PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO PHOTO-DETECTOR DEVICES

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company of Berlin and Munich, German Federal Republic, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which is to be performed, to be particularly described in and by the following statement:—

The invention relates to photo-detector devices having provided a frequency-selective filter to select a portion of the frequency band of electromagnetic radiation to which the photo-detector is responsive.

Semiconductor detectors generally are sensitive over a wide range of frequencies, although it is frequently only a narrow spectral range that is to be employed as an operating frequency band. The frequencies to which semiconductor detectors are responsive that are outside the required operating band can give rise to undesired interference currents due to the influence of unwanted light. Therefore, in order to reduce these interference currents, it is desirable to provide semiconductor detectors with frequency selective optical filters which serve to eliminate electromagnetic radiation energy at frequencies outside the operating band. This can be readily effected employing commercially available optical filters, except for the fact that in a mass production of optical semiconductor components, important factors oppose the use of commercially available filters. As in known, optical filters are expensive, and their use leads to a considerable increase in the cost of the end product. The cost involved in attaching the filter assembly would also lead to another, not inconsiderable increase in the financial outlay for the end product. Thus solely for economical considerations, it is not advisable to equip photo-detectors with commercially available filters.

The use of pre-manufactured, optical filters in photo-detectors also restricts the technical possibilities of use, in that only a specific assortment of filters, having specific technical characteristics data and specific shapes and sizes are available. Any desired deviation from such predetermined characteristic data and dimensions would add to the cost or make impossible the use of pre-manufactured filters.

One object of the present invention is to provide a photo-detector device, the technical data of which can be matched to the specific requirement of a photo-detector in simple manner and low cost, and which can be applied to the mass production of photo-detectors at a viable cost outlay.

The invention consists in a photo-detector device in which a semiconductor photo-sensitive element responding to electromagnetic radiation in a relatively wide operating frequency range is provided with a filter on its surface, said filter comprising a stack of superimposed layers that co-operate to form two or more superimposed interference filters acting in the manner of Fabry-Pero filters to be selectively transmissive to a relatively narrow spectral range within said operating range.

Filters arranged directly on the detector surface have the advantage, in comparison to filters which are not directly applied to the surface, that generally speaking the reflection losses are lower, and in addition laterally incident interference light is withheld from the detector. Furthermore, when filters are not arranged directly on the detector surface, but form separate entities, their use involves a considerably higher cost outlay for the acquisition and assembly of the devices. In particular in the case of mass production of photo-detector devices, this extra cost outlay is extremely high.

Furthermore, the new possibilities offered by using filter layers arranged directly on the detector surface are extremely great, due to the fact that the filter layers can be easily adapted to specific detector characteristic data.

The invention will now be described with reference to the drawings, in which:—

Figure 1 is a schematic explanatory cross section through one known embodiment of a photo-detector device with a filter on the detector surface;

Figure 2 is an explanatory cross section at the portion corresponding to "A" of Figure 1, taken through a plurality of layers acting as one single Fabry-Perot interference filter, and formed on a silicon surface;

Figure 3 shows a cross-section at the portion corresponding to "A" of Figure 1, taken through a first exemplary embodiment of the present invention, having sufficient layers to form a double Fabry-Perot interference filter on a silicon surface;

Figure 4 is a graph illustrating the spectral sensitivity of a silicon photo-diode device equipped with filters as shown in Figure 3 for comparison with the related curve for a device not equipped with filters; and

Figure 5 illustrates an explanatory cross-section at the portion corresponding to "A" of Figure 1, taken through a multilayer filter shown directly on a silicon surface, for the sake of simplicity, the intervening Fabry-Perot filter that would be present in an embodiment of the present invention being omitted for the sake of clarity.

The known arrangement shown in Figure 1 has a photo-detector device *1* formed by a semiconductor body 2, which possesses a zone 3 of one conductivity type, e.g. n-doped, and a further zone 4 of the other conductivity type, e.g. a p^+-zone doped into the semiconductor body 2 beneath a surface 5 of the semiconductor.

A metal contact 6 is arranged on the semiconductor surface 5 in the region of the zone 4, for the supply of current to the photo-detector device 1. The remainder of the semiconductor surface 5 is covered with an optical filter 7, consisting in a single Fabry-Perot filter, that is described in detail with reference to the known arrangement shown in Figure 2. Beneath the semiconductor surface 8, which lies opposite the semiconductor surface 5, there is a n^+-doped zone 9 provided in the n-doped semiconductor body 2. A continuous contact layer 10 is arranged on the surface 8 of the zone 9. A dash-dotted, circle "A" in Figure 1 indicates a portion which will be represented in detail in other Figures relating to different embodiments of optical filter layers.

The $p^+/n/n^+$ doping of the photo-detector described in Figure 1 can be replaced by the homologous doping $n^+/p/p^+$. In both cases, ohmic contacts are obtained. The filter 7 arranged on the detector surface can in accordance with the invention be a double or multiple Fabry-Perot interference filter, and may also be in the form of a combination of such filters with different types of layer filters, such as an absorption filter, an interference filter or notch filter.

Figure 2 shows the portion corresponding to "A" from Figure 1, with a stack of three superimposed layers acting as a single Fabry-Perot interference filter on a silicon surface. The optical filter 7 on the semiconductor surface 5 of the silicon semiconductor body 2 in this explanatory illustration consists of a silver layer 12 arranged directly on the semi-conductor surface 5, a SiO_2-layer 13 being arranged above the silver layer 12, and having a layer thickness of $\lambda/2$, where λ is the centre wavelength of the spectral band which is transmitted through the filter, and in this case equals 405 nm, and finally a covering silver layer 14. In place of silver layers, it is also possible to employ aluminium layers, or other reflective metal layers, for example. An incident light beam in the direction of arrow 11 is split up into transmitted beam components indicated by arrows 11*a* and reflected beam components indicated by arrows 11*b*. Multiple reflections take place within the optical filter 7, as indicated by the arrows 11*c*.

The layer thicknesses of the silver layers 12 and 14 in this explanatory illustration are contrived to be such that they produce 10% transmission for the wavelength 555 nm. The silver layers 12 and 14 can be replaced by dielectric reflectors, having a high-refraction layer and a low-refraction $\lambda/4$ layer. In the explanatory illustration shown in Figure 2, the silver layer 12 can be replaced by a $\lambda/4$ layer which consists of SiO_2 and is arranged on the semiconductor surface 5, and an overlaying $\lambda/4$ layer consisting of silicon, whilst the silver layer 14 can be replaced by a $\lambda/4$ layer consisting of silicon. It is unnecessary to provide a further, low-refraction $\lambda/4$ layer on the last-mentioned silicon layer, if the medium adjoining the filter surfaces possesses a lower optical index of refraction than silicon, such as air, for example. When metallic or dielectric reflectors are employed in the construction of Fabry-Perot interference filters, it should be noted that outside the transmitted spectral beam, metallic reflectors are virtually constantly reflective over a relatively wide spectral range. Dielectric reflectors, on the other hand, transmit specific spectral ranges with greater or lesser intensity, in dependence upon the wavelength above and below the frequency of the transmitted, spectral beam.

Figure 3 illustrates the portion corresponding to "A" from Figure 1, of an exemplary embodiment of the present invention using a double Fabry-Perot interference filter on a silicon surface. On the surface 5 of the silicon semiconductor body 2 the following layers are deposited in turn: a $\lambda/4$ SiO_2-layer 15, a $\lambda/4$ Si-layer 16, a a $\lambda/2$ SiO_2-layer 17, a $\lambda/4$ Si-layer 18, a $\lambda/4$ SiO_2-layer 19, a $\lambda/4$ Si-layer 20, a $\lambda/2$ SiO_2-layer 21 and a $\lambda/4$ Si-layer 22, where λ= 950 nm. An incident light beam in the direction of the arrow 23 is split into transmitted beam components indicated by the arrows 24, and reflected beam components indicated by the arrows 25. Within the filter, multiple reflections occur as indicated by arrows 27 and 28. The multiple reflections also involve a certain subtransmissiveness in the path direction, as indicated for example by arrows 29, and a certain sub-transmissiveness in the direction of the reflected beam, as indicated for example by arrows 30.

The series connection of more than two Fabry-Perot filters allows the production of arbitrary multiple Fabry-Perot interference filters. The layer sequence of high-refraction and low-refraction $\lambda/4$ and $\lambda/2$ layers does not necessarily require to obey the above order. It is also possible to reverse the described high-refraction and low-refraction layers, in which case the production of Fabry-Perot filters requires the $\lambda/2$ layers to the highly-refractive, and not low-refractive as in the quoted example.

Figure 4 graphically shows a curve 50 indicating the spectral sensitivity of a silicon photo-diode, and a curve 51 illustrates the spectral sensitivity of a silicon photo-diode provided with a filter as described in Figure 3. The sensitivity range of the device formed by a photo-diode provided with a filter is thus matched to the emission range of a GaAs-diode, a luminescence diode, having an emission maximum of 950 nm.

Figure 5 illustrates the portion corresponding to "A" from Figure 1, from a multi-layer notch filter shown for simplicity above and directly on a silicon surface without the associated Fabry-Perot filters. On the surface 5 of a silicon semiconductor 2, superimposed layers all having a layer thickness of $\lambda/4$ are arranged in turn: a low refraction SiO_2-layer 31, a high-refraction silicon layer 32, a low-refraction SiO_2-layer 33, a high-refraction silicon layer 34, a low-refraction SiO_2-layer 35, a high-refraction Si-layer 36, a low-refraction SiO_2-layer 37, and a high-refraction Si-layer 38. An incident light beam in the direction of arrow 39 is split into reflected beam components in the direction of arrows 40 and a transmitted beam component in the direction of arrow 41. A filter of this type virtually forms a notch filter, whose path edge exhibits the wave value λ, which is calculated from 4 times the layer thickness of one individual filter layer.

Photo-detector devices are generally equipped with filters by employing combinations of different types of filter with the aim of optimising the desired effect. The optimisation produces a maximum permeability to optical radiation in the operating range of the photo-detector, and at the same time a minimum permeability to optical radiation lying within the sensitivity range of the corresponding photo-detector, but outside the operating range of the associated detector.

The filters can be used to coat different types of photo-detectors, in particular photo-resistors or photo-diodes.

The layers of the filter, arranged on the detector surface, may consist of at least two of the materials aluminium oxide (Al_2O_3), germanium (Ge), silicon (Si), silicon oxide (SiO), silicon dioxide (SiO_2), titanium dioxide (TiO_2), tantalum pentoxide (Ta_2O_5), magnesium fluoride (MgF_2), silver (Ag) and aluminium (Al).

The use of the quoted materials for the production of thin layer filters in combination with a layer formed double Fabry-Perot interference filter on semiconductor bodies has proved particularly suitable in respect of mechanical, thermal and optical adaptability.

Absorption filters can consist of inorganic and/or organic substances. The application of absorption filter to semi-conductor surfaces is generally extremely simple, compared with the application of corresponding thin film filters, in the case of which it is necessary to deposit extremely small layer thickesses homogeneously over the entire semiconductor surface. Absorption filters can frequently be applied in the form of lacquer layers to the surface to be provided with filters.

The application of different types of filter to a semi-conductor surface which is to be provided with layers is generally the normal method of producing filters, since co-operation between different types of filter frequently produces the optimum effect.

A combination of thin film double Fabry-Perot interference filters and absorption filters is advantageous, since although such thin film filters generally allow a relatively narrowband light beam to be filtered out, usually it is impossible to achieve sufficient elimination for all the other wavelengths. However, this elimination can be attained by the additional use of suitable absorption filters.

Advantageously, narrowband notch filters of the type shown in Figure 5 may be incorporated on a double Fabry-Perot filter or filters, in exemplary embodiments of the invention. Frequently it is desirable to filter out specific beams in such manner that the absorption profile exhibits an approximately rectangular shape. For this purpose, thin film filters and absorption filters with as steep as possible absorption profiles can be combined in such a way that the resultant radiation exhibits a substantially rectangular absorption profile.

The filter layers may be deposited on the detector surface by means of vapour deposition, sputtering, pyrolytic deposition, sedimentation from a suspension, or by the application of lacquers, preferably with centrifuging.

Of the aforementioned methods vacuum deposition is extremely useful, as it allows the production of substantially homogenous layer thicknesses, which can be varied by varying the vapour deposition time.

The filter layers may be deposited over that entire surface of a semiconductor wafer which is to be coated, and the wafer subsequently cut into individual photo-detector devices.

The coating of the entire surface of semiconductor wafers with filter layers and subsequent division of the semiconductor wafer into individual semiconductor crystals constitutes a method of producing photo-detector devices which is particularly economical in respect of labour time and costs.

WHAT WE CLAIM IS:—

1. A photodetector device in which a semiconductor photo-sensitive element responding to electromagnetic radiation in a relatively wide operating frequency range is provided with a filter on its surface, said filter comprising a stack of superimposed layers that co-operate to form two or more superimposed interference filters acting in the manner of Fabry-Perot filters to be selectively transmissive to a relatively narrow spectral range within said operating range.

2. A device as claimed in Claim 1 in which said filter also incorporates a thin-film notch filter superimposed upon said Fabry-Perot filters.

3. A device as claimed in Claim 1 or Claim 2, in which there is at least one absorption filter layer superimposed upon said Fabry-Perot filters.

4. A photo-detector device substantially as described with reference to Figure 3, or as described with reference to Figures 3 and 5.

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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig.1

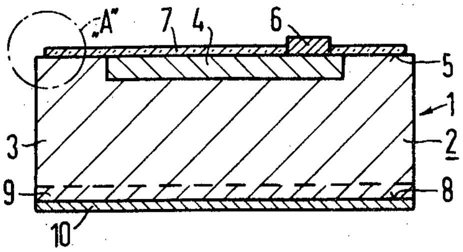


Fig.2

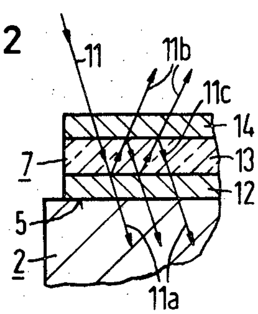


Fig.3

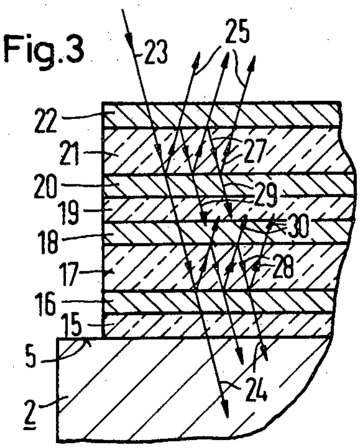
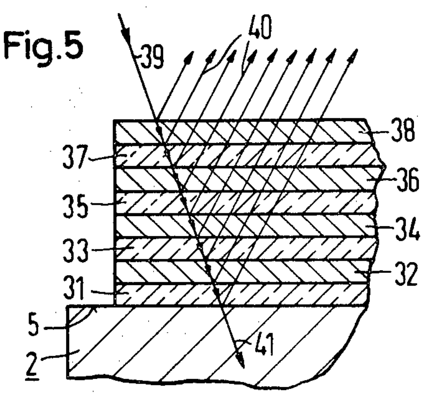


Fig.5



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Sheet 2

Fig. 4