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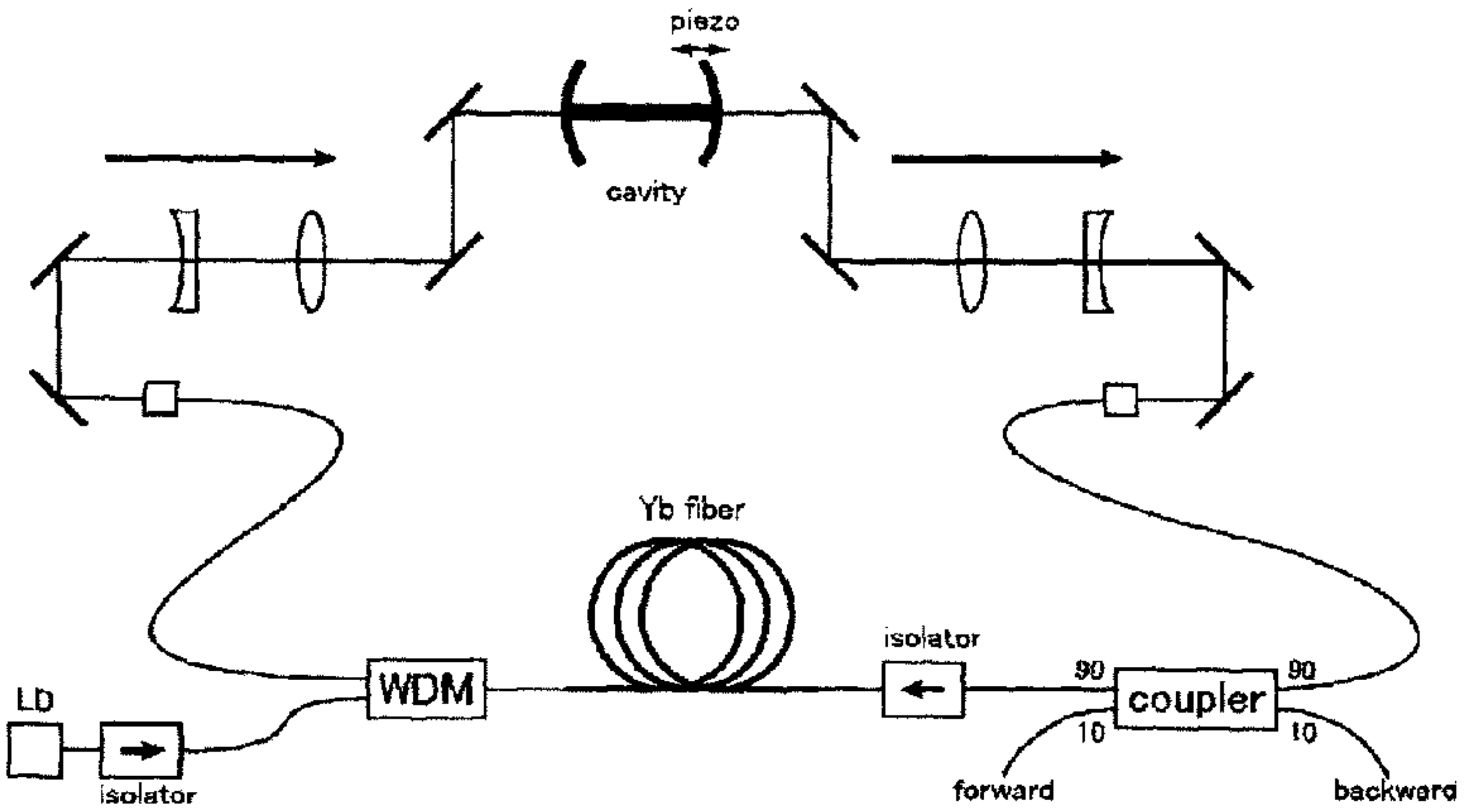
(54) **Titre :** SOURCE DE LUMIERE LASER UTILISANT LA DIFFUSION COMPTON
(54) **Title:** LIGHT SOURCE LASER UTILIZING LASER COMPTON SCATTERING



(57) **Abrégé/Abstract:**
A laser oscillation device stabilizing resonance, even when an optical resonator's finesses are increased, and generating stronger laser light by accumulating laser light in the resonator. The laser oscillation device includes a laser light source for excitation which generates laser light for excitation, a rare-earth fiber which generates laser light having a desired wavelength when laser light generated by the laser light source for excitation is supplied, an optical resonator, including two concave or flat mirrors that accumulate laser light generated with the fiber, an optical isolator, between the resonator and the fiber, that guides laser light from the fiber to one side of the resonator while blocking laser light in the opposite direction, and a circulation optical path that introduces laser light emitted from the other side of the resonator and accelerates resonance by returning the laser light to the resonator via the fiber and the optical isolator.

Abstract

A laser oscillation device stabilizing resonance, even when an optical resonator's finesses are increased, and generating stronger laser light by accumulating laser light in the resonator. The laser oscillation device includes a laser light source for excitation which generates laser light for excitation, a rare-earth fiber which generates laser light having a desired wavelength when laser light generated by the laser light source for excitation is supplied, an optical resonator, including two concave or flat mirrors that accumulate laser light generated with the fiber, an optical isolator, between the resonator and the fiber, that guides laser light from the fiber to one side of the resonator while blocking laser light in the opposite direction, and a circulation optical path that introduces laser light emitted from the other side of the resonator and accelerates resonance by returning the laser light to the resonator via the fiber and the optical isolator.

DESCRIPTION

LIGHT SOURCE LASER UTILIZING LASER COMPTON SCATTERING

TECHNICAL FIELD

[0001]

The present invention relates to a laser device which generates strong laser light, and in particular, relates to light source laser utilizing laser Compton scattering enabling stable oscillation even when finesses of an optical resonator is increased.

BACKGROUND ART

[0002]

Recently, there has been performed development of a small-sized light source device utilizing laser Compton scattering. Strength of such a light source device as light source depends on strength of a realizable laser target. In a case of being based on pulse-driven linear accelerator, laser light is adopted with a method to use high-strength pulse laser or to be used as being temporally burst-amplified.

[0003]

In contrast, in a case to increase mean strength of laser with a continuously-operated system based on an accumulation ring type device and a superconducting accelerator utilizing Compton scattering as illustrated in Fig. 7, high-strength laser targets are continuously required.

[0004]

In a traditional X-ray generating device (e.g., see Patent Literature 1) which generates an X-ray with laser inverse Compton scattering at collision between laser light and electrons, strong laser light is generated using a laser generating device which includes a known high-strength mode-locking oscillator (e.g., mode-locking oscillator having performance of 500 W, 10 psec/pulse, wavelength of 1064 nm, and a repetition frequency of 150 MHz) and an optical accumulation resonator.

[0005]

Here, the optical accumulation resonator denotes a resonator which confines laser light in a space formed by closing an optical path with a plurality of mirrors. This is a promising technology with which high-strength laser light can be continuously actualized as effectively strengthening light from a relatively low-power laser light source.

[0006]

Fig. 8 illustrates a structural example of a traditional laser accumulation device. Output from a laser resonator is accumulated in an external resonator which is separately prepared. For accumulating light in the resonator, it is required to satisfy conditions under that a steady wave is generated in the resonator, that is, that a distance between mirrors is matched with an integral multiple of a half wavelength. A resonance width thereof is determined by a reflection rate of resonator mirrors and becomes narrow with usage of mirrors having high reflection rate for obtaining a higher increase rate. With a resonator having an increase rate of 1000, the resonance width becomes on the order of subnanometers in positional accuracy of the resonator mirrors, so that a resonance state is easily destroyed with environmental disturbance such as vibration. Here, in order to maintain a laser accumulation state as mechanically controlling resonance conditions, it is required to perform advanced feedback control with piezoelectric driving of the resonance mirrors. Presently, technical limitations for maintaining stable resonance stay with the increase rate on the order of 1000.

Cited Literature

Patent Literature

[0007]

Patent Literature 1: Japanese Patent Application Laid-Open No. 2009-16488

SUMMARY OF THE INVENTION

[0008]

However, since a high-strength mode-locking oscillator used in such a traditional laser oscillation device is extremely expensive, there has been a problem that the laser oscillation device itself becomes expensive. Further, a traditional laser oscillation device has a drawback to require an advanced technology for controlling a resonance state of an optical resonator in high accuracy, which determines technical limitations of an increase rate.

[0009]

Further, with a traditional laser oscillation device, there has been a problem that stable accumulation cannot be performed without considerably high accuracy of feedback control for accumulating laser pulses generated by a high-strength mode locking oscillator as guiding to an optical accumulation resonator. Furthermore, with a traditional laser oscillation device, there has been a problem that laser pulse energy in an optical accumulation resonator can be obtained only on the order of 100 μJ/pulse with accumulation amplification by a factor only on the order of 1000.

[0010]

In view of the above, an object of the present invention is to provide a laser oscillation device capable of stabilizing resonance even when finesses of an optical resonator is increased and generating laser light stronger than a traditional one by accumulating laser light in the optical resonator.

[0011]

To address the above issues, the present invention, as a first embodiment, provides a laser oscillation device which generates laser light by causing laser light generated with a rare-earth fiber to resonate using an optical resonator, comprising: a laser light source for excitation which generates laser light for excitation; a fiber laser amplifier which amplifies laser light with core excitation of a single-mode rare-earth fiber generating the laser light having a desired wavelength when laser light generated by the laser light source for excitation is supplied; an optical resonator which is structured with a surface mirror group including two concave mirrors arranged as being mutually opposed or a plurality of flat mirrors and which accumulates laser light emitted from the fiber laser amplifier; an optical isolator which is interposed between the optical resonator and the fiber laser amplifier and which guides laser light from the fiber laser amplifier to one side of the optical resonator while blocking laser light in the opposite direction; and a self-oscillation amplifying circulation optical path into which laser light emitted from the other side of the optical resonator is introduced and in which self-oscillation is induced so that laser light automatically circles continuously along the circulation optical path, by returning the laser light to the optical resonator via the fiber laser amplifier and the optical isolator and entering emitted light from the optical resonator to the fiber laser amplifier again. Here, a saturable absorbing mirror is inserted at a part of the circulation optical path and an optical path length of the circulation optical path is adjusted to an integral multiple of the optical resonance circuit.

[0012]

Further, the present invention, as a second embodiment, provides a laser oscillation device which generates laser light by causing laser light generated with a rare-earth fiber to resonate using an optical resonator, comprising: a laser light source for excitation which generates laser light for excitation; a fiber laser amplifier which amplifies laser light with core excitation of a single-mode rare-earth fiber generating the laser light having a desired wavelength when laser light generated by the laser light source for excitation is supplied; a branching/multiplexing unit which receives laser light from the laser light source for excitation at a first terminal thereof and which emits the laser light to the fiber laser amplifier; a first reflector which is connected to a second terminal of the branching/multiplexing unit; an optical resonator which is structured with a surface mirror group including two concave mirrors arranged as being mutually opposed or a plurality of flat mirrors and which accumulates laser light emitted from the fiber laser amplifier; and a second reflector which reflects laser light at one side emitted from the optical resonator and supplied via the fiber laser amplifier and which accelerates resonance of the laser light having the desired wavelength as returning the laser light to the optical resonator via the fiber laser amplifier, wherein a self-oscillation amplifying circulation optical path is structured to enter emitted light from the optical resonator again to the fiber laser amplifier, in which self-oscillation is induced so that laser light automatically circles continuously along the circulation optical path.

Here, a saturable absorbing mirror is inserted at a part of the circulation optical path and an optical path length of the circulation optical path is adjusted to an integral multiple of the optical resonance circuit.

[0013]

Here, the rare-earth fiber has a feature of including a core to which Yb is doped. Further, laser light emitted from the other side of the optical resonator is introduced, a part of the introduced laser light to the outside is emitted, and resonance is accelerated by returning most of the laser light to the optical resonator via the rare-earth fiber and the optical isolator.

[0014]

Further, the optical resonator has a feature of being a Fox Smith interferometer type structured with two concave mirrors and one flat mirror.

[0015]

With the above, according to the laser oscillation device of the present invention, it may be possible to stabilize resonance even when finesses of the optical resonator is increased and to generate strong laser light as accumulating laser light in the optical resonator.

[0016]

Further, even in a case that a concave mirror group or a flat mirror group with a reflection rate of 99.99% is used in the high-finesses optical resonator, the present device may provide stable resonance and generate strong laser light as accumulating laser light in the optical resonator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017]

Fig. 1 is a view illustrating a concept of a circling oscillation type optical accumulation device.

Fig. 2 illustrates a structure of a laser oscillation device with the circling oscillation type accumulation according to a first embodiment of the present invention.

Fig. 3 illustrates a structure of a laser oscillation device with a loop-back oscillation type optical accumulation according to a second embodiment of the present invention.

Fig. 4 indicates excitation LD current and oscillation strength in the present device.

Fig. 5 indicates behaviors of light strength in the present device.

Fig. 6 indicates an application of the present invention to laser for driving an electron gun.

Fig. 7 is a view for describing a concept of a Compton light source.

Fig. 8 is an explanatory view of a structure of a traditional laser accumulation device.

EMBODIMENT OF THE INVENTION

[0018]

1. Description of a first embodiment of the present invention

Fig. 1 is a view illustrating a concept of a circling oscillation type optical accumulation device. Fig. 2 illustrates a structure of a laser oscillation device with the circling oscillation type optical accumulation being the first embodiment of the present invention.

[0019]

As illustrated in Figs. 1 and 2, laser light resonating in and passing through an external resonator of the laser oscillation device being the first embodiment of the present invention is re-entered to a laser amplifying portion as seed light to be amplified with induced emission, and then, the laser light is re-entered to the resonator.

[0020]

When a gain at the amplifying portion exceeds a loss of the circling including the resonator portion, the system is to be in an oscillation state and laser light automatically continues to circle on an optical path. The oscillation starts with spontaneous emission optical noise of the amplifier. A spectrum component received by chance into a resonance width of the resonator among noise light passes through the resonator, and then, is to be amplified in circling as being seed light thereafter. Eventually, the entire energy to excite the amplifier is aggregated into the component and the system is to be in a steady state when the amplifying portion is saturated.

[0021]

The above is different from a traditional type in that the resonator portion and the amplifying portion configure the laser oscillator as being integrated as a whole. In the traditional type, deviation from resonance conditions due to vibration and the like is forcedly prevented with a high-speed and high-accuracy feedback technology. In contrast, since the oscillation circuit itself automatically follows resonance conditions, the new type has an advantage that a resonance state is maintained without any control performed.

[0022]

An amplifying portion having a high gain is required for compensating a loss of a complicated optical path transmitted through a resonator. Therefore, a fiber amplifier capable of obtaining a high gain with a single path is a key of development of the system. In the present invention, a closed optical system (circling oscillation) which generates self-oscillation was conceived owing to basic study on an optical accumulation resonator and high-efficiency fiber laser amplifying method. In the optical resonator of a high finesse type of the present invention, only resonating laser light is accumulated. Accordingly, accumulation of laser light is actualized with stable laser light amplification by returning laser light transmitted through the optical resonator to a high-efficiency fiber laser amplifier.

[0023]

Confirmation was obtained on capability of amplifying laser light resonating in the optical resonator with the high-efficiency fiber laser amplifier and accumulating laser light obtained through stable amplification in the optical resonator.

[0024]

At that time, confirmation was obtained on existence of laser light in the optical resonator having energy of 10,000 times of energy of laser light entering to the optical resonator.

[0025]

Then, confirmation was obtained on capability of generating beams of a range from a soft X-ray to a γ-ray as placing the optical resonator in an emission path of an accelerator which accelerates an electron beam, guiding the electron beam sufficiently accelerated at the accelerator to the emission path, and colliding the electron beam directly with laser light in the optical resonator.

[0026]

The laser oscillation device according to the first embodiment of the present invention illustrated in Fig. 2 includes a laser diode, an optical isolator, a branching/multiplexing unit (WDM), a Yb fiber, an optical isolator, a first optical system, an optical resonator, a second optical system, and an output coupler. The laser oscillation device circulates laser light obtained with excitation of the Yb fiber and causes the laser light to resonate as accumulating in the optical resonator, so that strong laser light is generated in the optical resonator.

[0027]

The laser diode is structured with a semiconductor laser element and the like which generate laser light having a wavelength required for exciting the Yb fiber. When drive voltage is received, the laser diode generates laser light and supplies the laser light to the optical isolator on a route of the laser diode, the optical fiber and a terminal of the optical isolator.

[0028]

According to a configuration of the optical isolator, laser light supplied to a terminal is emitted from a terminal after passing therethrough. Further, laser light supplied to the terminal is blocked so as not to be emitted from the terminal. When laser light is supplied from the laser diode, the optical isolator introduces the laser light via the optical fiber which is connected to the terminal and makes the laser light pass therethrough to emit the laser light from the terminal, so that the laser light is supplied to the branching/multiplexing unit on a route in the order of the terminal, the optical fiber and the branching/multiplexing unit. Further, when laser light supplied to the terminal via the optical fiber as being emitted from the branching/multiplexing unit, the laser light is blocked to protect the laser diode.

[0029]

According to a configuration of the branching/multiplexing unit, when laser light having a first wavelength and laser light having a second wavelength are entered from respective terminals at one side, multiplexing thereof is performed to be emitted from a terminal at the other side. Further, when multiplexed laser light is entered from the terminal, branching thereof is performed and the branched laser light is emitted respectively from the terminals. When laser light is emitted from the optical isolator and supplied to the terminal which is connected to the optical fiber, the branching/multiplexing unit introduces and supplies the laser light to the Yb fiber which is connected to the terminal. Further, when laser light is emitted from the Yb fiber and supplied to the terminal, the branching/multiplexing unit branches the laser light, emits the laser light having the branched wavelength from the terminal, and supplies the laser light to the optical isolator on a route in the order of the terminal of the branching/multiplexing unit, the optical fiber and the terminal of the optical isolator.

[0030]

The Yb fiber is a double-clad type fiber having Yb doped to a core. When laser light (laser light for excitation) with a predetermined wavelength is excited as being supplied from the branching/multiplexing unit, the Yb fiber generates laser light with a wavelength being different therefrom and supplies the laser light to a terminal of the output coupler as well as to the terminal of the branching/multiplexing unit.

[0031]

Further, according to a configuration of the optical isolator, laser light supplied to a terminal is introduced and emitted from a terminal after passing therethrough. Further, laser light supplied to the terminal is blocked so as not to be emitted from the terminal. When laser light emitted from the branching/multiplexing unit is supplied on a route in the order of the terminal of the branching/multiplexing unit, the optical fiber and the terminal, the optical isolator supplies the laser light to the first optical system on a route in the order of the terminal, the optical fiber and the first optical system while making the laser light pass therethrough. Further, when laser light is supplied from the first optical system on a route in the order of the first optical system, the optical fiber and the terminal, the optical isolator blocks the laser light to prevent the laser light from returning to the branching/multiplexing unit.

[0032]

The first optical system includes a terminal which is connected to the optical isolator via the optical fiber, four mirrors which reflect laser light, and a concave lens and a convex lens which adjust a laser light diameter and the like. The first optical system introduces laser light supplied to the terminal, adjusts a diameter, a polarization direction and the like while reflecting the laser light, and enters the laser light to the optical resonator which is placed in the emission path of the accelerator for accelerating an electron beam.

[0033]

The optical resonator includes a resonator body (not illustrated) which is placed in the emission path of the accelerator for accelerating an electron beam, a concave mirror which is attached to the resonator body having a reflection rate being 90% or higher and a curvature radius of 250 mm, a concave mirror which is attached to the resonator body having a reflection rate being 90% or higher and a curvature radius of 250 mm as being apart from the concave mirror by a distance corresponding to a wavelength of laser light in a fashion that concave faces thereof are mutually opposed, and a piezoelectric element which adjusts a position, an attaching angle and the like of the concave mirror with deformation thereof in accordance with applied voltage as being placed between a back face of the concave mirror and the resonator body. When laser light is supplied from the first optical system or the second optical system to the back face of each concave mirror, the optical resonator causes the laser light to transmit through the concave mirror and adjusts a phase thereof while confining and accumulating the laser light between the concave mirrors. In parallel to the above operation, a part of strong laser light accumulated between the concave mirrors is emitted from the respective concave mirrors and supplies the laser light to the first optical system and the second optical system.

[0034]

The second optical system includes four mirrors which reflect laser light, a concave lens and a convex lens which adjust a laser light diameter, and a terminal which is connected to the optical isolator via the optical fiber. The second optical system introduces laser light supplied to the terminal, adjusts a diameter, a polarization direction and the like while reflecting the laser light and enters the laser light to the optical resonator. Further, the second optical system introduces laser light emitted from the optical resonator, adjusts a diameter, a polarization direction and the like while reflecting the laser light, and supplies the laser light to a terminal of the output coupler via an optical fiber as emitting from the terminal.

[0035]

According to a configuration of the output coupler, when laser light is supplied to each terminal at one side, the laser light is introduced thereto and emitted from each terminal at the other side as being distributed in a ratio of 9:1. Further, when laser light is supplied to each terminal at the other side, the laser light is introduced and emitted from each terminal at the one side as being distributed in a ratio of 9:1. When laser light emitted from the Yb fiber is supplied to the terminal, the laser light is introduced and distributed in a ratio of 9:1. An amount being 90% of the laser light is emitted from the terminal and supplied to the second optical system on a route in the order of the terminal, the optical fiber and the terminal of the second optical system while the remaining amount being 10% thereof is emitted from the terminal and supplied to an external measuring instrument for oscillation monitoring, and the like. Further, when laser light having the wavelength is emitted from the terminal of the second optical system and supplied on a route in the order of the terminal of the second optical system, the optical fiber and the terminal, the laser light is introduced and distributed in a ratio of 9:1. An amount being 90% of the laser light is emitted from the terminal and returned for maintaining oscillation to the optical resonator on a circulation path in the order of the terminal, the Yb fiber, the branching/multiplexing unit, the optical isolator, the first optical system and the optical resonator while an amount being 10% is emitted from the terminal and supplied to an external measuring instrument for oscillation monitoring, and the like.

[0036]

As described above, in the first embodiment of the present invention, laser light generated by the Yb fiber is accumulated and caused to resonate as being guided to the optical resonator using a route in the order of the Yb fiber, the branching/multiplexing unit, the optical isolator, the first optical system and the optical resonator and a route in the order of the Yb fiber, the output coupler, the second optical system and the optical resonator. Further, oscillation is maintained by returning laser light transmitted through one concave mirror which structures the optical resonator to the optical resonator on the circulation path in the order of the optical resonator, the second optical system, the output coupler, the Yb fiber, the branching/multiplexing unit, the optical isolator, the first optical system and the optical resonator. Accordingly, it is possible to accumulate strong laser light in the optical resonator.

[0037]

According to the above, it is possible to generate beams of a range from a soft X-ray to a γ-ray by guiding an electron beam sufficiently accelerated at the accelerator to the emission path and colliding the electron beam directly with laser light in the optical resonator.

[0038]

Here, laser energy in the optical resonator is determined by finesse of the optical resonator and a circulation optical path gain when laser light emitted from the optical resonator is returned to the optical resonator on the route in the order of the optical resonator, the second optical system, the optical fiber, the output coupler, the Yb fiber, the terminal of the branching/multiplexing unit, the optical fiber, the optical isolator, the first optical system and the optical resonator. Therefore, strong laser light can be accumulated only by adopting a high finesse type using mirrors with a reflection rate of 99.99% as two concave mirrors which structure the optical resonator.

[0039]

Further, since a variety of members, devices and the like such as a Yb fiber are not arranged in the optical resonator for usage of the optical resonator, strong laser light can be emitted while maintaining stable resonance even with increased finesse of the optical resonator.

[0040]

Further, laser light can be stably accumulated owing to self-oscillation. In addition, when a polarization selecting device, strength converter and the like are installed outside an optical resonator, laser light with required specification can be selected and accumulated in the optical resonator.

[0041]

Furthermore, it is possible to generate beams of a range from a soft X-ray to a γ-ray by placing the optical resonator in an emission path of an accelerator which accelerates an electron beam, guiding the electron beam sufficiently accelerated at the accelerator to the emission path, and colliding the electron beam directly with laser light in the optical resonator.

[0042]

Here, it is possible to obtain high brightness for beams of a range from a soft X-ray to a γ-ray even with a small-sized accelerator by increasing laser energy of laser light in the optical resonator. With the above, it is possible to circumstantially examine characteristics of important material for applications including biological molecules.

[0043]

2. Description of a second embodiment of the present invention

Fig. 3 illustrates a structure of a laser oscillation device with a loop-back oscillation type optical accumulation being the second embodiment of the present invention.

As illustrated in Fig. 3, the laser oscillation device includes a laser diode, an optical isolator, a branching/multiplexing unit (WDM), a Yb fiber, a reflector, an optical system, and an optical resonator. The laser oscillation device accumulates laser light obtained with excitation of the Yb fiber and causes the laser light to resonate in the optical resonator, so that strong laser light is generated.

[0044]

The laser diode is structured with a semiconductor laser element and the like which generate laser light having a wavelength required for exciting the Yb fiber. When drive voltage is received, the laser diode generates laser light and supplies the laser light to the optical isolator on a route of the laser diode, the optical fiber and a terminal of the optical isolator.

[0045]

According to a configuration of the optical isolator, laser light supplied to a terminal is emitted from a terminal after passing therethrough. Further, laser light supplied to the terminal is blocked so as not to be emitted from the terminal. When laser light is supplied from the laser diode via an optical fiber which is connected to the terminal, the optical isolator makes the laser light pass therethrough to emit the laser light from the terminal, so that the laser light is supplied to the branching/multiplexing unit on a route in the order of the terminal, the optical fiber and the terminal of the branching/multiplexing unit. Further, when laser light supplied to the terminal via the optical fiber as being emitted from the branching/multiplexing unit, the laser light is blocked to protect the laser diode.

[0046]

According to a configuration of the branching/multiplexing unit, when laser light having a first wavelength and laser light having a second wavelength are entered from respective terminals at one side, multiplexing thereof is performed to be emitted from a terminal at the other side. Further, when multiplexed laser light is entered from the terminal, branching thereof is performed and the branched laser light is emitted respectively from the terminals. When laser light having a predetermined wavelength is supplied from the optical isolator via an optical fiber which is connected to the terminal, the branching/multiplexing unit introduces and supplies the laser light to the Yb fiber which is connected to the terminal. Further, when laser light is supplied from the Yb fiber which is connected to the terminal, the branching/multiplexing unit branches the laser light, emits the laser light having the branched wavelength from the terminal, and supplies the laser light to the reflector.

[0047]

The reflector is formed with end face polishing at the terminal of the branching/multiplexing unit and the like. When laser light is emitted from the terminal of the branching/multiplexing unit, the reflector reflects and returns the laser light to the terminal of the branching/multiplexing unit.

[0048]

The Yb fiber is a double-clad type fiber having Yb doped to a core. When laser light (laser light for excitation) with a predetermined wavelength is excited as being supplied from the branching/multiplexing unit, the Yb fiber generates excited laser light and supplies the laser light to a terminal of the optical system as well as to the terminal of the branching/multiplexing unit.

[0049]

The optical system includes a terminal which is connected to the Yb fiber, four mirrors which reflect laser light, and two convex lenses with a focal length of +150 m to collimate laser light and adjust a diameter thereof. The optical system reflects laser light supplied to the terminal and emits the laser light with reflection while adjusting a diameter, a polarization direction and the like.

[0050]

The optical resonator includes a flat mirror with a reflection rate of 90% or higher which is arranged as being inclined 45 degrees against an optical axis of laser light supplied from the optical system, a flat mirror with a reflection rate of 90% or higher which is arranged as being perpendicular to an optical axis of laser light transmitted through the flat mirror (or reflected laser light) and which reflects incident laser light and emits a part thereof to the outside, a flat mirror with a reflection rate of 100% which returns the laser light to the flat mirror by reflecting laser light reflected by the flat mirror and reflected again by the flat mirror, and a piezoelectric element which adjusts a position, an attaching angle and the like of the flat mirror with deformation thereof in accordance with applied voltage as being arranged at one of the flat mirrors (e.g., at a back face of the flat mirror). When laser light is supplied from the optical system to the back face of the flat mirror, the optical resonator causes the laser light to transmit through the flat mirror and adjusts a phase thereof while confining and accumulating the laser light among the flat mirrors.

[0051]

In parallel to the above operation, a part of strong laser light accumulated among the flat mirrors is emitted from the flat mirror and supplied to an external laser light utilization device such as an X-ray generating device which generates a strong X-ray, for example, utilizing an inverse Compton effect at the time when an electron and laser light are collided.

[0052]

As described above, according to the present invention, in a case of considering an application as a laser target for a Compton light source, it is attractive that higher peak strength can be obtained with the same mean power as long as oscillation can be caused in a mode-locking pulse fashion. Presently, it is considered to be multiple longitudinal mode oscillation with concurrent oscillation under a plurality of resonance conditions of a resonator. Here, when an optical path length of an entire system is adjusted to an integral multiple of an optical path length of a resonator portion while a saturable absorbing mirror is inserted at a part of a circulation optical path, phases of a number of longitudinal modes can be matched and harmonic mode-locking can be performed.

[0053]

Further, there is a possibility that double wave laser with high efficiency and high repetition when an SHG crystal is placed in a resonator portion in addition to being in a mode-locking pulse fashion. If resonator loss is mainly determined with wavelength conversion, all excitation light power is shifted into double waves and high efficiency is obtained. When an optical path length of the resonator portion is matched with accelerator repetition and an entire circulation length is adjusted to an integral multiple thereof, it can be also considered to be applied as drive laser for an optical cathode electron gun.

[0054]

3. Description of a verification experiment of a principle of the present invention

Results of a verification experiment of a principle of the present invention will be described in the following.

The verification experiment was performed with a low-power system targeting to verify the principle of a device according to the present invention. Excited light with 500 mW at maximum due to a laser diode with a wavelength of 976 nm was introduced from a WDM coupler using core-excited and Yb-added single mode fiber as an amplifier. The amplifier has a gain of 38 (measured with laser having a wavelength of 1064 nm). Waveguide paths other than an amplifying fiber are structured with single mode fibers as well. After being emitted from the fiber to a space, laser light is entered to a resonator via a lens system for matching and a pair of mirrors for position-angle adjusting. After being emitted from the resonator, laser light is entered to the fiber again similarly via the matching system. After performing adjustment in established procedure, efficiency of the fiber input-output is 60% or higher without large loss. A coupler with a ratio of 9:1 is arranged at a midpoint of the fiber optical path to monitor a part of the circling light. A light circling direction is limited by an isolator which is arranged at a midpoint of the fiber optical path.

[0055]

Fig. 4 indicates a result with the device of the present invention as varying output of an excitation LD while measuring power from a monitoring port.

[0056]

The resonator used in the above measuring has finesse of 30,000 (increase rate of 20,000) structured with resonator mirrors with a reflection rate of 99.99%. According to the indication, oscillation starts at the time when LD current exceeds 350 mA and circling light is increased in proportion to excitation power. Light strength actualized in the resonator is estimated to be 440 W from light strength measured at a monitoring port. Based on observation of the resonator with an IR viewer, it is confirmed that high-strength light is surely accumulated as illustrated in Fig. 6. The above shows that laser light of 440 W can be actualized with low-power excitation laser only on the order of 500 mV without any control performed

[0057]

Fig. 5 indicates a result of oscillation stability with the device of the present invention in a short time scale as observing output light with a photodiode.

Fig. 5 indicates behaviors in a case of using resonance mirrors with a reflection rate of 90% (increase rate of 20) and a case of using those with a reflection rate of 99.99% (increase rate of 20,000). In a case with a high finesse resonator, fine vibration appears on oscillation light strength. This is considered to be because the system was continuously in a transient state as a result that sensitivity of resonance conditions due to environmental vibration and the like became high with narrowing of the resonance width. It was a state of trying to restore resonance with natural oscillation even with fluctuation of the resonance state due to vibration. It is expected that the fluctuation can be suppressed to some extent by increasing stiffness of a resonator body.

[0058]

In a case of considering an application as a laser target for a Compton light source, it is attractive that higher peak strength can be obtained with the same mean power as long as oscillation can be caused in a mode-locking pulse fashion. Presently, it is considered to be multiple longitudinal mode oscillation with concurrent oscillation under a plurality of resonance conditions of a resonator. Here, when an optical path length of an entire system is adjusted to an integral multiple of an optical path length of a resonator portion while a saturable absorbing mirror is inserted at a part of a circulation optical path, it is considered that phases of a number of longitudinal modes can be matched and that harmonic mode-locking can be performed.

[0059]

Fig. 6 illustrates an application example of the present invention to laser for driving an electron gun. Fig. 6 indicates a possibility that double wave laser with high efficiency and high repetition when an SHG crystal is placed in a resonator portion in addition to being in a mode-locking pulse fashion. If resonator loss is mainly determined with wavelength conversion, all excitation light power is shifted into double waves and high efficiency is obtained. When an optical path length of the resonator portion is matched with accelerator repetition and an entire circulation length is adjusted to an integral multiple thereof, it can be also considered to be applied as drive laser for an optical cathode electron gun.

[0060]

4. Conclusions

A technology of a laser accumulation device is one of methods to efficiently actualize laser light with continuously high strength. Owing to combining the technology with a high gain amplifier, the system can be in a self-oscillation state and technical difficulty of resonator control can be solved. In addition to being effective for a laser Compton light source, this method is expected to have a possibility of various applications with combination of pulsing and SHG.

INDUSTRIAL APPLICABILITY

[0061]

The present invention has industrial applicability as relating to a laser device which generates strong laser light, and in particular, relating to light source laser utilizing laser Compton scattering enabling stable oscillation even when finesses of an optical resonator is increased.

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

1. A laser oscillation device which generates laser light by causing laser light generated with a rare-earth fiber to resonate using an optical resonator, comprising:

a laser light source for excitation which generates laser light for excitation;

a fiber laser amplifier which amplifies laser light with core excitation of a single-mode rare-earth fiber generating the laser light having a desired wavelength when laser light generated by the laser light source for excitation is supplied;

an optical resonator which is structured with a surface mirror group including two concave mirrors arranged as being mutually opposed or a plurality of flat mirrors and which accumulates laser light emitted from the fiber laser amplifier;

an optical isolator which is interposed between the optical resonator and the fiber laser amplifier and which guides laser light from the fiber laser amplifier to one side of the optical resonator while blocking laser light in the opposite direction; and

a self-oscillation amplifying circulation optical path into which laser light emitted from the other side of the optical resonator is introduced and in which self-oscillation is induced so that laser light automatically circles continuously along the circulation optical path, by returning the laser light to the optical resonator via the fiber laser amplifier and the optical isolator and entering emitted light from the optical resonator to the fiber laser amplifier again.

2. A laser oscillation device which generates laser light by causing laser light generated with a rare-earth fiber to resonate using an optical resonator, comprising:

a laser light source for excitation which generates laser light for excitation;

a fiber laser amplifier which amplifies laser light with core excitation of a single-mode rare-earth fiber generating the laser light having a desired wavelength when laser light generated by the laser light source for excitation is supplied;

a branching/multiplexing unit which receives laser light from the laser light source for excitation at a first terminal thereof and which emits the laser light to the fiber laser amplifier;

a first reflector which is connected to a second terminal of the branching/multiplexing unit;

an optical resonator which is structured with a surface mirror group including two concave mirrors arranged as being mutually opposed or a plurality of flat mirrors and which accumulates laser light emitted from the fiber laser amplifier; and

a second reflector which reflects laser light at one side emitted from the optical resonator and supplied via the fiber laser amplifier and which accelerates resonance of the laser light having the desired wavelength as returning the laser light to the optical resonator via the fiber laser amplifier,

wherein a self-oscillation amplifying circulation optical path is structured to enter emitted light from the optical resonator again to the fiber laser amplifier, in which self-oscillation is induced so that laser light automatically circles continuously along the circulation optical path.

3. The laser oscillation device according to claim 1 or claim 2, wherein a saturable absorbing mirror is inserted at a part of the circulation optical path, and an optical path length of the circulation optical path is adjusted to an integral multiple of the optical resonance circuit.

4. The laser oscillation device according to claim 1 or claim 2, wherein the rare-earth fiber includes a core to which Yb is doped.

5. The laser oscillation device according to claim 1 or claim 2, wherein the optical resonator is a Fox Smith interferometer type structured with two concave mirrors and one flat mirror.

FIG. 1

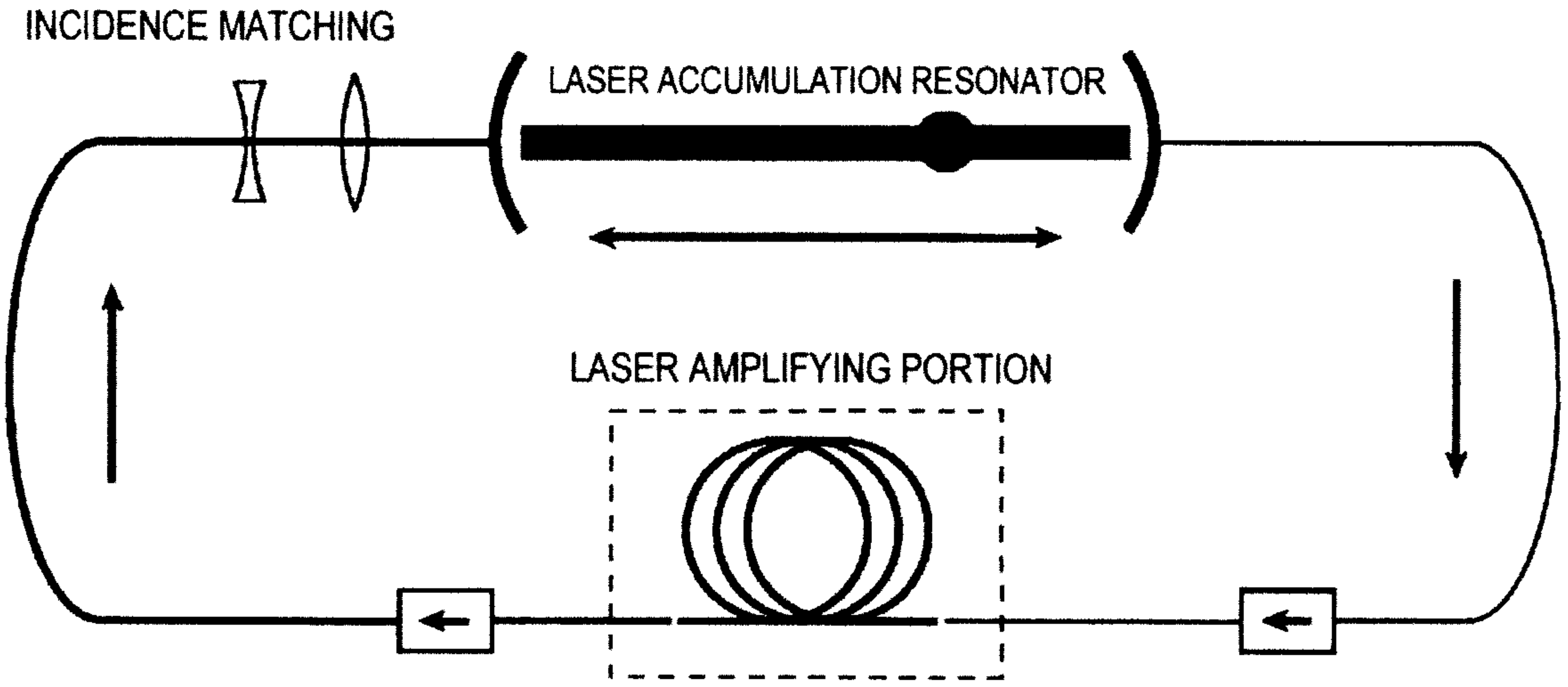

INCIDENCE MATCHING
LASER ACCUMULATION RESONATOR
LASER AMPLIFYING PORTION

FIG. 2

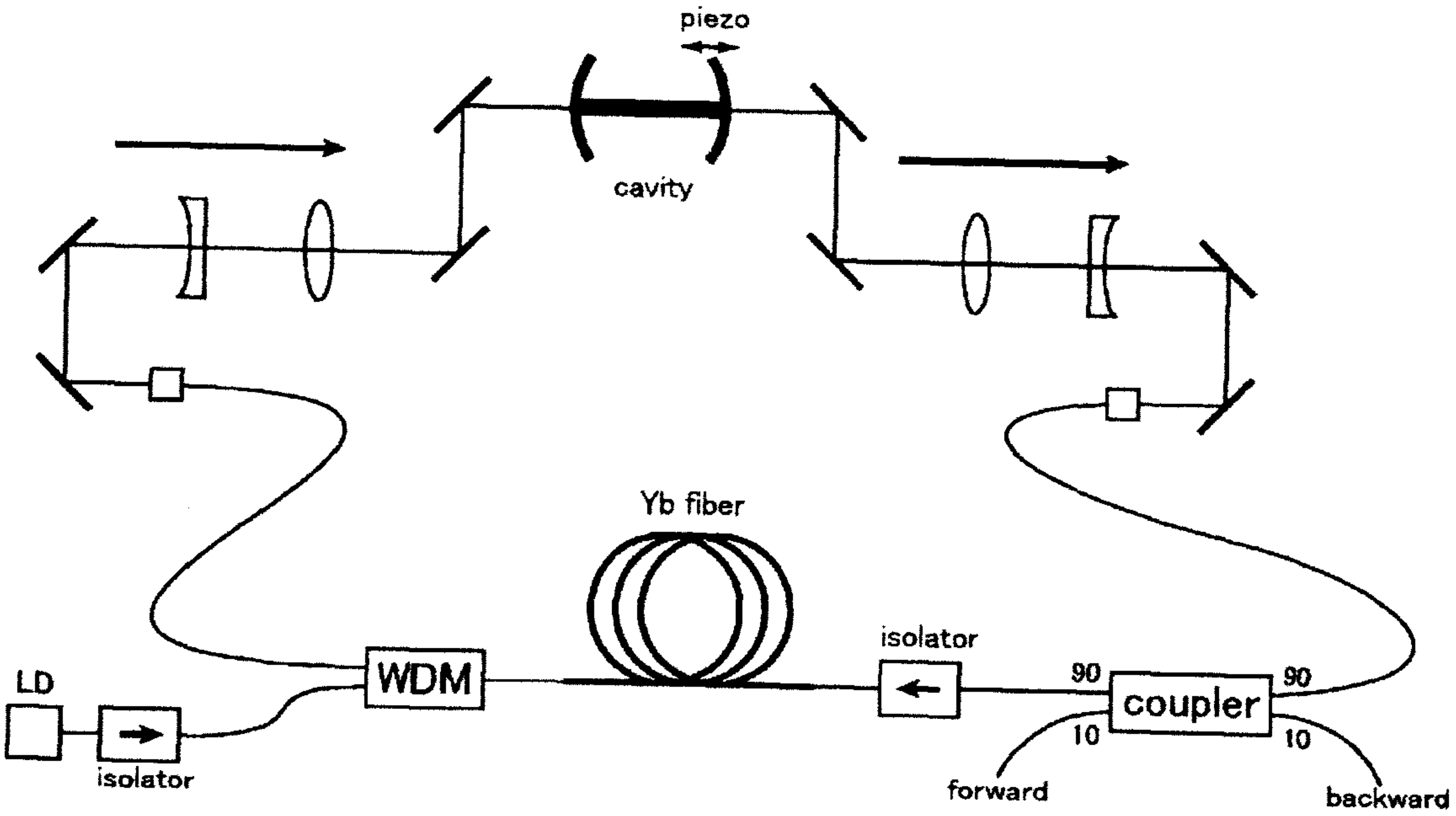

piezo
cavity
Yb fiber
LD
isolator
WDM
isolator
90
coupler
90
10
10
forward
backward

FIG. 3

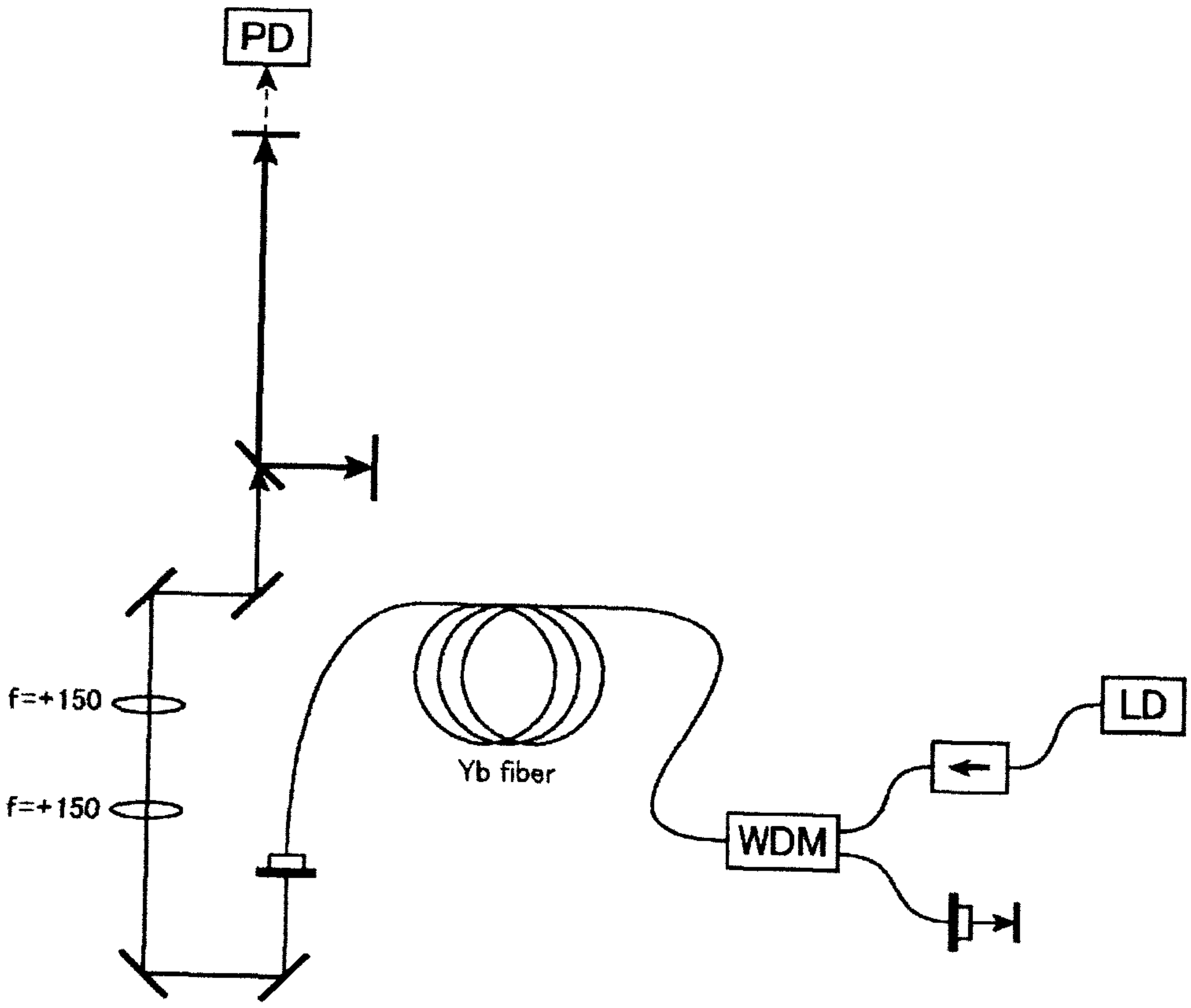


FIG. 4

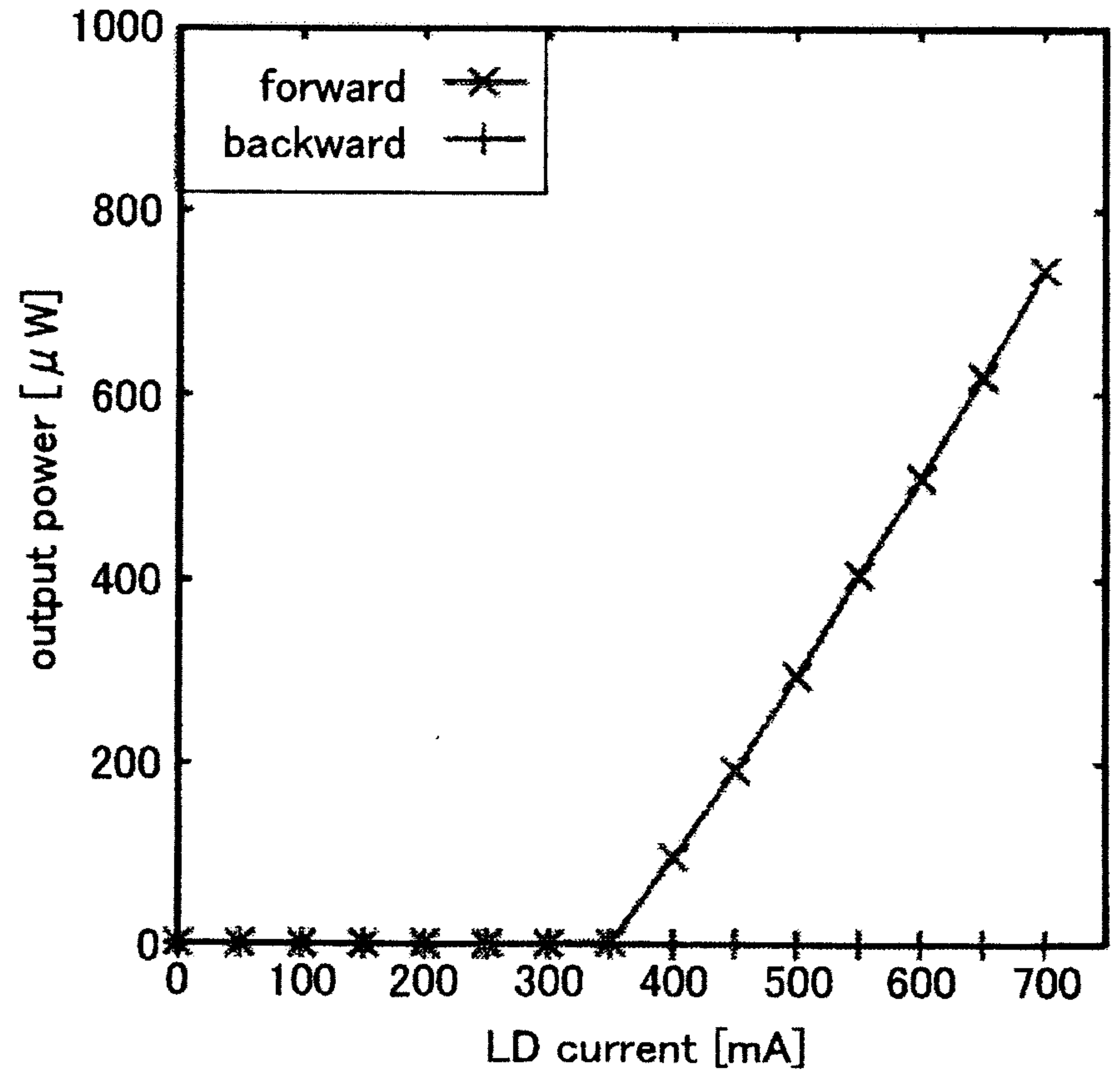
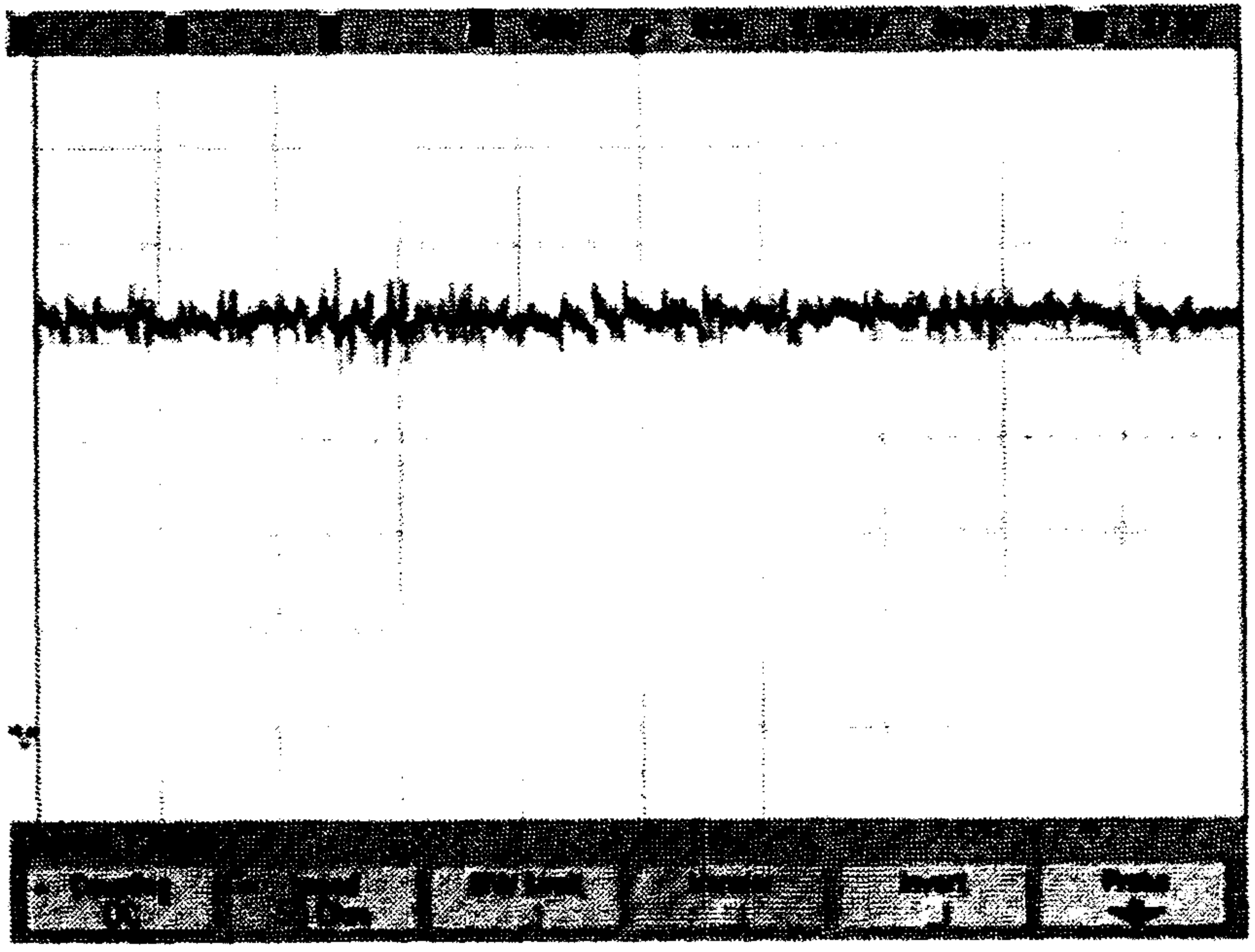

1000
800
600
400
200
0
output power [μ W]
0
100
200
300
400
500
600
700
LD current [mA]
forward
backward

FIG. 5

90% cavity mirror



99.99% cavity mirror

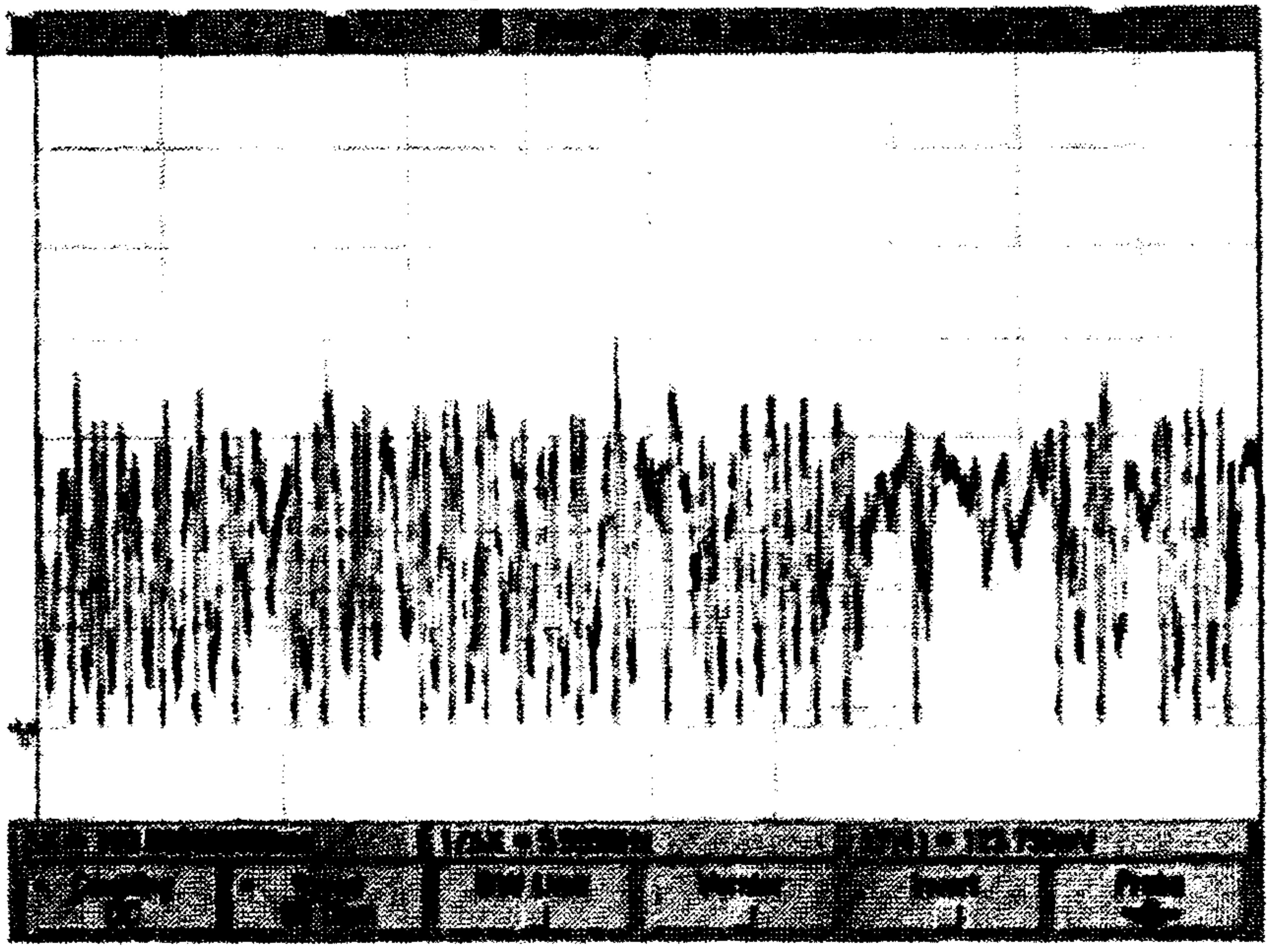


FIG. 6

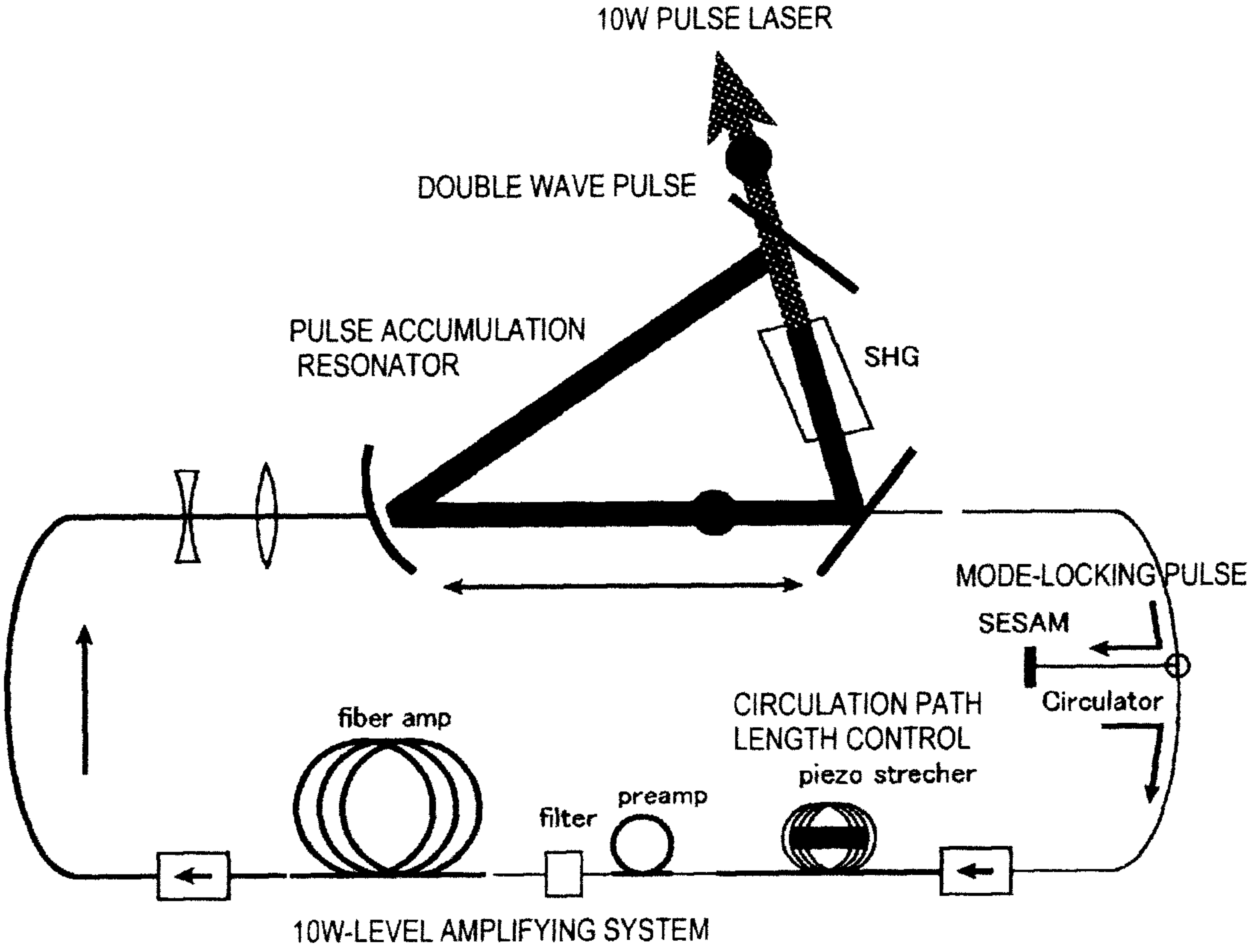

10W PULSE LASER
DOUBLE WAVE PULSE
PULSE ACCUMULATION RESONATOR
SHG
MODE-LOCKING PULSE
SESAM
Circulator
CIRCULATION PATH LENGTH CONTROL
piezo strecher
fiber amp
filter
preamp
10W-LEVEL AMPLIFYING SYSTEM

FIG. 7 (PRIOR ART)

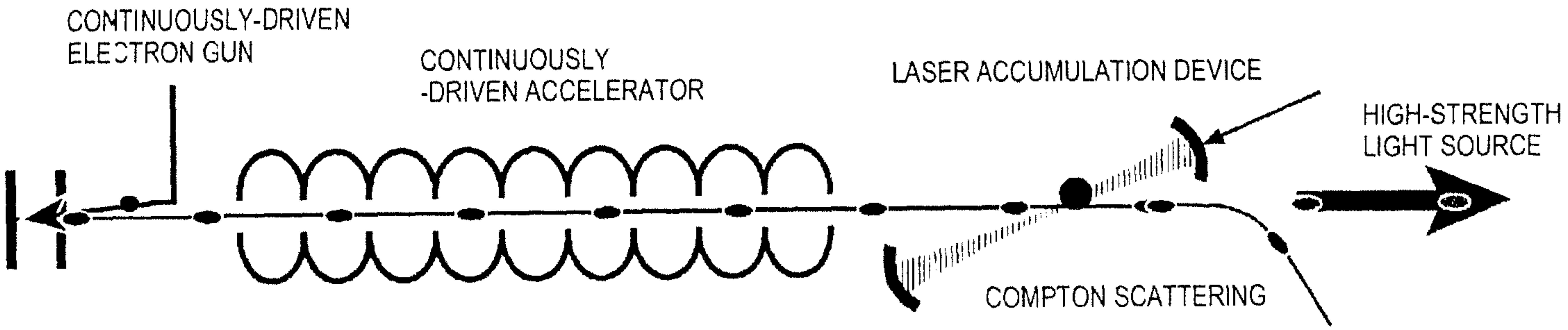
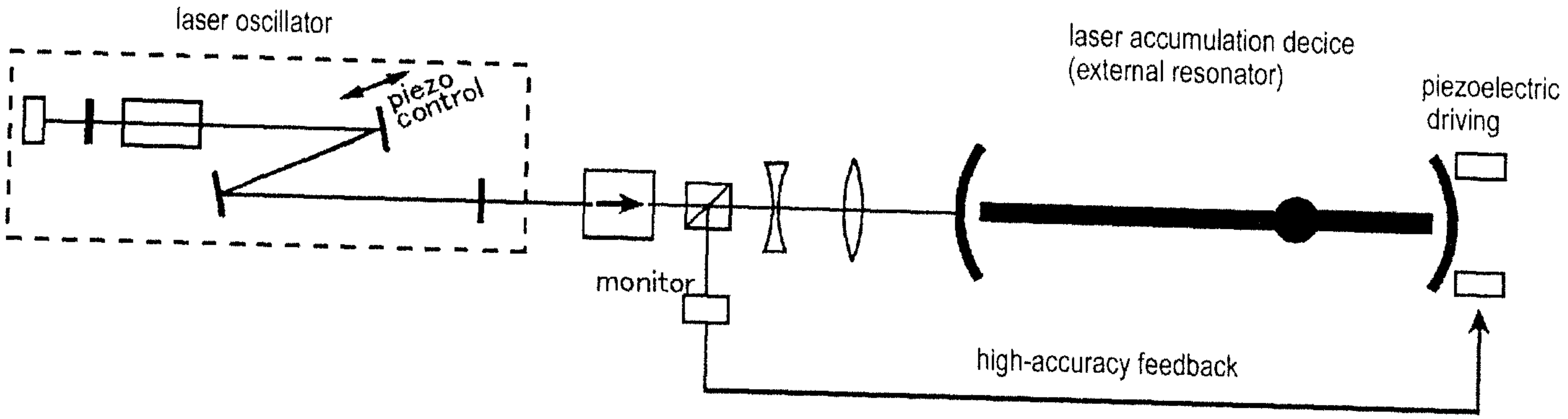
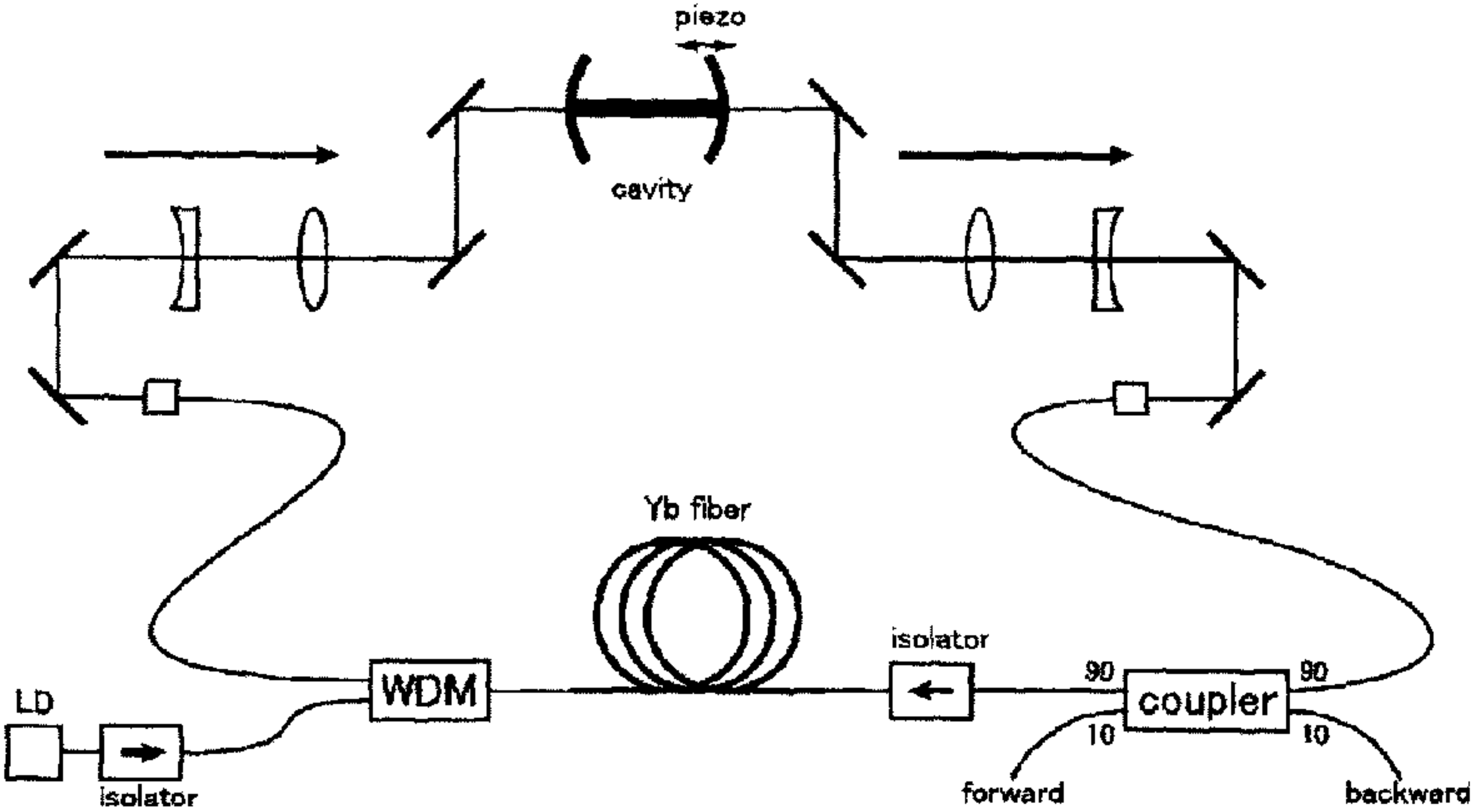


FIG. 8 (PRIOR ART)




piezo
cavity
Yb fiber
isolator
WDM
LD
isolator
90
90
coupler
10
10
forward
backward