Title: SIDE EMITTING/DETECTING OPTICAL FIBRE AND METHODS OF ITS PRODUCING

Abstract: The invention relates to fibre optics, particularly to the optical signal transmission through the end of optical fibre orthogonally to its symmetry axis, and can be applied in illumination engineering, phototherapy, fibre-optical endoscopy, laser surgery, optical tomography, optical instrument engineering and in other fields. The proposed side emitting/detecting optical fibre with total internal reflection surface sloped to the fibre axis and output/input plane parallel to the fibre axis is characterized in that the reflecting surface and the output/input plane are optically monolithically integrated at the end of optical fibre core by filling the space between the output/input plane and cylindrical lateral surface of the core in front of the reflective surface with material of the fibre core or with similar optically transparent material, at that the distance of the output/input plane from the fibre core is equal or exceeds external radius of the fibre. The proposed configuration provides several technical advantages, particularly, smaller size (which is more convenient in use and reduces the optical material consumption), shorter light pass from/to the fibre core (which assures more precise localisation of the emitted/detected radiation at the contact surface, as well as enhanced radiation collection efficiency), solid optical assembly (which excludes radiation refraction during its deflection, minimizes optical losses and assures more safe operation), as well as makes possible to obtain qualitative optical contact with a planar surface, oriented parallel to the fibre axis, without any additional components.
SIDE EMITTING/DETECTING OPTICAL FIBRE AND METHODS OF ITS PRODUCING

Technical Field

The present invention relates to fibre optics, particularly to the optical signal transmission through the optical fibre end orthogonally to the fibre axis, and can be used in illumination engineering, phototherapy, endoscopy, laser surgery, optical tomography, optical instrumentation and other industry fields.

Background Art

Side emitting/detecting optical fibres can be used in various irradiation and optical sensing facilities. Such devices have several advantages, comparing with traditional radiation input/output design via fibre endface that is orthogonal to the fibre axis. For example, in optical tomography, laser Dopplerography, skin spectrometry and in other applications for in-vivo optical diagnostics, radiation is often transmitted via optical fibres, aligned orthogonally to the skin surface (patent GB 2132483). Such devices perform their functions generally well, but the bended optical fibres take a lot of space and are not reliable in operation due to possible fibre breakage and other defects caused by bending of the fibres.

Devices with beam deflecting endprobes are more compact and reliable. Such devices are used, for example, in the equipments for phototherapy and laser surgery; fibres used in such devices often are called as "side-firing fibres". Several designs of such fibre probes are known, e. g. with sloped flat or curved reflector, facing to the fibre end (patent US 5366456), with bended fibre bundle end (patent US 5416878), with sloped-polished optical fibre core, assuring the beam deflection due to the total internal reflection (patent US 5537499).

After reflection from the slope-polished end of the fibre core, the radiation in such "side-firing" optical fibres is partially focused due to the refraction on the cylindrical side surface of the fibre core. This increases power density of the radiation nearby the headpiece, which
is positive, for example, in the case of laser scalpel. However, presence of the cylindrical surface in certain applications acts negatively, if the mentioned endprobe is used for detection of radiation from the side, for example, in contact with plan skin surface. Then considerable part of the radiation to be detected is lost due to reflection and refraction on the cylindrical interface.

There is known the probe for blood flow measuring (patent JP 2203838). According the patent, transparent unilateral right-angle micro prism is attached to the fibre end, grinded orthogonally to the fibre axis. The 45° facet of the micro prism, due the total internal reflection, acts as a reflector for the beam deflection. The fibre end and the micro prism are embedded into a specially shaped headpiece shell. Such a design provides planar surface for radiation input/output, assuring good optical contact with skin or other plane surface under investigation and significantly reducing transmission losses, comparing with other similar solutions. Mentioned solution is also well suited for the devices with lateral emission, assuring conical exit beam, similar as from the fibres with traditional planar end, orthogonal to the fibre axis. However, the known fibre probe has rather complicated design, being composed of three main parts (optical fibre, micro-prism and headpiece shell), laborious manufacturing process (high precision assembly), relatively large dimensions (approximately three times exceeding the fibre diameter) and, finally, relatively low positioning accuracy at the investigated skin surface location, because the area of the lateral input surface of the prism approximately four times exceeds the cross-section of the fibre core. This is the reason of relatively low effectiveness of radiation collection - only small portion of the radiation, incoming via the contact surface and prism, further will be transmitted by the fibre core. Considerable expenditure of the raw materials for manufacturing of the prism and headpiece shell also can be regarded as a drawback. High manufacturing laboriousness and costs of main elements determine high cost of the whole device, restricting its wide application.

There is known optical fibre with modified optical signal output end configuration, thus assuring ray cone deviation and emission orthogonally to the fibre longitudinal axis through the lateral surface of the optical fibre output end (patent US 6856728). The invention, described in the mentioned patent, also disclose the method of optical fibre output end production. The method includes such steps, as removing a part of the fibre end
surface to make it inclined to the optical fibre axis; optical fibre end surface polishing to produce certain profile; coating of the shaped surface with reflective coating. The disadvantage of known method consists in presence of cylindrical lateral surface, which gives negative influence in case of application for detection of lateral radiation. In this case a considerable part of introduced radiation will be lost in result of reflection and refraction on the cylindrical interface.

There is known the design of radiating optical fibre end (patent US 5772657), where the optical fibre end has sloped surface, which assure deflection of axial radiation in orthogonal direction relatively to the optical fibre axis in result of total internal reflection. The shape of the optical fibre cladding is modified to assure the outgoing light beam deflection orthogonally to the fibre axis - the radiation outlet zone is plane-polished parallel to the fibre axis by removing part of the optical cladding. However, such output surface design cannot eliminate unwanted refraction on the core/coating interface. Also it is quite difficult to realize such a solution, because the optical coating for most types of optical fibres is significantly thinner than the core diameter. Consequently, to make the planar part of the coating wider than the core diameter (as it is proposed in the patent), the optical coating thickness should be artificially increased, which is quite difficult from the technological point of view. Besides, since the planar fragment of the radiation outlet surface lies between the fibre external cover and the core, the mechanical contact of the radiation output plane and the external surface never can be achieved (always a gap between two planes will remain), which means light loss due to absence of good optical contact. The mentioned drawbacks restrict effective radiation detection from the examined planar surface, for example skin, via the external plane oriented parallel to the optical fibre axis.

Disclosure of Invention

The aim of the invention is to avoid drawbacks of the prior art, particularly to create smaller simplified optical fibre end or distal probe design, assuring higher precision of the emission/detection zone location and enhanced effectiveness of the detected radiation collection.
The mentioned aim is reached by inclining the total internal reflection endface relatively to the optical fibre axis and introducing a planar output/input surface parallel to the fibre axis, filling the space between the output/input planar surface and the lateral surface of the cylindrical core with optically transparent material, that of the fibre core or similar, thus optically monolithically integrating the reflecting surface and the output/input planar surface at the end of optical fibre core.

**Brief Description of Drawings**

Fig. IA represents the prior art design of side emitting optical fibre end, axial section.
Fig. IB represents the cross-section of side emitting optical fibre end, prior art.
Fig. 2 represents design of the side emitting/detecting optical fibre end with the output/input zone of optical signal.
Fig. 3 illustrates the sequence of manufacturing steps of the side emitting/detecting optical fibre, according to the first embodiment of the invention.
Fig. 4 illustrates the sequence of manufacturing steps of the side emitting/detecting optical fibre, according to the second embodiment of the invention.
Fig. 5 illustrates the sequence of manufacturing steps of the side emitting/detecting optical fibre, according to the third embodiment of the invention.
Fig. 6 illustrates the sequence of manufacturing steps of the side emitting/detecting optical fibre, according to the fourth embodiment of the invention.
Fig. 7 illustrates the sequence of manufacturing steps of the side emitting/detecting optical fibre, according to the fifth embodiment of the invention.
Fig. 8 illustrates the method of manufacturing of side emitting/detecting optical fibre, which provides attachment of separately made sleeve on the optical fibre end.

To reach the set goal, the design illustrated in the Fig. 2 is used. The radiation is deflected at the optical fibre end by means of total internal reflection, complemented with additional integrated smooth planar output/input lateral surface 10, parallel to the fibre symmetry axis. The core end surface 20, cleaned of the external coating, is sloped to meet the condition of total internal reflectance, i.e. at all its points the angle of the surface normal against the fibre symmetry axis is greater than the critical angle of total internal reflection \( \text{arc sin} \left( \frac{n_i}{n_f} \right) \), were \( n_i \) and \( n_f \) are the refraction indices of air and optical fibre core.
material, respectively. To avoid the radiation scattering, both surfaces 10 and 20 are smoothly polished. The space between surfaces 20 and 10, which is situated beyond the cylindrical core lateral surface, is entirely filled with the fibre core material or with other transparent material having the refraction index equal or close to $r_{i_2}$. In this way the orthogonal ray refraction on the core cylindrical lateral surfaces is excluded. The area of the input/output surface 10 is comparable with the optical fibre cross-section area 30, but its distance to the fibre axis is equal to or greater than the radius R of the fibre external protective coating.

This fibre end design solution integrating two optical surfaces performs its function without any additional elements.

Several methods of realization of the mentioned design are proposed, subject to the technical feasibility and optical fibre core and coating materials. All the proposed methods assure homogeneous filling of the space between working surfaces 10 and 20 with optically transparent material.

Fig. 3 illustrates the method of manufacturing of the side emitting/detecting optical fibre, which intends enlargement of the optical fibre end with following grinding and/or polishing. This method is applicable, for example, to optical fibres with core made of glass, including SiO$_2$ glass. The coating near fibre end is cleaned, for example, for 3 cm along the core. Then fibre end enlargement (e.g. ball-shaped or of similar geometry) with diameter exceeding the core diameter, is made, for instance, by melting the core end with a gas burner. The two opposite sides of the enlargement are grinded/polished mutually parallel, parallel to the fibre axis and equidistant from it (close to the optical fibre core radius). The internal reflecting surface 20 is grinded/polished in such a way, that it crosses the core cylindrical surface at the beginning of the enlarged portion. The rest of untreated enlarged portion is grinded/polished orthogonally to the both lateral sides and parallel to the fibre axis at a distance $\geq R$ from it, thus forming the input/output surface 10. It is possible to modify the method, making the endprobe of some other optically transparent material with conforming refraction index, for example, of optical polymer.
Fig. 4 illustrates the method of manufacturing of the side emitting/detecting optical fibre, which intends to build up an additional part of the optical fibre core near its end opposite to the inclined polished reflecting surface 20 with following grinding and/or polishing of the build up part. According to the method, it is foreseen to fill the space between the input/output surface 10 and the facing cylindrical lateral surface of the fibre core with additionally fed material - either the core material or another transparent material with corresponding refraction index, for example, optical polymer or optical adhesive. To make side emitting/detecting optical fibre according to the proposed method, the coating is cleaned from the fibre core at approximately 1 cm long portion, starting from the end. The internally reflecting surface 20 is sloped grinded/polished. Part of the core in front of the surface 20 behind the core lateral surface is thickened with appropriate material in a width equal to the core diameter, for example, by pouring liquid optical polymer or adhesive in the mould. After curing of the poured material, for example, by heating or acting with UV radiation, good optical contact will be created with the lateral cylindrical surface of the core. Further the added cured material is processed, including grinding/polishing parallel to the fibre axis, so creating the input/output surface 10. It is also possible to modify this method, particularly on the stage of core lateral (input/output) surface thickening by use an index-matching liquid, being poured to the appropriately shaped receptacle with plain transparent input/output window.

Fig. 5 illustrates the method of manufacturing of the side emitting/detecting optical fibre, which intends thermal pressure shaping of the end of the optical fibre. This method is suitable to treat optical fibre made of plastic low-melting materials, for example, of polymer optical fibres. Comparing with the two previous methods, the last one is more economical, it allows reducing hand-work, rendering automatic scale production and cut down materials losses. To make side emitting/detecting optical fibre by the mentioned method, it is necessary to create a die mould for thermal shaping with internal cavity, corresponding to the shape shown in the Fig. 2. The coating is cleaned from the core near to the fibre end, for example, along 1 cm. The cleaned fibre end is introduced into the die mould, it melts and takes the necessary shape by heating the die mould and pressing the fibre end in the axial direction. Then the die mould is cooled up to the core end stiffening temperature and the transformed fibre end can be taken out of the mould.
Fig. 6 illustrates the method of manufacturing of the side emitting/detecting optical fibre, which uses a part of the same fibre (with a plane-polished end, orthogonal to the fibre axis) to fill the space between both working planes. The method intends to make a planar cut, sloped to the fibre axis, for example, at the angle 45°, near the end of the cleaned fibre core. After polishing and/or other treatment of both cut surfaces in order to obtain good optical contact, the cut off fragment is turned by 180° around the axis, orthogonal to the cut plane, and then attached to the sloped fibre end, for example, by the optical adhesive. Further, the end reflecting surface 20 should be cut sloped to the fibre axis and polished to obtain the fibre end configuration, shown in the Fig. 2.

Fig. 7 illustrates the method of manufacturing of the side emitting/detecting optical fibre, which intends to create the sloped reflecting surface 20 at the fiber end (for example, by grinding and polishing) and to attach (for example with optical adhesive) an optical component, made of transparent material with appropriate refraction index to the cylindrical lateral surface in front of the reflecting surface 20. This component is shaped as the additionally fed material illustrated at Fig. 4. The mentioned method is more appropriate for the mass production.

Fig. 8 illustrates the method of manufacturing of the side emitting/detecting optical fibre, which intends to fix a separately made sleeve at the end of the optical fibre. Since both surfaces 10 and 20 are integrated in the monolith coaxial sleeve mounted on the fibre core, this method is more convenient from the technological point of view for mass production. According to the proposed solution the sleeve made of transparent material is shaped as it is shown in the Fig. 2, for example, by using appropriately designed die mould for optical polymer. Then the coating is cleaned from the fibre near the polished end, orthogonal to the fibre axis, and the sleeve is strung on the core and fixed on it by optical adhesive.

Thus, the proposed methods, if compared with the known technical solutions, assure the following technical advantages:

- smaller dimensions of the side emitting/detecting optical fibres, which are more convenient in use and reduce the optical material consumption,
- shorter optical pass of radiation between the fibre core and the input/output planar surface, assuring more precise location of the emitted/detected radiation on the contact surface, for example, on skin, and enhancing effectiveness of the radiation collecting.
- solid optical assembly excluding refraction during the beam deflection, thus minimising the optical losses and assuring more safe operation,
- high-quality optical contact right at the place of mechanical contact in the interface parallel to the fibre axis.
Claims

1. A side emitting/detecting optical fibre with total internal reflection interface sloped to the fiber axis and output/input plane parallel to the fibre axis characterized in that the reflecting surface and the output/input plane are optically monolithically integrated at the end of fibre core end by filling the space between output/input plane and cylindrical lateral surface of the core in front of the reflective surface with the fibre core material or a similar optically transparent material.

2. The side emitting/detecting optical fibre according to claim 1 characterized in that the output/input plane is placed at the distance of external radius of the optical fibre from the fibre axis, or exceeding this distance.

3. A method of optical fibre manufacturing according to the claims 1 or 2, which includes thickening of preliminary cleaned optical fibre core end, for example, by melting it into spherical shape with diameter exceeding that of the core, and further appropriate shaping of the thickened part, for example, by grinding and/or polishing.

4. The method of optical fibre manufacturing according to the claims 1 or 2, which includes creating of a internally reflective surface at the end of preliminary cleaned optical fibre core, for example, by sloped polishing relatively to the fibre axis, building up a transparent material around the cylindrical lateral surface in front of the reflecting surface, and forming planar output/input surface of the built-up part, for example, by grinding and/or polishing.

5. The method of optical fibre manufacturing according to the claims 1 or 2, where, in order to form appropriately the end of the optical fibre core, the core material is melted and hardened under pressure in a correspondingly shaped die mould, for example, a polymer thermal die mould.

6. The method of optical fibre manufacturing according to the claims 1 or 2, where the space between the both working surfaces is filled with a part of the same fibre
core that is separated in advance by a planar cut of the core close to its end, sloped to the fibre axis, for example, at 45° angle, and, after 180° rotation around the axis which is oriented orthogonally to the cut plane, attached again to the slope-cut fibre core end, for example, by means of an optical adhesive, with subsequent creation of the total internal reflection surface at the fibre end, for example, by sloped polishing relatively to the fibre axis.

7. The method of optical fibre manufacturing according to the claims 1 or 2, where after creating the total internal reflection surface, for example, by sloped polishing relatively to the fibre axis, an optical element of homogeneous transparent material with corresponding refraction index, shaped as the additional optical material per claim 4 is attached, for example, glued in front of the internally reflective surface.

8. The method of optical fibre manufacturing according to the claims 1 or 2, where the internally reflecting and output/input surfaces are continuously integrated in a coaxial fibre core sleeve, made of transparent material with corresponding refraction index and attached, for example, glued to the polished end of the fibre core.
AMENDED CLAIMS
[recommended by the International Bureau on 27 November 2008 (27.1.2008)]

1. A side emitting/detecting optical fibre with total internal reflection interface sloped to the fibre axis and output/input plane parallel to the fibre axis characterized in that the reflecting surface and the output/input plane are optically monolithically integrated at the end of fibre core by filling the space between output/input plane and cylindrical lateral surface of the core in front of the reflective surface with the fibre core material or a similar optically transparent material.

2. The side emitting/detecting optical fibre according to claim 1 characterized in that the output/input plane is placed at the distance of external radius of the optical fibre from the fibre axis, or exceeding this distance.

3. A method of optical fibre manufacturing according to the claims 1 or 2, which includes thickening of preliminary cleaned optical fibre core end, for example, by melting it into spherical shape with diameter exceeding that of the core, and further appropriate shaping of the thickened part, for example, by grinding and/or polishing.

4. The method of optical fibre manufacturing according to the claims 1 or 2, which includes creating of a internally reflective surface at the end of preliminary cleaned optical fibre core, for example, by sloped polishing relatively to the fibre axis, building up a transparent material around the cylindrical lateral surface in front of the reflective surface, and forming planar output/input surface of the built-up part, for example, by grinding and/or polishing.

5. The method of optical fibre manufacturing according to the claims 1 or 2, where, in order to form appropriately the end of the optical fibre core, the core material is melted and hardened under pressure in a correspondingly shaped die mould, for example, a polymer thermal die mould.

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core that is separated in advance by a planar cut of the core close to its end, sloped to the fibre axis, for example, at 45° angle, and, after 180° rotation around the axis which is oriented orthogonally to the cut plane, attached again to the slope-cut fibre core end, for example, by means of an optical adhesive, with subsequent creation of the total internal reflection surface at the fibre end, for example, by sloped polishing relatively to the fibre axis.

7. The method of optical fibre manufacturing according to the claims 1 or 2, where after creating the total internal reflection surface, for example, by sloped polishing relatively to the fibre axis, an optical element of homogeneous transparent material with corresponding refraction index, shaped as the additional optical material per claim 4 is attached, for example, glued in front of the internally reflective surface.

8. The method of optical fibre manufacturing according to the claims 1 or 2, where the internally reflecting and output/input surfaces are continuously integrated in a coaxial fibre core sleeve, made of transparent material with corresponding refraction index and attached, for example, glued to the polished end of the fibre core.
Fig. 1
Prior art

Fig. 1B
Prior art
Fig. 5
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

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

INV. G02B 6/26
G02B 6/255

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B A61B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

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'P' document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search

15 September 2008

Date of mailing of the international search report

24/09/2008

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Authorized officer

Luck, Wulf

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