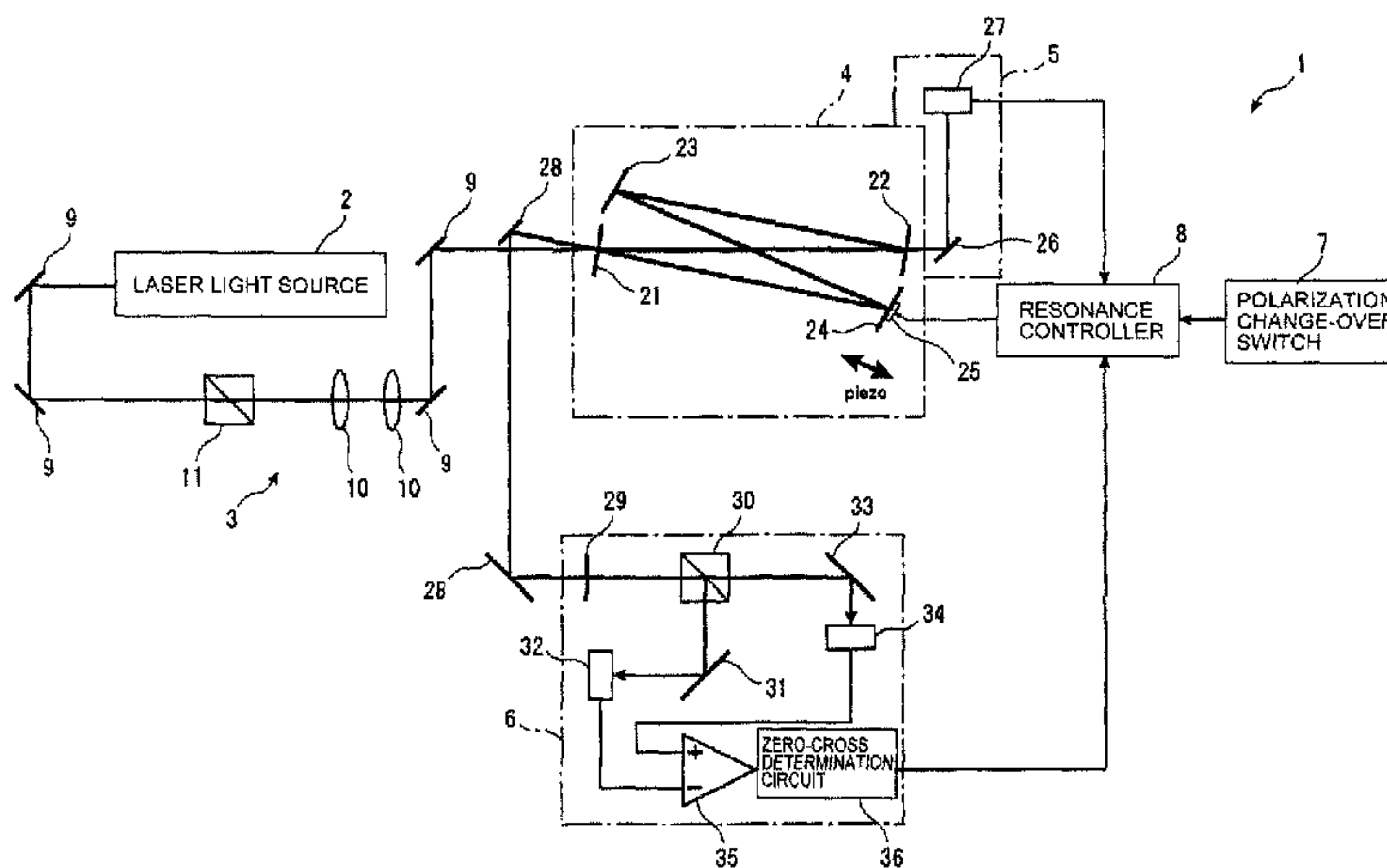




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 (54) Title: THREE-DIMENSIONAL OPTICAL RESONANCE DEVICE, POLARIZED LASER OSCILLATION METHOD, AND POLARIZED LASER OSCILLATION SYSTEM



(57) **Abrégé/Abstract:**

Provided is polarized laser oscillation capable of guiding laser to a three-dimensionally-arranged optical resonator to resonate with right polarization or left polarization and easily switching therebetween. The polarized laser oscillation includes guiding laser to an optical resonator 4, circulating the laser with a pair of flat mirrors 21, 22 and a pair of concave mirrors 23, 24 which are three-dimensionally arranged at the optical resonator 4, adjusting an optical path length formed with the flat mirrors 21, 22 and the concave mirrors 23, 24 by deforming a piezoelectric element 25 as applying ramp-like drive voltage to the optical resonator 4, determining whether or not zero-crossing for right polarization or zero-crossing for left polarization occurs at a difference value between a P-polarized component and an S-polarized component of the laser as guiding laser transmitted through the flat mirror 21 to a zero-cross feedback signal generator 6, and causing right polarized laser or left polarized laser to resonate in the optical resonator 4 as fixing a voltage value of the drive voltage applied to the piezoelectric element 25 from the resonance controller 8 based on the determination result.

ABSTRACT

Provided is polarized laser oscillation capable of guiding laser to a three-dimensionally-arranged optical resonator to resonate with right polarization or left polarization and easily switching therebetween. The polarized laser oscillation includes guiding laser to an optical resonator 4, circulating the laser with a pair of flat mirrors 21, 22 and a pair of concave mirrors 23, 24 which are three-dimensionally arranged at the optical resonator 4, adjusting an optical path length formed with the flat mirrors 21, 22 and the concave mirrors 23, 24 by deforming a piezoelectric element 25 as applying ramp-like drive voltage to the optical resonator 4, determining whether or not zero-crossing for right polarization or zero-crossing for left polarization occurs at a difference value between a P-polarized component and an S-polarized component of the laser as guiding laser transmitted through the flat mirror 21 to a zero-cross feedback signal generator 6, and causing right polarized laser or left polarized laser to resonate in the optical resonator 4 as fixing a voltage value of the drive voltage applied to the piezoelectric element 25 from the resonance controller 8 based on the determination result.

THREE-DIMENSIONAL OPTICAL RESONANCE DEVICE, POLARIZED LASER
OSCILLATION METHOD, AND POLARIZED LASER OSCILLATION SYSTEM

TECHNICAL FIELD

[0001]

The present invention relates to a resonance device, a polarized laser oscillation method, and a polarized laser oscillation system for a small-sized X-ray source to generate an X-ray using laser inverse Compton scattering and the like.

BACKGROUND ART

[0002]

As a polarized laser oscillation method used for generating an X-ray using laser inverse Compton scattering and the like, there has been known a method to generate strong polarized laser while guiding laser obtained from a laser generator to an optical resonator and causing the laser to resonate.

SUMMARY OF THE INVENTION

[0003]

However, with such a polarized laser generation method, since circular polarization properties of laser cannot be split by an optical resonator using two mirrors, it is required to switch circular polarization using a polarizer, a Faraday rotator, a quarter-wave plate and the like. Accordingly, there has been a problem of complicated adjustment caused accordingly.

[0004]

Further, with such a polarized laser generation method, switching between right circular polarization and left circular polarization is required to be performed by adjusting a polarizer, a Faraday rotator, a quarter-wave plate and the like respectively. Accordingly, in addition to difficulty to increase speed of the switching, there has been a problem that pure circular polarized laser cannot be guaranteed.

[0005]

Further, with a polarized laser generating device using a polarized laser generation method described above, since the entire device is upsized, an X-ray source is to be upsized when the device is used for the X-ray source by utilizing laser inverse

Compton scattering and the like.

[0006]

Accordingly, there has been a problem that an X-ray source incorporating a polarized laser generating device is difficult to be used with an X-ray for magnetism analysis, biological investigation, drug development and the like.

[0007]

An object of the present invention is to provide a polarized laser oscillation method using an optical resonance device capable of causing laser obtained from a laser light source to resonate with either right polarization or left polarization as guiding to an optical resonator which is three-dimensionally arranged and easily performing switching therebetween.

[0008]

Further, another object of the present invention is to provide a polarized laser oscillation system which generates ultrashort pulse polarized radiation at a collision point arranged in a three-dimensionally-structured optical resonator owing to collision between a high-energy electron beam emitted from a high-energy electron beam generating unit and pulse laser. of right polarization or left polarization with a beam size of m or smaller and energy strength of 1 mJ/pulse or higher generated at the collision point in the three-dimensional optical resonator.

[0009]

In view of the above issues, the present invention, as a first embodiment, provides a three-dimensional optical resonance device, comprising: an optical resonator which includes a pair of flat mirrors and a pair of concave mirrors as being three-dimensionally arranged and which introduces laser light emitted from a laser light source unit with an incident optical system and selecting right circular polarization or left circular polarization in accordance with a length of an optical path adjusted by a piezoelectric element while circulating the laser light on the length-adjusted optical path to cause the laser light to resonate.

[0010]

Here, the laser light source unit includes a CW laser oscillator or a mode-locking laser pulse oscillator as a laser

oscillator, and a polarization face and a beam diameter of laser emitted from the laser light source which generates laser being a CW laser type or a pulse laser type are adjusted.

[0011]

Here, the three-dimensional optical resonance device includes a resonance monitoring unit which measures strength of laser light resonating in the optical resonator. Further, the three-dimensional optical resonance device includes a zero-cross feedback signal generator which generates a zero-cross feedback signal as splitting laser transmitted through any of the flat mirrors and the concave mirrors among laser light resonating in the optical resonator into a P-polarized component and an S-polarized component, measuring strength of each polarized component, and obtaining a differential value therebetween.

[0012]

The three-dimensional optical resonance device includes a polarization change-over switch which outputs an instruction signal to assign the selected right circular polarization or left circular polarization, and a resonance controller which adjusts the length of the optical path by controlling drive voltage of the piezoelectric element arranged in the optical resonator based on output of the polarization change-over switch, output of the resonance monitoring unit and output of the zero-cross feedback signal generator and which selectively accumulates laser of right circular polarization or left circular polarization into the optical resonator.

[0013]

Here, right polarization pulse laser or left polarization pulse laser with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher is collided with an electron beam emitted from the incident optical system at a collision point arranged in the optical resonator to generate ultrashort pulse polarized radiation with a radiation amount thereof measured.

[0014]

Further, an electron beam with normalized emittance of 10 mmmrad or less emitted from the laser light source unit and pulse laser in the optical resonator are collided at the collision point with a collision angle in a range from 8 to 20 degrees

and collision accuracy of 1 μ m or less and ultrashort pulse polarized radiation being a X-ray or a γ -ray with characteristics having energy of 0.25 keV or higher is generated and drawn to the outside.

[0015]

The present invention, as a second embodiment, provides a polarized laser oscillation method, comprising: guiding laser light emitted from a laser light source unit to an optical resonator; adjusting an optical path length in the optical resonator by deforming a piezoelectric element by applying ramp-like drive voltage while circulating the laser light in the optical resonator with a pair of flat mirrors and a pair of concave mirrors; splitting laser light transmitted through the pair of concave mirrors or the pair of flat mirrors into a P-polarized component and an S-polarized component and measuring strength of each polarized component; generating a zero-cross feedback signal based on strength difference value of the polarized components; and right polarized laser light or left polarized laser light is caused to resonate and is accumulated in the optical resonator by fixing a voltage value of the drive voltage.

[0016]

Further, the present invention, as a third embodiment, provides a polarized laser oscillation system, comprising: a laser light source unit which has at least either one of a CW laser oscillator and a mode-locking laser pulse oscillator and which emits laser light of a CW laser type or a pulse laser type; an incident optical system which arranges a polarization face and a beam diameter of the laser light emitted from the laser light source unit; an optical resonator which is configured to cause laser light to resonate by introducing the laser light emitted from the laser light source unit with the incident optical system and selecting right circular polarization or left circular polarization in accordance with an adjusted length of an optical path while circulating the laser light on the optical path with the length being adjusted by a piezoelectric element, wherein the optical resonator includes a pair of flat mirrors and a pair of concave mirrors; a resonance monitoring unit which measures strength of the laser light resonating in the optical resonator; a zero-cross feedback signal generator which generates a zero-cross feedback signal by splitting laser light transmitted through any of the flat mirrors and the concave mirrors among the laser light resonating in the optical resonator into P-polarized light and S-polarized

light, measuring strength thereof, and obtaining a differential value therebetween; a polarization change-over switch which outputs an instruction signal to assign said right circular polarization or said left circular polarization selected at the optical resonator; and a resonance controller which adjusts the length of the optical path by controlling drive voltage of the piezoelectric element arranged in the optical resonator based on output of the polarization change-over switch, output of the resonance monitoring unit and output of the zero-cross feedback signal generator and which selectively accumulates laser light of said right circular polarization or said left circular polarization into the optical resonator.

[0017]

With the above, the present invention may enable polarized laser oscillation using the three-dimensional optical resonance device capable of causing laser obtained from the laser light source to resonate with either right polarization or left polarization as guiding to the optical resonator which is three-dimensionally arranged and easily performing switching therebetween.

[0018]

Further, the present invention may actualize the polarized laser oscillation system which generates ultrashort pulse polarized radiation at the collision point arranged in the optical resonator owing to collision between a high-energy electron beam emitted from a high-energy electron beam generating unit and pulse laser of right polarization or left polarization with a beam side of 10 m or smaller and energy strength of 1 mJ/pulse or higher generated at the collision point in the optical resonator. BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

Fig. 1 is a schematic structural view illustrating an embodiment of a polarized laser oscillation method and a device thereof according to the present invention.

Fig. 2 is a perspective view illustrating a detailed structural example of a three-dimensional optical resonator illustrated in Fig. 1.

Fig. 3 is a schematic structural view illustrating an example of a polarized radiation generation method and a

polarized radiation generating system according to the present invention.

Fig. 4 is a structural view of an optical resonator with four non-planar mirrors of the present invention.

Fig. 5 is a schematic structural view illustrating a layout of a system used in a preliminary experimental test.

Fig. 6 is a graph indicating an example of a typical signal to be observed in a case that incident laser has linear polarization.

Fig. 7 is a graph plotting a function of " $F(\delta)=E^r/E^i$ " under conditions of " $R_1=0.99$ ", " $T_1=0.01$ " and " $R=0.98$ ".

Fig. 8 is a graph plotting calculation results of a difference signal " $E_s^r-E_p^r$ " and a sum signal " $E_s^r+E_p^r$ " of components " E_s^r " and " E_p^r " of a reflection wave " E^r " indicated by a column vector in expression 11 under conditions of " $R_1=0.99$ ", " $T_1=0.01$ ", " $R=0.98$ " and " $\phi_{geo}=-0.0575$ rad".

Fig. 9 is a graph plotting calculation results of a difference signal " $E_s^r-E_p^r$ " and a sum signal " $E_s^r+E_p^r$ " of components " E_s^r " and " E_p^r " of a reflection wave " E^r " indicated by the column vector in expression 11 under conditions of " $R_1=0.999$ ", " $T_1=0.001$ ", " $R=0.998$ " and " $\phi_{geo}=-0.0575$ rad".

Fig. 10 is a structural view illustrating a general outline of experimental equipment prepared for verifying calculation.

Fig. 11 is a graph indicating signals observed in the vicinity of a resonant point of a three-dimensional optical resonator illustrated in Fig. 10.

EMBODIMENT OF THE INVENTION

[0020]

1. Introduction

Highly-accurate optical resonators are used in a variety of scientific fields. Beam strength can be increased by several steps by entering laser beam from a laser oscillator into an optical resonator. In a field of accelerator physics, this technology is required for developing a small-sized X-ray light source based on a laser Compton scattering method.

[0021]

Resonance of an optical resonator requires maintaining at a sharp peak. There have been developed a variety of types for obtaining a difference signal from a resonance curve usable for controlling a movement direction of a servo system.

[0022]

The Pound-Drever-Hall method to measure a phase shift of a reaction wave as introducing a frequency side band at an outer side of a resonance peak is one of methods which are widely used. In a tilt-locking method as another method, a phase shift of a reaction wave is detected using interference between a fundamental mode and a higher lateral mode. In the Hansch-Couillaud (HC) method, an optical resonator is set to have a resonance-polarization-dependent structure by placing birefringent material in an optical resonator and polarization variation of reaction wave caused by phase shift due to resonance is measured. In a multi-mirror optical resonator system using mirrors installed as being inclined, characteristics of a linear polarization-dependent structure may occur owing to mirror stress even in a system with two mirrors. Accordingly, modification of the HC method can be actualized without additional material.

[0023]

A four-mirror optical resonator having a three-dimensional (non-planar) structure can generate a fine spot at one point in the optical resonator. When a laser Compton X-ray source is used, effective laser-electron crossing can be provided with a four-mirror optical resonator, so that generated X-ray performance (or convergence performance) can be improved.

[0024]

Normally, a non-planar optical resonator has circular-polarization-dependent characteristics due to image rotation in a three-dimensional optical path. The inventors propose a new method for obtaining a difference signal from resonance of a non-planar optical resonator utilizing the circular-polarization-dependent characteristics. This method is modification of the HC method having circular polarization dependency.

[0025]

2. Experimental equipment

(1) Outline of non-planar optical resonator

Fig. 4 illustrates a structure of a non-planar four-mirror optical resonator of the present invention. An optical path is formed along sides of a bilaterally-symmetric tetrahedron with faces being isosceles triangles, each having sides of "a", "a"

and "b". Side "a" is 420 mm long and side "b" is 100 mm long. The mirrors located at respective vertexes "P₁", "P₂", "P₃" and "P₄" form a confined light resonator in the order thereof. The mirrors at vertexes "P₁" and "P₂" are flat mirrors and the mirrors at vertexes "P₃" and "P₄" are concave mirrors. All of the mirrors (flat mirrors and concave mirrors) used in this experiment have a reflection rate of 99% and a transmission factor of 1%. Point "Q₁" is a midpoint between vertex "P₁" and vertex "P₃". Point "Q₂" is a midpoint between vertex "P₂" and vertex "P₄".

[0026]

(2) Influence of geometric phase

A non-planar optical resonator has uniqueness in degeneracy and separation of resonance of circular polarization. Influences of a geometric phase are studied in the following procedure.

[0027]

Regarding influences at vertex "P₂", unit vectors "k₁" and "k₂" are a light beam (incident light) from vertex "P₁" to vertex "P₂" and a light beam from vertex "P₂" to vertex "P₃" respectively.

[Expression 1]

$$\hat{k}_1 = \frac{\vec{P}_1 P_2}{|\vec{P}_1 P_2|}, \quad \hat{k}_2 = \frac{\vec{P}_2 P_3}{|\vec{P}_2 P_3|}$$

[0028]

Here, normal vectors "n₁" and "n₂" of reflection light at vertexes "P₂" and "P₃" can be expressed with the following expression.

[Expression 2]

$$\hat{n}_1 = \frac{\vec{P}_2 Q_1}{|\vec{P}_2 Q_1|}, \quad \hat{n}_2 = \frac{\vec{P}_3 Q_2}{|\vec{P}_3 Q_2|}$$

[0029]

Then, faces including the incident light and the reflection light can be expressed with vectors "a₁", "a₂" expressed as the following expressions using definitions of unit vectors "k₁", "k₂" and normal vectors "n₁", "n₂".

[Expression 3]

$$\hat{a}_1 = \frac{\hat{n}_1 \times \hat{k}_1}{|\hat{n}_1 \times \hat{k}_1|}, \quad \hat{a}_2 = \frac{\hat{n}_2 \times \hat{k}_2}{|\hat{n}_2 \times \hat{k}_2|}$$

[0030]

Here, angle " α_{12} " between vector " a_1 " and vector " a_2 " denotes image rotation occurring at one side of the four-mirror optical resonator and can be calculated with the following expression.

[Expression 4]

$$\sin \alpha_{12} = \pm |\hat{a}_1 \times \hat{a}_2|$$

[0031]

With such a non-planar optical resonator, since image rotation at each reflection point is to be accumulated, an angle " $4\alpha_{12}$ " (hereinafter, suitably called a geometric phase " ϕ_{geo} ") is obtained as an entire effect with one round of an optical path in the non-planar optical resonator. Further, image rotation corresponds to phase shift in a case with a rotatory polarization. Further, since a sign of phase shift with right polarization is opposite to that with left polarization, resonance degeneration between two circular polarizations is split.

[0032]

For example, the angle " $4\alpha_{12}$ " is " -0.0575 rad (as neglecting integer portion of 2π) with the resonator proposed here.

[0033]

(3) Measurement of resonance with optical resonator

The inventors evaluated polarization characteristics of the optical resonator proposed here with a preliminary experimental test. Fig. 5 illustrates a layout of the system prepared for the above.

[0034]

At that time, a single-mode CW laser (manufactured by Innolight GmbH, Prometheus-model) was used as a light source. Polarization of incident laser light was discriminated with a polarized beam splitter ("PBS"). A pair of lenses ("matching") is arranged so that the incident laser is matched with a mode being specific for the optical resonator. An entering position and an angle of the incident laser against the optical resonator ("3D-4 mirror cavity") were adjusted by a pair of flat mirrors. One ("concave") of the optical resonator mirrors was attached onto a piezoelectric control stage having a piezoelectric element ("piezo") to be capable of varying a length (optical

path length) of the optical resonator. Resonance in the optical resonator was evaluated by measuring transmitted laser through the optical resonator by a pin photodiode ("PD") while applying ramp voltage (voltage gradually increasing like a slope) to the piezoelectric element.

[0035]

Fig. 6 illustrates a typical signal observed when incident laser has linear polarization. The graph is obtained by measuring the transmitted laser through the optical resonator with the photodiode while making the optical path length of the optical resonator sweep using the piezoelectric element. The upper graph indicates the entire period of a free spectrum range. The highest peak corresponds to a fundamental lateral mode. The lower graph is obtained by enlarging one of the peaks of the fundamental mode.

[0036]

Fig. 6 illustrates a double-peak structure in which one of two resonance peaks corresponds to right polarization and the other corresponds to left polarization. Since the incident laser includes two types of circular polarization respectively by the same amount, the optical resonator provides resonance with a slightly different phase based on both resonance conditions.

[0037]

3. Method of locking technology

(1) Calculation

[Description of reflection wave]

Complex resonance " E^r " of a reflection wave at each resonance mirror in the optical resonator can be expressed as follows.

[Expression 5]

$$\begin{aligned}
 E^r &= E^i \left[\sqrt{R_1} - \frac{T_1}{\sqrt{R_1}} \frac{Re^{i\delta}}{1 - Re^{i\delta}} \right] \\
 &= E^i \left[\sqrt{R_1} - \frac{T_1 R_1}{\sqrt{R_1} (1 - R_1)^2 + 4R_1 \sin^2(\delta/2)} \frac{\cos \delta - R_1 + i \sin \delta}{1 - Re^{i\delta}} \right] \equiv E^i F(\delta)
 \end{aligned}$$

[0038]

Here, " E^i " denotes complex resonance of an incident wave and " R_1 " and " T_1 " denote a reflection rate and a transmission factor of a resonance mirror placed at an entering-emitting port

of the optical resonator respectively. "R" denotes a value which corresponds to fineness "F" of the optical resonator defined as " $F=\pi/(1-R)$ ". Here, it is possible to consider "R" as a reflection rate of a resonance mirror used in a two-mirror optical resonator which has the same accuracy as that of a four-mirror optical resonator. Further, " δ " denotes a phase difference derived from resonance conditions.

[0039]

Fig. 7 is a graph plotting a function of " $F(\delta)=E^r/E^i$ " under conditions of " $R_1=0.99$ ", " $T_1=0.01$ " and " $R=0.98$ ". The upper line indicates a real number portion and the lower line indicates an imaginary number portion of the phase difference " δ ".

[0040]

[Description of polarization]

Wave polarization can be described with the following expression by applying Jones matrix to the abovementioned optical resonator.

[Expression 6]

$$E = \begin{pmatrix} E_p \\ E_s \end{pmatrix}$$

Here, respective elements " E_p " and " E_s " of a column vector "E" denote P-polarization and S-polarization respectively. The electric field is in parallel to and is perpendicular to the table. When a wave is spectrally separated by a polarized beam splitter (PBS) which is horizontally placed on the table, two elements can be measured separately.

[0041]

Circular polarization wave can be expressed as follows.

[Expression 7]

$$\hat{E}_R = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ -i \end{pmatrix}, \quad \hat{E}_L = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ i \end{pmatrix}$$

Here, column vectors " E_R " and " E_L " denote right polarization and left polarization of unit resonance, respectively. Since the eigenstate of a non-planar optical resonator corresponds to circular polarization, an incident wave can be conveniently described as superimposition of unit resonance of right polarization " E_R " and unit resonance of left polarization " E_L ".

[0042]

Further, column vector "E₄₅" being unit resonance of line polarization as being inclined 45 degrees against the table face can be expressed as follows.

[Expression 8]

$$\hat{E}_{45} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix} = \frac{1+i}{2} \hat{E}_R + \frac{1-i}{2} \hat{E}_L$$

[0043]

(2) Method of proposed system

As described at 2-(2), resonance conditions of right polarization and left polarization are shifted respectively to have an opposite sign owing to an additional geometric phase. A right polarization component "E^r_R" or a left polarization component "E^r_L" of a reflection wave can be expressed using the additional geometric phase "φ_{geo}" as follows.

[Expression 9]

$$E'_R = E'_R \hat{E}_R = E'_R F(\delta - \phi_{geo}) \hat{E}_R$$

[Expression 10]

$$E'_L = E'_L \hat{E}_L = E'_L F(\delta + \phi_{geo}) \hat{E}_L$$

[0044]

Here, in a case that Fig. 8 is with an incident wave, the right polarization component "E^r_R" and the left polarization component "E^r_L" of a reflection wave mutually act in the optical resonator. The superimposed reflection wave "E^r" generated owing to the above is expressed as the following expression.

[Expression 11]

$$\begin{aligned} E^r &= E'_R + E'_L = \frac{1+i}{2} F(\delta - \phi_{geo}) \hat{E}_R + \frac{1-i}{2} F(\delta + \phi_{geo}) \hat{E}_L \\ &= \begin{pmatrix} \frac{1+i}{2\sqrt{2}} F(\delta - \phi_{geo}) + \frac{1-i}{2\sqrt{2}} F(\delta + \phi_{geo}) \\ \frac{i(1+i)}{2\sqrt{2}} F(\delta - \phi_{geo}) + \frac{i(1-i)}{2\sqrt{2}} F(\delta + \phi_{geo}) \end{pmatrix} = \begin{pmatrix} E'_p \\ E'_s \end{pmatrix} \end{aligned}$$

[0045]

Fig. 8 is a graph plotting calculation results of a difference signal "E_s^r-E_p^r" and a sum signal "E_s^r+E_p^r" of components "E_s^r" and "E_p^r" of a reflection wave "E^r" indicated by a column vector in expression 11 under conditions of "R₁=0.99", "T₁=0.01", "R=0.98" and "φ_{geo}=-0.0575 rad". Here, for easy understanding of relation with Fig. 10, Fig. 8 indicates "PD1-PD2" as the difference signal "E_s^r-E_p^r" and "PD1+PD2" as the sum signal "E_s^r+E_p^r".

[0046]

The above corresponds to the structure of the optical resonator to be the test target here. " $E_s^r - E_p^r$ " is the difference signal for locking the optical resonator proposed here.

[0047]

Further, Fig. 9 indicates calculation with higher accuracy. This is a calculation example under conditions of " $R_1=0.999$ ", " $T_1=0.001$ ", " $R=0.998$ " and " $\phi_{geo}=-0.0575$ rad".

[0048]

As is evident from Figs. 8 and 9, the difference signal " $E_s^r - E_p^r$ " indicated by "PD1-PD2" crosses zero at peaks of resonance. Owing to selecting signs of the difference signal " $E_s^r - E_p^r$ " which crosses zero (from minus to plus or from plus to minus), the system can be locked with one circular polarization resonance of either of right circular polarization and left circular polarization.

[0049]

(3) Experiment

In order to verify the calculation, the inventors conducted an experiment using the device illustrated in Fig. 10. A linear polarization wave was entered into the three-dimensional optical resonator "3D-cavity". Reflection light from the flat mirror "reflection" placed at the entering-emitting port (laser beam in the three-dimensional optical resonator "3D-cavity") was guided to a detection system "detection system" structured with the polarization beam splitter "PBS" and the two pin photodiodes "PD1" and "PD2".

[0050]

The pin photodiode "PD1" monitored the P-polarization strength " E_p " and the pin photodiode "PD2" monitored the S-polarization strength " E_s ". Signals from the respective pin photodiodes "PD1" and "PD2" were supplied to the differential amplifier "differential amplifier" and difference voltage " $E_s - E_p$ " was output as an output signal "output".

[0051]

A polarization face of incident laser beam and a polarization face of the detection system "detection system" were coordinated by adjusting an angle of a half-wave plate " $\lambda/2$ " placed at the input side of the detection system "detection system" so as to valance outputs of the two pin photodiodes "PD1"

and "PD2" even when the half-wave plate " $\lambda/2$ " and the three-dimensional optical resonator "3D-cavity" are mutually distanced.

[0052]

The above situation corresponds to that the laser beam entering to the input side of the polarization beam splitter "PBS" is expressed as expression 8. The resonance state of the three-dimensional optical resonator "3D-cavity" was monitored by measuring strength of transmitted light from the three-dimensional optical resonator "3D-cavity" (laser beam in the three-dimensional optical resonator "3D-cavity") using a pin photodiode "PD0".

[0053]

The inventors measured the output signal "output" of the differential amplifier "differential amplifier" while scanning the optical path length of the three-dimensional optical resonator "3D-cavity" using a piezoelectric control mirror having the position thereof adjusted by the piezoelectric element "piezo". Fig. 11 illustrates signals observed at the vicinity of resonance points of the three-dimensional optical resonator "3D-cavity". The lowermost line is a signal of the pin photodiode "PD0" measuring the transmitted light as indicating the resonance points of the three-dimensional optical resonator "3D-cavity". The center line is the output signal "output" of the differential amplifier "differential amplifier" and the output signal is matched with the calculation result of Fig. 8. The output signal "output" of the differential amplifier "differential amplifier" crosses zero respectively at the two resonance points and have mutually different signs at the vicinity of the respective circular polarization peaks. Accordingly, owing to that the optical path length of the three-dimensional optical resonator "3D-cavity" is adjusted so that the output signal "output" of the differential amplifier "differential amplifier" is matched with either of the respective zero-crossing points, locking can be performed at either of the two resonance peaks of the three-dimensional optical resonator "3D-cavity".

[0054]

According to the present invention, the three-dimensional optical resonator "3D-cavity" can be caused to resonate with

either right polarization or left polarization owing to locking at one of the two resonance peaks of the three-dimensional optical resonator "3D-cavity" using the abovementioned locking method.

[0055]

<First embodiment>

Fig. 1 is a schematic structural view illustrating an embodiment of a polarized laser oscillation method and a polarized laser oscillation system of the present invention utilizing the abovementioned principle.

[0056]

A polarized laser oscillation system 1 illustrated in this drawing is provided with a laser light source 2 which includes a CW laser oscillator and a mode-locking laser pulse oscillator and which generates laser such as CW laser and pulse laser, an incident optical system 3 which adjusts a polarization face and a beam diameter of laser emitted from the laser light source 2, a three-dimensional optical resonator 4 which receives laser emitted from the incident optical system 3 and accumulates the laser as selecting right circular polarization or left circular polarization in accordance with an adjusted optical path length, a resonance monitoring unit 5 which monitors strength of laser resonating in the three-dimensional optical resonator 4, a zero-cross feedback signal generator 6 which generates a zero-cross feedback signal as separating laser transmitted through a flat mirror 21 among laser resonating in the three-dimensional optical resonator 4 into P-polarized light and S-polarized light, measuring strength thereof and obtaining a differential value therebetween, a polarization change-over switch 7 which outputs an instruction signal to assign right circular polarization or left circular polarization which is selected at the three-dimensional optical resonator 4, and a resonance controller 8 which controls the optical path length of the three-dimensional optical resonator 4 based on output of the polarization change-over switch 7, output of the resonance monitoring unit 5 and output of the zero-cross feedback signal generator 6 and selectively accumulates laser of right circular polarization or left circular polarization into the three-dimensional optical resonator 4. The polarized laser oscillation system 1 generates high-strength pulse laser with

right or left circular polarization in the three-dimensional optical resonator 4 having a time width of 30 psec or shorter, a beam size of 10 μm or smaller, and energy strength of 1 mJ/pulse or higher while the laser light source 2 and the three-dimensional optical resonator 4 are controlled by the resonance controller 8 based on the instruction signal output from the polarization change-over switch 7, a monitored result of the resonance monitoring unit 5, a zero-cross detection signal output from the zero-cross feedback signal generator 6 and the like.

[0057]

The laser light source 2 includes the CW laser oscillator which generates CW laser, the mode-locking laser pulse oscillator which generates pulse laser, and the like. The laser light source 2 generates laser such as CW laser and pulse laser as activating either the CW laser oscillator or the mode-locking laser pulse oscillator based on an instruction from the resonance controller 8 and enters the laser into the incident optical system 3.

[0058]

The incident optical system 3 includes a plurality of flat mirrors 9 which guide the laser emitted from the laser light source 2 to the three-dimensional optical resonator 4, a plurality of collimated lenses 10 which adjust a polarization face and a beam diameter of the laser emitted from the laser light source 2 as being placed on an optical path which is defined by the respective flat mirrors 9, and a polarization beam splitter 11 which makes laser be linearly polarized as being placed on the optical path which is defined by the respective flat mirrors 9. The incident optical system 3 enters the laser into the three-dimensional optical resonator 4 while adjusting a polarization face and a beam diameter of the laser emitted from the laser light source 2.

[0059]

As illustrated in Fig. 2, the three-dimensional optical resonator 4 includes two ring members 12, 13 which are made of material being resistant to electron beams and radiation with a small coefficient of thermal expansion and which is sized to be capable of being accommodated in a collision chamber arranged at an emission path of a high-energy electron beam generating

device, four rod members 14 which are made of material being resistant to electron beams and radiation with a small coefficient of thermal expansion and which keep the respective ring members 12 distanced in parallel by a predetermined distance, a flat plate 15 which is made of material being resistant to electron beams and radiation with a small coefficient of thermal expansion and which is attached to the one ring member 12 as being inclined 45 degrees clockwise against the horizontal direction, two reflection mirror holding frames (stages) 16, 17 which are made of material being resistant to electron beams and radiation with a small coefficient of thermal expansion and which are attached to round holes formed at the flat plate 15, a flat plate 18 which is made of material being resistant to electron beams and radiation with a small coefficient of thermal expansion and which is attached to the other ring member 13 as being inclined 45 degrees counterclockwise against the horizontal direction, and two reflection mirror holding frames (stages) 19, 20 which are made of material being resistant to electron beams and radiation with a small coefficient of thermal expansion and which are attached to round holes formed at the flat plate 18.

[0060]

Further, the three-dimensional optical resonator 4 includes the flat mirror 21 which has a reflection rate of 0.999 and a transmission factor of 0.001 and which reflects laser from the other ring member 13 side while causing laser emitted from the incident optical system 3 to transmit therethrough as being attached to the reflection mirror holding frame 16 placed at an entering port for laser emitted from the incident optical system 3 among the respective reflection mirror holding frames 16, 17, 19, 20; a flat mirror 22 which has a reflection rate of 0.999 and a transmission factor of 0.001 and which reflects laser transmitted through the flat mirror 21 and laser reflected by the flat mirror 21 as being arranged at the reflection mirror holding frame 19 at the ring member 13 faced to the ring member 12 with the flat mirror 21 arranged among the respective reflection mirror holding frames 16, 17, 19, 20; a concave mirror 23 which has a reflection rate of 0.999 and a transmission factor of 0.001 and which reflects laser reflected by the flat mirror 22 and condenses the laser to be 10 μm or smaller in beam size

at a collision point set on an electron beam path 37 as being arranged at the reflection mirror holding frame 17 at the ring member 12 with the flat mirror 21 arranged among the respective reflection mirror holding frames 16, 17, 19, 20; a concave mirror 24 which has a reflection rate of 0.999 and a transmission factor of 0.001 and which restores laser collimated by the concave mirror 23 to parallel laser and returns the laser to the flat mirror 21 as being arranged at the reflection mirror holding frame 20 at the ring member 13 faced to the ring member 12 with the concave mirror 23 among the respective reflection mirror holding frames 16, 17, 19, 20; and a piezoelectric element 25 which is arranged between the concave mirror 24 and the reflection mirror holding frame 20 and which adjusts the position of the concave mirror 24 as being deformed in accordance with drive voltage supplied from the resonance controller 8.

[0061]

Then, the laser emitted from the incident optical system 3 is introduced and accumulated as being confined in a route in the order of the flat mirror 21, the flat mirror 22, the concave mirror 23, the concave mirror 24 and the flat mirror 21 with selection of right circular polarization or left circular polarization corresponding to the optical path length adjusted by the piezoelectric element 25.

[0062]

The resonance monitoring unit 5 includes a flat mirror 26 which reflects laser transmitted through the flat mirror 22 of the three-dimensional optical resonator 4 and a pin photodiode 27 which receives laser reflected by the flat mirror 26 and which generates a monitor signal having a voltage value corresponding to laser strength (a signal indicating strength of laser resonating in the three-dimensional optical resonator 4). The resonance monitoring unit 5 generates the monitor signal as measuring strength of laser transmitted through the flat mirror 22 of the three-dimensional optical resonator 4 and supplies the signal to the resonance controller 8.

[0063]

The zero-cross feedback signal generator 6 includes a plurality of flat mirrors 28 which reflect laser transmitted through the flat mirror 21 out of resonating laser in the three-dimensional optical resonator 4 and guides the laser to

a position being apart from the three-dimensional optical resonator 4 by a predetermined distance, a half-wave plate 29 which adjusts a polarization face of the laser reflected by the flat mirror 28 of the final stage as being adjusted to form an attaching angle corresponding to a distance from the three-dimensional optical resonator 4, a polarization beam splitter 30 which splits the laser with the polarization face adjusted by the half-wave plate 29 into P-polarized light and S-polarized light, a flat mirror 31 which reflects laser of the S-polarized light side split by the polarization beam splitter 30, a pin photodiode 32 which receives the laser of the S-polarized light side reflected by the flat mirror 31 and generates an S-polarized light strength signal indicating laser strength of the S-polarized light side, a flat mirror 33 which reflects laser of the P-polarized light side split by the polarization beam splitter 30, a pin photodiode 34 which receives the laser of the P-polarized light side reflected by the flat mirror 33 and generates a P-polarized light strength signal indicating laser strength of the P-polarized light side, a differential amplifier 35 which calculates difference between the S-polarized light strength signal output from the pin photodiode 32 and the P-polarized light strength signal output from the pin photodiode 34 and generates a difference signal, and a zero-cross determination circuit 36 which generates a zero-cross feedback signal indicating a result of determination whether or not zero-crossing occurs at the difference signal output from the differential amplifier 35, whether zero-crossing occurs from the plus side to the minus side or from the minus side to the plus side when zero-crossing occurs, and the like. The zero-cross feedback signal generator 6 performs introducing of the laser transmitted through the flat mirror 21 out of the resonating laser in the three-dimensional optical resonator 4, splitting of the laser into P-polarized light and S-polarized light, measuring of strength thereof, obtaining of the difference value therebetween, generating the zero-cross feedback signal indicating whether or not zero-crossing occurs at the difference signal output from the differential amplifier 35, whether zero-crossing occurs from the plus side to the minus side or from the minus side to the plus side when zero-crossing occurs, and the like, and supplying the signal to the resonance

controller 8.

[0064]

The polarization change-over switch 7 generates, based on settings, an instruction signal to alternately assign right circular polarization or left circular polarization in accordance with an instruction signal assigning right circular polarization (or left circular polarization) or a high frequency signal output from the high frequency signal generating unit and supplies the signal to the resonance controller 8.

[0065]

The resonance controller 8 includes a calculation substrate on which a microprocessor to perform a variety of calculations, a LSI with a calculating function assembled or the like is mounted. The resonance controller 8 generates drive voltage having a ramp-shaped voltage value or a voltage value required for selecting laser of right circular polarization or left circular polarization in the three-dimensional optical resonator 4 based on the instruction signal output from the polarization change-over switch 7, a monitor signal output from the resonance monitoring unit 5 and a zero-cross feedback signal output from the zero-cross feedback signal generator 6, and supplies the drive voltage to the piezoelectric element 25 of the three-dimensional optical resonator 4. Thus, the resonance controller 8 controls the optical path length of the three-dimensional optical resonator 4 and selectively accumulates laser of right circular polarization or left circular polarization into the three-dimensional optical resonator 4.

[0066]

Next, operation of the polarized laser oscillation system 1 will be described with reference to the schematic structural view of Fig. 1 and the perspective view of Fig. 2.

[0067]

When an activation switch of the polarized laser oscillation system 1 is turned on and laser such as CW laser starts to be emitted from the laser light source 2, the laser enters to the flat mirror 21 of the three-dimensional optical resonator 4 with a polarization face and a beam diameter of the laser adjusted by the incident optical system 3 and the laser transmitted through the flat mirror 21 is confined in the route

in the order of the flat mirror 21, the flat mirror 22, the concave mirror 23, the concave mirror 24 and the flat mirror 21.

[0068]

Further, in parallel to the above operation, the resonance monitoring device 5 generates a monitor signal as measuring strength of laser transmitted through the flat mirror 22 of the three-dimensional optical resonator 4 and supplies the signal to the resonance controller 8.

[0069]

Further, in parallel to the above operation, according to the zero-cross feedback signal generator 6, the laser transmitted through the flat mirror 21 is introduced out of the resonating laser in the three-dimensional optical resonator 4 and is split into P-polarized light and S-polarized light, and then, strength thereof is measured and a difference value therebetween is obtained. Subsequently, a zero-cross feedback signal is generated as determining whether or not zero-crossing occurs and is supplied to the resonance controller 8.

[0070]

Furthermore, in parallel to the above operation, drive voltage with a voltage value increased like a ramp-shape is generated by the resonance controller 8 and is supplied to the piezoelectric element 25 in the three-dimensional optical resonator 4, so that the optical path length of the three-dimensional optical resonator 4 is adjusted.

[0071]

Here, either right circular polarization or left circular polarization (e.g., right circular polarization) is assigned with an instruction signal output from the polarization change-over switch 7. Under the above conditions, when a zero-cross feedback signal indicating detection of right circular polarization is generated by the zero-cross feedback signal generator 6 and a monitor signal indicating that laser is resonating in the three-dimensional optical resonator 4 is output from the resonance monitoring unit 5, the resonance controller 8 fixes the voltage value of the drive voltage as detecting the above.

[0072]

Accordingly, the optical path length in the three-dimensional optical resonator 4 is fixed at that time and

resonance against the laser of right circular polarization is maintained in the three-dimensional optical resonator 4 for a specified period.

[0073]

Similar control is performed as well in a case that high-strength pulse laser generated with mode-locking oscillation is emitted from the laser light source 2, so that pulse laser of right circular polarization (high-strength pulse laser) or pulse laser of left circular polarization (high-strength pulse laser) resonates and is accumulated in the three-dimensional optical resonator 4 and the above is maintained at least for 0.001 sec.

[0074]

Here, a line width of the pulse laser is determined by a mode-locking oscillation frequency and a time width of the pulse laser. Further, a beam size of the pulse laser at the collision point is 10 μm or smaller in the three-dimensional optical resonator 4. Accordingly, as long as the time width of the pulse laser is 30 psec or shorter, it is possible to set energy strength at the collision point in the three-dimensional optical resonator 4 to be 1 mJ/pulse or higher.

[0075]

Similar control is performed as well in a case that an instruction signal assigning right circular polarization and left circular polarization alternately is output from the polarization change-over switch 7, so that pulse laser of right circular polarization (high-strength pulse laser) and pulse laser of left circular polarization (high-strength pulse laser) alternatively resonate and are accumulated in the three-dimensional optical resonator 4.

[0076]

In this case as well, a line width of the pulse laser is determined by a mode-locking oscillation frequency and a time width of the pulse laser. Further, a beam size of the pulse laser at the collision point is 10 μm or smaller in the three-dimensional optical resonator 4. Accordingly, as long as the time width of the pulse laser is 30 psec or shorter, it is possible to set energy strength at the collision point in the three-dimensional optical resonator 4 to be 1 mJ/pulse or higher.

[0077]

As described above, in the embodiment, it is possible to cause laser obtained from the laser light source 2 to resonate either with right polarization or left polarization as guiding the laser to the three-dimensional optical resonator 4 and to easily perform switching only with operation of the polarization change-over switch 7.

[0078]

Further, in the embodiment, it is possible to cause high-strength pulse laser obtained from the laser light source 2 to resonate either with right polarization or left polarization as guiding the laser to the three-dimensional light source 4 and to generate pulse laser having a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher at the collision point arranged in the three-dimensional optical resonator 4.

[0079]

Further, in the embodiment, it is possible to cause high-strength pulse laser having a time width of 30 psec or shorter obtained from the laser light source 2 to resonate either with right polarization or left polarization as guiding the laser to the three-dimensional optical resonator 4 and to generate pulse laser having a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher at the collision point arranged in the three-dimensional optical resonator 4.

[0080]

Furthermore, according to the embodiment, it is possible to alternatively generate right polarization pulse laser and left polarization pulse laser having a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher at the collision point arranged in the three-dimensional optical resonator 4 as guiding high-strength pulse laser obtained from the laser light source 2 to the three-dimensional optical resonator 4.

[0081]

<Second embodiment>

Fig. 3 is a schematic structural view illustrating an example of a polarized radiation generation method and a polarized radiation generating system using the polarized laser oscillation system 1 illustrated in Fig. 1. In this drawing, the same numeral is given to a portion corresponding to Fig. 1 or Fig. 2.

[0082]

A polarized radiation generating system 51 illustrated in the drawing includes a high frequency signal generating unit 52 which generates a high frequency signal required for synchronizing the system, a high-energy electron beam generating unit 53 which includes an accelerator and which emits an electron beam as accelerating electrons by using high frequency voltage synchronized with the high frequency signal output from the high frequency signal generating unit 52, the polarized laser oscillation system 1 which includes the laser light source, the mode-locking laser oscillator and the like and which generates laser obtained with CW oscillation or pulse laser synchronized with the high frequency signal output from the high frequency signal generating unit 52, a collision chamber 54 which accommodates the three-dimensional optical resonator 4 structuring the polarized laser oscillation system 1 so that collision occurs with collision accuracy of 1 μm or less while a collision angle between the electron beam emitted from the high-energy electron beam generating unit 53 and laser in the three-dimensional optical resonator 4 is in a range from 8 to 20 degrees and which generates radiation with inverse Compton scattering occurs when collision occurs with the laser in the three-dimensional optical resonator 4, and a radiation detecting unit 55 which draws radiation generated at the collision chamber 54 and which measures a radiation amount.

[0083]

Then, high-strength polarization pulse laser which has left circular polarization characteristics (or left circular polarization characteristics) having ultrahigh cycling characteristics of 100 MHz or higher with a pulse time width of 30 psec or shorter and a beam size of 10 μm or smaller is generated at the three-dimensional optical resonator 4 of the polarized laser oscillation system 1 while the high-energy electron beam generating unit 53 and the polarized laser oscillation system 1 are perfectly synchronized owing to the high frequency signal output from the high frequency signal generating unit 52. A high-energy electron beam having high quality characteristics with normalized emittance of 10 mmmrad or less is emitted from the high-energy electron beam generating unit 53. Then, the high-energy electron beam and the

high-strength polarization pulse laser are collided in the collision chamber 54.

[0084]

With the above, it is possible that ultrashort pulse polarized radiation having energy of 0.25 keV or higher is generated with inverse Compton scattering and is guided to the outside as being drawn by the radiation detecting unit 55 and that a radiation amount of the radiation guided to the outside is measured and displayed with an indicator (not illustrated) or the like.

[0085]

As described above, in the embodiment, ultrashort pulse polarized radiation can be generated at the collision point arranged in the three-dimensional optical resonator 4 owing to collision between the high-energy electron beam emitted from the high-energy electron beam generating unit 53 and the pulse laser of right polarization or left polarization with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher generated at the collision point in the three-dimensional optical resonator 4.

[0086]

Further, in the embodiment, ultrashort pulse polarized radiation having energy of 0.25 keV or higher can be generated at the collision point arranged in the three-dimensional optical resonator 4 owing to collision between the high-energy electron beam having high quality characteristics with normalized emittance of 10 mmmrad or less emitted from the high-energy electron beam generating unit 53 and the pulse laser of right polarization or left polarization with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher generated at the collision point in the three-dimensional optical resonator 4 with a collision angle in a range from 8 to 20 degrees being close to frontal collision and collision accuracy of 1 μm or less.

[0087]

Further, in the embodiment, ultrashort pulse polarized radiation with characteristics having energy of 0.25 keV or higher can be generated at the collision point arranged in the three-dimensional optical resonator 4 owing to collision between the high-energy electron beam having high quality

characteristics with normalized emittance of 10 mmmrad or less emitted from the high-energy electron beam generating unit 53 and the high-strength polarization pulse laser having right or left circular polarization which has ultrahigh cycling characteristics of 100 MHz or higher with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher generated at the collision point in the three-dimensional optical resonator 4 with a collision angle in a range from 8 to 20 degrees being close to frontal collision and collision accuracy of 1 μm or less.

[0088]

Furthermore, in the embodiment, an X-ray or a γ -ray with ultrashort pulse polarization having energy of 0.25 keV or higher can be generated at the collision point arranged in the three-dimensional optical resonator 4 owing to collision between the high-energy electron beam having high quality characteristics with normalized emittance of 10 mmmrad or less emitted from the high-energy electron beam generating unit 53 and the pulse laser of right polarization or left polarization with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher generated at the collision point in the three-dimensional optical resonator 4 with a collision angle in a range from 8 to 20 degrees being close to frontal collision and collision accuracy of 1 μm or less.

INDUSTRIAL APPLICABILITY

[0089]

The present invention has industrial applicability as relating to a polarized laser oscillation method, a polarized radiation generation method, and a device and a system thereof for a small-sized X-ray source to generate an X-ray using laser inverse Compton scattering and the like, and in particular, relating to a polarized laser oscillation method, a polarized radiation generation method, and a device and a system thereof being capable of freely selecting right or left circular polarization.

EXPLANATION OF REFERENCES

[0090]

- 1: Polarized laser oscillation system
- 2: Laser light source
- 3: Incident optical system

- 4: Three-dimensional optical resonator
- 5: Resonance monitoring unit
- 6: Zero-cross feedback signal generator
- 7: Polarization change-over switch
- 8: Resonance controller
- 9: Flat mirror
- 10: Collimated lens
- 11: Polarization beam splitter
- 12: Ring member
- 13: Ring member
- 14: Rod member
- 15: Flat plate
- 16: Reflection mirror holding frame
- 17: Reflection mirror holding frame
- 18: Flat plate
- 19: Reflection mirror holding frame
- 20: Reflection mirror holding frame
- 21: Flat mirror
- 22: Flat mirror
- 23: Concave mirror
- 24: Concave mirror
- 25: Piezo element (Piezoelectric element)
- 26: Flat mirror
- 27: Pin photodiode
- 28: Flat mirror
- 29: Half-wave plate
- 30: Polarization beam splitter
- 31: Flat mirror
- 32: Pin photodiode
- 33: Flat mirror
- 34: Pin photodiode
- 35: Differential amplifier
- 36: Zero-cross determination circuit
- 37: Electron beam path
- 51: Polarized radiation generating system
- 52: High frequency signal generating unit
- 53: High-energy electron beam generating unit
- 54: Collision chamber
- 55: Radiation detecting unit

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

[CLAIM 1]

A three-dimensional optical resonance device,
comprising:

an optical resonator which includes a pair of flat mirrors and a pair of concave mirrors as being three-dimensionally arranged and which introduces laser light emitted from a laser light source unit with an incident optical system and selecting right circular polarization or left circular polarization in accordance with a length of an optical path adjusted by a piezoelectric element while circulating the laser light on the length-adjusted optical path to cause the laser light to resonate.

[CLAIM 2]

The three-dimensional optical resonance device according to claim 1,

wherein the laser light source unit includes a CW laser oscillator or a mode-locking laser pulse oscillator as a laser oscillator, and

a polarization face and a beam diameter of the laser light emitted from the laser light source unit which generates laser light being a CW laser type or a pulse laser type are adjusted.

[CLAIM 3]

The three-dimensional optical resonance device according to claim 1 or claim 2, further comprising a resonance monitoring unit which measures strength of the laser light resonating in the optical resonator.

[CLAIM 4]

The three-dimensional optical resonance device according to claim 2, further comprising a zero-cross feedback signal generator which generates a zero-cross feedback signal by splitting laser light transmitted through any of the flat mirrors and the concave mirrors among the laser light resonating in the optical resonator into a P-polarized component and an S-polarized component, measuring strength of each polarized component, and obtaining a differential value therebetween.

[CLAIM 5]

The three-dimensional optical resonance device according to claim 4, further comprising:

a polarization change-over switch which outputs an instruction signal to assign the selected right circular polarization or left circular polarization; and

a resonance controller which adjusts the length of the optical path by controlling drive voltage of the piezoelectric element arranged in the optical resonator based on output of the polarization change-over switch, output of the resonance monitoring unit and output of the zero-cross feedback signal generator and which selectively accumulates laser light of right circular polarization or left circular polarization into the optical resonator.

[CLAIM 6]

The three-dimensional optical resonance device according to claim 1,

wherein said laser light comprises right polarization pulse laser light or left polarization pulse laser light

with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher and said right or left polarization pulse laser light is collided with an electron beam emitted from the incident optical system at a collision point arranged in the optical resonator to generate ultrashort pulse polarized radiation with a radiation amount thereof measured.

[CLAIM 7]

The three-dimensional optical resonance device according to claim 6,

wherein an electron beam, emitted from an electron beam generating unit, with normalized emittance of 10 mmrad or less and the pulse laser light in the optical resonator are collided at the collision point with a collision angle in a range from 8 to 20 degrees and collision accuracy of 1 μm or less and ultrashort pulse polarized radiation with characteristics having energy of 0.25 keV or higher is generated and drawn to the outside.

[CLAIM 8]

The three-dimensional optical resonance device according to claim 7,

wherein the ultrashort pulse polarized radiation is a X-ray or a γ -ray.

[CLAIM 9]

A polarized laser oscillation method, comprising:
guiding laser light emitted from a laser light source unit to an optical resonator;
adjusting an optical path length in the optical resonator by deforming a piezoelectric element by applying

ramp-like drive voltage while circulating the laser light in the optical resonator with a pair of flat mirrors and a pair of concave mirrors;

splitting laser light transmitted through the pair of concave mirrors or the pair of flat mirrors into a P-polarized component and an S-polarized component and measuring strength of each polarized component;

generating a zero-cross feedback signal based on strength difference value of the polarized components; and

right polarized laser light or left polarized laser light is caused to resonate and is accumulated in the optical resonator by fixing a voltage value of the drive voltage.

[CLAIM 10]

The polarized laser oscillation method according to claim 9,

wherein pulse laser light is emitted from the laser light source unit with mode-locking oscillation, and

wherein pulse laser light having a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher is generated at a collision point which is arranged in the optical resonator.

[CLAIM 11]

The polarized laser oscillation method according to claim 10,

wherein an electron beam, emitted from an electron beam generating unit, with normalized emittance of 10 mmmrad or less and the generated pulse laser light in the optical resonator are collided at the collision point with a collision angle in a range from 8 to 20 degrees and

collision accuracy of 1 μm or less and pulse polarized radiation being an X-ray or a γ -ray with characteristics having energy of 0.25 keV or higher is generated and drawn to the outside.

[CLAIM 12]

The polarized laser oscillation method according to claim 10,

wherein laser oscillation operation of the laser light source unit, resonance operation of the optical resonator, and emission operation of the laser light are synchronized, and

wherein the generated pulse laser light is of left circular polarization or right circular polarization and has ultrahigh cycling characteristics of 100 MHz or higher.

[CLAIM 13]

A polarized laser oscillation system, comprising:

a laser light source unit which has at least either one of a CW laser oscillator and a mode-locking laser pulse oscillator and which generates laser light of a CW laser type or a pulse laser type;

an incident optical system which arranges a polarization face and a beam diameter of the laser light emitted from the laser light source unit;

an optical resonator which is configured to cause laser light to resonate by introducing the laser light emitted from the laser light source unit with the incident optical system and selecting right circular polarization or left circular polarization in accordance with an adjusted length of an optical path while circulating the laser light on the optical path with the length being adjusted by a

piezoelectric element, wherein the optical resonator includes a pair of flat mirrors and a pair of concave mirrors;

a resonance monitoring unit which measures strength of the laser light resonating in the optical resonator;

a zero-cross feedback signal generator which generates a zero-cross feedback signal by splitting laser light transmitted through any of the flat mirrors and the concave mirrors among the laser light resonating in the optical resonator into P-polarized light and S-polarized light, measuring strength thereof, and obtaining a differential value therebetween;

a polarization change-over switch which outputs an instruction signal to assign said right circular polarization or said left circular polarization selected at the optical resonator; and

a resonance controller which adjusts the length of the optical path by controlling drive voltage of the piezoelectric element arranged in the optical resonator based on output of the polarization change-over switch, output of the resonance monitoring unit and output of the zero-cross feedback signal generator and which selectively accumulates laser light of said right circular polarization or said left circular polarization into the optical resonator.

[CLAIM 14]

The polarized laser oscillation system according to claim 13,

wherein pulse laser light is emitted with mode-locking oscillation of the laser light source unit, and

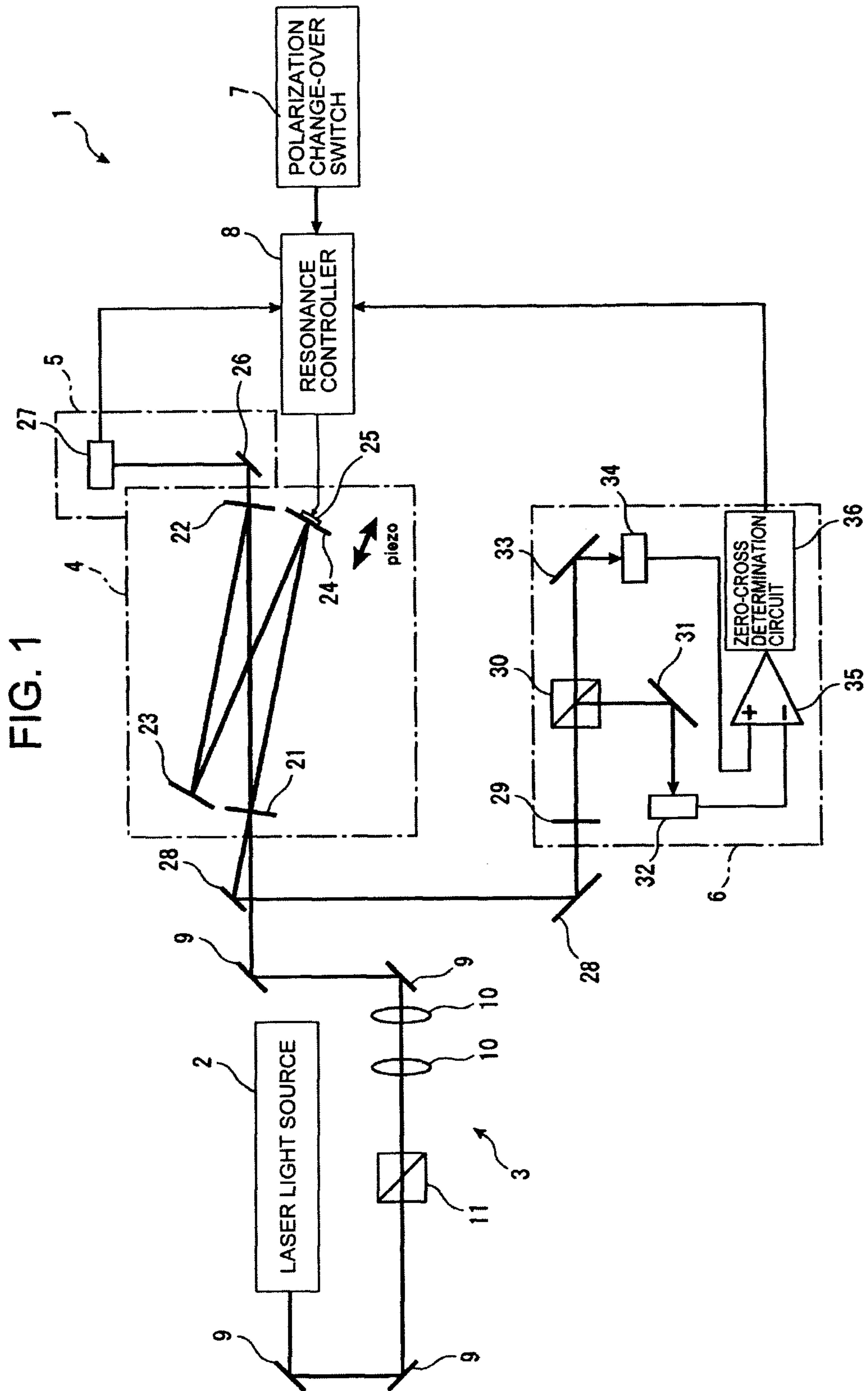
pulse laser light with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher is generated at a collision point which is arranged in the optical resonator.

[CLAIM 15]

The polarized laser oscillation system according to claim 14,

wherein pulse laser light with a time width of the pulse laser light being 30 psec or shorter is emitted with mode-locking oscillation of the laser light source unit, and

pulse laser light with a beam size of 10 μm or smaller and energy strength of 1 mJ/pulse or higher is generated at a collision point which is arranged in the optical resonator.



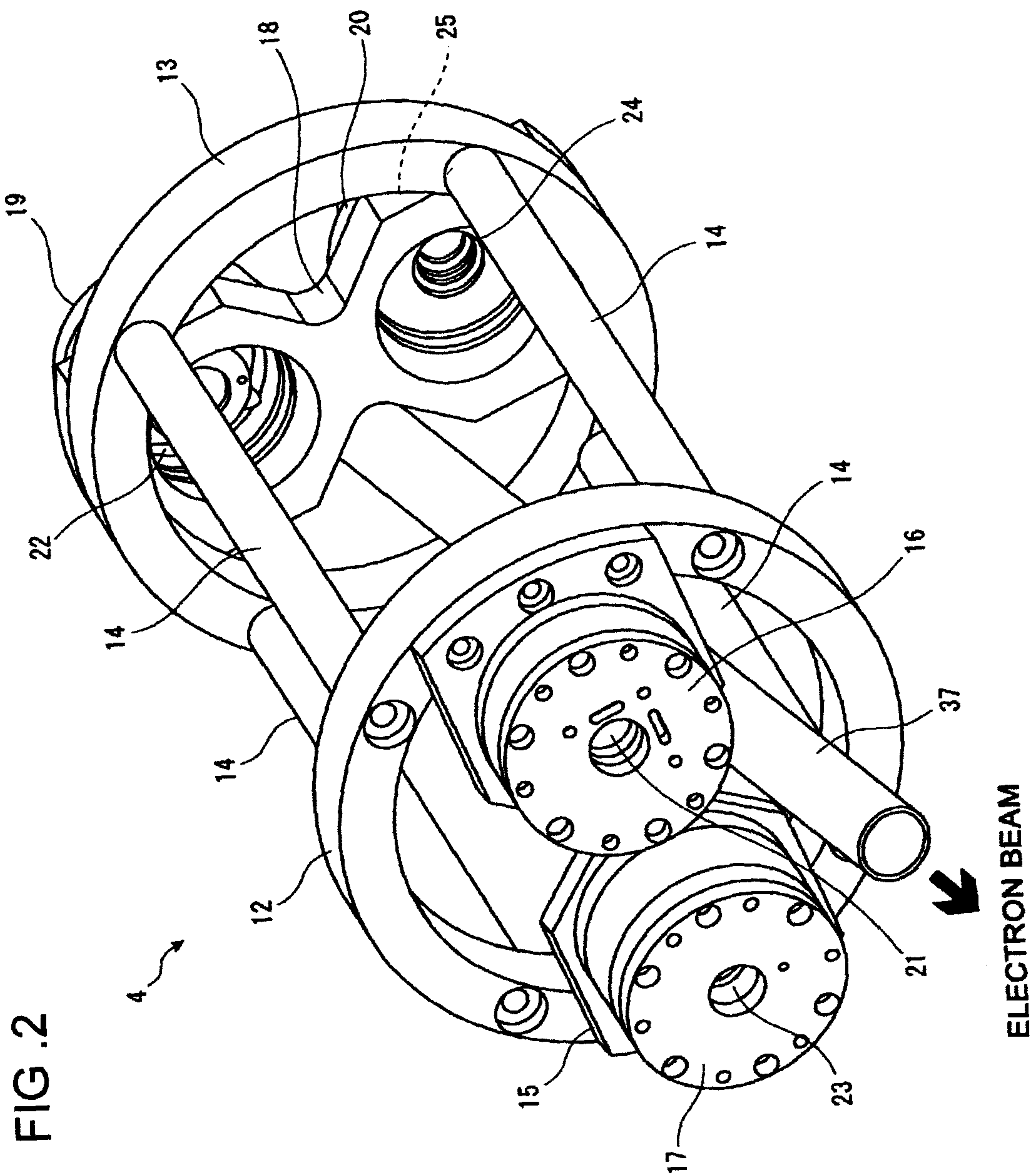


FIG. 2

FIG. 3

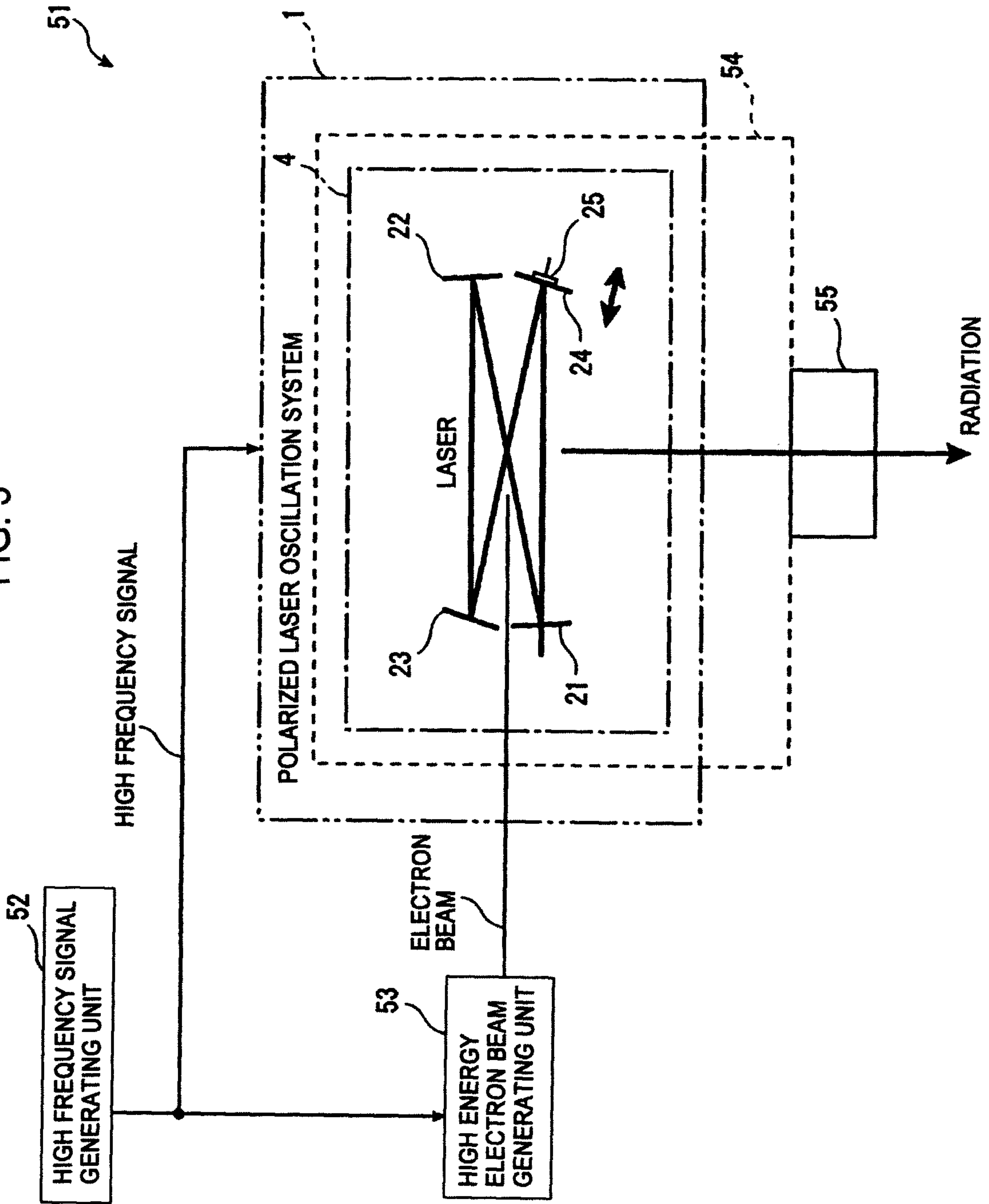


FIG. 4

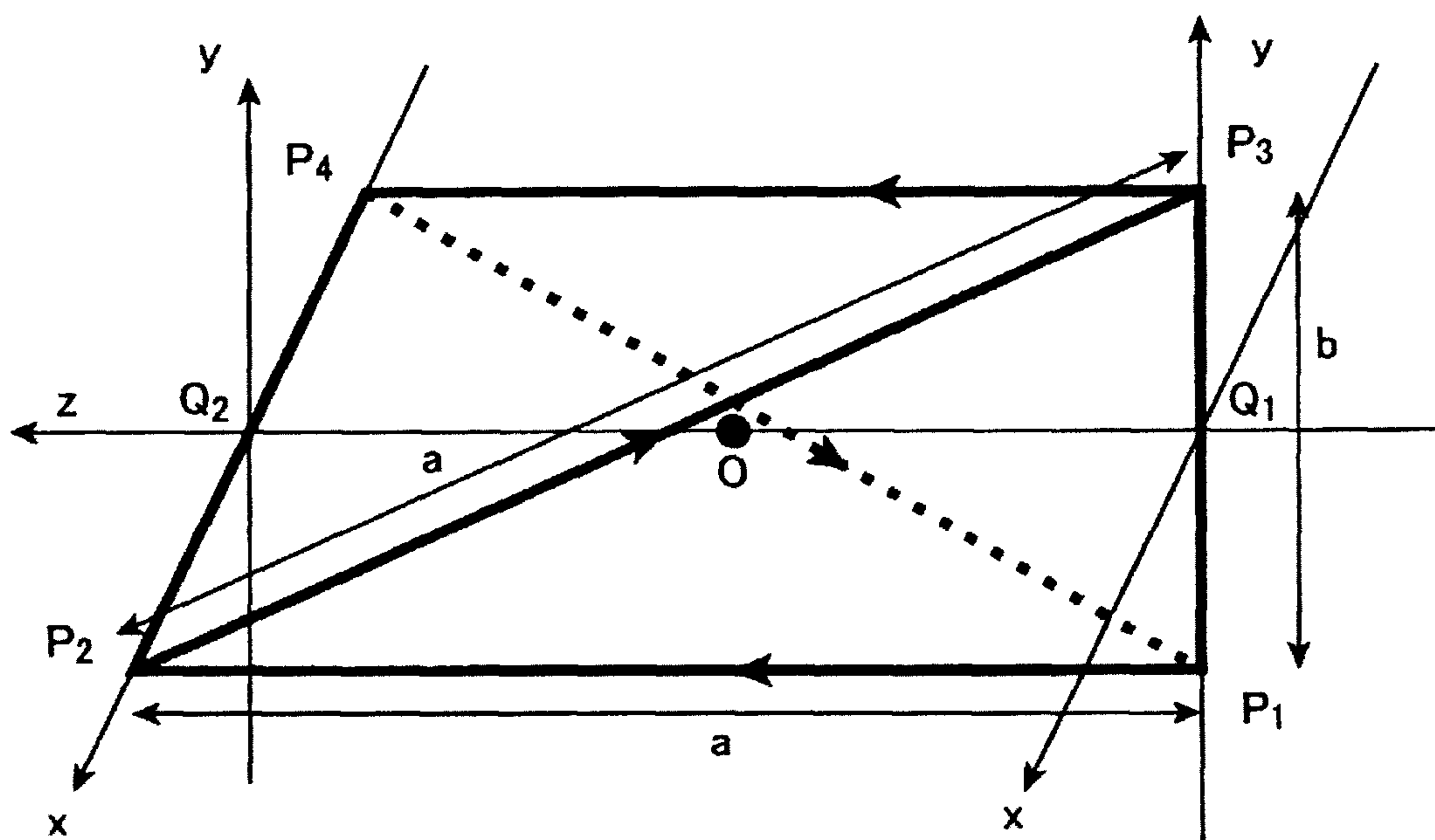


FIG. 5

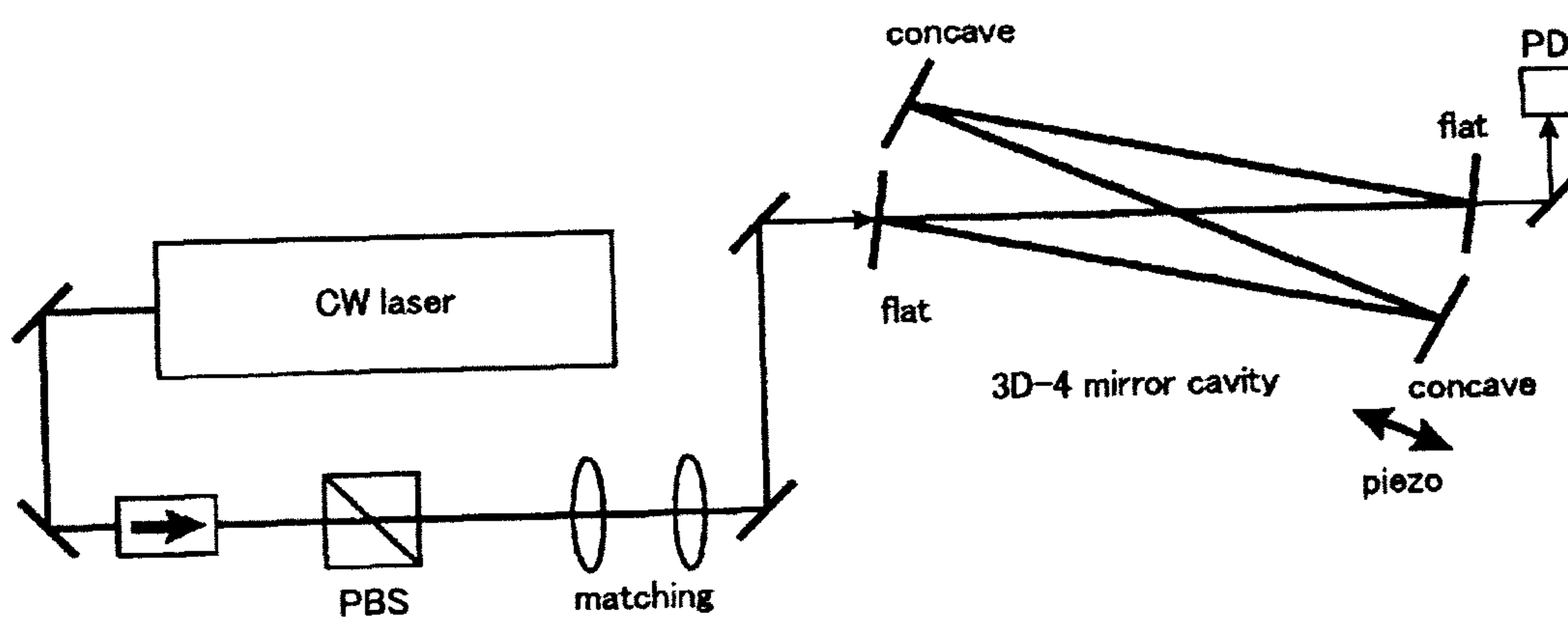


FIG. 6

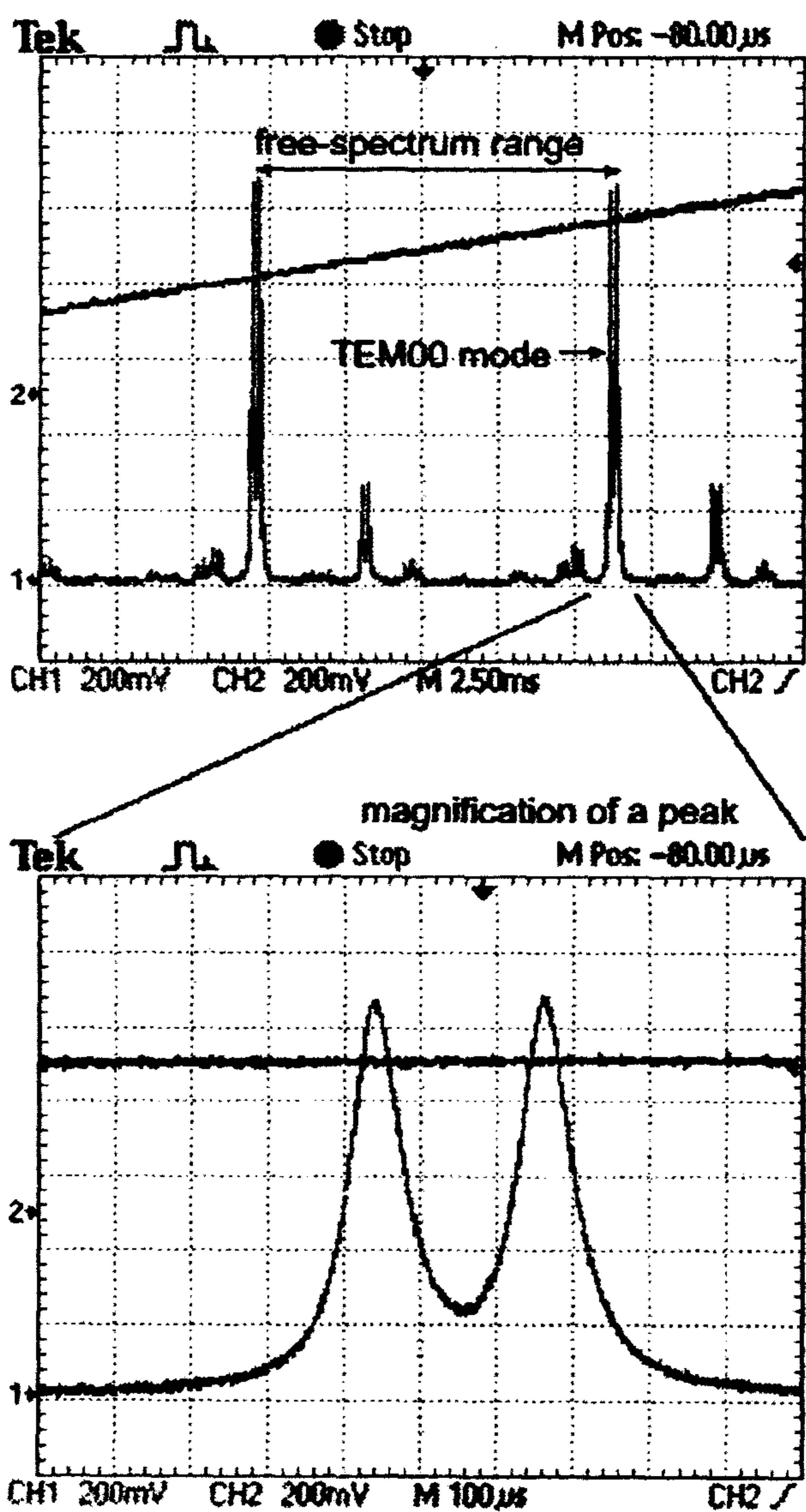


FIG. 7

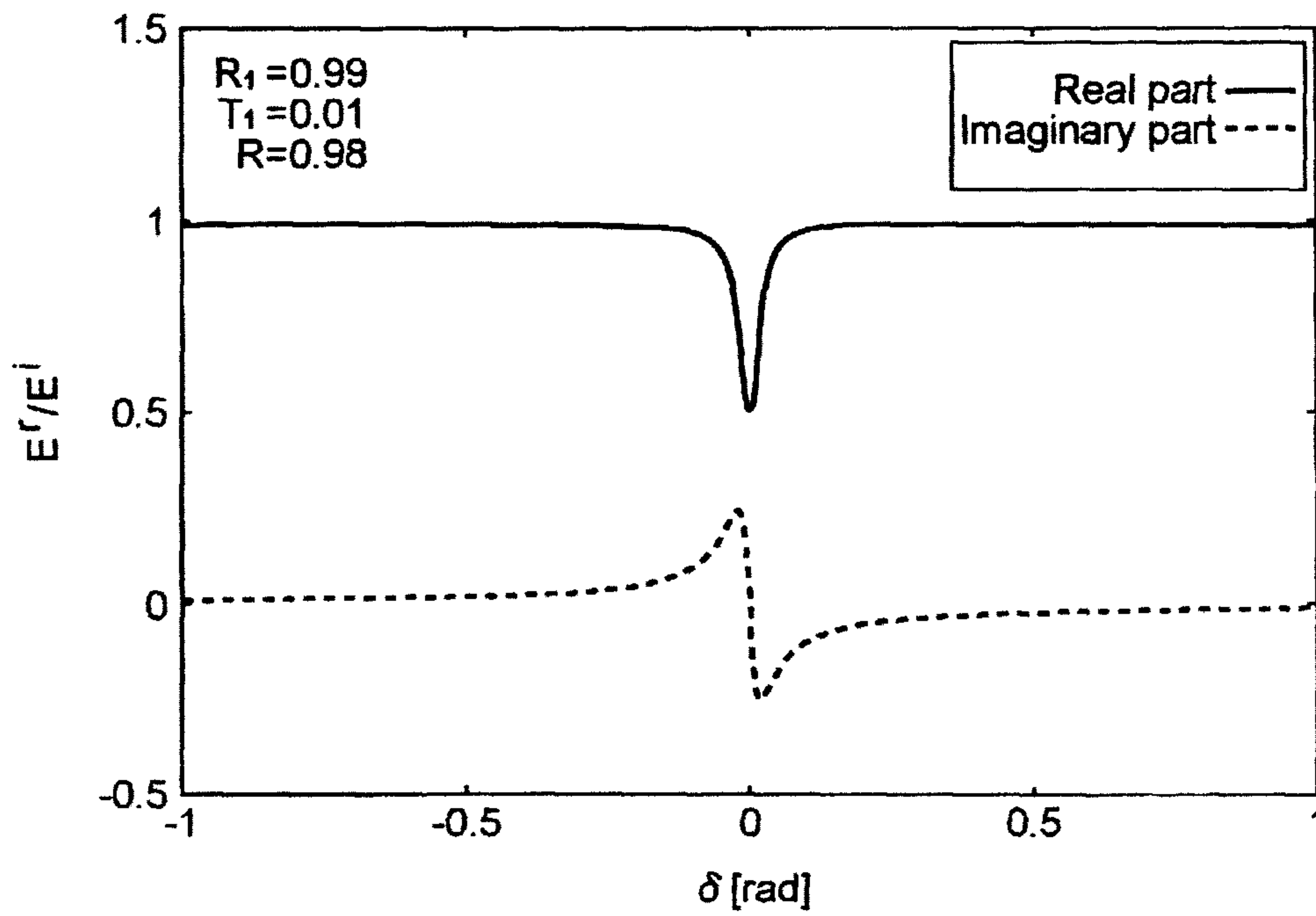


FIG. 8

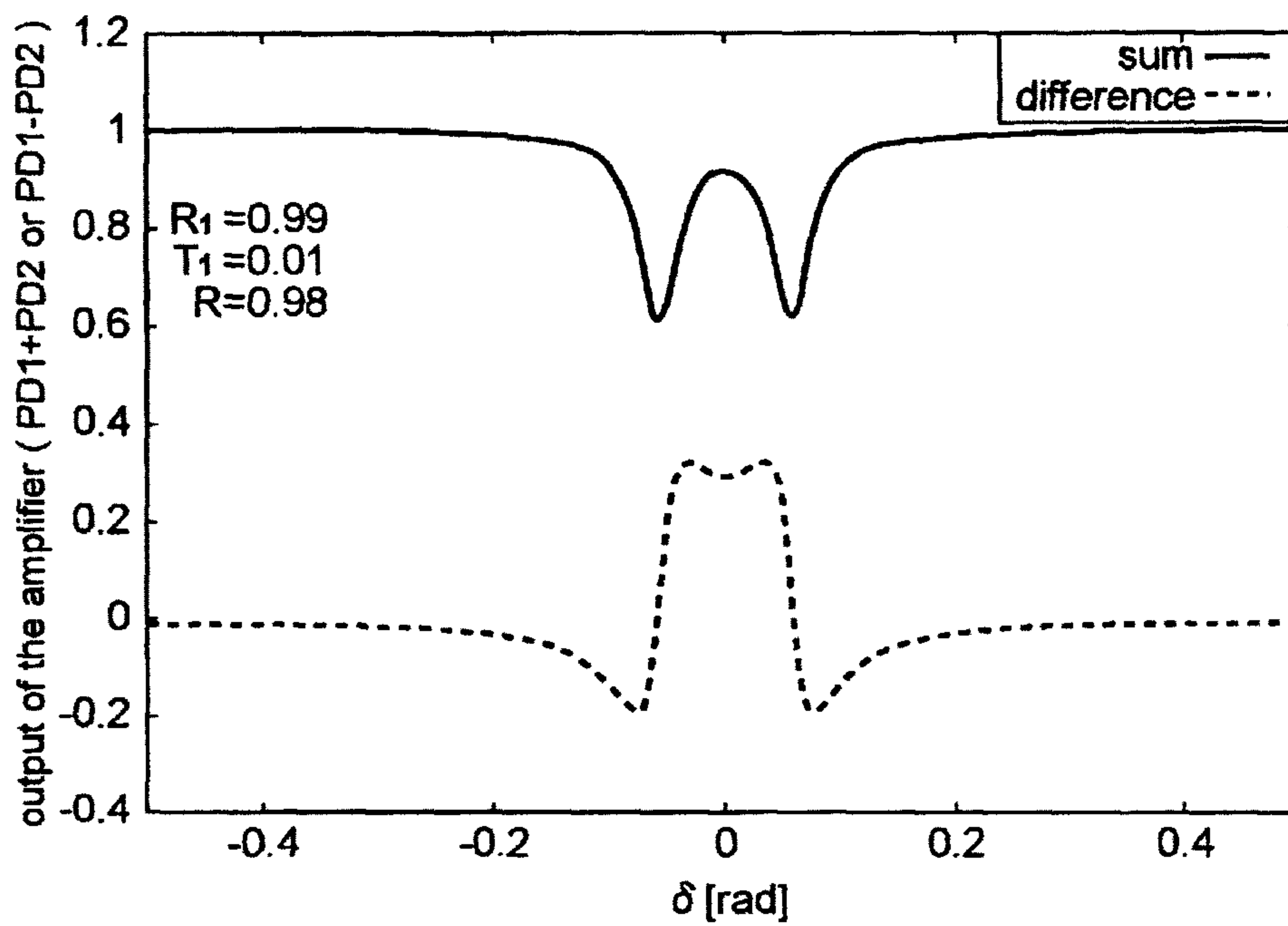


FIG. 9

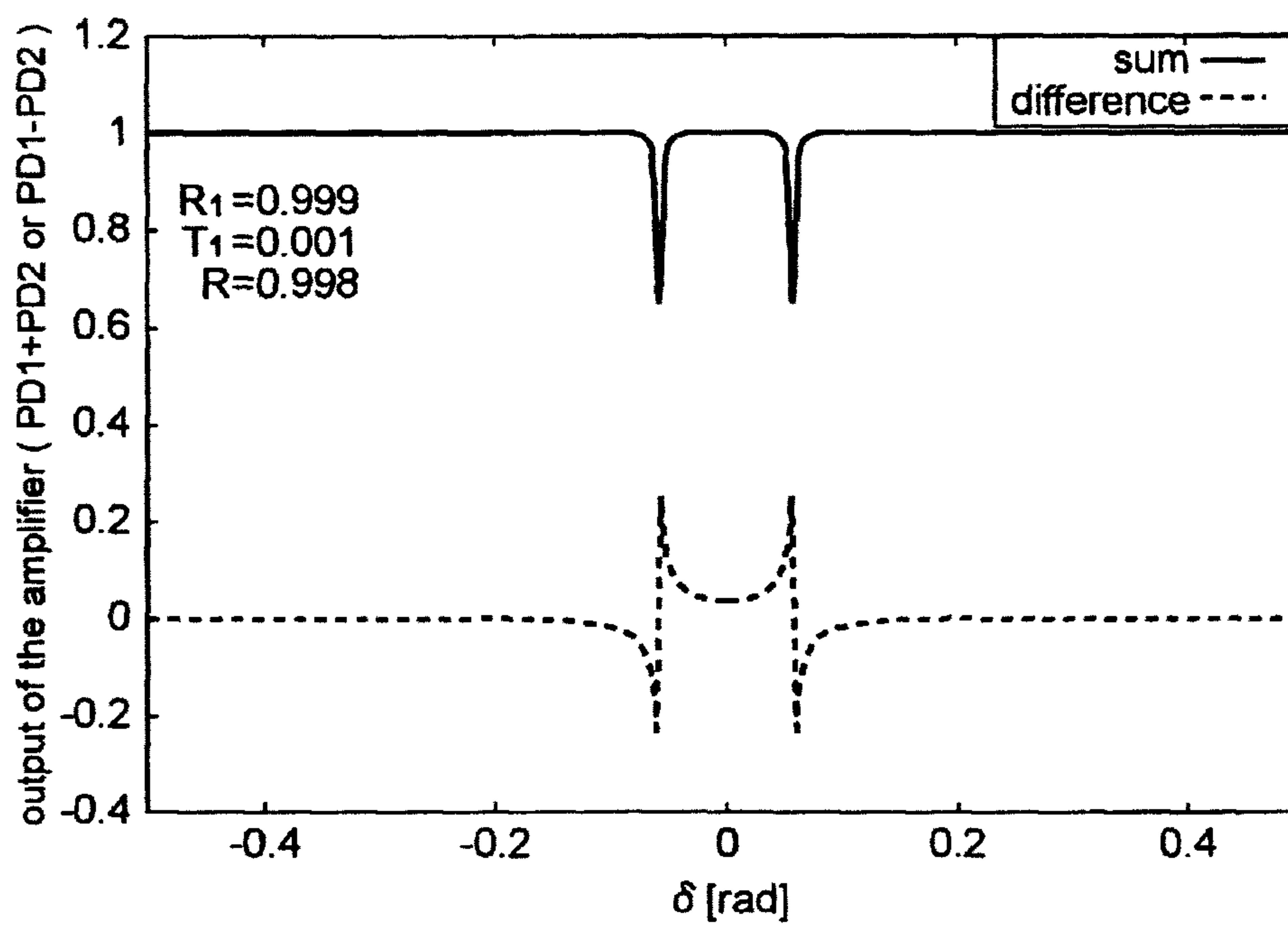


FIG. 10

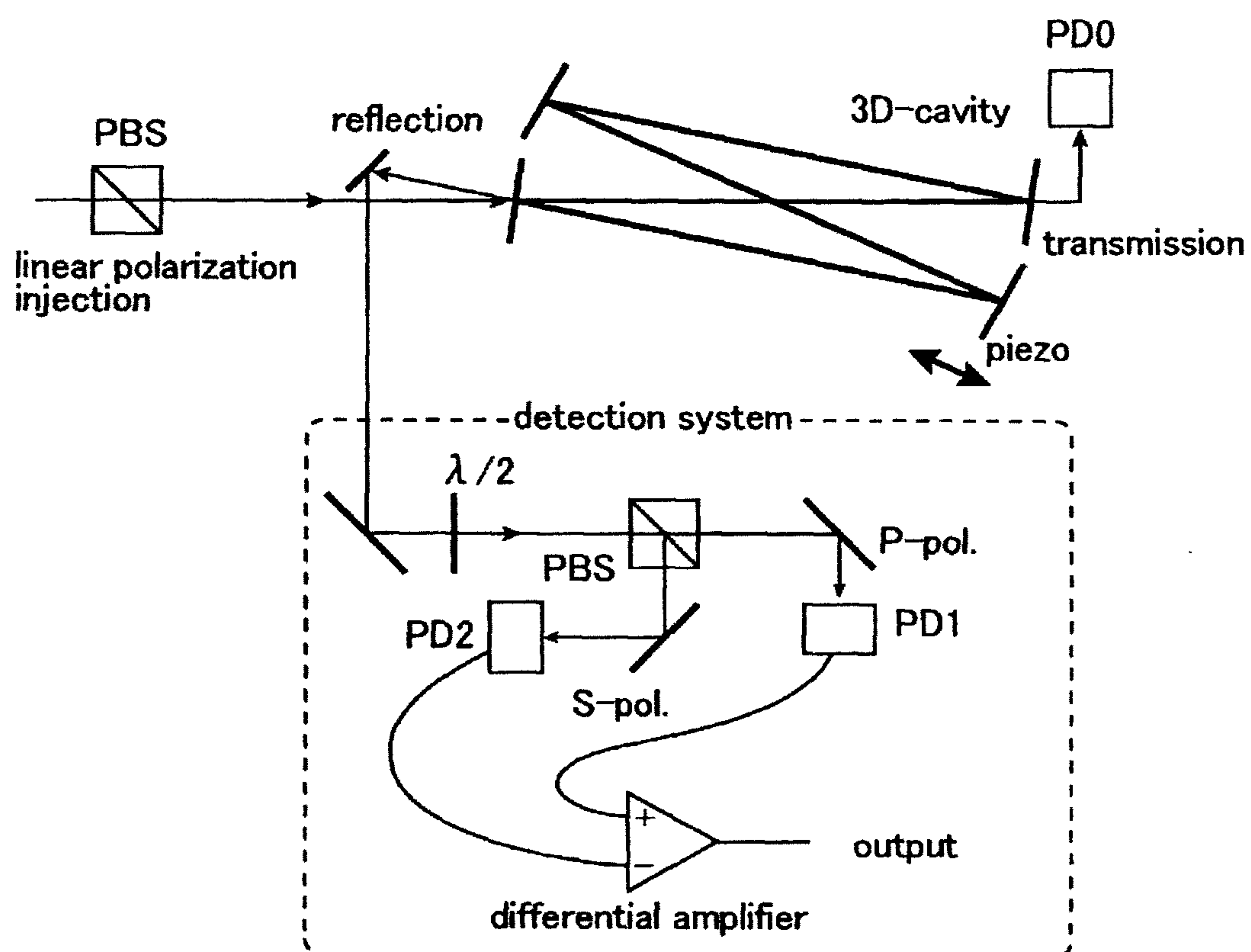


FIG. 11

