

DESCRIPTION

SECOND HARMONIC GENERATOR AND LASER APPLIED UNITS

5

Technical Field

This invention relates to an optoelectronic field and, more specifically, to a visible laser light source and laser applied units employing a visible laser light source, such as a laser printer, fine particle detector,
10 optical shaping unit, optical recorder and the like.

Background Art

With the progress of the advanced information communication age, demand for adaptation to short
15 wavelengths is arising to meet requirements for improved recording density and high-speed printing in an optical recording field such as optical disk drives and laser printers. However, as light sources capable of providing a blue color range (wavelength of 400 to 480 nm) which is
20 in high demand for commercialization, only gas lasers such as He-Cd (helium-cadmium) and Ar (argon) lasers are available, which have been unsuitable for use in optical disk drives, for example, because they are bulky and power consuming. Although the above gas lasers are actually
25 incorporated in some laser printers as a light source, there is the possibility that they will be an obstacle to future reductions in the size and power consumption of

laser printers for the above reason.

To overcome the above problem, technology which makes use of second harmonic generation (to be abbreviated as "SHG" hereinafter) to reduce wavelength is proposed.

5 Progress has been made in studies on technology for practical application of this SHG light source along with an increase in the output of a semiconductor laser. The scene behind this is that discharge is not necessary for this SHG light source unlike conventional gas lasers,
10 there is the possibility that (1) the size and (2) power consumption of the SHG light source will be reduced, and the SHG light source has high reliability depending on the output stability and long service life of an excitation semiconductor laser ((3) output stability and (4) long
15 service life).

There is also proposed a method for obtaining blue radiation 12 as a second oscillation wave, that is, an SHG wave, from an SHG light source having the same output wavelength as that of the afore-mentioned gas laser, for
20 example, wherein the output of a semiconductor laser 1 generating near infrared light as shown in Fig. 10 is taken as a first oscillation wave, that is, a fundamental wave, and resonated in a monolithic external resonator 44 which is composed of a nonlinear optical crystal (W.J.
25 Kozlovsky and W. Lenth, "Generation of 41 mW of blue radiation by frequency doubling of a GaAlAs diode laser", Appl. Phys. Lett., Vol.56 No.23, p.2291, 1990). The

nonlinear optical crystal (to be referred to as "SHG crystal" because wavelength conversions hereinafter are all for SHG) is KN (KNbO_3 : potassium niobate).

However, the above SHG light source involves the following advanced technical problems. One of them is that it is necessary to adjust the oscillation wavelength of the semiconductor laser 1 which is easily affected by disturbance to a wavelength at which the SHG conversion efficiency of a KN crystal becomes maximal. For this purpose, an optical isolator 42 must be inserted to protect the semiconductor laser from light reflected by the KN crystal. Another problem is that reflected light from the resonator must be received by an optical detector 45 to control the length of an external resonator including the KN crystal in the order of the wavelength of the fundamental wave and the electrical output of the optical detector 45 is supplied to a feedback circuit 46 to control the output of the semiconductor laser for stable oscillation. Therefore, it is expected to be difficult to find solutions to these technical problems for commercialization.

Means for solving the above technical problems include an intracavity doubling SHG laser system in which an oscillation wave from a solid laser is taken as a fundamental wave and an SHG crystal is arranged in the resonator of the solid laser. In other words, in the intracavity doubling SHG laser system, oscillation

wavelength is rarely affected by disturbance such as the above reflected light because the resonator forming the solid laser comprises mirrors having a high reflectance for the wavelength of an oscillation wave from the solid
5 laser arranged at both ends thereof. The intracavity doubling SHG laser system is further characterized in that SHG conversion efficiency is hardly affected by fluctuations in oscillation wavelength caused by changes in the length of a resonator in the order of wavelength
10 resulted by temperature variations and vibrations, unlike an external resonator SHG system.

A laser using a LiSAF (Cr:LiSrAlF₆; chromium added lithium strontium aluminum fluoride) crystal as a laser crystal which oscillates at a wavelength of 750 to 1,000
15 nm has recently been proposed as a semiconductor laser excited wavelength variable solid laser (USP 4,811,349).

The inventors of the present invention have studied a method for causing a nonlinear optical crystal to generate SHG light having a blue color range as a second
20 oscillation wave, using laser light from this semiconductor laser excited LiSAF crystal as a first oscillation wave (fundamental wave), and found two new problems involved.

Fig. 9 is a structural diagram for second harmonic
25 generation by a LiSAF crystal and a nonlinear optical crystal. A first laser mirror 3 formed of a dielectric multi-layer film reflecting 99 % or more of a fundamental

wave oscillated from the LiSAF crystal 4 and transmitting
excitation light is formed on the surface of the LiSAF
crystal 4 where excitation light 11 from a semiconductor
laser (unshown) is input and a laser resonator is formed
5 between the first laser mirror and a second laser mirror 7
as a curvature mirror arranged on the output side thereof.
The resonator has therein an SHG crystal 6 and a
birefringent crystal 5 which is an element for controlling
the wavelength of the fundamental wave and SHG light is
10 output from the second laser mirror 7. The second laser
mirror 7 is coated with a coating to reflect 99 % or more
of the fundamental wave and transmit SHG light.

The first problem in the structure of Fig. 9 is that
it is impossible to generate SHG light efficiently because
15 the beam waist of a resonator beam 32 of the generated
fundamental wave is located at the first laser mirror 3 on
the LiSAF crystal 4 and is large in diameter at the
nonlinear optical crystal 6 for generating SHG light.
This is because SHG conversion efficiency generally
20 depends on the beam diameter of the fundamental wave
within the nonlinear optical crystal and the smaller the
beam diameter, the more efficiently the SHG light can be
generated.

The second problem is that part of SHG light 31 is
25 reflected by the birefringent crystal which is a
wavelength control element 5 because the SHG light
generated by the nonlinear optical crystal crosses the

polarization direction of the fundamental wave at a right angle. This is because the birefringent crystal transmits the fundamental wave because it is inclined at the Brewster angle with respect to the polarization of the
5 fundamental wave, but has a low transmittance for the polarization of SHG light.

Disclosure of Invention

The inventors have found that the above problems can be solved by specifying a combination of components of the
10 resonator for generating SHG light. The present invention is predicated upon this finding.

In other words, the present invention is a second harmonic generator comprising a semiconductor laser as an excitation light source and a resonator having a solid
15 laser crystal excited by the excitation light source, a control element for controlling the wavelength of a first oscillation wave generated from the solid laser crystal and a nonlinear optical crystal for wavelength converting the first oscillation wave as a fundamental wave into a
20 second harmonic wave as a second oscillation wave, wherein the components of the resonator are arranged in the order of a first laser mirror, solid laser crystal, wavelength control element, nonlinear optical crystal and second laser mirror from the input side of the excitation light.

25 When the components of the resonator are arranged in the order of the first laser mirror, solid laser crystal, wavelength control element, nonlinear optical crystal and

second laser mirror from the input side of the excitation light source, the beam waist of the fundamental wave in the resonator can be located at the nonlinear optical crystal and a second harmonic wave can be generated
5 efficiently.

When the first laser mirror is a curvature mirror which transmits 85 % or more of the excitation light and reflects 99% or more of the first oscillation wave and the second laser mirror is a plane mirror which reflects 99 %
10 or more of the first oscillation wave and transmits 85 % or more of the second oscillation wave, it is possible to reduce a loss in the resonator and further generate the second harmonic wave efficiently.

Moreover, the second laser mirror may be formed on
15 one surface of the nonlinear optical crystal.

When a LiSAF (Cr:LiSrAlF_6 ; chromium added lithium strontium aluminum fluoride) crystal is used as the above solid laser crystal, the first oscillation wave having a wavelength of 800 to 900 nm and the second oscillation
20 wave having a blue color range (400 to 450 nm) can be generated.

When a LiSGAF (Cr:LiSrGaF_6 ; chromium added lithium strontium gallium fluoride) crystal is used as the above solid laser crystal, the first oscillation wave having a
25 wavelength of 800 to 1,000 nm can be generated, whereby the second oscillation wave having a wavelength of 400 to 500 nm can be generated.

A single birefringent crystal inclined at the Brewster angle is used as the control element for controlling the wavelength of the first oscillation wave generated from the LiSAF crystal and arranged between the
5 LiSAF crystal and the nonlinear optical crystal to prevent reflection of SHG light as described above, thereby making it possible to reduce the loss of SHG light in the resonator and generate SHG light efficiently.

Any one of quartz (SiO_2), LiNbO_3 and LiTaO_3 may be
10 used as the birefringent crystal. Preferably, a single quartz plate having a thickness of 0.4 to 3 mm may be used as the birefringent crystal.

It is known that an oscillation threshold value in the resonator is increased by inserting into the resonator
15 a birefringent crystal as the wavelength control element for controlling the oscillation wavelength of the solid laser crystal. This is because the oscillation characteristic of a laser resonator depends on a loss in the resonator, which is increased by inserting a
20 birefringent crystal, and hence, a threshold value until oscillation is achieved becomes high. When the transmission wavelength width of the wavelength control element is narrow, the amount of light reflected and not transmitted by the wavelength control element increases,
25 resulting in an increased loss and a high oscillation threshold value. Fig. 3 shows the calculation of a transmission wavelength width based on the number of

quartz plates of the birefringent crystal inclined at the Brewster angle. It is understood from Fig. 3 that the transmission wavelength width is narrowed by increasing the number of quartz plates of the birefringent crystal, 5 that is, the thickness of the birefringent crystal. Thereby it is revealed that transmission wavelength width can be expanded by reducing the thickness of the birefringent crystal, thereby making it possible to reduce the loss and the oscillation threshold value.

10 Further, Fig. 4 shows laser oscillation wavelength interval with respect to the thickness of the birefringent crystal when the birefringent crystal is formed of a single quartz plate. The term "laser oscillation wavelength interval" used herein denotes the interval 15 between the wavelengths of simultaneous laser oscillations, that depends on the gain characteristic of a laser medium for each wavelength. Since, when the gain characteristic is wide, the wavelength range of possible laser oscillations is wide, simultaneous laser 20 oscillations may occur according to the transmission wavelength interval of the wavelength control element. It is seen from Fig. 4 that the interval between the wavelengths of laser oscillations becomes narrower as the thickness of the birefringent filter increases. This is 25 because, when the thickness is large, the interval between the adjacent wavelengths of possible laser oscillations is narrow and a laser which can oscillate at a broad

bandwidth, such as a LiSAF laser, may oscillate at two or more oscillation wavelengths. Since a general laser mirror has a reflection bandwidth of 50 nm, an oscillation wavelength interval of 25 nm or more, about half the above
5 reflection bandwidth, is required to suppress two or more simultaneous oscillations. Therefore, the thickness of the birefringent crystal needs to be 3 mm or less according to Fig. 4. Since wavelength control becomes difficult when the thickness of the crystal is too small,
10 the thickness of the crystal needs to be 0.4 mm or more according to Fig. 4. Therefore, the thickness of the birefringent crystal is preferably in the range of 0.4 to 3 mm.

Moreover, when at least one of LBO (LiB_3O_5), BBO (β -
15 BaB_2O_4), CLBO ($\text{CsLiB}_6\text{O}_{10}$) and CBO (CsB_3O_5) having a relatively wide phase match half value width is used as the nonlinear optical crystal which is a SHG crystal, SHG light can be generated efficiently even when the oscillation wavelength width of the fundamental wave is
20 wide.

Stability and size reduction can be achieved by arranging at least two of the components constituting the resonator on the same structural member and the components constituting the resonator above a temperature control
25 element. A small-sized, power saving second harmonic generator which is characteristic of SHG system can be realized by employing these means.

Brief Description of Drawings

Fig. 1 is a diagram for explaining an embodiment of the invention.

Fig. 2 is a diagram for explaining another embodiment
5 of the invention.

Fig. 3 is a diagram for explaining the comparison of transmission wavelength width which differs according to the number of quartz crystals of a birefringent crystal.

Fig. 4 is a diagram for explaining the oscillation
10 wavelength interval with respect to the thickness of a birefringent crystal.

Fig. 5 is a diagram for explaining a laser printer according to an embodiment of the invention.

Fig. 6 is a diagram for explaining a fine particle
15 detector according to an embodiment of the invention.

Fig. 7 is a diagram for explaining an optical shaping unit according to an embodiment of the invention.

Fig. 8 is a diagram for explaining an optical recorder according to an embodiment of the invention.

Fig. 9 is a diagram for explaining a comparative
20 embodiment.

Fig. 10 is a diagram for explaining an SHG light source of the prior art.

Best Mode for Carrying out the Invention

25 The present invention is described in detail with reference to the following embodiments. However, it is understood that the present invention is not limited to

these embodiments.

(Embodiment 1)

Fig. 1 is a diagram for explaining an embodiment of the present invention. Excitation beams 11 radiated from a semiconductor laser 1 are converged by converging optics 2 to excite a solid laser crystal 4. An AlGaInP semiconductor laser manufactured by Spectra Diode Laboratory Co. which has an output of 500 mW and an oscillation wavelength of 670 nm is used as the semiconductor laser 1. Two cylindrical lenses and a single lens ($f = 30$ mm) are used as the converging optics 2.

The excited solid laser crystal 4 generates a first laser beam as a fundamental wave in a laser resonator which comprises a first laser mirror 3 which is a curvature mirror on the input side and a second laser mirror 7 formed on the output end surface of an SHG crystal 6 and reflecting the first oscillation wave. In the laser resonator, the laser crystal 4, a wavelength control element 5 and the SHG crystal 6 are arranged. To the first laser mirror 3 is applied a high reflection (to be abbreviated as HR hereinafter) coating having a transmittance of 85 % or more for the wavelength of excitation light from the semiconductor laser and a reflectance of 99 % or more for the wavelength of the fundamental wave. In this embodiment, the resonator structure is a concave-plane type resonator, the first

laser mirror 3 has a curvature radius of 25 mm, and the length of the resonator is 20 mm. A LiSAF crystal ($\phi 3 \times 5$ mm) containing 1.5 mol% of Cr is used as the laser crystal 4. To the end surface of the crystal is applied an anti-
5 reflection (to be abbreviated as AR hereinafter) coating having a reflectance of 2 % or less for the wavelength of excitation light and the wavelength of the fundamental wave. The SHG crystal 6 is an LBO crystal measuring 3 x 3 x 5 mm. To the output side, that is, the rear end surface
10 of the LBO crystal are applied an HR coating having a reflectance of 99 % or more for the wavelength of the fundamental wave and an AR coating having a reflectance of 1 % or less for the wavelength of the SHG wave to make it the second laser mirror 7. To the input side, that is,
15 the front end surface of the LBO crystal is applied an AR coating having a reflectance of 0.2 % or less for the wavelength of the fundamental wave. A birefringent crystal made of a single quartz plate is used as the wavelength control element 5 and inclined at the Brewster
20 angle with respect to the optical axis to turn around the optical axis so that the wavelength of the fundamental wave is controlled to a wavelength at which the conversion efficiency of the LBO crystal as the SHG crystal 6 becomes maximal. Thereby, an SHG output of 10 mW was obtained.
25 Further, the first laser mirror 3, the laser crystal 4 and the wavelength control element 5 are installed on the same structural member 8, the SHG crystal 6 is installed on a

structural member 9, and these members are fixed on a Peltier element 10 as a temperature control element to control the temperature of the entire resonator.

With this structure, the beam waist of the
5 fundamental wave is located within the SHG crystal 6 and generated SHG light 12 is output efficiently without being interfered by the wavelength control element. The resonator is small in size and a stable SHG light source is realized by controlling the temperature of the entire
10 resonator.

(Embodiment 2)

Fig. 2 is a diagram of a resonator for explaining another embodiment of the present invention. Excitation optics composed of a semiconductor laser and converging
15 optics are the same as those of Embodiment 1. An excited laser crystal 4 generates a fundamental wave as a first oscillation wave in a laser resonator which comprises a first laser mirror 3 arranged on the input side thereof as a curvature mirror and a second laser mirror 7 as a plane
20 mirror. In the laser resonator, the laser crystal 4, an SHG crystal 6 and a wavelength control element 5 are arranged. To the curvature laser mirror as the first laser mirror 3 is applied an HR coating having a transmittance of 85 % or more for the wavelength of
25 excitation light and a reflectance of 99 % or more for the wavelength of the fundamental wave. To the plane laser mirror as the second laser mirror 7 are applied an HR

coating having a reflectance of 99 % or more for the wavelength of the fundamental wave and an AR coating having a reflectance of 1 % or less for the wavelength of SHG light. In this embodiment, the resonator structure is

5 a concave-plane type resonator, the curvature laser mirror as the first laser mirror 3 has a curvature radius of 25 mm, and the length of the resonator is 20 mm. A LiSAF crystal ($\phi 3 \times 5$ mm) containing 1.5 mol% of Cr is used as the laser crystal 4. To both end surfaces of the crystal

10 is applied an AR coating having a reflectance of 2 % or less for the wavelength of the fundamental wave and the wavelength of excitation light. The SHG crystal 6 is an LBO crystal measuring $3 \times 3 \times 5$ mm. To both end surfaces of the LBO crystal is applied an AR coating having a

15 reflectance of 0.2 % or less for the wavelength of the fundamental wave and 1 % or less for the wavelength of the SHG light. A birefringent crystal made of a single 0.5 mm thick quartz plate is used as the wavelength control element 5 and inclined at the Brewster angle with respect

20 to the optical axis to turn around the optical axis so that the wavelength of the fundamental wave is controlled to a wavelength at which the conversion efficiency of the LBO crystal as the SHG crystal 6 becomes maximal. Thereby an SHG output of 10 mW was obtained. Like Embodiment 1, a

25 stable SHG output was obtained by installing the components of the resonator on the same structural members to control the temperature of the entire resonator.

(Comparative Embodiment)

Fig. 9 is a diagram of a resonator for explaining a comparative embodiment. Excitation optics composed of a semiconductor laser and converging optics are the same as those of Embodiment 1.

A laser crystal 4 excited by excitation beams 11 radiated from the semiconductor laser generates a fundamental wave as a first oscillation wave in a laser resonator which is formed between a first laser mirror 3 coated with an HR coating reflecting 99 % or more of the fundamental wave and formed on the input side, that is, front end surface of the laser crystal 4, and a second laser mirror 7 as a curvature laser mirror coated with an AR coating reflecting 1 % or less of the wavelength of the SHG wave and an HR coating reflecting 99 % or more of the wavelength of the fundamental wave and arranged on the output side of the resonator.

In this embodiment, the resonator structure is a plane-concave type resonator, the curvature laser mirror as the second laser mirror 7 has a curvature radius of 25 mm, the length of the resonator is 20 mm. A LiSAF crystal ($\phi 3 \times 5$ mm) containing 1.5 mol% of Cr is used as the laser crystal 4 and coated with an AR coating having a reflectance of 2 % or less for the wavelength of the fundamental wave and the wavelength of excitation light on both end surfaces thereof. The SHG crystal 6 is an LBO crystal measuring 3 x 3 x 5 mm. To both end surfaces of

the LBO crystal is applied an AR coating having a reflectance of 0.2 % or less for the wavelength of the fundamental wave and 1 % or less for the wavelength of the SHG wave. A birefringent crystal made of a single 0.5 mm
5 thick quartz plate is used as the wavelength control element 5 and inclined at the Brewster angle with respect to the optical axis to turn around the optical axis so that the wavelength of the fundamental wave is controlled to a wavelength at which the conversion efficiency of the
10 LBO crystal as the SHG crystal 6 becomes maximal. However, the beam waist of the resonance beam 32 of the fundamental wave is located at the laser mirror of the LiSAF crystal 4, the beam diameter is large at the nonlinear optical crystal 5 for generating SHG light, and
15 part of the SHG light is reflected by the birefringent crystal as the wavelength control element. As the result, an SHG output of only 5 mW was obtained.

(Embodiment 3)

Fig. 5 is a diagram for explaining an application
20 example in which the present invention is applied in a laser printer. SHG output 33 radiated from the second harmonic generator 100 described in Embodiment 1 passes through an acousto-optical (to be abbreviated as AO
hereinafter) modulator 401, a reflection mirror 402, a
25 beam expander 403, a rotary polygon mirror 404 and an f θ lens 405, and is converged upon a photosensitive drum 406. The AO modulator 401 modulates the SHG output 33 according

to image information, and the rotary polygon mirror 404 scans in a horizontal direction (of the paper of the drawing).

With this combination, secondary information is
5 recorded on the photosensitive drum 406 as partial potential differences. The photosensitive drum 406 turns, adhered by toner according to the potential differences, and reproduces information on recording paper.

(Embodiment 4)

10 Fig. 6 is a diagram for explaining a detector for detecting fine particles on a Si wafer as an application example in which the present invention is applied in a fine particle detector. SHG output 33 radiated from the second harmonic generator 100 described in Embodiment 1 is
15 input into an optical head 500, converged up to a diffraction limit by a reflection mirror 502 and a converging lens 503 and radiated onto the Si wafer 501. Light beams 505 scattered from light converged up to a wavelength order of $0.4 \mu\text{m}$ are received by an optical
20 detector 504, their intensities are recorded, and the optical head 500 moves from a central portion to an end portion of the Si wafer 501, whereby the distribution of fine particles on the Si wafer is measured. Fine particles having a diameter up to $1/10$ the wavelength of
25 the SHG wave can be detected.

(Embodiment 5)

Fig. 7 is a diagram for explaining an application

example in which an embodiment of the present invention is applied in an optical shaping unit. The second harmonic generator 100 described in Embodiment 1 is used as a light source. A blue curing resin 601 is charged into a
5 container and SHG output 33 radiated from the second harmonic generator 100 described in Embodiment 1 is caused by a mirror 602 to scan the surface of a liquid two-dimensionally. At this point, only a surface portion of the blue curing resin 601 that absorbs light cures. After
10 the formation of one layer is completed, an elevator 604 falls to form the next layer continuously. With this operation, a solid model 605 having a desired shape can be formed.

(Embodiment 6)

15 Fig. 8 is a diagram for explaining an application example in which an embodiment of the present invention is applied in an optical recorder. An optical disk drive of opto-magneto recording system is used. An SHG laser beam 33 radiated from the second harmonic generator 100
20 described in Embodiment 1 is expanded by a beam expander 701 and then becomes parallel beams. Part of the beams reflected by a beam splitter 702 are received by a photo detector 708 for front monitoring to monitor the SHG laser beam 33 so as to control output. The beams passing
25 through the beam splitter 702 are converged upon a medium 705 by a converging optic 704. Reflected light is partially reflected by the beam splitter 702 and divided

by a beam splitter 706 into two beams which are then received by two photo-detectors 707 to perform autofocusing and signal detection. A fixed magnetic field is applied to the medium 705, the SHG laser beam 33 is modulated and the focusing temperature is raised to a Curie temperature of the medium 705 to reverse magnetization for recording. When the laser beam is on, recording is made by reversing the magnetization of the medium. The recording frequency is set to 10 MHz. At the time of signal reproduction, the same SHG laser beam is used to obtain a well reproduced signal.

According to the present invention, in an intracavity doubling SHG laser system using a wavelength variable laser, particularly a LiSAF laser crystal, the components of the resonator are arranged in the order of the first laser mirror, laser crystal, wavelength control element, SHG crystal and second laser mirror from the input side of excitation light. As the result, the beam waist of the fundamental wave is located within the SHG crystal, generated SHG light is output without being interfered by the wavelength control element, and a small-sized high-efficiency second harmonic generator can be realized. Further, a stable SHG light source is implemented by controlling the temperature of the entire resonator.

25 Industrial Applicability

As described on the foregoing pages, according to the present invention, a small high-efficiency second harmonic

generator and laser applied units thereof such as a laser printer, fine particle detector, optical shaping unit, optical recorder and the like can be provided.



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CLAIMS

1. A second harmonic generator comprising:
a semiconductor laser as an excitation light source;
and
5 a resonator having a solid laser crystal excited by
said excitation light source, a control element for
controlling the wavelength of a first oscillation wave
generated from said solid laser crystal, and a nonlinear
optical crystal for wavelength converting the first
10 oscillation wave as a fundamental wave into a second
harmonic wave as a second oscillation wave,
wherein the components of said resonator are arranged
in the order of a first laser mirror, said solid laser
crystal, said control element, said nonlinear optical
15 crystal and a second laser mirror from the input side of
said excitation light.
2. The second harmonic generator according to claim 1,
wherein said first laser mirror is a curvature mirror
which transmits 85 % or more of the wavelength of the
20 excitation light source and reflects 99 % or more of the
first oscillation wave, and said second laser mirror is a
plane mirror which reflects 99 % or more of the first
oscillation wave and transmits 85 % or more of the second
oscillation wave.
- 25 3. The second harmonic generator according to claim 1,
wherein said second laser mirror is formed on one surface
of said nonlinear optical crystal.



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4. The second harmonic generator according to claim 1,
wherein said solid laser crystal is LiSAF (Cr:LiSrAlF₆;
chromium added lithium strontium aluminum fluoride) or
LiSGAF (Cr:LiSrGaF₆; chromium added lithium strontium
5 gallium fluoride).
5. The second harmonic generator according to claim 1,
wherein a single birefringent crystal inclined at the
Brewster angle is used as said control element for
controlling the wavelength of the first oscillation wave
10 generated from said solid laser crystal.
6. The second harmonic generator according to claim 1,
wherein at least one of LBO (LiB₃O₅), BBO (β -BaB₂O₄), CLBO
(CsLiB₆O₁₀) and CBO (CsB₃O₅) is used as said nonlinear
optical crystal.
- 15 7. The second harmonic generator according to claim 1,
wherein at least two of the components constituting said
resonator are arranged on the same structural member.
8. The second harmonic generator according to claim 1,
wherein the components constituting said resonator are
20 arranged above a temperature control element.
9. A laser applied unit which employs the second
harmonic generator according to any one of claims 1 to 8.
10. The laser applied unit of claim 9 which is a laser
printer.
- 25 11. The laser applied unit of claim 9 which is a fine
particle detector.
12. The laser applied unit of claim 9 which is an optical



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shaping unit.

13. The laser applied unit of claim 9 which is an optical recorder.

ABSTRACT

A second harmonic generator comprising a semiconductor laser as an excitation light source and a resonator having a solid laser crystal excited by the excitation light source, a control element for controlling the wavelength of a first oscillation wave generated from the solid laser crystal and a nonlinear optical crystal for wavelength converting the first oscillation wave as a fundamental wave into a second harmonic wave as a second oscillation wave, wherein the components of the resonator are arranged in the order of a first laser mirror, solid laser crystal, wavelength control element, nonlinear optical crystal and second laser mirror from the input side of the excitation light.

FIG. 1

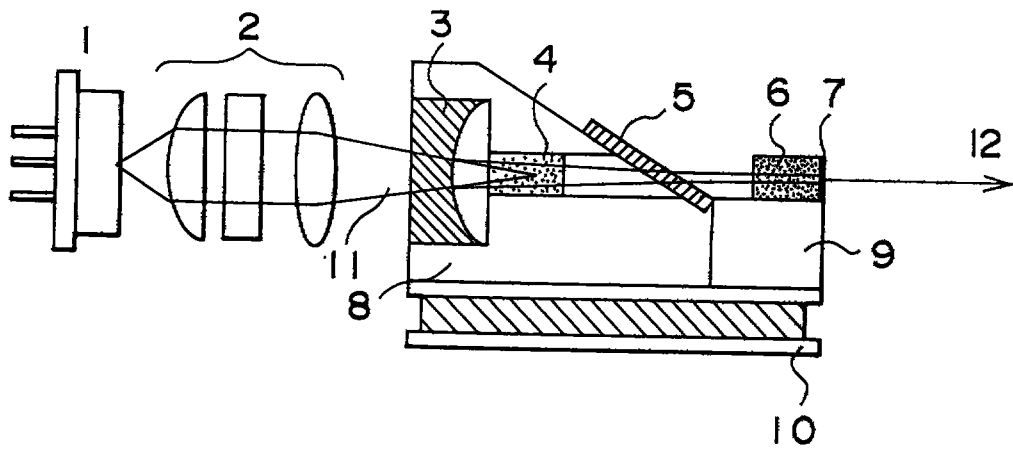


FIG. 2

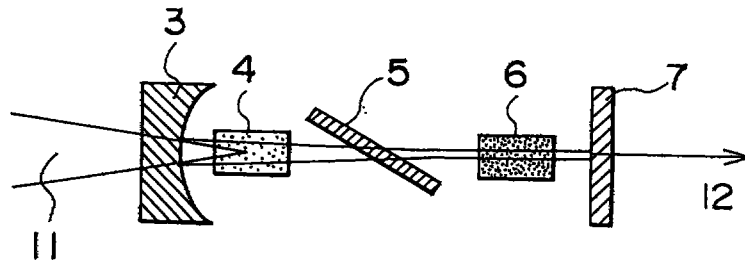


FIG. 3

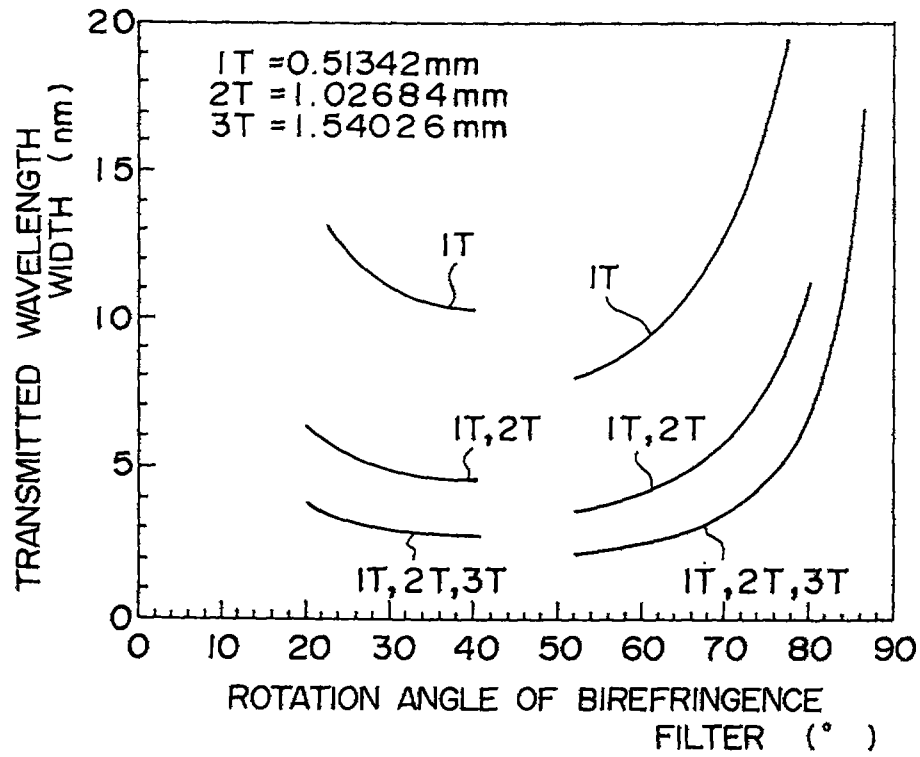


FIG. 4

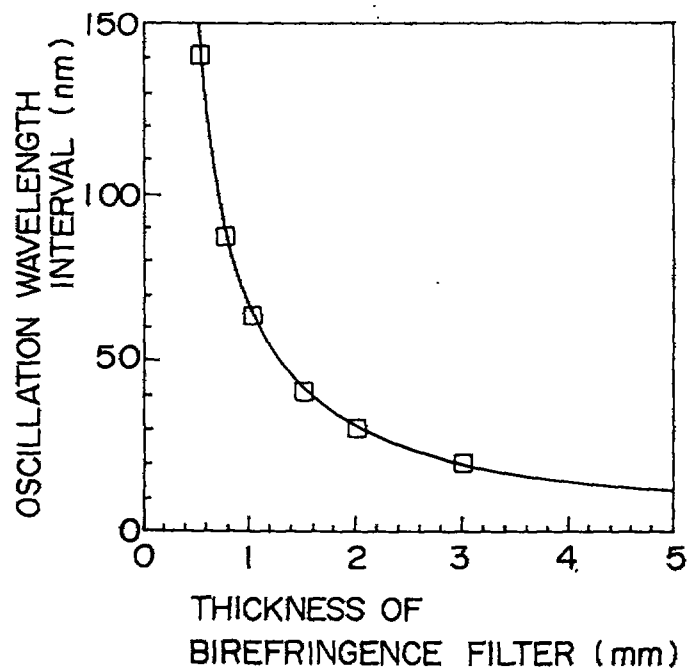


FIG. 5

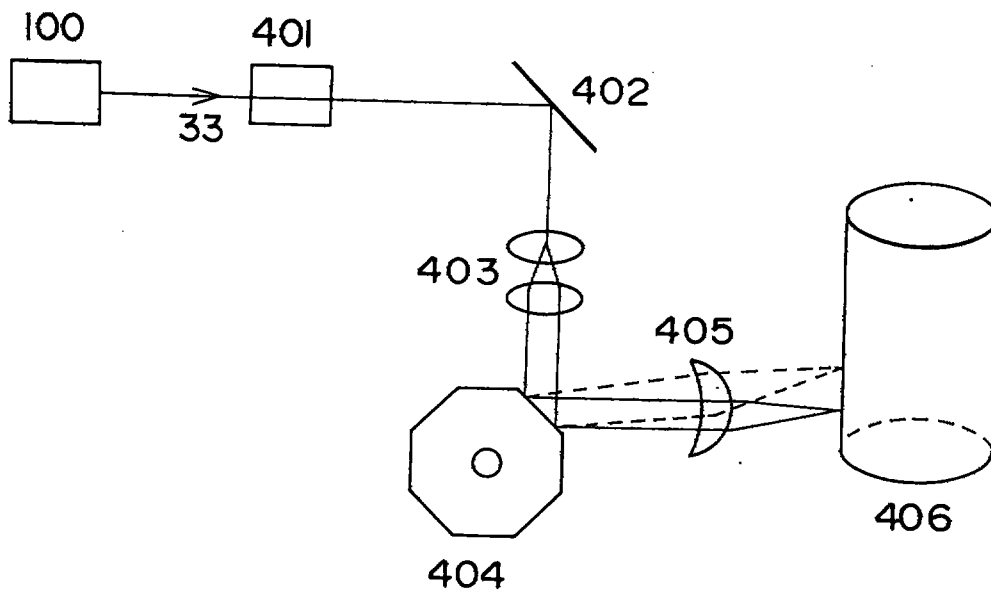


FIG. 6

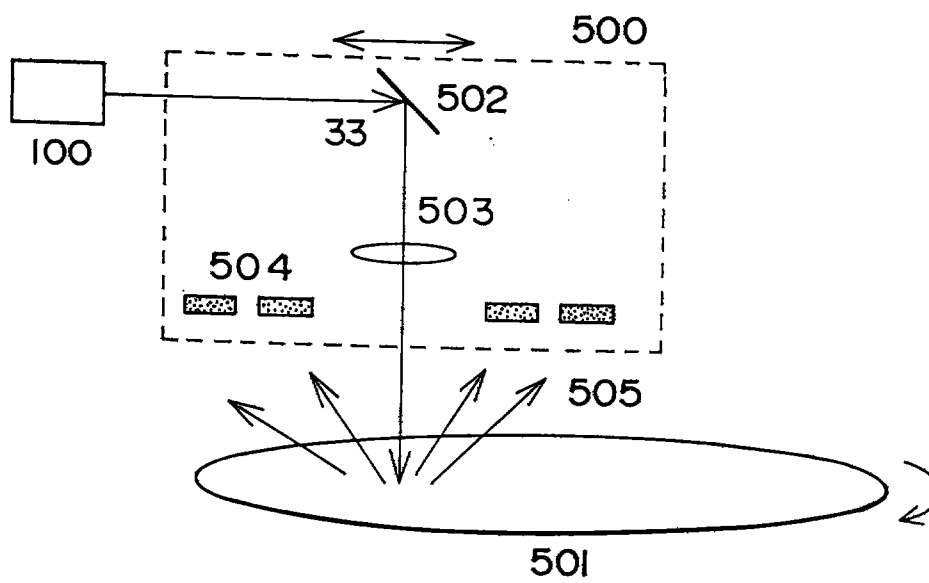


FIG. 7

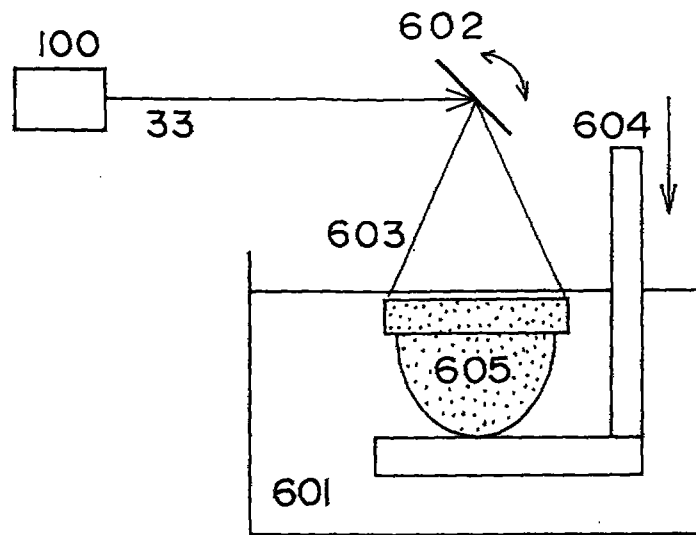


FIG. 8

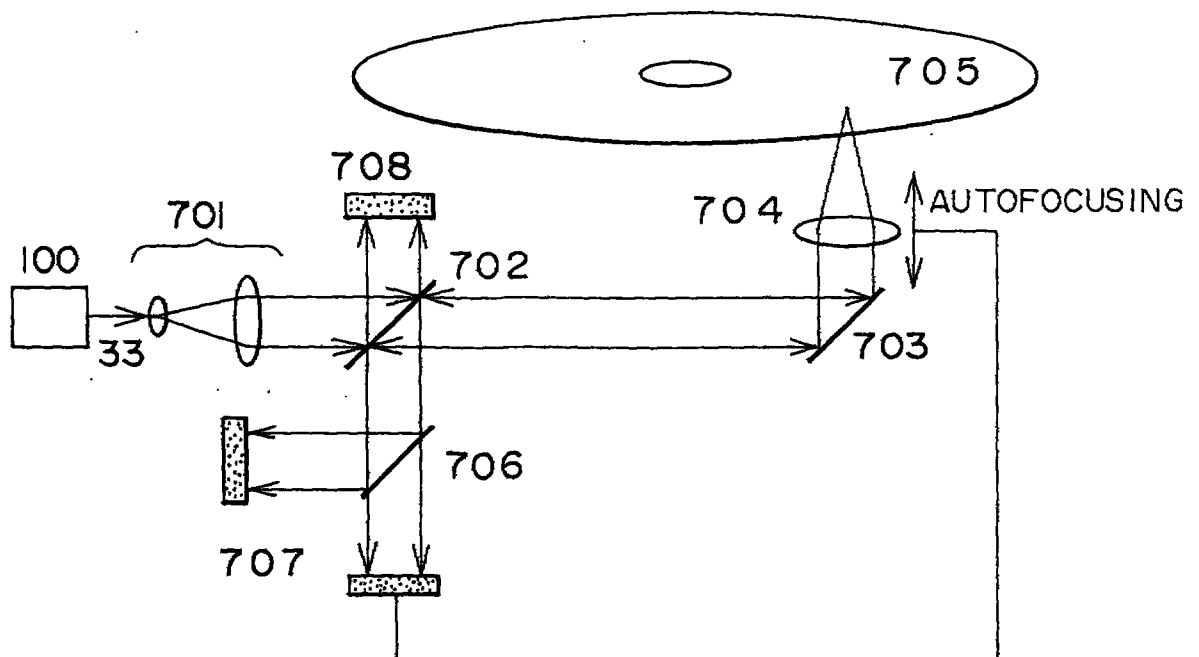


FIG. 9

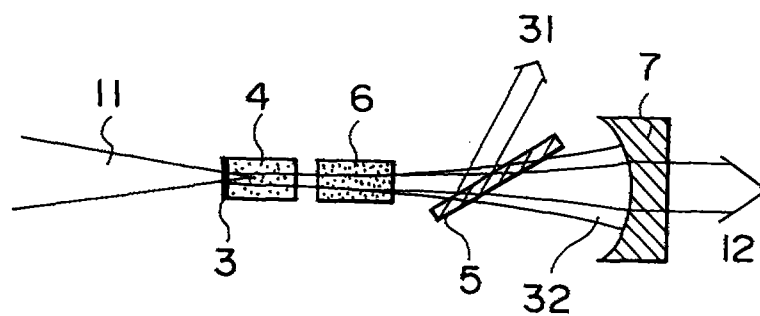
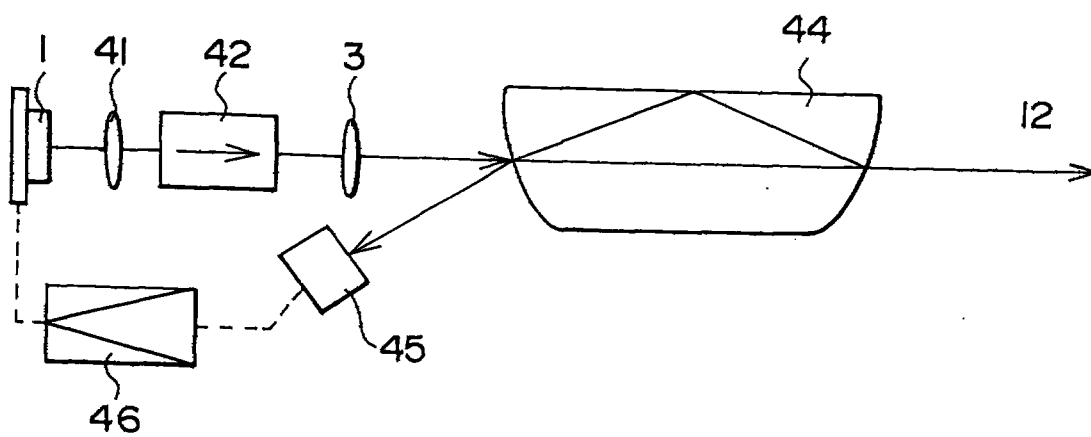
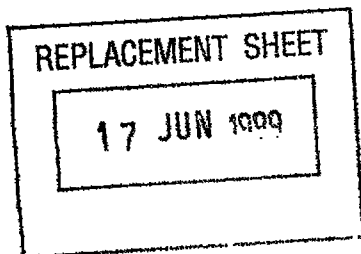


FIG. 10





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polarization direction of the fundamental wave at a right angle. This is because the birefringent crystal transmits the fundamental wave because it is inclined at the Brewster angle with respect to the polarization of the fundamental wave, but has a low transmittance for the polarization of SHG light.

5 Disclosure of the Invention

The inventors have found that the above problems can be solved by specifying a combination of components of the resonator for generating SHG light. The present invention is predicated upon this finding.

In accordance with the invention, there is provided a second harmonic generator
10 comprising:

a semiconductor laser as an excitation light source; and

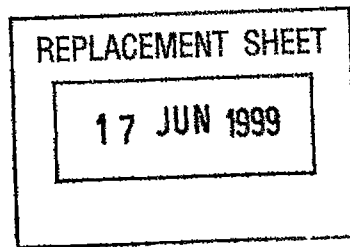
a resonator having a solid laser crystal excited by said excitation light source, a control element for controlling the wavelength of a first oscillation wave generated from said solid laser crystal, and a nonlinear optical crystal for wavelength converting the first oscillation
15 wave as a fundamental wave into a second harmonic wave as a second oscillation wave,

wherein the components of said resonator are arranged in the order of a first laser mirror, said solid laser crystal, said control element, said nonlinear optical crystal and a second laser mirror from the input side of said excitation light, and wherein said first laser mirror is a curvature mirror which transmits 85% or more of the wavelength of the excitation
20 light source and reflects 99% or more for the first oscillation wave and said second laser mirror is a plane mirror which reflects 99% or more of the first oscillation wave and transmits 85% or more of the second oscillation wave.

Moreover, the second laser mirror may be formed on one surface of the nonlinear optical crystal.

25 When a LiSAF (Cr:LiSrAlF₆; chromium added lithium strontium aluminum fluoride) crystal is used as the above solid laser crystal, the first oscillation wave having a wavelength of 800 to 900 nm and the second oscillation wave having a blue color range (400 to 450 nm) can be generated.

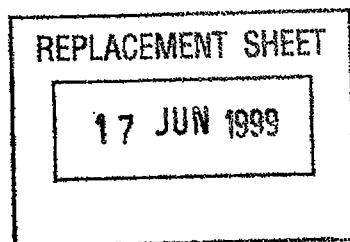
When a LiSGAF (Cr: LiSrGaF₆; chromium added lithium strontium gallium fluoride)
30 crystal is used as the above solid laser crystal, the first oscillation wave having a wavelength



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of 800 to 1,000 nm can be generated, whereby the second oscillation wave having a wavelength of 400 to 500 nm can be generated.



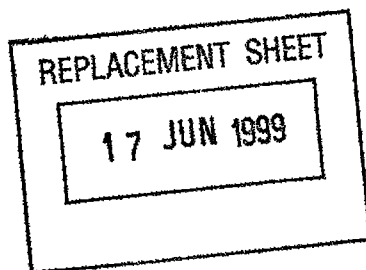
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CLAIMS:

1. A second harmonic generator comprising:
a semiconductor laser as an excitation light source; and
a resonator having a solid laser crystal excited by said excitation light source, a control
5 element for controlling the wavelength of a first oscillation wave generated from said solid
laser crystal, and a nonlinear optical crystal for wavelength converting the first oscillation
wave as a fundamental wave into a second harmonic wave as a second oscillation wave,
wherein the components of said resonator are arranged in the order of a first laser
mirror, said solid laser crystal, said control element, said nonlinear optical crystal and a
10 second laser mirror from the input side of said excitation light, and wherein said first laser
mirror is a curvature mirror which transmits 85% or more of the wavelength of the excitation
light source and reflects 99% or more for the first oscillation wave and said second laser
mirror is a plane mirror which reflects 99% or more of the first oscillation wave and transmits
85% or more of the second oscillation wave.
- 15 2. The second harmonic generator according to claim 1, wherein said second laser mirror
is formed on one surface of said nonlinear optical crystal.
3. The second harmonic generator according to claim 1, wherein said solid laser crystal
is LiSAF (Cr:LiSrAlF_6 ; chromium added lithium strontium aluminum fluoride) or LiSGAF
(Cr:LiSrGAF_6 ; chromium added lithium strontium gallium fluoride).
- 20 4. The second harmonic generator according to claim 1, wherein a single birefringent
crystal inclined at the Brewster angle is used as said control element for controlling the
wavelength of the first oscillation wave generated from said solid laser crystal.
5. The second harmonic generator according to claim 1, wherein at least one of LBO
(LiB_3O_5), BBO ($\beta\text{-BaB}_2\text{O}_4$), CLBO ($\text{CsLiB}_6\text{O}_{10}$) and CBO (CsB_3O_5) is used as said nonlinear
25 optical crystal.
6. The second harmonic generator according to claim 1, wherein at least two of the
components constituting said resonator are arranged on the same structural member.
7. The second harmonic generator according to claim 1, wherein the components
constituting said resonator are arranged above a temperature control element.
- 30 8. A laser applied unit which employs the second harmonic generator according to any



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one of claims 1 to 7.

9. The laser applied unit of claim 8 which is a laser printer.
10. The laser applied unit of claim 8 which is a fine particle detector.
11. The laser applied unit of claim 8 which is an optical shaping unit.
- 5 12. The laser applied unit of claim 8 which is an optical recorder.