

Description

The invention relates to a semiconductor device for determining or controlling the position of a radiation beam which is incident upon a major surface of a radiation-sensitive semiconductor body provided with at least two radiation-sensitive diodes which form a rectifying junction with an adjacent part of the semiconductor body and are provided with electrical connections to drain away electric current produced by the incident radiation.

The position of the radiation beam is to be understood to mean the position of the balance of the beam. As usual, the term balance is to be understood to mean the point at which the number of photons incident per unit time is the same on either side of this point. With symmetrical beams this point coincides with the axis of the beam.

Radiation-sensitive semiconductor devices of the aforementioned kind are used, for example, in photo-sensitive circuit arrangements for picture display and in arrangements for tracking or positioning light beams (or beams of radiation of other kinds). Other applications of radiation detection are in the field of spectroscopic analysis, especially in the wavelength range of from 200 to 1100 nm, and, for example, soft X-ray radiation. Such arrangements are also used for detection of particle radiation (for example electrons, α particles or high-energetic particles). Such semiconductor devices (especially in the wavelength range of visible light) are also used in measuring apparatus for position determination, after example for measuring a bend, or, for example, in automatic assembly lines.

The invention further relates to a focus error detection system provided with a semiconductor device according to the invention.

A semiconductor device of the kind mentioned in the opening paragraph is described in the Netherlands Patent Application No. 8003906 of the Applicant laid open to public inspection on February 1st 1982. This Application describes a focus error detection system for detecting a deviation between a first radiation-reflecting surface and a second focusing surface of an objective system (for example for a compact disk or video disk arrangement), in which a so-called quadrant diode is utilized.

The quadrant diode described therein acts very rapidly, indeed, and has a transition curve of high steepness, but during mounting, the diode has to be mounted so that with correct focusing the radiation beam strikes the semiconductor surface exactly between the four quadrants of the diode. In view of the tolerances then required (the relative distance of the quadrants is approximately 5 μ m), such a mounting process with associated adjustment is different and time-consuming.

Similar with a view to mounting arise in a focus

error detection system in which a beam splitting element followed by a radiation-sensitive detection system comprising a plurality of detectors separated from each other by narrow strips is arranged in the path of the beam reflected by the radiation-reflecting surface, the subbeams formed by the beam-splitting element being incident upon the separation strips. In the latter case, it can be ensured that the centres of the radiation spots formed by the subbeams in the detector surface are incident upon the separation strips with a correct focusing by causing the separation strips to enclose an acute angle with each other. By means of a mechanical displacement of the detector surface, a correct initial adjustment can then be obtained, as is described more fully in Netherlands Patent Application No. 8202058 of the Applicant. This mechanical adjustment may vary with time and/or with temperature, however, after which a new and often laborious adjustment of the detector plane is necessary.

The invention has for its object to provide a semiconductor device of the kind mentioned in the opening paragraph, which can be used inter alia in such a focus detection system, in which the zero adjustment can be effected in a considerably simpler manner. Such a semiconductor device can further be designed and used for applications other than the aforementioned applications.

The object of the invention is met by the features recited in claim 1.

The invention is based on the recognition of the fact that in such a semiconductor device a simple electromechanical or electronic zero adjustment is possible by utilizing the differential current through the diodes which adjustment replaces in the case of the focus detection system the mechanical adjustment (displacement and locking). Thus, a less accurate mounting is sufficient, while nevertheless a satisfactory high-frequency behaviour is maintained. The said zero adjustment may be effected, for example, by means of a variable resistor or via a potentiometer circuit, in which event in the electronic circuit variations in the photocurrent produced are also taken into account.

It will be appreciated that the balance zero adjustment is not necessarily situated at the same distance from the diodes and can be displaced by modification of the bias voltage of one or both diodes along their connection line. The adjustment system in which the device is included adjusts the position of the incoming radiation in such a manner that the balance of the incoming radiation beam with the exception of a minimum error signal) coincides with the zero adjustment or calibration adjustment.

The said diodes may be metallic zones forming a Schottky-junction with the adjustment semiconductor material. Preferably, however these diodes are formed by semiconductor zones forming pn-junctions with an adjacent part of the semiconductor body.

The photocurrents detected by the diodes may be recorded directly, if desired, for further signal processing. Preferably, however, the adjustment circuits for the zero adjustment produce output signals which are related to the diode currents.

The invention will now be explained more fully with reference to a few embodiments, in which

Fig. 1 shows a cross-section of a part of a semiconductor device, with reference to which the basic idea of the invention will be described,

Fig. 2 shows diagrammatically an embodiment of the device according to the invention, inclusive of the adjustment circuit.

Fig. 3 shows in a plan view and Fig. 4 shows in cross-section taken on the line IV-IV in Fig. 3 another semiconductor device,

Fig. 5 shows the device of Figs. 3 and 4 inclusive of the adjustment circuit,

Fig. 6 shows diagrammatically a plan view of another semiconductor device according to the invention,

Fig. 7 shows a cross-section taken on the line VII-VII in Fig. 6,

Fig. 8 shows a cross-section taken on the line VIII-VIII in Fig. 6,

Fig. 9 shows an embodiment of an arrangement provided with a focus detection system according to the invention,

Fig. 10 shows the associated electronic processing circuit, while

Fig. 11 shows diagrammatically a preferred embodiment of the semiconductor device as used in the arrangement of Fig. 9,

Fig. 12 shows diagrammatically a variation thereof,

Fig. 13 shows diagrammatically a cross-section of another embodiment of the device according to the invention, and

Fig. 14 is a plan view of the device shown in Fig. 13.

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

Fig. 1 shows diagrammatically in cross-section a part of a semiconductor device according to the invention. This device comprises a semiconductor body 1 of silicon. This semiconductor body 1 comprises a low-ohmic substrate 2 on which is formed an epitaxial layer 3 having a thickness of approximately 10 μm and a resistivity of the order of 20 to 200 Ωcm . The semiconductor body 1 is provided at a practically flat surface 4 with radiation-sensitive diodes having rectifying junctions 5, 5'. The semiconductor body 1 is

provided for this purpose at its surface 4 with semiconductor zones 6 of the p-type, which form with the epitaxial layer 3 rectifying junctions 5 (pn junctions in this embodiment); the surface zone 11 located between the semiconductor zones 6 forms with the adjacent part of the epitaxial layer 3 a rectifying junction 5'.

The surface 4 of the semiconductor body 1 is further covered with a passivating anti-reflection layer 7 of silicon oxide or silicon oxide with, for example, silicon nitride. The layer 7 is provided with contact windows 8 for conducting contacts 9 (9A, 9B). On the lower side of the semiconductor body, the substrate 2 is contacted by means of a contact metallization 10.

By means of an electrical voltage at the contacts 9, 10, the pn junctions 5, 5', can be biased in the reverse direction. As a result, a depletion region, indicated in Fig. 1, by broken lines, is formed at each pn junction 5, 5' in the epitaxial layer 3 and the associated semiconductor zones 6, 11. As far as these depletion regions extend in the epitaxial layer 3, they are denoted by reference numeral 12. The electric field lines due to electric fields prevailing in such regions 12 are indicated by arrows 13. The high-ohmic layer (11) may have such a low doping that the boundary indicated by the broken line of the depletion region at a sufficiently high bias voltage at the diodes extends practically as far as the surface. The current I_0 introduced by the voltage difference between the zones 6A and 6B is thus adjustable to a high extent and gradually passes into a (low) current, which is determined by "punch-through", of one diode to the other. With very low values of I_0 , however, the high-frequency properties of the device become unfavourable because the charge carriers then obtain a mobility which is determined for the major part by the interface with the dielectric layer 7.

The high-ohmic region 11 may be realized, for example, by ion implantation, the doping of the semiconductor material between the zones 6A and 6B being substantially compensated for. The dose that causes the layer 11 to be produced is also influenced by the fixed charges present in the dielectric layer 7.

However, the high-ohmic layer 11 may also be obtained by means of a gate electrode which is transparent to the incident radiation and is applied to such a bias voltage that a current I_0 can flow between the zones 6A and 6B with a voltage difference between these zones. Combinations of the use of a gate electrode and ion implantation are also possible.

When a light beam or radiation beam is incident on the surface 4 of the semiconductor body 1, which has a sufficiently high energy (at least equal to the band gap of the forbidden band of the semiconductor material), additional charge carriers (holes and electrons) are generated in the semiconductor body. In the depletion regions, these additional charge carriers are dissipated due to the prevailing field and thus con-

tribute to a photoelectric current through the pn junction 5.

If the balance of the radiation beam is incident about halfway between the semiconductor zones 6 (beam b in Fig. 1), additional charge carriers are generated in the depletion region, mainly at the area of the region 14, and these charge carriers contribute to a photocurrent I. The photocurrent I in this embodiment flows from the contact metallization 10 on the lower side and is split up at the area of the region 14 into two substantially equal subcurrents I_A and I_B , which flow through the high-ohmic zone 11 to the semiconductor zones 6 and then to the contacts 9^A and 9^B. The high-ohmic zone 11 has a width, which is a few times (for example five times) the diameter of the radiation beam b.

In practice, this width generally depends upon the tolerances of the optical system; this width is chosen so that it is of the same order as the range of said diameter of the radiation beam when the latter is focused to the optimum on the device. On the other hand, this width is preferably chosen as small as possible in connection with high-frequency properties and steepness of the transition curve of the radiation-sensitive semiconductor device.

The balance of the beam b' also shown in Fig. 1 is not incident halfway between the semiconductor zones 6 upon the surface 4. The charge carriers mainly generated in the region 14' again give rise to a photocurrent I', which photocurrent is split up at the region 14' into subcurrents I_A' and I_B' . The charge carriers (in this case holes) which contribute to the current I_A' , are subjected due to the smaller distance of the region 14' from the semiconductor zone 6^A than that of the region 14' from the semiconductor zone 6^B to a smaller resistance than the charge carriers which contribute to I_B' . The current I' consequently now is split up into unequal parts I_A' and I_B' where $I_A' > I_B'$.

According to the invention, such voltages are now applied to the contacts 9^A, 9^B that the region 6^B has supplied to it (in this embodiment) a more negative bias voltage than the region 6^A. In the present embodiment, this gives rise to a compensation current I_0 in the high-ohmic region 11, which current is adjusted by means of a feedback mechanism still to be described, such as, for example, an amplifier circuit that is fed back, in a manner such that I_A' effectively becomes smaller and I_B' effectively becomes larger. As soon as $I_A' - I_0 = I_B' + I_0$, the currents through the contacts 9^A and 9^B are substantially equal and the beam b' is apparently centred between the zones 6^A and 6^B.

The dimensions of the zones 6, 11 depend, as stated, upon the application. The contacts 9^A, 9^B then have such a relative spacing, however, that during operation the beam b is incident nearly always between these contacts.

If such a semiconductor device with the associated feedback mechanism is mounted in an

optical system, after the whole has been assembled, the beam b can be caused to be incident apparently halfway between the zones 6^A and 6^B by applying a difference voltage to the contacts 9^A, 9^B. A focusing system, detection system or other optical system provided with such a device then has an electronic or electromechanical zero adjustment, which is generally considerably more rapid and simpler than a purely mechanical adjustment.

It should be noted with respect to the above considerations that, when varying the voltages (which are negative in this embodiment) at the contacts 9^A, 9^B, the shape of the depletion zone 12 changes slightly. However, this does not influence the proper operation of the device, as described above (compensation of the difference in photocurrent components by means of a current through the high-ohmic surface zone 11). The high-ohmic zone 11 may have in plan view various forms; it may be, for example, linear, circular or ellipsoidal.

Fig. 2 shows diagrammatically how the aforementioned zero adjustment can be attained independently of the location at which the beam b strikes the surface 4. The current I_A and I_B are supplied to two inputs of operational amplifiers 15^A, 15^B, which are fed back via feedback resistors 16^A, 16^B. The two remaining inputs of the operational amplifiers 15^A, 15^B are interconnected and are also connected, for example, to earth.

By means of a variable voltage divider 17, whose variable connection 18 is connected to a voltage which is derived via an auxiliary circuit from the overall photocurrent I, a voltage difference can be applied between the inputs 19^A and 19^B of the operational amplifiers 15. Current variations in the photocurrents I_A and I_B are measured, like these photocurrents themselves, after amplification at the outputs 20^A and 20^B of the amplifiers 15^A and 15^B.

The final adjustment of such a device in an optoelectronic arrangement can be made after this optoelectronic arrangement has been assembled and, for example, the focus of an objective system has been correctly adjusted. The position of an incident beam is then measured by measuring the difference of the photocurrents I_A and I_B . With reference to this measurement, the voltage difference between the semiconductor zones 6^A and 6^B can be adjusted by means of the voltage divider 17 so that I_A is equal to I_B (calibration point). The beam b is then apparently centred. When the voltage difference between the semiconductor zones 6^A and 6^B is maintained, a difference in currents, measured between the outputs 20^A, 20^B, is now a measure for a deviation of the point of incidence of the radiation beam with respect to the said calibration point. The signal $(I_A - I_B)$ can now be used as a control signal; a deviation ΔI corresponds to a given deviation of the point of incidence of the beam b with respect to the calibration point.

Thus, a control system is obtained, which can be

mounted with large tolerances and in which the calibration is effected substantially entirely electrically or electronically. Of course other circuits may be used than the variable voltage divider 17 and the operational amplifiers that are fed back (shown here diagrammatically).

The overall photocurrent I can be measured both directly and by means of an operational amplifier circuit comprising an operational amplifier 15 and a feedback resistor 16, as shown in Fig. 2.

Figures 3 and 4 show a semiconductor device according to the invention comprising a semiconductor body 1 in which the overall photocurrent I is split up into four subcurrents I_A, I_B, I_C, I_D . If the beam b is incident halfway between the semiconductor zones 6, as shown in Fig. 5, the photocurrents through the contacts $9^A, 9^B, 9^C, 9^D$ are substantially equal. A mismatching during assembly, as a result of which, after final adjustment of the optical system, the beam is incident at b' (Fig. 3), can again be corrected in the same manner as described above.

Fig. 5 shows how for this purpose the subphotocurrents I_A, I_B, I_C, I_D originating from the contacts $9^A, 9^B, 9^C, 9^D$ are supplied again to a control circuit comprising two subcircuits which are substantially equal to the circuit shown in Fig. 2. By means of the voltage dividers 17, the semiconductor zones 6^A and 6^B and 6^C and 6^D respectively, are again relatively shifted in voltage so that, when the radiation beam is incident at b' , the currents I_A, I_B, I_C, I_D are again substantially equal.

If after this calibration the position of the incident beam has slightly shifted with respect to this point b' , differences in the output currents I_A, I_B, I_C and I_D will occur. These output currents can then be supplied again to a control system which controls the location of the incident beam in a similar manner described for a quadrant diode in the article "Optical video disks with undulating tracks" by J.J.M. Braat and G. Bouwhuis in the magazine "Applied Optics", Volume 17, No. 13, p.2022-2028 (1st of July 1978).

The device shown in Figs. 3, 4 comprises besides the semiconductor zones $6^A, 6^B, 6^C$ and 6^D a semiconductor zone 6^E , which entirely surrounds these zones. The pn junction 5^E associated with this zone is cut off by means of a voltage source in such a manner that the associated depletion region 12^E contacts the depletion regions 12 associated with the pn junction 5 between the epitaxial layer 3 and the zones $6^A, 6^B, 6^C, 6^D$ and 11. A voltage difference between the zone 6^E and the zones 6^A-D is permissible because in the intermediate region no measures are taken which influence the formation of the high-ohmic layer 11. This measure results in that charge carriers generated by light not incident upon the zones $6^A, 6^B, 6^C$ and $6^D, 11$ and parasitically generated charge carriers (originating, for example, from the edge of the crystal) substantially solely contribute to the current through the

pn junction 5^E so that due to a diffusion they cannot provide parasitic contributions to a photoelectric current through one of the pn junctions 5 of the semiconductor zones $6^A, 6^B, 6^C, 6^D$.

A semiconductor device of the kind shown in Figures 3, 4 can be manufactured by techniques generally known in the semiconductor technology. The starting material is an n-type silicon substrate 2, on which the n-type epitaxial layer is grown. The surface regions 6 are obtained, for example, by means of implantation of p-type impurities followed by a diffusion or annealing step. The surface regions 6 may also be provided directly by diffusion.

Although satisfactory results can be obtained with the device of Figs. 3, 4 in positioning in two dimensions, the transmission characteristics are not fully linear. A better linearity is obtained by means of the device shown in Figs. 6, 7, 8, in which a second set of semiconductor zones 58 of the n-type with an interposed high-ohmic zone 57 fulfil the same function as the p-type zones 6, 11, but now in a direction at right angles to the connection between the semiconductor zones 6. Where, as stated above, holes are collected in the regions 7, 11, the n-type regions 57, 58 form potential minima for electrons generated in the semiconductor body.

The device comprises a p- or π -type substrate 2, on which an n- or ν -type epitaxial layer is grown. Before the epitaxial growth, the buried layers 57, 58 are defined, the semiconductor zones 58 being doped more highly by selective implantation. These n-type semiconductor zones 58 are contacted via highly doped n⁺ zones 59 and metal layers $9^C, 9^D$. Furthermore, the device comprises at the surface 4 a similar substructure as described with reference to Figs. 1 and 2. The metal layers $9^A, 9^B, 9^C, 9^D$ are connected to the inputs $19^A, 19^B, 19^C, 19^D$ of adjustment circuits of the kind described above, which form part of a processing unit 40 shown diagrammatically. Thus, a bi-dimensional system is obtained for calibrating a beam position, the adjustment of one coordinate being mainly determined by the hole current and that of the other coordinate being mainly determined by the electron current. Depending upon the application, the regions 57, 58 may have in plan view again various shapes.

The substrate 2 may also be of the n-type, provided that the doping of the regions 57, 58 is sufficiently high so that potential wells for electrons can be produced.

In the processing unit 40, the subcurrents are added again to determine the overall photocurrent, while this unit 40 supplies at the outputs 60 signals for, for example, controlling the beam b or for other applications.

A semiconductor device according to the invention may be used, for example, in a focus detection system of the kind shown in Fig. 9. Fig. 9 shows in a

radial sectional view a small part of a circular disk-shaped record carrier 21. The radiation-reflecting information structure is situated on the upper side of the record carrier and consists of a large number of information regions (not shown) which are arranged in accordance with information tracks 22. The information structure is scanned by a reading beam b supplied by a radiation source 23, for example a semiconductor diode laser. A lens 24 forms from the diverging beam a parallel beam having such a cross-section that the pupil of an objective system 25 is filled adequately. This objective system then produces a radiation spot V of minimum dimensions on the information structure.

The reading beam is reflected by the information structure and when the record carrier is moved relative to the reading beam, the reflected beam is modulated in time in accordance with the information stored in the record carrier. In order to separate the modulated beam from the beam emitted by the radiation source, a beam-splitting prism 26 is arranged between the radiation source and the objective system. This prism can comprise two prismatic parts 27 and 28, between which a beam-splitting layer 29 is provided. Reference numerals 30 and 31 denote the entrance surface and the exit surface, respectively, of the prism 26. The layer 29 may be semitransparent mirror. In order to limit the radiation loss in the reading unit to a minimum, a polarization-sensitive separation layer may be used. In this case, there has to be arranged between the objective system and the prism 26 a $\lambda/4$ plate 32, where λ is the wavelength of the reading beam b . This prism is traversed twice by the reading beam and rotates the polarization plane of this beam through 90° in all. The beam emitted by the radiation source is then transmitted substantially completely by the prism, whereas the modulated beam is reflected substantially completely to a radiation-sensitive detection system 33, which supplies a signal which is modulated in accordance with the information stored in the record carrier.

In order to produce a focus error signal, which gives an indication about the value and the direction of a deviation between the focusing surface of the objective system and the surface of the information structure, a roof prism 34 is provided on the exit surface 31 of the beam-splitting prism 26 and the radiation-sensitive detection system 33 is composed of, for example, two radiation-sensitive devices of the kind described with reference to Figs. 1 and 2. These two devices are denoted by reference numerals 36 and 37 in Fig. 11, which illustrates the principle of the focus error detection. This Figure shows *inter alia* an elevation of the semiconductor devices taken on the line XI-XI in Fig. 9 and a diagrammatic representation of the auxiliary electronic means for adjusting the difference voltages for obtaining the apparent zero adjustment.

The refracting rib 35 of the prism 34 may be parallel to the optical axis (OO' in Fig. 9) of the reading unit. Preferably, however, as shown in Fig. 9, the roof prism is arranged so that the refracting rib 35 is at right angles to the optical axis OO' . In fact a tracking error signal can then be derived from the detector signals too.

The roof prism splits up the beam b into two subbeams b_1 and b_2 , which are incident upon the devices 36 and 37, respectively.

Figs. 9 and 11 show the situation in which the reading beam is focused exactly on the surface of the information structure. The reading unit may be designed so that the focus of the reflected beam is then located exactly in the surface 2 of the semiconductor devices 1 of the detectors 36, 37, which detectors have a structure similar to that shown in Figs. 1, 2. With a correct focusing, the subbeams b_1 and b_2 are incident symmetrically upon the high-ohmic zones 11 associated with the detectors 36 and 37 between the semiconductor zones 6^A , 6^B (line a in Fig. 11).

Upon the occurrence of a focus error, the energy distribution within the subbeams b_1 and b_2 , respectively, varies with respect to the associated detectors, which can also be considered as a displacement of the radiation spots V_1 and V_2 produced by the subbeams with respect to the detectors. If the focus of the beam originating from the radiation source should be located above the surface of the information structure, the beams b_1 and b_2 would be displaced inwards and the semiconductor zones 6^A and 6^D would receive less radiation energy than the semiconductor zones 6^B and 6^C (line a'). If the focus of the reading beam emitted by the radiation source should be located below the surface of the information structure, the reverse situation would apply and the semiconductor zones 6^B and 6^C would receive less radiation energy than the semiconductor zones 6^A , 6^B and 6^D (line a'' in Fig. 11a).

It has to be ensured that with a correct focusing the balance of the radiation spots V_1 and V_2 is apparently located halfway between the zones 6^A and 6^B and the zones 6^C and 6^D , respectively. In order that after the assembly any difference in photocurrent can be compensated for on behalf of a correct zero adjustment of the optical system, the arrangement of Fig. 11 again comprises a plurality of electronic control circuits, whose operation is equal to that of the preceding embodiments.

After the said zero adjustment has been effected, the signals originating from the operational amplifiers 15 can be used for signal processing. For this purpose, the signals 47 and 48 (cf. Figs. 10, 11) which are a measure for the photo currents through the zones 6^A and 6^B , are supplied to a first summator 50, while the signals 46 and 49 are supplied to a second summator 51. When the signals of these adders are supplied to a differential amplifier 52, a focus error signal

S_r is obtained. The information signal S_i can be obtained by a third summator 53, whose inputs are connected to the outputs of the summators 50 and 51.

When, as shown in Fig. 9, the refracting rib 35 of the prism 34 is arranged at right angles to the optical axis OO' , the radiation spots V_1 and V_2 are relatively displaced in a direction which is effectively at right angles to the track direction. In this case, a tracking signal, a signal giving an indication about the position of the reading spot V with respect to the centre of a track to be read, can be derived from the signals 46, 47, 48 and 49 originating from the operational amplifier 15 (Fig. 11). This signal S_r is obtained, as indicated in Fig. 10, by supplying the signals 46 and 47 to a summator 54 and by supplying the signals 48 and 49 to a summator 55 and by supplying the signals of the summators to a differential amplifier 56. The signal S_r is therefore given by :

$$S_r = (S_{46} + S_{47}) - (S_{48} + S_{49}).$$

If the arrangement shown in Figs. 9, 10 is not used for producing a tracking signal S_r , in the semiconductor device the zone 6_B can coincide with the zone 6_C, as shown in Fig. 12. The focus error signal S_f is given by :

$$S_f = (S_{41} + S_{43}) - S_{42}.$$

The focus detection system is described with reference to its use in an optical reading unit, but may also be used in a writing unit or in a combined writing/reading unit. The writing unit is composed in a manner analogous to that of the reading unit described. For writing information, for example by melting depressions into a metal layer, a larger amount of energy is required than for reading, while moreover the writing beam has to be modulated in time in accordance with the information to be written. As a radiation source in the writing unit, use may be made of a gas laser, such as a He-Ne laser, in which a modulator, such as an electro-optical or an acousto-optical modulator, has to be arranged in the path of the writing beam. Alternatively, a diode laser may be used, in which event the modulation of the writing beam may be obtained by variation of the electric current through the diode laser so that no separate modulator is required.

The semiconductor device shown in Figs. 1 and 2 may also be used for measuring small displacements, for example on behalf of mechanical tests (bending, strain measurement etc.).

As already stated above, the high-ohmic layer 11 may be formed in a manner other than by doping. Fig. 13 shows diagrammatically in cross-section and Fig. 14 shows in plan view a device according to the invention, in which in the operating condition the layer 11 is formed by means of a gate electrode 80, which is transparent at least in part to the incident radiation.

This gate electrode 80 is disposed on a dielectric layer 7 of, for example, silicon oxide which, as in the preceding embodiments, may also serve as an antireflection layer. The gate electrode 80 is applied to such a potential that in the operating condition a current can flow between the zones 6A and 6B if these zones are applied to different voltages. This voltage difference in turn determines the location of the calibration point on the connection line between the zones 6A and 6B. When these zones have a relative distance of, for example, 14 μm , the calibration point can be displaced electronically in this manner over about 6 μm .

Although this will mostly be the case, the high-ohmic layer 11 need not have a conductivity type opposite to that of the subjacent layer 3. In principle, it is sufficient for the layer 11 to have such a low netcharge carrier concentration that a certain "punch-through" is possible between the semiconductor zones or diodes 6A and 6B.

In the semiconductor bodies, the conductivity types of the semiconductor regions may be converted (simultaneously) whilst simultaneously adapting the electrical voltages in the adjustment system. In the arrangement of Fig. 11, the radiation-sensitive devices 36, 37 can be formed in one semiconductor body, after which mutual electrical isolation is obtained, for example, by etching a groove, which, if required may again be filled with insulating material.

Furthermore, semiconductor materials other than silicon may be used, such as, for example, germanium or compounds of the III-V type, such as gallium arsenide. Instead of by semiconductor zones 6, the depletion regions 12 may also be formed by metallic zones forming Schottky contacts on the semiconductor layer 3, which metallic zones then have to be transparent to radiation, of course. For this purpose, they are made for example of antimonydoped tin oxide or of (p- or n-type) indium oxide that may be doped with tin.

Instead of providing the semiconductor zones 6 in the epitaxial layer 3, they may also be provided directly in the substrate, in which event the substrate material has a resistivity of, for example, 10 $\Omega \text{ cm}$. Furthermore, the high-ohmic zone need not necessarily contact the surface 4 and may be separated therefrom by a part of the substrate. Such a configuration may be obtained by providing the zones 11 by ion implantation at a high energy and is particularly suitable for detection of high-energetic particles. Moreover, the adjustment circuits may be realized advantageously in the same semiconductor body as the body in which the radiation-sensitive device (and any auxiliary electronic means) is situated.

The focus error detection system described does not utilize special properties of the optical information structure or of the surface on which focusing has to take place. It is required and sufficient only that this surface is radiation-reflecting. The focus error detec-

tion system can therefore be used in various arrangements, in which focusing has to be very accurate, for example in microscopes.

Claims

1. A semiconductor device for determining or controlling the position of a radiation beam (b, b') which is incident upon a major surface (4) of a radiation-sensitive semiconductor body (1) provided with at least two radiation-sensitive diodes which contain at the surface (4) zones (6) that form a rectifying junction (5) with an adjacent part (3) of the semiconductor body (1) and are provided with electrical connections (9^A, 9^B) to drain away electric current produced by the incident radiation, characterized in that a high-ohmic zone (11) that connects the zones (6) and, at least in the operating condition, forms a channel through which a current flows from one zone (6) to the other, is located between the diodes, while the device is further provided with an adjustment circuit (15, 16, 17, 18, 19, 20) by which the rectifying junctions (5) associated with the diodes can be biased with an appropriate relative difference such that, independently of the location at which the radiation beam strikes the major surface (4) between the diodes, the electric currents produced through the two diodes are substantially the same.

2. A semiconductor device as claimed in Claim 1, characterized in that the radiation-sensitive diodes are constituted by at least two semiconductor zones (6^A, 6^B) of the first conductivity type, which form a pn junction (5) with an adjacent part (3) of the semiconductor body (1).

3. A semiconductor device as claimed in Claim 1 or 2, characterized in that the high-ohmic zone (11) is of the first conductivity type and forms a pn junction (5') with the adjacent part (3) of the semiconductor body (1).

4. A semiconductor device as claimed in any one of the preceding Claims, characterized in that the high-ohmic zone (11) is formed by means of a gate electrode (80), which is located on a dielectric layer (7) and is applied to a suitable potential.

5. A semiconductor device as claimed in any one of the preceding Claims, characterized in that the relative distance of the radiation-sensitive diodes amounts to a few times the width of the radiation beam (b, b').

6. A semiconductor device as claimed in any one of Claims 2 to 5, characterized in that the semiconductor body (1) is further provided with at least two semiconductor zones (58) of the second conductivity type opposite to the first conductivity type having electrical connections (9^C, 9^D) to dissipate electric current produced by the incident radiation, while a high-ohmic zone (57) is present also between the semiconductor zones (58) of the second conductivity type and the

device is further provided with an adjustment circuit (40) by which the semiconductor zones (58) of the second conductivity type can be biased with an appropriate relative difference such that, independently of the location at which the radiation beam (b, b') strikes the major surface (4), the currents produced through the semiconductor zones (58) of the second conductivity type are substantially the same.

7. A semiconductor device as claimed in any one of the preceding Claims, characterized in that the adjustment circuits (40) supply output signals (60) which are related to the electric currents through the semiconductor zones (6, 58).

8. A semiconductor device as claimed in Claim 6, characterized in that at the area of the incident radiation the high-ohmic zone (11) between the semiconductor zones (6) of the first conductivity type is substantially perpendicular to the high-ohmic zone (57) between the semiconductor zones (58) of the second conductivity type.

9. A semiconductor device as claimed in Claim 6, characterized in that the semiconductor zones (58) of the second conductivity type and the high-ohmic zone (57) form a pn junction with it least a part (2) of the semiconductor body (1).

10. An opto-electronic focus error detection system for detecting in a optical system a deviation between a radiation-reflecting element and a focusing surface of an objective system (25), more particularly for an arrangement for reading a record carrier (21) having an optical radiation reflecting information structure (22), or an arrangement for optically writing information (22) into a record carrier (21), characterized in that the focus error detection system comprises a semiconductor device as claimed in any one of the preceding Claims.

11. An opto-electronic focus error detection system as claimed in Claim 10, characterized in that two subbeams (b₁, b₂) formed by a beam-splitting element (26) in the path of radiation, reflected by the radiation-reflecting element, strike two high-ohmic zones (11, 11') of the first conductivity type located between semiconductor zones (6^A, 6^B and 6^C, 6^D) of the first conductivity type and outputs (46, 47, 48, 49) of the adjustment circuit are connected to inputs of an electronic circuit (50, 51, 52), in which a focus error (S_f) is derived.

12. An opto-electronic focus error detection system as claimed in Claim 11, characterized in that at least one semiconductor zone (6^A, 6^B) of the first conductivity type is common to two adjoining high-ohmic zones (11, 11') of the first conductivity type.

Ansprüche

1. Halbleiteranordnung zum Bestimmen oder Regeln der Lage eines Strahlungsbündels (b, b'), das



tion system can therefore be used in various arrangements, in which focusing has to be very accurate, for example in microscopes.

Claims

1. A semiconductor device for determining or controlling the position of a radiation beam (b, b') which is incident upon a major surface (4) of a radiation-sensitive semiconductor body (1) provided with at least two radiation-sensitive diodes which contain at the surface (4) zones (6) that form a rectifying junction (5) with an adjacent part (3) of the semiconductor body (1) and are provided with electrical connections (9^A, 9^B) to drain away electric current produced by the incident radiation, characterized in that a high-ohmic zone (11) that connects the zones (6) and, at least in the operating condition, forms a channel through which a current flows from one zone (6) to the other, is located between the diodes, while the device is further provided with an adjustment circuit (15, 16, 17, 18, 19, 20) by which the rectifying junctions (5) associated with the diodes can be biased with an appropriate relative difference such that, independently of the location at which the radiation beam strikes the major surface (4) between the diodes, the electric currents produced through the two diodes are substantially the same.

2. A semiconductor device as claimed in Claim 1, characterized in that the radiation-sensitive diodes are constituted by at least two semiconductor zones (6^A, 6^B) of the first conductivity type, which form a pn junction (5) with an adjacent part (3) of the semiconductor body (1).

3. A semiconductor device as claimed in Claim 1 or 2, characterized in that the high-ohmic zone (11) is of the first conductivity type and forms a pn junction (5') with the adjacent part (3) of the semiconductor body (1).

4. A semiconductor device as claimed in any one of the preceding Claims, characterized in that the high-ohmic zone (11) is formed by means of a gate electrode (80), which is located on a dielectric layer (7) and is applied to a suitable potential.

5. A semiconductor device as claimed in any one of the preceding Claims, characterized in that the relative distance of the radiation-sensitive diodes amounts to a few times the width of the radiation beam (b, b').

6. A semiconductor device as claimed in any one of Claims 2 to 5, characterized in that the semiconductor body (1) is further provided with at least two semiconductor zones (58) of the second conductivity type opposite to the first conductivity type having electrical connections (9^C, 9^D) to dissipate electric current produced by the incident radiation, while a high-ohmic zone (57) is present also between the semiconductor zones (58) of the second conductivity type and the

device is further provided with an adjustment circuit (40) by which the semiconductor zones (58) of the second conductivity type can be biased with an appropriate relative difference such that, independently of the location at which the radiation beam (b, b') strikes the major surface (4), the currents produced through the semiconductor zones (58) of the second conductivity type are substantially the same.

7. A semiconductor device as claimed in any one of the preceding Claims, characterized in that the adjustment circuits (40) supply output signals (60) which are related to the electric currents through the semiconductor zones (6, 58).

8. A semiconductor device as claimed in Claim 6, characterized in that at the area of the incident radiation the high-ohmic zone (11) between the semiconductor zones (6) of the first conductivity type is substantially perpendicular to the high-ohmic zone (57) between the semiconductor zones (58) of the second conductivity type.

9. A semiconductor device as claimed in Claim 6, characterized in that the semiconductor zones (58) of the second conductivity type and the high-ohmic zone (57) form a pn junction with it least a part (2) of the semiconductor body (1).

10. An opto-electronic focus error detection system for detecting in a optical system a deviation between a radiation-reflecting element and a focusing surface of an objective system (25), more particularly for an arrangement for reading a record carrier (21) having an optical radiation reflecting information structure (22), or an arrangement for optically writing information (22) into a record carrier (21), characterized in that the focus error detection system comprises a semiconductor device as claimed in any one of the preceding Claims.

11. An opto-electronic focus error detection system as claimed in Claim 10, characterized in that two subbeams (b₁, b₂) formed by a beam-splitting element (26) in the path of radiation, reflected by the radiation-reflecting element, strike two high-ohmic zones (11, 11') of the first conductivity type located between semiconductor zones (6^A, 6^B and 6^C, 6^D) of the first conductivity type and outputs (46, 47, 48, 49) of the adjustment circuit are connected to inputs of an electronic circuit (50, 51, 52), in which a focus error (S_f) is derived.

12. An opto-electronic focus error detection system as claimed in Claim 11, characterized in that at least one semiconductor zone (6^A, 6^B) of the first conductivity type is common to two adjoining high-ohmic zones (11, 11') of the first conductivity type.

Ansprüche

1. Halbleiteranordnung zum Bestimmen oder Regeln der Lage eines Strahlungsbündels (b, b'), das



auf eine Hauptoberfläche (4) eines strahlungsempfindlichen Halbleiterkörpers (1) trifft, der mit mindestens zwei strahlungsempfindlichen Dioden versehen ist, die an der Oberfläche (4) Zonen (6) aufweisen, die einen gleichrichtenden Übergang (5) bilden mit einem angrenzenden Teil (3) des Halbleiterkörpers (1) und mit elektrischen Anschlüssen (9^A, 9^B) versehen sind um elektrischen Strom abzuführen, der von der einfallenden Strahlung erzeugt worden ist, dadurch gekennzeichnet, daß eine hochohmige Zone (11), welche die Zonen (6) verbindet und, wenigstens im Betrieb, einen Kanal bildet, durch den ein Strom von der einen Zone (6) zu der anderen Zone fließt, zwischen den Dioden liegt, während die Anordnung weiterhin mit einem Einstellkreis (15, 16, 17, 18, 19, 20) versehen ist, durch den die den Dioden zugeordneten gleichrichtenden Übergänge (5) mit einer geeigneten relativen Differenz derart vorgespannt werden können, daß, unabhängig von der Stelle, an der das Strahlungsbündel die Hauptoberfläche (4) zwischen den Dioden trifft, die von den beiden Dioden erzeugten elektrischen Ströme im wesentlichen einander gleich sind.

2. Halbleiteranordnung nach Anspruch 1, dadurch gekennzeichnet, daß die strahlungsempfindlichen Dioden durch wenigstens zwei Halbleiterzonen (6^A, 6^B) vom ersten Leitungstyp gebildet werden, die mit einem angrenzenden Teil (3) des Halbleiterkörpers (1) einen PN-Übergang (5) bilden.

3. Halbleiteranordnung nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die hochohmige Zone (11) vom ersten Leitungstyp ist und mit einem angrenzenden Teil (3) des Halbleiterkörpers (1) einen PN-Übergang bildet.

4. Halbleiteranordnung nach einem der vorstehenden Ansprüche, dadurch gekennzeichnet, daß die hochohmige Zone (11) durch eine Gate-Elektrode (80) gebildet ist, die auf einer dielektrischen Schicht (7) liegt und der ein geeignetes Potential zugeführt wird.

5. Halbleiteranordnung nach einem der vorstehenden Ansprüche, dadurch gekennzeichnet, daß der relative Abstand zwischen den strahlungsempfindlichen Dioden um einige Male größer ist als die Breite des Strahlungsbündels (b, b').

6. Halbleiteranordnung nach einem der Ansprüche 2 bis 5, dadurch gekennzeichnet, daß der Halbleiterkörper (1) weiterhin mit wenigstens zwei Halbleiterzonen (58) vom zweiten, dem ersten Leitungstyp entgegengesetzten Leitungstyp versehen und elektrische Anschlüsse (9^C, 9^D) aufweist zum Aufnehmen durch die auftreffende Strahlung erzeugten elektrischen Stromes, während zwischen den Halbleiterzonen (58) vom zweiten Leitungstyp ebenfalls eine hochohmige Zone (57) vorhanden ist und die Anordnung weiterhin mit einem Einstellkreis (40) versehen ist, durch den die Halbleiterzonen (58) vom zweiten Leitungstyp mit einer geeigneten relativen Differenz

vorgespannt sein kann, derart, daß unabhängig von der Stelle, an der das Strahlungsbündel (b, b') die Hauptfläche (4) trifft, die durch die Halbleiterzonen (58) vom zweiten Leitungstyp erzeugten Ströme einander im wesentlichen gleich sind.

7. Halbleiteranordnung nach einem der vorstehenden Ansprüche, dadurch gekennzeichnet, daß die Einstellkreise (40) Ausgangssignale (60) liefern, die sich auf die elektrischen Ströme durch die Halbleiterzonen (6, 58) beziehen.

8. Halbleiteranordnung nach Anspruch 6, dadurch gekennzeichnet, daß im Bereich der einfallenden Strahlung die hochohmige Zone (11) zwischen den Halbleiterzonen (6) vom ersten Leitungstyp im wesentlichen senkrecht zu der hochohmigen Zone (57) zwischen den Halbleiterzonen (58) vom zweiten Leitungstyp steht.

9. Halbleiteranordnung nach Anspruch 6, dadurch gekennzeichnet, daß die Halbleiterzonen (58) vom zweiten Leitungstyp und die hochohmige Zone (57) einen PN-Übergang mit wenigstens einem Teil (2) des Halbleiterkörpers (1) bilden.

10. Optoelektronisches Fokusfehlerdetektionssystem zum in einem optischen System Detektieren einer Abweichung zwischen einem strahlungsreflektierenden Element und einer Fokussierungsfläche eines Objektivs (25), insbesondere für eine Anordnung zum Lesen eines Aufzeichnungsträgers (21) mit einer optischen Strahlung reflektierenden Informationsstruktur (22), oder eine Anordnung zum optischen Einschreiben von Information (22) in einem Aufzeichnungsträger (21) dadurch gekennzeichnet, daß das Fokusfehlerdetektionssystem eine Halbleiteranordnung nach einem der vorstehenden Ansprüche aufweist.

11. Optoelektronisches Fokusfehlerdetektionssystem nach Anspruch 10, dadurch gekennzeichnet, daß zwei durch ein Strahlspaltelement (26) in der Strecke der Strahlung gebildete, durch das strahlungsreflektierende Element reflektierte Teilstrahlen (b₁, b₂) zwei hochohmige Zonen (11, 11') vom ersten Leitungstyp zwischen Halbleiterzonen (6^A, 6^B und 6^C, 6^D) vom ersten Leitungstyp berühren und Ausgänge (46, 47, 48, 49) des Einstellkreises mit Eingängen einer elektronischen Schaltung (50, 51, 52) verbunden sind, in denen ein Fokusfehler (S_f) abgeleitet wird.

12. Optoelektronisches Fokusfehlerdetektionssystem nach Anspruch 11, dadurch gekennzeichnet, daß wenigstens eine Halbleiterzone (6^A, 6^B) vom ersten Leitungstyp den zwei aneinander grenzenden hochohmigen Zonen (11, 11') vom ersten Leitungstyp gemeinsam ist.

Revendications

1. Dispositif semiconducteur pour déterminer ou



commander la position d'un faisceau de rayonnement incident à une surface principale d'un corps semiconducteur sensible au rayonnement et présentant au moins deux diodes sensibles au rayonnement, diodes qui forment une jonction redresseuse avec une partie contiguë du corps semiconducteur et qui sont pourvues de connexions électriques pour évacuer du courant électrique engendré par le rayonnement incident, caractérisé en ce qu'une zone à résistance élevée (11) reliant les zones (6) et formant, au moins dans l'état de fonctionnement, un canal par lequel circule un courant d'une zone (6) à l'autre, est située entre les diodes, alors que le dispositif est encore pourvu d'un circuit d'ajustement (15, 16, 17, 18, 19, 20) par lequel les jonctions redresseuses (5) associées aux diodes peuvent être polarisées avec une différence mutuelle appropriée telle que, indépendamment de l'endroit où le faisceau de rayonnement frappe la surface principale (4) entre les diodes, les courants électriques engendrés à travers les deux diodes sont sensiblement les mêmes.

2. Dispositif semiconducteur selon la revendication 1, caractérisé en ce que les diodes sensibles au rayonnement sont constituées par au moins deux zones semiconductrices (6^A, 6^B) du premier type de conductivité qui forment une jonction pn (5) avec une partie contiguë (3) du corps semiconducteur (1).

3. Dispositif semiconducteur selon la revendication 1 ou 2, caractérisé en ce que la zone à résistance élevée (11) est du premier type de conductivité et forme une jonction pn (5') avec la partie contiguë (3) du corps semiconducteur (1).

4. Dispositif semiconducteur selon l'une quelconque des revendications précédentes, caractérisé en ce que la zone à résistance élevée (11) est constituée au moins par une électrode de grille (80) située sur une couche diélectrique (7) et qui est mise à un potentiel convenable.

5. Dispositif semiconducteur selon l'une quelconque des revendications précédentes, caractérisé en ce que la distance qui sépare les diodes sensibles au rayonnement est quelques fois plus grande que la largeur du faisceau de rayonnement (b, b').

6. Dispositif semiconducteur selon l'une quelconque des revendications 2 à 5, caractérisé en ce que le corps semiconducteur (1) présente encore au moins deux zones semiconductrices (58) du second type de conductivité opposé au premier, ayant des connexions électriques (9^C, 9^D) pour dissiper un courant électrique engendré par le rayonnement incident, alors qu'entre les zones semiconductrices (58) du second type de conductivité, est également située une zone à résistance élevée (57), et en ce que le dispositif est encore pourvu d'un circuit d'ajustement (40) par lequel les zones semiconductrices (58) du second type de conductivité peuvent être polarisées avec une différence mutuelle appropriée telle que, indépendant de l'endroit où le faisceau de rayonne-

ment (b, b') frappe la surface principale (4), les courants engendrés à travers les zones semiconductrices (58) du second type de conductivité sont sensiblement les mêmes.

7. Dispositif semiconducteur selon l'une quelconque des revendications précédentes, caractérisé en ce que les circuits d'ajustement (40) fournissent des signaux de sortie (60) qui sont liés aux courants électriques à travers les zones semiconductrices (6, 58).

8. Dispositif semiconducteur selon la revendication 6, caractérisé en ce qu'à l'endroit du rayonnement incident, la zone à résistance élevée séparant les zones semiconductrices (6) du premier type de conductivité est sensiblement perpendiculaire à la zone à résistance élevée (56) séparant les zones semiconductrices (58) du second type de conductivité.

9. Dispositif semiconducteur selon la revendication 6, caractérisé en ce que les zones semiconductrices (58) du second type de conductivité et la zone à résistance élevée (57) forment avec au moins une partie (2) du corps semiconducteur (1) une jonction pn.

10. Système optoélectronique de détection d'erreurs de focalisation pour détecter, dans un système optique, un écart entre un élément réfléchissant le rayonnement et une surface de focalisation d'un système d'objectif (50), notamment pour un agencement de lecture d'un support d'enregistrement (21) ayant une structure d'information optique (22) réfléchissant le rayonnement ou pour un agencement d'enregistrement optique d'information (22) dans un support d'enregistrement (21), caractérisé en ce que le système de détection d'erreurs de focalisation comporte un dispositif semiconducteur selon l'une quelconque des revendications précédentes.

11. Système optoélectronique de détection d'erreurs de focalisation selon la revendication 10, caractérisé en ce que deux sous-faisceaux (b₁, b₂), formés par un élément diviseur de faisceau (26) dans le trajet de rayonnement et ? réfléchis par l'élément réfléchissant le rayonnement, frappent deux zones à résistance élevée (11, 11') du premier type de conductivité situées entre des zones semiconductrices (6^A, 6^B et 6^C, 6^D) du premier type de conductivité et en ce que des sorties (46, 47, 48, 49) du circuit d'ajustement sont reliées à des entrées d'un circuit électronique 50, 51, 52) dans lequel est déduite une erreur de focalisation (S_f).

12. Système optoélectronique de détection d'erreur de focalisation selon la revendication 11, caractérisé en ce qu'au moins une zone semiconductrice (6^A, 6^B) du premier type de conductivité est commune à deux zones contiguës à résistance élevée (11, 11') du premier type de conductivité.