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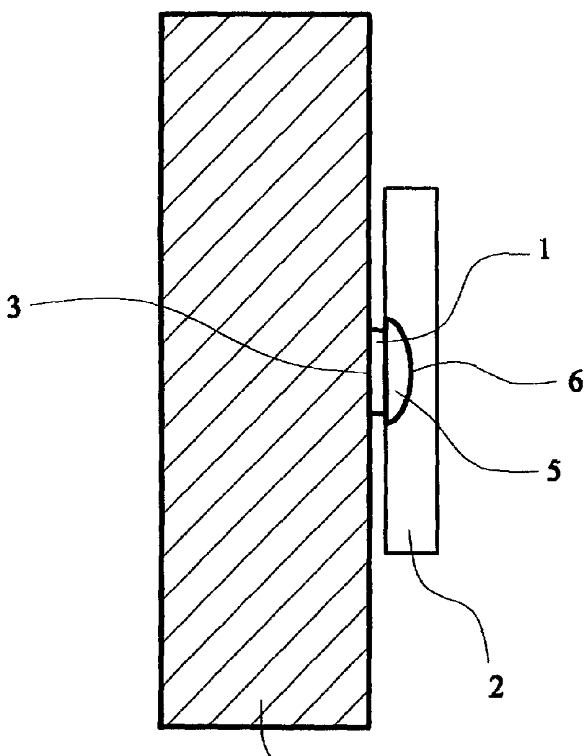
(54) Title: LIGHT EMITTING DIODE ARRANGEMENTS



(57) Abstract: To increase the amount and/or directionality of light from a light emitting diode (LED) 1 located on or in a semiconductor substrate (2), a first side of the diode which faces away from the substrate is provided with a reflector (3) (shown as a mirror electrode on a second larger substrate (4), but it may be a specular coating on the LED), and the substrate (2) includes an optical focussing (e.g. Lens), interference (e.g. Fresnel lens) or diffractive (e.g. grating) element (5) adjacent a second side of the diode opposed to the first side. Preferably the element (5) is formed within the thickness of the substrate (2) by etching downwards from the surface remote from substrate (4). The height variation in a grating element (5) may be binary or multi-valued, and the grating may be one two or three-dimensional. The side of the LED adjacent reflector (3) may be curved.

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— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Light Emitting Diode Arrangements

The present invention relates to light emitting diodes (LEDs). It is particularly but not exclusively directed to LEDs which emit electromagnetic radiation through a side surface of the semiconductor structure which lies parallel to the diode junction.

Light emitting diodes have many applications, including telecommunications, spectroscopy and gas sensing. A recent development is that of room temperature infra-red light emitting diodes which cover the 3 to 12 micron spectral region where gases such as carbon dioxide, carbon monoxide, nitrogen oxides, sulphur oxides and carbohydrates have strong selective absorption bands enabling quantitative gas detection.

It is clearly advantageous to be able to maximise the optical output power of a light emitting diode. For example in infra-red gas sensing at low concentrations, such as in the parts-per-billion (ppb) to parts-per-million (ppm) range, the output powers of existing devices are not sufficient to provide conditions allowing a good signal-to-noise ratio.

A major reason for the low output power is the inefficiency in transmitting the light generated at the diode junction to the exterior, and a principal cause thereof is total internal reflection within the device. As is well known, light can only pass from an optically dense medium (high real refractive index of value n) to air (where n is nominally unity) if its angle of incidence is no greater than $\sin^{-1}(1/n)$, and it otherwise undergoes total internally reflection. Thus, for a side emitting LED based on indium antimonide (InSb), where n = 4, and assuming a uniform angular distribution of optical emission from the diode junction over a solid hemispherical angle 2π towards a planar side surface of the device, only 3% of the light emitted within the junction is directly transmitted through the planar surface.

Additionally, the latter small amount of light is emitted over a large solid angle. It is commonly difficult or impractical to collect light within a large solid angle by the use of external optics, thereby adding to the disadvantages when a directed beam of light is required.

The present invention is directed to reducing the mount of light lost due to reflection within LEDs, and/or to increasing the directionality of light emitted from LEDs. The first step should reduce the optical output power necessary from the diode junction for a given device overall output, or should increase the device overall output for a given output from the diode junction. The second step should reduce the optical output power necessary from the diode junction for a given device output in a predetermined direction, or should increase the device output in a predetermined direction for a given output from the diode junction.

It is known to provide an LED between a reflector and a textured surface, one example being described in "Compound Semiconductors" 6(4), May/June 2000, page 55. However, the textured surface is generally random, and does not provide optimal light directing properties for efficient light extraction therethrough.

It is also known to provide a Fresnel lens as a separate layer on the underside of a semiconductor substrate on the other side of which is an LED (see US 5,181,220). While this may improve light extraction, there appears to be no clear disclosure of an underlying reflector.

The present invention provides a light emitting diode arrangement comprising a light emitting diode on or in a semiconductor substrate, a first side of the diode which faces away or outwardly from the substrate being provided with a reflector, wherein the semiconductor substrate includes an optical focussing, interference or diffractive element adjacent a second side of the diode opposed to the first side.

By providing an optical element with well defined light directing properties (for example either a grating type structure or a lens) it is possible to arrange that the number of reflections before a light beam leaves the device is minimised, so reducing losses due to optical absorption within the device inter alia. Ideally much of the light which does not leave at first incidence on the optical element output surface is redirected to the reflector with a much reduced angle of incidence whereby after reflection it is much more likely to be able to leave via the optical element. For example, where the element is a grating, the light returning therefrom does not necessarily have the same (reflected) angle as the light incident thereon.

The focussing element may comprise a curved surface for example a part spherical or hemispherical surface.

The interference element may comprise a Fresnel lens. The latter could also be regarded as a focussing element.

The diffractive element may be a simple one dimensional diffraction grating or a Fresnel lens, but preferably it is a three dimensional grating (regions of differing heights with differing periodicities - equivalent to the superposition of two or more one or two dimensional gratings), or a two dimensional grating.

The diffractive element grating may be defined by periodically varying thicknesses of transparent material.

Where the optical element varies in thickness it may do so in analogue manner, as in the part spherical or hemispherical lens mentioned above, or in a diffraction grating. However, adjacent regions of the optical element may take discrete values of thickness, and this is preferred when a diffractive or interference element is used. Most simply there are only two thickness values, but preferably there are 3, 4, or even 8, since increasing the number of values can assist in efficiently light extraction.

The focussing, interference or diffractive element is preferably formed within the thickness of the semiconductor substrate, e.g. by being formed from the material of the substrate. In a preferred embodiment, the substrate is etched downward from the face opposed to the LED to define the element.

Alternatively, however, the element may be formed from a separate material on the semiconductor substrate in optical contact therewith. For example a further semiconductor layer may be deposited on the substrate and be shaped to provide a focussing interference or diffractive element, for example by etching or in milling. Alternatively a separate layer of material may be secured in optical contact with the substrate and be shaped to provide a focussing or diffractive element either before or after the securing step. The securing may be effected by a sufficiently thin layer of adhesive using special tooling and controlled pressure.

By "optical contact" is meant that the gap between the device and the element is no greater than one quarter of the LED wavelength within the material (i.e. vacuum wavelength divided by n), thus providing a condition in which total internal reflection is effectively prevented and permitting light generated within the device to penetrate through the element surface over a wide range of incident angles.

Where a separate element is provided it preferably has a refractive index differing from that of the adjacent semiconductor substrate by no more than 1, more preferably no more than 0.5, even more preferably no more than 0.3. Most preferably, the two indices are substantially equal, e.g. by using the same material.

The reflector may be provided by the supporting substrate itself, if it is formed of a material which is reflective per se, or includes a reflective coating. Alternatively a reflective coating may be applied to the LED surface.

The reflector may provide specular or diffuse reflection.

In one embodiment, the supporting substrate is etched to form a curved surface, for example ellipsoidal or part spherical, and the adjacent LED surface is shaped correspondingly. The resulting directed reflection can improve efficiency of light extraction.

Further details and advantages of the invention will become apparent upon a reading of the appended claims, to which the reader is referred, and upon a consideration of the following description of embodiments of the invention made with reference to the accompanying drawing, in which:

Figure 1 shows a first embodiment of the invention in diagrammatic cross-section; and

Figure 2 shows a second embodiment of the invention in diagrammatic cross-section.

Figure 1 shows a first arrangement according to the invention in which an LED mesa 1 is formed upon (and normally integrally with) a semiconductor substrate 2. The exterior face of the mesa 1 is in contact with a reflective (mirror) electrode 3 on and supported by a further substrate 4. A microlens 5 having a part spherical surface 6 is defined within the substrate 2 by etching down from the surface opposed to the LED mesa.

Figure 2 is similar to Figure 1, except that the lens 5 is replaced by a two or three dimensional height stepped diffraction grating 7.

Although a supporting substrate 4 is provided in the embodiments, it will be appreciated that this feature may be unnecessary if alternative means for mounting the LED/substrate 2 is provided. In such a case the reflector may be a coating on the appropriate face of the LED.

CLAIMS

1. A light emitting diode arrangement comprising a light emitting diode on or in a semiconductor substrate, a first side of the diode which faces away from the substrate being provided with a reflector, wherein the semiconductor substrate includes an optical focussing interference or diffractive element adjacent a second side of the diode opposed to the first side.

2. An arrangement according to claim 1 wherein said focussing element includes a curved surface.

3. An arrangement according to claim 2 wherein said focussing element includes a part spherical or hemispherical surface.

4. An arrangement according to claim 1 wherein said diffractive element is a grating.

5. An arrangement according to claim 4 wherein said grating is a two or three dimensional grating.

6. An arrangement according to claim 1 wherein said interference element is a Fresnel lens.

7. An arrangement according to any one of claims 4 to 6 wherein said element is a variable height element of transparent material.

8. An arrangement according to claim 7 wherein adjacent regions of the diffractive element take discrete values of thickness.

9. A light emitting diode according to claim 8 wherein there are two said values.

10. A light emitting diode according to claim 8 wherein there are four said values.

11. An arrangement according to any preceding claim wherein said element is formed within the thickness of said semiconductor substrate.

12. An arrangement according to claim 11 wherein said element is formed from said semiconductor substrate.

13. An arrangement according to any preceding claim wherein said first side is supported on a supporting substrate.

14. An arrangement according to claim 13 wherein the supporting substrate and said first face are shaped to provide contact therebetween substantially over the whole first face.

15. An arrangement according to claim 13 or claim 14 wherein the supporting substrate is said reflector, being of reflective material or comprising a reflective coating.

16. An arrangement according to any one of claims 1 to 14 wherein the reflector is a coating on said first side.

17. An arrangement according to any preceding claim wherein the first side of the diode is curved.

18. An arrangement according to any preceding claim wherein said reflector is specular.

19. A method of making a light emitting diode arrangement comprising providing a light emitting diode between a reflector and a semiconductor substrate, and removing material from the surface of the substrate opposed to the LED to define therein a focussing, interference or diffractive optical element.

20. A method according to claim 19 wherein the element is shaped to provide different thicknesses.

21. A method according to claim 20 wherein said different thicknesses take discrete values.

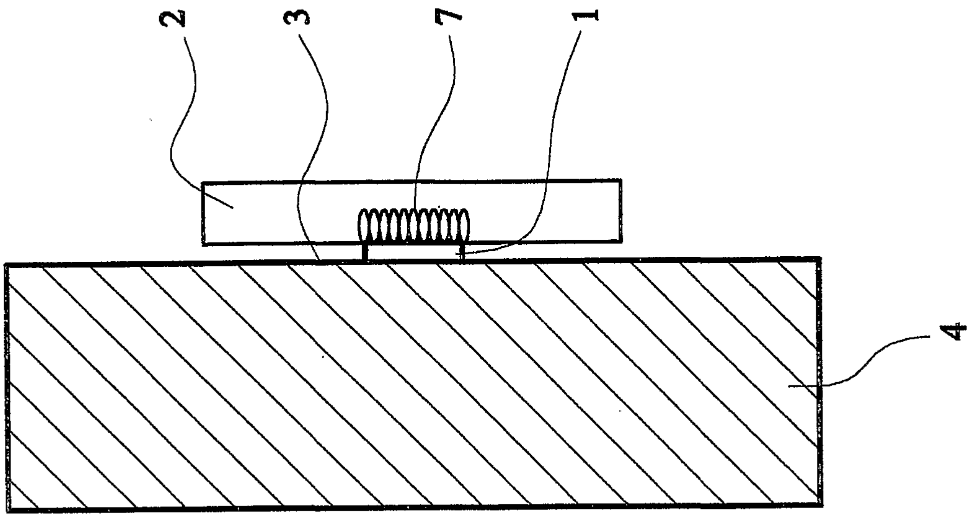

FIG. 2

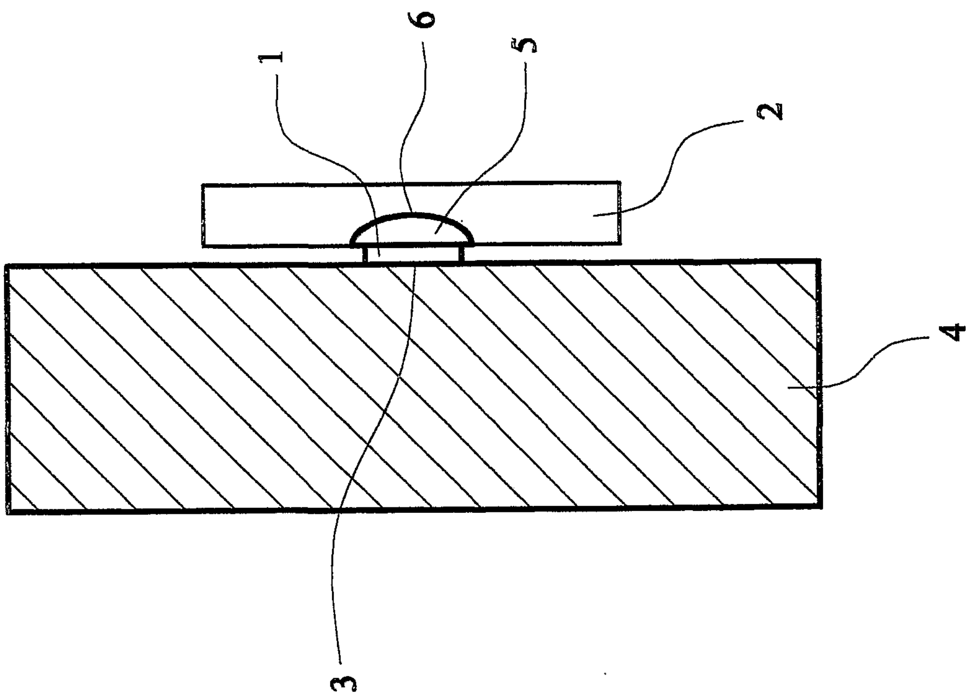

FIG. 1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/03172

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L33/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 306 (E-446), 17 October 1986 (1986-10-17) -& JP 61 121373 A (OKI ELECTRIC IND CO LTD), 9 June 1986 (1986-06-09) abstract; figures	1-3,11, 12,16
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Laere, A

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International Application No
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