Title: GRIN LENS WITH BARRIER LAYER FOR USE IN ELECTRO-OPTICAL PACKAGE

Abstract: An optical component (1) for transmitting radiation comprises a graded index lens (3) formed of diffusion-doped glass having a barrier layer (9) of moisture-impermeable material formed on a surface (6) thereof. An optical fibre (2) is bonded to the barrier layer using resin (8). The barrier layer prevents diffusion of ions between the lens and the resin, and thus prevents moisture damage to the surface of the lens.
GRIN LENS WITH BARRIER LAYER FOR USE IN ELECTRO-OPTICAL PACKAGE

This invention relates to an optical component having a graded index lens made from diffusion doped glass for transmitting radiation into or out of an optical fibre. In particular, although not exclusively, the invention relates to the preparation of a graded-index lens to improve adhesion of an optical fibre thereto.

Optical devices such as laser packages for use in optoelectronics require some means for directing electromagnetic radiation into an optical fibre at the output of the device. In general, a graded-index lens (a diffusion doped glass lens which operates by a graded refractive index) is bonded into the package, enabling subsequent attachment of an optical fibre to an output surface of the lens. This arrangement is used widely in the laser and fibre-optic industry since it allows the fibre to be attached after complete construction and sealing of the laser package. This has significant advantages for manufacturing cost and automation logistics.

A glass ferrule on the end of the optical fibre is typically bonded to the output face of the lens using an optical cure resin. This procedure is carried out while the ferrule and fibre are aligned to the best focus position. The resin is then cured with UV light.

It has been discovered that there are serious problems with adhesion of the ferrule to the lens when the assembly is exposed to damp heat. Over time, the bonding between the ferrule and the lens weakens, which leads to significant optical loss and sometimes catastrophic mechanical failure. There is therefore a need for a method of preventing loss of adhesive strength at the interface between optical cure resin and glass.

The precise mechanism by which the resin bond is compromised is not known. However, it has been found that a resin bond between two ferrules has a significantly greater resistance to damp heat than the bond between a ferrule and graded-index lens. It may be concluded from this that the material of the lens is sensitive to moisture permeating through the resin at the interface, causing the adhesion to break down. In
addition, the surface of the lens external face is affected by the presence of moisture, producing a crazed surface. It seems plausible that the method of producing the refractive index profile of the lens by ion exchange leaves some species of the glass weakly bound, and therefore sensitive to the presence of moisture.

In accordance with one aspect of the present invention there is provided an optical component for transmitting radiation, comprising a graded index lens formed of diffusion doped glass having a barrier layer of moisture-impermeable material formed on a surface thereof. A layer of adhesive material is bonded to the barrier layer, and an optical fibre bonded to the layer of adhesive material. The lens may be an output lens for an optical device which emits electromagnetic radiation.

The barrier layer prevents the migration of ions or other species between the adhesive, which is preferably resin, and the body of the ion-diffused glass structure. This prevents moisture or water molecules inducing the resin to reduce its bonding characteristics to the glass interfaces at one or both sides of the resin layer.

The barrier layer is preferably formed from a thin dense layer such as silica. The silica layer may be deposited with ion assisted deposition, which provides a dense structure, although it will be appreciated that other techniques or other materials may be used.

The thickness of the barrier layer is chosen primarily to inhibit diffusion, but may also be designed to minimise the detrimental effect on optical reflections. For example, the barrier layer preferably has thickness designed to minimise reflections between the two contacting glasses and resin layer. This thickness may be approximately $n\lambda/4$ where $\lambda$ is the wavelength of radiation focussed by the lens and $n$ is an odd integer. It will be appreciated that the lens may focus a range of wavelengths and the thickness should preferably be chosen to minimise reflections across as much of this range as possible.

An antireflective coating may be applied to the opposite surface of the lens so as to inhibit reflections at the air-lens interface where radiation from an optical device enters
the lens. The surface having the barrier layer formed thereon is preferably inclined away from a direction perpendicular to the axis of the lens so as to prevent any reflected radiation returning to the optical device.

The barrier layer is preferably refractive index matched to the glass of the optically transparent body and the adhesive material. This further helps in the prevention of reflections.

A glass ferrule may be provided around the end of the fibre bonded to the adhesive material.

The invention also provides an optoelectronic apparatus comprising an optical device for supplying electromagnetic radiation and an optical component, as described above, provided at the output of the optical device so that the surface having a barrier layer formed thereon is the output surface of the apparatus. The optical device and optical component may be bonded in a sealed package so that the barrier layer is accessible from outside the sealed package.

In accordance with another aspect of the invention there is provided a graded index lens for use in optoelectronic systems, formed of diffusion doped glass and comprising a moisture-impermeable barrier layer on a surface thereof for bonding to an optical fibre. The surface may be inclined from perpendicular to the axis of the lens. An opposite surface preferably has an antireflective coating formed thereon.

In accordance with a further aspect of the invention there is provided a method of preparing a graded index lens, formed of diffusion-doped glass, for bonding to an optical fibre, the method comprising coating a surface of the lens with a barrier layer of moisture-impermeable material.

The lens may be located at an output of an optical device for emitting electromagnetic radiation. The lens and device may be incorporated into a sealed package in such a way
that the barrier layer is accessible from outside the sealed package. It will be appreciated that the barrier layer may be deposited on the lens either before or after the lens is incorporated into the sealed package. An optical fibre may then be bonded to the barrier layer using resin.

Thus the invention, at least in its preferred embodiments, solves a fundamental reliability problem which has existed for a number of years. It is inexpensive and simple to produce, and can be designed to have minimal detrimental optical effect.

Some preferred embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of a prior art apparatus for directing the output of a laser assembly into an optical fibre;

Figure 2 is a cross-section through the apparatus of Figure 1;

Figure 3 is a schematic view of an apparatus similar to that of Figure 1 including a moisture barrier layer bonded to a lens; and

Figure 4 is a cross-section through the apparatus of Figure 3.

Figures 1 and 2 are schematic views of a prior art apparatus for directing the output of a laser assembly 1 into an optical fibre 2. A graded-index lens 3 is located adjacent the output of the laser assembly 1. Such lenses are well known and comprise a cylinder of glass which has been treated by ion diffusion to give a parabolic profile of refractive index perpendicular to the cylinder axis. The refractive index is greatest along the axis of the cylinder and smallest at the circumference. The treatment is generally performed in a heated salt bath where a heavier alkali metal replaces some of the constituent of the glass. Figure 2 shows the path 10 of a beam of electromagnetic radiation focussed by the lens 3.
In practice there is usually an air gap between the laser assembly 1 and the lens 3. In order to reduce reflections as radiation from the laser enters the lens 3, the input surface 4 of the lens 3 facing the laser assembly 1 is coated with an antireflection (AR) coating 5. The AR coating 5 is typically chosen to have a refractive index of $\sqrt{n_1 n_2}$ where $n_1$ and $n_2$ are the refractive indices of the lens 3 and air, respectively. The AR coating 5 has a thickness of $\lambda/4$, or odd multiples thereof, where $\lambda$ is the wavelength of radiation emitted by the laser 1. A typical AR coating is made from magnesium fluoride, which has a refractive index of 1.38.

The laser assembly 1 and lens 3 are incorporated into a hermetically sealed package (not shown) from which the lens 3 protrudes to enable access to the output surface 6 facing away from the laser assembly 1. The optical fibre 2 is embedded in a ferrule 7 which is bonded to the output surface 6 of the lens using a layer of resin 8. This procedure is carried out while the ferrule 7 and fibre 2 are aligned to the best focus position. The resin 8 is then cured with UV light. The thickness of the resin layer 8 is generally of the order of 10 to 20 microns.

No AR coating is normally provided on the output surface 6 of the lens because the lens 3, resin 8, ferrule 7 and fibre 2 all have similar refractive indices, so there is a degree of index matching between them, and an AR coating is not necessary.

As shown in Figure 2, the output surface 6 is angled so that any radiation which is reflected at the interface (for example if the fibre and lens are not perfectly index matched) is not returned to the laser assembly. This angled interface further removes the need for an AR coating on the output surface 6.

As previously mentioned, the adhesion between the resin layer 8 and the glass of the lens 3 is reduced after prolonged exposure to damp heat. It is conjectured that this occurs because moisture passes from the resin into the lens 3. The glass of the lens 3
has been modified by the ion diffusion process to form a graded refractive index, and this leaves it weakly bonded and susceptible to moisture attack.

Figures 3 and 4 show schematically an apparatus which prevents moisture transfer from the resin layer 8 to the lens 3. The apparatus is similar to that shown in Figures 1 and 2, but includes a barrier layer 9 of moisture-impermeable, optically transparent material between the lens 3 and resin 8. This layer 8 is of a nature and sufficiently dense to prevent permeation or diffusion of water molecules, and in the preferred embodiment is formed on the output surface of the lens by ion assisted deposition of silica.

The thickness of the barrier layer 9 is chosen primarily to inhibit diffusion so that moisture cannot permeate and reach the lens material, but a secondary consideration is that it will not have a detrimental effect on optical reflections. The technology required to effect an impermeable layer is the same as that developed for optical thin films and does not need to be described here.

Although optical considerations are secondary, it is still desirable that the barrier layer 9 does not introduce additional optical effects. The barrier layer 9 should therefore be index matched to the lens 3 and resin material 8 if possible so as not to introduce reflections. The barrier layer 9 should also be an odd multiple of $\lambda/4$ in thickness, where $\lambda$ is the wavelength of radiation emitted by the laser 1. In general, the laser will emit radiation having a range of wavelengths. For example, the wavelength of light emitted by a 1550 nm laser can vary between 1520 nm and 1600 nm, and the precision required in the thickness of the barrier layer is therefore ±2.5%. In practice, for single layers the variation in reflectivity with wavelength is very small over a reasonable range. A barrier layer 9 of the order of 0.5 – 1 µm thick is generally sufficiently thick to prevent moisture diffusion, but this can be increased according to the above conditions if required.
The material and structural properties of the barrier layer 9 may also be chosen to improve the adhesive performance between the resin 8 and specific types of glass such as ion diffused glass or glasses sensitive to the presence of moisture.

It will be appreciated that variations from the above described embodiment may still fall within the scope of the invention. For example, the lens has been described as directing radiation emitted by a laser, but may be used with any optical device, for example an optical amplifier. In addition, the lens need not form the output of a sealed optical package; the barrier layer may be applied to any interface between an optical fibre and any optical component formed from diffusion-doped glass, which may be a graded-index lens, other form of lens, or even a window. The interface may be at the input to an optical device where radiation is received from an optical fibre.

Furthermore, although the barrier layer has been described as being formed of ion deposited silica, it will be appreciated that any layer which is sufficiently optically transparent and impermeable to moisture may be used.
CLAIMS:

1. An optical component for transmitting radiation, comprising:
   a graded index lens formed of diffusion-doped glass;
   a barrier layer of moisture-impermeable material formed on a surface of the lens;
   a layer of adhesive material bonded to the barrier layer; and
   an optical fibre bonded to the layer of adhesive material.

2. An optical component as claimed in claim 1, wherein the barrier layer is formed
   from silica.

3. An optical component as claimed in claim 1 or 2, wherein the surface of the lens
   having the barrier layer formed thereon is inclined to a direction perpendicular to the
   optical axis of the lens

4. An optical component as claimed in any preceding claim, further comprising an
   antireflective coating on an opposite surface of the lens to the surface bonded to the
   optical fibre.

5. An optical component as claimed in any preceding claim, wherein the lens is an
   output lens for an optical device for emitting electromagnetic radiation, and the surface
   bonded to the optical fibre is the output surface of the component.

6. An optical component as claimed in any preceding claim, further comprising a
   glass ferrule around the end of the fibre bonded to the adhesive material.

7. An optical component as claimed in any preceding claim, wherein the barrier
   layer is refractive index matched to the diffusion-doped glass of the lens and the
   adhesive material.
8. An optical component as claimed in any preceding claim, wherein the adhesive material is an optical cure resin.

9. An optical component as claimed in any preceding claim, wherein the adhesive material is water permeable.

10. An optical component as claimed in any preceding claim, wherein the thickness of the barrier layer is chosen to minimise optical reflections.

11. An optical component as claimed in any preceding claim, wherein the barrier layer has a thickness of approximately \( n\lambda/4 \) where \( \lambda \) is the wavelength of radiation focussed by the lens and \( n \) is an odd integer.

12. An optoelectronic apparatus, comprising:

   an optical device for supplying electromagnetic radiation; and

   an optical component as claimed in any preceding claim provided at the output of the optical device so that the surface bonded to the optical fibre forms an output surface of the apparatus.

13. An apparatus as claimed in claim 12, wherein the optical device and optical component are incorporated in a sealed package in such a way that the barrier layer is accessible from outside the sealed package.

14. A graded index lens for use in optoelectronic systems, formed of diffusion-doped glass and comprising a moisture-impermeable barrier layer on a surface thereof for bonding to an optical fibre.

15. A lens as claimed in claim 14, wherein the surface having the barrier layer is not perpendicular to the optical axis of the lens.
16. A lens as claimed in claim 14 or 15, further comprising an antireflective coating formed on an opposite surface to the surface having the barrier layer.

17. A sealed optoelectronics package, comprising:

- an optical device for supplying electromagnetic radiation;
- a graded index lens as claimed in claim 14, 15 or 16 forming an output lens; and
- an optical fibre bonded to the impermeable barrier layer of the output lens.

18. A method of preparing a graded index lens, formed of diffusion-doped glass, for bonding to an optical fibre, the method comprising coating a surface of the lens with a barrier layer of moisture-impermeable material.

19. A method as claimed in claim 18, wherein the barrier layer is formed from silica.

20. A method as claimed in claim 18 or 19, wherein the barrier layer is deposited on the optically transparent body using ion assisted deposition.

21. A method as claimed in claim 18, 19 or 20, wherein the surface of the lens coated by the barrier layer is inclined from a direction perpendicular to the optical axis of the lens.

22. A method as claimed in any of claims 18 to 21, further comprising coating a surface of the lens, opposite to the surface coated with the barrier layer, with an antireflective coating.

23. A method as claimed in any of claims 18 to 22, further comprising locating the lens at an output of an optical device for emitting radiation.

24. A method as claimed in claim 23, further comprising incorporating the optical component and the optical device into a sealed package in such a way that the barrier layer is accessible from outside the sealed package.
25. A method as claimed in any of claims 18 to 24, wherein the thickness of the barrier layer is chosen to minimise optical reflections.

26. A method as claimed in any of claims 18 to 25, wherein the barrier layer is formed with thickness $n\lambda/4$ where $\lambda$ is the wavelength of radiation focussed by the lens and $n$ is an odd integer.

27. A method of bonding an optical fibre to an optical component, comprising:

preparing the optical component using a method as claimed in any of claims 18 to 26; and

bonding the optical fibre to the barrier layer using resin.

28. A method as claimed in claim 27, wherein the resin is water permeable.

29. A method as claimed in claim 27 or 28, further comprising optically curing the resin.

30. A method as claimed in claim 27, 28 or 29, further comprising embedding an end of the optical fibre in a ferrule prior to bonding to the barrier layer.

31. A method of preparing a sealed optoelectronics package including a graded index output lens for bonding to an optical fibre, comprising coating an output surface of the lens with a barrier layer of moisture-impermeable material.
Figure 1

Figure 2
**A. CLASSIFICATION OF SUBJECT MATTER**

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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)

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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)

EPO-Internal, PAJ, WPI Data, INSPEC

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td></td>
<td>page 2, paragraph 38 - page 3, paragraph 54; figure la</td>
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Further documents are listed in the continuation of box C.

| Patent family members are listed in annex. |

* Special categories of cited documents:

*A* document defining the general state of the art which is not considered to be of particular relevance

*E* earlier document but published on or after the international filing date

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**Date of the actual completion of the international search**

22 July 2005

**Date of mailing of the international search report**

04/08/2005

**Name and mailing address of the ISA**

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Frisch, A
## INTERNATIONAL SEARCH REPORT

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