

Description

This invention relates to optical devices employing a resonant cavity.

Optical filters employing resonant cavities are known, for example, from US 3589794 ("Optical Circuits", Enrique A J Marcatili, assigned to Bell Telephone Laboratories). That patent discloses a variety of optical filter devices based on resonant cavities employing an optical waveguide loop to form the end reflectors of the cavity.

Depending on the configuration of the device, the resonance of the cavity permits a variety of filter functions to be implemented such as, for example, band-pass filters, band-stop filters, channel-dropping filters and so forth. The devices described there are considered advantageous since they can readily be formed from optical waveguides embedded in a substrate.

Another form of an optical resonant device is known from GB 2180392A (R J Mears et al.) which discloses a laser device based on an optical fibre structure. The device described consists of an optical resonant cavity formed by the fibre and terminating in a mirror at each end. The device operates as an optically pumped laser light source, with a pump wavelength different to the lasing wavelength.

According to the present invention, an optical fibre based laser device comprises an optical fibre resonant cavity having first and second reflectors adapted to reflect radiation at the resonating wavelength characterised in that at least one of the reflectors is an optical loop reflector comprising a directional optical waveguide coupler having two pairs of adjacent ports, one pair of adjacent ports being connected by a looped optical path, one port of the other pair of ports being coupled to the optical fibre resonant cavity.

The reflectivity of the fibre loop termination can be selected by appropriately choosing the coupling ratio of the directional coupler at the wavelength concerned: if the coupling ratio is 50:50 then the loop termination will theoretically be 100% reflective if the ratio is 100:0 or 0:100 then the loop termination will be completely transparent; any other degree of reflectivity can be obtained by using couplers with coupling ratios intermediate these extremes.

Preferably, the reflectivity of the termination at the lasing and pump wavelengths can be selected by employing a directional coupler which has wavelength-selective coupling properties such that its coupling ratio is close to 50:50 at the lasing wavelength and different from this even ratio at the pump wavelength.

An optical fibre based laser device having a fibre loop termination as reflector at the lasing

wavelength is attractive for several reasons: coupling losses which would otherwise occur between the cavity and the reflectors are eliminated or greatly reduced, and the optical waveguide reflectors are temperature and mechanically stable. Moreover, the reflectivity of the fibre loop termination can be made at least very close to 100% at the lasing wavelength while at the same time providing good transmission of light at the pump wavelength into the cavity.

Similarly the reflectivity of the other termination can be readily adjusted to provide the required degree of transmission at the lasing wavelength in order to pass the optical output of the laser.

It is envisaged that in certain situations, a hybrid device could be produced in which one of the reflectors comprises a conventional mirror. Preferably, however, each of first and second reflectors comprises an optical fibre loop termination.

One of the most advantageous features of the invention is that the whole device, including its pump power supply path and its output path comprises a continuous optical fibre waveguide, which may, however, consist of several optical fibre sections spliced together. Furthermore, in comparison with the conventional alternatives, a wholly fibre based device offers a significant saving in production costs.

In one example, the loop termination forming one of the reflectors is substantially 100% reflecting at the laser wavelength (assuming zero losses) and the reflectivity of the other reflector is chosen for optimum output. The device can be pumped by a band of wavelengths shorter than the lasing wavelengths. This light can be coupled into the fibre through the 100% reflecting reflector, by choosing a fibre loop termination which is transmissive at the pump wavelength band.

A directional coupler is a device which will transfer a proportion of optical power from one waveguide (fibre) into another. These devices generally have four ports, two "in" and two "out", designated according to the relevant direction of propagation of light through the device. A coupler is operable bi-directionally in the sense that light can travel through the device from left to right or right to left. Thus, light propagating into one of the "inputs" of the device will be divided and will appear in both "outputs"; conversely light propagating into an "output" will appear in both "inputs". If the two "output" (or "input") ports are joined together to form a loop then light propagation into a corresponding "input" ("output") will be divided and reflected back to the "inputs" ("outputs"). The propagation of optical power reflected back along the incident fibre depends upon the coupling coefficient of the optical coupler. By varying this coupling coefficient, power reflectivities from 0 to

100% may be achieved.

The directional couplers used in fibre loop terminations should meet several performance requirements. The couplers should have low excess loss, (ie the proportion of light lost in traversing the coupler should be small) and they should be both mechanically and temperature stable. A coupler which satisfies these requirements is the tapered, fused fibre coupler.

For example, it is particularly preferably if the coupler of the first fibre termination is arranged such that substantially 50% of radiation at the resonant wavelength entering the coupler from the cavity through a port of one pair of ports is coupled with each of the first and second ports of the other pair of ports, and the coupler of the other reflector is arranged such that proportions other than 50% of radiation at the resonant wavelength entering the port coupled with the resonant cavity is coupled with the first and second ports of the other pair of ports.

In this specification, the optical fibres are preferably monomode optical fibres although in some applications multimode optical fibres are also acceptable.

In this specification, the term optical is intended to refer to that part of the electro-magnetic spectrum which is generally known as the visible region together with those parts of the infra-red and ultra-violet regions at each end of the visible region which are capable of being transmitted by dielectric optical waveguides such as optical fibres.

Examples of a laser according to the invention will now be described and contrasted with a conventional construction of the device with reference to the accompanying drawings, in which:

Figure 1 illustrates a conventional optical fibre laser; and

Figure 2 illustrates an example of a laser according to the invention.

Figure 1 illustrates a fibre laser resonator having a doped, optical fibre resonating cavity 1 positioned between a pair of lenses 2, 3. A mirror 4 is positioned adjacent the lens 2 and is substantially 100% reflecting at the laser wavelength (assuming zero losses). A mirror 5 is positioned adjacent the lens 3 and has a reflectivity which is chosen empirically for optimum output. In other words, the mirror 5 is partially transmissive for radiation at the laser wavelength. The laser is pumped by a band of wavelengths, shorter than the laser wavelength, originating from a pump source 6. Light from the pump source is coupled into the fibre 1 through the mirror 4 which is transmissive at the pump wavelength band.

Figure 2 illustrates an example of a fibre laser resonator according to the invention. Those parts of the resonator in Figure 2 which are the same as

the resonator of Figure 1 are indicated by the same reference numerals. In this case, the pump radiation source 6 is coupled into the doped fibre 1 via an optical fibre 7 with a directional coupler 8. The directional coupler 8 has two pairs of first and second ports, 9,10; 11,12. Incoming radiation at any one of the ports 9,10; 11,12 of one pair is coupled in predetermined portions 0-100% with the two ports of the other pair. Thus, for example, radiation incoming at the port 11 will be coupled with the ports 9, 10. The ports 9, 10 are coupled together via a loop of optical fibre 13.

The structure of the directional coupler 8 is such that when the coupling of the device is exactly 50%, all light input at one of the ports will be reflected back along its input path. Thus, by arranging the coupler 8 to have 50% coupling at the lasing wavelength, the coupler behaves as a 100% reflecting mirror. However, since the coupling ability of the coupler 8 is wavelength dependent, it does not completely reflect radiation at the band of wavelengths of the pump 6 and so these wavelengths are coupled into the optical fibre 1.

Another optical coupler 14 similar to the coupler 8 is connected to the other end of the fibre 1. One port 16 of a first pair of ports 15,16 of the coupler 14 is connected to the fibre 1, whilst the second port 15 of this first pair is free to pass the resultant output radiation from the laser into an output optical fibre 20. The second pair of ports 17,18 of the coupler 14 are coupled together via a loop of optical fibre 19. The degree of coupling achieved by the coupler 14 is set to allow a proportion of light received by the coupler from the optical fibre 1 to be transmitted to the output fibre 20 (ie the coupler with loop is not 100% reflective at the lasing wavelength).

The coupling ratio of directional couplers can be made to vary with wavelength. This effect can be used to couple pump light into the laser cavity with little loss. The coupling ratio of coupler 8 is arranged to be 50% at the lasing wavelength and 0 or 100% at the pump wavelength. Wavelength selectivity can also be used to suppress unwanted laser transitions.

The couplers 18, 14 can be of the fused fibre, or polished block types and the degree of coupling achieved can be set during manufacture or can be variable by making the surrounding material of variable refractive index. For example, this surrounding material may be made of electro-optic material.

The looped connections need not be provided by separate lengths of optical fibre, but may, for example, be formed integrally with the couplers at manufacture. Indeed, the complete device including resonant cavity and reflectors may be formed from a single optical fibre.

To provide further wavelength selectivity a concatenation of loop reflector terminations may be used in combination with the laser described.

Note that, for a zero loss coupler, the power reflectivity R is given by:-

$$R = 4K(1-K)$$

where K is the coupling co-efficient. (K=0 represents zero coupling, K=0.5 is 50% coupling and K=1 is complete cross coupling).

Claims

1. An optical fibre based laser device comprising an optical fibre resonant cavity having first and second reflectors (8, 13 and 14, 19) adapted to reflect radiation at the resonating wavelength characterised in that at least one of the reflectors (8, 13 and 14, 19) is an optical loop reflector comprising a directional optical waveguide coupler (8) having two pairs of adjacent ports, one pair of adjacent ports (9, 10) being connected by a looped optical path (13), one port (11) of the other pair of ports (11, 12) being coupled to the optical fibre resonant cavity.
2. A laser device as claimed in claim 1 in which the optical loop reflector (8, 13) comprising said first reflector is arranged to be reflective at the chosen lasing wavelength and to be at least partially transmissive at the chosen pump wavelength.
3. A laser device as claimed in claim 1 in which the optical loop reflector (14, 19) comprising said second reflector is partially transmissive at the lasing wavelength.
4. A laser device as claimed in any preceding claim in which each of said reflectors (8, 13 and 14, 19) comprises an optical fibre loop reflector.
5. A laser as claimed in claim 4 in which the two loop reflectors (8, 13 and 14, 19) and the resonant cavity comprise a single optical fibre.

Revendications

1. Un dispositif laser à base de fibre optique comprenant une cavité résonante en fibre optique comportant un Premier et un deuxième réflecteurs (8, 13, et 14, 19) aptes à réfléchir un rayonnement à la longueur d'onde résonante caractérisé en ce qu'au moins l'un des réflecteurs (8, 13, et 14, 19) est un réflecteur

en boucle optique comprenant un coupleur directionnel (8) de guide d'ondes optique comportant deux paires de ports adjacents, une paire de ports adjacents (9,10) étant reliée par un trajet optique (13) à boucle, un port (11) de l'autre paire de ports (11, 12) étant couplé à la cavité résonante en fibre optique.

2. Un dispositif laser selon la revendication 1 dans lequel le réflecteur optique en boucle comprenant ledit premier réflecteur (8, 13) est agencé pour être réfléchissant à la longueur d'ondes choisie et pour transmettre au moins partiellement à la longueur d'onde de pompe choisie.
3. Un dispositif laser selon la revendication 1 dans lequel le réflecteur optique en boucle comprenant ledit deuxième réflecteur (14, 19) transmet partiellement à la longueur d'onde de laser.
4. Un dispositif laser selon une revendication précédente quelconque dans lequel chacun desdits réflecteurs (8, 13, et 14, 19) comprend un réflecteur en boucle en fibre optique.
5. Un dispositif laser selon la revendication 4 dans lequel les deux réflecteurs (8, 13, et 14, 19) et la cavité résonante comprennent une fibre optique unique.

Patentansprüche

1. Laservorrichtung auf optischer Faserbasis, welche aufweist:
einen optischen Faser-Resonanzhohlraum mit einem ersten und einem zweiten Reflektor (8, 13 und 14, 19), welche dazu angepaßt sind, Strahlung bei der Resonanzwellenlänge zu reflektieren,
dadurch gekennzeichnet, daß
zumindest einer der Reflektoren (8, 13 und 14, 19) ein optischer Schleifenreflektor ist, welcher einen optischen Wellenleiterrichtkoppler (8) enthält mit zwei Paaren nebeneinanderliegender Anschlüsse, wobei ein Paar nebeneinanderliegender Anschlüsse (9, 10) durch einen optischen Schleifenpfad (13) verbunden ist, wobei ein Anschluß (11) des anderen Paares von Anschlüssen (11, 12) mit dem optischen Faser-Resonanzhohlraum gekoppelt ist.
2. Laservorrichtung nach Anspruch 1, in welcher der optische Schleifenreflektor (8, 13), welcher den ersten Reflektor enthält so angeordnet ist, daß er bei der ausgewählten Laserwellenlänge reflektierend ist und daß er zumindest teilweise



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2. A laser device as claimed in claim 1 in which the optical loop reflector (8, 13) comprising said first reflector is arranged to be reflective at the chosen lasing wavelength and to be at least partially transmissive at the chosen pump wavelength. 20
3. A laser device as claimed in claim 1 in which the optical loop reflector (14, 19) comprising said second reflector is partially transmissive at the lasing wavelength. 25
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1. Un dispositif laser à base de fibre optique comprenant une cavité résonante en fibre optique comportant un Premier et un deuxième réflecteurs (8, 13, et 14, 19) aptes à réfléchir un rayonnement à la longueur d'onde résonante caractérisé en ce qu'au moins l'un des réflecteurs (8, 13, et 14, 19) est un réflecteur 40

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durchlässig bei der ausgewählten Pumpwellenlänge ist.

3. Laservorrichtung nach Anspruch 1, wobei der optische Schleifenreflektor (14, 19), welcher den zweiten Reflektor enthält, teilweise durchlässig ist bei der Laserwelllänge. 5
4. Laservorrichtung nach einem der vorhergehenden Ansprüche, bei welcher jeder der Reflektoren (8, 13 und 14, 19) einen optischen Faser-Schleifenreflektor aufweist. 10
5. Laser nach Anspruch 4, bei welchem die zwei Schleifenreflektoren (8, 13 und 14, 19) und der Resonanzhohlraum eine einzige optische Faser aufweisen. 15

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