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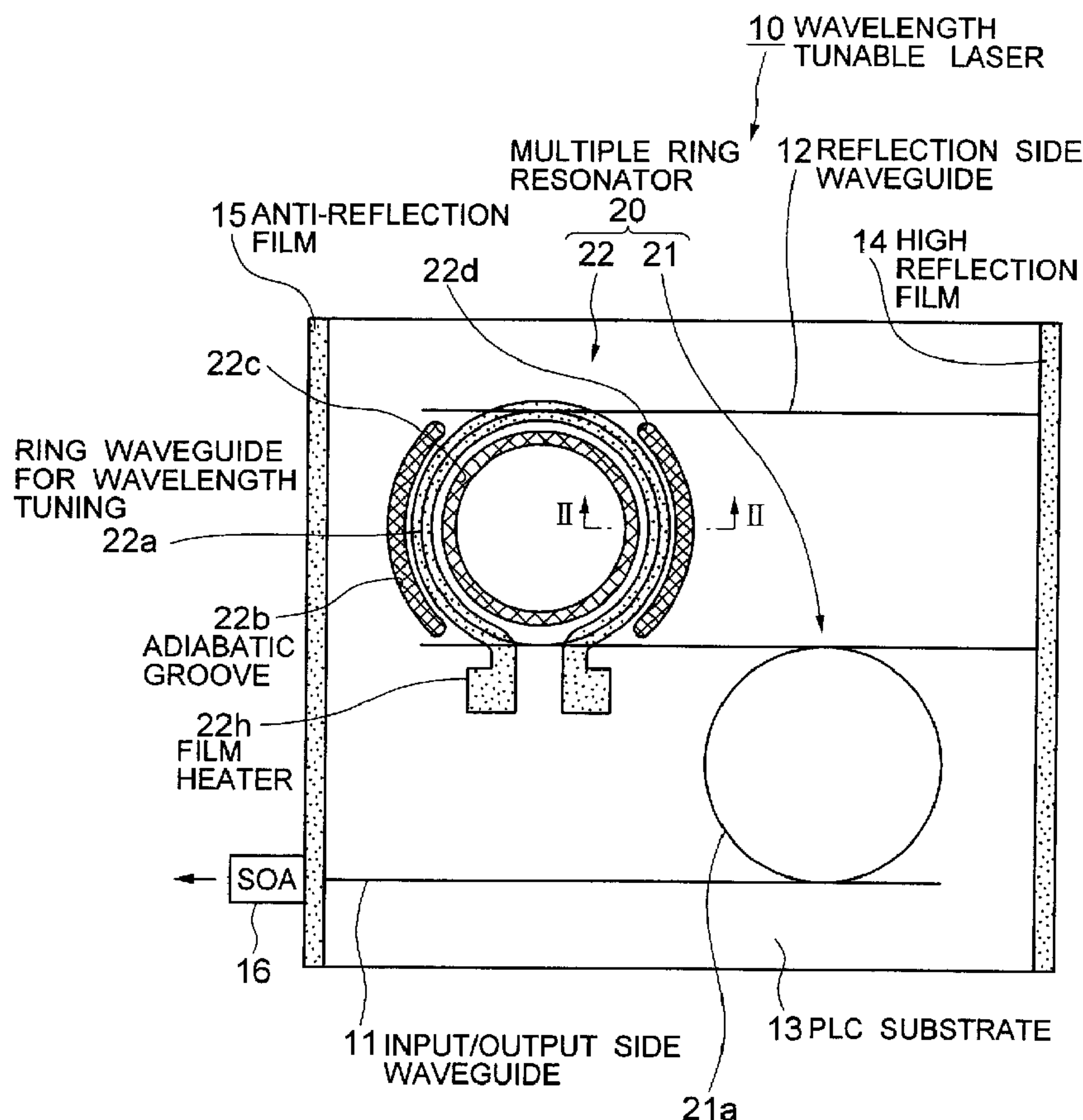
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(54) Titre : LASER ACCORDABLE EN LONGUEUR D'ONDE FAISANT APPEL A DES RESONATEURS EN ANNEAU
COMBINES MULTIPLES

(54) Title: WAVELENGTH TUNABLE LASER USING A PLURALITY OF COMBINED RING RESONATORS



(57) Abrégé/Abstract:

A wavelength tunable laser comprises a multiple ring resonator, an input/output side waveguide coupled to a ring resonator, a reflection side waveguide coupled to a ring resonator, a PLC substrate where the input/output side waveguide and the reflection

(57) **Abrégé(suite)/Abstract(continued):**

side waveguide are formed, a high reflection film set on the reflection side waveguide, a SOA connected to the input/output side waveguide through an anti-reflection film, a film heater which is placed above a ring waveguide for wavelength tuning in the PLC substrate and provides heat to the ring waveguide for wavelength tuning, and an adiabatic groove, which restrains conducting heat provided by the film heater to the PLC substrate except for the ring waveguide for wavelength tuning.

ABSTRACT

A wavelength tunable laser comprises a multiple ring resonator, an input/output side waveguide coupled to a ring resonator, a reflection side waveguide coupled to a ring resonator, a PLC substrate where the input/output side waveguide and the reflection side waveguide are formed, a high reflection film set on the reflection side waveguide, a SOA connected to the input/output side waveguide through an anti-reflection film, a film heater which is placed above a ring waveguide for wavelength tuning in the PLC substrate and provides heat to the ring waveguide for wavelength tuning, and an adiabatic groove, which restrains conducting heat provided by the film heater to the PLC substrate except for the ring waveguide for wavelength tuning.

WAVELENGTH TUNABLE LASER USING A PLURALITY OF
COMBINED RING RESONATORS

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a wavelength tunable laser with a wavelength monitor (hereinafter called merely "a wavelength tunable laser") in which the wavelength monitor detects the operating wavelength. The wavelength tunable laser is used for, for example, a WDM (Wavelength Division Multiplexing) transmission system.

2. Description of the Related Art

15 Embarking on a broadband era, the WDM transmission system which enables communication through a plurality of light wavelengths per system is increasingly introduced in order for an effective use of an optical fiber. Recently, a DWDM (Dense Wavelength Division Multiplexing) device has also been used
20 expensively which multiplexes several dozen of light wavelengths and enables them to be transmitted at a higher-speed. Accordingly, a light source corresponding to every light wavelength used is required by each WDM transmission system, and a number of light sources are increasingly required to
25 handle the high-multiplexing. A ROADM (Reconfigurable optical add/drop multiplexers) which adds/drops an optical wavelength at each node has also been examined recently for commercial use. If the ROADM system is introduced, a transmission

capacity can be expanded by multiplexing a wavelength and optical paths can be switched by tuning a wavelength, which leads to an optical network with high flexibility.

5 A DFB-LD (Distributed feedback laser diode) oscillates in a SLM (Single longitudinal mode) has been conventionally widely used as a light source for the WDM transmission system because it is easy to use and has a high reliability. The DFB-LD has a diffraction grating at about
10 30 nm in depth formed in the whole area thereof, so that a SLM oscillation is stably obtained at a wavelength corresponding to a product of a grating cycle times twice an equivalent refractive index. However, because the DFB-LD is unable to tune oscillating wavelengths in a wide range, a WDM
15 transmission system needs devices with wavelengths at every ITU (international telecommunication unit) grid. Therefore, the cost of a shelf control and excess stock to repair has been increased because different devices are required by each wavelength. Moreover, if a normal DFB-LD is used in the ROADM
20 which switches optical paths according to a wavelength, a tunable range of a wavelength window is limited to about 3 nm which can be varied by temperature change. Thus, it is difficult to configure an optical network fully leveraging the feature of ROADM which efficiently utilizes wavelength
25 resources.

In order to overcome the problem with the present DFB-LD and to achieve SLM oscillation in a wide wavelength range, intense study is now under way for a wide range wavelength

tunable laser. In the following, a conventional wavelength tunable laser is explained showing some examples from a non-patent literature 1.

The wavelength tunable lasers are classified in two
5 types, one has a wavelength tunable mechanism inside of its laser device and the other has a wavelength tunable mechanism outside of its laser device.

As for the former type, a DBR-LD (Distributed Bragg Reflector Laser Diode) is proposed where an active region to
10 generate a gain and a DBR region to reflect light with a diffraction grating are formed in the same laser device. A wavelength tunable range of this DBR-LD is about 10 nm at the widest. A DBR-LD using an uneven pattern of diffraction
15 grating is also proposed as the former type where an active region to generate a gain and DBR regions placed in front and in backside of the active region are formed in the same laser device. A number of reflection peaks are generated in the DBR regions in front and in backside of the active region
20 by the uneven pattern of diffraction grating, and intervals of reflection peaks in the front DBR region is slightly different from intervals of reflection peaks in the backside DBR regions. The "Vernier effect" can be obtained by this structure, which enables the tuning of a wavelength over a very wide range. The DBR-LD using the uneven pattern of
25 diffraction grating can be operated to tune over a wavelength range of 100 nm or more and to tune quasi-continuously a

wavelength range of 40 nm.

On the other hand, a wavelength tunable laser proposed as the latter type which returns a specific wavelength into a laser device by tuning over a diffraction
5 grating. This type of wavelength tunable laser requires monitoring an oscillating wavelength gradually.

Conventionally, a wavelength selective component such as an Etalon is installed in the module to monitor an oscillating wavelength.

10 [Non-Patent Literature 1] "Optical Integrated Devices" by Kohroh Kobayashi, pp104-122, the second impression of the first edition, published by Kyoritsu Shuppan Co., Ltd., December 2000

Many other types of configurations are proposed as the
15 conventional wavelength tunable lasers, however, they have disadvantages such as a mode hopping occurrence, a complicated method for wavelength control, low vibration resistance and high price due to an enlarged device. Therefore, it has been difficult for those lasers to be put
20 into practical use.

As for the DBR-LD, a wavelength can be tuned by injecting carriers into the DBR region so as to vary a refractive index of the wavelength at the DBR region.

However, current injection causes a formation of a crystal
25 defect, which changes a rate of refractive index fluctuation to current injection extremely. Accordingly, it is difficult

to keep laser oscillation at a certain wavelength over a long term. Moreover, because a compound semiconductor cannot be processed in and bigger than 2-inch size with the current technology, a laser device becomes enlarged and complex, so
5 the current cost is difficult to be reduced.

On the other hand, as for the configuration where a wavelength tunable mechanism is set outside of a laser device, mode jumping occurs easily due to oscillation, so a large mechanism with vibration resistance is required to avoid it.
10 Accordingly, the module size becomes enlarged and the price increases.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to
15 overcome the problems with conventional wavelength tunable lasers for practical use and to provide a wavelength tunable laser which achieves high reliability, high performance, low cost, low power consumption and stable operation.

20 A wavelength tunable laser relating to the present invention comprises a multiple ring resonator wherein a plurality of ring resonators are combined with each other by an optical coupling unit, and ring waveguides for wavelength tuning and wavelength fixing included by the ring resonators
25 have different optical path lengths from each other. The wavelength tunable laser further comprises an input/output

side waveguide whose end is coupled to one of the plurality of ring resonators by an optical coupling unit, a reflection side waveguide whose end is coupled to another ring resonator of the plurality of the ring resonators by an optical
5 coupling unit, a substrate on which the multiple ring resonator, the input/output side waveguide and the reflection side waveguide are formed, a light reflection unit set at a remaining end of the reflection side waveguide, a light input/output unit connected at the light input/output
10 terminal to a remaining end of the input/output side waveguide, a heat supply unit placed on the surface of the substrate which is just above the ring waveguide for wavelength tuning for supplying the heat to the ring waveguide for wavelength tuning, and a thermal conduction
15 restrain unit restraining conducting heat provided by the heat supply unit to the substrate except the ring waveguide for wavelength tuning.

Light outputted from the light input/output unit goes through the light input/output terminal, the input/output
20 side waveguide, the optical coupling unit, the multiple ring resonator, the optical coupling unit, the reflection side waveguide, the light reflection unit, the reflection side waveguide, the optical coupling unit, the multiple ring resonator, the optical coupling unit, the input/output side
25 waveguide and returns to the light input/output terminal. This return light is the strongest at a resonant wavelength

of the multiple ring resonator. The reason is that each ring resonator which comprises the multiple ring resonator has a slightly different FSR (Free spectral range) and that greater reflection occurs at a wavelength where periodical variations
5 of reflection (transmission) at each ring resonator are matched (resonant wavelength).

Also, a wavelength where respective cycles are matched varies greatly according to variation of a circumference length and a refractive index of the waveguide of
10 each ring resonator, so tunable operation for a wavelength can be made efficient.

The refractive index of the waveguide can be changed by a thermo-optical effect. The thermo-optical effect is a phenomenon where the refractive index of a material is increased by
15 heat, which can occur commonly in any material. Accordingly, the resonant wavelength of the multiple ring resonator can be tuned by utilizing temperature characteristics of a plurality of ring resonators, in other words, the resonant wavelength of the multiple ring resonator can be tuned by providing heat
20 from the heat supply unit to the ring waveguide for wavelength tuning. As described, in the present invention, the multiple ring resonator is configured by connecting serially a plurality of ring resonators which have slightly different circumferences respectively, and the vernier effect that occurs
25 thereby is skillfully utilized.

In this case, the thermal conduction restrain unit

restrains conducting heat provided by the heat supply unit to the substrate except for the ring waveguide for wavelength tuning. Consequently heat provided by the heat supply unit is conducted to the ring waveguide for wavelength tuning without
5 loss, and low power consumption and a fast response can be achieved.

The substrate is such as a PLC substrate. The light input/output unit is such as a semiconductor optical amplifier (hereinafter called "SOA"), an optical fiber
10 amplifier, a semiconductor laser. The heat supply unit is such as a heat application unit providing positive heat, a cooling unit providing negative heat and heat application/cooling unit providing both positive and negative heat (for example, Peltier device). More specifically, it
15 may be a film heater set on a substrate. The film heater is easily manufactured by forming such as a metallic film on a substrate. Additionally, a temperature adjustment unit may be comprised further to keep a certain temperature on a substrate in order to have a FSR of a ring resonator for
20 waveguide fixing matched with an ITU grid.

The thermal conduction restrain unit may be an adiabatic groove formed in a peripheral area of a ring waveguide for wavelength tuning in a substrate. This adiabatic groove may be formed from the surface of a
25 substrate through to the underneath of a ring waveguide for wavelength tuning back to the surface of the substrate. In

this case, thermal conduction is restrained from underneath of a ring waveguide for wavelength tuning to a substrate, which increases the adiabatic effect more. Note that, the adiabatic groove may be a cavity, or alternatively, a
5 material filled in a substrate which has higher thermal resistance than the substrate.

According to the present invention, a wavelength tunable laser where a multiple ring resonator and a light input/output unit are combined offers the following
10 advantages. A ring resonator for wavelength fixing does not have an adiabatic structure therein so as to keep a low thermal resistance condition, and achieves stable operation thereof in variation of ambient temperature. On the other hand, a ring resonator for wavelength tuning with a heat
15 supply unit attached thereto has an adiabatic groove nearby so that thermal resistance thereof increases and power consumption is reduced. As described, thermal resistances are arranged at each ring resonator formed in a substrate in accordance with purposes of the ring resonators so that low
20 power consumption and stable operation can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view showing a wavelength tunable laser relating to a first embodiment of the present invention.

25 FIG. 2 is a cross-sectional view of the wavelength tunable laser in FIG. 1 along with the line II - II, FIG. 2A

shows a first example, and FIG. 2B shows a second example.

FIG. 3 is a plan view showing a wavelength tunable laser relating to a second embodiment of the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

In the following, embodiments of the present invention will be described in detail by referencing the attached drawings.

10

(First embodiment)

As shown in FIG. 1, a wavelength tunable laser 10 of the present embodiment comprises a multiple ring resonator 20, an input/output side waveguide 11, a reflection side waveguide 12, a high reflection film 14, a light input/output unit 16, a film heater 22h and adiabatic grooves 22b, 22c and 22d.

The multiple ring resonator 20 comprises two ring resonators 21 and 22 combined. A ring resonator 21 has a ring waveguide 21a, and the other ring resonator, a resonator 22 has a ring waveguide 22a. The ring waveguides 21a and 22a are coupled by a directional coupler and a waveguide (hereinafter both numerals are omitted). Here, the two ring resonators 21 and 22 are serially connected in the multiple ring resonator 20 relating to the embodiments for the present invention.

The input/output side waveguide 11 is coupled to the ring waveguide 21a of the ring resonator 21 through a directional coupler. Also, the reflection side waveguide 12 is coupled to the ring waveguide 22a of the ring resonator 22 through a directional coupler. The high reflection film 14 is set at the end of the reflection side waveguide and has a function to reflect light signal, which is outputted from the multiple ring resonator 20 to the reflection side waveguide 12, to the reflection side waveguide 12 side. The SOA 16 is connected at its input/output terminal to the input/output side waveguide 11 through an anti-reflection film 15.

The multiple ring resonator 20, the input/output side waveguide 11 and the reflection side waveguide 12 are formed in the PLC substrate 13.

The film heater 22h surrounding the ring waveguide 22a is formed on the PLC substrate 13 and provides heat to the ring waveguide 22a. The adiabatic grooves 22b and 22d covering the film heater 22h at the peripheral side are formed in the PLC substrate 13 and the adiabatic groove 22c covering the film heater 22h at the inner peripheral side are formed in the PLC substrate 13. Those adiabatic grooves 22b, 22c and 22d prevent heat provided by the film heater 22h from acting on other component parts in the PLC substrate 13. Especially, the adiabatic grooves 22b, 22c and 22d prevent heat provided by the film heater 22h from varying optical path length, that is a circumferential length, and a

refractive index of the ring waveguide 21a in the ring resonator 21.

Optical path lengths of the ring waveguide 21a for fixing a wavelength and the ring waveguide 22a for tuning a wavelength are set in different lengths of each other. The film heater 22h is made of such as aluminum film and created into a circular shape along with the ring waveguide 22a for wavelength tuning. Both sides of the circular shape are conducting electrodes. Because optical path lengths of the ring waveguides 21a and 22a are set in different, the multiple ring resonator 20 in which the ring resonators 21 and 22 are combined is to resonate at a wavelength where frequencies of the ring resonators 21 and 22 with different cycles from each other are crossed. Also, a resonant wavelength of the multiple ring resonator 20 can be tuned according to circumferential lengths and refractive index fluctuations of the ring waveguides 21a and 22a. So, in the present embodiment, the resonant wavelength of the multiple ring resonator 20 is tuned by the circumferential lengths and refraction indexes of the ring waveguide 21a and 22a varied by heat provided from the film heater 22h.

As the light input/output unit 16, a semiconductor optical amplifier, SOA, is used. Alternatively, an optical fiber amplifier may be used. Here the PLC substrate 13 may be set on a Peltier device as a temperature control device. This Peltier device keeps a certain temperature of the PLC

substrate 13 in order that a FSR of the ring resonator 21 is matched with an ITU grid.

According to the present embodiment of the present invention shown in FIG. 1, light outputted from the SOA 16 goes through the light input/output terminal, the light input/output side waveguide 11, the directional coupler, the multiple ring resonator 20, the directional coupler, the reflection side waveguide 12 and reaches the high reflection film 14, and is reflected by the high reflection film 14 and is returned through the reflection side waveguide 12, the directional coupler, the multiple ring resonator 20, the directional coupler, the input/output side waveguide 11 to the light input/output terminal.

The return light becomes the strongest at a wavelength where the multiple ring resonator 20 resonates. The reason is that each ring resonator 21 and 22 configuring the multiple ring resonator 20 has slightly different FSRs respectively and reflection occurs in larger scale at a wavelength where periodical changes of reflections (transmission) occurring at each ring resonator 21 and 22 are matched (a resonant wavelength).

Additionally, because the resonant wavelength of the multiple ring resonator 20 varies greatly according to variation of the circumferential lengths and the refractive indexes of the waveguides in each ring resonator 21 and 22, tuning operation for a wavelength can be efficient at the

multiple ring resonator 20 based on heat supply from the film heater 22h. The refractive index of the waveguide can be varied by thermo-optic effect. That is, the film heater 22h provides heat to the ring waveguide 22a for wavelength tuning so that
5 a plurality of the ring resonators 21 and 22 can utilize temperature characteristics, and a resonant wavelength of the multiple ring resonator 20 can be tuned. Thus, the multiple resonator 20 is configured with connecting serially the ring resonators 21 and 22 where both circumferences are slightly
10 different from each other, which causes the vernier effect that is utilized skillfully in the present embodiment.

At this point, adiabatic grooves 22b, 22c and 22d restrain the conducting heat from the film heater 22h to the PLC substrate 13 except for the ring waveguide 22a for
15 wavelength tuning. Consequently, heat provided by the film heater 22h is conducted to the ring waveguide 22a for wavelength tuning without any loss of heat, and low power consumption and fast response can be achieved.

The adiabatic grooves 22b, 22c and 22d are
20 illustrated in FIG. 2A and FIG. 2B. As shown in FIG. 2A, the adiabatic grooves 22b, 22c and 22d are preferably deeper than the ring waveguide 22a for wavelength tuning so as to reinforce adiabatic efficiency. The adiabatic grooves 22b and 22d is positioned outside of the ring waveguide 22a for
25 wavelength tuning, and formed in a circular arch shape along with the ring waveguide 22a for wavelength tuning. The

adiabatic groove 22c is positioned inside of the ring waveguide 22a for wavelength tuning, and formed in circular shape along with the ring waveguide 22a for wavelength tuning.

The PLC substrate 13 is formed on a silicon substrate 31 with a cladding layer 32 including a core layer 33. The core layer 33 inside of the cladding layer 32 is corresponding to the ring waveguide 21a of the ring resonator 21. The ring waveguide 22a of the ring resonator 22 is structured as a core layer laid within a cladding layer, as well as the ring waveguide 21a. As for the ring waveguide 22a, the adiabatic grooves 22b, 22c and 22d prevent heat therefrom.

Next, a method for forming the adiabatic grooves 22b, 22c and 22d is explained. First, the cladding layer 32 having the core layer 33 is created on the silicon substrate 31 with a common method for PLC manufacturing. Then, the adiabatic grooves 22b, 22c and 22d are obtained by etching the cladding layer 32.

As for a structure of the adiabatic grooves shown in FIG. 2B, the adiabatic groove 22e is formed under the ring waveguide 22a for waveguide tuning. That is, the adiabatic grooves 22b, 22c, 22d and 22e are formed from the surface of the PLC substrate 13 through the underneath of the ring waveguide for waveguide tuning 22a and to the surface of the PLC substrate 13. In this case, because heat conduction is restrained from the underneath of the ring waveguide for

wavelength tuning 22a to the PLC substrate 13, adiabatic effect is increased.

Next, a method for forming the adiabatic groove 22e is explained. First, a sacrificial layer which is made of another material is created on the silicon substrate 31, and a
5 cladding layer 32 having a core layer 33 is formed thereon. Subsequently, the cladding layer 32 is etched to create the adiabatic grooves 22b, 22c and 22d. Finally, the adiabatic groove 22e is obtained by etching only the sacrificial layer.

10 The wavelength tunable laser 10 described in details above will be explained further.

In the wavelength tunable laser 10 relates to the embodiments of the present invention, periodical variation of reflecting (transmitting) an optical signal by the ring
15 resonator 21 is conformed to a regular cycle of an ITU grid so that a wavelength is fixed by using the ring resonator 21. The periodical variation of reflecting (transmitting) an optical signal by the ring resonator 21 used for fixing a wavelength adjusts temperature over the whole PLC substrate
20 13. More specifically, the whole PLC substrate 13 is kept at a certain temperature so as to restrain variation of a circumferential length and a refractive index of the ring waveguide 21a and to fix an optical path length of the ring waveguide 21a, which conforms the periodical variation of
25 reflecting (transmitting) an optical signal performed by the ring resonator 21 to the regular cycle (wavelength) of the

ITU grid.

So the ring resonator 21 for wavelength fixing does not need a heater for adjusting a phase and a wavelength is to be unvarying therein even if outside temperature varies.

5 The ring resonator 22 for wavelength tunable operation requires a thermal phase shifter with low power consumption, that is, the film heater 22h. As described, the wavelength tunable laser 10 needs to comprise the ring resonators 21 and 22 which have different characteristics from each other.

10 In other words, it is preferable that the wavelength tunable laser 10 employs respectively the ring resonator 21 for wavelength fixing with low thermal resistance where the refractive index does not easily vary with changing outside temperature and the ring resonator 22 for wavelength tuning
15 with high thermal resistance to reduce power consumption.

The adiabatic grooves 22b, 22c and 22d formed in the peripheral area of the ring waveguide 22a for wavelength tuning are efficient for having different thermal resistances on the same surface of the PLC substrate 13. Additionally, the
20 bridge structure with the adiabatic groove 22e where the ring waveguide 22a for wavelength tuning is floated is also efficient.

End faces of the PLC substrate 13 are coated with the anti-reflection film 15 and the high reflection film 14, and
25 the SOA 16 is connected to the the anti-reflection film 15 side. The SOA may be connected to the PLC substrate 13

indirectly placing a lens therebetween, or may be implemented directly on the PLC substrate 13 with an implementing method such as passive alignment, other than the direct connection shown in the drawings. The multiple ring resonator 20 is
5 configured in two stages. The adiabatic grooves 22b, 22c and 22d are formed in the peripheral area of the ring waveguide 22a for wavelength tuning, and they collect heat generated by the film heater 22h efficiently. Because thermal resistance is increased by the adiabatic grooves 22b, 22c and 22d, power
10 consumption of the thermal phase shifter can be reduced. An adiabatic groove is not formed in the peripheral area of the ring waveguide 21a for wavelength fixing, so thermal resistance is low and temperature of the silicon substrate 30 can be easily conducted to the ring waveguide for wavelength
15 fixing 21a. In addition, even if ambient temperature outside of the package changes, temperature is not easily varied in the ring waveguide 21a for wavelength fixing with low thermal resistance, and stable operation can be expected.

The example shown in FIG. 2B is about the structure
20 of the peripheral area of the ring waveguide 22a for wavelength tuning which is floated. It can increase a thermal resistance more than the example shown in FIG. 2A, so power consumption can be reduced further. Also, because an adiabatic structure is not installed in the peripheral area
25 of the ring waveguide 21a for wavelength fixing as well as the example of FIG. 2A, a wavelength does not vary a lot

according to ambient temperature and stable operation can be expected.

As described in the above, according to the present embodiment, stable operation is achieved, even in varying ambient temperature, with the wavelength tunable laser 10 combined the multiple ring resonator 20 and SOA 16 where the ring waveguide 21a for wavelength fixing does not have an adiabatic structure thereby so as to keep a low thermal resistance condition. On the other hand, the ring waveguide 10 22a for wavelength tuning with the film heater 22h attached thereto has the adiabatic grooves 22b, 22c and 22d formed nearby so as to increase thermal resistance and to reduce power consumption. Thus, the ring resonators 21 and 22 formed in the PLC substrate 13 have different thermal resistances each 15 other in accordance with those purposes so that low power consumption and stable operation can be achieved.

(Second embodiment)

The first embodiment shown in FIG. 1 described a ring resonator for wavelength tuning which is used in one stage, 20 however, the present invention is not limited in the case above and can be applied in the structure where ring resonators for wavelength tuning are installed in a plurality of stages. This will be explained in the followings as a 25 second embodiment.

A wavelength tunable laser 40 according to the

present embodiment comprises, as shown in FIG. 3, a multiple ring resonator 41, an input/output side waveguide 11, a reflection side waveguide 12, a high reflection film 14, a SOA (semiconductor optical amplifier) 16, a film heaters 22h and 23h, adiabatic grooves 22b, 22c, 22d, 23b, 23c and 23d.

The multiple ring resonator 41 is configured by three ring resonators 21, 22 and 23 and are combined. One ring resonator, the ring resonator 21, has a ring waveguide 21a and the other ring resonators, the ring resonators 22 and 23 have ring waveguides 22a and 23a. The ring waveguides 21a and 22a, 22a and 23a are coupled each other through directional couplers and waveguides (hereinafter both numerals are omitted). Here, the multiple ring resonators 41 relating to this embodiment of the present invention is configured by three ring resonators 21, 22 and 23 are serially connected.

The input/output side waveguide 11 is coupled to a ring waveguide 21a of the ring resonator 21 through a directional coupler. Also, the reflection side waveguide 12 is coupled to a ring waveguide 23a of the ring resonator 23 through a directional coupler. The high reflection film 14 is set at the end of the reflection side waveguide 12 and has a function to reflect a light signal, which is outputted from the multiple ring resonator 41 to the reflection side waveguide 12, to the reflection side waveguide 12 side. The SOA 16 is connected to the input/output side waveguide 11 at

its input/output terminal (a numeral is omitted) through an anti-reflection film 15.

The multiple ring resonator 41, the input/output side waveguide 11 and the reflection side waveguide 12 are created
5 in the PLC substrate 13.

The film heaters 22h and 23h are formed on the PLC substrate 13 surrounding the ring waveguides 22a and 23a respectively and provide heat to the ring waveguides 22a and 23a. The adiabatic grooves 22b, 22d, 23b and 23d are formed
10 on the PLC substrate 13 covering the film heaters 22h and 23h at the peripheral side, and the adiabatic grooves 22c and 23c are formed on the PLC substrate 13 covering the film heaters 22h and 23h at the inner peripheral side. Those adiabatic grooves 22b, 22c, 22d, 23b, 23c and 23d prevent heat provided
15 by the film heaters 22h and 23h from influencing other component parts in the PLC substrate 13. Especially, these adiabatic grooves 22b, 22c, 22d, 23b, 23c and 23d prevent heat from the ring waveguide 21a of the ring resonator 21 so as not to vary an optical path length thereof, that is a
20 circumferential length thereof, and a refractive index thereof.

The ring waveguide 21a for wavelength fixing and the ring waveguides 22a and 23a for wavelength tuning are set with different optical path lengths from each other. The
25 film heaters 22h and 23h are made of aluminum film and the like in circular arch shape along with the ring waveguides

22a and 23a for wavelength tuning and both sides of the circular shape are conducting electrodes. Because optical path lengths of the ring waveguides 21a, 22a and 23a are set different, the multiple ring resonator 41 in which the
5 ring resonators 21, 22 and 23 are combined is configured to resonate at a wavelength where frequencies of the ring resonators 21, 22 and 23 with different cycles from each other are crossed. Also, a resonant wavelength of the multiple ring resonator 41 can be tuned according to varia-
10 tion of circumferential lengths and refractive index of the ring waveguides 21a, 22a and 23a. Therefore, according to the present embodiment, the ring waveguides 21a, 22a and 23a are provided heat from the film heaters 22h and 23h to vary circumferential lengths and refractive index of
15 the ring waveguides 21a, 22a and 23a, which tunes a resonant wavelength of the multiple ring resonator 41. Other configurations are the same as the embodiment shown in FIG. 1.

The wavelength tunable laser 40 is configured to select resonation mode utilizing a characteristic of a drop
20 port in the ring resonators 21, 22 and 23, that is transmitting a wavelength, so as to oscillate in single axis mode. Circumferences of the ring resonators 21, 22 and 23 in three stages comprised by the multiple ring resonator 41 are set in slightly different lengths from each other. Accordingly,
25 even if a tuning range of the resonant wavelength of the three ring resonators 21, 22 and 23 is as wide as several

dozen nm, those three ring resonators 21, 22 and 23 resonate only at a wavelength where respective frequencies of the ring resonators 21, 22 and 23 are crossed and an oscillation in the single axis mode is generated at the wavelength.

5 Wavelength tuning is mainly operated by conducting electricity to the film heater 22h and 23h formed in the ring resonators 22 and 23. For example, when circumferences (that is, optical path lengths) of the ring resonators 21, 22 and 23 are respectively 4000 μm , 4400 μm , 4040 μm , the ring resonator
10 22 operates as a wavelength tuning means for fine adjustment and the film heater 23h operates as a wavelength tuning means for coarse adjustment. Also, wavelength control within as small as several dozen pm is operated to conduct electricity to a phase control area of the SOA 16. According to the
15 wavelength tunable laser 40 of the present embodiment, the same function and effect as the first embodiment can be achieved.

Industrial applicability

20 As described in the above, a wavelength tunable laser combining a multiple ring resonator and a light input/output unit is effective as follows. A ring resonator for fixing a wavelength does not have an adiabatic structure installed therein so as to keep low thermal resistance, and stable
25 operation thereof is achieved. A peripheral area of a ring resonator for tuning a wavelength in which a heat supply unit

is placed has adiabatic grooves formed thereby, which increase a thermal resistance so as to achieve lower power consumption. Thus, each ring resonator in a substrate has thermal resistance arranged respectively according to
5 purposes of the ring resonators so that low power consumption and stable operation can be achieved.

The embodiments of the present invention in which an exclusive property or privilege is claimed are defined as follows:

1. A waveguide tunable laser comprising:

a multiple ring resonator where a plurality of ring resonators is combined;

an input/output unit for inputting/outputting an optical signal to/from the multiple ring resonator;

a reflection unit for reflecting the optical signal outputted from the multiple ring resonator and returning the optical signal to the multiple ring resonator;

a substrate in which the multiple ring resonator is formed;

a heat supply unit arranged on the substrate for providing heat to the plurality of ring resonators and controlling a resonant wavelength of the plurality of ring resonators; and

a thermal conduction restrain unit for limiting heat supply from the heat supply unit only to a particular ring resonator and shutting off heat supply to remaining ring resonators;

wherein the multiple ring resonator comprises a ring resonator for wavelength fixing.

2. The wavelength tunable laser, according to claim 1, wherein the thermal conduction restrain unit is an adiabatic

groove formed in the substrate around a ring waveguide for wavelength tuning.

3. The wavelength tunable laser, according to claim 2, wherein the adiabatic groove is formed from a surface of the substrate through an underneath of the ring waveguide for wavelength tuning to the surface of the substrate.

4. The wavelength tunable laser, according to claim 1, wherein the multiple ring resonator further comprises a ring resonator for wavelength tuning serially connected via a directional coupler to the ring resonator for wavelength fixing.

5. The wavelength tunable laser, according to claim 1, wherein the multiple ring resonator further comprises a plurality of ring resonators for wavelength tuning serially connected via a plurality of directional couplers with the ring resonator for wavelength fixing.

6. The wavelength tunable laser, according to claim 1, which uses a semiconductor optical amplifier as the input/output unit.

7. The wavelength tunable laser, according to claim 1, which uses a film heater as the heat supply unit.

FIG. 1

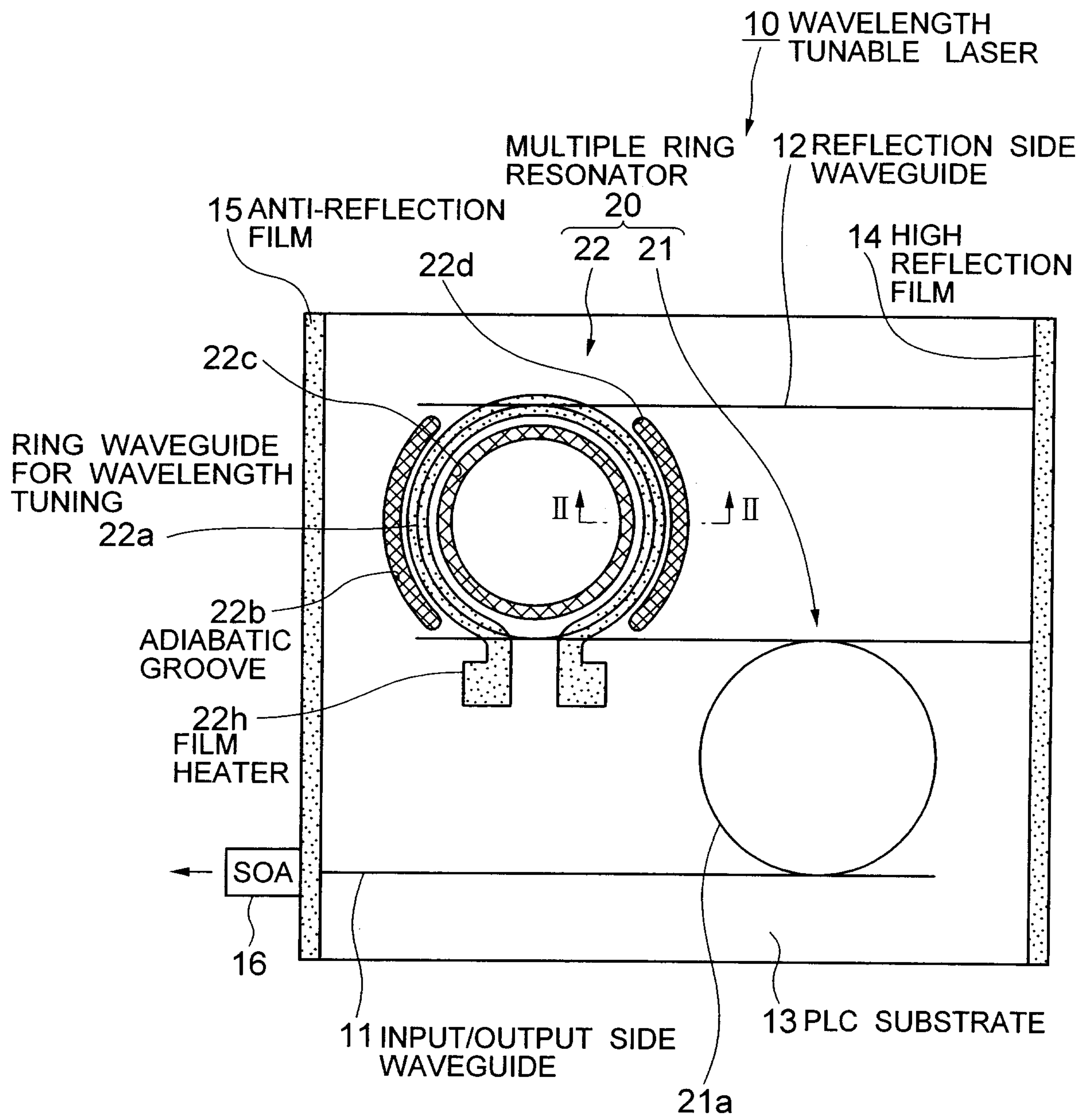


FIG. 2A

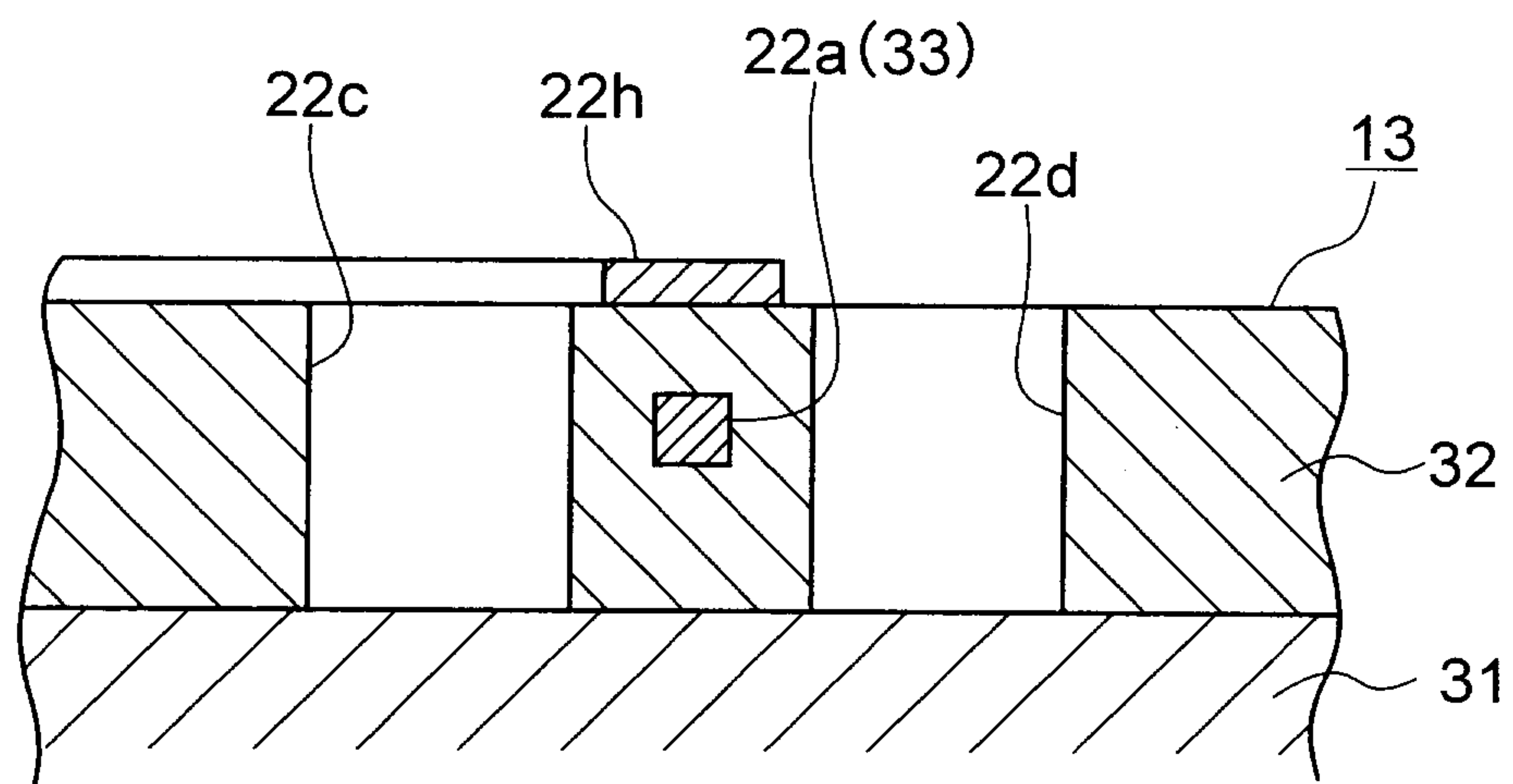


FIG. 2B

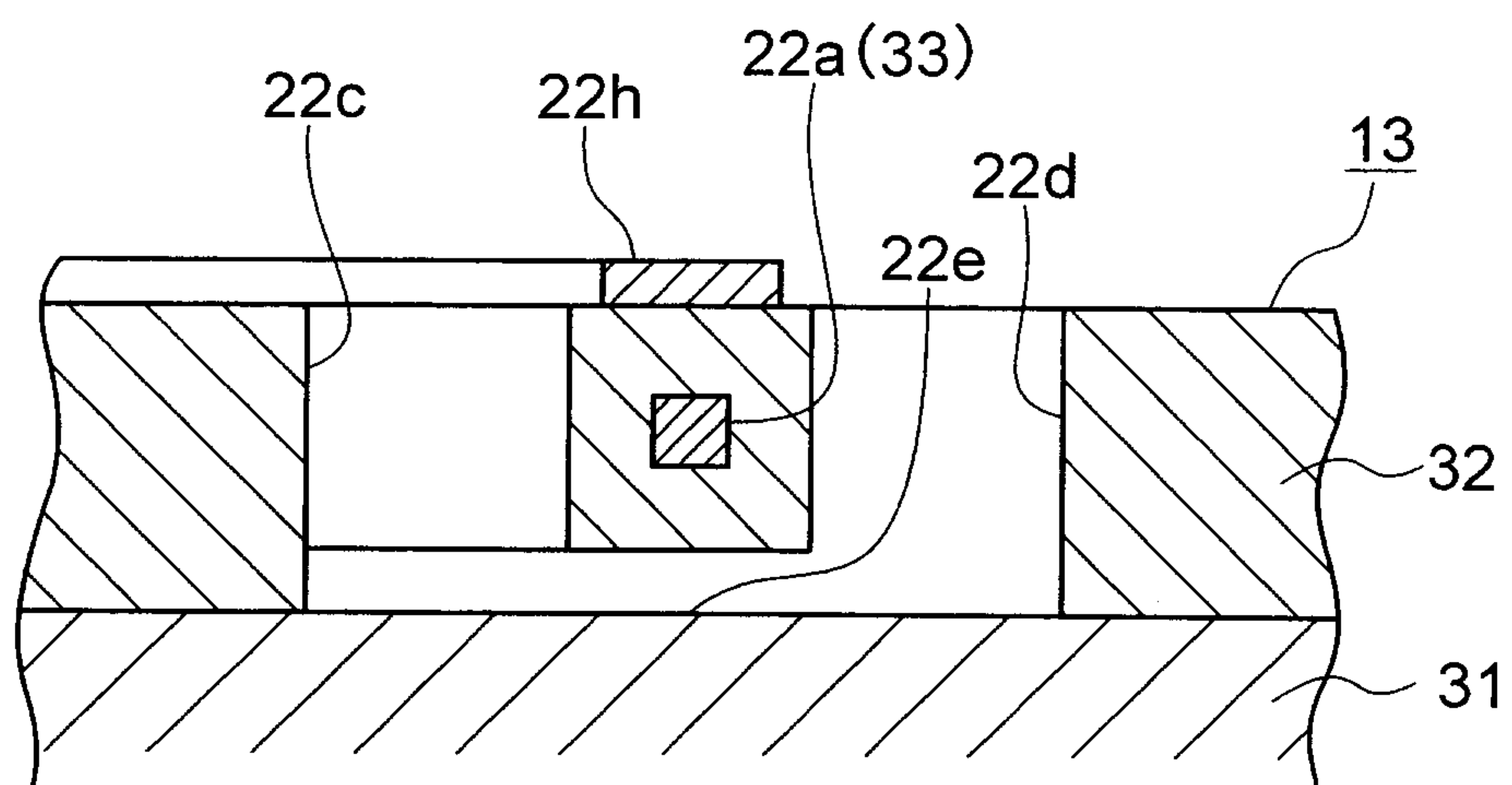


FIG. 3

