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(54) PHOTOACOUSTIC IMAGE-GENERATING APPARATUS AND ACOUSTIC UNIT

PHOTOAKUSTISCHE BILDERZEUGUNGSVORRICHTUNG UND AKUSTIKEINHEIT

APPAREIL DE GÉNÉRATION D'IMAGE PHOTOACOUSTIQUE ET UNITÉ ACOUSTIQUE

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Description**BACKGROUND OF THE INVENTION**

1. Field of the Invention

[0001] The present invention relates to a photoacoustic image generation apparatus and an acoustic wave unit, and more particularly, to a photoacoustic image generation apparatus, which when a test object is irradiated with a laser beam having a plurality of wavelengths, generates a photoacoustic image on the basis of photoacoustic signals detected with respect to the respective wavelengths, and an acoustic wave unit.

2. Description of the Related Art

[0002] Hitherto, for example, as disclosed in JP2005-21380A and A High-Speed Photoacoustic Tomography System based on a Commercial Ultrasound and a Custom Transducer Array, Xueding Wang, Jonathan Cannata, Derek DeBusschere, Changhong Hu, J. Brian Fowkes, and Paul Carson, Proc. SPIE Vol. 7564, 756424 (Feb. 23, 2010), a photoacoustic image forming apparatus that forms an image of the inside of a living body using a photoacoustic effect has been known. In the photoacoustic image forming apparatus, a living body is irradiated with pulsed light such as a pulse laser beam. Body tissues absorbing energy of the pulsed light expand in volume inside the living body irradiated with the pulsed light, and thus acoustic waves are generated. It is possible to detect the acoustic waves using an ultrasonic probe or the like, and to form a visible image of the inside of the living body on the basis of the detected signal (photoacoustic signal). In a photoacoustic image forming method, acoustic waves are generated in a specific light absorber, and thus it is possible to form an image of specific tissues in the living body, for example, blood vessels.

[0003] Incidentally, many of body tissues have an optical absorption property varying depending on a wavelength of light, and generally, the optical absorption property is unique for each tissue. For example, Fig. 12 illustrates molecular absorption coefficients of oxygenated hemoglobin (hemoglobin combined with oxygen: oxy-Hb) which is contained in a large amount in an artery of a human and deoxygenated hemoglobin (hemoglobin not combined with oxygen: deoxy-Hb) which is contained in a large amount in a vein, depending on light wavelengths. An optical absorption property of an artery corresponds to that of oxygenated hemoglobin, and an optical absorption property of a vein corresponds to that of deoxygenated hemoglobin. There is known a photoacoustic image forming method of irradiating blood vessel parts with a light beam having two different types of wavelengths and of distinctively forming images of an artery and a vein (for example, see JP2010-046215A), using a difference in light absorptivity according to the wavelengths.

[0004] Herein, with regard to a variable wavelength laser, JP2009-231483A discloses that a laser beam having a desired wavelength is obtained by disposing an etalon or a birefringent filter as a wavelength selection element within an optical resonator and adjusting the rotation angle thereof. In addition, JP2000-105464A discloses that an etalon as wavelength selection means is disposed within an optical resonator and that the etalon is scanned at a constant speed. JP2000-105464A discloses that laser oscillation is performed only when a transmission wavelength of the etalon is consistent with longitudinal mode oscillation of a laser beam and that the oscillation of the laser beam is performed in a pulsed manner when a scanning speed of the etalon is increased.

[0005] Further laser devices of interest are disclosed in US 2010/049049, JP 2006-324601. US 2007/015 992 A1 discloses an optoacoustic imaging device able to emit laser pulse sequences at different wavelengths.

SUMMARY OF THE INVENTION

[0006] In JP2009-231483A, in order to switch and emit a laser beam having a plurality of wavelengths, it is necessary to adjust a rotation angle of the etalon or the birefringent filter at every laser emission. In photoacoustic imaging, for example, it is considered that when a test object is irradiated with pulse laser beams having a first wavelength and a second wavelength, the wavelength selection element is adjusted to irradiate the test object with the laser beam having the first wavelength, the detection of all photoacoustic signals of the laser beam having the first wavelength is terminated, and then the wavelength selection element is adjusted so as to emit the laser beam having the second wavelength, and the test object is irradiated with the laser beam having the second wavelength. In the photoacoustic imaging, an object having a movement such as a human is often selected. Therefore, when an object moves during switching from the first wavelength to the second wavelength, mismatching may occur between a photoacoustic signal at the time of irradiation with the laser beam having the first wavelength and a photoacoustic signal at the time of irradiation with the laser beam having the second wavelength.

[0007] In the photoacoustic imaging, in terms of the prevention of the above-mentioned mismatching, for example, it is considered that the irradiation with a laser beam may be performed by switching the first wavelength and the second wavelength for each pulse. In other words, for example, it is considered that the irradiation with the laser beam may be repeatedly performed in a predetermined wavelength sequence including the first wavelength and the second wavelength in this order. JP2000-105464A discloses a laser device that changes a wavelength of a laser beam with which the irradiation is performed for each pulse. However, in JP2000-105464A, since a laser is oscillated only when the transmission wavelength of the etalon is consistent with the longitudinal mode oscillation of the laser beam,

a laser beam having only a specific wavelength sequence can be obtained, and a laser beam having any wavelength sequence cannot be obtained.

[0008] The invention is contrived in view of such situations, and an object thereof is to provide an acoustic wave unit capable of emitting a pulse laser beam in a desired wavelength sequence from a wavelength variable laser light source, and a photoacoustic image generation apparatus including the acoustic wave unit.

[0009] In order to achieve the above-described object, the invention provides a photoacoustic image generation apparatus including: a laser source unit that sequentially emits a plurality of pulse laser beams in a predetermined wavelength sequence having at least two different wavelengths, the laser source unit including a laser rod, an excitation light source that irradiates the laser rod with excitation light, an optical resonator that has a pair of mirrors facing each other with the laser rod interposed therebetween, a Q switch which is inserted into the optical resonator, and a birefringent filter which is inserted into the optical resonator and changes an oscillation wavelength of the optical resonator in association with rotational displacement of the birefringent filter; and an acoustic wave unit that generates a photoacoustic image, the acoustic wave unit including detection means that detects a photoacoustic signal generated within an object when the object is irradiated with the pulse laser beam having each wavelength included in the predetermined wavelength sequence and generates pieces of photoacoustic data corresponding to the respective wavelengths, intensity ratio extraction means that extracts a magnitude relation between relative signal intensities of the pieces of photoacoustic data corresponding to the respective wavelengths, photoacoustic image construction means that generates the photoacoustic image on the basis of the extracted magnitude relation, and a trigger control circuit that causes the laser rod to be irradiated with excitation light from the excitation light source while rotating the birefringent filter at a predetermined rotation speed depending on the number of wavelengths included in the wavelength sequence, and after the irradiation with the excitation light, turns on the Q switch at a timing when a rotational displacement position of the birefringent filter is set to a position corresponding to the wavelength of the pulse laser beam to be emitted to cause the pulse laser beam to be emitted.

[0010] In the invention, the trigger control circuit continuously rotates the birefringent filter in a predetermined direction at the predetermined rotation speed.

[0011] In the invention, the predetermined rotation speed may be determined on the basis of a change characteristic of the oscillation wavelength with respect to the rotational displacement position in the birefringent filter, the number of wavelengths included in the wavelength sequence, and the number of times of emission of the pulse laser beam per unit time.

[0012] When the number of times of a free spectral range repeated during one rotation is set to k [times/ro-

tation], the number of wavelengths included in the wavelength sequence is set to n [pieces], and the number of times of emission of the pulse laser beam per unit time is set to m [times/second], the predetermined rotation speed of the birefringent filter may be determined as a value calculated by a relation of $v = m / (k \times n)$ [rotations/second].

[0013] The trigger control circuit may determine a timing at which the excitation light is irradiated and a timing at which the Q switch is turned on, on the basis of birefringent filter state information indicating the rotational displacement position of the birefringent filter.

[0014] When the birefringent filter state information is set to information indicating a position obtained by subtracting the amount of rotational displacement of the birefringent filter during a period of time required for the excitation of the laser rod from a position of the birefringent filter which corresponds to the wavelength of the pulse laser beam to be emitted, the trigger control circuit may cause the laser rod to be irradiated with excitation light.

[0015] The trigger control circuit may rotate the birefringent filter so that the amount of change in the birefringent filter state information during a predetermined period of time is set to the amount of change depending on the predetermined rotation speed.

[0016] Moreover, the laser source unit may further include driving means that rotates the birefringent filter, rotational displacement detection means that detects the rotational displacement of the birefringent filter, and a rotation control unit that controls the driving means so that the amount of rotational displacement of the birefringent filter which is detected by the rotational displacement detection means during a predetermined period of time is set to an amount depending on the predetermined rotation speed.

[0017] The acoustic wave unit may further include intensity information extraction means that generates intensity information indicating signal intensity on the basis of the pieces of photoacoustic data corresponding to the respective wavelengths. The photoacoustic image construction means may determine a gradation value of each pixel of the photoacoustic image on the basis of the intensity information and may determine a display color of each pixel on the basis of the extracted magnitude relation.

[0018] The predetermined wavelength sequence may include a first wavelength and a second wavelength. The acoustic wave unit may further include complex number creation means that generates complex number data in which one of first photoacoustic data corresponding to a photoacoustic signal, detected when irradiation with the pulse laser beam having the first wavelength is performed, and second photoacoustic data corresponding to a photoacoustic signal, detected when irradiation with the pulse laser beam having the second wavelength is performed, is set to a real part and the other one is set to an imaginary part, and photoacoustic image recon-

struction means that generates a reconstructed image from the complex number data using a Fourier transform method. The intensity ratio extraction means may extract phase information as the magnitude relation from the reconstructed image, and the intensity information extraction means may extract the intensity information from the reconstructed image.

[0019] The detection means may further detect reflected acoustic waves with respect to acoustic waves transmitted to the object to generate reflected acoustic wave data, and the acoustic wave unit may further include acoustic wave image generation means that generates an acoustic wave image on the basis of the reflected acoustic wave data.

[0020] In a photoacoustic image generation apparatus and an acoustic wave unit of the invention, a birefringent filter which is inserted into an optical resonator and changes an oscillation wavelength in association with rotational displacement of the birefringent filter is rotated at a rotation speed depending on the number of wavelength sequences of a pulse laser beam to be emitted from a laser source unit, and a Q switch which is inserted into the optical resonator is turned on at a timing when a rotational displacement position of the birefringent filter is set to a position corresponding to the wavelength of the pulse laser beam to be emitted. As the rotation speed of the birefringent filter increases, the speed of the wavelength switching can be increased. On the contrary, as the rotation speed thereof decreases, the number of selectable oscillation wavelengths can be increased. The rotation speed of the birefringent filter of the present invention is controlled depending on the number of wavelengths included in a wavelength sequence. Based on such a configuration, the wavelengths of the pulse laser beam to be emitted from the laser source unit can be controlled to have any wavelength sequence by the acoustic wave unit. In addition, the acoustic wave unit of the present invention determines an emission timing of the pulse laser beam, and thus it is not necessary to acquire a signal such as a synchronization signal indicating laser emission from the laser source unit, in the start of sampling of a photoacoustic signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

Fig. 1 is a block diagram of a photoacoustic image generation apparatus according to a first embodiment of the invention.

Fig. 2 is a block diagram illustrating a configuration of a laser source unit according to the first embodiment.

Fig. 3 is a perspective view illustrating a configuration example of a birefringent filter, driving means, and rotational displacement detection means.

Fig. 4 is a graph illustrating an example of a wavelength transmission characteristic for rotational displacement of the birefringent filter.

placement of the birefringent filter.

Fig. 5 is a graph illustrating an oscillation wavelength characteristic when the birefringent filter is rotated at a speed of one rotation per second.

Fig. 6 is a timing chart illustrating various types of triggers and an emission timing.

Fig. 7 is a flow chart illustrating an operation procedure of the photoacoustic image generation apparatus according to the first embodiment.

Fig. 8 is a timing chart illustrating various types of triggers and an emission timing in a case where a wavelength sequence includes six wavelengths.

Fig. 9 is a block diagram illustrating a photoacoustic image generation apparatus according to a second embodiment of the invention.

Fig. 10 is a block diagram illustrating an operation procedure of the photoacoustic image generation apparatus according to the second embodiment.

Fig. 11 is a block diagram illustrating a configuration of a laser source unit according to a modified example.

Fig. 12 is a graph illustrating molecular absorption coefficients of oxygenated hemoglobin and deoxygenated hemoglobin depending on light wavelengths.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] Hereinafter, embodiments of the invention will be described in detail with reference to the accompanying drawings. Meanwhile, in examples of the invention, ultrasonic waves are used as acoustic waves, but the acoustic waves may be acoustic waves having an audible frequency by selecting an appropriate frequency according to an object to be tested or measurement conditions. Fig. 1 illustrates a photoacoustic image generation apparatus according to a first embodiment of the invention. A photoacoustic image generation apparatus 10 includes an ultrasonic wave probe (probe) 11, an ultrasonic wave unit 12, and a laser source unit 13. The laser source unit 13 emits a pulse laser beam with which a test object is to be irradiated. The laser source unit 13 emits a plurality of pulse laser beams in a predetermined wavelength sequence including at least two different wavelengths. Hereinafter, a description will be mainly given on the assumption that the wavelength sequence includes a first wavelength and a second wavelength in this order and the laser source unit 13 emits a pulse laser beam having the first wavelength and a pulse laser beam having the second wavelength in this order.

[0023] For example, a wavelength of approximately 750 nm is considered as the first wavelength (center wavelength), and a wavelength of approximately 800 nm is considered as the second wavelength. Referring to Fig. 12 described above, a molecular absorption coefficient of oxygenated hemoglobin (hemoglobin combined with oxygen: oxy-Hb) which is contained in a large

amount in an artery of a human at a wavelength of 750 nm is lower than a molecular absorption coefficient of that at a wavelength of 800 nm. On the other hand, a molecular absorption coefficient of deoxygenated hemoglobin (hemoglobin not combined with oxygen: deoxy-Hb) which is contained in a large amount in a vein at a wavelength of 750 nm is higher than a molecular absorption coefficient of that at a wavelength of 800 nm. It is possible to discriminate between a photoacoustic signal from the artery and a photoacoustic signal from the vein by examining whether a photoacoustic signal obtained at the wavelength of 750 nm is relatively larger or smaller than a photoacoustic signal obtained at the wavelength of 800 nm, using such a property.

[0024] The pulse laser beam emitted from the laser source unit 13 is guided to a probe 11 using light guiding means such as an optical fiber, and is irradiated toward a test object from the probe 11. An irradiation position of the pulse laser beam is not particularly limited, and the pulse laser beam may be irradiated from any place other than the probe 11. Ultrasonic waves (acoustic waves) are generated within the test object by a light absorber absorbing energy of the irradiated pulse laser beam. The probe 11 includes an ultrasonic wave detector. The probe 11 includes, for example, a plurality of ultrasonic wave detector elements (ultrasonic wave vibrators) which are arranged one-dimensionally, and the acoustic waves (photoacoustic signal) from the inside of the test object are detected by the ultrasonic wave vibrators that are arranged one-dimensionally.

[0025] The ultrasonic wave unit 12 includes a reception circuit 21, AD conversion means 22, a reception memory 23, complex number creation means 24, photoacoustic image reconstruction means 25, phase information extraction means 26, intensity information extraction means 27, detection and logarithmic transformation means 28, photoacoustic image construction means 29, a trigger control circuit 30, and control means 31. The reception circuit 21 receives a photoacoustic signal detected by the probe 11. The AD conversion means 22, which is detection means, samples the photoacoustic signal received by the reception circuit 21 and generates photoacoustic data which is digital data. The AD conversion means 22 samples the photoacoustic signal with a predetermined sampling period in synchronization with an AD clock signal.

[0026] The AD conversion means 22 stores photoacoustic data in the reception memory 23. The AD conversion means 22 stores, in the reception memory 23, photoacoustic data corresponding to the respective wavelengths of the pulse laser beam emitted from the laser source unit 13. In other words, the AD conversion means 22 stores, in the reception memory 23, first photoacoustic data obtained by sampling a photoacoustic signal detected by the probe 11 when a test object is irradiated with a pulse laser beam having a first wavelength and second photoacoustic data obtained by sampling a photoacoustic signal detected by the probe 11

when the test object is irradiated with a second pulse laser beam.

[0027] The complex number creation means 24 reads out the first photoacoustic data and the second photoacoustic data from the reception memory 23, and generates complex number data in which any one of the first photoacoustic data and the second photoacoustic data is set to a real part and the other one is set to an imaginary part. Hereinafter, a description will be given on the assumption that the complex number creation means 24 generates the complex number data in which the first photoacoustic data is set to a real part and the second photoacoustic data is set to as an imaginary part.

[0028] The photoacoustic image reconstruction means 25 inputs the complex number data from the complex number creation means 24. The photoacoustic image reconstruction means 25 performs image reconstruction from the input complex number data using a Fourier transform method (FTA method). A well-known method of the related art which is disclosed in, for example, a document "Photoacoustic Image Reconstruction-A Quantitative Analysis" Jonathan I. Sperl et al. SPIE-OSA, Vol. 6631 663103 can be applied to the image reconstruction using the Fourier transform method. The photoacoustic image reconstruction means 25 inputs Fourier transformed data indicating the reconstructed image to the phase information extraction means 26 and the intensity information extraction means 27.

[0029] The phase information extraction means 26 extracts a magnitude relation between relative signal intensities of pieces of photoacoustic data corresponding to the respective wavelengths. In this embodiment, the phase information extraction means 26 sets the reconstructed image reconstructed by the photoacoustic image reconstruction means 25 to input data. In addition, the phase information extraction means 26 generates, when the real part and the imaginary part are compared with each other, phase information indicating how relatively large either of the two parts is, using the input data which is the complex number data. For example, when the complex number data is expressed by $X+iY$, the phase information extraction means 26 generates the relation of $\theta = \tan^{-1}(Y/X)$ as phase information. Meanwhile, when the relation of $X=0$ is satisfied, the relation of $\theta=90^\circ$ is established. When first photoacoustic data (X) constituting the real part is equal to second photoacoustic data (Y) constituting the imaginary part, the phase information satisfies the relation of $\theta=45^\circ$. As the first photoacoustic data becomes relatively larger, the phase information becomes closer to the relation of $\theta=0^\circ$. As the second photoacoustic data becomes larger, the phase information becomes closer to the relation of $\theta=90^\circ$.

[0030] The intensity information extraction means 27 generates intensity information indicating signal intensity on the basis of the pieces of photoacoustic data corresponding to the respective wavelengths. In this embodiment, the intensity information extraction means 27 sets the reconstructed image reconstructed by the photoa-

coustic image reconstruction means 25 to input data, and generates the intensity information from the input data which is complex number data. For example, when the complex number data is expressed by $X+iY$, the intensity information extraction means 27 extracts $(X^2+Y^2)^{1/2}$ as intensity information. The detection and logarithmic transformation means 28 generates an envelope of data indicating the intensity information extracted by the intensity information extraction means 27, and then widens a dynamic range by performing logarithmic transformation on the envelope.

[0031] The photoacoustic image construction means 29 inputs the phase information from the phase information extraction means 26, and inputs the intensity information after the detection and logarithmic transformation process from the detection and logarithmic transformation means 28. The photoacoustic image construction means 29 generates a photoacoustic image which is a distribution image of a light absorber, on the basis of the input phase information and intensity information. For example, the photoacoustic image construction means 29 determines luminance (gradation value) of each pixel in the distribution image of the light absorber, on the basis of the input intensity information. In addition, for example, the photoacoustic image construction means 29 determines color of each pixel (display color) in the distribution image of the light absorber, on the basis of the phase information. The photoacoustic image construction means 29 determines color of each pixel on the basis of the input phase information, for example, using the range of phases 0° to 90° in a color map associated with a predetermined color.

[0032] Here, since the range of phases 0° to 45° is a range in which the first photoacoustic data is larger than the second photoacoustic data, a generation source of a photoacoustic signal is considered to be a vein through which blood flows, the blood mainly containing deoxygenated hemoglobin in which the amount of absorption of a wavelength of 756 nm is greater than that of a wavelength of 798 nm. On the other hand, since the range of phases 45° to 90° is a range in which the first photoacoustic data is smaller than the second photoacoustic data, the generation source of the photoacoustic signal is considered to be an artery through which blood flows, the blood mainly containing oxygenated hemoglobin in which the amount of absorption of a wavelength of 756 nm is less than that of a wavelength of 798 nm.

[0033] Consequently, as the color map, a color map is used in which color gradually changes so as to become blue at the phase of 0° and to become colorless (white) as the phase approaches 45° and in which color gradually changes so as to become red at the phase of 90° and to become white as the phase approaches 45° . In this case, in the photoacoustic image, a portion corresponding to the artery can be expressed by red, and a portion corresponding to the vein can be expressed by blue. Only color coding between the portion corresponding to the artery and the portion corresponding to the vein may be

performed on the basis of the phase information by maintaining a constant gradation value, without using the intensity information. The image display means 14 displays the photoacoustic image generated by the photoacoustic image construction means 29 on a display screen.

[0034] Subsequently, a configuration of the laser source unit 13 will be described in detail. Fig. 2 illustrates a configuration of the laser source unit 13. The laser source unit 13 includes a laser rod 51, a flash lamp 52, mirrors 53 and 54, a Q switch 55, a birefringent filter (BRF) 56, driving means 57, and rotational displacement detection means 58. The laser rod 51 is a laser medium. Examples of the laser rod 51 include alexandrite crystal, Cr:LiSAF (Cr:LiSrAlF₆), Cr:LiCAF (Cr:LiCaAlF₆) crystal, and Ti:Sapphire crystal. The flash lamp 52 is an excitation light source, and the laser rod 51 is irradiated with excitation light. Any of light sources other than the flash lamp 52 may be used as the excitation light source. For example, Nd-YAG (SHG) is used as the excitation light source.

[0035] The mirrors 53 and 54 face each other with the laser rod 51 interposed therebetween, and an optical resonator is constituted by the mirrors 53 and 54. The mirror 54 is assumed to be the output side. The Q switch 55 and the birefringent filter 56 are inserted into the optical resonator. An insertion loss within the optical resonator rapidly changes from a high loss (low Q) to a low loss (high Q) by the Q switch 55, and thus a pulse laser beam can be obtained. The birefringent filter 56 changes a transmission wavelength in association with rotational displacement and changes an oscillation wavelength of the optical resonator. The driving means 57 rotates the birefringent filter 56. The rotational displacement detection means 58 detects the rotational displacement of the birefringent filter 56. The rotational displacement detection means 58 outputs BRF state information indicating the rotational displacement position of the birefringent filter 56 to the ultrasonic wave unit 12.

[0036] Referring back to Fig. 1, the control means 31 controls each unit within the ultrasonic wave unit 12. The trigger control circuit 30 rotates the birefringent filter 56 within the laser source unit 13 at a predetermined rotation speed depending on the number of wavelengths included in a wavelength sequence of a pulse laser beam to be emitted from the laser source unit 13. The rotation speed of the birefringent filter can be determined, for example, on the basis of a change characteristic of an oscillation wavelength with respect to the rotational displacement position in the birefringent filter 56, the number of wavelengths included in the wavelength sequence, and the number of times of emission of the pulse laser beam per unit time (interval of time between pulse laser beams).

[0037] The trigger control circuit 30 outputs a BRF control signal for controlling the rotation of the birefringent filter 56. The driving means 57 of the laser source unit 13 rotates the birefringent filter 56 in response to the BRF control signal. For example, the trigger control circuit 30 rotates the birefringent filter so that the amount of change

in BRF state information during a predetermined period of time is set to the amount of change depending on a predetermined rotation speed, on the basis of the BRF control signal.

[0038] In addition to the above description, the trigger control circuit 30 outputs a flash lamp trigger signal for controlling the emission of the flash lamp 52 to the laser source unit 13, and causes the laser rod 51 to be irradiated with excitation light from the flash lamp 52. The trigger control circuit 30 outputs the flash lamp trigger signal on the basis of a BRF state signal. For example, when the BRF state information is set to information indicating the position obtained by subtracting the amount of rotational displacement of the birefringent filter 56 during a period of time required for the excitation of the laser rod 51 from the position of the birefringent filter 56 which corresponds to the wavelength of the pulse laser beam to be emitted, the trigger control circuit 30 outputs the flash lamp trigger signal and causes the laser rod 51 to be irradiated with excitation light.

[0039] After the irradiation with the excitation light, the trigger control circuit 30 outputs a Q switch trigger signal to the Q switch 55 at a timing when the rotational displacement position of the birefringent filter 56 is set to the position corresponding to the wavelength of the pulse laser beam to be emitted. In other words, the trigger control circuit 30 outputs the Q switch trigger signal when the BRF state information is set to information indicating the position of the birefringent filter 56 which transmits the wavelength of the pulse laser beam to be emitted. The Q switch 55 rapidly changes the insertion loss within the optical resonator from a high loss to a low loss (Q switch is turned on) in response to the Q switch trigger signal, and thus the pulse laser beam is emitted from the mirror 54 on the output side.

[0040] The trigger control circuit 30 outputs a sampling trigger signal (AD trigger signal) to the AD conversion means 22 in accordance with a timing of the Q switch trigger signal, that is, the emission timing of the pulse laser beam. The AD conversion means 22 starts the sampling of a photoacoustic signal on the basis of the sampling trigger signal.

[0041] Fig. 3 illustrates a configuration example of the birefringent filter 56, the driving means 57, and the rotational displacement detection means 58. In this example, the driving means 57 is a servo motor, and the rotational displacement detection means 58 is a rotary encoder. The birefringent filter 56 rotates in association with the rotation of an output axis of the servo motor. The rotary encoder detects the rotational displacement of the birefringent filter 56 by a rotating plate with a slit which is mounted to the output axis of the servo motor and a transmission-type photointerrupter, and generates the BRF state information. For example, the trigger control circuit 30 monitors the BRF state information, and controls a voltage or the like to be supplied to the servo motor based on the BRF control signal so that the amount of rotational displacement of the rotation axis of the servo motor,

which is detected by the rotary encoder during a predetermined period of time is maintained at a predetermined amount, thereby rotating the birefringent filter 56 at a predetermined speed.

[0042] Fig. 4 illustrates an example of a wavelength transmission characteristic (oscillation wavelength characteristic) with respect to the rotational displacement of the birefringent filter 56. The birefringent filter 56 changes an oscillation wavelength of an optical resonator, for example, between 700 nm and 840 nm. For example, the birefringent filter 56 repeats a free spectral range (FSR) three times between the rotational displacement positions of 0° and 90° (in 1/4 rotation), and repeats the FSR twelve times for each rotation.

[0043] Fig. 5 illustrates an oscillation wavelength characteristic when the above-mentioned birefringent filter 56 is rotated at a speed of one rotation per second. When the birefringent filter 56 which has a wavelength transmission characteristic illustrated in Fig. 4 is rotated at a speed of one rotation per one second, the birefringent filter 56 repeats the FSR three times for 1/4 seconds, and repeats the FSR twelve times (12 Hz) per second. As the rotation speed of the birefringent filter 56 increases, the number of times of repetition of the FSR per second is increased, and as the rotation speed thereof decreases, the number of times of repetition of the FSR per second is decreased.

[0044] Fig. 6 is a timing chart illustrating various types of triggers and an emission timing. (a) of Fig. 6 illustrates an oscillation wavelength characteristic (transmission wavelength characteristic of the birefringent filter 56) of an optical resonator with respect to a time change. (b) of Fig. 6 illustrates a flash lamp trigger, and (c) of Fig. 6 illustrates a Q switch trigger. (d) of Fig. 6 illustrates an emission timing of a flash lamp and an emission timing of a pulse laser beam. Meanwhile, in Fig. 5, for the purpose of simplifying the description, a description is given on the assumption that the flash lamp 52 and the Q switch 55 instantaneously respond to a trigger, but actually a delay time is present. However, since the delay is approximately several μ seconds to 100 μ seconds, the delay is negligible.

[0045] First, the trigger control circuit 30 outputs the flash lamp trigger signal to the flash lamp 52 at time t1 in order to cause a pulse laser beam having a wavelength of 750 nm to be emitted from the laser source unit 13 ((b) of Fig. 6), and turns on the flash lamp 52 ((d) of Fig. 6). Thereafter, the trigger control circuit 30 outputs the Q switch trigger signal at time t2 when the rotational displacement position of the birefringent filter 56 is set to a position corresponding to the wavelength of 750 nm ((c) of Fig. 6), and turns on the Q switch 55 to cause the pulse laser beam having a wavelength of 750 nm to be emitted from the optical resonator.

[0046] Subsequently, the trigger control circuit 30 outputs the flash lamp trigger signal to the flash lamp 52 at time t3 in order to cause a pulse laser beam having a wavelength of 800 to be emitted from the laser source

unit 13 ((b) of Fig. 6), and turns on the flash lamp 52 ((d) of Fig. 6). Thereafter, the trigger control circuit 30 outputs the Q switch trigger signal at time t4 when the rotational displacement position of the birefringent filter 56 is set to a position corresponding to the wavelength of 800 nm ((c) of Fig. 6), and turns on the Q switch 55 to cause the pulse laser beam having a wavelength of 800 nm to be emitted from the optical resonator.

[0047] Here, the time t1 when the flash lamp trigger signal is output is a time obtained by subtracting a time required for the excitation of the laser rod 51 from the time t2 when the rotational displacement position of the birefringent filter 56 is set to the position corresponding to the wavelength of 750 nm. In addition, the time t3 when the flash lamp trigger signal is output is a time obtained by subtracting a time required for the excitation of the laser rod 51 from the time t4 when the rotational displacement position of the birefringent filter 56 is set to the position corresponding to the wavelength of 800 nm. The rotational displacement positions of the birefringent filter 56 which correspond to the time t1 and the time t3 can be obtained from the rotational displacement positions of the birefringent filter 56 which correspond to the wavelengths of 750 nm and 800 nm, the rotation speed of the birefringent filter 56, and time required for the excitation of the laser rod 51.

[0048] Hereinafter, similarly, the trigger control circuit 30 outputs the flash lamp trigger signal to the flash lamp 52 at time t5, time t7, time t9, and time t11. In addition, the trigger control circuit outputs the Q switch trigger signal to the Q switch 55 at time t6, time t8, time t10, and time t12, and causes the pulse laser beam having a wavelength depending on the transmission wavelength of the birefringent filter 56 at each time to be emitted. The transmission wavelengths of the birefringent filter 56 at time t6 and time t10 are 750 nm, and the transmission wavelengths of the birefringent filter at time t8 and time t12 are 800 nm, and thus the laser source unit 13 sequentially and repeatedly emits the pulse laser beams having wavelengths of 750 nm and 800 nm in this order.

[0049] In the example of Fig. 6, the laser source unit 13 alternately emits two pulse laser beams of a pulse laser beam having a wavelength of 750 nm and a pulse laser beam having a wavelength of 800 nm for 1/12 seconds. The laser source unit 13 emits the pulse laser beam twenty-four times per second while switching the two wavelengths (24 Hz operation). In other words, the pulse laser beam having a set of two wavelengths is emitted in units of twelve sets per second.

[0050] Fig. 7 illustrates an operation procedure of the photoacoustic image generation apparatus 10. Herein, a description will be given on the assumption that a region of a test object which is irradiated with a laser beam is divided into a plurality of partial regions. The trigger control circuit 30 outputs the BRF control signal for rotating the birefringent filter 56 within the laser source unit 13 at a predetermined rotation speed to the laser source unit 13, prior to the irradiation with the pulse laser beam with

respect to the test object (step A1). For example, when the birefringent filter 56 repeats an FSR twelve times during one rotation and the pulse laser beam having a wavelength of 750 nm and the pulse laser beam having a wavelength of 800 nm are sequentially emitted for 1/12 seconds (in the case of 24 Hz operation), the trigger control circuit 30 outputs the BRF control signal for rotating the birefringent filter 56 once per second.

[0051] When the photoacoustic signal is ready to be received, the trigger control circuit 30 outputs the flash lamp trigger signal to the laser source unit 13 at a predetermined timing in order to cause the pulse laser beam having a first wavelength (750 nm) constituting a wavelength sequence to be emitted (step A2). The flash lamp 52 of the laser source unit 13 is turned on in response to the flash lamp trigger signal, and thus the laser rod 51 starts to be excited (step A3). The trigger control circuit 30 turns on the flash lamp 52, for example, at a timing calculated back from a timing at which the rotational displacement position of the birefringent filter 56 is set to the position corresponding to the wavelength of 750 nm, on the basis of the BRF state information.

[0052] After the flash lamp 52 is turned on, the trigger control circuit 30 turns on the Q switch 55 at a timing when the rotational displacement position of the birefringent filter 56 is set to the position corresponding to the first wavelength (750 nm) constituting the wavelength sequence, on the basis of the BRF state information (step A4). The laser source unit 13 emits the pulse laser beam having a wavelength of 750 nm by the Q switch 55 being turned on.

[0053] The pulse laser beam having a wavelength of 750 nm which is emitted from the laser source unit 13 is guided to, for example, the probe 11, and a first partial region of the test object is irradiated with the pulse laser beam from the probe 11. A light absorber absorbs energy of the irradiated pulse laser beam within the test object, and thus a photoacoustic signal is generated. The probe 11 detects the photoacoustic signal generated within the test object. The photoacoustic signal detected by the probe 11 is received by the reception circuit 21.

[0054] The trigger control circuit 30 outputs the sampling trigger signal to the AD conversion means 22 in accordance with a timing at which the Q switch trigger signal is output. The AD conversion means 22 samples the photoacoustic signal received by the reception circuit 21 with a predetermined sampling period (step A5). The photoacoustic signal sampled by the AD conversion means 22 is stored as first photoacoustic data in the reception memory 23.

[0055] The control means 31 determines whether a remaining wavelength to be emitted is present or not, in other words, whether the pulse laser beams of all the predetermined wavelengths constituting the wavelength sequence have been emitted or not (step A6). When a remaining wavelength is present, the process returns to step A2 in order to emit the pulse laser beam having the next wavelength, and the flash lamp trigger signal is out-

put to the laser source unit 13 from the trigger control circuit 30. In step A3, the flash lamp 52 is turned on in response to the flash lamp trigger signal, and in step A4, the trigger control circuit 30 turns on the Q switch 55 at a timing when the birefringent filter 56 is set to be at the rotational displacement position corresponding to the second wavelength (800 nm) constituting the wavelength sequence, to cause the pulse laser beam to be emitted.

[0056] The pulse laser beam having a wavelength of 800 nm which is emitted from the laser source unit 13 is guided to, for example, the probe 11, and the first partial region of the test object is irradiated with the pulse laser beam from the probe 11. The probe 11 detects a photoacoustic signal generated by the light absorber within the test object absorbing the pulse laser beam having a wavelength of 800 nm. The trigger control circuit 30 outputs the sampling trigger signal to the AD conversion means 22 in accordance with the output of the Q switch trigger signal, and the AD conversion means 22 samples the photoacoustic signal in step A5. The photoacoustic signal sampled by the AD conversion means 22 is stored as second photoacoustic data in the reception memory 23. The photoacoustic image generation apparatus 10 performs step A1 to step A5 on the wavelengths constituting the wavelength sequence and irradiates the test object with the pulse laser beam having the wavelengths constituting the wavelength sequence, thereby detecting a photoacoustic signal from the test object.

[0057] When the control means 31 determines in step A6 that a remaining wavelength is not present, the control means determines whether all the partial regions have been selected (step A7). When the partial region to be selected remains, the process returns to step A2. The photoacoustic image generation apparatus 10 performs step A2 to step A6 on each partial region, sequentially irradiates each partial region with pulse laser beams having the wavelengths (750 nm and 800 nm) constituting the wavelength sequence, and stores the first photoacoustic data and the second photoacoustic data which correspond to each partial region, in the reception memory 23. When the irradiation with the pulse laser beam and the detection of the photoacoustic signal are performed on all the partial regions, photoacoustic data required to generate a photoacoustic image of one frame is gathered.

[0058] When the control means 31 determines in step A7 that all the partial regions have been selected, the process proceeds to the generation of the photoacoustic image. The complex number creation means 24 reads out the first photoacoustic data and the second photoacoustic data from the reception memory 23, and generates complex number data in which first photoacoustic image data is set to a real part and second photoacoustic image data is set to an imaginary part (step A8). The photoacoustic image reconstruction means 25 performs image reconstruction from the complex number data generated in step A8, using a Fourier transform method (FTA method) (step A9).

[0059] The phase information extraction means 26 extracts phase information from the reconstructed complex number data (reconstructed image) (step A10). For example, when the reconstructed complex number data is expressed by $X+iY$, the phase information extraction means 26 extracts the relation of $\theta=\tan^{-1}(Y/X)$ as the phase information (but, when the relation of $X=0$ is satisfied, the relation of $\theta=90^\circ$ is satisfied). The intensity information extraction means 27 extracts intensity information from the reconstructed complex number data (step A11). For example, when the reconstructed complex number data is expressed by $X+iY$, the intensity information extraction means 27 extracts $(X^2+Y^2)^{1/2}$ as the intensity information.

[0060] The detection and logarithmic transformation means 28 performs a detection and logarithmic transformation process on the intensity information extracted in step A11. The photoacoustic image construction means 29 generates a photoacoustic image on the basis of the phase information extracted in step A10 and the performing of the detection and logarithmic transformation process, on the intensity information extracted in step A11 (step A 12). For example, the photoacoustic image construction means 29 generates the photoacoustic image by determining luminance (gradation value) of each pixel in a distribution image of a light absorber on the basis of the intensity information and by determining color of each pixel on the basis of the phase information. The generated photoacoustic image is displayed on the image display means 14.

[0061] Here, the rotation speed of the birefringent filter 56 may be appropriately determined depending on the number of wavelengths included in a wavelength sequence of a pulse laser beam to be emitted. Hereinafter, a case where the wavelength sequence includes six wavelengths (720 nm, 740 nm, 760 nm, 780 nm, 800 nm, and 820 nm) will be described. Fig. 8 is a timing chart illustrating various types of triggers and an emission timing when a wavelength sequence includes six wavelengths. (a) of Fig. 8 illustrates an oscillation wavelength characteristic (transmission wavelength characteristic of the birefringent filter 56) of an optical resonator with respect to a time change (b) of Fig. 8 illustrates a flash lamp trigger, and (c) of Fig. 8 illustrates a Q switch trigger. (d) of Fig. 8 illustrates an emission timing of a flash lamp and an emission timing of a pulse laser beam.

[0062] As illustrated in Fig. 4, when the birefringent filter 56 repeating an FSR twelve times in one rotation is rotated once for four seconds, the birefringent filter 56 is rotated 1/4 per second and repeats the FSR three times per second ((a) of Fig. 8). First, the trigger control circuit 30 outputs the flash lamp trigger signal to the flash lamp 52 at time t21 in order to cause a pulse laser beam having a wavelength of 720 nm to be emitted from the laser source unit 13 ((b) of Fig. 8), and turns on the flash lamp 52 ((d) of Fig. 8). Thereafter, the trigger control circuit 30 outputs the Q switch trigger signal at time t22 when the rotational displacement position of the birefringent filter

56 is set to the position corresponding to the wavelength of 720 nm ((c) of Fig. 8), and causes the pulse laser beam having a wavelength of 720 nm to be emitted from the optical resonator by the Q switch 55 being turned on.

[0063] Subsequently, the trigger control circuit 30 outputs the flash lamp trigger signal to the flash lamp 52 at time t23 in order to cause a pulse laser beam having a wavelength of 740 nm to be emitted from the laser source unit 13 ((b) of Fig. 8), and turns on the flash lamp 52 ((d) of Fig. 8). Thereafter, the trigger control circuit 30 outputs the Q switch trigger signal at time t24 when the rotational displacement position of the birefringent filter 56 is set to the position corresponding to the wavelength of 740 nm ((c) of Fig. 8), and causes the pulse laser beam having a wavelength of 740 nm to be emitted from the optical resonator by the Q switch 55 being turned on.

[0064] Hereinafter, similarly, the trigger control circuit 30 outputs the flash lamp trigger signal to the flash lamp 52 at time t25, time t27, time t29, and time t31. In addition, the trigger control circuit outputs the Q switch trigger signal to the Q switch 55 at time t26, time t28, time t30, and time t32, and causes the pulse laser beam having a wavelength depending on the transmission wavelength of the birefringent filter 56 at each time to be emitted. The transmission wavelengths of the birefringent filter 56 at time t26, time t28, time t30, and time t32 are 760 nm, 780 nm, 800 nm, and 820 nm, respectively, and the laser source unit 13 emits six pulse laser beams having a wavelength increasing by 20 nm for 1/3 seconds in a range between 720 nm and 820 nm.

[0065] In an example of Fig. 8, the laser source unit 13 emits a pulse laser beam having six wavelengths of 720 nm to 820 nm for 1/3 seconds. The laser source unit 13 emits the pulse laser beam eighteen times per second while switching the six wavelengths (18 Hz operation). In other words, the pulse laser beam having a set of six wavelengths is emitted in units of three sets per second.

[0066] It is preferable that the rotation speed of the birefringent filter 56 be set so that a pulse laser beam having wavelengths constituting a wavelength sequence can be emitted in one FSR. For example, when the number of times of the FSR repeated by the birefringent filter 56 during one rotation is set to k [times/rotation], the number of wavelengths included in the wavelength sequence is set to n [pieces], and the number of times of emission of the pulse laser beam per unit time is set to m [times/second], the rotation speed of the birefringent filter 56 can be set to a value determined by the relation of $v=m/(k \times n)$ [rotations/second]. In this case, m pulse lasers can be emitted per second while switching n wavelengths for each FSR (m Hz operation).

[0067] In this embodiment, the flash lamp 52 is turned on to excite the laser rod 51 while rotating the birefringent filter 56 at a predetermined rotation speed. After the excitation of the laser rod, the Q switch 55 is turned on at a timing when the rotational displacement position of the birefringent filter 56 is set to a position corresponding to a wavelength of a pulse laser beam to be emitted. As the

rotation speed of the birefringent filter 56 decreases, for example, the number of oscillation wavelengths capable of being selected in one FSR of the birefringent filter 56 can be increased. On the other hand, when the number of wavelengths included in the wavelength sequence is two, the speed of the switching of the two wavelengths can be increased by increasing the rotation speed of the birefringent filter 56. In this manner, in this embodiment, it is possible to emit a pulse laser beam in a desired wavelength sequence from the laser source unit 13 by controlling the rotation speed of the birefringent filter 56. In this embodiment, the Q switch trigger signal is output from the ultrasonic wave unit 12, and thus it is not necessary to acquire information such as a synchronization signal indicating a laser emission timing from the laser source unit 13.

[0068] In this embodiment, complex number data is generated in which one of the first photoacoustic data and the second photoacoustic data which are obtained at two wavelengths is set to a real part and the other is set to an imaginary part, and a reconstructed image is generated from the complex number data using a Fourier transform method. In this case, it is possible to effectively perform the reconstruction as compared with a case where the first photoacoustic data and the second photoacoustic data are separately reconstructed. A pulse laser beam of a plurality of wavelengths is irradiated, and a photoacoustic signal (photoacoustic data) at the time of the irradiation with a pulse laser beam having each wavelength is used, and thus it is possible to perform functional imaging using optical absorption properties of the respective light absorbers being different from each other depending on wavelengths.

[0069] In addition, in this embodiment, for example, when a light irradiation region is divided into three partial regions, a first partial region is sequentially irradiated with a pulse laser beam having a first wavelength and a pulse laser beam having a second wavelength, and a second partial region is sequentially irradiated with the pulse laser beam having the first wavelength and the pulse laser beam having the second wavelength, and then a third partial region is sequentially irradiated with the pulse laser beam having the first wavelength and the pulse laser beam having the second wavelength. In this embodiment, any partial region is continuously irradiated with the pulse laser beam having the first wavelength and the pulse laser beam having the second wavelength, and then the irradiation moves to the next partial region. In this case, it is possible to shorten the time from the irradiation with the pulse laser beam having the first wavelength to the irradiation with the second wavelength at the same position, as compared with a case where the three partial regions are irradiated with the pulse laser beam having the first wavelength and are then irradiated with the pulse laser beam having the second wavelength. It is possible to suppress mismatching between the first photoacoustic data and the second photoacoustic data by shortening the time between the irradiation with the

pulse laser beam having the first wavelength and the irradiation with the pulse laser beam having the second wavelength.

[0070] Subsequently, a second embodiment of the invention will be described. Fig. 9 illustrates a photoacoustic image generation apparatus according to the second embodiment of the invention. In a photoacoustic image generation apparatus 10a according to this embodiment, an ultrasonic wave unit 12a includes data separation means 32, ultrasonic image reconstruction means 33, detection and logarithmic transformation means 34, ultrasonic image construction means 35, image synthesis means 36, and a transmission control circuit 37, in addition to the configuration of the ultrasonic wave unit 12 in the photoacoustic image generation apparatus 10 according to the first embodiment which is illustrated in Fig. 1. The photoacoustic image generation apparatus 10a according to this embodiment is different from that in the first embodiment in that the apparatus generates an ultrasonic image in addition to a photoacoustic image. Other parts may be the same as those in the first embodiment.

[0071] In this embodiment, a probe 11 outputs (transmits) ultrasonic waves to a test object and detects (receives) reflected ultrasonic waves from the test object with respect to the transmitted ultrasonic waves, in addition to the detection of a photoacoustic signal. A trigger control circuit 30 transmits an ultrasonic wave transmission trigger signal for instructing the transmission of ultrasonic waves to the transmission control circuit 37 at the time of the generation of an ultrasonic image. When the transmission control circuit 37 receives the trigger signal, the transmission control circuit causes ultrasonic waves to be transmitted from the probe 11. The probe 11 detects reflected ultrasonic waves from the test object after the transmission of the ultrasonic waves.

[0072] The reflected ultrasonic waves detected by the probe 11 are input to AD conversion means 22 through a reception circuit 21. The trigger control circuit 30 transmits a sampling trigger signal to the AD conversion means 22 in accordance with the transmission timing of the ultrasonic waves, and starts to sample the reflected ultrasonic waves. The AD conversion means 22 stores sampling data of the reflected ultrasonic waves (reflected ultrasonic data) in the reception memory 23.

[0073] The data separation means 32 separates the reflected ultrasonic data stored in the reception memory 23 and first and second photoacoustic data from each other. The data separation means 32 transmits the reflected ultrasonic data to the ultrasonic image reconstruction means 33, and transmits the first and second photoacoustic data to complex number creation means 24. The generation of the photoacoustic image on the basis of the first and second photoacoustic data is the same as that in the first embodiment. The data separation means 32 inputs sampling data of the separated reflected ultrasonic waves to the ultrasonic image reconstruction means 33.

[0074] The ultrasonic image reconstruction means 33 generates pieces of data of lines of the ultrasonic image on the basis of reflected ultrasonic waves (sampling data thereof) which are detected by a plurality of ultrasonic vibrators of the probe 11. For example, the ultrasonic image reconstruction means 33 adds data from 64 ultrasonic vibrators of the probe 11 on the basis of a delay time depending on the position of the ultrasonic vibrator to generate data for one line (delay addition method).

[0075] The detection and logarithmic transformation means 34 obtains an envelope of the pieces of data of the lines which are output by the ultrasonic image reconstruction means 33, and performs logarithmic transformation on the obtained envelope. The ultrasonic image construction means 35 generates an ultrasonic image on the basis of the data of the lines on which the logarithmic transformation is performed. The ultrasonic image reconstruction means 33, the detection and logarithmic transformation means 34, and the ultrasonic image construction means 35 constitute ultrasonic image generation means that generates an ultrasonic image on the basis of reflected ultrasonic waves.

[0076] The image synthesis means 36 synthesizes the photoacoustic image and the ultrasonic image. For example, the image synthesis means 36 performs image synthesis by superimposing the photoacoustic image and the ultrasonic image on each other. At this time, it is preferable that the image synthesis means 36 perform positioning so that corresponding points of the photoacoustic image and the ultrasonic image are set to be at the same position. The synthesized image is displayed on image display means 14. It is also possible to display the photoacoustic image and the ultrasonic image on the image display means 14 side by side without performing image synthesis, or to switch and display the photoacoustic image and the ultrasonic image.

[0077] Fig. 10 illustrates an operation procedure of the photoacoustic image generation apparatus 10a. Hereinafter, a description will be given on the assumption that a region of a test object which is irradiated with a laser beam is divided into a plurality of partial regions. The trigger control circuit 30 outputs the BRF control signal for rotating birefringent filter 56 within a laser source unit 13 at a predetermined rotation speed to the laser source unit 13 (step B1).

[0078] When a photoacoustic signal is ready to be received, the trigger control circuit 30 outputs a flash lamp trigger signal in order to cause a pulse laser beam having a first wavelength (750 nm) constituting a wavelength sequence to be emitted (step B2). A flash lamp 52 is turned on in response to the flash lamp trigger signal, and thus a laser rod 51 starts to be excited (step B3).

[0079] After the flash lamp 52 is turned on, the trigger control circuit 30 turns on a Q switch 55 at a timing when a rotational displacement position of the birefringent filter 56 is set to the position corresponding to the first wavelength (750 nm) constituting the wavelength sequence, on the basis of the BRF control signal (step B4). The

laser source unit 13 emits a pulse laser beam having a wavelength of 750 nm by the Q switch 55 being turned on.

[0080] The pulse laser beam having a wavelength of 750 nm which is emitted from the laser source unit 13 is guided to, for example, the probe 11, and a first partial region of the test object is irradiated with the pulse laser beam from the probe 11. A light absorber absorbs energy of the irradiated pulse laser beam within the test object, and thus a photoacoustic signal is generated. The probe 11 detects the photoacoustic signal generated within the test object. The trigger control circuit 30 outputs a sampling trigger signal to the AD conversion means 22 in accordance with the output of a Q switch trigger signal. The AD conversion means 22 receives the photoacoustic signal detected by the probe 11 through the reception circuit 21, and samples the photoacoustic signal with a predetermined sampling period (step B5). The photoacoustic signal sampled by the AD conversion means 22 is stored as first photoacoustic data in the reception memory 23.

[0081] The control means 31 determines whether a remaining wavelength is present, in other words, whether the pulse laser beams of all the wavelengths constituting the wavelength sequence have been emitted or not (step B6). When a remaining wavelength is present, the process returns to step B2 in order to emit the pulse laser beam having the next wavelength, and the flash lamp trigger signal is output to the laser source unit 13 from the trigger control circuit 30. In step B3, the flash lamp 52 is turned on in response to the flash lamp trigger signal, and in step B4, the trigger control circuit 30 turns on the Q switch 55 at a timing when the birefringent filter 56 is set to be at the rotational displacement position corresponding to the second wavelength (800 nm) constituting the wavelength sequence, to cause the pulse laser beam to be emitted.

[0082] The pulse laser beam having a wavelength of 800 nm which is emitted from the laser source unit 13 is guided to, for example, the probe 11, and the first partial region of the test object is irradiated with the pulse laser beam from the probe 11. The probe 11 detects the photoacoustic signal generated by the light absorber within the test object absorbing the pulse laser beam having a wavelength of 800 nm. The trigger control circuit 30 outputs the sampling trigger signal to the AD conversion means 22 in accordance with the output of the Q switch trigger signal, and the AD conversion means 22 samples the photoacoustic signal in step B5. The photoacoustic signal sampled by the AD conversion means 22 is stored as second photoacoustic data in the reception memory 23. The photoacoustic image generation apparatus 10 performs step B1 to step B5 to each wavelengths constituting the wavelength sequence, and irradiates the test object with the pulse laser beam having each wavelengths constituting the wavelength sequence, thereby detecting a photoacoustic signal from the test object. The step B1 to step B5 may be the same as step A1 to step A5 of Fig. 7.

[0083] When the control means 31 determines in step B6 that a remaining wavelength is not present, the process proceeds to the transmission and reception of ultrasonic waves. The trigger control circuit 30 transmits the ultrasonic waves to the test object from the probe 11 through the transmission control circuit 37 (step B7). In step B7, the ultrasonic waves are transmitted to the same region as the partial region of the test object which is irradiated with the pulse laser beam. The probe 11 detects reflected ultrasonic waves with respect to the transmitted ultrasonic waves (step B8). The detected reflected ultrasonic waves are sampled in the AD conversion means 22 through the reception circuit 21, and are stored as reflected ultrasonic data in the reception memory 23.

[0084] The control means 31 determines whether all the partial regions have been selected (step B9). When the partial region to be selected remains, the process returns to step B2. The photoacoustic image generation apparatus 10a performs step B2 to step B6 on each partial region, sequentially irradiates each partial region with pulse laser beams having the wavelengths (750 nm and 800 nm) constituting the wavelength sequence, and stores the first photoacoustic data and the second photoacoustic data in the reception memory 23. In addition, step B7 and step B8 are performed to store the reflected ultrasonic data in the reception memory 23. When the irradiation with the pulse laser beam, the detection of the photoacoustic signal, and the transmission and reception of the ultrasonic waves are performed on all the partial regions, data required to generate a photoacoustic image and an ultrasonic image of one frame is gathered.

[0085] When the control means 31 determines in step B9 that all the partial regions have been selected, the process proceeds to the generation of the photoacoustic image and the ultrasonic image. The data separation means 32 separates the first and second photoacoustic data and the reflected ultrasonic data from each other. The data separation means 32 transmits the separated first and second photoacoustic data to the complex number creation means 24, and transmits the reflected ultrasonic data to the ultrasonic image reconstruction means 33. The complex number creation means 24 generates complex number data in which first photoacoustic image data is set to a real part and second photoacoustic image data is set to an imaginary part (step B10). The photoacoustic image reconstruction means 25 performs image reconstruction from the complex number data generated in step B10, using a Fourier transform method (FTA method) (step B11).

[0086] The phase information extraction means 26 extracts phase information from the reconstructed complex number data (step B12). The intensity information extraction means 27 extracts intensity information from the reconstructed complex number data (step B13). The detection and logarithmic transformation means 28 performs a detection and logarithmic transformation process on the intensity information extracted in step B13. The photoacoustic image construction means 29 generates

a photoacoustic image on the basis of the phase information extracted in step B12 and the performing of the detection and logarithmic transformation process, on the intensity information extracted in step B13 (step B14). Here, step B10 to step B14 may be the same as step A8 to step A12 of Fig. 7.

[0087] The ultrasonic image reconstruction means 33 generates pieces of data of lines of the ultrasonic image using, for example, a delay addition method. The detection and logarithmic transformation means 34 obtains an envelope of the pieces of data of the lines which are output by the ultrasonic image reconstruction means 33, and performs logarithmic transformation on the obtained envelope. The ultrasonic image construction means 35 generates an ultrasonic image on the basis of the pieces of data of the lines on which the logarithmic transformation is performed (step B15). The image synthesis means 36 synthesizes the photoacoustic image and the ultrasonic image and displays the synthesized image on the image display means 14 (step B16).

[0088] In this embodiment, the photoacoustic image generation apparatus generates an ultrasonic image in addition to a photoacoustic image. It is possible to observe a portion not capable of being formed as an image in the photoacoustic image by referring to the ultrasonic image. Other effects are the same as those in the first embodiment.

[0089] Meanwhile, in the above-described embodiments, an example in which first photoacoustic data and second photoacoustic data are created as complex numbers has been described, but the first photoacoustic data and the second photoacoustic data may be separately reconstructed without being created as complex numbers. Furthermore, herein, a ratio between the first photoacoustic data and the second photoacoustic data is calculated by the creation of complex numbers and by using phase information, but the same effect is obtained even though the ratio is calculated from intensity information of both the pieces of data. In addition, the intensity information can be generated on the basis of signal intensity in a first reconstructed image and signal intensity in a second reconstructed image.

[0090] In the generation of a photoacoustic image, the number of wavelengths of a pulse laser beam with which a test object is to be irradiated is not limited two, and the test object may be irradiated with three or more pulse laser beams, and thus the photoacoustic image may be generated on the basis of pieces of photoacoustic data corresponding to the respective wavelengths. In this case, for example, the phase information extraction means 26 may generate a magnitude relation between relative signal intensities of the pieces of photoacoustic data corresponding to the respective wavelengths, as phase information. In addition, the intensity information extraction means 27 may generate the signal intensities in the pieces of photoacoustic data corresponding to the respective wavelengths, which are grouped into one, as intensity information.

[0091] In the above-described embodiments, a description has been made on the assumption that the trigger control circuit 30 monitors BRF state information and controls a rotation speed of the birefringent filter 56 to have a predetermined rotation speed on the basis of the BRF control signal, but is not limited thereto. Fig. 11 illustrates a modified example of a laser source unit. A laser source unit 13a includes a rotation control unit 59 in addition to the configuration of the laser source unit 13 illustrated in Fig. 2. The rotation control unit 59 controls a voltage or the like to be supplied to driving means 57 so that the amount of rotational displacement which is detected by rotational displacement detection means 58 during a predetermined period of time is set to an amount according to a predetermined rotation speed of the birefringent filter 56. The trigger control circuit 30 instructs the rotation control unit 59 on the rotation speed of the birefringent filter 56 on the basis of the BRF control signal. The rotation control unit 59 drives the driving means 57 so that the rotation speed of the birefringent filter 56 is set to the instructed rotation speed.

Claims

1. A photoacoustic image generation apparatus (10) comprising:

a laser source unit (13) configured to sequentially emit a plurality of pulse laser beams in a predetermined wavelength sequence having at least two different wavelengths, the laser source unit including a laser rod (51), an excitation light source (52) configured to irradiate the laser rod with excitation light, an optical resonator that has a pair of mirrors (53, 54) facing each other with the laser rod interposed therebetween, a Q switch (55) which is inserted into the optical resonator, and a birefringent filter (56) which is inserted into the optical resonator and is configured to change an oscillation wavelength of the optical resonator in association with rotational displacement of the birefringent filter; and an acoustic wave unit (12) configured to generate a photoacoustic image, the acoustic wave unit including detection means configured to detect a photoacoustic signal generated within an object when the object is irradiated with the pulse laser beam having each wavelength included in the predetermined wavelength sequence and to generate pieces of photoacoustic data corresponding to the respective wavelengths, intensity ratio extraction means configured to extract a magnitude relation between relative signal intensities of the pieces of photoacoustic data corresponding to the respective wavelengths, photoacoustic image construction means (29) configured to generate the photoa-

- coustic image on the basis of the extracted magnitude relation, and a trigger control circuit (30) configured to cause the laser rod to be irradiated with excitation light from the excitation light source while rotating the birefringent filter at a predetermined rotation speed depending on the number of wavelengths included in the wavelength sequence, and after the irradiation with the excitation light, to turn on the Q switch at a timing when a rotational displacement position of the birefringent filter is set to a position corresponding to the wavelength of the pulse laser beam to be emitted to cause the pulse laser beam to be emitted, wherein the trigger control circuit (30) is configured to continuously rotate the birefringent filter (56) in a predetermined direction at the predetermined rotation speed.
2. The photoacoustic image generation apparatus (10) according to claim 1, wherein the predetermined rotation speed is determined on the basis of a change characteristic of the oscillation wavelength with respect to the rotational displacement position in the birefringent filter, the number of wavelengths included in the wavelength sequence, and the number of times of emission of the pulse laser beam per unit time.
 3. The photoacoustic image generation apparatus (10) according to claim 1 or 2, wherein when the number of times of a free spectral range repeated during one rotation is set to $k[\text{times/rotation}]$, the number of wavelengths included in the wavelength sequence is set to $n[\text{pieces}]$, and the number of times of emission of the pulse laser beam per unit time is set to $m[\text{times/second}]$, the predetermined rotation speed of the birefringent filter is determined as a value calculated by a relation of $v=m/(k \times n)[\text{rotations/second}]$.
 4. The photoacoustic image generation apparatus (10) according to any one of claims 1 to 3, wherein the trigger control circuit (30) determines a timing at which the excitation light is irradiated and a timing at which the Q switch (55) is turned on, on the basis of birefringent filter state information indicating the rotational displacement position of the birefringent filter (56).
 5. The photoacoustic image generation apparatus (10) according to claim 4, wherein when the birefringent filter state information is set to information indicating a position obtained by subtracting the amount of rotational displacement of the birefringent filter (56) during a period of time required for the excitation of the laser rod (51) from a position of the birefringent filter which corresponds to the wavelength of the pulse laser beam to be emitted, the trigger control circuit (30) causes the laser rod to be irradiated with excitation light.
 6. The photoacoustic image generation apparatus (10) according to claim 4 or 5, wherein the trigger control circuit (30) rotates the birefringent filter (56) so that the amount of change in the birefringent filter state information during a predetermined period of time is set to the amount of change depending on the predetermined rotation speed.
 7. The photoacoustic image generation apparatus (10) according to any one of claims 1 to 5, wherein the laser source unit (13) further includes driving means (57) that rotates the birefringent filter (56), rotational displacement detection means (58) that detects the rotational displacement of the birefringent filter, and a rotation control unit (59) that controls the driving means so that the amount of rotational displacement which is detected by the rotational displacement detection means during a predetermined period of time is set to an amount depending on the predetermined rotation speed.
 8. The photoacoustic image generation apparatus (10) according to any one of claims 1 to 7, wherein the acoustic wave unit (12) further includes intensity information extraction means (27) that generates intensity information indicating signal intensity on the basis of the pieces of photoacoustic data corresponding to the respective wavelengths, and wherein the photoacoustic image construction means (29) determines a gradation value of each pixel of the photoacoustic image on the basis of the intensity information and determines a display color of each pixel on the basis of the extracted magnitude relation.
 9. The photoacoustic image generation apparatus (10) according to claim 8, wherein the predetermined wavelength sequence includes a first wavelength and a second wavelength, wherein the acoustic wave unit (12) further includes complex number creation means that generates complex number data in which one of first photoacoustic data corresponding to a photoacoustic signal, detected when irradiation with the pulse laser beam having the first wavelength is performed, and second photoacoustic data corresponding to a photoacoustic signal, detected when irradiation with the pulse laser beam having the second wavelength is performed, is set to a real part and the other one is set to an imaginary part, and photoacoustic im-

age reconstruction means that generates a reconstructed image from the complex number data using a Fourier transform method, and wherein the intensity ratio extraction means extracts phase information as the magnitude relation from the reconstructed image, and the intensity information extraction means extracts the intensity information from the reconstructed image.

10. The photoacoustic image generation apparatus (10) according to any one of claims 1 to 9,

wherein the detection means further detects reflected acoustic waves with respect to acoustic waves transmitted to the object to generate reflected acoustic wave data, and wherein the acoustic wave unit (12) further includes acoustic wave image generation means that generates an acoustic wave image on the basis of the reflected acoustic wave data.

Patentansprüche

1. Fotoakustikbild-Erzeugungsvorrichtung (10) umfassend:

eine Laserquelleneinheit (13) eingerichtet zum sequentiellen Emittieren einer Vielzahl von gepulsten Laserstrahlen in einer vorbestimmten Wellenlängensequenz mit wenigstens zwei verschiedenen Wellenlängen, wobei die Laserquelleneinheit einen Laserstab (51), eine Anregungs-Lichtquelle (52), die eingerichtet ist, den Laserstab mit Anregungslicht zu bestrahlen, einen optischen Resonator mit einem Paar von Spiegeln (53, 54), die einander mit zwischenliegendem Laserstab gegenüberstehen, einem Q-Switch (55), der in den optischen Resonator eingebracht ist, und ein doppelbrechendes Filter (56), das in den optischen Resonator eingebracht ist und eingerichtet ist, die Oszillationswellenlänge des optischen Resonators gemäß einer Rotationsverschiebung des doppelbrechenden Filters zu verändern; und eine Akustikwelleneinheit (12), die eingerichtet ist, ein Fotoakustikbild zu erzeugen, wobei die Akustikwelleneinheit Detektionsmittel umfasst, die eingerichtet sind, ein Fotoakustiksignal zu detektieren, das innerhalb eines Objekts erzeugt wird, wenn das Objekt mit dem gepulsten Laserstrahl bestrahlt wird, der jede Wellenlänge, die in einer vorbestimmten Wellenlängensequenz enthalten ist, aufweist und Stücke von Fotoakustikdaten zu erzeugen, die den jeweiligen Wellenlängen entsprechen, Intensitätsverhältnis-Extrahiermittel, die eingerichtet sind, eine

Stärkenrelation zwischen relativen Signalintensitäten der Stücke von Fotoakustikdaten zu extrahieren, die den jeweiligen Wellenlängen entsprechen, Fotoakustikbild-Konstruktionsmittel (29), die eingerichtet sind, das Fotoakustikbild auf Basis der extrahierten Stärkenrelation zu erzeugen, und einem Triggersteuerschaltkreis (30), der eingerichtet ist zu veranlassen, dass der Laserstab mit Anregungslicht von der Anregungslichtquelle bestrahlt wird während der doppelbrechende Filter mit einer vorbestimmten Rotationsgeschwindigkeit rotiert, die von der Anzahl der Wellenlängen abhängt, die in der Wellenlängensequenz enthalten sind, und nach der Bestrahlung mit dem Anregungslicht den Q-Switch zu Zeitpunkten einzuschalten, wenn die Rotationsverschiebungsposition des doppelbrechenden Filters auf eine Position eingestellt ist, die der Wellenlänge des zu emittierenden gepulsten Laserstrahls entspricht, um zu veranlassen, dass der gepulste Laserstrahl emittiert wird, wobei der Triggersteuerschaltkreis (30) eingerichtet ist, das doppelbrechende Filter (56) in einer vorbestimmten Richtung mit einer vorbestimmten Rotationsgeschwindigkeit kontinuierlich zu rotieren.

2. Fotoakustikbild-Erzeugungsvorrichtung (10) nach Anspruch 1, wobei die vorbestimmten Rotationsgeschwindigkeit auf Basis einer Veränderungscharakteristik der Oszillationswellenlänge bezüglich der Rotationsverschiebungsposition in dem doppelbrechenden Filter, der Anzahl von Wellenlängen, die in der Wellenlängensequenz enthalten sind, und der Anzahl von Emissionszeitpunkten des gepulsten Laserstrahls pro Zeiteinheit bestimmt wird.
3. Fotoakustikbild-Erzeugungsvorrichtung (10) nach Anspruch 1 oder 2, wobei die Anzahl der Zeitpunkte eines freien Spektralbereichs, der während einer Rotation wiederholt wird, auf $k[\text{Anzahl}/\text{Rotation}]$ eingestellt ist, die Anzahl von in der Wellenlängensequenz enthaltenen Wellenlängen auf $n[\text{Stücke}]$ eingestellt ist, und die Anzahl von Emissionszeitpunkten des gepulsten Laserstrahls pro Zeiteinheit auf $m[\text{Anzahl}/\text{Sekunde}]$ eingestellt ist, wobei die vorbestimmte Rotationsgeschwindigkeit des doppelbrechenden Filters als ein Wert bestimmt wird, der durch die Relation $v=m/(kxn)[\text{Rotationen}/\text{Sekunde}]$ berechnet wird.
4. Fotoakustikbild-Erzeugungsvorrichtung (10) nach einem der Ansprüche 1 bis 3, wobei der Triggersteuerschaltkreis (30) einen Zeitpunkt bestimmt, zu welchem das Anregungslicht abgestrahlt wird, und einen Zeitpunkt, zu welchem der Q-Switch (55) angeschaltet wird, auf Basis von Doppelbrechungsfilter-

Zustandsinformation, die die Rotationsverschiebungsposition des doppelbrechenden Filters (56) angibt.

5. Fotoakustikbild-Erzeugungsvorrichtung (10) nach Anspruch 4, wobei, wenn die Doppelbrechungsfilter-Zustandsinformation auf eine Information eingestellt ist, die eine Position angibt, die durch Subtrahieren der Rotationsverschiebung des doppelbrechenden Filters (56) während einer Zeitperiode, die zur Anregung des Laserstrahls (51) benötigt wird, von einer Position des doppelbrechenden Filters, der der Wellenlänge des zu emittierenden gepulsten Laserstrahls entspricht, erhalten wird, der Triggersteuerschaltkreis (30) veranlasst, dass der Laserstrahl mit Anregungslicht bestrahlt wird. 5
10
6. Fotoakustikbild-Erzeugungsvorrichtung (10) nach Anspruch 4 oder 5, wobei der Triggersteuerschaltkreis (30) das doppelbrechende Filter (56) derart rotiert, dass die Veränderung der Doppelbrechungsfilter-Zustandsinformation während einer vorbestimmten Zeitperiode auf die Veränderungsmenge eingestellt ist, die von der vorbestimmten Rotationsgeschwindigkeit abhängt. 15
20
25
7. Fotoakustikbild-Erzeugungsvorrichtung (10) nach einem der Ansprüche 1 bis 5, wobei die Laserquelleinheit (13) weiterhin ein Ansteuermittel (57), das das doppelbrechende Filter (56) rotiert, ein Rotationsverschiebungs-Positionsmittel (58), das die Rotationsverschiebung des doppelbrechenden Filters detektiert, und eine Rotationssteuereinheit (59) enthält, die das Ansteuermittel derart steuert, dass die Rotationsverschiebung, die durch das Rotationsverschiebungs-Detektionsmittel während einer vorbestimmten Zeitperiode detektiert wird, auf eine Menge eingestellt ist, die von der vorbestimmten Rotationsgeschwindigkeit abhängt. 30
35
40
8. Fotoakustikbild-Erzeugungsvorrichtung (10) nach einem der Ansprüche 1 bis 7,
wobei die Akustik-Welleneinheit (12) weiterhin ein Intensitätsinformations-Extraktionsmittel (27) umfasst, das Intensitätsinformation erzeugt, die eine Signalintensität auf Basis der Stücke von Fotoakustikdaten angibt, die der jeweiligen Wellenlänge entsprechen, und wobei das Fotoakustikbild-Konstruktionsmittel (29) einen Gradationswert von jedem Pixel des Fotoakustikbildes auf Basis der Intensitätsinformation bestimmt und eine Anzeigefarbe von jedem Pixel auf Basis der extrahierten Stärkenrelation bestimmt. 45
50
55
9. Fotoakustikbild-Erzeugungsvorrichtung (10) nach Anspruch 8,

wobei die vorbestimmte Wellenlängenfrequenz eine erste Wellenlänge und eine zweite Wellenlänge umfasst,

wobei die Akustik-Welleneinheit (12) weiterhin ein Komplexzahl-Erzeugungsmittel umfasst, das Komplexzahldaten erzeugt, in welchen entweder erste Fotoakustikdaten, die einem Fotoakustiksignal entsprechen, das detektiert wird, wenn eine Bestrahlung mit dem gepulsten Laserstrahl mit der ersten Wellenlänge durchgeführt wird, oder zweite Fotoakustikdaten, die einem Fotoakustiksignal entsprechen, das detektiert wird, wenn eine Bestrahlung mit dem gepulsten Laserstrahl mit der zweiten Wellenlänge durchgeführt wird, als ein Realteil eingestellt, und der andere als ein Imaginärteil eingestellt ist, und ein Fotoakustikbild-Rekonstruktionsmittel, das ein von den Komplexzahldaten rekonstruiertes Bild erzeugt unter Verwendung eines Fourier-Transformationsverfahrens, und wobei das Intensitätsverhältnis-Extraktionsmittel Phaseninformation extrahiert als die Stärkenrelation von dem rekonstruierten Bild und das Intensitätsinformations-Extraktionsmittel die Intensitätsinformation von dem rekonstruierten Bild extrahiert.

10. Fotoakustikbild-Erzeugungsvorrichtung (10) nach einem der Ansprüche 1 bis 9,

wobei das Detektionsmittel weiterhin reflektierte Akustikwellen bezüglich Akustikwellen, die zu dem Objekt transmittiert werden, detektiert, um reflektierte Akustikwellendaten zu erzeugen, und

wobei die Akustikwelleneinheit (12) weiterhin ein Akustikwellen-Bilderzeugungsmittel enthält, das ein Akustikwellenbild auf Basis der reflektierten Akustikwellendaten erzeugt.

Revendications

1. Appareil de génération d'image photoacoustique (10), comprenant :

une unité de source laser (13) configurée pour émettre séquentiellement une pluralité de faisceaux laser à impulsions suivant une séquence de longueurs d'ondes prédéterminée présentant au moins deux longueurs d'onde différentes, l'unité de source laser incluant un barreau laser (51), une source de lumière d'excitation (52) configurée pour irradier le barreau laser avec une lumière d'excitation, un résonateur optique présentant une paire de miroirs (53, 54) se faisant face, le barreau laser étant intercalé entre ceux-ci, un commutateur Q (55) introduit

- dans le résonateur optique, et un filtre biréfringent (56) introduit dans le résonateur optique et configuré pour modifier une longueur d'onde d'oscillation du résonateur optique en association avec un déplacement en rotation du filtre biréfringent, et
- une unité d'ondes acoustiques (12), configurée pour générer une image photoacoustique, l'unité d'ondes acoustiques incluant un moyen de détection configuré pour détecter un signal photoacoustique généré dans un objet lorsque l'objet est irradié avec le faisceau laser à impulsions présentant chaque longueur d'onde incluse dans la séquence de longueurs d'ondes prédéterminée, et pour générer des morceaux de données photoacoustiques correspondant aux longueurs d'onde respectives ; un moyen d'extraction de rapport d'intensité, configuré pour extraire une relation de grandeur entre des intensités de signal relatives des morceaux de données photoacoustiques correspondant aux longueurs d'onde respectives ; un moyen de construction d'image photoacoustique (29), configuré pour générer l'image photoacoustique sur la base de la relation de grandeur extraite, et un circuit de commande de déclenchement (30), configuré pour provoquer l'irradiation du barreau laser avec une lumière d'excitation à partir de la source de lumière d'excitation tout en faisant tourner le filtre biréfringent à une vitesse de rotation prédéterminée en fonction du nombre de longueurs d'ondes incluses dans la séquence de longueurs d'onde, et après irradiation avec la lumière d'excitation, pour allumer le commutateur Q sur une temporisation lorsqu'une position de déplacement en rotation du filtre biréfringent est réglée sur une position correspondant à la longueur d'onde du faisceau laser à impulsions à émettre afin de provoquer l'émission du faisceau laser à impulsions,
- dans lequel le circuit de commande de déclenchement (30) est configuré pour faire tourner en continu le filtre biréfringent (56) dans une direction prédéterminée à la vitesse de rotation prédéterminée.
2. Appareil de génération d'image photoacoustique (10) selon la revendication 1, dans lequel la vitesse de rotation prédéterminée est déterminée sur la base d'une caractéristique de modification de la longueur d'onde d'oscillation par rapport à la position de déplacement en rotation dans le filtre biréfringent, au nombre de longueurs d'onde incluses dans la séquence de longueurs d'onde, et au nombre de fois pour l'émission du faisceau laser à impulsions par unité de temps.
 3. Appareil de génération d'image photoacoustique (10) selon la revendication 1 ou 2, dans lequel le nombre de fois pour un domaine spectral libre répété durant une rotation est réglé sur k [fois/rotation], le nombre de longueurs d'onde incluses dans la séquence de longueurs d'onde est réglé sur n [morceaux], le nombre de fois pour l'émission du faisceau laser à impulsions par unité de temps est réglé sur m [fois/secondes], et la vitesse de rotation prédéterminée du filtre biréfringent est déterminée comme une valeur calculée par une relation telle que $v = m/(k \times n)$ [rotations/seconde].
 4. Appareil de génération d'image photoacoustique (10) selon l'une quelconque des revendications 1 à 3, dans lequel le circuit de commande de déclenchement (30) détermine une temporisation sur laquelle la lumière d'excitation est irradiée et une temporisation sur laquelle le commutateur Q (55) est allumé, sur la base d'informations d'état de filtre biréfringent indiquant la position de déplacement en rotation du filtre biréfringent (56).
 5. Appareil de génération d'image photoacoustique (10) selon la revendication 4, dans lequel lorsque les informations d'état de filtre biréfringent sont réglées sur des informations indiquant une position obtenue en soustrayant la quantité de déplacement en rotation du filtre biréfringent (56) durant une période de temps requise pour l'excitation du barreau laser (51) à partir d'une position du filtre biréfringent, laquelle correspond à la longueur d'onde du faisceau laser à impulsions à émettre, le circuit de commande de déclenchement (30) provoque l'irradiation du barreau laser avec la lumière d'excitation.
 6. Appareil de génération d'image photoacoustique (10) selon la revendication 4 ou 5, dans lequel le circuit de commande de déclenchement (30) fait tourner le filtre biréfringent (56) de telle sorte que la quantité de modification des informations d'état de filtre biréfringent durant une période de temps prédéterminée est réglée sur la quantité de modification en fonction de la vitesse de rotation prédéterminée.
 7. Appareil de génération d'image photoacoustique (10) selon l'une quelconque des revendications 1 à 5, dans lequel l'unité de source laser (13) inclut en outre un moyen d'entraînement (57), lequel fait tourner le filtre biréfringent (56), un moyen de détection de déplacement en rotation (58), lequel détecte le déplacement en rotation du filtre biréfringent, et une unité de commande de rotation (59), laquelle commande le moyen d'entraînement de sorte que la quantité de déplacement en rotation détectée par le moyen de détection de déplacement en rotation durant une période de temps prédéterminée est réglée sur une quantité dépendant de la vitesse de rotation prédéterminée.

8. Appareil de génération d'image photoacoustique (10) selon l'une quelconque des revendications 1 à 7,

dans lequel l'unité d'ondes acoustiques (12) inclut en outre un moyen d'extraction d'informations d'intensité (27), lequel génère des informations d'intensité indiquant une intensité de signal sur la base des morceaux de données photoacoustiques correspondant aux longueurs d'onde respectives, et
 dans lequel le moyen de construction d'images photoacoustiques (29) détermine une valeur de gradation de chaque pixel de l'image photoacoustique sur la base des informations d'intensité, et détermine une couleur d'affichage de chaque pixel sur la base de la relation de grandeur extraite.

9. Appareil de génération d'image photoacoustique (10) selon la revendication 8, dans lequel

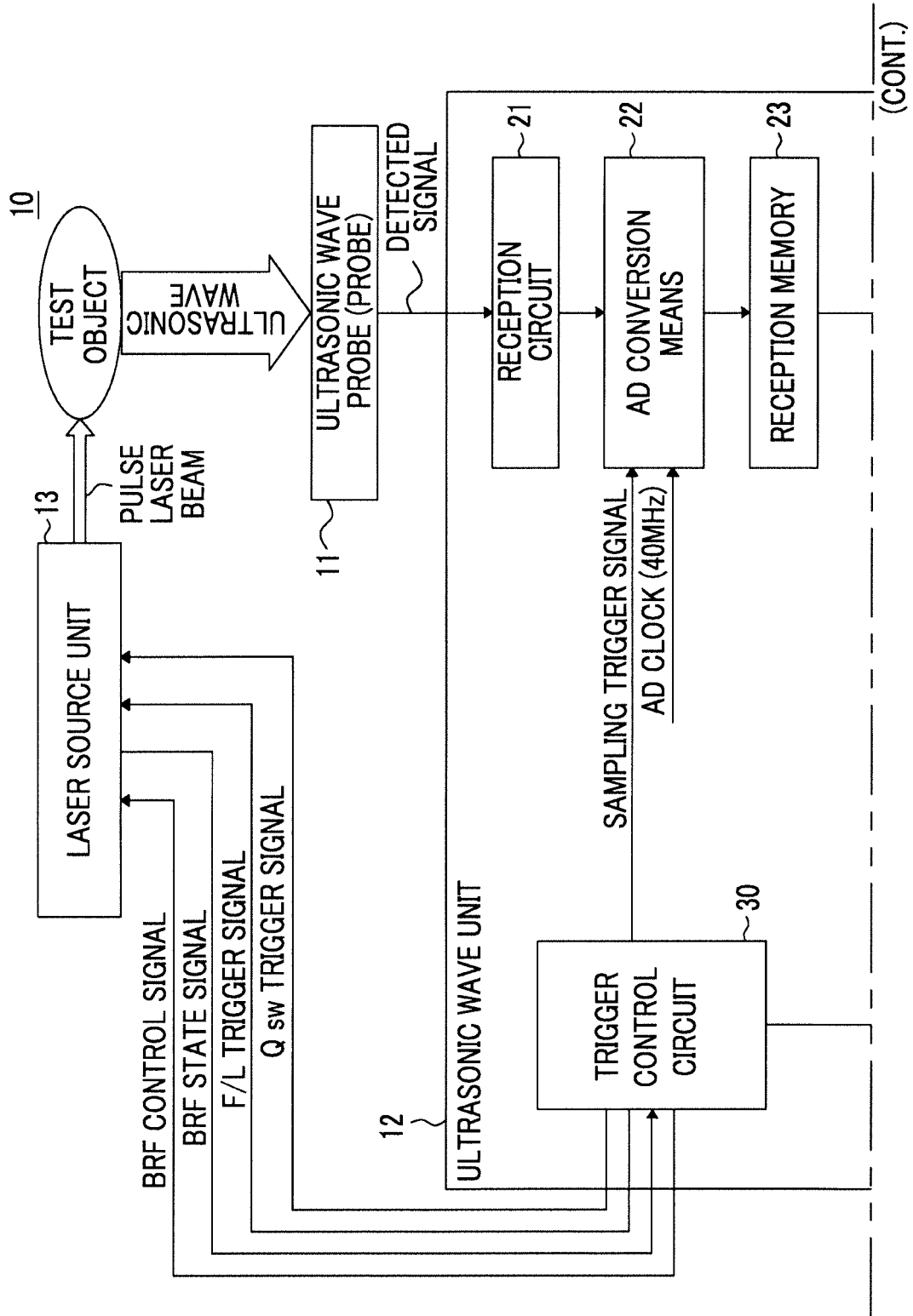
la séquence de longueurs d'onde prédéterminée inclut une première longueur d'onde et une seconde longueur d'onde,
 dans lequel l'unité d'ondes acoustiques (12) inclut en outre un moyen de création de nombre complexe, lequel génère des données de nombre complexe, où des données parmi des premières données photoacoustiques correspondant à un signal photoacoustique, détectées lors de la réalisation de l'irradiation avec le faisceau laser à impulsions présentant la première longueur d'onde, et des secondes données photoacoustiques correspondant à un signal photoacoustique, détectées lors de la réalisation de l'irradiation avec le faisceau laser à impulsions présentant la seconde longueur d'onde, sont réglées sur une partie réelle, et les autres données sont réglées sur une partie imaginaire, ainsi qu'un moyen de reconstruction d'image photoacoustique, lequel génère une image reconstruite à partir de données de nombre complexe à l'aide d'une méthode de transformée de Fourier, et
 dans lequel le moyen d'extraction de rapport d'intensité extrait des informations de phase comme relation de grandeur à partir de l'image reconstruite, et le moyen d'extraction d'informations d'intensité extrait les informations d'intensité de l'image reconstruite.

10. Appareil de génération d'image photoacoustique (10) selon l'une quelconque des revendications 1 à 9,

dans lequel le moyen de détection détecte en outre des ondes acoustiques réfléchies par rap-

port à des ondes acoustiques transmises à l'objet pour générer des données d'ondes acoustiques réfléchies, et
 dans lequel l'unité d'ondes acoustiques (12) inclut en outre un moyen de génération d'image d'ondes acoustiques, lequel génère une image d'ondes acoustiques sur la base des données d'ondes acoustiques réfléchies.

FIG. 1



(FIG.1 Continued)

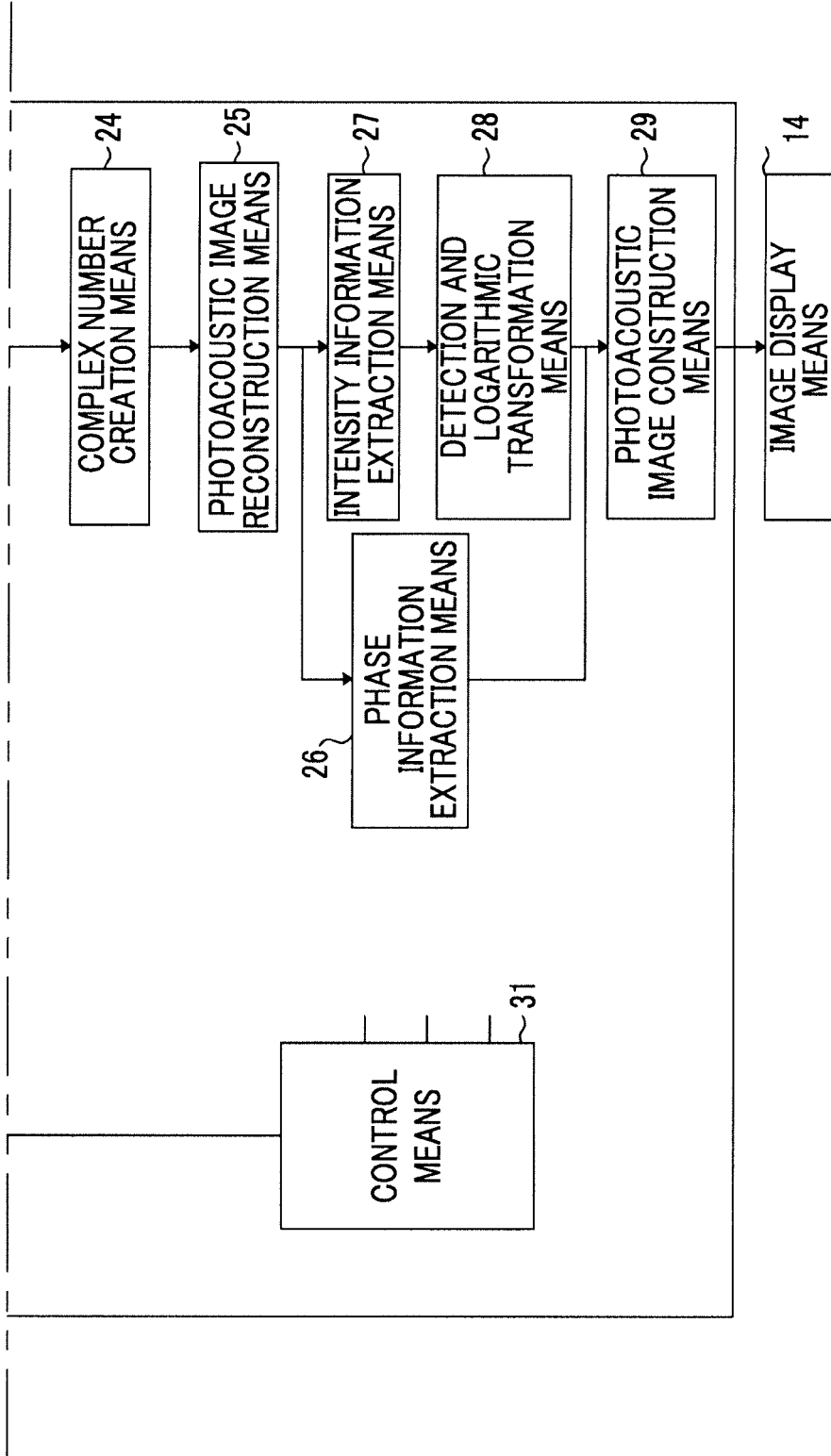


FIG. 2

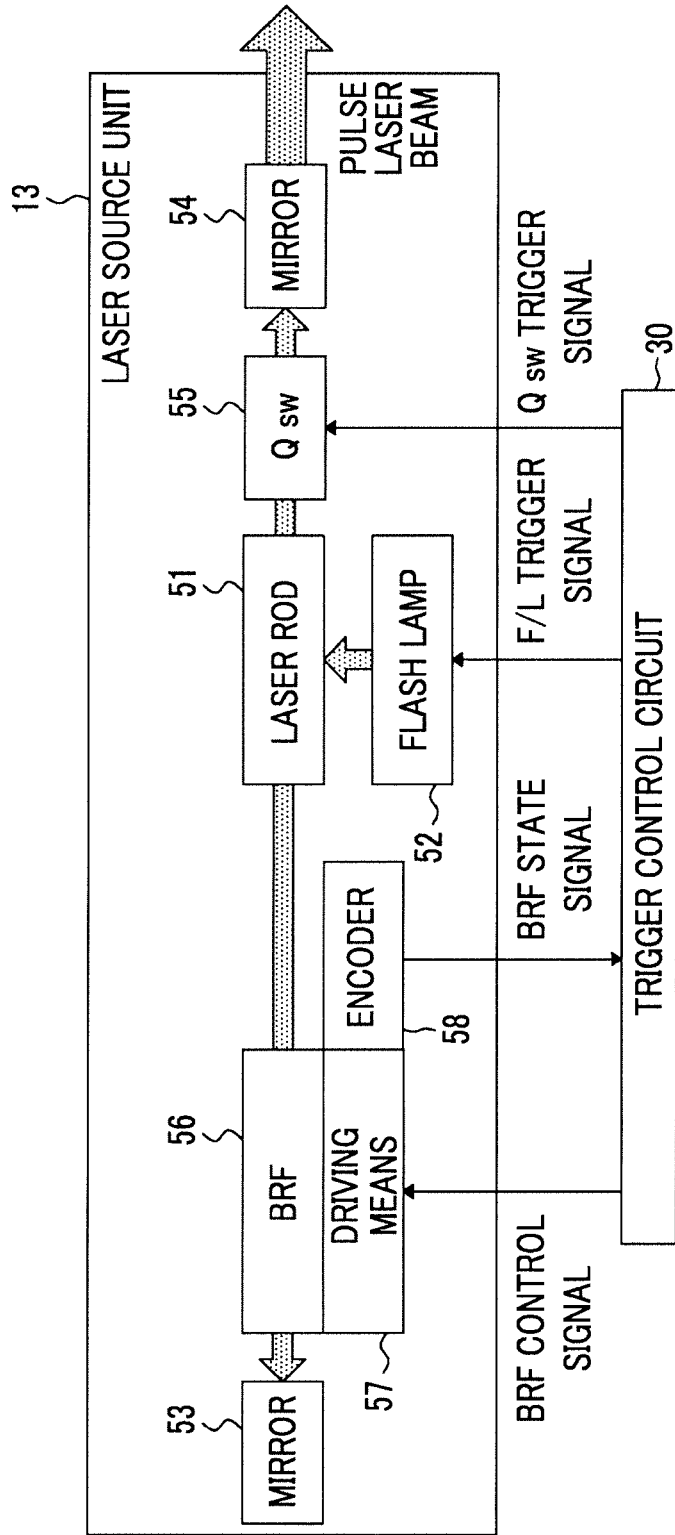


FIG. 3

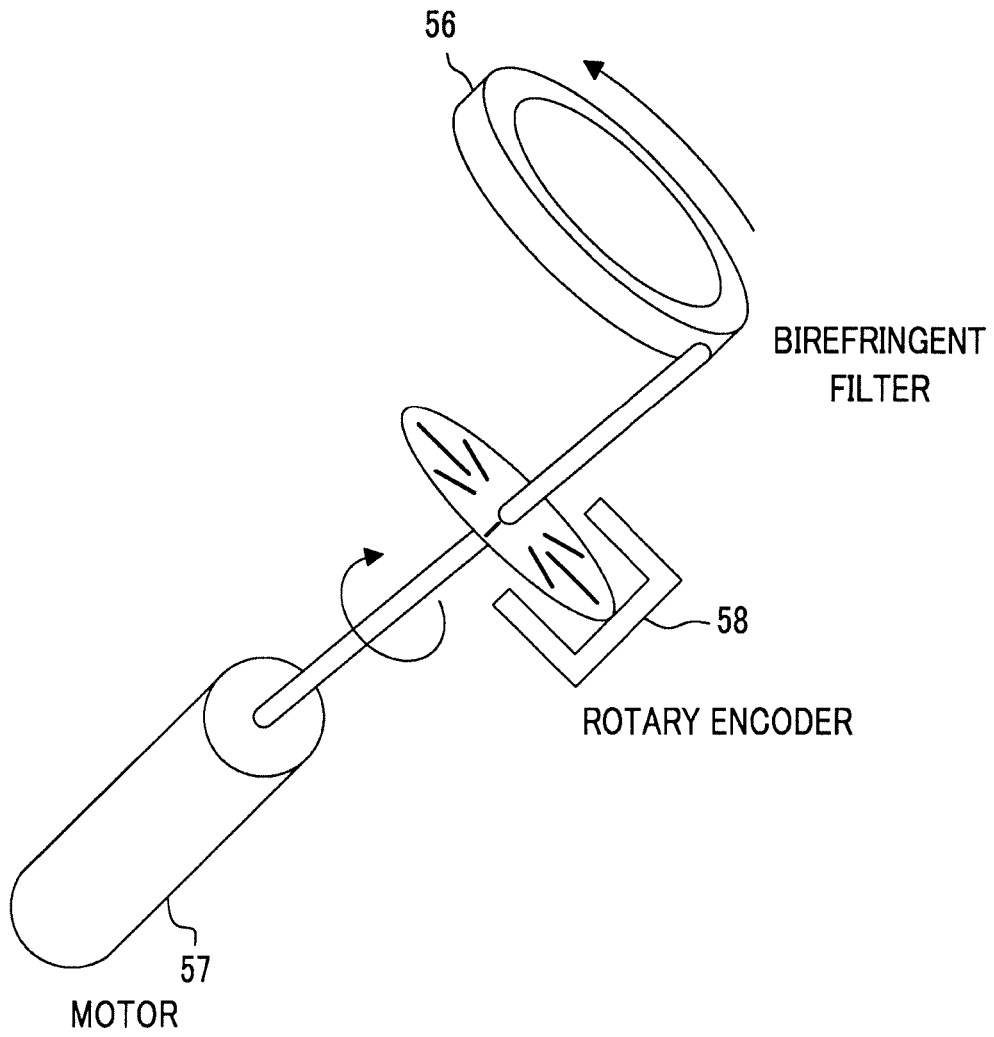


FIG. 4

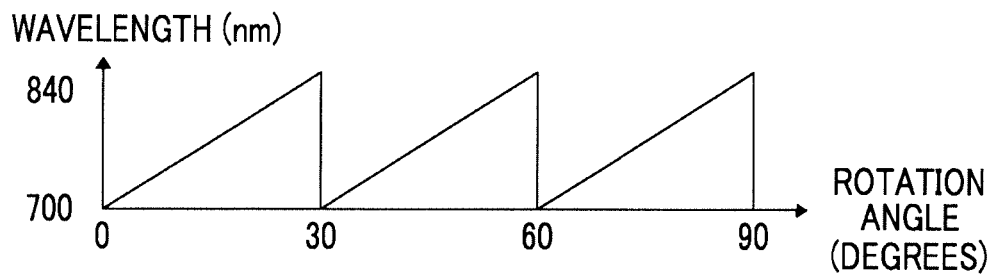


FIG. 5

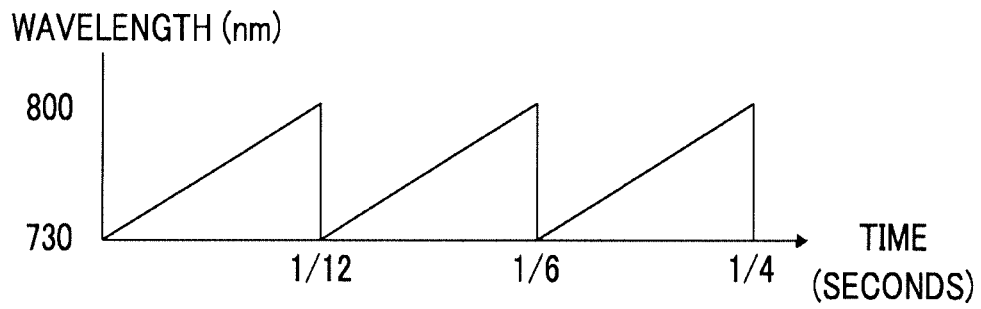


FIG. 6

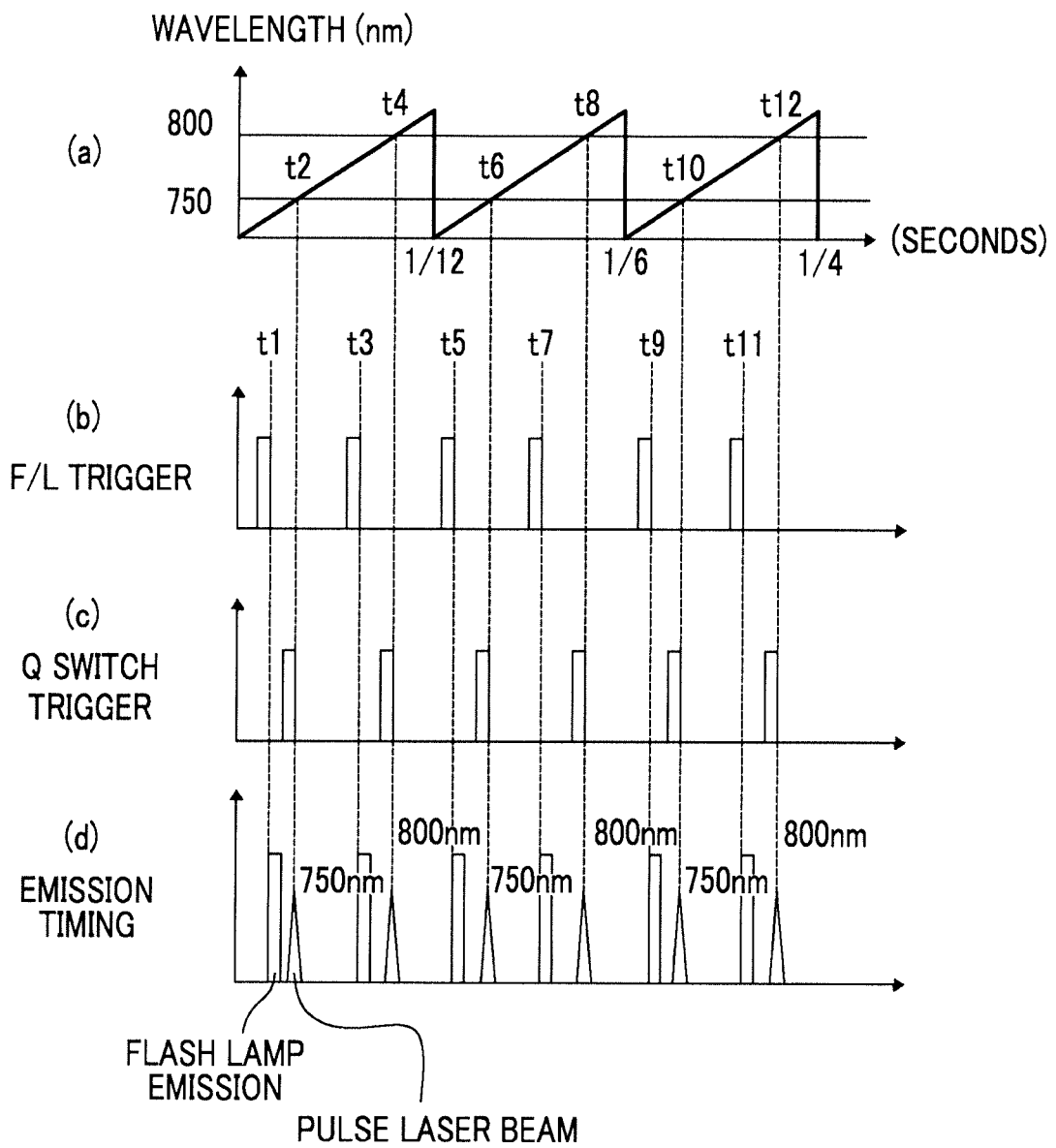


FIG. 7

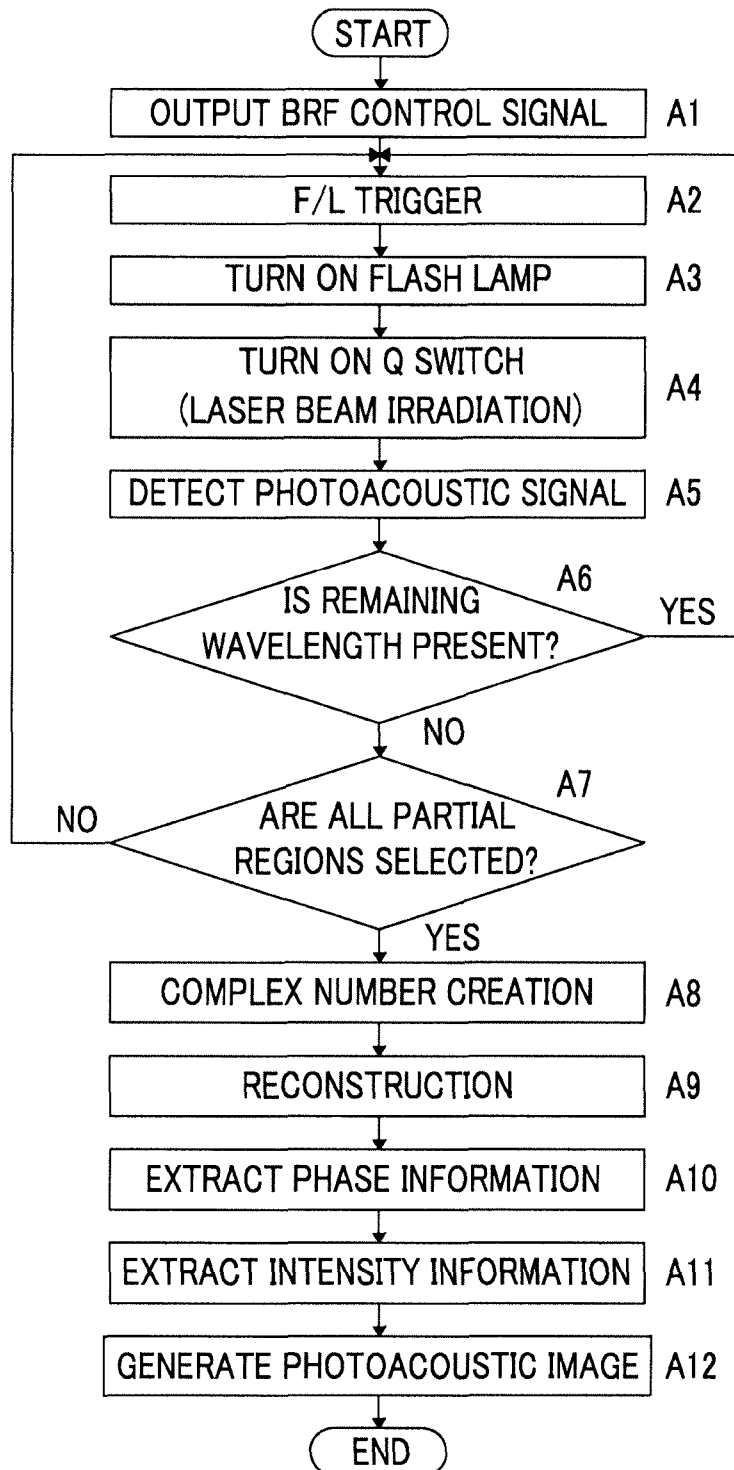


FIG. 8

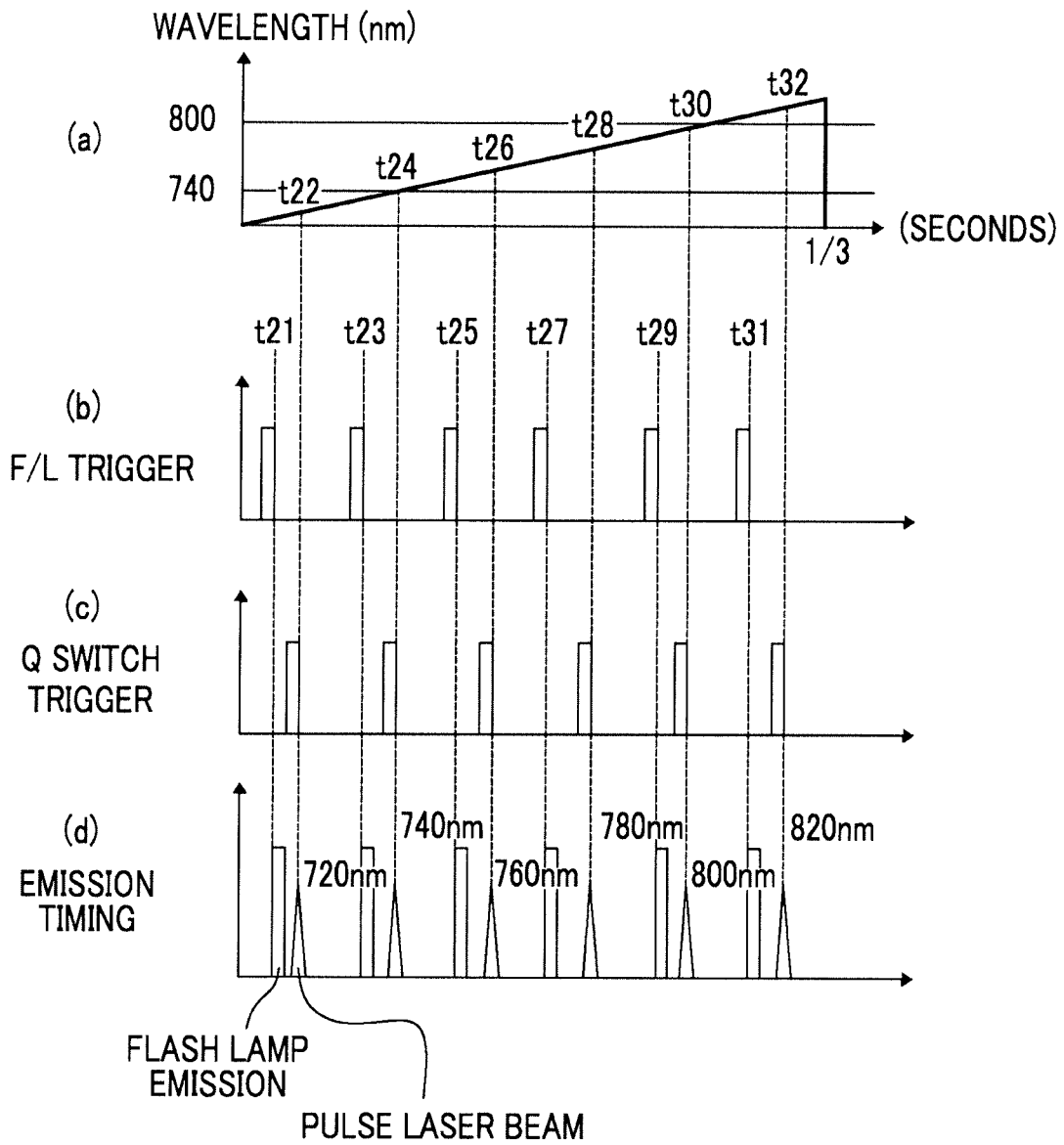
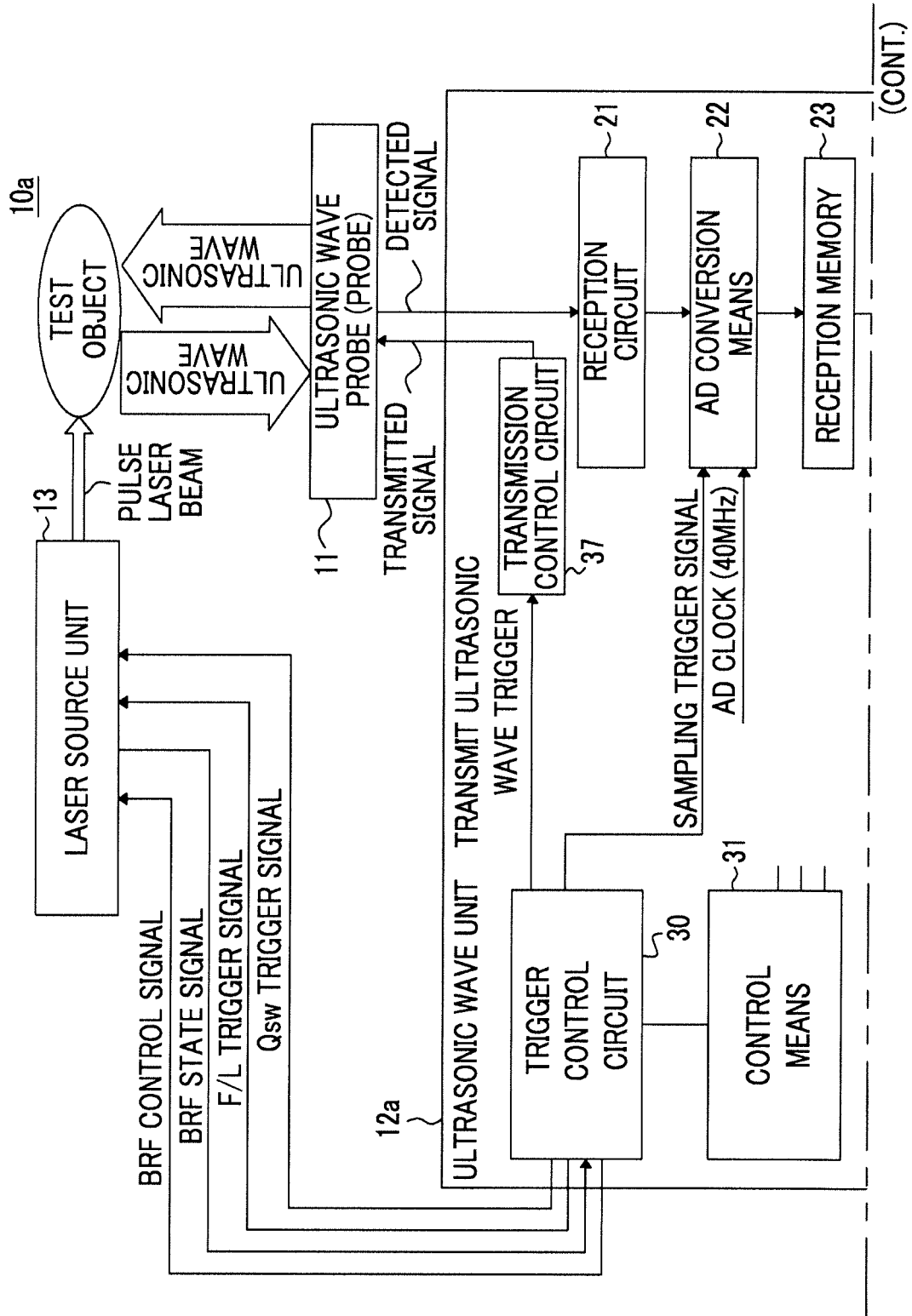


FIG. 9



(FIG.9 Continued)

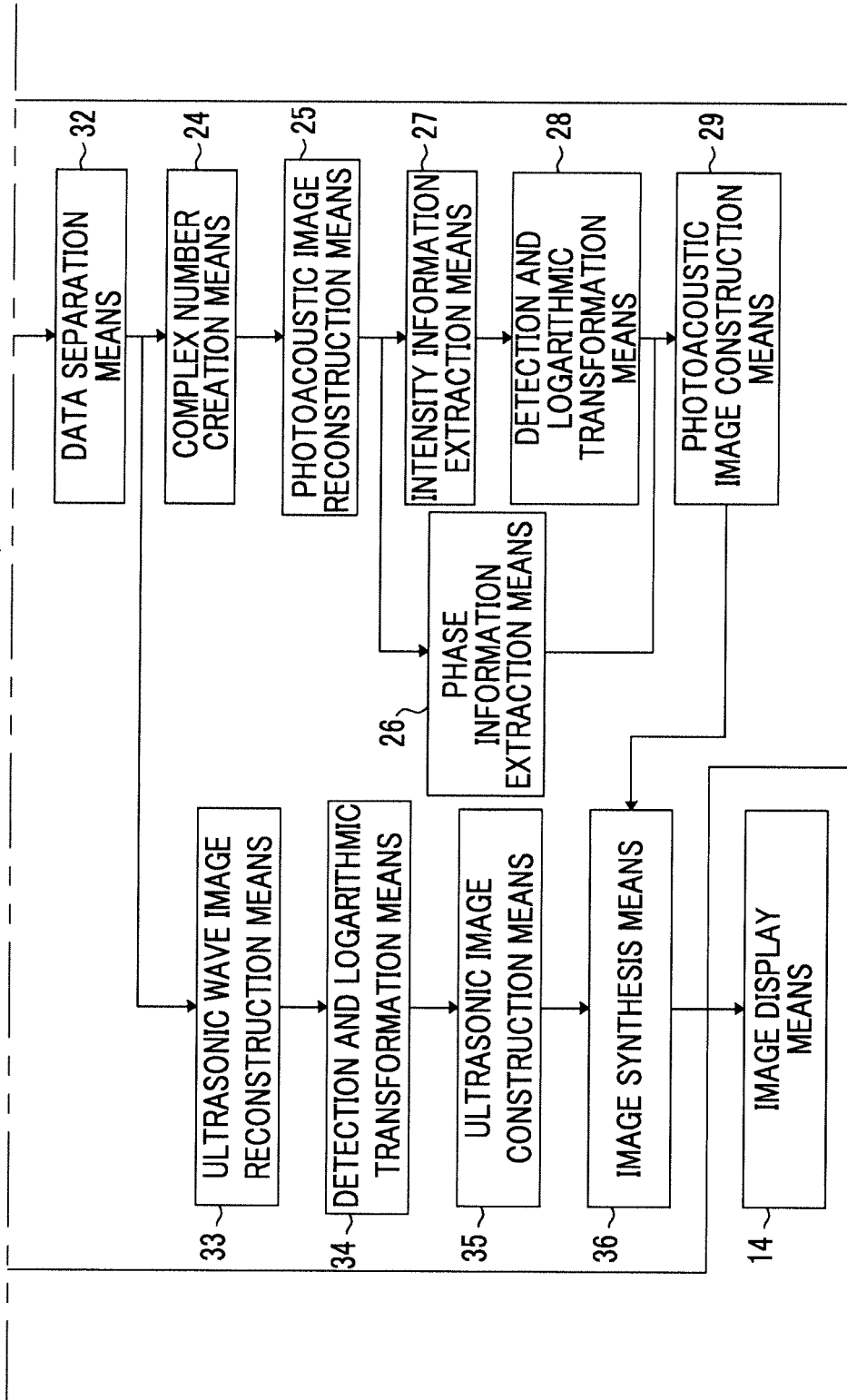
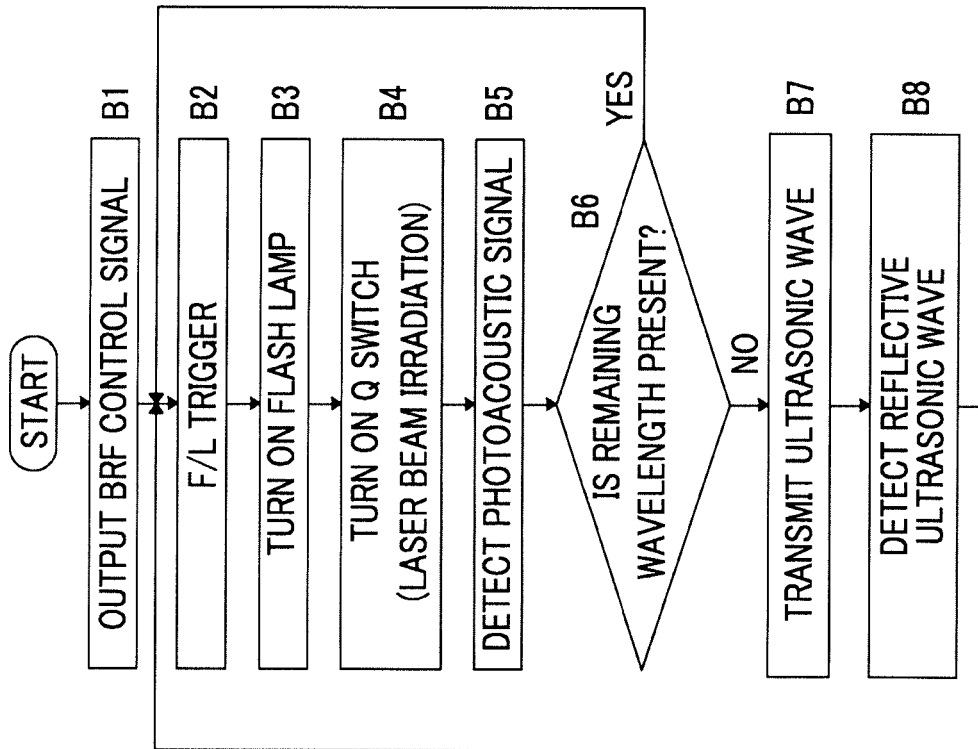


FIG. 10



(CONT.)

(FIG.10 Continued)

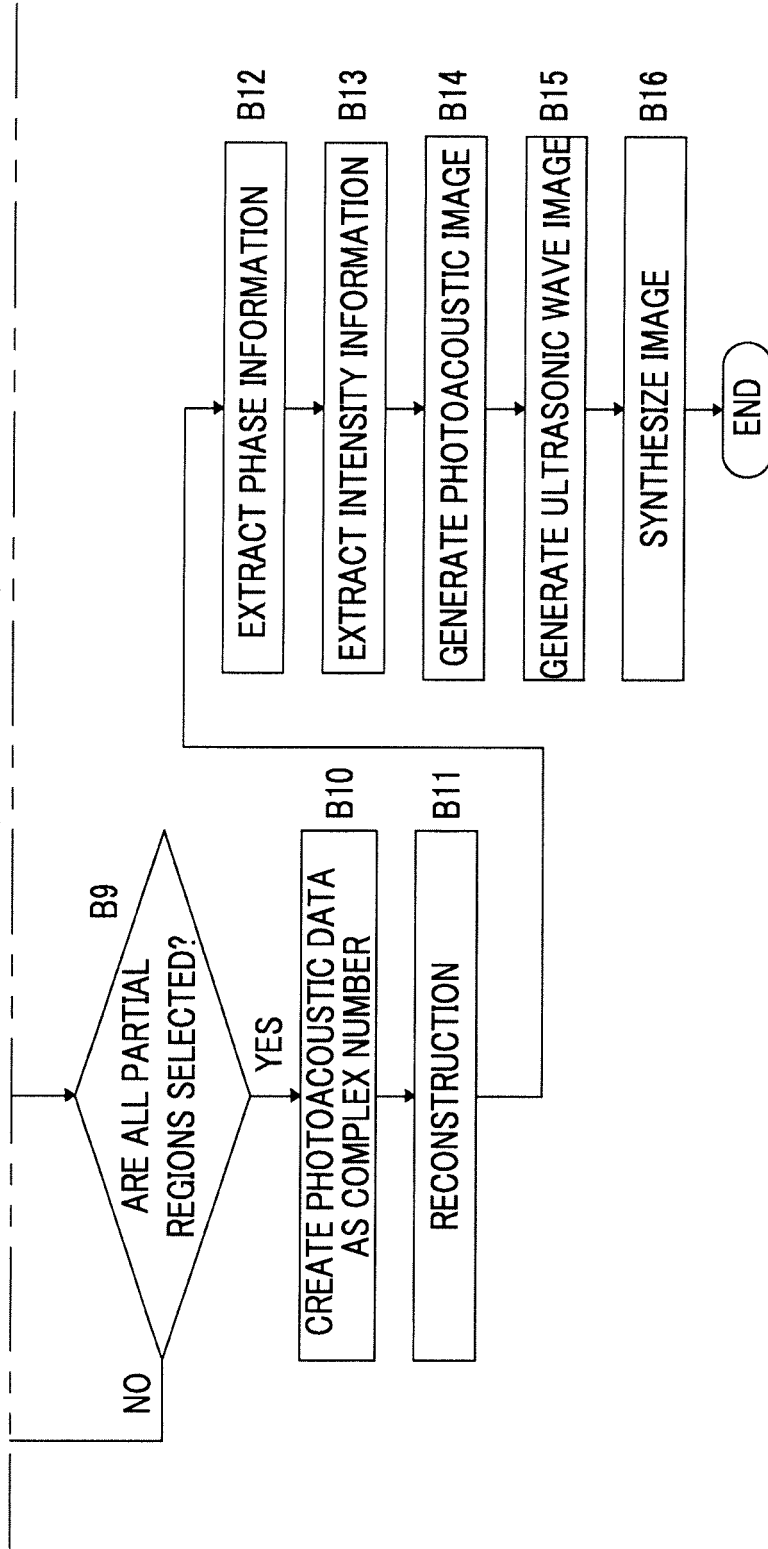


FIG. 11

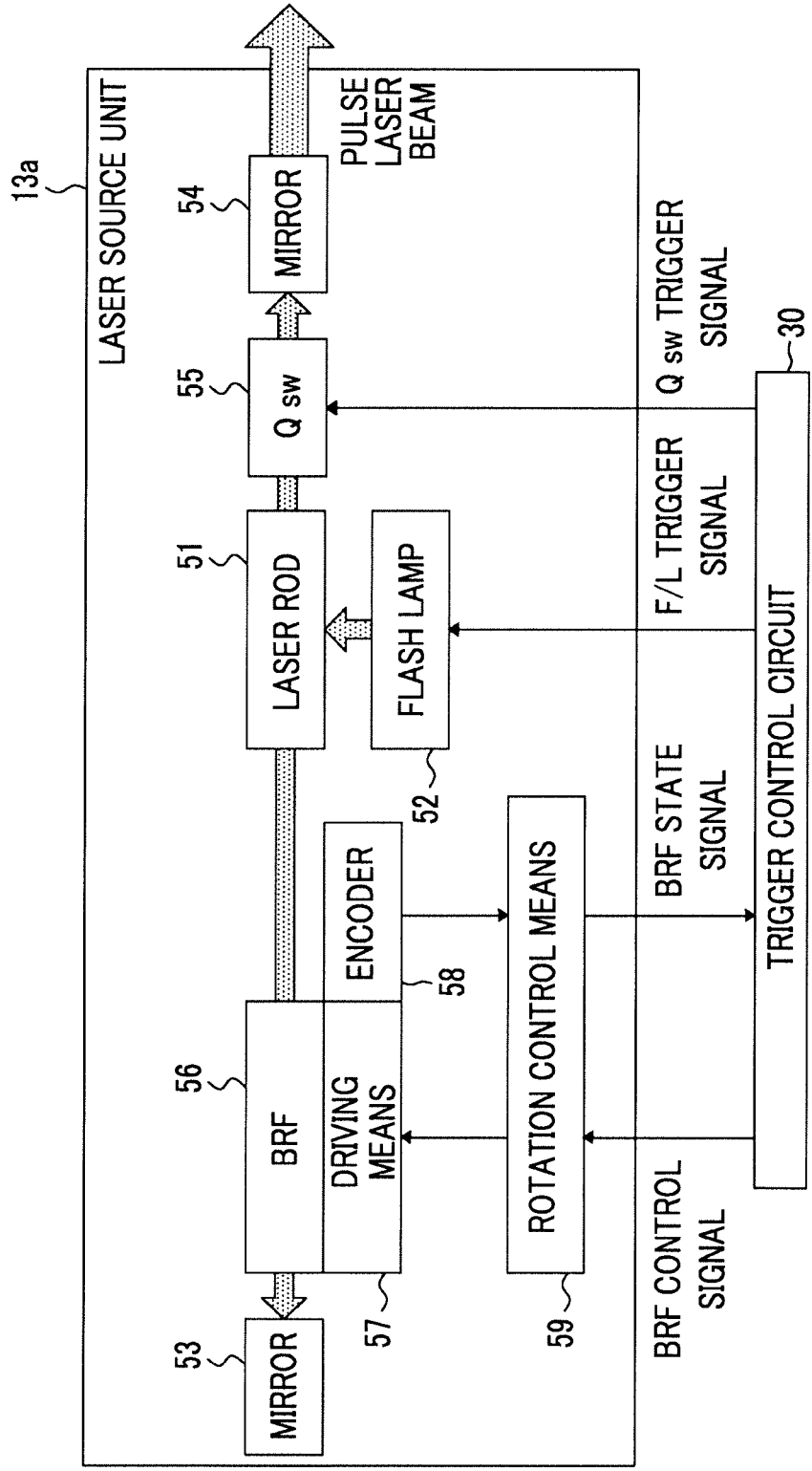
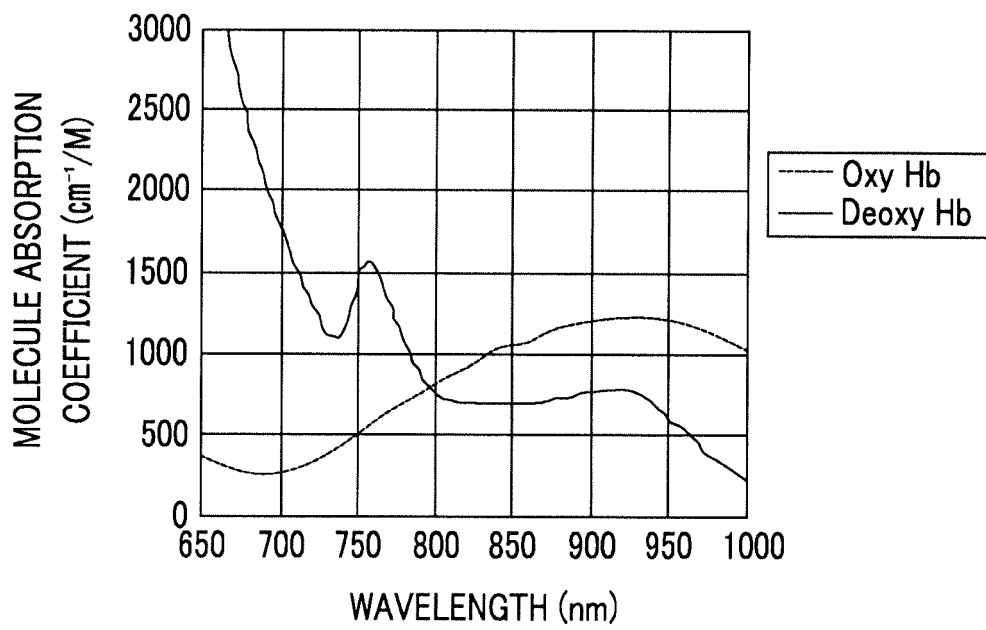


FIG. 12



REFERENCES CITED IN THE DESCRIPTION

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- **JONATHAN I. SPERL et al.** Photoacoustic Image Reconstruction-A Quantitative Analysis. *SPIE-OSA*, vol. 6631, 663103 [0028]

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摘要(译)

使用激光源单元以期望的波长序列发射脉冲激光束。将Q开关和双折射滤光器插入到包括一对反射镜并且彼此面对并且隔着激光棒彼此面对的光学谐振器中。双折射滤光器与旋转位移相关联地改变光学谐振器的振荡波长。触发控制电路根据要发射的脉冲激光束的波长序列中包括的波长的数量，以预定的旋转速度旋转双折射滤光片。另外，触发控制电路以激发光照射激光棒，并且在双折射滤光器的旋转位移位置被设置为与要发射的脉冲激光束的波长相对应的位置的时刻使Q开关导通。导致脉冲激光束发射。

