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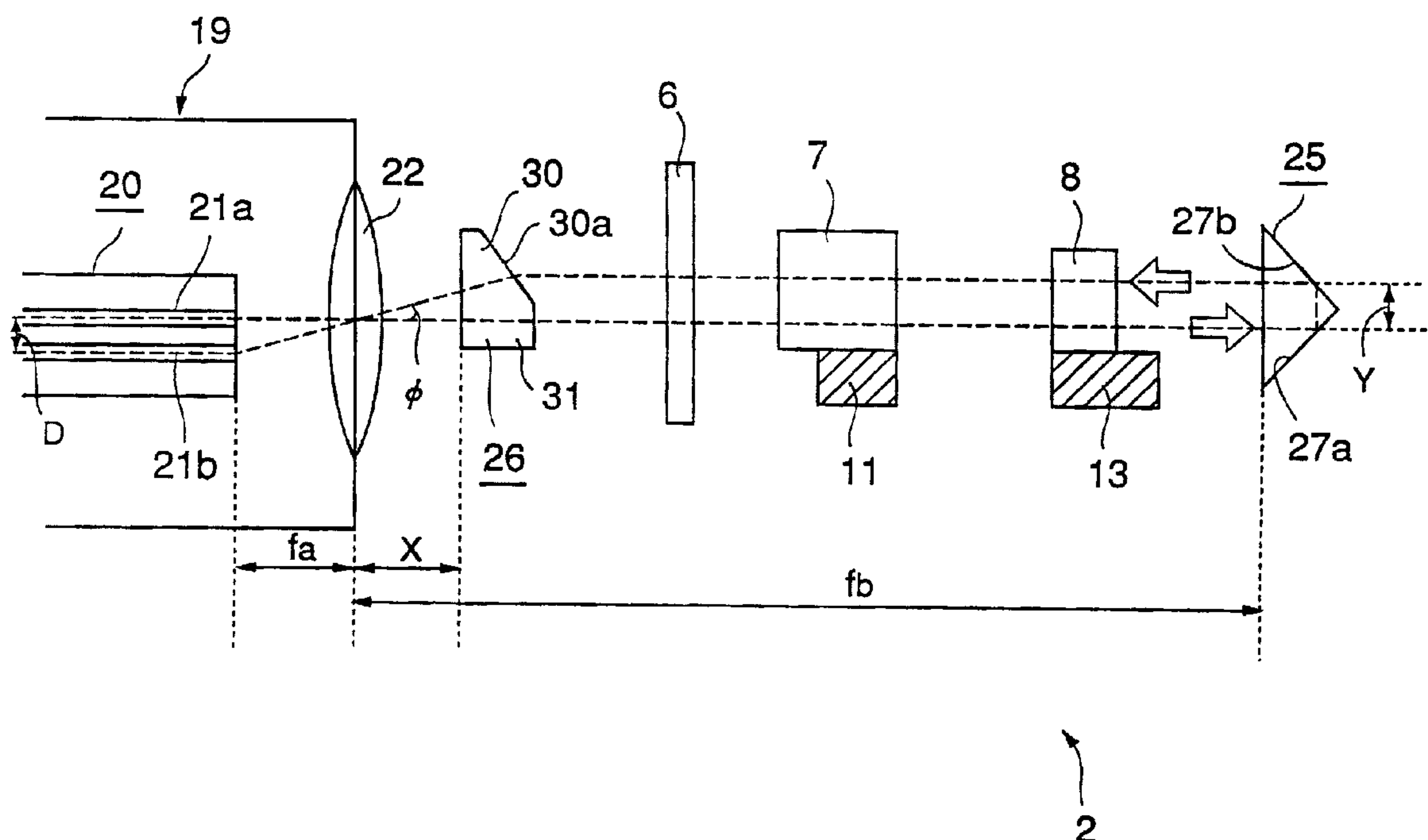
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(54) Titre : UNITE DE FILTRE OPTIQUE VARIABLE ET SYSTEME D'EGALISATION A GAIN VARIABLE

(54) Title: VARIABLE OPTICAL FILTER UNIT AND VARIABLE GAIN EQUALIZING SYSTEM



(57) Abrégé/Abstract:

Between a lens of a collimator and a retro-reflector as a total reflecting element, a prism, a polarizer, a Faraday rotator and a linear retarder are arranged in that order. A core/clad section serving as an input port of the collimator has its optical axis coincident with an optical axis of the lens. When a light exiting the collimator reaches the retro-reflector, the light is reflected, so that the incoming beam and the outgoing beam are parallel to each other, spaced by a given distance Y. The returning light, which is refracted by the prism, is incident on the core/clad section, serving as an output port of the collimator.



ABSTRACT OF THE DISCLOSURE

Between a lens of a collimator and a retro-reflector as a total reflecting element, a prism, a polarizer, a Faraday rotator and a linear retarder are arranged in that order. A core/clad section serving as an input port of the collimator has its optical axis coincident with an optical axis of the lens. When a light exiting the collimator reaches the retro-reflector, the light is reflected, so that the incoming beam and the outgoing beam are parallel to each other, spaced by a given distance Y . The returning light, which is refracted by the prism, is incident on the core/clad section, serving as an output port of the collimator.

**Variable Optical Filter Unit
and Variable Gain Equalizing System**

BACKGROUND OF THE INVENTION

Field of the Invention

[001] The present invention relates to a variable optical filter unit for varying a wavelength characteristic of an incident signal light, and a variable gain equalizing system for compensating a variation in the wavelength characteristic of the input signal light.

Description of the Related Art

[002] Recently, research and development has been made on Wavelength Division Multiplexing (WDM) long-distance optical transmission in the field of optical communications. In the WDM long-distance optical transmission system, a plurality of optical amplifiers (e.g. EDFAs (Erbium-Doped Optical Fiber Amplifiers)) is inserted in the optical transmission line. However, because the optical amplifier used for a certain wavelength band is different in gain depending on a wavelength, the signal light, which passed through the optical amplifier, is different in light amount depending on the wavelength. In the WDM long-distance optical transmission system, there is cumulative increase of the differences in the signal light intensity between the wavelengths, since the signal light passes a plurality of optical amplifiers. This causes great divergence in signal light intensity in wavelengths or channels. This further results in a difference in the ratio of signal light amount to noise magnitude (S/N ratio) between channels (wavelengths), and hence makes WDM impractical.

[003] The countermeasure to the problem resulting from the optical-amplifier gain characteristic includes, for example, a means to individually incorporate a gain equalizer in each optical amplifier, or to insert a plurality of gain equalizers into the optical transmission line, so that the difference in signal light amount between wavelengths, as caused by the optical amplifiers, can be compensated for by the gain equalizers, thereby equalizing the signal light amount for every wavelength.

[004] Conventionally, the gain equalizer is configured using an optical filter (e.g. dielectric multi-film filter, etalon filter, Mach-Zehnder filter) having a fixed light attenuation amount wavelength characteristic as a relationship between a light attenuation amount and a wavelength, on the assumption that the optical amplifier is steady in gain characteristic.

[005] However, the optical-amplifier gain characteristic is actually not steady, but varies due to the variation in input-signal light amount. This is a result of aging deterioration of the optical fiber constituting the optical transmission line, cut-working of the optical fiber upon extension of optical transmission line, or the variation in excitation state of the optical amplifier medium resulting from external disturbance such as temperature change in the environment when installing the optical amplifiers. Consequently, there are cases that the difference in input signal light intensity between wavelengths cannot be satisfactorily compensated for by the gain equalizer utilizing an optical filter, which is fixed in the light attenuation amount wavelength characteristic.

[006] Considering the above, there have been recent proposals of variable gain equalizers being capable of varying the light

attenuation amount wavelength characteristic. Various variable gain equalizers have been proposed, e.g. variable gain equalizers under thermo-optical control on the principle of a waveguide-type diffraction grating and Mach-Zehnder interferometer, variable gain equalizers with mechanical means on the principle of a split-beam Fourier filter, variable gain equalizers for gain-inclination correction comprising a variable optical filter unit on the principle of a birefringence filter having a sinusoidal-like filter characteristic, variable gain equalizers comprising a plurality of such variable optical filter units arranged in series, and so on.

[007] Out of the plurality of proposed variable gain equalizers, the present inventor has a preference for the variable gain equalizer using the variable optical filter unit. There are at least three different reasons for this choice. First, the variable gain equalizer has a high reliability in variably controlling the light attenuation amount wavelength characteristic, because this is done under electric control.

[008] Second, the variable optical filter unit is easy to manufacture and low in price, because it is possible to manufacture in bulk those optical elements that are arranged in a free space to provide an action to the transmitted light. Third, where the variable optical filter units are arranged in series to structure a variable gain equalizer, the light attenuation amount wavelength characteristic can be varied in various ways by individually controlling the variable optical filter units. Thus, the light attenuation amount wavelength characteristic has a high degree in variation of its in variable settings.

[0009] Fig. 5 typically shows an example of a variable gain equalizer system using the plurality of variable optical filter units. The variable gain equalizing system 1, shown in Fig. 5, is structured with a plurality of variable optical filter units 2 ($2_1, 2_2, \dots, 2_n$ (n is an integer equal to or greater than 2)), a monitor means 3, and a pattern form control means 4. The variable optical filter units 2 each possess a sinusoidal-like light attenuation amount wavelength characteristic. The variable gain equalizing system 1 is configured for producing a compensating light attenuation amount wavelength characteristic, as shown in curve A' of Fig. 6B, for compensating for an input signal-light (incident signal light) wavelength characteristic, e.g. as shown in curve A in Fig. 6A, by adding together the sinusoidal-like light attenuation amount wavelength characteristics of the variable optical filter units 2, and resulting in an output signal light, which has approximately the same light amount at every wavelength, as shown in Fig. 6C. Note that, throughout this specification, the expression "sinusoidal-like" not only stands for a sinusoidal like form, but also includes the waveforms approximate in form to the sinusoidal-like form.

[0010] In the variable gain equalizing system 1, the monitor means 3 for example monitors a wavelength characteristic of an input signal. Depending on the result of the monitoring process, the pattern-form control means 4 individually controls the variable optical filter units 2 to control at least one of amplitude and phase of the sinusoidal-like light attenuation amount wavelength characteristic of each variable optical filter unit 2, thereby variably controlling the light attenuation amount wavelength characteristic for compensating the variable gain equalizing system 1. Specifically, when, for example, the

input signal light has a waveform characteristic as shown in curve A of Fig. 6A, a light attenuation waveform characteristic for compensation is produced, as shown in the curve A' of Fig. 6B. Wherein the case that the input signal light is changed to a waveform characteristic as shown in curve B of Fig. 6A, the pattern-form control means 4 individually controls the variable optical filter units 2, to variably control the amplitude or phase of the sinusoidal-like light attenuation waveform characteristic of each of the variable optical filter units 2. By adding together the sinusoidal-like light attenuation amount wavelength characteristics of the variable optical filter units 2, a light attenuation amount wavelength characteristic for compensation is produced as shown in curve B' of Fig. 6B.

[0011] The variable gain equalizing system 1, shown in Fig. 5, is capable of changing the light attenuation amount wavelength characteristic for compensation in various ways, as described in the foregoing, can produces an output signal light, being nearly constant in light amount regardless of wavelength, as shown in Fig. 6C, even when the wavelength characteristic of the input signal light varies.

[0012] Fig. 7 typically shows an example of configuration of a variable optical filter unit 2 for constituting the variable gain equalizing system 1. The variable optical filter unit 2, shown in Fig. 7, is configured to have a polarizer 6, a Faraday rotator 7, a linear retarder 8, a Faraday rotator 9 and an analyzer 10, all arranged in that particular order on a light propagation path. Further, magnetic-field applying devices 11, 12 to apply magnetic fields to the Faraday rotators 7, 9, and a temperature control device 13 to control the temperature of the linear retarder 8 are provided.

[0013] The Faraday rotators 7, 9, are formed of magneto-optical crystals, e.g. YIG (Yttrium-iron-garnet), and utilize the Faraday effect to rotate a polarization state of an input light in a light propagation direction, depending on a magnitude of magnetization caused by a magnetic field applied by the magnetic-field applying devices 11, 12. The magnetic field applying means 11, 12 variably control the magnitude of a magnetic field applied to the Faraday rotators 7, 9 thereby variably controlling the magnitude of magnetization in a light propagation direction in the Faraday rotator 7, 9 and hence variably controlling the rotation angle (Faraday rotation angle) θ in the polarization state of the input light by the Faraday rotators 7, 9.

[0014] In the meanwhile, there exist microscopic gatherings of magnetization, called magnetic domains, in a magneto-optical crystal (multi-domain structure). If a magnetic field is externally applied, the magnetic domain grows gradually into a greater magnetic domain. Finally, the magnetic domains are integrated into a state of saturated magnetization. In the state of multi-domain structure, optical transmission loss occurs due to diffraction loss caused by a multiplicity of domain boundaries. In order to reduce optical transmission loss, the magneto-optical crystal is desirably used in a saturated domain state.

[0015] Consequently, for the magnetic-field applying devices 11, 12, one preferably uses magnetic-field applying devices, which are capable of variably controlling the magnitude of magnetic domains in the Faraday rotators 7, 9, in the light propagation direction, while maintaining the saturated domain state of the Faraday rotators (magneto-optical crystals) 7, 9. Such a

magnetic-field applying device includes various structures. Herein, any of the structures for a magnetic-field applying device may be employed, and hence an explanation thereof is omitted.

[0016] Note that the magnetic-field applying devices 11, 12 are controlled such that the Faraday rotators 7, 9 are equal in Faraday rotation angle θ , for reasons, which will become clear later.

[0017] The linear retarder 8, formed of a birefringence crystal, e.g. a quartz or rutile crystal, is a device to separate, with a phase difference, transmission light into one component, which is polarized in an optical-axis direction of the crystal, and a second component, which is polarized in a direction orthogonal to the optical-axis direction of the crystal. The temperature control device 13, for variably controlling the temperature of the linear retarder 8 itself, is structured, for example, by a Peltier device.

[0018] In the meanwhile, simulations have been made, using computations with the Jones matrix, on how the amount of the signal light changes when passing the optical variable filter unit 2, depending on a variation of the Faraday rotation angle θ of the Faraday rotators 7, 9 and depending on a variation of the temperature of the linear retarder 8. Due to this, it has been confirmed that the light attenuation amount wavelength characteristic of the variable optical filter unit 2 varies, as shown in Fig. 8, in the case that the Faraday rotation angle θ is varied, and, as shown in Fig. 9, in the case the temperature of the linear retarder 8 is varied.

[0019] The solid line A, shown in Fig. 8, represents a Faraday rotation angle θ of 45° , the broken line B for a Faraday rotation angle θ of 55° , the broken line C for a Faraday rotation angle θ of 60° , the dotted line D for a Faraday rotation angle θ of 75° and the solid line E for a Faraday rotation angle θ of 90° .

[0020] As can be seen from the graph of the light attenuation amount wavelength characteristic shown in Fig. 8, the variable optical filter unit 2 has a sinusoidal-like light attenuation amount wavelength characteristic. It is important to note that the sinusoidal-like waveform varies only in amplitude with variation in the Faraday rotation angle e without change in phase and period.

[0021] The solid line A, shown in Fig. 9, is on a waveform example of a light attenuation waveform characteristic in the variable optical filter unit 2 for a case, in which the linear retarder 8 is at a temperature of 10°C . The dotted line B represents a case, in which the linear retarder 8 is at a temperature of 20°C , and the dotted line C represents a case, in which the linear retarder 8 is at a temperature of 30°C . As can be seen from the graph of the light attenuation waveform characteristic, it can be conformed that the sinusoidal like waveform on the light attenuation waveform characteristic of the variable optical filter unit 2 varies in phase, but not in period, when variation in the temperature of the linear retarder 8 is varied.

[0022] As shown in Figs. 8 and 9, the sinusoidal-like characteristic exhibited in the light attenuation waveform characteristic of the variable optical filter unit 2 is due to a variation depending on a wavelength, because the phase

difference Δ in the separation light by the linear retarder 8 is of wavelength dependency. Also, when the temperature of the linear retarder 8 changes, the birefringence of the linear retarder 8 changes to vary the phase difference Δ of the separation light by the linear retarder 8 and, as a consequence, the phase in the light attenuation amount wavelength characteristic of the variable optical filter unit 2 varies. On the contrary, the reason that no change of the period in the light attenuation amount wavelength characteristic of the variable optical filter unit 2 by temperature change in the linear retarder 8 occurs, lies in the fact that the variation amount in the separation-light phase difference Δ due to the temperature change is not dependent upon a wavelength, and is nearly constant at every wavelength.

[0023] Namely, in the variable optical filter unit 2 shown in Fig. 7, the amplitude of the sinusoidal-like light attenuation amount wavelength characteristic of the variable optical filter unit 2 can be controlled by variably controlling the Faraday rotation angle θ of the Faraday rotators 7, 9. Also, by variably controlling the temperature of the linear retarder 8, the phase of the sinusoidal-like light attenuation amount wavelength characteristic of the variable optical filter unit 2 can be controlled. Namely, the temperature control means 13 functions as a phase difference varying device for controlling the separation-light phase difference Δ due to the linear retarder 8 to thereby vary the phase of the sinusoidal-like light attenuation amount wavelength characteristic of the variable optical filter unit 2.

[0024] Furthermore, the period of the sinusoidal-like light attenuation amount wavelength characteristic of the variable

optical filter unit 2 is determined depending upon a crystal thickness in the light propagation direction of the linear retarder 8. Previously determined is a crystal thickness d in the light propagation direction of the linear retarder 8 for a predetermined period of the light attenuation amount wavelength characteristic. The linear retarder having a determined thickness d will be provided in the variable optical filter unit 2. Incidentally, although the crystal thickness in the light propagation direction of the linear retarder 8 is varied by variably controlling the temperature of the temperature control means 13, such variation is negligibly small and accordingly, if the temperature of the linear retarder 8 is varied, the period of the light attenuation amount wavelength characteristic will nearly be not changed.

[0025] The polarizer 6 and the analyzer 10 constitute linear polarizers, each comprising e.g. a polarizing splitting wedge using a birefringence crystal, so that the amount of the light of an incident light polarizing state, is not changed after transmission.

[0026] The polarizer 6, the linear retarder 8 and the analyzer 10 are preferably arranged in the following relationship, so that all the peaks on the sinusoidal-like waveform of the light attenuation amount wavelength characteristic of the variable optical filter unit 2 are rendered zero in transmission loss, based on the principles as outlined in Fig. 8 or Fig. 9. For example, when the polarizer 6 and the analyzer 10 are in an orthogonal-Nicol relationship, the linear retarder 8 is set up such that the birefringence crystal constituting the linear retarder 8 is inclined by 45° in an optical axis direction relative to a direction of transmission through the polarizer 6

and analyzer 10. Meanwhile, when the polarizer 6 and the analyzer 10 are in a parallel-Nicol relationship, the linear retarder 8 is set up such that the birefringence crystal forming the linear retarder 8 is parallel in the optical axis direction relative to the direction of transmission through the polarizer 6 and analyzer 10.

[0027] Also, the reason for controlling the magnetic-field applying device 11, 12 such that the Faraday rotators 7, 9 are equal in Faraday rotation angle θ , as described in the foregoing, lies in the fact that transmission loss for principally all the peak values of the sinusoidal-like waveform of the light attenuation amount wavelength characteristic of the variable optical filter unit 2 is rendered to zero, similarly to what is described above. In this manner, the reason for rendering transmission loss to zero for all the peak values on the sinusoidal-like waveform of the light attenuation waveform characteristics is to keep the amount of transmission loss in the variable gain equalizing system 1 as low as possible when the variable gain equalizing system 1 is constructed by connecting a plurality of variable optical filter units 2 in series, as shown in Fig. 5.

[0028] Note that the equal Faraday rotation angle θ in the Faraday rotators 7, 9 is also chosen to simplify the configuration of control, besides the reasons mentioned above.

[0029] In the above example, the temperature control means 13 of the linear retarder 8 variably controls the phase in the sinusoidal-like light attenuation waveform characteristic of the variable optical filter unit 2. However, it is possible to interpose a variable retarder using a Faraday rotator between the Faraday rotator 9 and the analyzer 10 without providing a

temperature control means 13 as disclosed in JP-A-6-130339, so that the variable phaser can variably control the phase in the light attenuation amount wavelength characteristic of the variable optical filter unit 2.

[0030] In the meanwhile, there is a proposal on a variable optical filter unit 2 as shown in Fig. 10 in view of reducing the size and cost of the variable optical filter unit 2. The variable optical filter unit 2 shown in Fig. 10 has a polarizer 6, a Faraday rotator 7, a linear retarder 8, and a total reflecting mirror 18 as a total reflecting element, arranged in that order with respect to a light propagation direction. Also, provided are a magnetic field applying device 11 for applying a magnetic field to the Faraday rotator 7 and a temperature control device 13 for variably controlling the temperature of the linear retarder 8. Note that, herein, the same structural parts as those of the variable optical filter unit 2 shown in Fig. 7 are denoted with the same reference numerals, so that an explanation of the duplicated common parts can be omitted.

[0031] In the variable optical filter unit 2 shown in Fig. 10, the light passing the polarizer 6 reaches the total reflecting mirror 18 through the Faraday rotator 7 and the linear retarder 8, in that given order, where it is totally reflected by the total reflecting mirror 18. The returning light leaves the polarizer 6 after passing through the linear retarder 8 and the Faraday rotator 7, in reversed order as mentioned above. The variable optical filter unit 2 shown in Fig. 10 can act upon light to produce a sinusoidal-like light attenuation amount wavelength characteristic, similarly to the variable optical filter unit 2 shown in Fig. 7.

[0032] Incidentally, the polarizer 6 also serves as the analyzer 10, being part of the variable optical filter unit 2 shown in Fig. 7. In the case of Fig. 10, the polarizer 6 and the analyzer 10 are in a state equivalent to a parallel-Nicol relationship. Accordingly, the linear retarder 8 is preferably arranged in its crystal optical axis direction parallel with a direction of transmission through the polarizer 6.

[0033] Further, one can consider that a collimator 19, as shown in Fig. 11, is placed at a light input/output section of the variable optical filter unit 2 shown in Fig. 10. The collimator 19 comprises a two-cored ferrule 20 and a lens 22. The two-cored ferrule 20 has optical-fiber cores/clads 21a, 21b arranged parallel to each other, separated by a spacing (e.g. 250 μm). One of the cores/clads 21a, 21b serves as an input optical fiber while the other serves as an output optical fiber.

[0034] In the case that such a collimator 19 is arranged at the light input/output section of the variable optical filter unit 2 of Fig. 10, the light, which leaves the input optical fiber of the cores/clads 21a, 21b, is incident on the polarizer 6 through the lens 22. Then, as in the foregoing, the returning light is totally reflected upon the total reflecting mirror 18 and passes the lens 22 to enter the collimator 19 and to propagate to the other core/clad serving as the output optical fiber.

[0035] In the collimator 19 shown in Fig 11, the cores/clads 21a, 21b are symmetrically centered on an optical axis of the lens 22. In this case, in order that the light leaving one of the cores/clads 21a, 21b and being reflected upon the total reflecting mirror 18, reenters the other core/clad, it is necessary to have a spacing f_a between a tip of the core/clad 21a, 21b and a principal plane of the lens 22, being equal to a

spacing fb between the principal plane of the lens 22 and the total reflecting mirror 18.

[0036] In the meanwhile, it is preferred to use a general-purpose collimator for reasons of cost reduction. However, in a general-purpose collimator, the spacing fa between the tip of the core/clad 21a, 21b and the principal plane of the lens 22 amounts to approximately 1-4 mm. In order to employ a general-purpose collimator, it is necessary to set the spacing fb between the principal plane of lens 22 and the reflecting mirror 18 to approximately 1-4 mm. However, there exist extreme difficulties in arranging a polarizer 6, a Faraday rotator 7, a linear retarder 8, and further a magnetic-field applying device 11 and a temperature control device 13 in such a narrow gap.

[0037] This makes it impossible to use a general-purpose collimator. The use of an expensive collimator causes an increase in cost of a variable optical filter unit 2, and a variable gain equalizing system using the same variable optical filter unit 2.

[0038] On the other hand, when fabricating a collimator 19 by setting the spacing fb between the principal plane of the lens 22 of the collimator 19 and the total reflecting mirror 18 as to facilitate the arrangement of the optical elements such as the Faraday rotator 7, and setting the spacing fa between the lens 22 and the tip of the core/clad 21a, 21b equal to the spacing fb, the collimator 19 is greater in size compared to the general-purpose product, resulting in a size increase in a variable optical filter unit 2 and variable gain equalizing system 1.

[0039] Furthermore, one considered that, in order to avoid size increase of the collimator 19, optical elements such as a

polarizer 6, might be inserted between the lens 22 and the tip of the core/clads 21a, 21b. In this case, there exist a difficulty in adjusting the positions of the lens 22, the optical elements such as the polarizer 6, and the tip of the core/clad 21a, 21b such that the loss in optical coupling of the returning light, being totally reflected by the total reflecting mirror 18 with the core/clad 21a or 21b, is minimized. This then lowers production efficiency. In this case, the collimator 19 is expensive despite avoiding size increase of the collimator 19, resulting in cost increase of a variable optical filter unit 2 and variable gain equalizing system 1, similarly to that described. The present invention has been made in order to solve the above problem, and it is an object to provide a variable optical filter unit and variable gain equalizing system low in price and small in size, using a general-purpose collimator.

SUMMARY OF THE INVENTION

[0040] In order to achieve the object, a variable optical filter unit having a sinusoidal-like light attenuation amount wavelength characteristic, and having an integrated collimator with an input optical fiber and an output optical fiber being arranged parallel to each other and a lens arranged with a spacing to a tip of the input and output optical fibers, commonly for input and output, is described, the variable optical filter unit comprising: arranged on a light exit side of the collimator, in an order, a polarizer and a total reflecting element for totally reflecting a signal light to return a propagation direction of the light; provided between the polarizer and the total reflecting element a Faraday rotator for

rotating a polarizing plane of an incident light according to an applied magnetic field, a birefringence crystal for providing, depending on a wavelength, a phase difference between a component propagating with polarization in a crystal optical axis direction and a component propagating with polarization in a direction orthogonal thereto, and a phase difference changing device for changing, without depending on the wavelength, the phase difference between the component propagating with polarization in the crystal optical axis direction and the component propagating with polarization in the direction orthogonal thereto; a propagation light path changing element being provided to input and propagate a returning light totally reflected by the total reflecting element onto the output optical fiber of the collimator. This structure is means for solving the foregoing problem.

[0041] Also, a variable optical filter unit having a sinusoidal-like light attenuation waveform characteristic, and having a collimator integrated with a tip of an optical fiber and a lens arranged on a side of the tip of the optical fiber through a spacing, is described, the variable optical filter unit comprising: arranged on a light exit side of the collimator, in an order, a polarizer, and a total reflecting element for totally reflecting a signal light to return a propagation direction of the light; provided between the polarizer and the total reflecting element a Faraday rotator for rotating a polarizing plane of an incident light according to an applied magnetic field; a birefringence crystal for providing, depending on a wavelength, a phase difference between a component propagating with polarization in a crystal optical axis direction and a component propagating with polarization in a direction orthogonal thereto; and a phase difference changing

device for changing, without depending on the wavelength, the phase difference between the component propagating with polarization in the crystal optical axis direction and the component propagating with polarization in the direction orthogonal thereto; a propagation path of the returning light totally reflected by the total reflecting element and directed toward the collimator being coincident with a propagation path of the outgoing light directed from the collimator toward the total reflecting element; an optical circulator being inserted in an optical fiber connected to the collimator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0042] Fig. 1 is a model diagram typically showing a variable optical filter unit featured in a first embodiment;

[0043] Fig. 2 is a model diagram typically showing a variable optical filter unit featured in a second embodiment;

[0044] Fig. 3 is a model diagram typically showing a variable optical filter unit featured in a third embodiment;

[0045] Fig. 4 is an explanatory diagram showing a modification of the present invention;

[0046] Fig. 5 is an explanatory diagram typically showing one example of a variable gain equalizing system arranged with a plurality of variable optical filter units;

[0047] Fig. 6 is a graph showing an example for a wavelength characteristic pattern of an input signal light in the variable gain equalizing system of Fig. 5, a light attenuation amount wavelength characteristic possessed by the variable gain

equalizing system, and an example for a wavelength characteristic pattern of an output signal light in the variable gain equalizing system;

[0048] Fig. 7 is a diagram for explaining a related art of a variable optical filter unit comprising the variable gain equalizing system shown in Fig. 5;

[0049] Fig. 8 is a graph showing one example of sinusoidal like waveform change in light attenuation amount wavelength characteristic of the variable optical filter unit, when the rotation angle (Faraday rotation angle) is varied in a light polarization state due to a Faraday rotator, in the variable optical filter unit of Fig. 7;

[0050] Fig. 9 is a graph showing one example of sinusoidal like waveform change in light attenuation amount wavelength characteristic of the variable optical filter unit where varied is the temperature of a linear retarder, in the variable optical filter unit of Fig. 7;

[0051] Fig. 10 is an explanatory view typically showing one example of a variable optical filter unit using a total reflecting element; and

[0052] Fig. 11 is a model diagram for showing one example of a collimator to be provided at a light input/output section of the variable optical filter unit of Fig. 10.

DETAILED DESCRIPTION

[0053] Now embodiments of the present invention will be explained below with reference to the drawings.

[0054] A variable-gain equalizing system of a first embodiment is features a variable optical filter unit unique in structure, as to be explained below. The other structure is similar to that of the variable-gain equalizing system shown in Fig. 5. In the explanation on the first embodiment, the same constituent parts as those of the variable-gain equalizing system shown in Fig. 5 are designated with the same reference characters, and explanation of the duplicated common parts is omitted.

[0055] Fig. 1 typically shows a structure of a variable optical filter unit featured in the first embodiment. As shown in Fig. 1, the variable optical filter unit 2 comprises, being arranged on a light propagation path, a polarizer 6, a Faraday rotator 7, a linear retarder 8, and a retro-reflector 25 as a total reflection element. Further, a collimator 19 is arranged with a lens 22 directed toward the polarizer 6. A prism 26, as a path-changing element for propagation-light, is inserted between the lens 22 of the collimator 19 and the polarizer 6 on the light propagation path. Furthermore, a magnetic-field applying device 11 is provided to apply a magnetic field to the Faraday rotator 7, and a temperature control device 13 is provided to control the temperature of the linear retarder 8, which functions as a phase-difference changing device. Note that the polarizer 6, the Faraday rotator 7, the linear retarder 8, the magnetic-field applying element 11 and the temperature control element 13 are similar in structure, respectively, to the constituent parts 6, 7, 8, 11 and 13 structuring the variable optical filter unit 2 of Fig. 7 or 10, and an explanation of these parts is therefore omitted.

[0056] The collimator 19 is structured with the integral two-cored ferrule 20 and the lens 22, as described before. In the

first embodiment, an optical axis of one of the core/clad 21a, 21b of the two-cored ferrule 20 serving as an input optical fiber (core/clad 21a in the example of Fig. 1) coincides with an optical axis of the lens 22.

[0057] The retro-reflector 25 has a first total reflecting surface 27a and a second total reflecting surface 27b. The first and second total reflecting surfaces 27a, 27b are arranged in an orthogonal relationship. In the example shown in Fig. 1, the retro-reflector 25 is formed such that the first total reflecting surface 27a has an inclination of 45° relative to a direction of propagation of the light transmitted through the linear retarder 8. Forming the retro-reflector 25 in this way, the light propagating from the linear retarder 8 to the retro-reflector 25 is totally reflected upon the first total reflecting surface 27a and directed toward the second total reflecting surface 27b. The light is further totally reflected upon the second total reflecting surface 27b and propagates toward the polarizer 6. Thus, the propagation path for the outgoing light from the polarizer 6 toward the retro-reflector 25 and the propagation path for the returning light from the retro-reflector 25 toward the polarizer 6 are parallel, and separated by a distance Y.

[0058] The prism 26 comprises a returning-light refracting portion 30 and a parallel plate portion 31. The returning-light refracting portion 30 has a slant surface 30a having an inclination relative to a propagating direction of returning light. By the slant surface 30a, returning light is refracted in its light propagating direction and changed in its light propagating direction to be incident on the core/clad 21b serving as the output optical fiber. Therefore, the prism 26

serves as a propagation-light path-changing element, so that the returning light is incident onto the output optical fiber.

[0059] In order for the prism 26 to function as the propagation-light path-changing element, Equation 1 must be satisfied. In Equation 1, an angle ϕ is defined by a the direction of propagation of the returning light, which has been refracted by the light refracting portion 30 of the prism 26, and an optical axis of the lens 22. Further, Equation 2 must be satisfied. Here, a spacing X is defined between the principal plane of the lens 22 and the prism 26, on the assumption that the returning-light refracting portion 30 is sufficiently small in thickness.

$$\text{[Equation 1]} \quad \phi = \tan^{-1} \frac{D}{fa} (\text{rad})$$

$$\text{[Equation 2]} \quad X = \frac{Y}{\tan \phi}$$

[0060] Further, in Equation 1, D designates a spacing between an optical axis of the core/clad 21a and an optical axis of the core/clad 21b, and fa designates a spacing between a tip of the core/clad 21a, 21b and the principal plane of the lens 22, and in Equation 2 Y designates a spacing between a propagation path of the outgoing light from the polarizer 6 to the retro-reflector 25 as the total reflection element and a propagation path of the returning light totally reflected by the retro-reflector 25 and directed toward the polarizer 6 (in other words, deviation between the outgoing and returning light paths).

[0061] The returning-light refracting portion 30 of the prism 26 is formed to satisfy Equation 1 and Equation 2, and the parallel plate portion 31 is formed to transmit outgoing light without changing the direction of light propagation.

[0062] The first embodiment has the structure to make parallel the propagation path for the outgoing light from the polarizer 6 to the retro-reflector 25 as a total reflecting element, and the propagation path for the returning light totally reflected by the retro-reflector 25 and directed toward the polarizer 6, and further the structure to refract the returning light by the light refracting portion 30 of the prism 26, so that the returning light is incident and propagates onto the core/clad 21b of the two-cored ferrule 20 serving as an output optical fiber of the collimator 19. Consequently, even if properly setting the spacing fb between the principal plane of the lens 22 and the retro-reflector 25 regardless of the spacing fa between the tip of the core/clad 21a, 21b and the principal plane of the lens 22, the returning light can be positively incident on the core/clad 21b by the prism 26 as the propagation light changing element.

[0063] This makes it easy to implement a variable optical filter unit 2 as in the foregoing by employing a general-purpose collimator, i.e. collimator having a spacing fa of approximately 1 -4 mm between the tip of the core/clad 21a, 21b and the principal plane of the lens 22. Due to this, it is possible to provide an inexpensive, small-sized variable optical filter unit 2 and a variable-gain equalizing system 1 using the same.

[0064] Note that, in order to narrow the spacing X between the principal plane of lens 22 and the prism 26 in view of size-reduction, of the variable optical filter unit 2, it is desired

to decrease the deviation between the outgoing and returning light paths as demonstrated in Equation 2.

[0065] An explanation of a second embodiment is set out below. Fig. 2 typically shows the main parts of a variable optical filter unit, which constitute a variable-gain equalizing system of a second embodiment. Note that, in explaining the second embodiment, the same structural parts as those of the foregoing variable-gain equalizing system 1 and variable optical filter unit 2 are designated with the same reference characters, in order to omit the explanation of duplicated common parts. Therefore, although the variable optical filter unit 2 has the foregoing polarizer 6, Faraday rotator 7, linear retarder 8, magnetic-field applying device 11 and temperature control device 13, these components are omitted in Fig. 2.

[0066] The variable optical filter unit 2 featured in the second embodiment is structured with a collimator 19 comprising the two-cored ferrule 20 and the lens 22, as shown in Fig. 2. These components are arranged in such a way that the core/clad 21a, 21b of the two-cored ferrule 20 are symmetrically arranged around the optical axis of the lens 22.

[0067] For employing such a collimator 19, the angle ϕ' defined between a propagation path of the returning light coming from a prism 26 and being incident on the lens 22 and an optical axis of the lens 22, must be equal to the angle ϕ' defined between the outgoing light propagating from the lens 22 to the prism 26 and the optical axis of the lens 22.

[0068] Accordingly, the second embodiment has a prism 26 on the light propagation path, having the unique shape, as shown in Fig. 2. The prism 26 has an outgoing light refracting portion

33 and a returning light refracting portion 34 serving as path-changing element for propagating light. The outgoing light refracting portion 33 has a structure to refract the outgoing light outputted from the lens 22 (light having an inclination ϕ' relative to the optical axis of the lens 22), so that the propagation direction of the outgoing light is parallel to the optical axis of the lens 22. The returning light refracting portion 34 is structured to refract the returning light, which was totally reflected by the retro-reflector 25 (light parallel with the optical axis of the lens 22) to give it an inclination of nearly the same angle ϕ' as that of the outgoing side relative to the optical axis of the lens 22. The inclination ϕ' can be determined by Equation 3.

$$[\text{Equation 3}] \quad \phi' = \tan^{-1}(D/(2fa)) \quad (\text{rad})$$

[0069] In Equation 3, D designates a spacing between the optical axis of the core/clad 21a and the optical axis of the core/clad 21b, and fa designates a spacing between the tip of the core/clad 21a, 21b and the principal plane of the lens 22.

[0070] Further, the spacing between the intersection P of outgoing light and returning light and the principal plane of the lens 22 is equal to the spacing fa between the tip of the core/clad 21a, 21b and the principal plane of the lens 22. In theory, the prism 26 would be preferably arranged such that the prism 26 at its portion on the collimator side is positioned at the intersection P of the outgoing light and returning light. However, the outgoing light and returning light actually have a beam diameter. Consequently, the prism 26 is preferably positioned with a spacing to the intersection P of outgoing light and returning light as shown in Fig. 2, in order not to

apply the beam to an intersecting point of the outgoing light refracting portion 33 and the returning light refracting portion 34.

[0071] According to the second embodiment, the propagation path of the outgoing light from the polarizer 6 to the retro-reflector 25 as a total reflecting element and the propagation path of the returning light totally reflected by the retro-reflector 25 and directed toward the polarizer 6 are parallel, and further a structure is provided to refract the returning light, so that it propagates to and is incident on the core/clad 21b of the two cored ferrule 20 serving as an outputting optical fiber of the collimator 19. Consequently, the spacing fb between the principal plane of the lens 22 and the retro-reflector 25 can be properly set, regardless of the spacing fa between the tip of the core/clad 21a and the principal plane of the lens 22. This makes it possible to employ a general-purpose collimator 19, thus reducing the size and cost of the variable optical filter unit 2 or variable-gain equalizing system 1.

[0072] An explanation of a third embodiment of the present invention is set out below.. A variable optical filter unit, which is featured in a variable-gain equalizing system of the third embodiment, uses a single-cored collimator 35 (35a, 35b) as shown in Figs. 3A and 3B instead of employing a collimator 19 using a two-cored ferrule 20 as shown in the foregoing embodiments. The third embodiment is characterized by the use of the single-cored collimator 35, and its unique structure, which is a consequence of using the collimator 35. The other structural elements are similar to those of the foregoing embodiments. In explaining the third embodiment, the same structural parts as those of the foregoing variable-gain

equalizing system 1 and variable optical filter unit 2 are designated with the same reference characters, in order to omit repeating explanations. Therefore, although the variable optical filter unit 2 shown in Figs. 3A and 3B has a polarizer 6, a Faraday rotator 7, a linear retarder 8, a magnetic field applying device 11 and temperature control device 13 similarly to those shown in the foregoing embodiment, these components are not shown in Figs. 3A and 3B.

[0073] The single-cored collimator 35 comprises one optical fiber 36 and a lens 37 with their optical axes aligned. The third embodiment has two collimators 35, one of which (collimator 35a in the example of Fig. 3A, 3B) serves as an input collimator while the other (collimator 35b) serves as an output collimator.

[0074] In the example shown in Fig. 3A, the collimators 35a, 35b are arranged with intersecting optical axes (perpendicularly arranged in the example shown in Fig. 3A). Also, a prism 26 having a parallel plate portion 40 and a total reflecting portion 41 is provided on the light propagation path. The parallel plate portion 40 is a portion to transmit light without changing the propagation direction thereof. The total reflecting portion 41 is formed such that for returning light the angle of incidence is greater than a critical angle, thereby totally reflecting the incident light. Therefore, the total reflecting portion 41 serves as a total reflecting element to totally reflect the returning light toward the outputting collimator.

[0075] In the example shown in Fig. 3A, the outgoing light coming from the input collimator 35a transmits through the parallel plate portion 40 of the prism 26 and travels toward the

retro-reflector 25 where it is totally reflected with an optical-path deviation γ by the retro-reflector 25 and travels toward the prism 26. The propagation direction of the returning light is changed to a direction toward the output collimator 35b by the total reflecting portion 41 of the prism 26.

[0076] In the example shown in Fig. 3B, the collimators 35a, 35b are arranged side-by-side with their optical axes being parallel. Meanwhile, there are provided a first total reflecting element (e.g. total reflecting mirror) 43 and a second total reflecting element (e.g. total reflecting mirror) 44. The returning light totally reflected by the retro-reflector 25 is changed in its propagation direction by the total reflecting element 43 from a state parallel with the outgoing light propagation path to a direction toward the second total reflecting element 44. The light is further changed by the second total reflecting element 44 to a direction coincident with the optical axis of the outputting collimator 35b, thus being incident and propagated onto the outputting collimator 35b. Therefore, the example shown in Fig. 3B comprises a propagation light path changing element by the first total reflecting element 43 and the second total reflecting element 44.

[0077] Also in the third embodiment, the spacing between the lens 37 and the retro-reflector 25 can be properly set without being regulated by the spacing between a tip of an optical fiber 36 of the collimator 35 and the lens 37, similarly to the foregoing embodiments. Consequently, a general-purpose single-cored collimator 35 can be employed. Furthermore, because there is no need to increase the spacing between the tip of the optical fiber 36 and the lens 37, it is possible to provide a

small-sized variable, optical filter unit 2 and a variable-gain equalizing system 1 using the same.

[0078] Note that this invention is not limited to the foregoing embodiments but can be realized by various other embodiments. For example, although the foregoing embodiments arranged the polarizer 6, the Faraday rotator 7 and the linear retarder 8 in this order, the order of arrangement of the Faraday rotator 7 and the linear retarder 8, for example, are not limitative, i.e. the linear retarder 8 and the Faraday rotator 7 may be arranged so that the linear retarder 8 is positioned between the polarizer 6 and the Faraday rotator 7. In this case, similar effects to those of the foregoing embodiments can be obtained.

[0079] Meanwhile, although the foregoing embodiments interpose the prism 26 as a propagation light path changing element and a first and a second total reflecting elements 43, 44 between the collimator 19, 35 and the polarizer 6, the propagation light path changing element is not restricted to be placed in a certain position. For example, it may be arranged anywhere on the light propagation path between the polarizer 6 and the retro-reflector 25. It is however noted that the polarizer 6, the Faraday rotator 7 and the linear retarder 8 are structured to pass both of outgoing light and returning light.

[0080] Furthermore, in the foregoing embodiments, the monitor device 3 of the variable gain equalizing system 1 monitored the input signal light to the variable gain equalizing system 1. It is possible to structure it such that, for example, the monitor device 3 is provided on an output side of the variable gain equalizing system 1 to feedback-control each variable of the optical filter unit 2.

[0081] Furthermore, although in the foregoing embodiments the temperature control device on the linear retarder 8 was provided as a phase difference varying device, a variable phaser using a Faraday rotator may be provided as a phase difference changing device as described before.

[0082] Furthermore, it is possible to adopt a structure as shown in Fig. 4. In the example shown in Fig. 4, a total reflecting mirror 45 is provided as a total reflecting element instead of the retro-reflector shown in the foregoing embodiments. This provides a structure, in which the propagation passage of the outgoing light in a direction of from the polarizer 6 to the total reflecting mirror 45 and the propagation passage of the returning light in a direction of from the total reflecting mirror 45 to the polarizer 6 coincide.

[0083] Meanwhile, as shown in Fig. 4, an optical fiber 36 using a single-cored collimator 35 and connected at one end to the collimator 35 is provided with an optical circulator 46. The optical circulator 46 is an optical module, in which the input light entering through port 1 is exiting through the port 2 and the output light entering through port 2 is exiting through port 3, as shown in Fig. 4. The light entering at port 1 exits at port 2, and propagates to optical fiber 36, and from a tip of the optical fiber 36 through a lens 37 toward the polarizer 6.

[0084] Meanwhile, the returning light totally reflected by the total reflecting mirror 45 enters and propagates through the optical fiber 36 via the lens 37, and then enters the optical circulator 46, port 3 being the output port.

[0085] Also in the case as illustrated in Fig. 4, the spacing between the principal plane of the lens 37 and the total

reflecting mirror 45 can be properly set, regardless of the spacing between the tip of the optical fiber 36 and the principal plane of the lens 37, similarly to the foregoing embodiment. Accordingly, it is possible to use a general-purpose collimator 35 and provide an inexpensive, small sized variable optical filter unit 2 and a variable gain equalizing system 1 using the same.

[0086] According to the present invention, because the propagation light path changing device is provided, the propagation light path changing device can guide the returning light totally reflected by the total reflecting element to the output optical fiber of the collimator, without the necessity to make the spacing between the optical fiber tip of the collimator and the lens principal plane equal to the spacing between the lens principal plane of the collimator and the total reflecting element. This makes it possible to use a general-purpose collimator and provide an inexpensive, small-sized variable optical filter unit and a variable gain equalizing system using the same.

[0087] In the case that the total reflecting element is structured by a retro-reflector, the propagation path of the outgoing light in a direction of from the polarizer to the retro-reflector and the propagation path of the returning light in a direction of retro-reflector to the polarizer are parallel, thereby providing flexibility in the arrangement of the optical elements such as a polarizer and Faraday rotator.

[0088] In the case that a prism is provided as propagation light path changing device or a parallel plate portion is provided in the prism, it is possible to promote cost reduction for the

variable optical filter unit and a variable gain equalizing system using same, because the prism is an inexpensive element.

[0089] In the case having a collimator in for the input signal as well as for the output signal, the spacing between an input optical fiber and an output optical fiber can be properly set, providing a good deal of flexibility in the design of a variable optical filter unit.

[0090] Also in the case that the optical fiber connected to the collimator is provided with an optical circulator, and that the propagation path of the outgoing light in a direction of from the collimator to the total reflecting element and the propagation passage of the returning light totally reflected by the total reflecting element and directed toward the collimator coincide, there is no need to make the spacing between the optical fiber tip and the lens principal plane of the collimator equal to the spacing between the lens principal plane of the collimator and the total reflecting device. This makes it possible to use a general-purpose collimator and provide an inexpensive, small-sized variable optical filter unit and a variable gain equalizing system using the same.

What is claimed is:

1. A variable optical filter unit having a sinusoidal-like light attenuation response wavelength characteristic, having a collimator integrated with an input optical fiber and an output optical fiber that are arranged side by side, and a lens arranged with a spacing to a tip of said input and output optical fibers commonly for input and output, said variable optical filter unit comprising:

arranged on a light exit side of said collimator, in an order:

a polarizer; and

a total reflecting element for totally reflecting a signal light to return a propagation direction of the light;

provided between said polarizer and said total reflecting element:

a Faraday rotator for rotating a polarizing plane of an incident light according to an applied magnetic field;

a birefringence crystal for providing, depending on a wavelength, a phase difference between a component propagating with polarization in a crystal optical axis direction and a component propagating with polarization in a direction orthogonal thereto; and

a phase difference changing device for changing, without depending on the wavelength, the phase difference between the component propagating with polarization in the crystal optical axis direction and the component propagating with polarization in the direction orthogonal thereto;

a propagation light path changing device being provided to direct returning light totally reflected by said total reflecting element to said output optical fiber of said collimator.

2. A variable optical filter unit according to claim 1, wherein said total reflecting element comprises a retro-reflector having a first total reflecting surface and a second total reflecting surface that are orthogonal to each other, the first total reflecting surface being provided having an inclination of approximately 45 degrees relative to a propagation direction of an incident light to totally reflect the incident light toward the second total reflecting surface, the second total reflecting surface being structured to totally reflect a light from the first total reflecting surface toward said polarizer, said retro reflector making parallel, and separated by a spacing, a propagation path of an outgoing light in a direction from said polarizer to said retro-reflector and a propagation path of a return light in a direction from said retro-reflector to said polarizer.

3. A variable optical filter unit according to claim 2, wherein said collimator has a structure in which an optical axis of said input optical fiber and an optical axis of said lens coincide, said propagation light path changing device comprising a prism to refract a returning light to be incident on said output optical fiber through said lens of said collimator.

4. A variable optical filter unit according to claim 3, wherein a parallel plate portion is provided in said prism, which operates as said propagation light path changing device, to transmit an outgoing light exiting through said lens from said input optical fiber of said collimator without changing a propagation direction thereof.

5. A variable optical filter unit according to claim 2, wherein said collimator comprises an input optical fiber and an output optical fiber that are symmetrically arranged about the

optical axis of said lens, said propagation light path changing device comprising a prism to refract the returning light to be incident on said output optical fiber through said lens of said collimator, said prism having an outgoing light refracting portion to refract an outgoing light, which propagated from said input optical fiber through said lens, and change a propagation direction of the outgoing light to a direction parallel with the optical axis of said lens of said collimator.

6. A variable optical filter unit according to claim 1, wherein said collimator comprises:

an input collimator integrated with an input optical fiber and a lens disposed with a spacing to a tip of said optical fiber; and

an output collimator integrated with an output optical fiber and a lens disposed with a spacing to a tip of said optical fiber.

7. A variable optical filter unit according to claim 2, wherein said collimator comprises:

an input collimator integrated with an input optical fiber and a lens arranged through a spacing to a tip of said optical fiber; and

an output collimator integrated with an output optical fiber and a lens arranged through a spacing to a tip of said optical fiber.

8. A variable optical filter unit according to any of claims 6 and 7, wherein said input collimator and said output collimator are arranged side by side, said propagation light path changing device having a first total reflecting element and a second total reflecting element, said first total reflecting element totally reflecting the returning light toward said second total

reflecting element, said second reflecting element totally reflecting the returning light from said first total reflecting element toward said output optical fiber of said output collimator.

9. A variable optical filter unit according to any of claims 6 and 7, wherein said input collimator and said output collimator are arranged in such a manner that their optical axes intersect, said propagation light path changing device comprising a total reflecting element to totally reflect the returning light toward said output collimator.

10. A variable optical filter unit having a sinusoidal-like light attenuation waveform characteristic, having a collimator integrated with a tip of an optical fiber and a lens disposed on a side of the tip of said optical fiber and spaced therefrom, said variable optical filter unit comprising:

- disposed on a light exit side of said lens of said collimator, in an order,

- a polarizer; and

- a total reflecting element for totally reflecting a signal light to return a propagation direction of the light;

- disposed between said polarizer and said total reflecting element:

- a Faraday rotator for rotating a polarizing plane of an incident light according to an applied magnetic field;
 - a birefringence crystal for providing, depending on a wavelength, a phase difference between a component propagating with polarization in a direction of an optical axis of the crystal and a component propagating with polarization in a direction orthogonal thereto; and

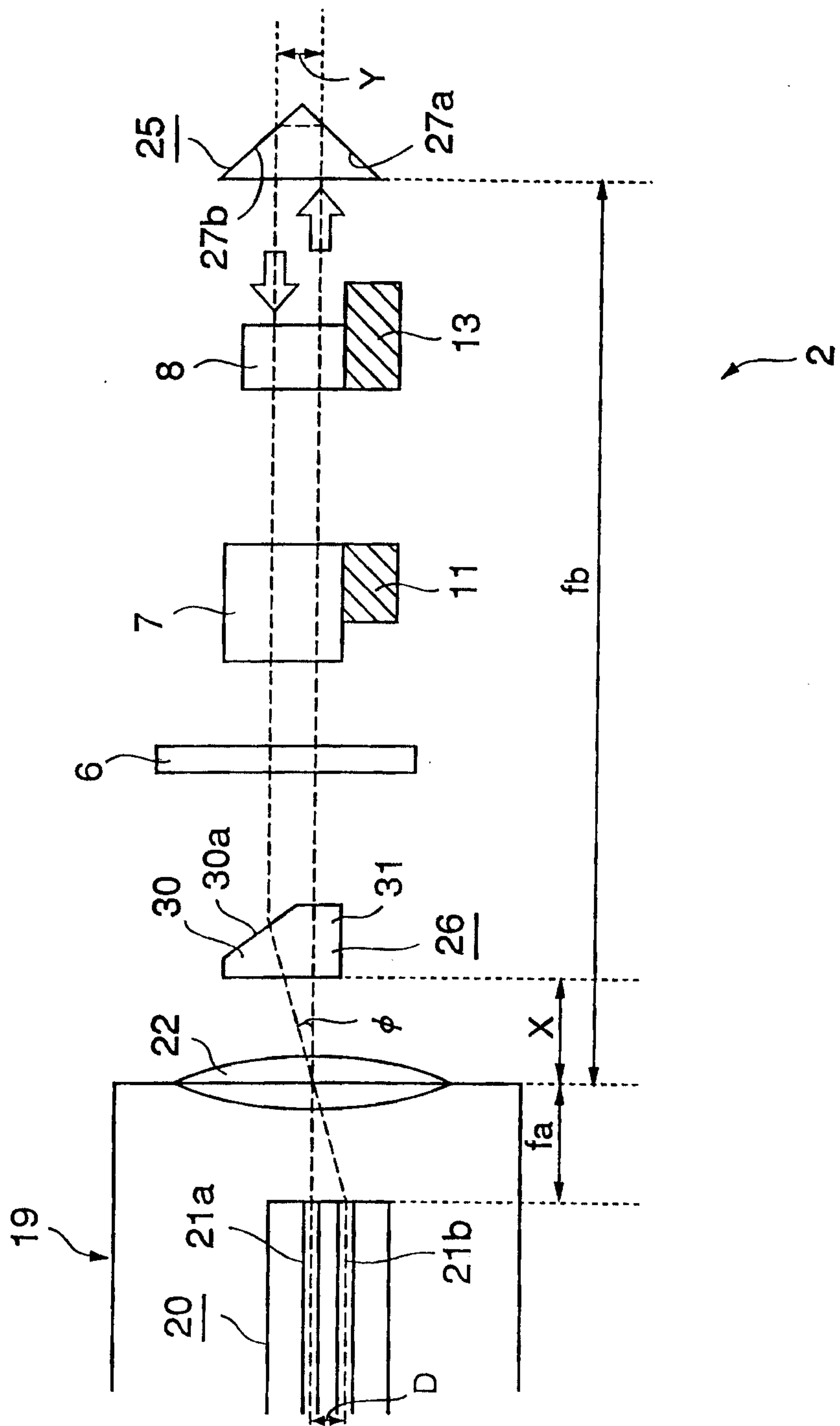
a phase difference changing device for changing, independent of the wavelength, the phase difference between the component propagating with polarization in the direction of the optical axis of the crystal and the component propagating with polarization in the direction orthogonal thereto;

a propagation path of the returning light totally reflected by said total reflecting element and directed toward said collimator being coincident with a propagation path of the outgoing light directed from said collimator toward said total reflecting element; and
an optical circulator being interposed in an optical fiber connected to said collimator.

11. A variable gain equalizing system, compensating variations in a wavelength characteristic of an input signal light, comprising:

a plurality of variable optical filter units having a sinusoidal-like light attenuation amount wavelength characteristic, arranged in a propagation direction of the light, having a structure to produce a compensating light attenuation amount wavelength characteristic having a pattern form to compensate for a waveform characteristic of the input signal light by adding together sinusoidal-like light attenuation characteristics of said plurality of variable optical filter units, and having a structure for varying at least one of phase and amplitude of the sinusoidal-like light attenuation amount wavelength characteristics of said variable optical filter units depending on variation in a light attenuation amount wavelength characteristic of the input signal light, each of said variable optical filter units being a variable optical filter unit according to any of claim 1 and 10.

Fig. 1



2
Fi 50

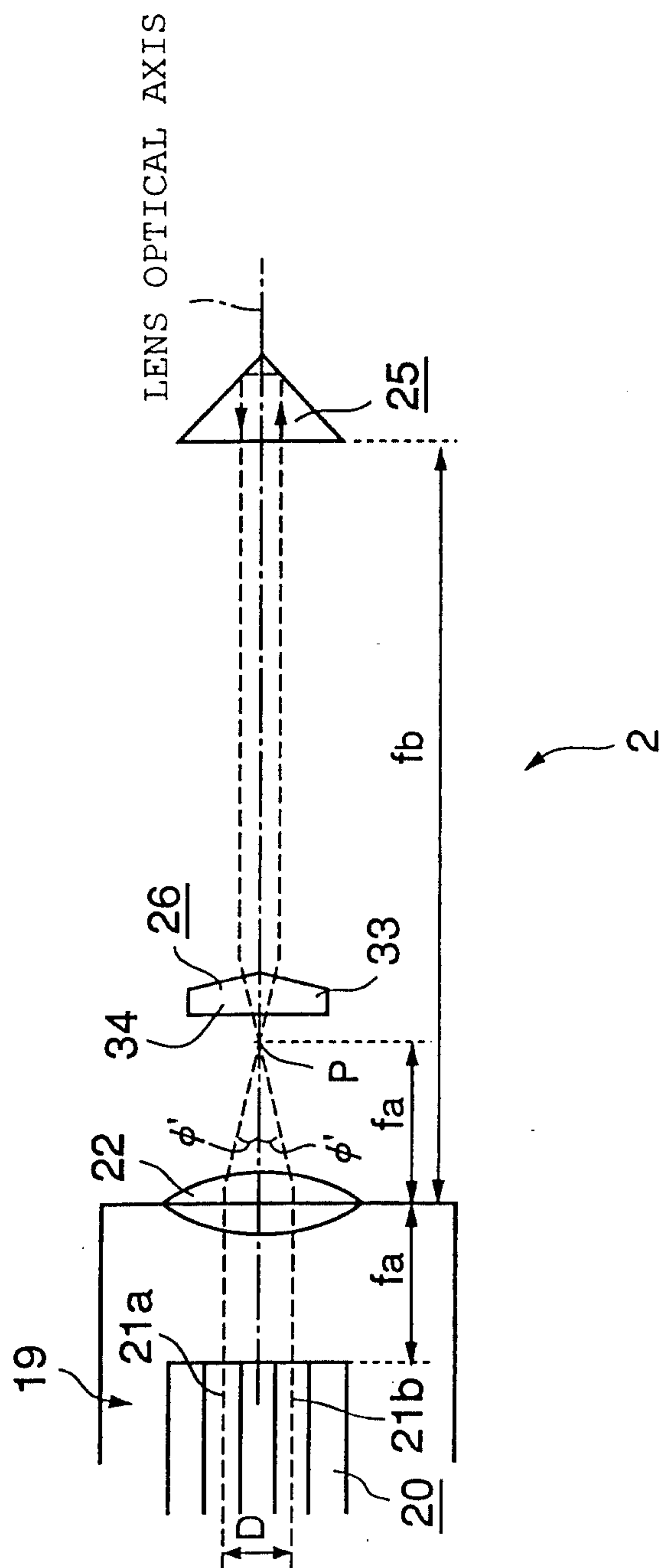


Fig. 3A

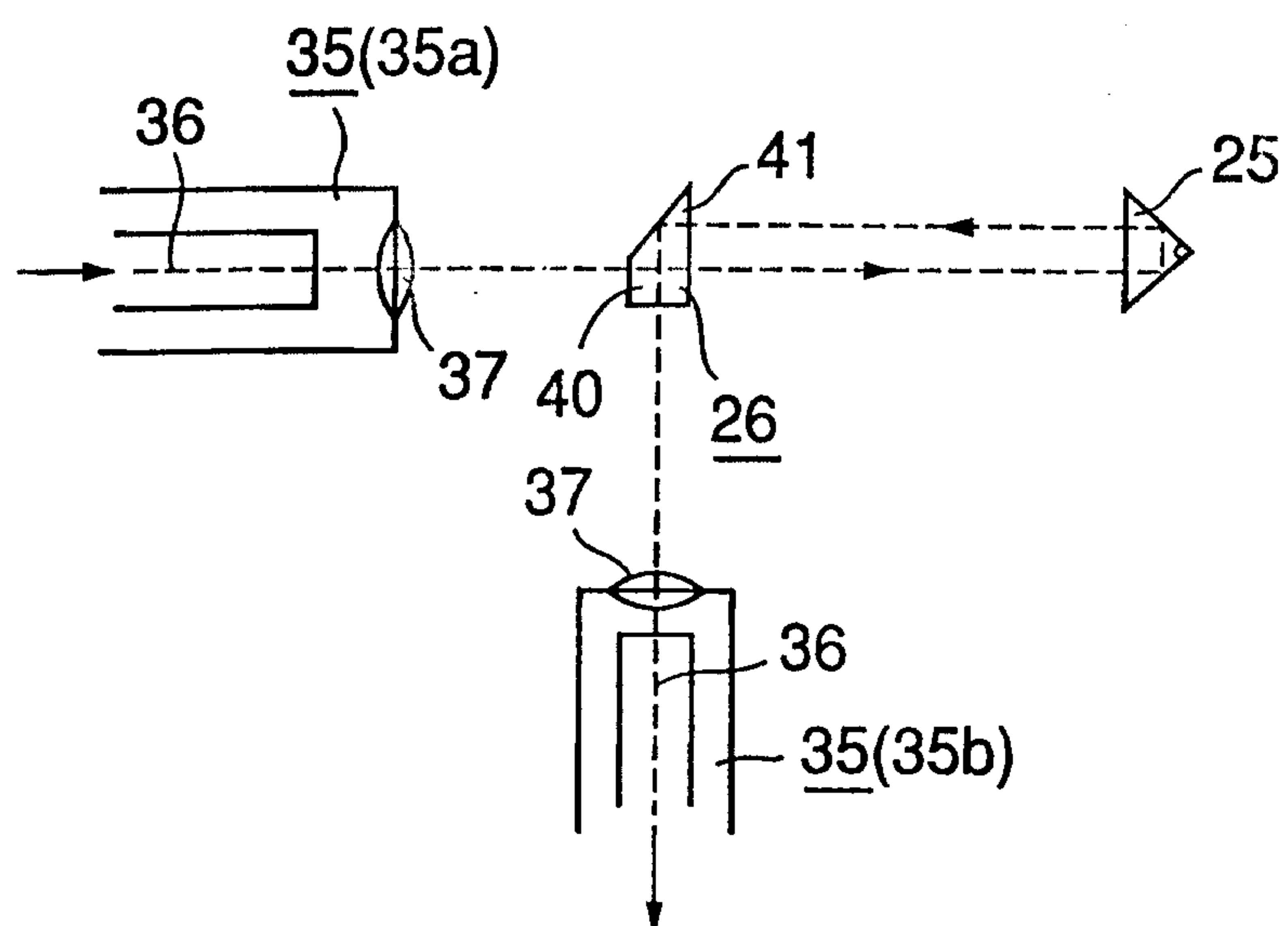


Fig. 3B

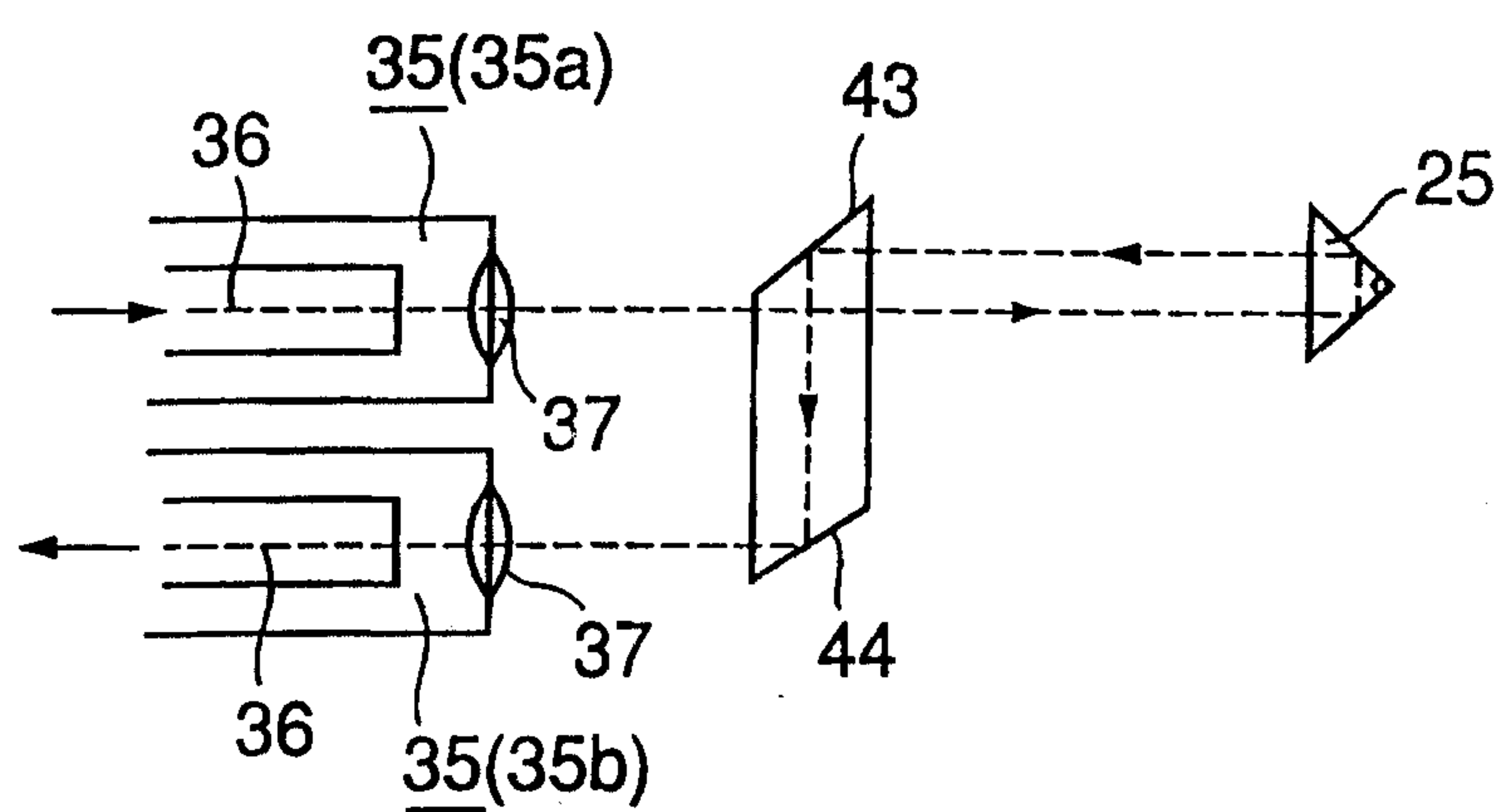


Fig. 4

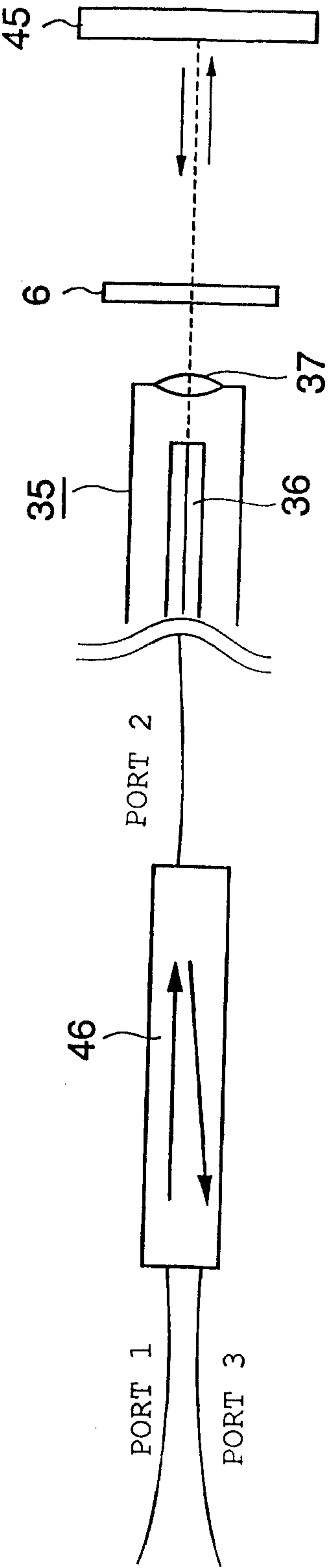


Fig. 5

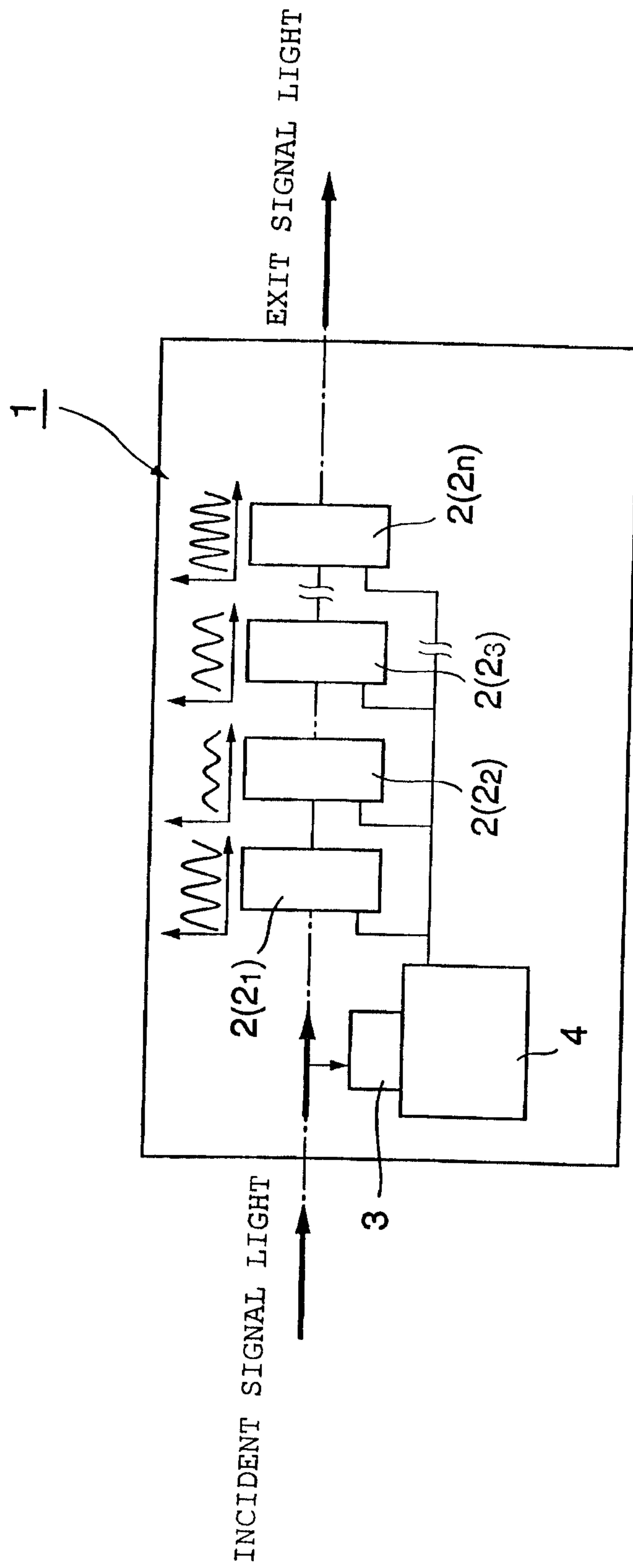


Fig. 6A

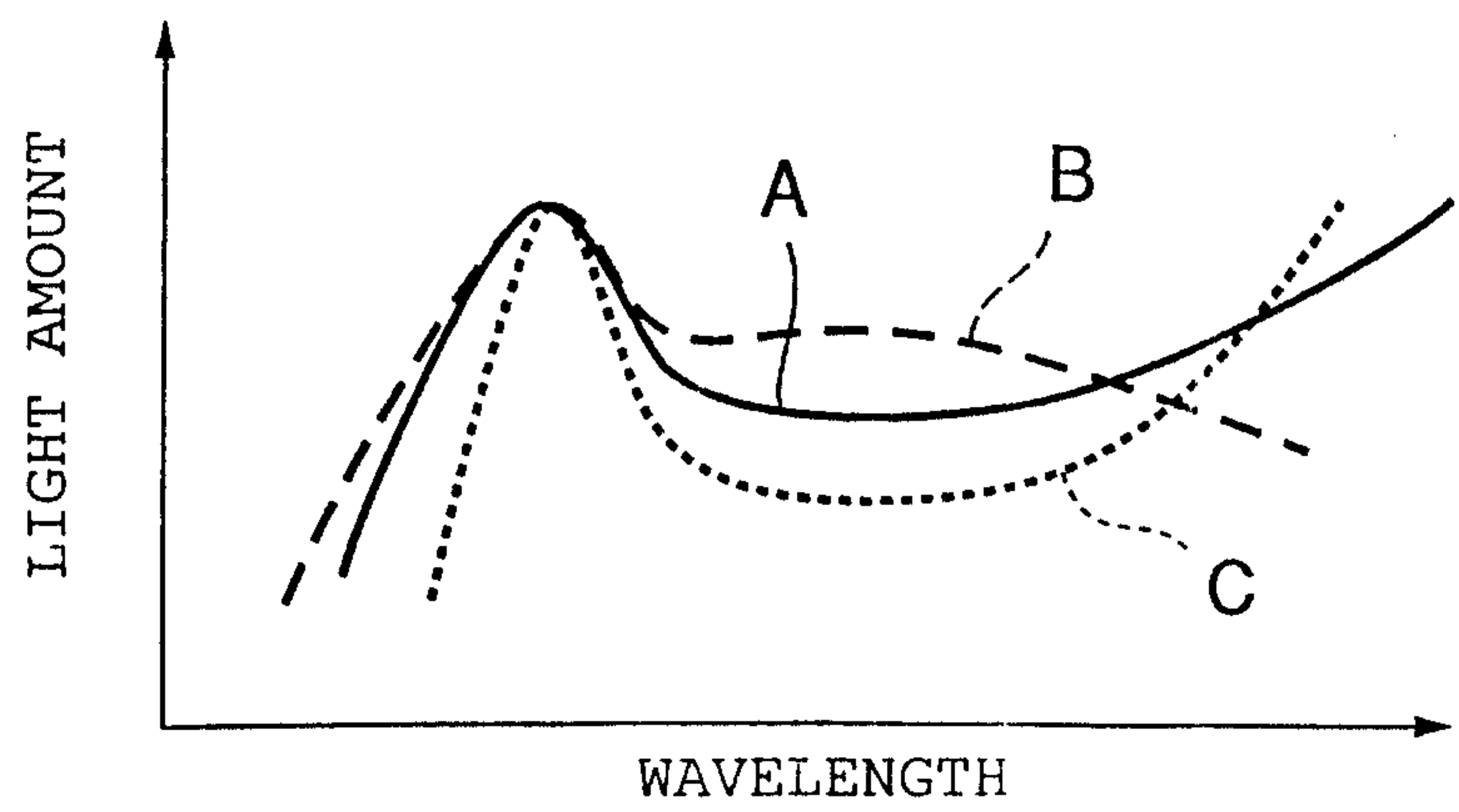


Fig. 6B

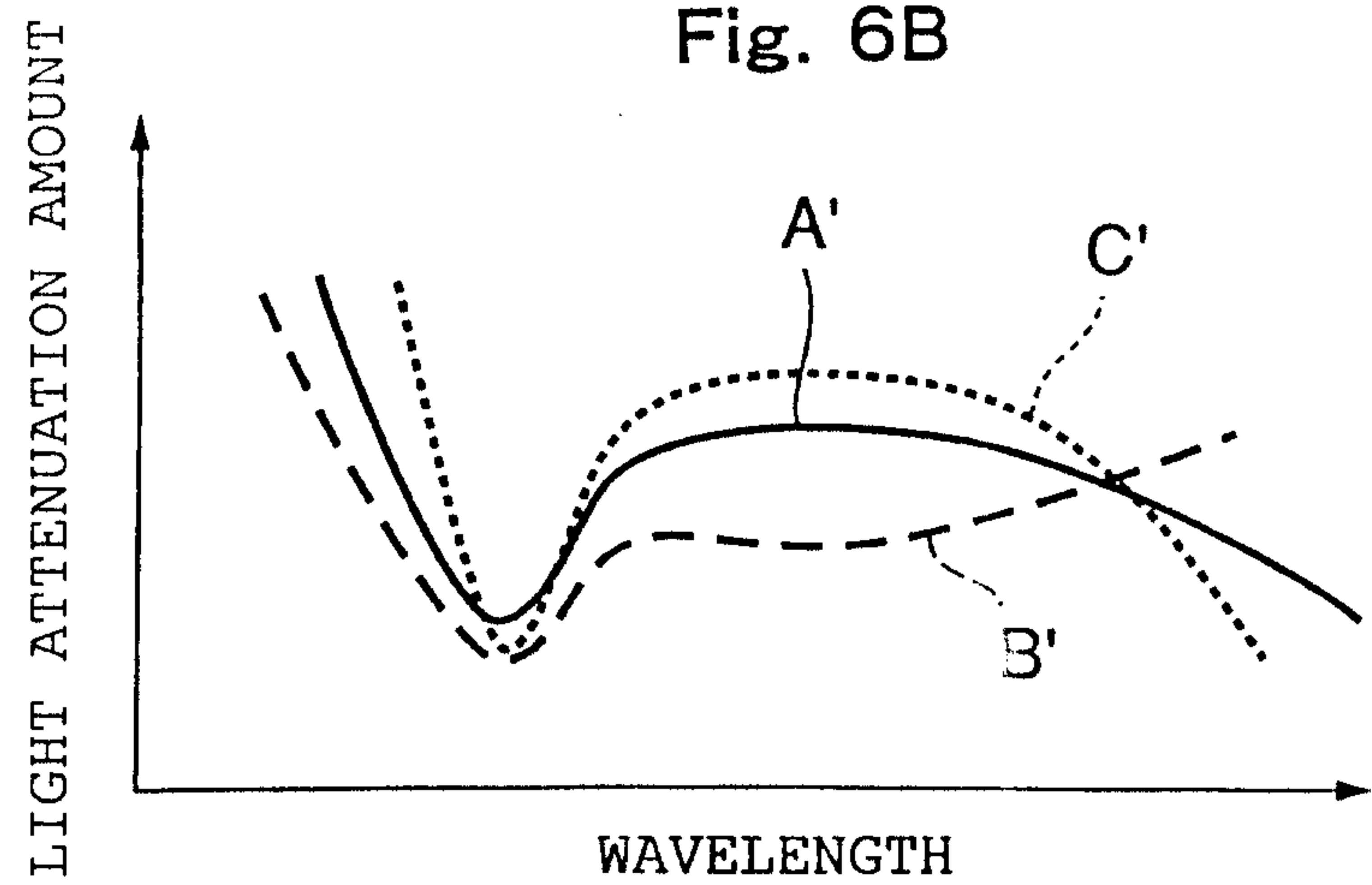


Fig. 6C

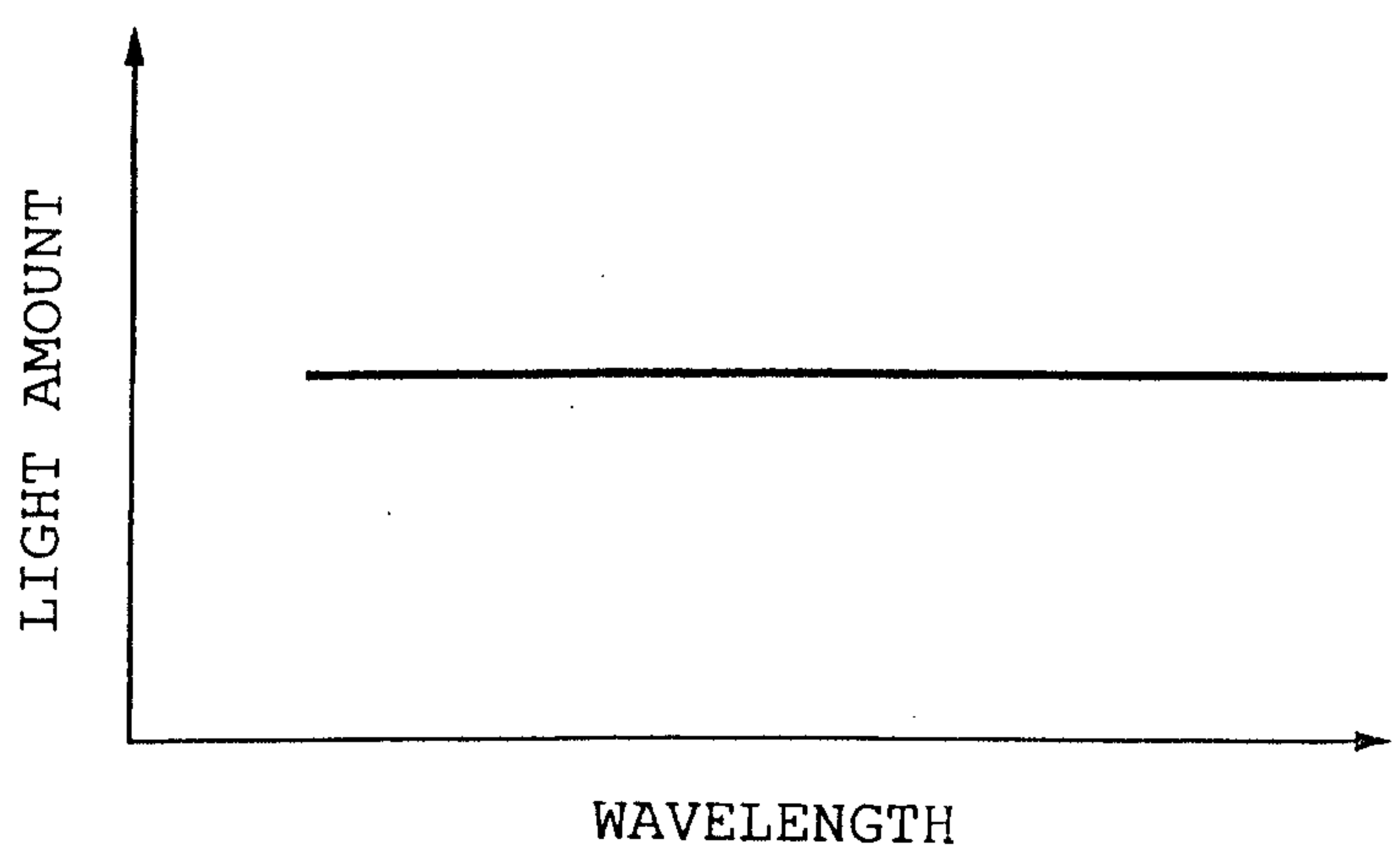


Fig. 7

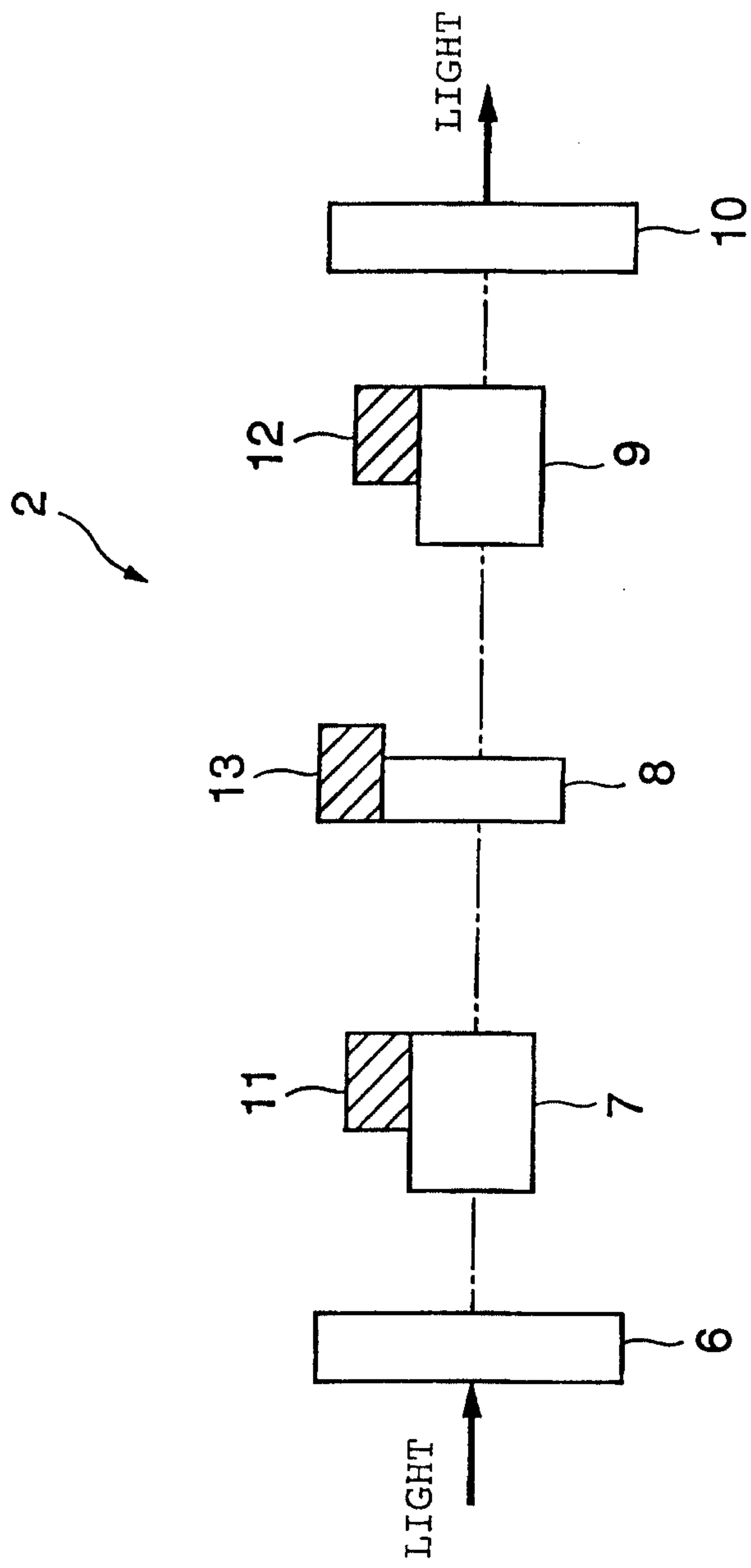


Fig. 8

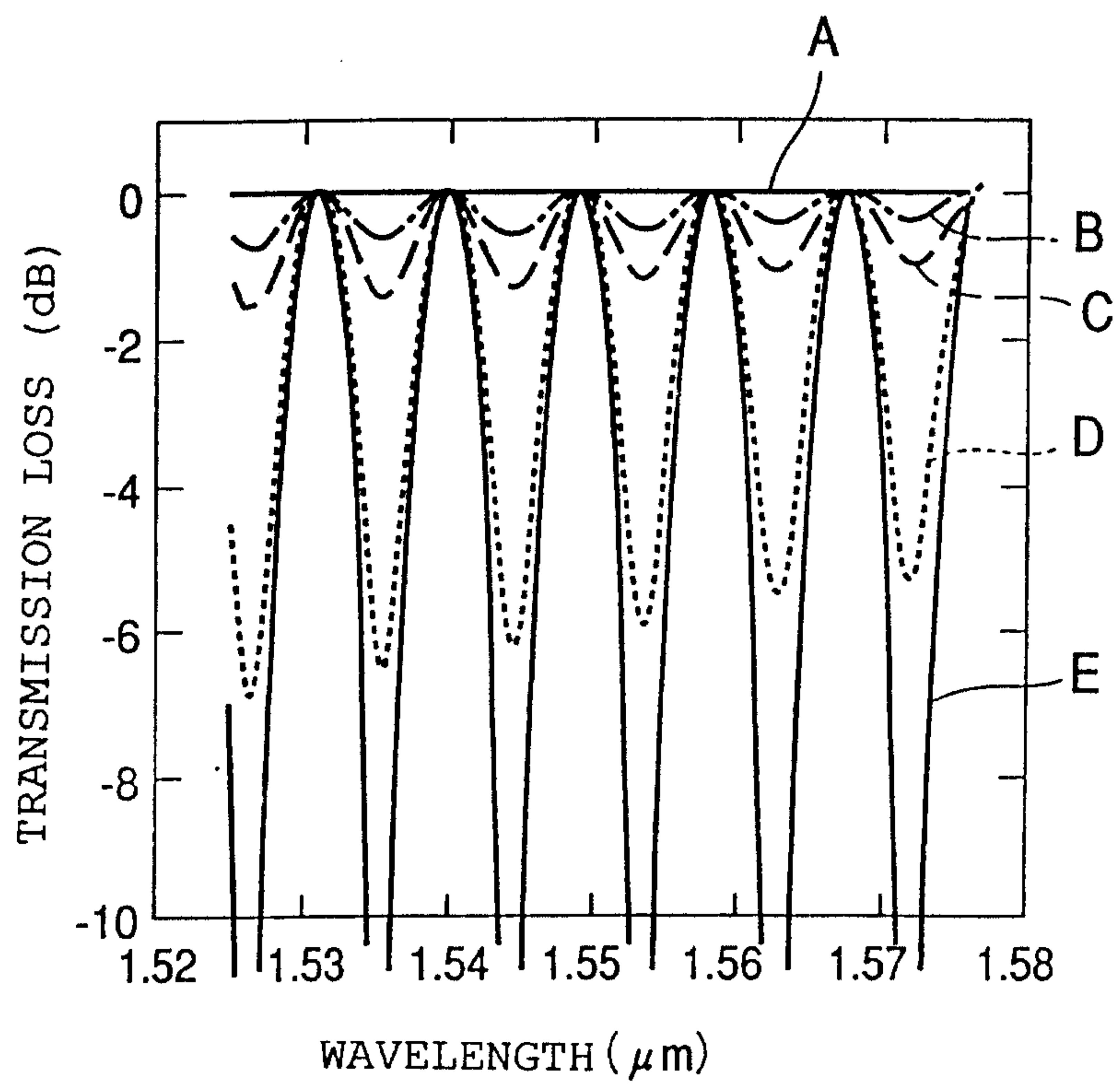


Fig. 9

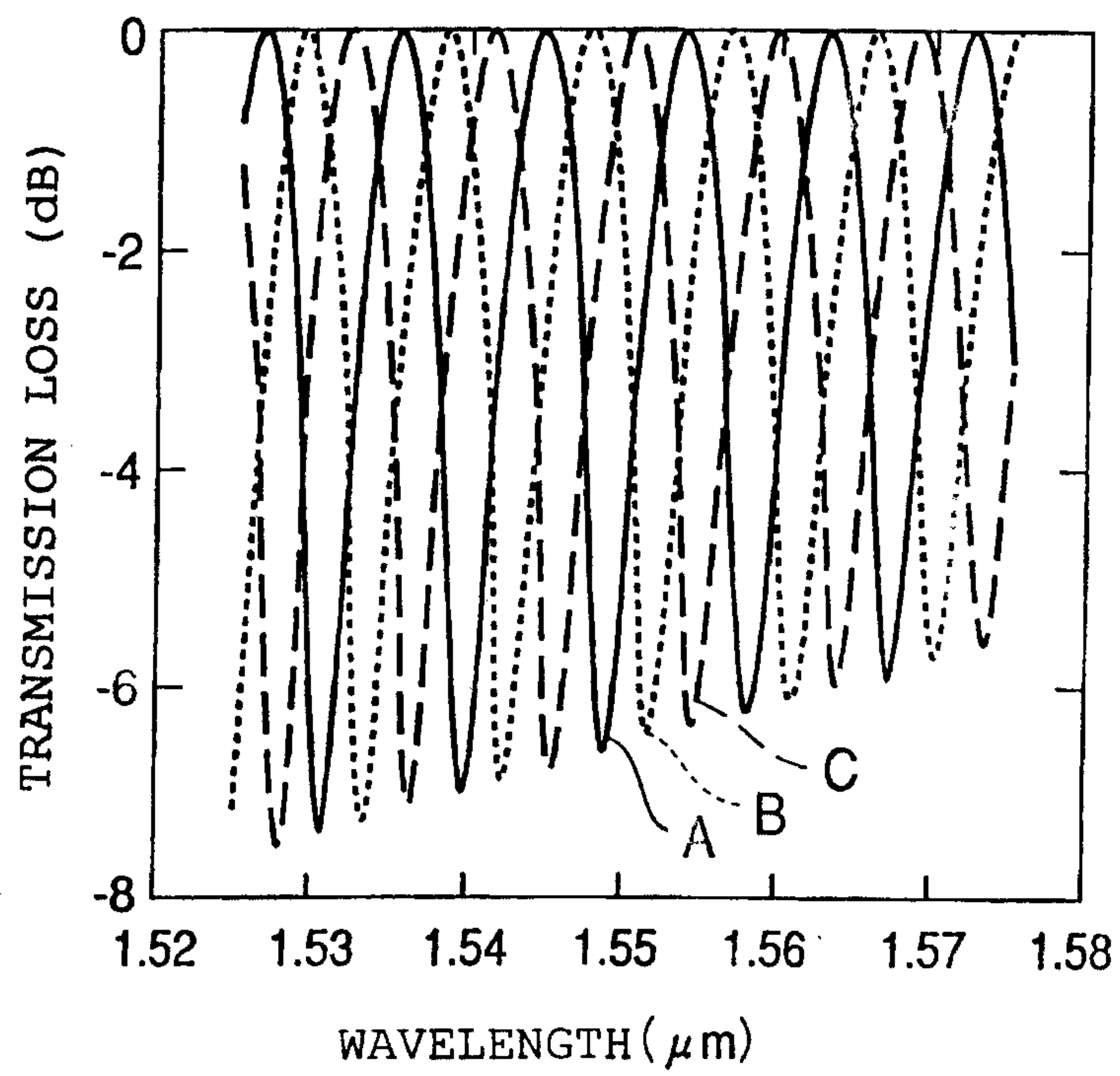


Fig. 10

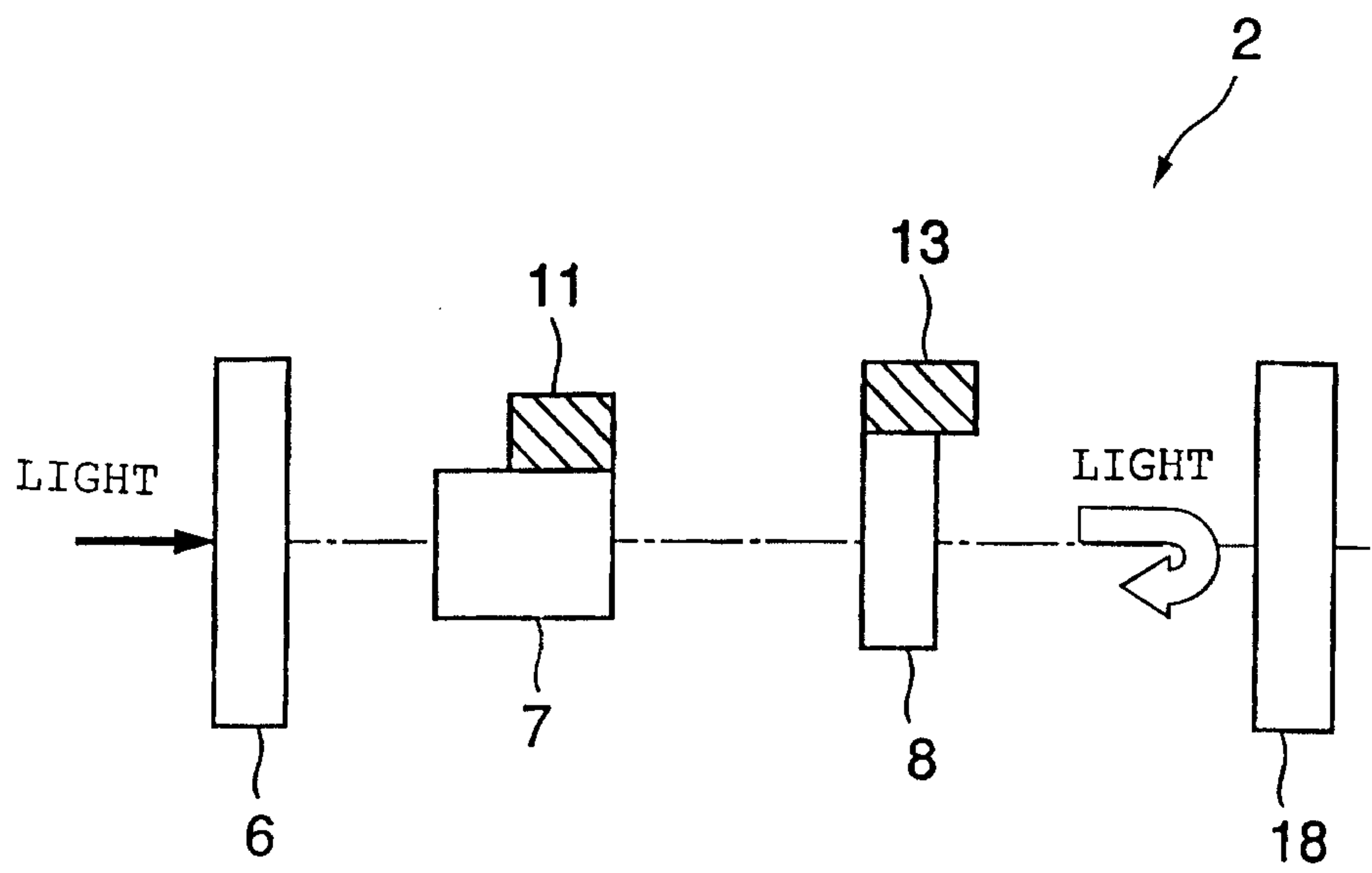


Fig. 11

