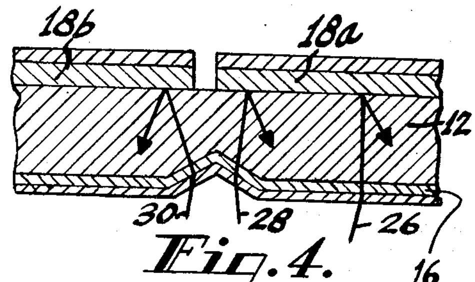


Fig. 4.

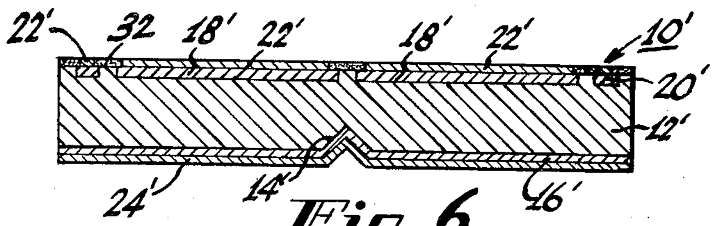


Fig. 6.

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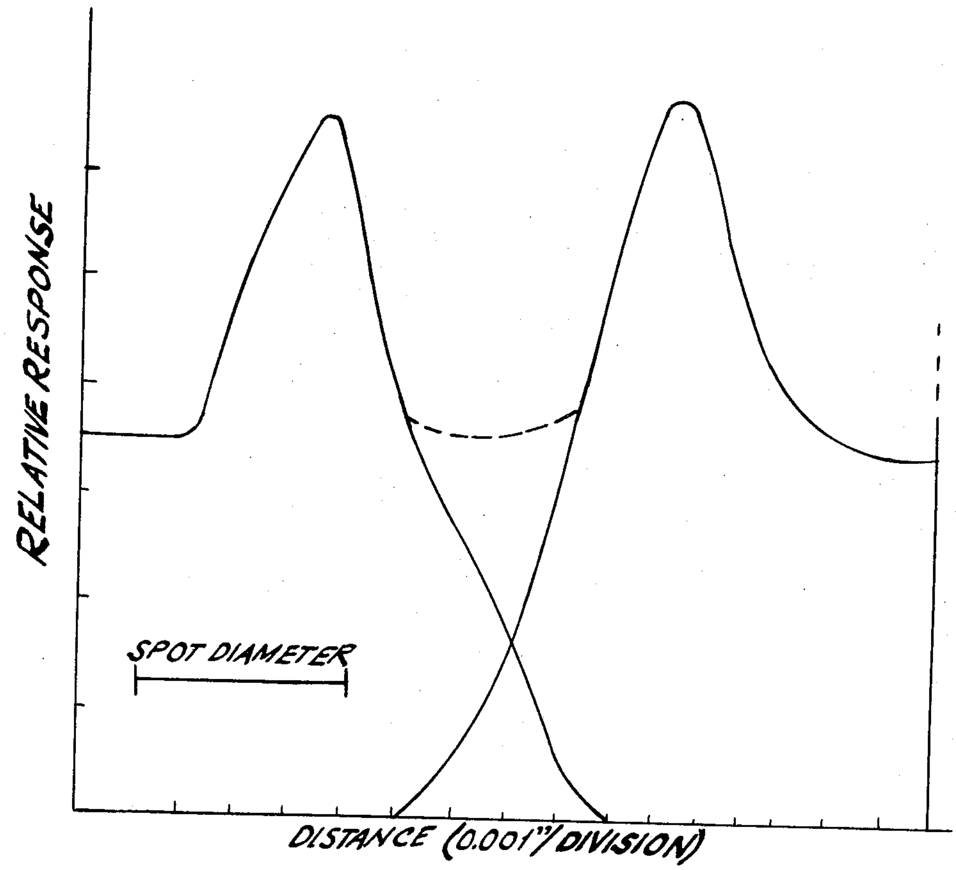

Fig. 5.

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QUADRANT PHOTODIODE

BACKGROUND OF THE INVENTION

The present invention relates to a photodiode and more particularly to a P-I-N quadrant photodiode used for tracking the position of a beam of light which is moved across the diode.

Recently P-I-N quadrant photodiodes have been developed for tracking a beam of focused light which is moved over the diode. In general, such diodes comprise a flat substrate of high resistivity, higher than 10,000 ohm-cm, P type silicon having a P type anode region extending over one surface and four quadrant shaped N type electrodes on the other surface. When a focused light spot is moved across the anode the signal is transferred from one of the quadrant shaped electrodes to the next. The abruptness with which this transfer occurs determines the positional resolution of the diode. Heretofore this positional resolution has been determined by the distance between adjacent quadrant electrodes and the optical cross-talk between adjacent quadrant electrodes.

The factor of the distance between the adjacent quadrants which effects the positional resolution of the diode can be minimized by reducing the physical separation between the adjacent quadrants. It has been found possible to reduce the spacing between adjacent quadrants to such an extent that the effective spacing is less than 0.004 inch as determined optically by using light at a wavelength of 0.9μm. However, for light at longer wavelengths, for example at 1.06μm, the positional resolution has been limited by optical cross-talk between the quadrants. This is a result of the fact that the absorption coefficient of silicon at the long light wavelengths is relatively small so that a fair fraction of the incident radiation reaches the quadrant electrode side of the diode and is reflected from it. Since this type of photodiode is usually used with optical systems having relatively low f numbers, the incident cone of radiation on the anode surface, although focused, continues to spread out inside the diode. It has been estimated that for a f:1 optical system, the effect of cross-talk will limit the positional resolution to about 0.010 inch. Therefore, it would be desirable to be able to minimize, if not prevent, optical cross-talk between the quadrants so as to improve the positional resolution of the diode.

SUMMARY OF THE INVENTION

A photodiode comprises a substrate of high resistivity semiconductor material having opposed flat surfaces and a V-shaped groove in one of the surfaces. A region of one conductivity type semiconductor material is adjacent to and extends across substantially the entire one surface of the substrate. A pair of regions of the opposite conductivity type semiconductor material are adjacent the other surface of the substrate. The pair of regions have edges which are in closely spaced relation with the spacing between the edges being directly opposed and extending along the grooves in the one surface of the substrate.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a plan view of one surface of one embodiment of the photodiode of the present invention.

FIG. **2** is a sectional view of the photodiode taken along line **2—2** of FIG. **1**.

FIG. **3** is a perspective view of the photodiode of FIG. **1** showing the other surface of the diode.

FIG. **4** is an enlarged sectional view of a portion of the photodiode.

FIG. **5** is a graph showing the signal response of a typical photodiode of the present invention.

FIG. **6** is a sectional view of another embodiment of the photodiode of the present invention.

DETAILED DESCRIPTION

Referring to FIGS. **1–3**, an embodiment of the photodiode of the present invention is generally designated as **10**. Photodiode **10** comprises a circular substrate **12** of a high resistivity semiconductor material having opposed flat surfaces. Typically the substrate **12** is of P type silicon having a resistivity greater than 10,000 ohm-cm. As shown in FIGS. **2** and **3**, the substrate **12** has a pair of V-shaped grooves **14** in one of its flat surfaces. The grooves **14** extend diametrically across the substrate **12** and are positioned 90° apart.

A thin region **16** of P type conductivity is within and extends across the entire grooved surface of the substrate **12** including the surfaces of the grooves **14**. The P type region **16** provides the anode of the diode **10**. In the other surface of the substrate **12** are four quadrant shaped regions **18** of N type conductivity. The quadrant shaped regions **18** are arranged in a circle with each straight edge of each quadrant being in closely spaced relation to a straight edge of an adjacent quadrant. As shown in FIG. **2**, the quadrant shaped regions **18** are positioned so that the spaces between the edges of the quadrants are directly opposed to and extend along the grooves **14** in the substrate. Thus, the spaces between the edges of the quadrant extend radially from a single point, the center of the surface of the substrate **12**, which is directly opposed to the crossing point of the grooves **14**. A narrow, annular guard ring region **20** of N type conductivity is in the same surface of the substrate **12** as the quadrant regions **18**. The guard ring **20** surrounds and is spaced from the quadrant regions **18**. A film **22** of a light reflecting material, such as aluminum, is coated over the surface of the quadrant regions **18** and the guard ring **20**. A film **24** of a light anti-reflecting material, such as a thin film of silicon-dioxide, is coated over the P type region **16**. The silicon dioxide film **24** should have an optical thickness of approximately one-fourth wavelength depending on the wavelengths of the light being detected.

To make the photodiode **10**, one starts with a flat substrate of high resistivity P type semiconductor material, such as silicon. The V-shaped grooves **14** are then formed in one surface of the substrate. This can be achieved by lapping, grinding, etching or ultrasonically cutting with a wedge shaped tool. A P type impurity, such as boron, is diffused into the grooved surface of the substrate to provide the P type anode region **16**, and an N type impurity, such as phosphorus, is diffused into the other surface of the substrate to provide the N type quadrant regions **18** and the guard ring region **20**. The P type impurity and the N type impurity may be diffused into the substrate using any well known diffusion technique. For example, the surfaces of the substrate may be coated with a material containing the particular impurity and then heated to diffuse the impurity into the substrate, or the impurity may be diffused into the substrate from a gas containing the impurity. Also, depending on the diffusion technique used, both impurities may be diffused into the substrate simultaneously or one at a time. After the diffusion operation, the quadrant regions **18** and guard ring region **20** are defined in the N type region. This can be achieved by coating the surface of the N type diffused region with a masking layer of silicon dioxide. Openings are provided into the masking layer along the lines of the spaces between the quadrant regions and the space between the quadrant regions and the guard ring region using the photo-lithographic technique well known in the art. The exposed area of the N type region is then etched away to form the quadrant regions and the guard ring region. The light reflection film **22** and the anti-light reflecting film **24** are then coated over the quadrant regions **18**, guard ring region **20** and P type region **16** respectively by evaporation of the material of the films in a vacuum.

In the use of the photodiode **10**, a spot of light is focused on the P type anode region **16** and scanned thereacross. This generates electron-pairs with the holes being collected by the common anode **16** and the electrons being collected by the quadrant electrodes **18**. By measuring the response of the quadrant electrodes **18**, the position of the light beam can be determined. Referring now to FIG. **4**, as the light beam moves over the portion of the P type anode region **16** which is between the grooves **14**, the incident light generates electron-hole pairs the electrons of which are collected by the quadrant electrode **18*a*** directly opposite the point of incidence as indicated by line **26** in FIG. **4**. As the beam of light moves onto a surface of a groove **14**, the light incident on the angled surface of the groove is refracted back to the quadrant electrode **18*a*** as indicated by line **28** in FIG. **4**. As the beam of light moves onto the other surface of the groove **14**, the light incident on the angled other surface is refracted toward the next adjacent quadrant electrode **18*b*** as indicated by the line **30** in FIG. **4**. Thus, the electrons generated by all light incident on the sides of the grooves are collected by an appropriate quadrant electrode so as to eliminate optical cross-talk between the quadrant electrodes. The width and length of the grooves **14** are not critical as long as the sides of the grooves are angled so as to refract the light toward the proper quadrant electrode.

Referring to FIG. **5**, there is shown the relative signal response on two adjacent quadrant electrodes of a photodiode **10** as a beam of light was scanned across the P type anode. The light was of a wavelength of 1.06μm, was 0.004 inches in diameter and was focussed on the photodiode using an *F*:2 optical system. As the light was scanned across the photodiode the response on each of two adjacent quadrant electrodes was measured and is shown in FIG. **5**. As can be seen in FIG. **5**, the signal response on each quadrant electrode is characterized by three regions. Going from left to right on the graph, the first region is a flat region wherein the light is entirely on a flat surface of the P type anode. The next region is one of increasing response wherein the light moves onto an angled surface of a groove. This region of increasing response is attributable to enhanced quantum efficiency resulting from the fact that the light incident on the side of the groove is totally internally reflected and becomes trapped in the diode. The third region is one of rapid fall-off as the light moves from one side of the groove to the other. As the light moves from one side of the groove to the other, a signal response of increasing magnitude is obtained in the adjacent quadrant electrode. The dotted line in the graph is the total of the two signals in the adjacent quadrant electrodes as the light moves across the bottom of the groove. As can be seen, the total response at the bottom of the groove is about the same as at the flat surface of the P type anode. From FIG. **6** it can be seen that the effective resolution of the photodiode is about 0.004 inches, which is mainly determined by the diameter of the beam of light. Thus, the photodiode has an effective resolution as good as that which was previously obtained using a beam of light of shorter wavelength.

Referring to FIG. **6**, there is shown another embodiment of the photodiode, generally designated as **10'** is made starting with a flat substrate **12'** of a high resistivity P type semiconductor material, such as silicon. A pair of V-shaped grooves **14'** and formed in one surface of the substrate **12'** in any of the manners previously described with regard to the photodiode **10**. A P type impurity, such as boron, is diffused into the grooved surface of the substrate to provide a thin P type anode region **16'**. A masking layer **32** of silicon dioxide is coated on the other surface of the substrate. Openings are formed in the masking layer **32** using the well known photo-lithographic techniques, which openings are of the size, shape and position of the quadrant regions and guard ring region to be formed. An N type impurity, such as phosphorus, is then diffused into the exposed area of the masked surface of the substrate to provide the quadrant regions **18'** and the guard ring region **20'**. A light reflecting film **22'** is then coated over the quadrant regions **18'** and an anti-reflecting film **24'** is coated over the P type anode region **16'**. The photodiode **10'** operates in the same manner as the photodiode **10** previously described.

Although the photodiode **10** has been described as having a P type substrate, a P type anode region and N type quadrant and guard ring regions, the photodiode can be made with a high resistivity N type substrate, an N type anode region and P type quadrant and guard ring regions. Such a photodiode would be made in the same methods as previously described except that one would start with a flat substrate of high resistivity N type semiconductor material, an N type dopant, such as phosphorus, would be diffused at the grooved surface of the substrate to provide the another region, and a P type dopant, such as boron, would be diffused into the other surface of the substrate to provide the quadrant and guard ring regions.

We claim:

1. A photodiode comprising

a substrate of high resistivity semiconductor material of one conductivity type having opposed flat surfaces and a V-shaped groove in one of said surfaces;

a region of the one conductivity type semiconductor material adjacent to and extending across substantially the entire one surface of the substrate; and

a pair of regions of the opposite conductivity type semiconductor material adjacent the other surface of the substrate, said pair of regions having edges in closely spaced relation with the spacing between said edges being directed opposed and extending along the groove in the one surface of the substrate.

2. A photodiode in accordance with claim 1 in which the region of one conductivity type extends across the surface of the groove as well as the one flat surface of the substrate.

3. A photodiode in accordance with claim 2 including a layer of a ligh reflecting material covering each of said pair of regions.

4. A photodiode in accordance with claim 3 in which the region of one conductivity type is P type and the pair of regions are N type conductivity.

5. A photodiode in accordance with claim 3 in which the region of one conductivity type is N type and the pair of regions are P type conductivity.

6. A photodiode in accordance with claim 1 including four regions of the opposite conductivity type semiconductor material adjacent the other surface of the substrate, each of said four regions having a pair of edges with each edge being in closely spaced relation to an edge of a separate one of another of said four regions, and the one surface of the substrate has a plurality of V-shaped grooves therein with the grooves being directly opposed and extending along the spacing between the edges of said four regions.

7. A photodiode in accordance with claim 6 in which the spaces between the edges of the four regions extend from a single point on the other surface of the substrate.

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