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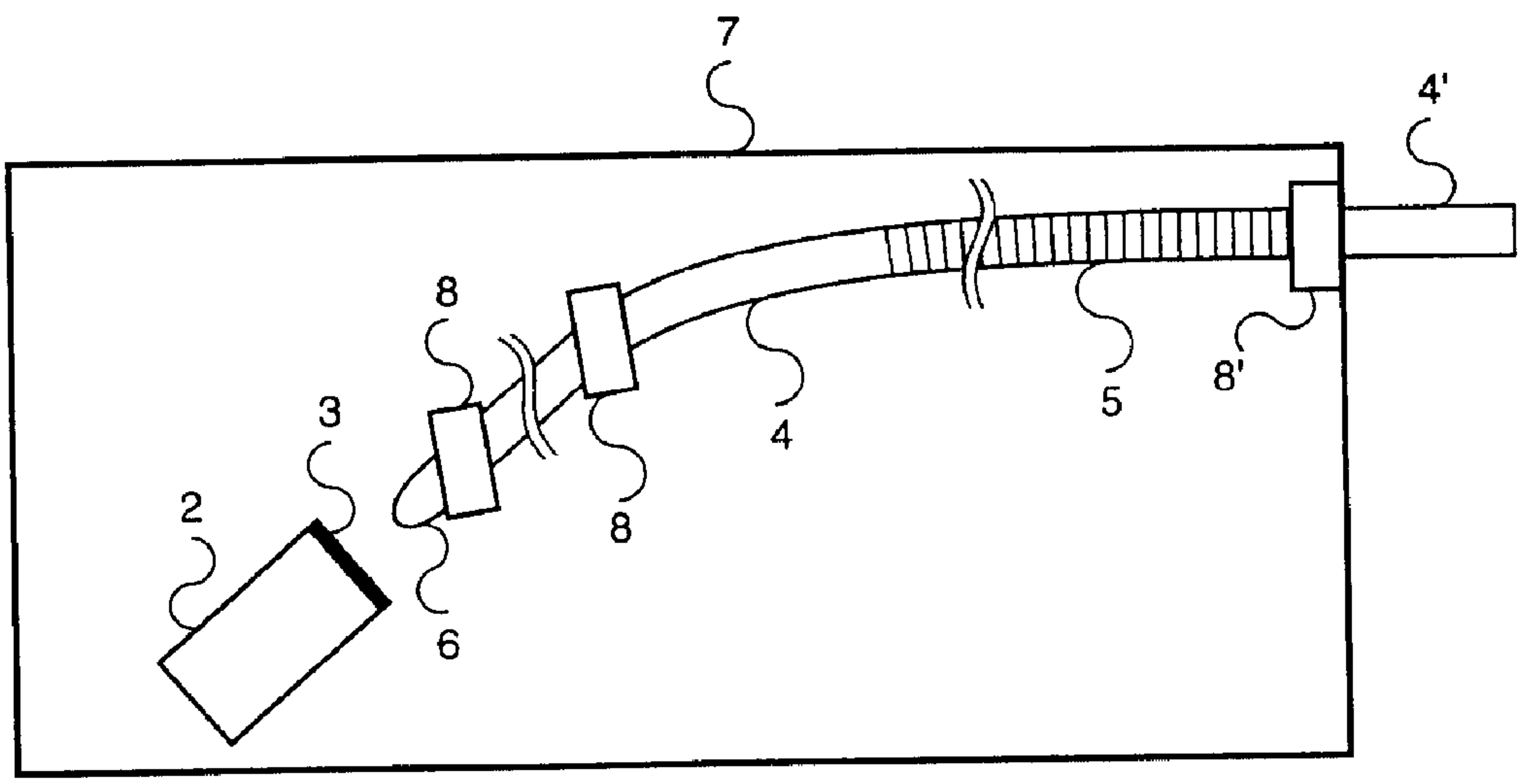
(54) **MODULE LASER A CAVITE EXTERNE ET REFLECTEUR A FIBRE OPTIQUE**

(54) **LASER MODULE WITH EXTERNAL CAVITY AND OPTICAL FIBRE REFLECTOR**



(57) A laser module comprises a Fabry-Perot cavity active element with a facet bearing an anti-reflection coating and an external cavity made by an optical fibre Bragg grating with low reflectivity. This grating presents a non-uniform profile of modulation of the refractive index, asymmetrical in the direction of the grating length, such as to give rise to a position of the equivalent mirror plane that is offset towards the end of the grating that is closer to the active element.

ABSTRACT

A laser module comprises a Fabry-Perot cavity active element with a facet bearing an anti-reflection coating and an external cavity made by an optical fibre Bragg grating with low reflectivity. This grating presents a non-uniform profile of modulation of the refractive index, asymmetrical in the direction of the grating length, such as to give rise to a position of the equivalent mirror plane that is offset towards the end of the grating that is closer to the active element.

LASER MODULE WITH EXTERNAL CAVITY AND OPTICAL FIBRE REFLECTOR

The present invention relates to sources for optical telecommunication systems, and more specifically it concerns a laser with external cavity made by an optical fibre Bragg grating. Such devices are known in the art as HDBR (Hybrid Distributed Bragg Reflector) lasers or Fibre Grating (FG) lasers.

Such devices generally comprise a Fabry-Perot semiconductor active element (laser diode) with a terminal facet bearing an anti-reflection coating, coupled to a grating written on a length of optical fibre tapered at one end and positioned with the tapered end adjacent to the facet bearing the anti-reflection coating. As described in the literature, lasers of this kind are particularly well suited for use as sources of pump radiation, single mode sources for optical telecommunication systems, in particular wavelength division multiplexing systems, mode locked lasers for the generation of pulses within a wide frequency range, etc.

For a review of the applications of such lasers, reference can be made for instance to the papers "Lightwave Applications of Fiber Bragg Gratings", by C. R. Giles, Journal of Lightwave Technology, Vol. 15, No. 8, August 1997, pages 1391 et seq., and "Fiber Gratings in Lasers and Amplifiers", by J. Archambault and S.G. Grubb, ibid. page 1379 et seq.

It is well known that some of the characteristics of the aforesaid lasers are linked to the overall length of the cavity, which in a hybrid laser is given by the sum of the length of the cavity of the active element, of the distance between the anti-reflection coated facet and the tip of the tapered fibre end and lastly of the length of the fibre portion between the tip and the equivalent mirror plane of the grating. The equivalent mirror plane, as is well known, is the plane wherein a mirror would have to be positioned in order that a pulse sent by a source and reflected by the mirror returns to the source in the same time the pulse sent into the grating would take to return. In particular, the shorter the cavity of the laser, the greater the modulation band obtainable and the better the mode separation. It is evident that the attainment of good characteristics in terms of modulation band and mode separation is of particular interest for the use of lasers as sources for telecommunication systems.

The conventional low-reflecting Bragg gratings (with output reflectivity of the order of 70%) currently used to form the external cavity of hybrid lasers have a profile of modulation of the refractive index that is symmetrical with respect to the central point of the grating, thus giving rise to an equivalent mirror plane positioned substantially at the centre of the grating. On the other handhighly reflecting gratings - with substantially 100% reflectivity - cannot be used, , for the external cavity of the laser, even if they would in themselves have an equivalent mirror plane offset towards one end. because they would not allow having sufficient powers in the fibre.

The gratings used for these applications have a length of the order of the centimetre and thus the length of the external cavity constitutes nearly the entirety of the length of the whole cavity, since the active element has a cavity length of the order of 200 μm. The use of conventional gratings may then give rise to a cavity length that is not sufficiently reduced to obtain satisfactory characteristics for the laser. One could think of reducing the drawback by writing the grating in the end portion of the fibre, but this gives rise to additional problems when the fibre is fastened by means of resins onto the support of the module. It is evident that one of the fastening points must be in correspondence with said end portion, to guarantee the constant alignment between the active element and the fibre, and under such conditions the resin interacts with the grating: the experience has shown that the resin, upon curing, causes alterations in the structure of the grating, thus rendering the solution unfeasible.

These problems are solved by the laser according to the invention, where the external cavity makes use of a fibre grating with such a profile of modulation of the refractive index as to give a reduced equivalent grating length whilst maintaining a low reflectivity: in this way, also the overall length of the cavity is sufficiently limited.

More in detail, a laser module is provided comprising a Fabry-Perot cavity active element with a facet treated with an anti-reflection coating and an external cavity made by a low reflectivity optical fibre grating. This grating presents a profile of modulation of the refractive index that is non-uniform and asymmetrical in the direction of the length, and is such as to give rise to a position of the equivalent mirror plane that is offset towards one end of the grating, and the grating is mounted in such a way that said end is the grating end closest to the laser. In a preferred embodiment, this profile of modulation is represented by a curve which has minimum and substantially null value, with substantially horizontal tangent, in correspondence with the grating end that is farther away from the laser, and then rises gradually and monotonically until a maximum value, also with substantially horizontal tangent, which is reached in correspondence with the other end of the grating, where the curve returns to the minimum value with a substantially vertical slope.

By way of non limiting example, the profile of modulation of the refractive index, in the portion with gradual variation, can have a trend represented by one of the following functions: $y = \exp(-x^2)$, $y = \sin^2 x$, $y = \tanh x$.

For the sake of further clarification, reference is made to the accompanying drawings, wherein:

- Figure 1 is a schematic view of a hybrid laser;
- Figure 2 shows the profile of modulation of the refractive index of the grating employed to form the external cavity, and
- Figures 3-5 are graphs allowing evaluating the performance of the laser according to the invention.

As Figure 1 shows, a hybrid laser, indicated in its entirety with reference numeral 1, comprises a Fabry-Perot cavity active element 2, made of semiconductor material and having a terminal facet 3 bearing an anti-reflection coating, and a length of optical fibre 4 whereon a grating 5 is written. By way of example, the active element 2 can be an InGaAsP:InP, SI-BH (Semi-Insulating Buried Heterostructure) laser, with a modulation band of the order of 10 GHz or more.

Fibre 4 terminates in a tapered end 6 positioned adjacent to facet 3 of active element 2. In a wholly conventional manner, the active element 2 and the fibre 4 are fastened onto a common support 7 (e.g. belonging to the package of the module) by means of a resin (specifically, an acrylic resin), as indicated in 8. The resin must block the entire end portion of fibre 4 comprising the tapered end 6, in order to guarantee the proper alignment of the fibre 4 with terminal facet 3 of active element 2. Yet, for the reasons explained in the introduction of the invention, the grating must be outside the fastening region.

In fastening the fibre onto support 7, it is to be taken into account that environmental conditions and mechanical stresses can cause variations of the grating pitch thereby affecting the emission wavelength of the module. Such variations can be due in particular to deformation of support 7 because of temperature changes or simply to pulling forces exerted on fibre tail 4'. To avoid such variations of the grating pitch, the fibre 4 will be fastened also in correspondence of the end of the support (the end wall of the package) as shown in 8' and the grating region will be slightly bent so as to damp any stress in the grating region itself.

As said before, the end portion of the fibre 4 adjacent to the tapered part 6 cannot be used for writing the grating. The fibre therefore contributes to the overall length of the laser cavity for the entire section spanning between the end of the tapered part and the equivalent mirror plane of the grating 4.

In order to reduce the overall length of the external cavity, the grating 4 used in the laser according to the invention is a grating with equivalent mirror plane offset towards the end closer to the active element.

Figure 2 shows a possible profile of modulation of the refractive index capable of shifting the equivalent mirror plane towards one grating end. The profile is an asymmetrical, non-uniform profile, and it is represented by a curve which has a substantially null minimum value, with horizontal tangent, in correspondence with the grating end that is the farther from the taper of the fibre, gradually and monotonically rises until reaching a maximum value, also with substantially horizontal tangent, which is attained in correspondence with the end of the grating that is closer to the taper, and returns to a substantially null value with substantially vertical slope. In the Figure, for the sake of drawing clarity, the pitch of the grating 4 is artificially lengthened with respect to reality.

Profiles of modulation of the refractive index that meet the requirements of the invention are for instance those corresponding to half of a Gaussian curve, i.e. a curve of the type $y = \exp(-x^2)$, or of a curve of the type $y = \sin^2 x$ or yet again of a curve of the type $y = \tanh x$. Figure 2 refers to the case of a half-Gaussian profile.

The method whereby a grating of this kind can be manufactured is the subject matter of a patent application with title "Fibre Bragg grating with offset equivalent mirror plane and method for its manufacture" in the name of the same Applicant, filed concurrently herewith.

A profile of this type actually moves the equivalent mirror plane towards one end of the grating, as is readily apparent when applying the description provided in L. A. Coldren, S. W. Corzine: "Diode lasers and photonic integrated circuits", Wiley & Sons, 1995, pp. 85 et seq., and as it is confirmed by the measurements carried out.

Considering by way of example a half-Gaussian profile like the one shown in Figure 2, a grating about 1 cm long with reflectivity of the order of 70% (which are typical values for these applications) has an equivalent length of about 2 mm. By way of comparison, a conventional grating with equal length and similar reflectivity would have an equivalent length of about 5 mm. Taking into account that the fibre end portion to leave available for fastening can be of the order of 3 mm, the invention allows to shorten the laser cavity by an amount practically corresponding to the fibre portion that is unusable because of the problems inherent to resin fastening.

The person skilled in the art is able to evaluate, by applying well known relationships, the advantage that such a reduction in the length of the cavity provides in terms of bandwidth and mode separation.

The graphs of Figures 3 - 5 allow evaluating the performance of a laser according to the invention. In particular, Figure 3 is the power/current characteristic at the output of the fibre and shows that the invention provides a good linearity; Figure 4, which is the amplitude/wavelength characteristic, shows the good single mode performance of the laser; lastly, Figure 5 shows that the invention allows obtaining a very wide modulation band.

It is evident that the description above is provided purely by way of non limiting example and that variations and modifications are possible without thereby departing from the scope of the invention.

CLAIMS:

1. Hybrid laser, comprising a Fabry-Perot cavity active element with a facet treated with an anti-reflection coating and an external cavity made by a low reflectivity grating obtained in a length of optical fibre having an end arranged adjacent to said facet, characterized in that said grating presents a non-uniform and asymmetrical profile of modulation of the refractive index in the direction of the length, such as to give rise to a position of the equivalent mirror plane that is offset towards the end of the grating closer to the active element.

2. Laser as claimed in claim 1, characterized in that said profile of modulation is represented by a curve which has minimum and substantially null value, with substantially horizontal tangent, in correspondence with the end of the grating farther from the active element, and which gradually and monotonically rises until a maximum value, also with substantially horizontal tangent, which is reached in correspondence with the other end of the grating, where it returns to the minimum value with substantially vertical slope.

3. Laser according to claim 2, characterized in that said curve is chosen from among the following curves: $y = \exp(-x^2)$, $y = \sin^2 x$, $y = \tanh x$.

4. Laser according to any preceding claim, characterized in that said length of optical fibre is fastened onto a support at both sides of the grating in such a manner that the fibre portion including the grating is slightly curved.

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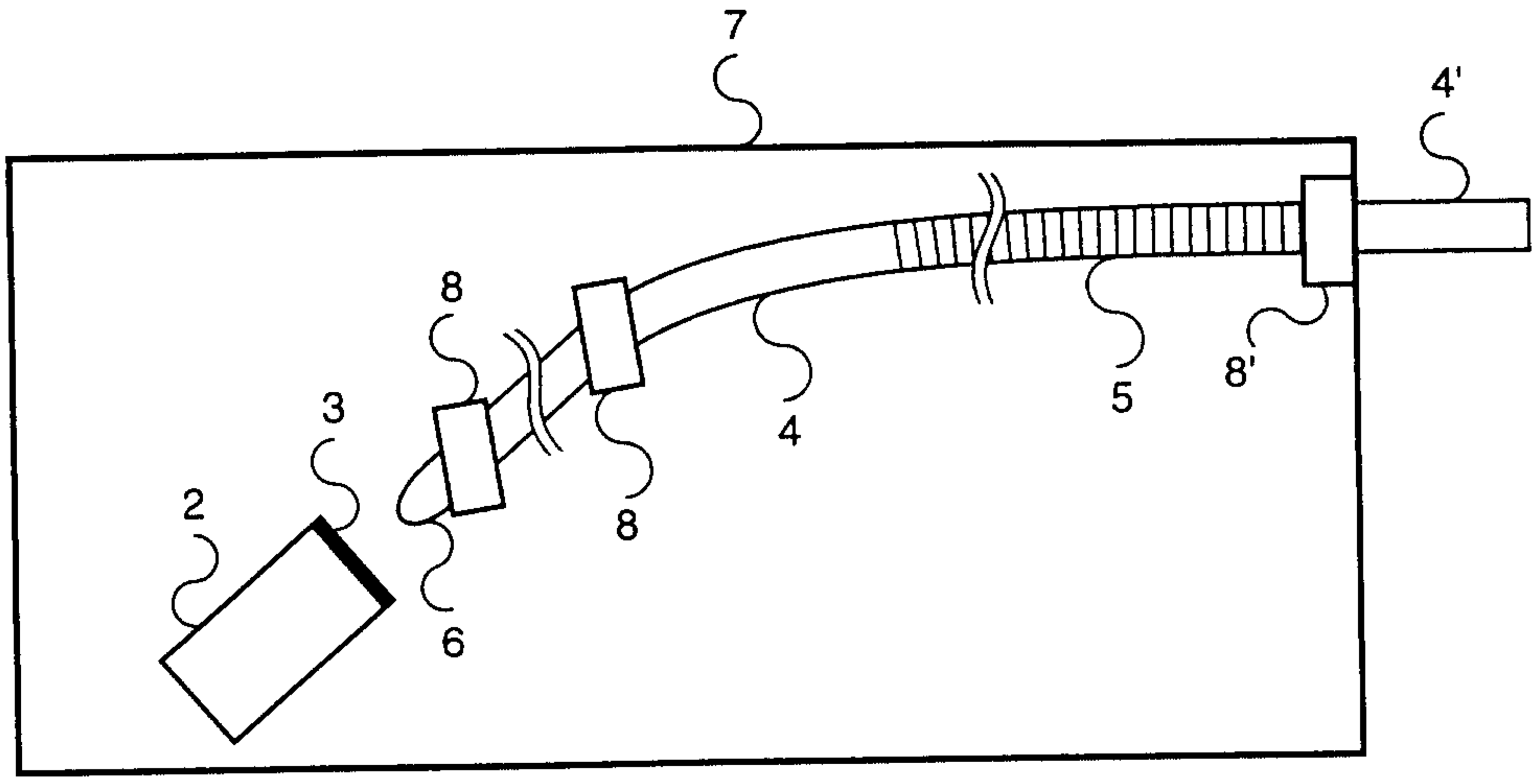

Fig. 1

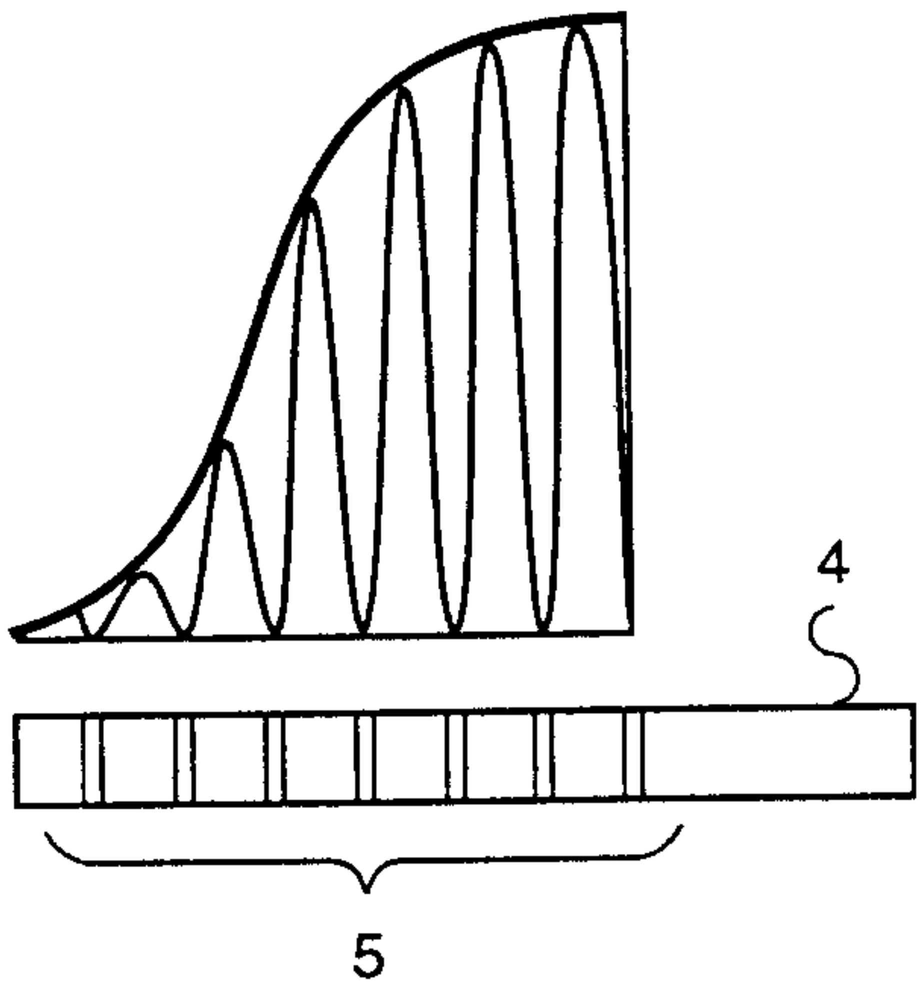

Fig. 2

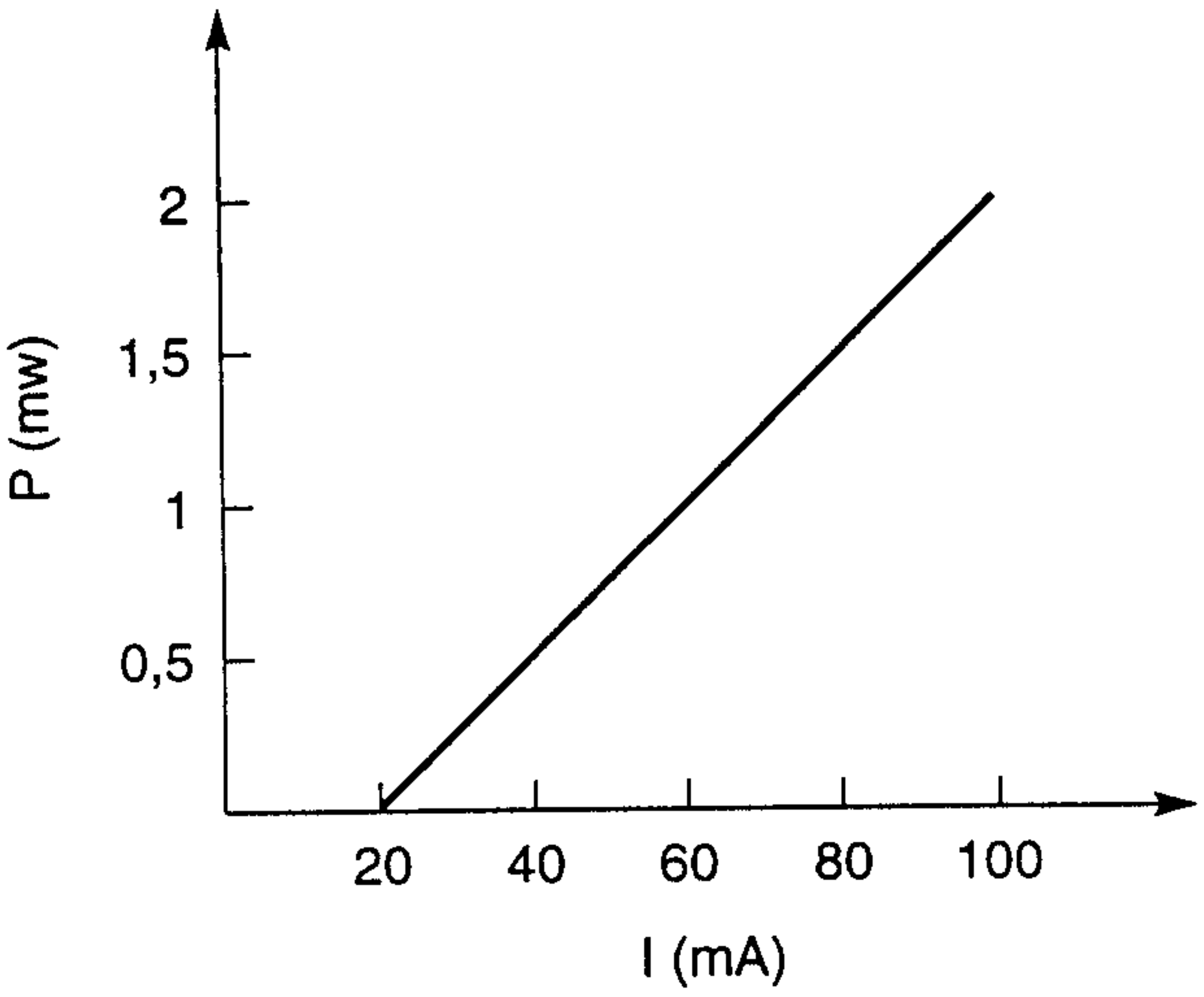

Fig. 3

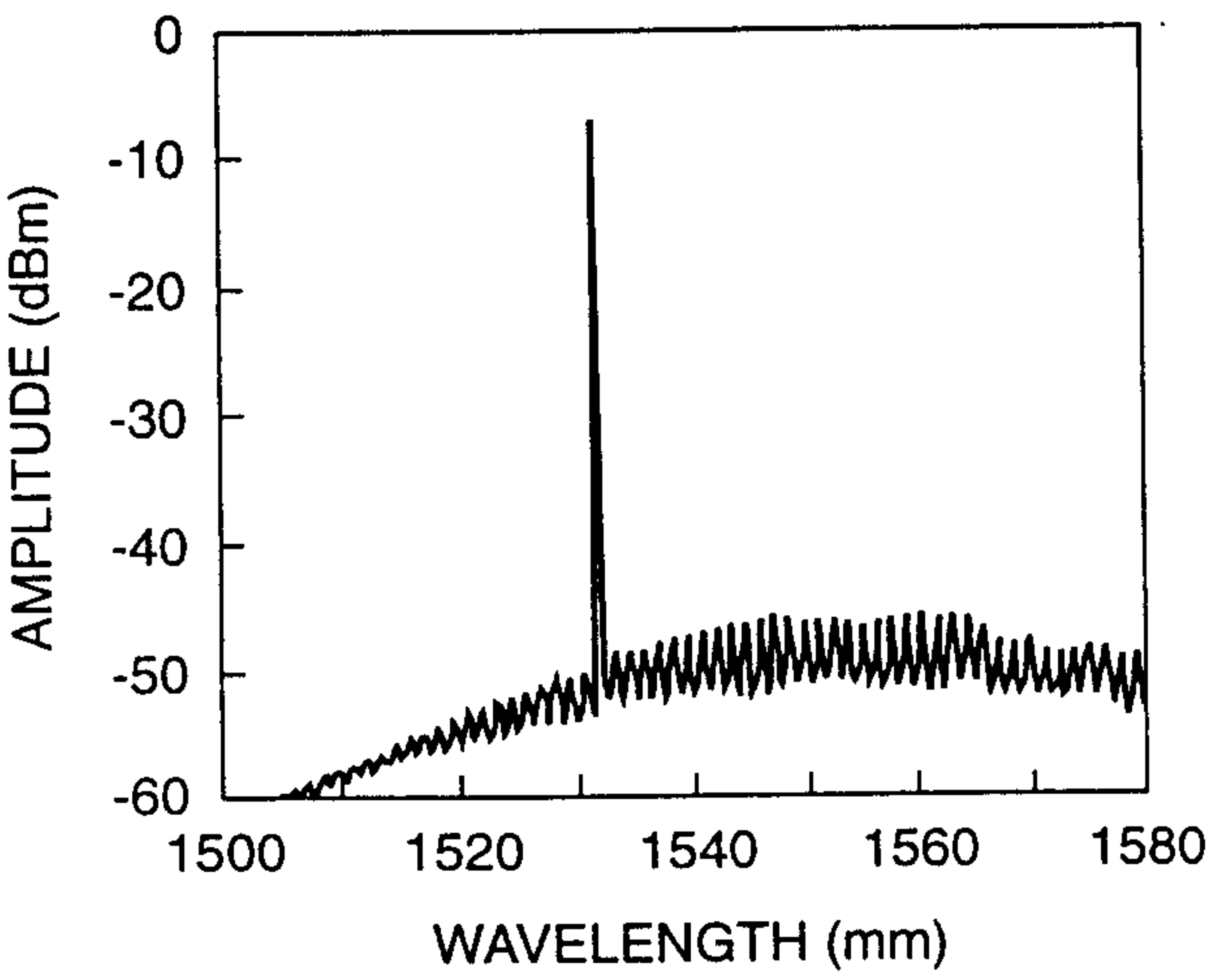

Fig. 4

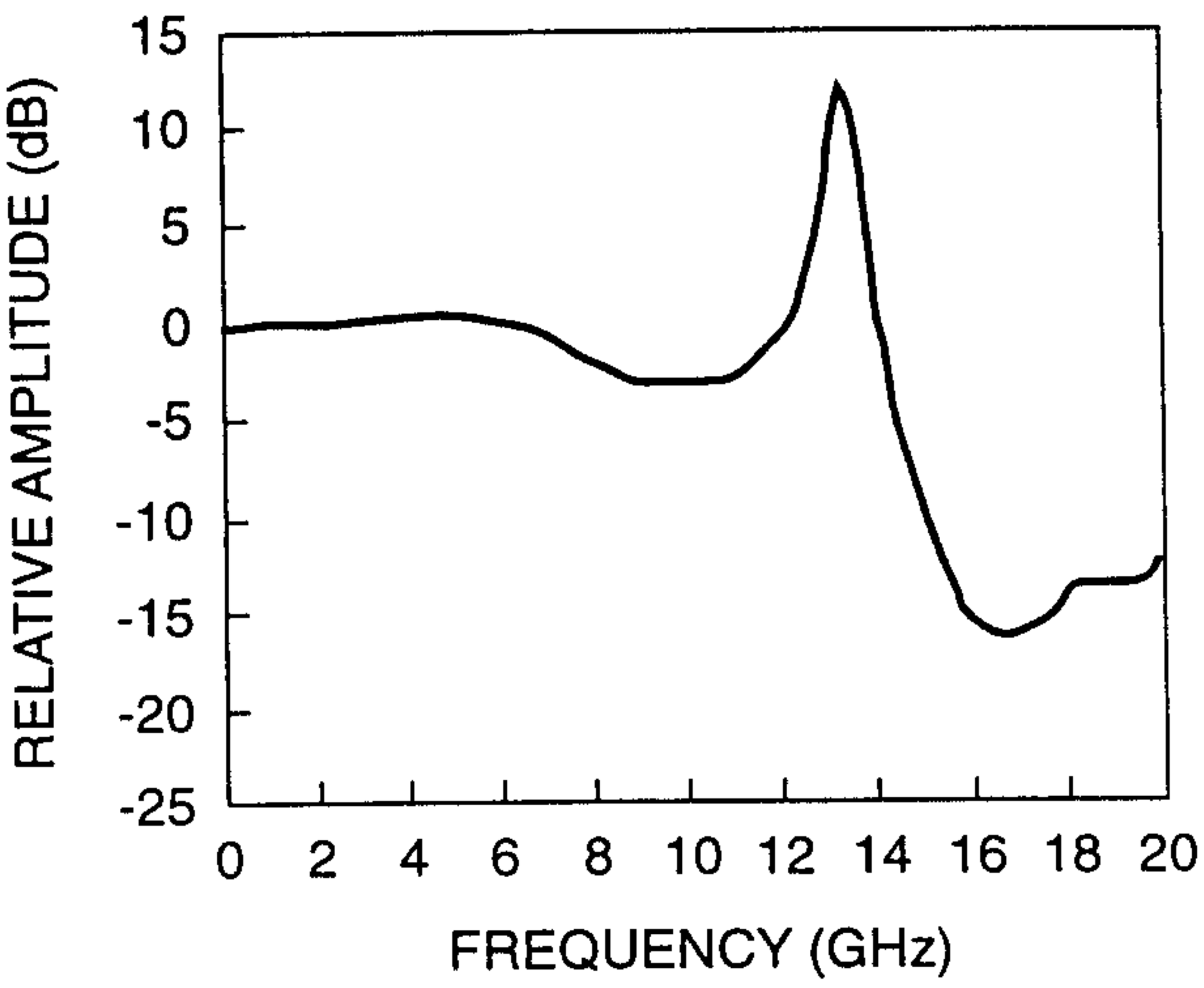

Fig. 5