



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

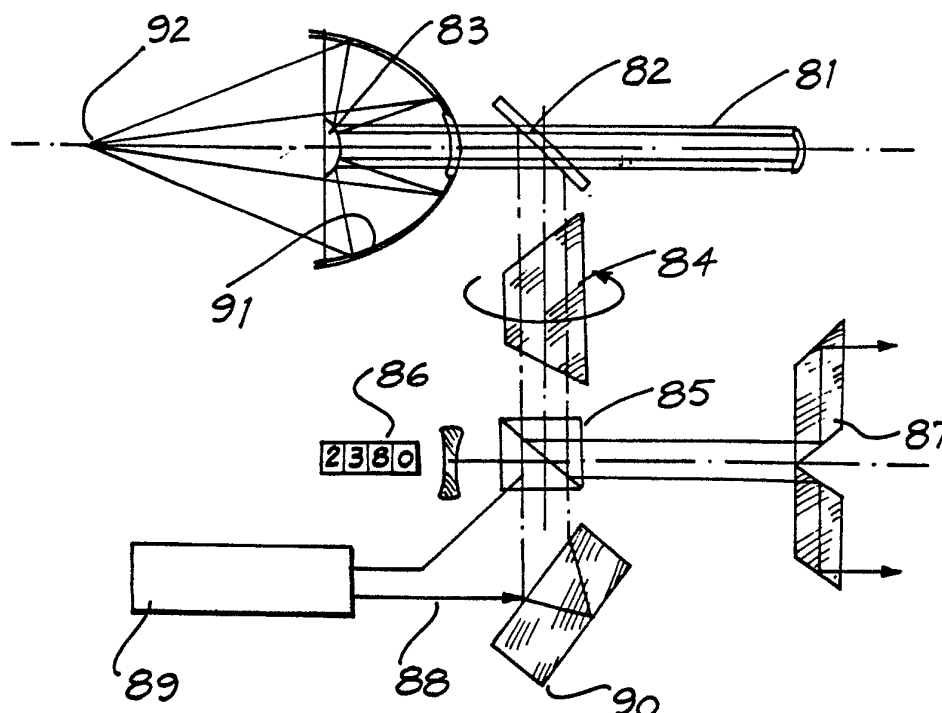
(51) International Patent Classification ⁴ : A61B 17/32, H01S 3/23	A1	(11) International Publication Number: WO 87/ 05794 (43) International Publication Date: 8 October 1987 (08.10.87)
---	-----------	--

(21) International Application Number: PCT/AU87/00089
 (22) International Filing Date: 3 April 1987 (03.04.87)
 (31) Priority Application Number: 78416
 (32) Priority Date: 3 April 1986 (03.04.86)
 (33) Priority Country: IL
 (71) Applicant (for all designated States except US): LASER-EX LIMITED [AU/AU]; 28 Greenhill Road, Wayville, S.A. 5034 (AU).
 (72) Inventor; and
 (75) Inventor/Applicant (for US only) : SHARON, Uzi [US/US]; 30a Ugarit Street, Tel-Baruch, Tel Aviv (IL).
 (74) Agent: TAYLOR, Paul; Arthur S. Cave & Co., Gold Fields House, 1 Alfred Street, Sydney, NSW 2000 (AU).

(81) Designated States: AT (European patent), AU, BE (European patent), BG, BR, CH (European patent), DE (European patent), DK, FI, FR (European patent), GB (European patent), HU, IT (European patent), JP, KR, LK, LU (European patent), MC, MG, MW, NL (European patent), NO, RO, SD, SE (European patent), SU, US.

Published
 With international search report.

(54) Title: LASER SURGERY SYSTEM



(57) Abstract

A laser micro-surgery system with two or more lasers (71, 72, 73) with different wavelengths has only essentially reflecting optical elements (74, 75, 76, 78, 79, 91) in the optical path so that on changing from one laser to another the target point (92) of the laser light is invariant as the wavelength of the light changes. The output laser beam (43) is in the shape of a hollow cone.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT Austria	FR France	ML Mali
AU Australia	GA Gabon	MR Mauritania
BB Barbados	GB United Kingdom	MW Malawi
BE Belgium	HU Hungary	NL Netherlands
BG Bulgaria	IT Italy	NO Norway
BJ Benin	JP Japan	RO Romania
BR Brazil	KP Democratic People's Republic of Korea	SD Sudan
CF Central African Republic	KR Republic of Korea	SE Sweden
CG Congo	LI Liechtenstein	SN Senegal
CH Switzerland	LK Sri Lanka	SU Soviet Union
CM Cameroon	LU Luxembourg	TD Chad
DE Germany, Federal Republic of	MC Monaco	TG Togo
DK Denmark	MG Madagascar	US United States of America
FI Finland		

LASER SURGERY SYSTEM

FIELD OF THE INVENTION:

There is provided an integrated optical system for micro-surgery by means of a laser. The system permits a high degree of accuracy of work and is adapted to minimize any possible damage to tissues in the path of the laser beam or beyond the "target" of said beam. It comprises two or more different lasers and means for the interchange of these at will.

BACKGROUND OF THE INVENTION

It is a paramount requirement of laser systems for use in micro-surgery, that the system will direct the required energy onto the desired area. A number of laser systems is marketed, but none of these meet the stringent requirements of delivering the required energy to the target in an accurate manner with minimum side-effects.

It is a further consideration, that such systems must have a certain spatial distribution of energy as regards the working area during surgery.

The important parameters of laser systems of this type are:

1. Shape of the focused laser beam;
2. The spot size of the beam at the target area;
3. The distribution of energy about the working area;
4. The possible damage to tissue in the path of the beam, located before the target area;
5. The depth of field of the microscope used;
6. The coordination and coincidence of the focal plane of the microscope with that of the focused laser beam, with problems arising out of:
 - i) alignment of the mechano-optical system;
 - ii) difference in the optical wavelength of the laser as regards IR radiation;
 - iii) means for aiming the laser beam and of the pointing devices, both regarding the IR laser and also the microscope system.
7. The requirement to be able to use different lasers and to interchange these at short notice without undue manipulation. As regards the above, it must be pointed



- 2 -

out that the focused laser beam is not an ideal cone having an infinitesimally small focused spot. The resulting spot size at the focus depends on the diameter of the laser beam which enters the lens, on the focal length of the lens and on the optical wavelength of the laser. The energy distribution of the laser is illustrated with reference to Fig. 1 where the dashed line triangle represents an ideal focused beam emerging from a lens of diameter D and focal length f . Even with a parallel laser beam the spot will have a certain size. From this follows that the energy distribution along the axis of the focused laser beam has a "waist" of a certain pattern, the energy being spread around the ideal focal point within a distance of $2r$ around the focal point.

There exist three optical elements, each of which has an optical axis, and these are combined in the system:

- i) The axis of the laser, the resulting spot size and its location;

- ii) The viewing system with its axis;
- iii) The aiming device and its axis.

The invention is illustrated with reference to the enclosed schematical drawings, which are not according to scale, and in which:

FIG. 1 illustrates the energy distribution of a focused laser beam;

FIG. 2a illustrates the focusing of a laser beam, of a viewing system and of an aiming light beam;

FIG. 2b illustrates the angular misalignment of optical axes;

FIG. 3 illustrates the danger of direct focusing of a laser beam onto an eye;

FIG. 4 illustrates the advantages of a hollow laser beam;

FIG. 5 illustrates the formation of a hollow laser beam by means of a Reflexicon;

FIG. 6 illustrates means for aiming a laser beam;

FIG. 7 illustrates an integrated aiming and energy laser system

FIG. 8 and 8a are a side-view and a view from the

- 3 -

rear of a system of the present invention.

The shape of a focused laser beam is not that of an ideal cone, having an infinitely small head. The resulting spot size depends on the diameter of the laser beam entering the lens, on the focal length of the lens and on the wavelength of the laser. The energy distribution in a focused laser beam is illustrated in FIG. 1, where 11 is the laser beam entering lens 12, f being the focus of the lens 12, the conus 13 defining the ideal focusing, whereas the curved line 14 defines the actual energy distribution.

There result problems arising from the above, namely the difference in focal length of each of the three elements, see FIG. 2a; and the misalignment of the optical axes, see FIG. 2b. When a microsurgical surgery system is used for ophthalmic surgery, there arise unique problems as the laser beam passes through an optical medium. When the target is the retina, the laser must be chosen in such a manner that there will be a minimum of energy absorption by the clear parts of the eye. When the work is on the fore-part of the eye, damage to parts of the eye in front of the target must be minimized.

As illustrated in FIG. 3, the corneal parts of the eye can be damaged when surgery is done on the lens of the eye. It has been suggested to use wide-angle optics to reduce the spot size of the laser and the effective depth of the laser focus.

SUMMARY OF THE INVENTION:

According to the invention there is provided a laser micro-surgery system adapted to focus laser energy to the desire location, with minimum interference with and damage to parts of the tissue which are not to be affected. The novel system has applications in different fields of surgery, but it is illustrated herein with a special emphasis on the use in eye surgery. This specific use is illustrative only and the invention is by no means restricted to this specific application. According to the invention there is provided an optical system by which there is obtained a hollow laser beam,

- 4 -

which is provided around a hollow core. As the entire energy of the laser beam is within this "tubular" hollow conical configuration, damage to parts of the eye in front of the working area are minimized.

5 Accordingly, there is provided a laser microsurgery system which comprises at least one laser, and generally two or three different lasers, which laser system comprises only reflecting optical elements which make possible the accurate focusing of radiations at a variety
10 of wavelengths, thus preventing the necessity of adjustments and refocusing when there is a changeover from one laser to another. There are provided aiming means coordinated with the laser or lasers. The focusing system advantageously comprises a folding
15 mirror, an inverting Wexocon or Reflexicon, a holding prism, a beam splitter and a reflective objective.

The hollow laser beam is formed by means of a Reflexicon, or equivalent optical element. Such beam is focused onto the target by means of a system comprising a
20 reflective lens onto which such hollow beam is pointed, and which reflects the beam onto the inner surface of a suitably shaped curved mirror, adapted to focus the beam in an accurate manner.

There is provided an aiming system, aligned with the energy laser beam. Such aiming beam comprises a
25 suitable laser (such as HeNe laser), which is passed via an Axicon, through a beam expander and with results in a hollow beam which is used for the intended aiming of the system onto the target.

30 The microsurgery system comprises essentially reflecting elements only, as with these the focal points are identical for varying optical wavelengths. The main element is the Cassagrenian mirrored device, of the type used in telescopes and microscopes. The system is built
35 around this main element, and comprises an aiming laser beam, and an energy laser beam used for the actual surgery.

According to a preferred embodiment, a number of lasers are used in the system, each serving at a certain

- 5 -

stage of the surgery. All of these are aligned with the aiming system, and changeover from one laser to another does not require refocusing or realignment. As shown in FIG. 3, the light beam 31, coming from a focusing lens, which is not shown, passes the cornea 32 already in a quite focused manner, and is focused onto the lens 33. The beam is apt to damage the cornea 32 due to the high energy density. The configuration of a laser beam according to the invention is illustrated with reference to schematical FIG. 4, which is not according to scale, where 41 is a laser beam directed on lens 42, all the energy being in the conical envelope 43, passing into the eye and being focused onto the lens 44 at 45, without affecting the frontal part of the eye.

The laser beam can be given this spatial configuration by various means, some of which are as follows:

As shown in FIG. 5, the beam from energy laser 51 having a Gaussian beam shape is directed onto a Reflexicon 52 resulting in a doughnut beam shape as illustrated at 53, providing the hollow laser beam 54 which is used for the intended purposes. The laser beam may be aimed at the target making use of the device illustrated in FIG. 6 where 61 designates a HeNe laser, the beam 62 of which is directed at the Axicon 63 and via beam expander 64 to the target 65. A system according to the present invention is illustrated with reference to FIG. 7 and 7a, which are respectively a schematical side-view in partial section through such device, while FIG. 71 is a sectional rear-view of the system.

There is provided a system for aligning the three axes of the laser system, and this by means of reflecting instead of refracting optics. The big advantage of reflecting optics is that the resulting focal point does not depend on the wavelength of the light used, and thus the resulting depth of field is the same for the components of the system. A preferred optical element for this purpose is a Cassagrenian mirror device which is used in telescopes and with microscopes. A device based

- 6 -

on this principle is illustrated with reference to FIG. 8 wherein:

5 A hollow laser beam 81 is directed via beam splitter 82 to the first surface-silvered mirror 83, and also to the image rotator 84 directing the beam onto the beam cube splitter 85, to display 86, and from same to stereo image splitter 87, there being directed a laser beam 88 from HeNe laser 89 to the HeNe beam doubler 90, from same to said beam cube splitter 85, and to display 10 86 and stereo image splitter 87.

The hollow laser energy beam reflected from the front-silvered mirror 83 is reflected onto the reflecting inner surface of the spherical or aspherical mirror 91 which focuses it onto target 92. The aiming is done by 15 means of the HeNe laser beam, and after such focusing the energy laser beam 81 can be used for surgery, as these are aligned and the focusing of the aiming beam also results in the focusing of the energy beam. This energy beam enters via the opening in the mirror 91.

20 In this system only reflective optical elements are used and this makes possible the focusing with different wave-lengths without any subsequent adjustment.

A triple-laser system is illustrated with reference to FIG. 7, where there are provided 3 interchangeable 25 lasers 71, 72 and 73 which may be, for example, Erbium, NdYAG and Ruby lasers, respectively. There is provided a laser-selecting folding mirror 74 actuated by knob 75 by which the lasers can be changed over from one to the other.

30 The laser beam selected is directed onto folding mirror 75 and from same to inverting Wexicon 76 which directs part of the beam onto folding prism 77 and part onto beam splitter and annular mirror 78, and via secondary mirror 79 and reflective objective 80 to first 35 mirror 91, back to mirror 79 and to focal point 92. The alignment is done by means of eyepieces 93 and 94. As the entire optical system comprises only reflecting elements, the focusing is valid for different wave-lengths, and thus the changeover from one laser to

- 7 -

the other does not require a new focusing.

The system makes possible to use for every step of surgery the most appropriate laser and thus different lasers can be used for cutting, for coagulation, etc.

5 It is an important feature that the system provides the possibility to change over from one laser type to another without the requirement for any complicated adjustments, or additional optical elements.

10 This is of considerable importance for various types of surgery, as the effect of different types of lasers on human tissues is a different one as regards cutting properties, coagulation, etc. Thus, it is possible to provide in one system a plurality of different lasers.

15 The present invention is illustrated herein with reference to a system which comprises 3 different lasers, but there can be provided 2 or more, as required. For example, lasers may be chosen amongst erbium lasers, Nd-YAG lasers, ruby lasers, CO₂-lasers, etc. As the
20 system is based on the use of reflective optical elements, to the exclusion of refractive optical elements as far as the laser beams are concerned, the system can be used with one basic focusing adjustment for a wide variety of wavelengths without subsequent repeat
25 adjustment. The novel system makes possible the use of high energy density level lasers of any desired wavelength, either in continuous or pulsed operation without spherical or other aberrations. When pulses are used, these may be of a very high energy intensity.

30 For example, there maybe used pulses in the 100-500 pico-second pulse duration with intensities of the order of 10^9 W/Cm^2 . A plurality of lasers is provided, and there is provided a laser selector which provides for the speedy changeover from one to the other.

35

- 8 -

THE CLAIMS:

1. A laser microsurgery system provided with more than one laser, provided with a system of reflecting optical elements, so that various wavelength radiations can be accurately focused without adjustments during changeovers of these from one to the other.
2. A microsurgery system according to claim 1, where a number of lasers are provide, each specifically suited for a certain stage of surgery.
3. A system according to claim 1 or 2, where the focusing system comprises in combination a folding mirror, an inverting Reflexicon or Wexicon, a folding prism, a beam splitter and a reflective objective.
4. A system according to claim 3, comprising an annular mirror.
5. A system according to any of claims 1 to 4, where there are provided at least 2 lasers selected from erbium, Nd-YAG, ruby and CO₂ lasers.
6. A system according to claims 1 to 4, for use in eye-surgery, where means are provided for generating a hollow conical focused laser beam.
7. A system according to any of claims 1 to 6, where the means for forming a hollow laser beam comprise an Axicon, or a Wexicon or an equivalent optical element.
8. A system according to claim 7, where the hollow beam is focused onto the target by means of a combination of a front-silvered convex mirror, which reflects the hollow beam onto the interior surface of a spherical or aspherical mirror which focuses the hollow beam onto the target.
9. A laser microsurgery system substantially as hereinbefore described with reference to the accompanying drawings.

1/4

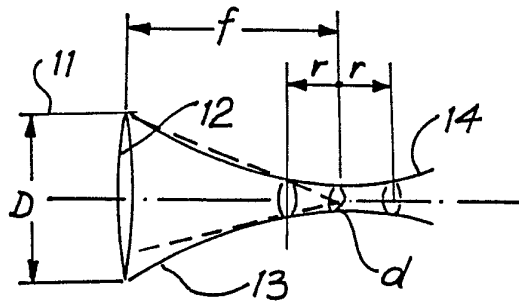
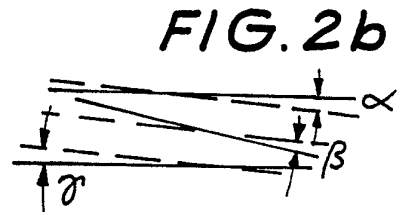


FIG. 1



ANGULAR MISALIGNMENT
of OPTICAL AXES

- 1. LASER
- 2. VIEWER
- 3. AIMING BEAM

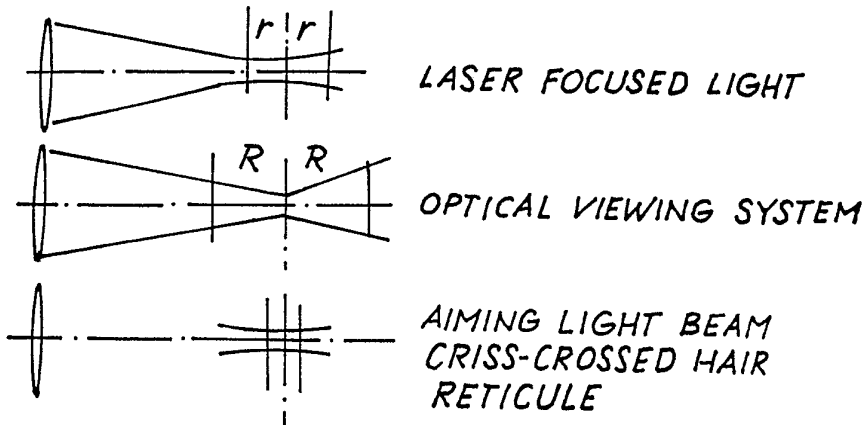


FIG. 2a

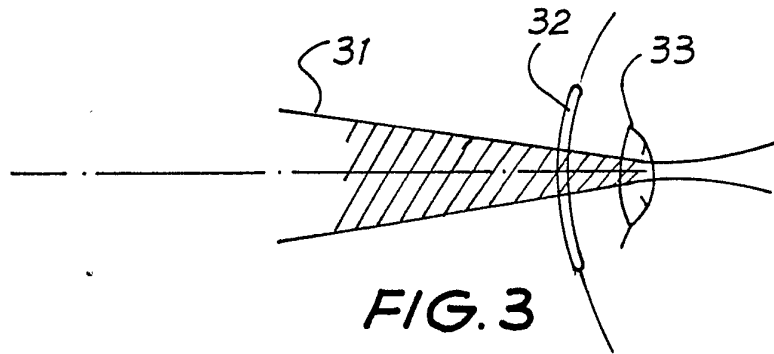


FIG. 3

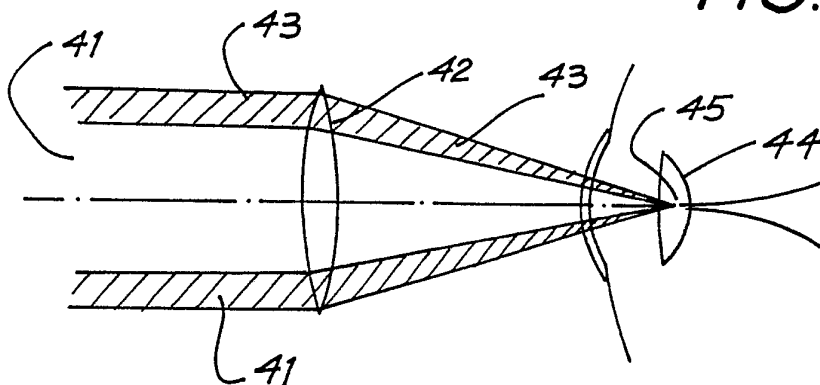
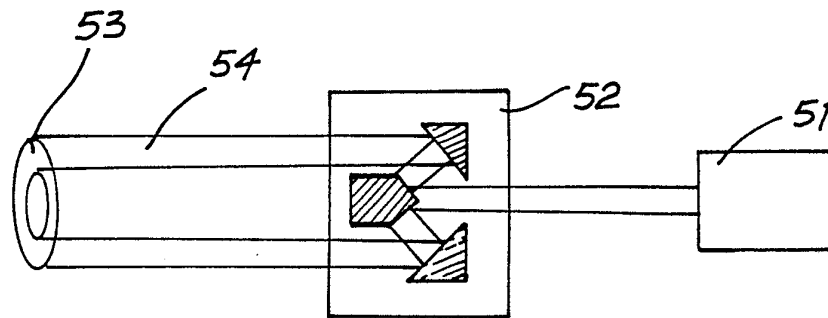
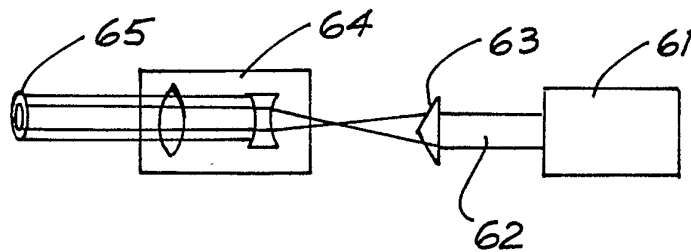
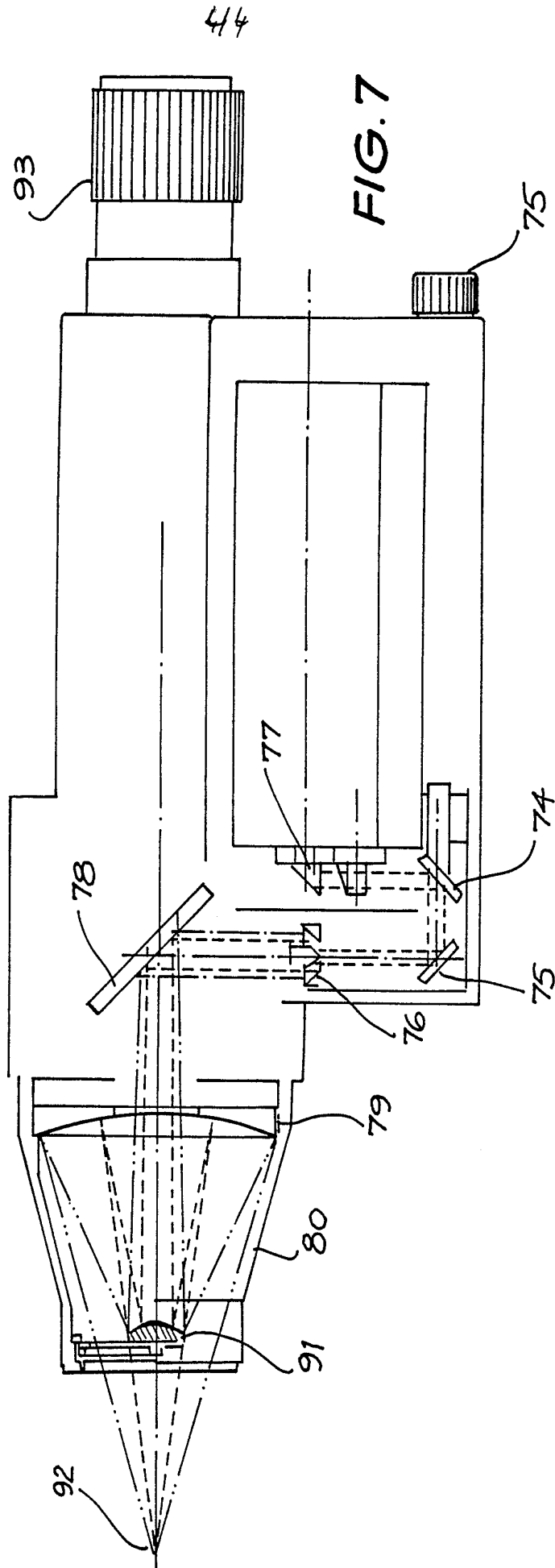


FIG. 4

2/4

*FIG. 5**FIG. 6***SUBSTITUTE SHEET**



INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 87/00089

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶ According to International Patent Classification (IPC) or to both National Classification and IPC Int. Cl.⁴ A61B 17/32, H01S 3/23																							
II. FIELDS SEARCHED Minimum Documentation Searched ⁷ <table style="width: 100%; border: none;"> <tr> <td style="width: 30%; border: none; vertical-align: top;"> Classification System IPC⁴ </td> <td style="width: 70%; border: none; vertical-align: top;"> Classification Symbols A61B 17/32, H01S 3/23 </td> </tr> </table> Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸ AU: IPC as above			Classification System IPC⁴	Classification Symbols A61B 17/32, H01S 3/23																			
Classification System IPC⁴	Classification Symbols A61B 17/32, H01S 3/23																						
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹ <table style="width: 100%; border: none;"> <tr> <th style="width: 10%; border: none; text-align: left; font-size: 0.8em;">Category ⁹</th> <th style="width: 70%; border: none; text-align: left; font-size: 0.8em;">Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²</th> <th style="width: 20%; border: none; text-align: left; font-size: 0.8em;">Relevant to Claim No. ¹³</th> </tr> <tr> <td style="border: none; vertical-align: top;">A</td> <td style="border: none;">AU,A, 88621/82 (MORRIS) 31 March 1983 (31.03.83)</td> <td style="border: none;"></td> </tr> <tr> <td style="border: none; vertical-align: top;">A</td> <td style="border: none;">GB,A, 1537696 (ISAKOV et al) 10 January 1979 (10.01.79)</td> <td style="border: none;"></td> </tr> <tr> <td style="border: none; vertical-align: top;">A</td> <td style="border: none;">US,A, 3769963 (GOLDMAN et al) 6 November 1973 (06.11.73)</td> <td style="border: none;"></td> </tr> <tr> <td style="border: none; vertical-align: top;">A</td> <td style="border: none;">AU,A, 84193/82 (SUMITOMO ELECTRIC INDUSTRIES, LTD) 2 December 1982 (02.12.82)</td> <td style="border: none;"></td> </tr> <tr> <td style="border: none; vertical-align: top;">A</td> <td style="border: none;">GB,A, 1522235 (LASER INDUSTRIES LTD) 23 August 1978 (23.08.78)</td> <td style="border: none;"></td> </tr> <tr> <td style="border: none; vertical-align: top;">A</td> <td style="border: none;">EP,A2, 76740 (ESSILOR INTERNATIONAL) 13 April 1983 (13.04.83)</td> <td style="border: none;"></td> </tr> </table>			Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³	A	AU,A, 88621/82 (MORRIS) 31 March 1983 (31.03.83)		A	GB,A, 1537696 (ISAKOV et al) 10 January 1979 (10.01.79)		A	US,A, 3769963 (GOLDMAN et al) 6 November 1973 (06.11.73)		A	AU,A, 84193/82 (SUMITOMO ELECTRIC INDUSTRIES, LTD) 2 December 1982 (02.12.82)		A	GB,A, 1522235 (LASER INDUSTRIES LTD) 23 August 1978 (23.08.78)		A	EP,A2, 76740 (ESSILOR INTERNATIONAL) 13 April 1983 (13.04.83)	
Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³																					
A	AU,A, 88621/82 (MORRIS) 31 March 1983 (31.03.83)																						
A	GB,A, 1537696 (ISAKOV et al) 10 January 1979 (10.01.79)																						
A	US,A, 3769963 (GOLDMAN et al) 6 November 1973 (06.11.73)																						
A	AU,A, 84193/82 (SUMITOMO ELECTRIC INDUSTRIES, LTD) 2 December 1982 (02.12.82)																						
A	GB,A, 1522235 (LASER INDUSTRIES LTD) 23 August 1978 (23.08.78)																						
A	EP,A2, 76740 (ESSILOR INTERNATIONAL) 13 April 1983 (13.04.83)																						
<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top; font-size: 0.8em;"> ¹⁰ 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 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed </td> <td style="width: 50%; border: none; vertical-align: top; font-size: 0.8em;"> "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "G" document member of the same patent family </td> </tr> </table>			¹⁰ 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 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "G" document member of the same patent family																			
¹⁰ 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 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "G" document member of the same patent family																						
IV. CERTIFICATION <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;"> Date of the Actual Completion of the International Search 1 July 1987 (01.07.87) </td> <td style="width: 50%; border: none; vertical-align: top;"> Date of Mailing of this International Search Report: (23.07.87) 23 JULY 1987 </td> </tr> <tr> <td style="width: 50%; border: none; vertical-align: top;"> International Searching Authority Australian Patent Office </td> <td style="width: 50%; border: none; vertical-align: top;"> Signature of Authorized Officer A.J. EVANS </td> </tr> </table>			Date of the Actual Completion of the International Search 1 July 1987 (01.07.87)	Date of Mailing of this International Search Report: (23.07.87) 23 JULY 1987	International Searching Authority Australian Patent Office	Signature of Authorized Officer A.J. EVANS																	
Date of the Actual Completion of the International Search 1 July 1987 (01.07.87)	Date of Mailing of this International Search Report: (23.07.87) 23 JULY 1987																						
International Searching Authority Australian Patent Office	Signature of Authorized Officer A.J. EVANS																						

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON
INTERNATIONAL APPLICATION NO. PCT/AU 87/00089

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Members			
AU 88621/82	BR 8205637 EP 75860 FI 823285 IN 158234 NO 823214	CA 1223644 ES 515900 GB 2108282 JP 58083951 NZ 201981	DK 4234/82 ES 522286 IL 66857 MX 152422 ZA 8206935		
AU 84193/82	CA 1179539 US 4586795	EP 65785	JP 57195205		
GB 1522235	AU 19967/76 IL 48554	BR 7607867 JP 52066444	DE 2652814 IS 4123143		
EP 76740	CA 1188372 US 4517980	FR 2513873	JP 58069557		

END OF ANNEX