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(54) Benævnelse: Single frequency thulium fibre laser

(57) Sammendrag:

The invention relates to an optical waveguide laser comprising an optical waveguide for propagating light along a longitudinal axis of the waveguide and adapted for receiving pump light for axial propagation therein, the optical waveguide laser comprising a resonator arrangement, the resonator arrangement comprising a) an active region formed over a length of the optical waveguide, the active region comprising an excitable material emitting light in response to stimulation by pump light thereby defining an optical gain profile and the excitable material comprises Tm; b) a frequency discriminating feedback element adapted to select a single longitudinal lasing mode by coordination with the frequency response of the optical gain of the excitable material; and c) a polarisation asymmetry element adapted for selecting a single polarisation mode of a given longitudinal mode by selectively suppressing propagation of the other polarisation mode of said longitudinal mode. The invention further relates to an article comprising an optical waveguide laser, its use and a method of manufacturing an optical waveguide laser. The object of the present invention is to provide relatively simple, compact and economic lasers for single-frequency operation in the wavelength range of 1.7 μm to 2.2 μm; in particular for a number of applications, including spectroscopy and for eye-safe optical sources in sensing and in LIDAR, etc.

fortsættes

70

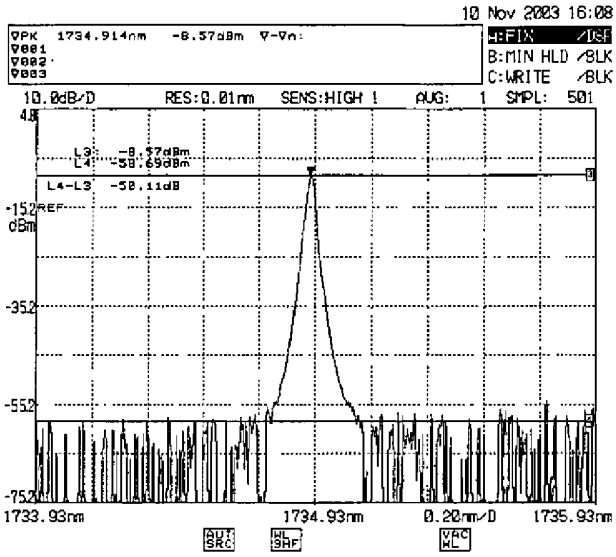
10 Nov 2003 16:08
PK 1734.914nm -8.57dBm V-Vn:
V001
V002
V003
B:MIN HLD /BLK
C:WRITE /BLK
10.0dB/D
RES:0.01nm
SENS:HIGH 1
AVG: 1
SMPL: 501
L3: -8.57dBm
L4: -58.69dBm
L4-L3 -50.11dB
REF
dBm
-15
-35
-55
-75
1733.93nm
1734.93nm
0.20nm/D
1735.93nm
AUTO SRC
WL SHF
VAC WL

FIG. 7

CLAIMS

1. An optical waveguide laser comprising an optical waveguide for propagating light along a longitudinal axis of the waveguide and adapted for receiving pump light for axial propagation therein, the optical waveguide laser comprising a resonator arrangement, the resonator arrangement comprising:

a) an active region formed over a length of the optical waveguide, the active region comprising an excitable material emitting light in response to stimulation by pump light thereby defining an optical gain profile; the excitable material comprises Tm;

b) a frequency discriminating feedback element adapted to select a single longitudinal lasing mode by coordination with the frequency response of the optical gain of the excitable material; and

c) a polarisation asymmetry element adapted for selecting a single polarisation mode of a given longitudinal mode by selectively suppressing propagation of the other polarisation mode of said longitudinal mode.

2. An optical waveguide laser according to claim 1, wherein thulium is present said active region of said optical waveguide in concentrations of above 500 ppm wt., such as above 900 ppm wt., such as above 2000 ppm wt.

3. An optical waveguide laser according to any of claims 1 or 2, wherein the length of the primary laser cavity is smaller than 10 cm, such as smaller than 5 cm, such as smaller than 2 cm, the primary laser cavity being spatially limited by said active region and said frequency discriminating element.

4. An optical waveguide laser according to any one of claims 1-3, wherein the optical waveguide is an optical fibre comprising a core region surrounded by a cladding region.

5. An optical waveguide laser according to claim 4, wherein the cladding region comprises first and second cladding regions.

6. An optical waveguide laser according to any one of claims 1-3, wherein the optical waveguide is a planar optical waveguide.

7. An optical waveguide laser according to any one of claims 4-6, wherein the core and/or cladding region(s) comprise silica.

8. An optical waveguide laser according to any one of claims 4-7, wherein said core and/or cladding regions comprise at least one refractive index modifying dopants, said dopants being selected among the group of elements consisting of boron (B), nitrogen (N), fluorine (F), aluminum (Al), phosphorus (P), titanium (Ti), germanium (Ge), and tin (Sn).

9. An optical waveguide laser according to any one of claims 4-8, wherein said core and/or cladding regions comprise at least one photosensitive dopants, said dopants being selected among the group of elements consisting of Ge, B, N, Sn.

10. An optical waveguide laser according to any one of claims 4-9, wherein said core and/or cladding regions further comprise at least one excitable materials, said excitable materials preferably being selected among the group of elements consisting of holmium (Ho), erbium (Er), ytterbium (Yb), samarium (Sm), neodymium (Nd) and praseodymium (Pr).

11. An optical waveguide laser according to any one of the preceding claims, wherein said pump light source is a semiconductor diode solid state laser or a semiconductor diode pumped fibre laser.

12. An optical waveguide laser according to any one of the preceding claims, wherein said polarisation asymmetry element is implemented by adapting said resonator arrangement to be birefringent.

13. An optical waveguide laser according to any one of claims 1-11, wherein said polarisation asymmetry element is implemented by adapting

said resonator arrangement to provide polarisation dependent optical feedback.

14. An optical waveguide laser according to any one of claims 1-11, wherein said polarisation asymmetry element is implemented by adapting said resonator arrangement – such as said optical waveguide - to provide polarisation dependent optical loss.

15. An optical waveguide laser according to any one of the preceding claims, wherein said frequency discriminating feedback element comprises a Bragg grating.

16. An optical waveguide laser according to claim 15, wherein said frequency discriminating feedback element is located in said active region of the optical waveguide in the form of a Bragg grating with an intermediate phase shift thereby implementing a DFB resonator arrangement.

17. An optical waveguide laser according to claim 15, wherein said frequency discriminating feedback element is implemented as two separated Bragg gratings, thereby implementing a DBR resonator arrangement.

18. An article comprising an optical waveguide laser according to any one of claims 1-17.

19. An article according to claim 18 comprising detector optics and electronics for signal processing, the article fully or partially forming a LIDAR system.

20. An article according to claim 18 comprising means for passage of laser light through a sample under investigation, detection optics and electronics for data reduction wherein, the article fully or partially forming a spectroscopic system.

21. An article according to claim 20 comprising means for passage of laser light through a gas, the spectroscopic system being adapted for trace gas detection.

22. Use of an optical waveguide laser according to any one of claims 1-17.

23. Use of an optical waveguide laser according to any one of claims 1-17 in an article according to any one of claims 18-21.

24. A method of manufacturing an optical waveguide laser, the method comprising:

1) providing an optical waveguide for propagating light along a longitudinal axis of the waveguide;

2) adapting said optical waveguide for receiving pump light from a pump light source for axial propagation therein;

3) providing a resonator arrangement in said optical waveguide laser, the step comprising the following sub-steps

3.1) forming an active region over a length of said optical waveguide by providing the active region with an excitable material emitting light in response to stimulation by pump light thereby defining a gain profile; the excitable material comprises Tm;

3.2) providing a frequency discriminating feedback element, the frequency discriminating feedback element being adapted to select a single longitudinal lasing mode by coordination with the frequency response of the gain of the excitable material; and

3.3) providing a polarisation asymmetry by adapting said resonator arrangement for selecting a single polarisation mode of a given longitudinal mode by selectively suppressing propagation of other polarisation modes of said longitudinal mode.

25. A method according to claim 24 wherein in step 3.1) Tm is present in said active region in concentrations of above 500 ppm wt., such as above 900 ppm wt., such as above 2000 ppm wt.

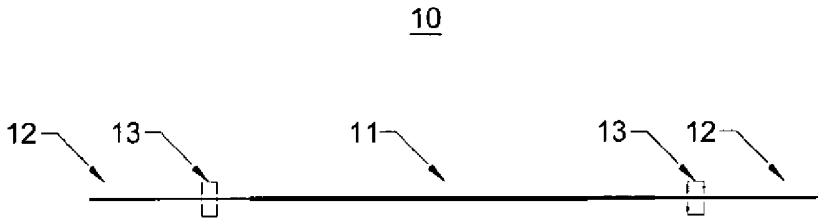
10
12
13
11
13
12

FIG. 1

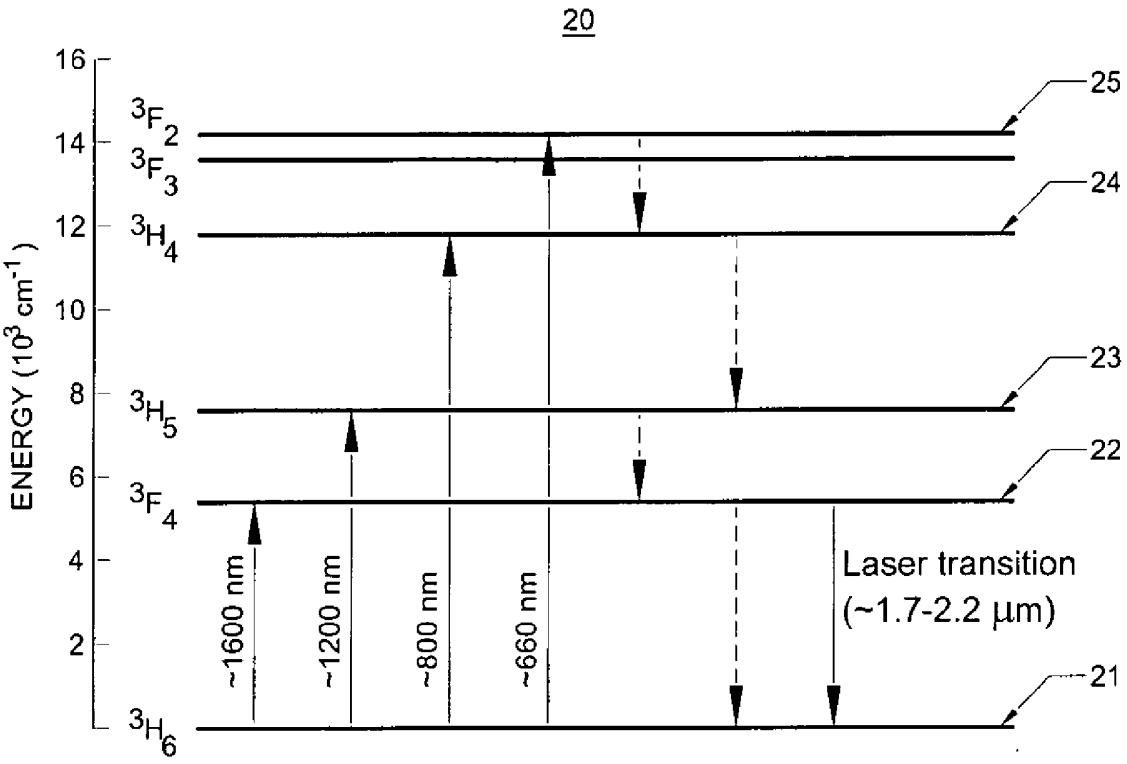
20
ENERGY (10^3 cm^{-1})
16
14
12
10
8
6
4
2
$^3F_2$
$^3F_3$
$^3H_4$
$^3H_5$
$^3F_4$
$^3H_6$
25
24
23
22
21
~1600 nm
~1200 nm
~800 nm
~660 nm
Laser transition
(~1.7-2.2 µm)

FIG. 2

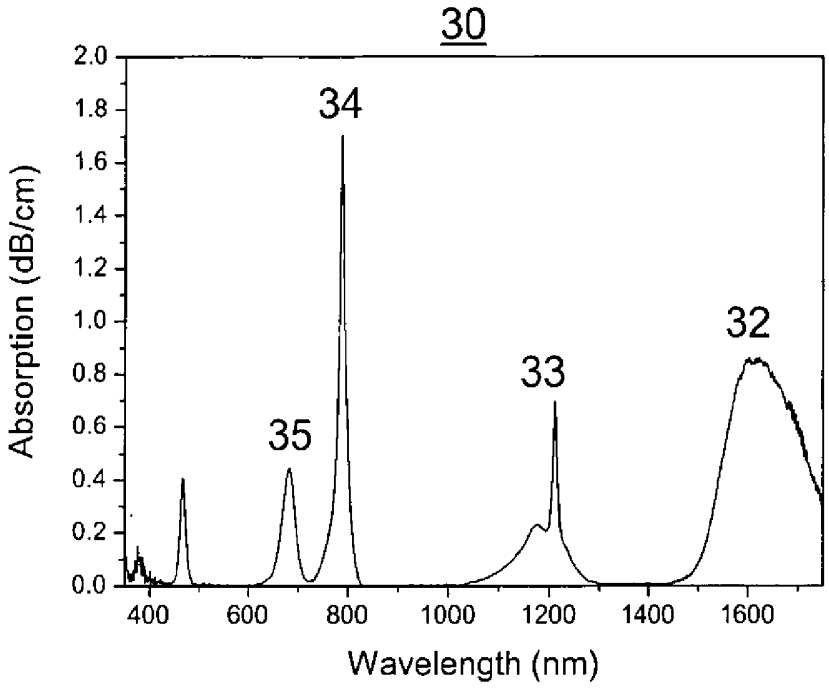
30
Absorption (dB/cm)
Wavelength (nm)
34
35
33
32
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
400
600
800
1000
1200
1400
1600

FIG. 3

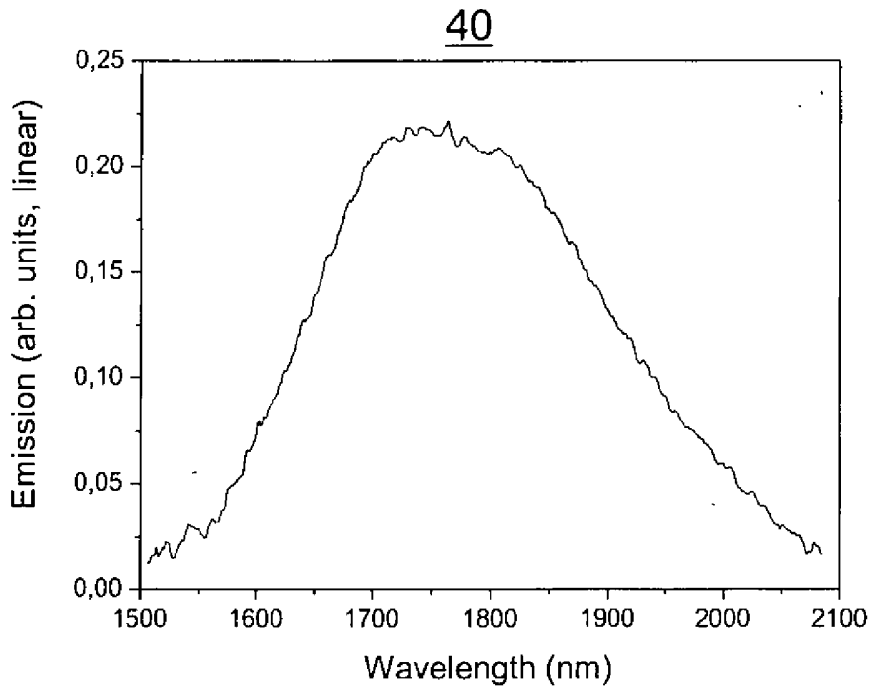
40
Emission (arb. units, linear)
Wavelength (nm)
0,25
0,20
0,15
0,10
0,05
0,00
1500
1600
1700
1800
1900
2000
2100

FIG. 4

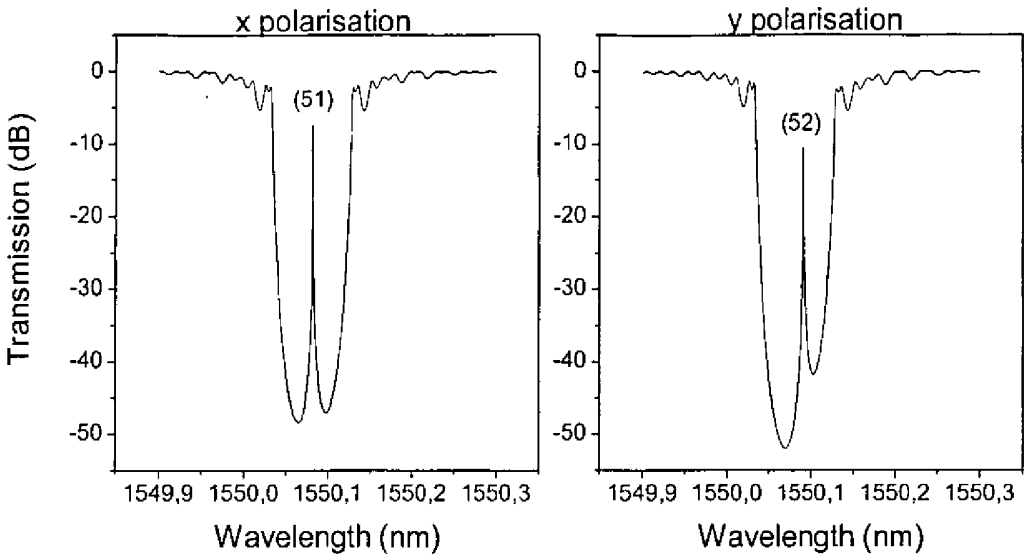
x polarisation
y polarisation
Transmission (dB)
0
-10
-20
-30
-40
-50
(51)
(52)
1549,9 1550,0 1550,1 1550,2 1550,3
Wavelength (nm)

FIG. 5

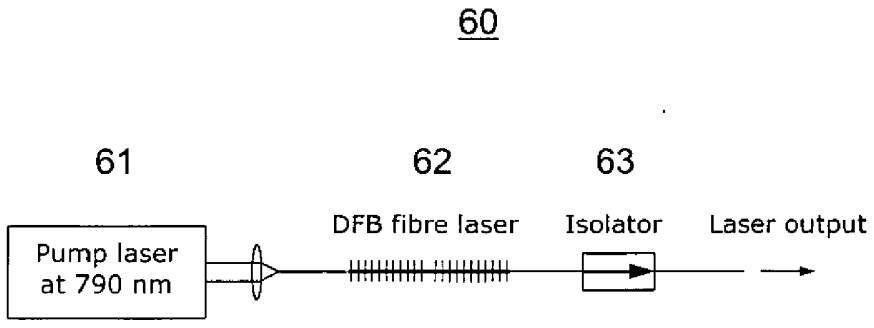
60
61
62
63
DFB fibre laser
Isolator
Laser output
Pump laser
at 790 nm

FIG. 6

70

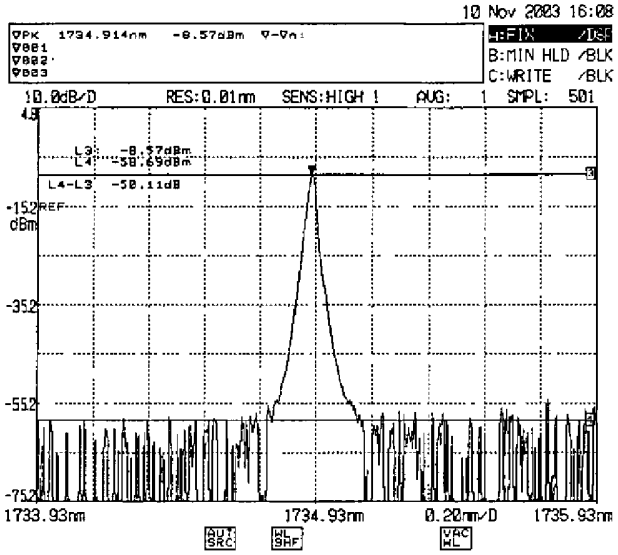

FIG. 7

80

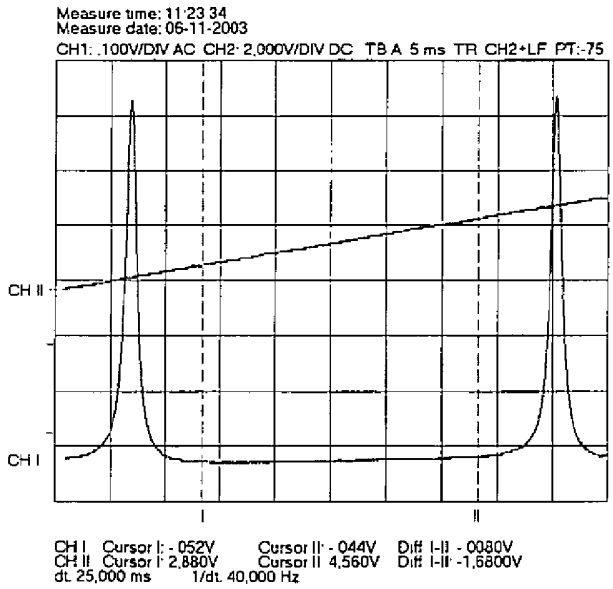

FIG. 8

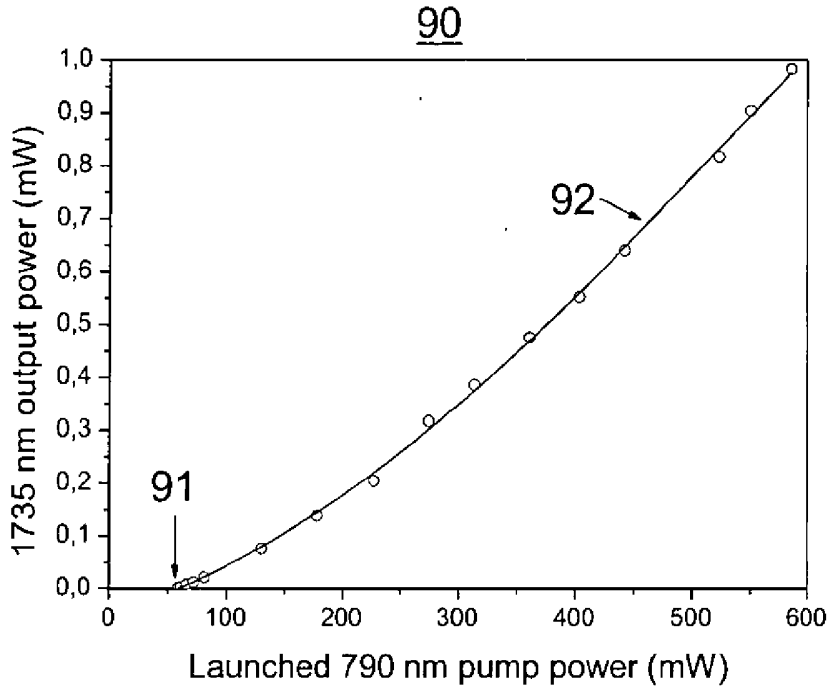
90
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
1735 nm output power (mW)
92
91
0
100
200
300
400
500
600
Launched 790 nm pump power (mW)

FIG. 9

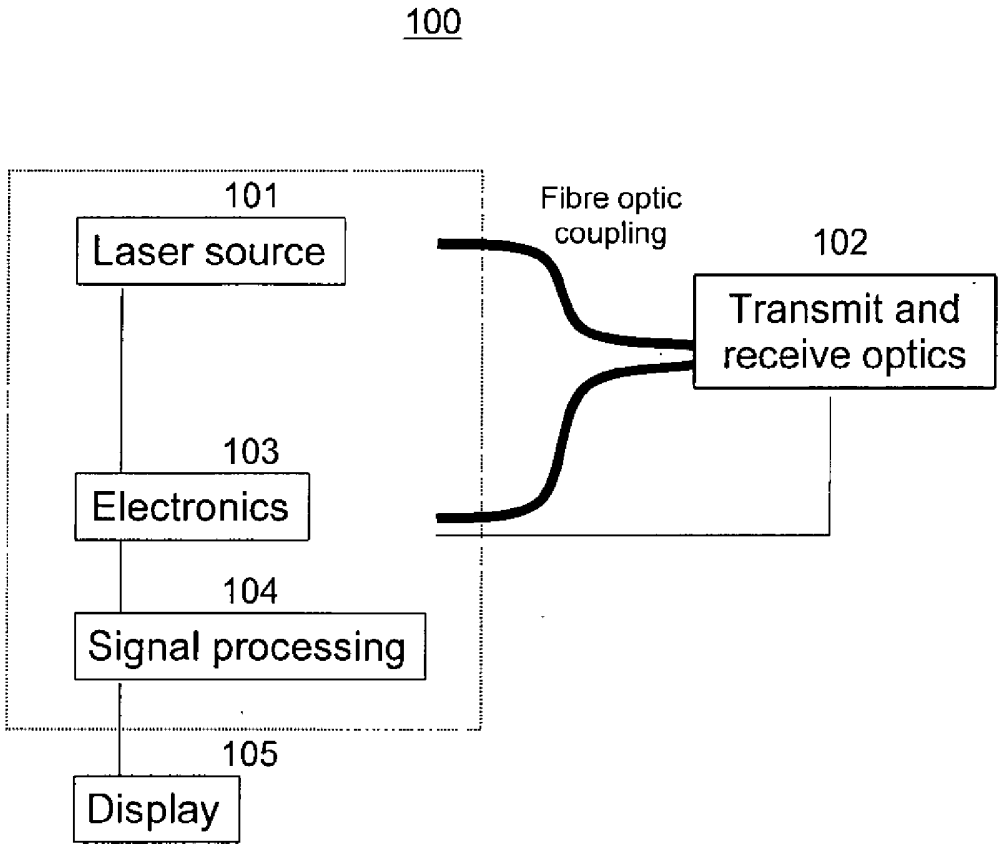
100
101
Laser source
Fibre optic coupling
102
Transmit and receive optics
103
Electronics
104
Signal processing
105
Display

FIG. 10

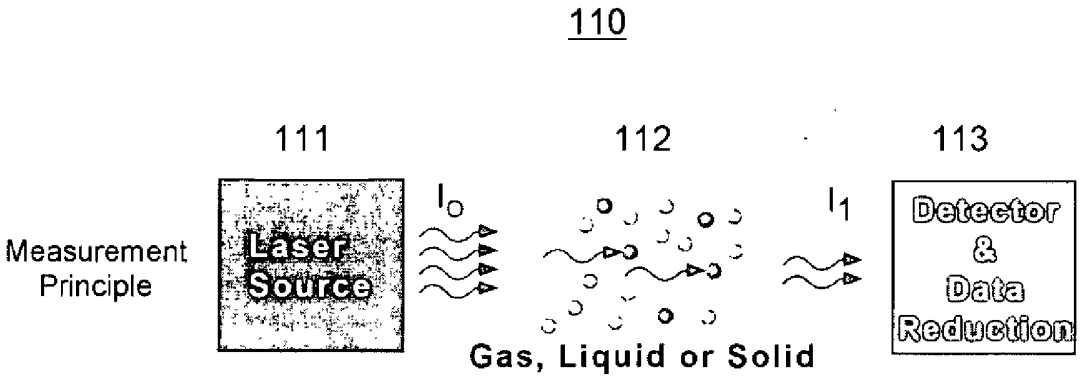
110
111
112
113
Measurement Principle
Laser Source
I_0
I_1
Detector & Data Reduction
Gas, Liquid or Solid

FIG. 11