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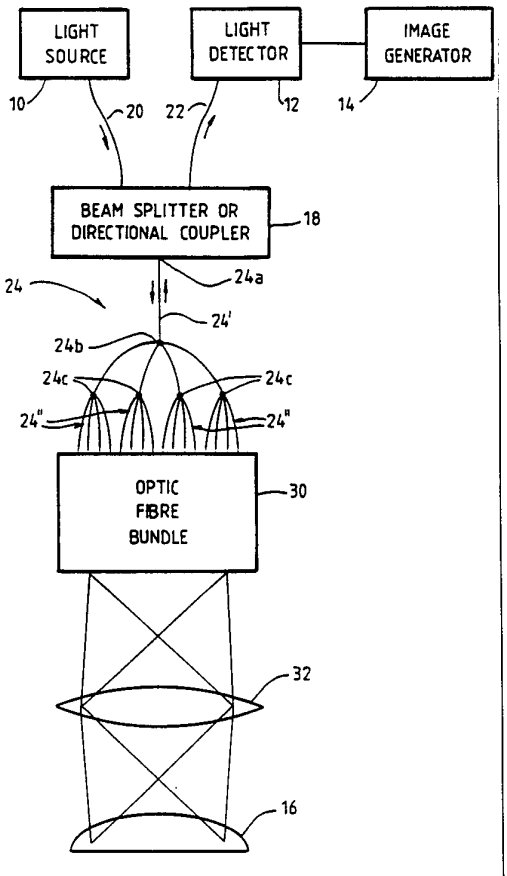
(54) Title: CONFOCAL MICROSCOPE AND ENDOSCOPE

(57) Abstract

A confocal microscope and a scanning head are disclosed. The microscope comprises a light source (10) and a detector (12). An optical fibre bundle (24) receives light from the light source (10) and transmits the light source to an object and allows light to return from the object. Switchable optical fibre or waveguide tree couplers (24b, 24c) selectively switch fibres in the optical fibre bundle to allow light to be transmitted and returned through the fibre bundle (24). A detector (12) detects the returned light to enable an image of the object to be produced. The scanning head includes scanning mirrors (44) for enabling a beam of light to scan an object, a beam steering lens (60) is located at a position displaced from an image plane and an objective lens (62) is provided for focussing light on or in an object.



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CONFOCAL MICROSCOPE AND ENDOSCOPE

This invention relates to a microscope and more particularly to a microscope using the principal of confocal microscopy.

The principal of confocal microscopy was disclosed in U.S. patent 3,013,467 to Minsky in 1957. With confocal microscopy, a point or spot (which may be diffraction-limited) within an object is illuminated and only light from that point is imaged, e.g. via a pin hole detector. By scanning the spot across a plane (e.g. with a translucent object) a clear image ("optical section") may be obtained.

International patent applications PCT/AU89/00298 and PCT/AU91/00129 describe the design of confocal microscopes which instead of a pin hole (or equivalent) of a conventional confocal microscope use an optical fibre or fibre bundle, thus allowing the distal end to be more freely mobile, transportable and miniaturisable.

The present invention relates to an improvement to confocal microscopes of the type described in the above mentioned International applications and which are particularly suited to produce images inside of the living body of animals or humans.

The invention may be said to reside in a confocal microscope comprising:

a light source;

an optical fibre bundle for receiving light from the light source and for transmitting the light to an object;

and for allowing light to return from the object through the optical fibre bundle;

switching means for selectively switching selected fibres in the optical fibre bundle so as to allow light to selectively be transmitted and returned through respective fibres in the optical fibre bundle; and

a detector for receiving returned light from the optical fibre bundle to enable an image of the object to be produced.

The use of switching means which enables the individual fibres in the bundle to be selectively switched to allow light to be transmitted through them enables selected fibres to be switched in sequence so that light is scanned across the focal plane on or within the object and light returning confocally from the object can be detected virtually instantaneously on its return from the object. Another alternative which could be particularly useful for real time imaging of fluorescent objects, is to generate an identical pattern of switching of the switch means which lags the original pattern so that light may be detected confocally a short time after it has illuminated the object. This is because peak fluorescence occurs at a time after illumination of an object.

Preferably the switching means comprises a plurality of switchable optical fibre or waveguide tree couplers, the plurality of tree couplers having a first end which receives light from a first light path and a plurality of second ends which are coupled to or integral with respective fibres of the fibre bundle.

In a further embodiment the switching means comprises a plurality of switches in the respective fibres of the

optical fibre bundle.

In this embodiment of the invention an optical element is provided at an image end of the optical fibre bundle for simultaneously launching light to the individual fibres of the optical fibre bundle and for collecting return light from the optical fibre bundle.

Preferably a beam splitter or directional coupler is disposed proximal to the optical fibre bundle, for receiving light from the light source and transmitting the light to the optical fibre bundle, and for receiving return light from the optical fibre bundle and for transmitting the light to the light detector.

Preferably the first light path comprises one or more optical fibres. However, in other embodiments the first light path could comprise a beam path with or without beam steering optics rather than, or as well as at least one optical fibre.

Preferably a lens element or lens array is provided between the object and the distal end of the optical fibre bundle.

A further aspect of the invention concerns a scanning head which may be used in a confocal microscope.

This aspect of the invention may be said to reside in a scanning head for receiving light from a light source and for transmitting return light to a detector, the scanning head comprising:

a scanning means for causing a beam of light to scan an object;

a beam steering lens for focussing the light, the

beam steering lens being displaced from an image plane at which the light focuses; and

an objective lens for focussing the light on or in an object.

Since this aspect of the invention utilises a beam steering lens which is displaced from the image plane scanning is performed asymmetrically (i.e. so that the lens is proximal to the image plane) thus eliminating detection of lens reflections. Furthermore, the scanning head may be dimensioned to fall within the range for minimum errors in scanning and flatness of field, without introducing added optics to correct for mirror separation.

Preferably a fibre output lens is arranged between the light source and the scanning means for focussing (in combination with the beam steering lens) the light beam at the image plane. The fibre output lens may be a standard microscope objective element, configured for its specific tube length, hence retaining resolution performance.

Preferably the image plane is on the object side of the beam steering lens such that the scanning head is the optical analogue of an eye piece, compatible with standard microscopes.

Preferably the scanning means comprises one or more scanning mirrors. However, in other embodiments other scanning devices such as acousto-optical devices could be utilised.

Preferably at least one optical fibre is provided between the light source and the fibre output lens for transmitting light from the light source to the fibre output lens.

Preferably a beam splitter or directional coupler is provided for directing the light from the light source to the scanning means and for directing return light from the scanning means to the light detector.

Preferred embodiments of the invention will be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a view of a first embodiment of the invention;

Figure 2 is a view of the second embodiment of the invention;

Figure 2A is a diagram illustrating control of the embodiments of figures 1 and 2; and

Figure 3 is a view of a scanning head according to a further aspect of the invention.

With reference to figure 1 the confocal microscope comprises a light source 10 and a detector 12. The detector 12 may be coupled to a computerised image generator 14 for enabling an image of an object 16 to be formed on a television screen or the like.

The light source 10 is coupled to a beam splitter or directional coupler 18 by a first optical fibre 20 and the light detector 12 is connected to the beam splitter or directional coupler 18 by a second optical fibre 22.

The beam splitter or directional coupler 18 is connected to an array of switched optical fibre or waveguide tree couplers 24. The array of switched tree couplers 24 comprises a first tree coupler 24' which has a first end 24a and a plurality of branches 24b which have second ends 24c. Thus, the first tree coupler 24' has one fibre or

connection in and "n" fibres or connections out. The first tree coupler may then be linked to a plurality of further tree couplers 24'' and if necessary the second ends of the further tree couplers 24'' may be yet connected to further tree couplers until the number of outputs from the array of tree couplers can be linked to (or form an integral part of) respective fibres in an optical fibre bundle 30 which includes a plurality of individual optical fibres (not shown). Thus, each individual optical fibre is connected to the output end of the array of tree couplers 24.

The tree couplers are switchable to enable light to pass through selected branches of the optical fibre or waveguide tree couplers so that light can be launched into selected individual optical fibres in the optical fibre bundle 30.

A lens or lens array 32 is arranged at the distal or object end of the optical fibre bundle 30 for focussing the light transmitted through the optical fibre bundle on or in the object 16. The return light from the object 16 which returns confocally from the object 16 may traverse the same pathway, as far as the beam splitter or directional coupler 18. The beam splitter or directional coupler 18 then directs the beam through the second optical fibre 22 to the light detector 12 for formation of an image of the object.

The image is generated by the light detector 12 and image generator 14 by switching the tree couplers 24', 24'' in such a way that light is scanned across the focal plane on or within the object 16. Light returning confocally from the object can be detected virtually instantaneously after it has traversed the same pathway, as far as the beam splitter 18, on its return from the object or alternatively, an identical pattern of switching in the

tree couplers 24', 24'' can be generated which lags the original pattern so that light may be detected confocally a short time after it has illuminated the object. This technique is useful in real-time imaging of fluorescence objects because peak fluorescence occurs at a finite time after illumination of an object.

The light emerging from the distal end of the fibre bundle 30 may be diffraction limited.

In an alternative arrangement to that shown in figure 1, the optical fibres 20 or 22 could be replaced by a path with or without beam steering optics to form the first light path instead of using optical fibres.

Figure 2 shows a second embodiment of the invention in which like elements are represented by the same reference numerals to those in figure 1. In this embodiment of the invention the optical fibre bundle 30 is provided with fibre on-off switches 34 in the individual fibres of the optical fibre bundle so that the switches are effectively integral with the individual fibres in the bundle thereby doing away with the need for an array of switched tree couplers. Optical elements 36 such as lenses or the like may be provided at the proximal end of the optical fibre bundle 30 to simultaneously launch light into the individual optical fibres of the optical fibre bundle 30 which is received from the beam splitter or directional coupler 18.

The in-fibre on-off switches 34 may be optical, optoacoustic or electro-optic or other type of switches which either prevent, preferably with minimal reflection, or allow light to pass down a particular fibre. An example

of in-fibre switching is given by Lytel-R. (1990) "Applications of Electro-optic Polymers to Integrated Optics", S.P.I.E., 1216, 30.

By means of in-fibre switching, at any one moment in time, light is allowed to pass down one or even several fibres of the bundle. As in figure 1, after light emerges from the distal end of a fibre in the optical fibre bundle 30 it is focussed on a point or spot on or within the object 16 and light returning confocally from the object may traverse the same pathway, as far as the beam splitter or directional coupler 18. By an appropriate pattern of switching within the bundle 30, scanning of light across the focal plane of the object may be achieved. The light may return from the object by the same path almost instantaneously or, as described above, the in-fibre switching may lag the original switching pattern.

Because the resolution of the image will be limited by the gaps between the individual fibres in the optical fibre bundles 30, in figures 1 and 2 improved resolution may be obtained by movements (which could, for example, be quite small - e.g. of a similar magnitude as the distance between the adjacent fibres in the bundle) of the distal end of the optical fibre bundles 30 in relation to the object 16. This would allow scanning in the focal plane of the object to be less discrete and more continuous in nature. The movement could be either of the fibre bundle tip or of the object or of both.

As is shown in figure 2A, three optical fibres 30a, 30b and 30c of the optical fibre bundle 30 which including a optical, optoacoustic, electro-optic or other type of switch 31 which are electrically, optically or otherwise

connected to a controller 33 (such as a computer or the like) for example by leads or connectors 35. Alternatively the controller could control optical switches by sending light to those switches (eg through the fibre optic bundle or array of tree couplers). The controller 33 applies output signals to the switches 31 to control the switches so that the switches either allow or prevent light to pass through the optical fibre 30a, 30b and 30c. A similar arrangement to that shown above may be used to control the switchable optical fibre or waveguide tree couplers described with reference to figure 1. Alternatively switchable waveguide tree couplers could form part of an integrated chip with optical and electronic components.

Figure 3 discloses a scanning head which is particularly useful in non-endoscopic applications of the microscope.

In figure 3 the scanning head comprises a head 42 which contains one or more scanning mirrors 44 and a fibre output lens 46 which receives light from an optical fibre or point source 48. The optical fibre or point source 48 is coupled to a beam splitter or directional coupler 50 which in turn is coupled to a light source 52 and light detector 54 by individual optical pathways or waveguides (such as optical fibres) 56 and 58.

The head 42 includes a beam steering lens 60. The beam steering lens 60 is displaced axially from an image plane of the lens 62 so that scanning is performed asymmetrically (i.e. so that the lens 60 is proximal to the image plane) thus eliminating detection of lens reflections. A microscope objective lens 62 is provided for focussing the light from the light source 52 on or in an object.

Return light from the object is returned along the same path as the incident light as far as beam splitter 50 and is directed by beam splitter 50 to light detector 54 via pathway 58 for formation of an image.

Since the scanning head performs scanning asymmetrically in relation to the beam steering lens 60 problems inherent in symmetrical designs in which there may be problems of confocal return from the lens and aberrations due to the lens elements being at suboptimal separations are eliminated.

The fibre output lens 46 is a standard microscope objective element, configured for its specified tube length, hence retaining resolution performance. The image is projected below the beam steering lens such that the scanning head is the optical analogue of an eyepiece, compatible with standard microscopes. The dimensions achieved fall within the range of minimum errors in scanning and flatness of field, without introducing added optics to correct for minor separation.

Since modifications within the spirit and scope of the invention may readily be effected by persons skilled within the art, it is to be understood that this invention is not limited to the particular embodiment described by way of example hereinabove.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A confocal microscope comprising:

a light source;

an optical fibre bundle for receiving light from the light source and for transmitting the light to an object;

and for allowing light to return from the object through the optical fibre bundle;

switching means for selectively switching selected fibres in the optical fibre bundle so as to allow light to selectively be transmitted and returned through respective fibres in the optical fibre bundle; and

a detector for receiving returned light from the optical fibre bundle to enable an image of the object to be produced.

2. The microscope of claim 1 wherein the switching means comprises a plurality of switchable optical fibre or waveguide tree couplers, the plurality of tree couplers having a first end which receives light from a first light path and a plurality of second ends which are coupled to or integral with respective fibres of the fibre bundle.

3. The microscope of claim 1 wherein the switching means comprises a plurality of switches in the respective fibres of the optical fibre bundle.

4. The microscope of claim 3 wherein an optical element is provided at an image end of the optical fibre bundle for simultaneously launching light to the individual fibres of the optical fibre bundle and for collecting return light from the optical fibre bundle.

5. The microscope of claim 1 wherein a beam splitter or directional coupler is disposed proximal to the optical fibre bundle, for receiving light from the light source and transmitting the light to the optical fibre bundle, and for receiving return light from the optical fibre bundle and for transmitting the light to the light detector.

6. The microscope of claim 1 wherein the first light path comprises one or more optical fibres.

7. The microscope of claim 1 wherein a lens element or lens array is provided between the object and the distal end of the optical fibre bundle.

8. A scanning head for receiving light from a light source and for transmitting return light to a detector, the scanning head comprising:

a scanning means for causing a beam of light to scan an object;

a beam steering lens for focussing the light, the beam steering lens being displaced from an image plane at which the light focuses; and

an objective lens for focussing the light on or in an object.

9. The scanning head of claim 8 wherein a fibre output lens is arranged between the light source and the scanning means for focussing, in combination with the beam steering lens, the light beam at the image plane.

10. The scanning head of claim 8 wherein the image plane is on the object side of the beam steering lens such that the scanning head is the optical analogue of an eye piece, compatible with standard microscopes.

11. The scanning head of claim 8 wherein the scanning means comprises one or more scanning mirrors. However, in other embodiments other scanning devices such as acousto-optical devices could be utilised.

12. The scanning head of claim 8 wherein at least one optical fibre is provided between the light source and the fibre output lens for transmitting light from the light source to the fibre output lens.

13. The scanning head of claim 8 wherein a beam splitter or directional coupler is provided for directing the light from the light source to the scanning means and for directing return light from the scanning means to the light detector.

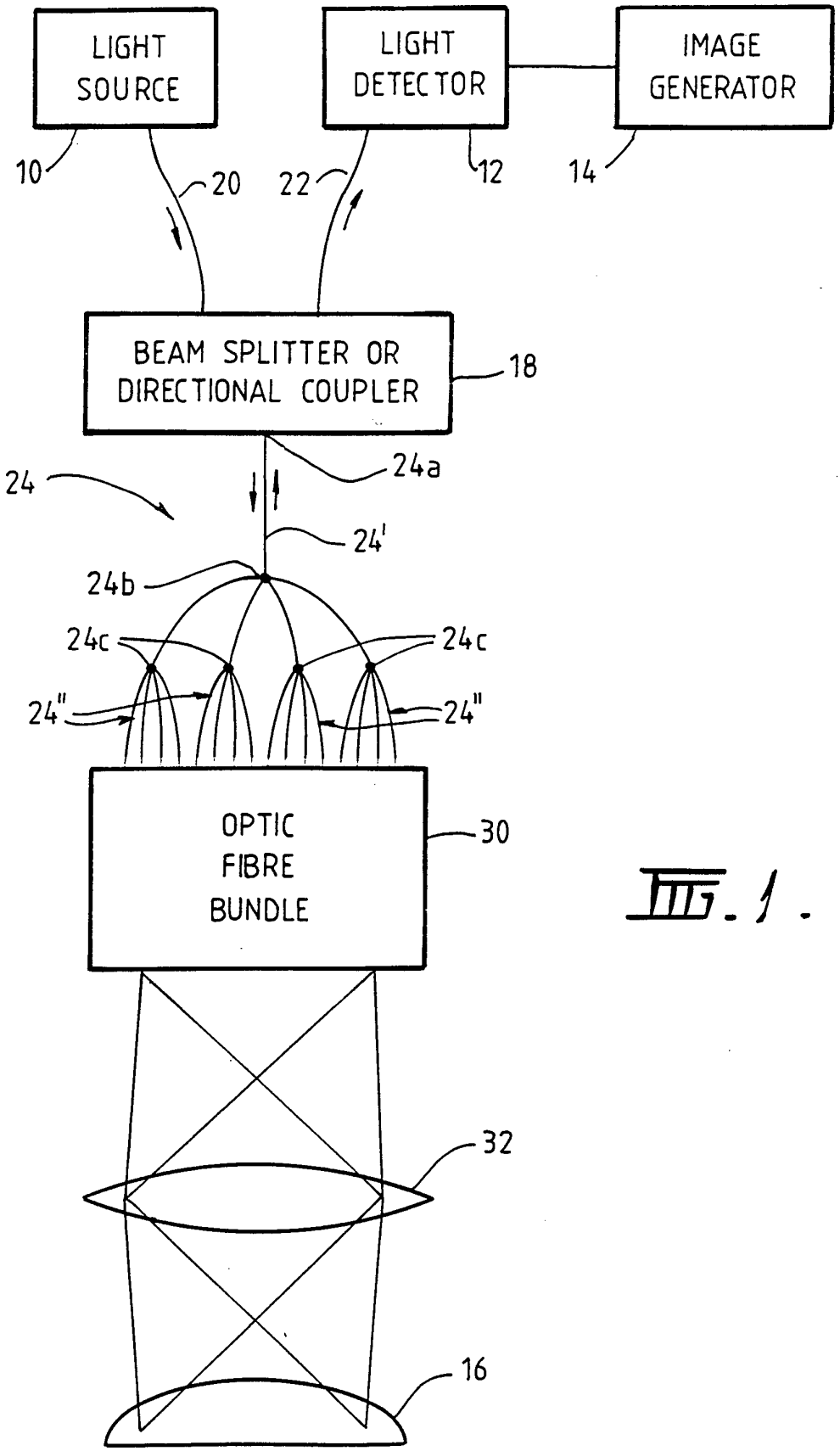
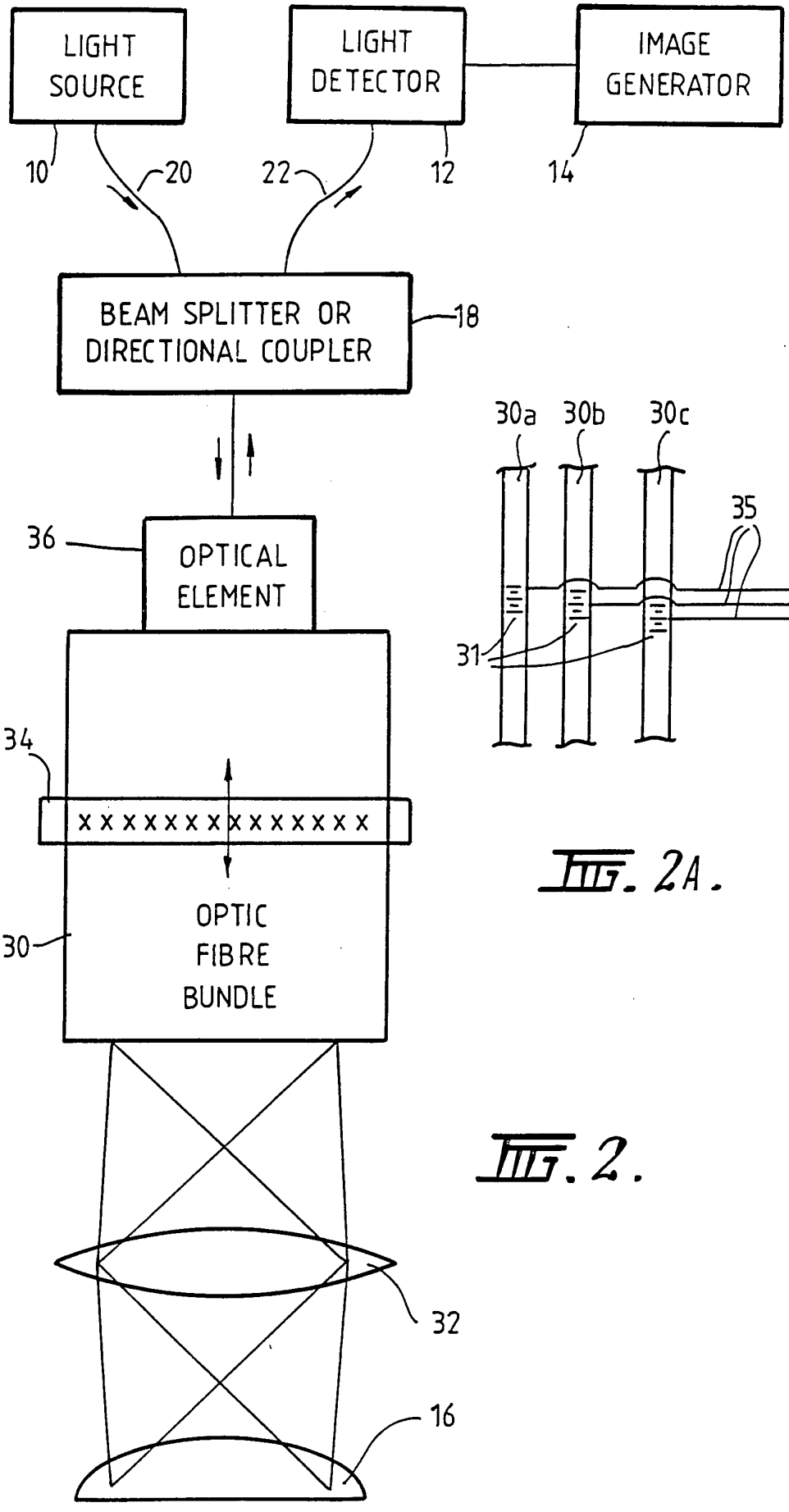

LIGHT SOURCE
LIGHT DETECTOR
IMAGE GENERATOR
10
20
22
12
14
BEAM SPLITTER OR DIRECTIONAL COUPLER
18
24
24a
24'
24b
24c
24c
24"
24"
OPTIC FIBRE BUNDLE
30
32
16

FIG. 1.


LIGHT SOURCE
LIGHT DETECTOR
IMAGE GENERATOR
10
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22
12
14
BEAM SPLITTER OR DIRECTIONAL COUPLER
18
36
OPTICAL ELEMENT
34
OPTIC FIBRE BUNDLE
30
32
16
30a
30b
30c
35
33
31

FIG. 2A.

FIG. 2.

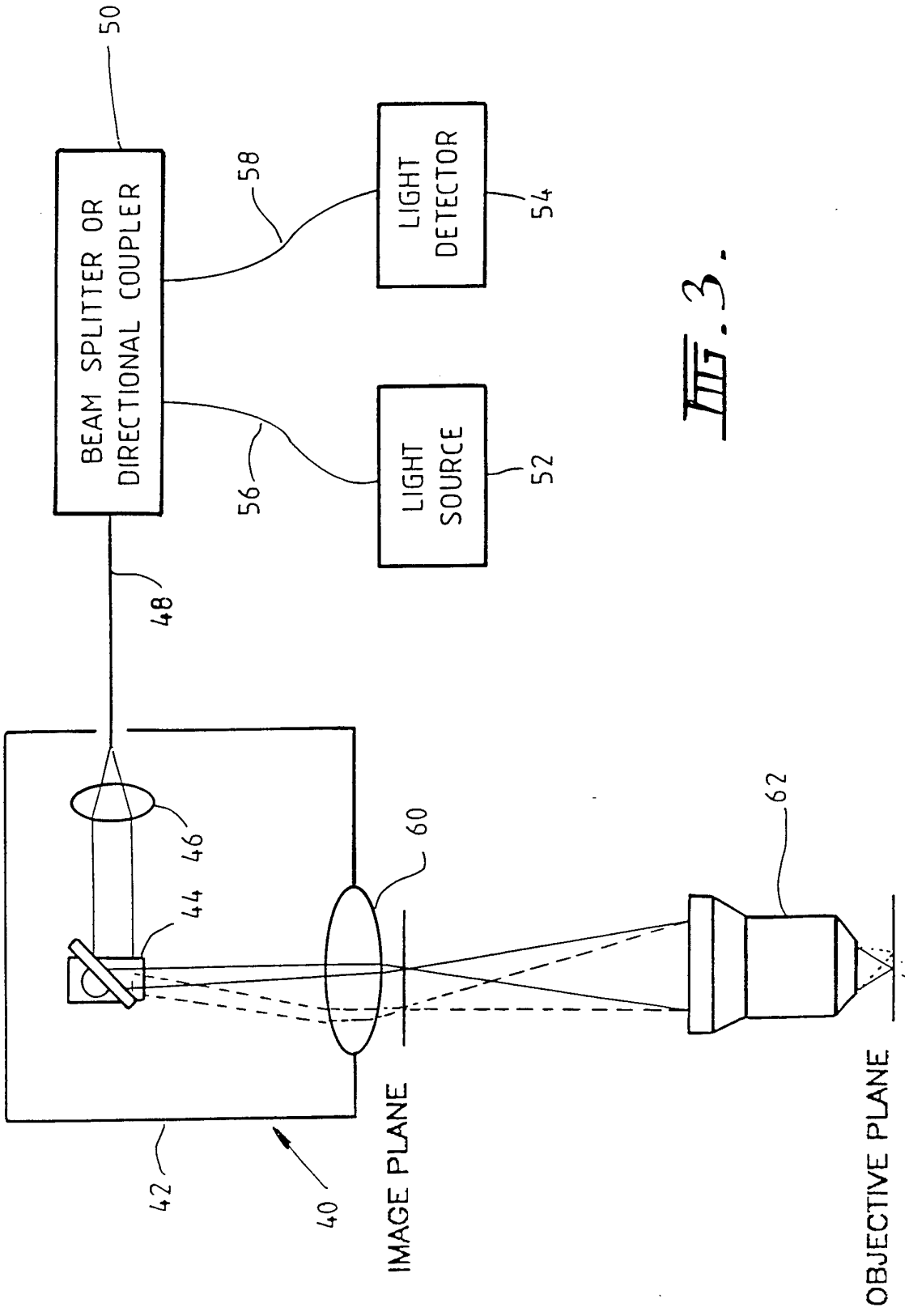
50
BEAM SPLITTER OR DIRECTIONAL COUPLER
58
LIGHT DETECTOR
54
56
LIGHT SOURCE
52
48
46
44
60
62
42
40
IMAGE PLANE
OBJECTIVE PLANE

FIG. 3.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 93/00534

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.[5] G02B 21/00, 21/02, 21/06, 21/18

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 G02B 21/00, 21/02, 21/06, 21/18

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

AU : IPC as above

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

DERWENT : CONFOCAL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	WO,A, 91/15792 (HARRIS) 17 October 1991 (17.10.91)	
A	WO,A, 90/00754 (HARRIS) 25 January 1990 (25.01.90)	
A	WO,A, 89/03057 (WASHINGTON UNIVERSITY) 6 April 1989 (06.04.89)	
A	NL,A, 9001202 (NV PHILIPS GLOWILAMPENFABRIEKEN) 16 December 1991 (16.12.91)	
A	EP,A, 418928 (FUJI PHOTO FILM KK) 27 March 1991 (27.03.91)	

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

[X] See patent family annex.

* Special categories of cited documents :

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"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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 January 1994 (25.01.94)	2 FEB 1994 (2.02.94)

Name and mailing address of the ISA/AU

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
A	EP,A, 283256 (TEKTRONIX INC) 21 September 1988 (21.09.88)	
A	US,A, 4410235 (KLEMENT et al) 18 October 1983 (18.10.83)	
A	DT,A, 2628543 (BBC AG BROWN) 8 December 1977 (08.12.77	

Box I **Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)**

This international search report has not established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II **Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. Claims 1-7

Confocal microscope with selectively switching selected fibres.

2. Claims 8-13

A scanning head with beam steering and objective lens.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically

claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: 1-7

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

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 Member					
WO	9115792	AU	76531/91	EP	523159		
WO	9000754	AU JP	39608/89 3087804	EP	393165	US	5120953
WO	8903057	AU US	25369/88 4884880	CA US	1302754 4884881	EP	339061
EP	418928	US JP	5081350 3235909	JP	4000409	JP	3168713
EP	283256	JP	63279548				
US	4410235	DE JP	2936463 56047004	FR	2465242	GB	2057709
							END OF ANNEX