

Laser Processing Device

Background of the Invention:

The present invention relates to the "giant pulse" technology of a laser-processing device, and more particularly to the control of first pulses of Q-switched laser oscillator output.

Laser-processing devices employing a solid-state laser light generated under Q-switch control include laser trimming devices and laser marking devices. The semiconductors and electrical components that account for a greater part of the objects to be processed by such devices have become of lighter-weight and smaller-size as data terminal equipment such as mini-disks (MD), digital video cameras (DVC), and portable telephones become increasingly compact. Price rates of these objects also are dropping as a consequence of current price competition.

In view of this situation, there is a demand for higher-speed processing to improve the productivity of laser processing devices. However, the Q-switch frequency for obtaining laser light of the optimum peak value for processing varies depending on the excitation method of the laser oscillator (for example, the lamp excitation method or laser diode excitation method) or the resonator constitution, even when the oscillation wavelength is the same.

In particular, in Q-switched solid-state laser oscillators, there is the problem of the excessive peak value of the first pulse, i. e., the first shot after suspension of

processing.

This problem occurs for the following reasons: When the time of storing light energy, referred to as "the excitation period," lasts for long duration due to, for example, the suspension of processing, the energy density stored in the laser medium attains a saturated value. When Q-switch laser oscillation of a short period is effected under these circumstances, energy that has attained the saturated value is discharged in the first pulse. Each of the laser pulses that are emitted following this first pulse, however, discharges the energy that has been stored in each excitation period of the short period and has not attained the saturated value. As a result, the peak value of the first pulse, which is discharged after the energy density has attained the saturated value, is higher than the peak value of laser pulses that are discharged before the energy density has attained the saturated value.

Fig. 1 is a block diagram of the principal components of a Q-switched oscillator according to a typical example of the prior art. Computer 1 provides control unit 2 with: Q-switch ON/OFF timing data as I/O data (data that designate the timing for irradiating the object to be processed with laser pulses), i.e., a processing period (the time of irradiating the object to be processed with a series of laser pulses), the Q-switch frequency, and the pulse width of the Q-switch frequency pulse. Control unit 2 generates Q-switch control pulse signals corresponding to the I/O data and provides the signals to Q-switch driver 4. Q-switch unit 8, which is provided in optical

resonator 7 of laser oscillator 6, is turned ON and OFF in response to the received pulse signals.

In the above description, turn-ON of Q-switch unit 8 refers to rapid reduction in the Q value of the optical resonator, thereby suppressing laser oscillation. Conversely, the Q value of the optical resonator returns to the normal value when the Q-switch unit is in the OFF state, whereby normal laser oscillation occurs.

When the Q-switch unit is switched over from the ON state to the OFF state, the light energy that has stored in the laser medium during the ON state of the Q-switch unit 8 is abruptly discharged, and a laser pulse having a high peak value is therefore emitted. This laser pulse of a high peak value is referred to as a "giant pulse" (refer to Fig. 3 described hereinbelow).

Fig. 2 is a block diagram showing the constitution of laser control unit 3 provided in control unit 2 of Fig. 1. Laser control unit 3 is provided with decoder 12, programmable frequency divider circuit 13, reference clock oscillator 15, and timer circuit 16.

Decoder 12 decodes I/O data supplied from computer 1. Programmable frequency divider circuit 13 frequency-divides the reference clock signal received from reference clock oscillator 15 and generates a Q-switch frequency pulse (period T_3) of the frequency designated by the decoded I/O data. Timer circuit 16 receives the Q-switch frequency pulse and supplies a Q-switch control pulse of pulse width T_4 to Q-switch driver

4.

Fig. 3 is a timing chart illustrating the timing of launch of laser pulses. In the example of this figure, the Q-switch unit 8 has been in an ON state for a period longer than Q-switch period T_3 before input of the first Q-switch control pulse to Q-switch unit 8, thereby causing light energy to be stored in the laser medium up to achievement of a saturated state.

When the first Q-switch control pulse is applied to Q-switch unit 8 at time t_0 , the suppression of oscillation of the oscillator is released and the light energy that has built up to a saturated state during the long excitation period is abruptly released and emitted as a giant pulse. The first giant pulse following a long excitation period is referred to as a "first pulse."

After the first pulse has been launched, the excitation time period $\#T_1$ until reception of the next Q-switch control pulse is relatively short, and in cases in which the light energy stored in the laser medium during this period $\#T_1$ does not attain the saturated value, the peak values of succeeding giant pulses are lower than the peak value of the first pulse. Since the Q-switch control pulses are supplied to Q-switch unit 8 at a fixed time interval after time t_0 , causing excitation periods of the same duration, giant pulses of the same peak value are launched beginning with the second giant pulse. The discrepancy in the pulse height between the first pulse and the following giant pulses ordinarily entails undesired non-uniform processing.

Laser processing devices and methods such as described in Japanese Patent Laid-open No. 354876/99 (hereinbelow referred to as "Reference 1") have been adopted to eliminate the problem that the generation of first pulses of an excessive pulse height prevents processing under ideal conditions.

To suppress the first pulse, the device of Reference 1 is provided with a first pulse suppression control circuit and a light energy discharge pulse generation circuit. The first pulse suppression control circuit gradually changes a Q-switch control pulse (command switch pulse) so as to discharge the light energy that has stored in the laser medium before processing or during suspension of processing. The light energy discharge pulse generation circuit controls the Q-switch such that light energy that remains yet in the end of the discharge is completely discharged.

This device is capable of suppressing first pulses. However, because it requires a preparation time for effecting discharge of the light energy stored in the laser medium, it has problems such as the inability to process at maximum speed due to the preparation time for eliminating the first pulses.

The laser processing device disclosed in Japanese Patent Laid-open No. 313145/98 (hereinbelow referred to as "Reference 2") is configured such that: the laser medium and polarization beam splitter are arranged as common parts; a laser resonator is arranged for each of the beams split by the polarization beam splitter; and Q-switch elements are arranged on the optical axes of each of these two laser resonators with the Q-switch elements

being independently ON/OFF controlled.

The feature of this laser-processing device resides in the separated and independent acquisition of the laser output of each laser resonator by independently controlling the Q-switch elements of each of the two laser resonators that have a common laser medium. Accordingly, the first laser resonator can be oscillated by the first pulse of a Q-switch pulse train of any Q-switch frequency, and the second laser resonator can be oscillated by the Q-switch pulse train that follows the first pulse. Thus, using only the output of the second laser resonator allows a giant pulse train to be obtained in which the first pulse has been eliminated.

This method, however, has the problems of complex configuration and high price.

A method that differs from the first-pulse control method of the above-described laser processing devices of the prior art is disclosed in Japanese Patent Application 2000-174490, which was filed by the present inventor. This method constitutes the preceding basis of the present invention and is therefore explained in detail below. This reference is referred to as "Reference 3" in the following description.

This preceding art differs from the previously described prior art in that the Q-switch unit is turned OFF and a continuous oscillation state is maintained during a prescribed period between the emission times of two successive giant pulses in order to prevent storage of light energy in the laser medium. Following the passage of this continuous oscillation period,

the Q-switch unit is turned ON and light energy is stored during a period until the start of the next OFF period of the Q-switch; and in that an optical switch for opening and closing the optical path is provided on the optical path of laser pulses outside the laser oscillator between the laser oscillator and the object to be processed.

Fig. 4 is a block diagram for illustrating the construction of the laser output device described in Reference 3.

Laser output device 30 is provided with: computer 38, measurement unit 35, Q-switch driver 33, optical switch driver 34, laser oscillator 31, and optical switch unit 32. Computer 38 supplies I/O data to measurement unit 35. I/O data include not only timing data for turning the Q-switch unit ON and OFF (the pulse frequency and pulse width of a pulse that controls the Q-switch) but timing data for opening and closing optical switch unit 32 (the pulse frequency and pulse width of pulses that control optical switches). Measurement unit 35 generates a Q-switch control pulse and an optical switch control pulse based on the I/O data. Q-switch driver 33 effects ON/OFF control of Q-switch unit 11a provided in optical resonator 11b of laser oscillator 31 in accordance with the Q-switch control pulse. Optical switch driver 34 performs ON/OFF control of optical switch unit 32 in accordance with the optical switch control pulse.

Fig. 5 is a block diagram showing the construction of measurement unit 35, and Fig. 6 is a timing chart of signals illustrating the operation of the device of Reference 3.

Measurement unit 35 is provided with measurement comparison/decision unit 17 and laser control unit 26.

Measurement comparison/decision unit 17 measures the amount of processing of the object to be processed, compares these measurement values with target values, determines whether or not prescribed processing has been attained, and when prescribed processing has not been achieved (when additional laser pulse irradiation is necessary), provides a (logic 1) pulse signal indicating this fact (necessity of the additional laser irradiation) as a determination result to laser control unit 26.

Laser control unit 26 is provided with decoder 20, programmable frequency divider circuit 21, reference clock oscillator 22, logic circuit 23, timer circuit 24, and programmable timer circuit 25.

Decoder 20 decodes I/O data for the control signals of Q-switch unit 11a and optical switch unit 32, received from computer 38, and provides the decoded I/O data to programmable frequency divider circuit 21 and programmable timer circuit 25.

Programmable frequency divider circuit 21 receives the reference clock signals generated by reference clock oscillator 22, frequency-divides the reference clock signals based on the I/O data and generates a Q-switch frequency pulse (Fig. 6(A)), and supplies the Q-switch frequency pulse to logic circuit 23. The frequency-division ratio at this time can be modified as appropriate.

Logic circuit 23 receives the Q-switch frequency pulse

from programmable frequency divider circuit 21 and also receives the determination results from measurement comparison/decision unit 17, generates the AND of the two input signals and supplies the AND signal to both timer circuit 24 and programmable timer circuit 25. This AND signal is rendered as a pulse signal synchronized with the Q-switch frequency pulse in case that additional laser pulse irradiation of the object to be processed is required. There is no output of signals from logic circuit 23, however, when additional laser pulse irradiation of the object is not required.

Based on the output signals from logic circuit 23, timer circuit 24 provides, as a laser emission command signal to optical switch driver 34, an optical switch pulse of a set pulse width T_4 synchronized with Q-switch frequency pulse (Fig. 6(E)).

Based on each of the signals from decoder 20, reference clock oscillator 22 and logic circuit 23, programmable timer circuit 25 supplies to Q-switch driver 33 a Q-switch pulse of pulse width T_1 designated by the decoded I/O data synchronized with the output signal of logic circuit 23 with the reference clock signal as the timing signal (Fig. 6(B)). In the example shown in Fig. 6, the interval T_1 of logic 1 of the Q-switch pulse corresponds to the ON interval of the Q-switch, i.e., the interval in which oscillation of the laser oscillator is suspended. This interval thus becomes the excitation period (or the pumping interval), and light energy accumulates in the laser medium. Stimulated emission occurs abruptly with the fall of

the Q-switch pulse, the accumulated energy is discharged, and a giant pulse is emitted (Fig. 6 (C) and (D)). The peak value of the giant pulse accordingly increases if the excitation period T_1 is lengthened. Thus, making the pulse width of the Q-switch pulse variable enables variation of the height of the giant pulse.

A continuous oscillation state is maintained in intervals of logic 0 of the Q-switch pulse and low-level sustained oscillation that corresponds to an oscillation threshold level is effected (Fig. 6 (C) and (D)). This sustained oscillation prevents the light energy from accumulating to the saturated value in the laser medium and thus solves the problem of the first pulse in the prior art.

Optical switch unit 32 blocks the laser light of this sustained oscillation so that the object to be processed is not irradiated. Optical switch unit 32 opens in interval T_4 in which a giant pulse is emitted in synchronization with the fall of the Q-switch pulse, and then closes until the next Q-switch period to block the laser light of the continuous oscillation.

As can be seen from the block diagram of Fig. 5, timer circuit 24 and programmable timer circuit 25 of the above-described device of Reference 3 operate entirely independently after receiving the output of logic circuit 23. The two circuits 24 and 25 are then "indirectly" synchronized by being individually synchronized with the Q-switch frequency pulse. To describe this process in more concrete terms, in Fig. 6, the trailing edge of the Q-switch pulse is synchronized to

the leading edge t_0 of the Q-switch frequency pulse, and, as shown in Fig. 6(E), the leading edge of the optical switch pulse is synchronized to the leading edge t_0 of the Q-switch frequency pulse, whereby the trailing edge of the Q-switch pulse (the starting time of the emission of a giant pulse) and the leading edge of an optical switch pulse (the starting time for turning ON the optical switch) are synchronized. However, if the necessity for the rise of an optical switch pulse to be simultaneous with the fall of a Q-switch pulse is taken into consideration, the method of indirect synchronization in this device cannot be considered ideal from the standpoint of control. This point is referred to hereinbelow as the first problem of the art of Reference 3.

In order to implement the indirect synchronization method in the device of Reference 3, the rise of the Q-switch pulse must precede the leading edge t_0 of a Q-switch frequency pulse exactly by time T_1 . For this purpose, the Q-switch pulse must rise after time T_2 measuring from the leading edge of the first Q-switch frequency pulse immediately preceding the second Q-switch frequency pulse associated with the Q-switch pulse of interest (see Fig. 6(B)). As a result, the emission of the first giant pulse is realized in synchronization with the second Q-switch frequency pulse. In other words, the first emission of a giant pulse is not performed in synchronization with the first Q-switch frequency pulse after a command to process, but is performed after a delay of one Q-switch period T_3 . This point is referred to hereinbelow as the second problem of the art of

Reference 3.

It is an object of the present invention to provide a laser processing device that remedies the above-described shortcomings of Reference 3, that solves the problem of first pulses with a simple construction and stable control, and moreover, that is capable of freely modifying the peak value of output laser pulses.

Summary of the Invention:

The laser processing device according to an aspect of the present invention is provided with:

a laser oscillator having an optical resonator provided with a Q-switch unit the operation of which is controlled by a Q-switch control pulse, said laser oscillator being checked from oscillation and storing optical energy through pumping when the Q-switch unit is turned ON, and performing oscillation as normal when the Q-switch unit is turned OFF under the control of the Q-switch control pulse;

an optical switch unit for transmitting or blocking laser light under the control of an optical switch pulse, said optical switch unit being arranged on the optical path between the laser oscillator and an object to undergo laser processing by laser pulses emitted from the laser oscillator;

a computer for supplying I/O data that designate: the start timing of laser processing; after the start timing of laser processing, the frequency of repetition at which the Q-switch

unit is caused to operate periodically; and the period in which the Q-switch is turned ON to designate a pumping period;

a control unit for generating: Q-switch frequency pulses having the frequency of repetition designated by the I/O data; Q-switch control pulses each having a first logic level to cause said Q-switch unit to turn ON and a second logic level to cause the Q-switch unit to turn OFF, and having a leading edge that exhibits a transition from the second logic level to the first logic level, a trailing edge that exhibits a transition from the first logic level to the second logic level wherein the leading edge of the Q-switch control pulses is synchronized with the trailing edges of the Q-switch frequency pulses in the period of each of the Q-switch frequency pulses, and a pulse width, i.e., the time duration between the leading edge and the trailing edge, that is equal to the period designated as a pumping period by the I/O data; and optical switch pulses, each having a first logic level to cause the optical switch to transmit laser light and a second logic level to cause the optical switch to block the laser light, and having the leading edge that exhibits a transition from the second logic level to the first logic level and a pulse width predetermined to be equal to the time duration of passing the laser light, the leading edge of the optical switch pulse being synchronized with the trailing edges of the Q-switch control pulses in the period of each of the Q-switch frequency pulses;

a Q-switch driver that receives the Q-switch control pulse for controlling the Q-switch unit in response to the Q-switch control pulse; and

an optical switch driver that receives the optical switch pulse for controlling the optical switch unit in response to the optical switch pulse.

According to one embodiment, "a control unit for generating optical switch pulses synchronized with the Q-switch control pulses" of this laser processing device may guarantee the direct synchronization of optical switch pulse to the Q-switch control pulse.

According to an alternative embodiment, the direct synchronization of the optical switch pulse and Q-switch control pulse may be realized specifically by the trailing edge of Q-switch control pulse being synchronized to the leading edge of optical switch pulse.

The first problem of the art of Reference 3 may thus be solved.

Furthermore, the second problem of Reference 3 may be solved by the function of the control unit of the present invention that "generates Q-switch control pulses that are synchronized with the Q-switch frequency pulses in each period of the Q-switch frequency pulses. In other words, the Q-switch control pulse may be synchronized with the Q-switch frequency pulse in the period of "each" of the Q-switch frequency pulses including the first Q-switch frequency pulse after the start time of laser processing.

Accordingly, the initial Q-switch control pulse may be generated synchronized with the initial Q-switch frequency pulse following the start timing of laser processing. As a

result, the start timing of laser processing or the first pulse following a period of suspension of laser processing may be generated synchronized to the first Q-switch frequency pulse.

This function of the control unit may be realized by the constitution "the leading edge of the Q-switch control pulse is synchronized with the trailing edge of Q-switch frequency pulse, and the trailing edge of the Q-switch control pulse is synchronized with the leading edge of the optical switch pulse". In other words, the Q-switch control pulse can be caused to rise in synchronization with the fall of the Q-switch frequency pulse. Accordingly, a laser pulse may be generated at the time shifted from the fall of each Q-switch frequency pulse by exactly the Q-switch control pulse width.

The problem of first pulses may be solved by the present invention as described hereinbelow.

The Q-switch control pulse that may be generated by the control unit of the present invention has a first logic level during the period designated as pumping intervals by I/O data and has a second logic level during the other period. The other period means the period other than the period designated as pumping intervals by I/O data.

Since the period before the start timing of processing or during suspension of processing is obviously included in "the other period, the Q-switch control pulse becomes the second logic level in the period before the start timing of processing or during suspension of processing. The Q-switch unit therefore continues in an OFF state in these periods, whereby the laser

oscillator maintains a continuous oscillation state. In this way, light energy can be prevented from accumulating in the laser medium before the start timing of processing or during suspension of processing.

As a result, the first pulse may be prevented from having a peak value that is higher than succeeding giant pulses.

Since the pulse width of the Q-switch control pulse generated by the first timer circuit may be programmable, the light energy that accumulates in the laser medium in a pumping interval is also programmable. The peak values of the generated giant pulses may therefore also be programmable.

A laser processing device that combines the features of both the device of Reference 3 and the laser processing device of the present invention may be created by adding the measurement comparison/decision unit of Reference 3 to the control unit of the laser processing device of the present invention and further adding the logic circuit of Reference 3 to the laser control unit of the laser processing device of the present invention.

In this embodiment, the control unit of the laser processing device of the present invention may further include a measurement comparison/decision unit that measures prescribed items of the object to be processed, compares these measured values with target values and determines whether or not additional laser processing is necessary.

Furthermore, the laser control unit of the laser processing device of the present invention may be provided with

a logic circuit arranged between the programmable frequency divider circuit and the first timer circuit. The logic circuit receives the Q-switch frequency pulse and the determination results of the measurement comparison/decision unit. This logic circuit transmits the Q-switch frequency pulse to the first timer in cases in which the measurement comparison/decision unit determines that additional laser processing is necessary and prevents transmission of the Q-switch frequency pulse to the first timer circuit in cases in which the measurement comparison/decision unit does not determine that additional laser processing is necessary.

By means of the above-described constitution, the present invention may have the following merits:

The peak value of the first pulse can be controlled to

a level of the pulses that succeed the first pulse by placing the optical resonator in a continuous oscillation state in a period before the start of processing or during suspension of processing.

Providing a circuit that enables programmable setting of the pumping interval enables programmable setting of the peak value of output laser pulses.

Synchronizing the leading edge of the Q-switch control pulse with the trailing edge of Q-switch frequency pulse and synchronizing the trailing edge of Q-switch control pulse with the leading edge of optical switch pulse enables both the stable and reliable synchronization of the timing of emission of giant pulses with the timing of opening of the optical switch unit and enables the generation of a single laser pulse train having a set peak value for each Q-switch frequency pulse.

Providing a circuit that effects programmable frequency-division of reference clock signals enables the programmable modification of the Q-switch frequency that serves as the reference timing for the operation of the laser processing device. As a result, a Q-switch period T_3 can be freely selected within the range $T_3 > T_1 + T_4$ so as to be appropriate to the processing of semiconductor components or electrical components.

The above and other objects, features, and advantages of the present invention will become apparent from the following description referring to the accompanying drawings which illustrate examples of preferred embodiments of the present

invention.

Brief Description of the Drawings:

Fig. 1 is a block diagram of the principal components of a Q-switch controlled laser oscillator according to a typical example of the prior art.

Fig. 2 is a block diagram showing the constitution of laser control unit 3 provided in control unit 2 of Fig. 1.

Fig. 3 is a timing chart illustrating the emission timing of laser pulses in the device of Fig. 1.

Fig. 4 is a block diagram for explaining the constitution of the laser processing device described in Reference 3.

Fig. 5 is a block diagram showing the constitution of measurement unit 35 of the device of Fig. 4.

Fig. 6 is a signal timing chart illustrating the operation of the device of Reference 3.

Fig. 7 is a block diagram showing the constitution of the first embodiment of the laser processing device of the present invention.

Fig. 8 is a block diagram showing the constitution of laser control unit 3 of the first embodiment.

Fig. 9 is a timing chart of signals that control each part of the laser processing device of the first embodiment.

Fig. 10 is a block diagram showing the constitution of the second embodiment of the laser processing device of the present invention.

Detailed Explanation of the Preferred Embodiments:

Embodiments of the present invention are next described with reference to the accompanying figures.

Fig. 7 is a block diagram showing the constitution of the first embodiment of a laser processing device of the present invention.

The laser processing device of the present embodiment is provided with: computer 1, control unit 2, Q-switch driver 4, optical switch driver 5, laser oscillator 6, and optical switch unit 9. Laser oscillator 6 includes optical resonator 7 the oscillation of which is controlled by Q-switch unit 8. Q-switch unit 8 is incorporated within optical resonator 7.

Computer 1 provides I/O data that designate the operating mode of Q-switch unit 8 and the operating mode of optical switch unit 9, to control unit 2. Control unit 2 includes laser control unit 3. Laser control unit 3 decodes I/O data, and generates a Q-switch control pulse for controlling Q-switch unit 8 and also an optical switch pulse for controlling optical switch unit 9 at the timing designated by the I/O data. Laser control unit 3 supplies the generated Q-switch control pulse and optical switch pulse to Q-switch driver 4 and optical switch driver 5, respectively. Q-switch driver 4 effects ON/OFF control of Q-switch unit 8 in response to the Q-switch control pulse. Q-switch unit 8 functions to decrease the Q value of optical resonator 7 when in the ON state, and functions such that the Q value of optical resonator 7 has a normal value when in the OFF state. The ON state of Q-switch unit 8 therefore corresponds to the state of suppressing the oscillation of laser oscillator

6 and its OFF state corresponds to the state of normal oscillation of laser oscillator 6.

Optical switch driver 5 effects ON/OFF control of optical switch unit 9 in accordance with the optical switch pulse. Optical switch unit 9 has a shutter function and either transmits or blocks the laser light in response to the optical switch pulse. Although optical switch unit 9 is arranged outside the laser oscillator in the present embodiment, it may also be arranged inside the laser oscillator.

Next, regarding the details of the construction of laser control unit 3, we refer to Fig. 8, in which is shown a block diagram of the configuration of laser control unit 3 of the present embodiment.

Laser control unit 3 is provided with decoder 12 for the Q-switch and optical switch control pulses, programmable frequency divider circuit 13, programmable timer circuit 14, reference clock oscillator 15, and timer circuit 16.

Decoder 12 decodes received I/O data and sends the decoded I/O data to both programmable frequency divider circuit 13 and programmable timer circuit 14.

Programmable frequency divider circuit 13 further receives the reference clock signals from reference clock oscillator 15, frequency-divides the reference clock signals, generates a Q-switch frequency pulse having a frequency that is designated by the decoded I/O data. Programmable frequency divider circuit 13 transmits the Q-switch frequency pulse to programmable timer circuit 14. The period of the Q-switch

frequency pulse is T_3 .

Programmable timer circuit 14 receives reference clock signals from reference clock oscillator 15, the Q-switch frequency pulse from programmable frequency divider circuit 13, and decoded I/O data from decoder 12; using the reference clock signals as timing signals (using the reference clock signals as the standard for timing), generates a Q-switch control pulse having a pulse width $\#T_1$ designated by the I/O data with a leading edge synchronized with the trailing edge of the Q-switch frequency pulse; and supplies the generated Q-switch control pulse to Q-switch driver 4. $\#T_1$ is variable corresponding to the peak value of the giant pulse designated by the I/O data.

Timer circuit 16 receives the reference clock signals and the Q-switch control pulse; using the reference clock signals as the timing signals, generates an optical switch pulse having a prescribed pulse width T_4 such that the leading edge of the optical switch signals is synchronized with the trailing edge of the Q-switch control pulse; and supplies the generated optical switch pulse to optical switch driver 5.

Next, regarding the operation of the circuit of Fig. 7 and Fig. 8, Q-switch frequency data for laser emission are first set in decoder 12 for the control of the Q-switch unit and optical switch unit. Programmable frequency divider circuit 13 next frequency-divides the reference clock signals received from reference clock oscillator 15 and generates a Q-switch frequency pulse having a desired frequency, in accordance with the decoded output data. The period of the Q-switch frequency

pulse is T3 (refer to Fig. 9(A) described hereinbelow). Q-switch unit 8 and optical switch unit 9 operate at the period of this Q-switch frequency pulse.

Since the leading edge of the Q-switch control pulse is synchronized with the trailing edge of the Q-switch frequency pulse (refer to Fig. 9(B) described hereinbelow), the first Q-switch control pulse can be generated in synchronization with the first Q-switch frequency pulse following issuance of a processing command. This point contrasts with the previously described device of Reference 3, in which the first Q-switch control pulse is synchronized with the second Q-switch frequency pulse.

In the present embodiment, logic 1 of the Q-switch control pulse causes the ON state of Q-switch unit 8, which in turn causes the oscillation of optical resonator 7 to be checked, thereby allowing light energy to accumulate in the laser medium. Thus, in the present embodiment, the period of the pulse width of the Q-switch control pulse (the interval of logic 1) #T1 is the pumping interval or excitation time (refer to Fig. 9(B) described hereinbelow). Q-switch unit 8 then enters the OFF state with the fall of the Q-switch control pulse, whereby the halt of oscillation of optical resonator 7 is relaxed and the stimulated emission of the accumulated energy occurs all at once, i.e., a giant pulse is launched. The laser medium begins to accumulate the next light energy when Q-switch unit 8 receives the next Q-switch control pulse.

The leading edge of the optical switch pulse that acts

upon optical switch unit 9 by means of optical switch driver 5 is synchronized with the trailing edge of the Q-switch control pulse (refer to Fig. 9(E)). Optical switch unit 9 therefore turns ON in synchronization with the rise of a giant pulse. Since the pulse width of optical switch pulse is T_4 , optical switch unit 9 is in an ON state only during interval T_4 and then turns OFF, whereby laser light, even if radiated, is blocked.

The Q-switch control pulse is at logic 0 during intervals other than interval #T1, i.e., during the interval T_3 -#T1 (refer to Fig. 9(B)), and Q-switch unit 8 is therefore kept in an OFF state. At this time, the number of atoms that are making the transition to the population inversion state by pumping and the number of atoms that are leaving the population inversion state by stimulated emission in the laser medium are in equilibrium, and a stationary continuous oscillation state is maintained, but the laser light of this continuous oscillation is blocked by optical switch unit 9, which is in the OFF state.

The density of energy that is stored in the laser medium during the interval T_3 -#T1 of this continuous oscillation state is extremely low. The light energy of a giant pulse is therefore substantially equivalent to the energy that accumulates in the laser medium in the interval of the pulse width #T1 of the Q-switch control pulse. Thus, if pulse width #T1 is constant, the height of a giant pulse is also constant. In addition, the programmable modification of pulse width #T1 enables the programmable modification of the peak values of the corresponding giant pulses.

The Q-switch control pulse maintains the state of logic 0 during an interval before a processing command is issued or during an interval of suspended processing, i.e., before the first Q-switch frequency pulse is issued from programmable frequency divider circuit 13. Accordingly, laser oscillator 6 is in a continuous oscillation state during these intervals, and the laser medium therefore does not accumulate energy of the density that exceeds the oscillation threshold. For this reason, the first pulse problem in which a first pulse has a higher peak value than the succeeding giant pulses is solved in the device of the present invention.

In the present embodiment, the output of programmable timer circuit 14 is supplied to timer circuit 16, synchronizing the trailing edge of the Q-switch control pulse and the leading edge of optical switch pulse.

This method contrasts with the method of the device of Reference 3 in which the trailing edge of the Q-switch control pulse is synchronized with the leading edge of the optical switch pulse indirectly by synchronizing the trailing edge of a Q-switch control pulse with a Q-switch frequency pulse and synchronizing the leading edge of an optical switch pulse with the Q-switch frequency pulse.

The method of this embodiment is more direct for achieving synchronization than the method of Reference 3 and can therefore realize control with more stability.

Fig. 9 is a timing chart of the signals that control each section of the laser processing device of the present

embodiment.

In the preparatory state of laser processing, an optical switch pulse having a logic level that places optical switch unit 9 in a blocking state (logic 0 in this embodiment) is supplied from laser control unit 3 to optical switch driver 5. Further, a Q-switch control pulse (logic 0) that places Q-switch unit 8 in an OFF state is supplied from laser control unit 3 to Q-switch driver 4, thereby laser oscillator 6 being placed in a state of weak continuous oscillation. Optical switch unit 9 blocks the output of this weak laser light to the outside.

When laser processing next starts, programmable frequency divider circuit 13 generates a Q-switch pulse train of repetition period T_3 in accordance with a command (I/O data) from computer 1 decoded by decoder 12 (Fig. 9(A)). This pulse train serves as the Q-switch frequency pulse. The Q-switch frequency pulse is the reference signal of the operation timing of laser emission and pulse control in the present invention.

Programmable timer circuit 14 generates a Q-switch control pulse synchronized with this Q-switch frequency pulse. This synchronization is realized by synchronizing the trailing edge of the Q-switch frequency pulse (in the present embodiment, the falling edge) with the leading edge of the Q-switch control pulse (in the present embodiment, the rising edge). The pulse width (the interval of logic 1) of the Q-switch control pulse is equal to time $\#T_1$ as designated by the decoded I/O data (Fig. 9(B)).

In the present embodiment, logic 1 of the Q-switch control

pulse places the Q-switch unit in the ON state. The oscillation of laser oscillator 6 is therefore checked and the accumulation of light energy in the laser medium starts simultaneously with the rise of the Q-switch control pulse, whereby energy density in the laser medium builds up. The increase in this energy density continues until the trailing edge of the Q-switch control pulse (in the present embodiment, the falling edge) (Fig. 9(C)). Q-switch unit 8 makes the transition to the OFF state at the falling edge of the Q-switch control pulse, and as a result, the energy that has accumulated in the laser medium is discharged all at once as a giant pulse (Fig. 9(D)). The period T_3 of the Q-switch control pulse and the pulse width T_1 of the Q-switch control pulse can be set to any value by commands from the computer 1.

Timer circuit 16 raises the optical switch pulse synchronous with the fall of the Q-switch control pulse. In the present embodiment, logic 1 of the optical switch pulse operates as an open signal of optical switch unit 9. Timer circuit 16 thus generates an optical switch pulse having a rising edge synchronized with the falling edge of the Q-switch control pulse and having a set pulse width T_4 (Fig. 9(E)). The optical switch unit 9 can thus be opened only during the set interval T_4 synchronized with the emission of a giant pulse (Fig. 9 (D) and (E)).

The peak value of giant pulses (more accurately, the time integral of the intensity curve of a giant pulse) is substantially proportional to the energy density in the laser

medium at the time of fall (trailing edge) of a Q-switch control pulse. The energy density in the laser medium is substantially proportional to the pulse width of the Q-switch control pulse #T1 while it does not attain the saturated value. The peak values of all giant pulses that pass through optical switch unit 9 including the first pulse can therefore be made uniform by setting time #T1 constant. In addition, programmable modification of the peak values of giant pulses can be realized by programmable modification of pumping time #T1 (Fig. 9(F)).

As described hereinabove, the laser medium emits giant pulses corresponding to pumping time #T1 and discharges the stored energy at the fall of the Q-switch control pulse. Immediately after emitting a giant pulse, the energy in the laser medium suddenly drops and laser oscillation ceases, but since pumping occurs continuously, the energy density in optical resonator 7 rises instantaneously and, upon attaining the oscillation threshold of laser light, a continuous oscillation occurs that is weak in comparison with giant pulses (Fig. 9 (C)).

Optical switch unit 9 is closed after the passage of interval T4 following the rise of the optical switch pulse, and this prevents further irradiation of the object to be processed by the laser light generated by the continuous oscillation.

This continuous oscillation continues until the time of the next rise (leading edge) of the Q-switch control pulse, and the energy density therefore does not rise to or above the oscillation threshold during this interval T2 (Fig. 9 (B)).

Output giant pulses therefore have a uniform peak value corresponding to pumping time #T1, and the first pulse after the start of laser processing or after suspension of processing consequently can be prevented from being abnormally high compared to succeeding giant pulses.

Fig. 10 is a block diagram showing the constitution of the second embodiment of the laser processing device of the present invention.

In the laser processing device of this embodiment, control unit 2 further includes measurement comparison/decision unit (MCDU) 17, and laser control unit 3 is further provided with logic circuit 18 between programmable frequency divider circuit 13 and programmable timer circuit 14. Measurement comparison/decision unit 17 performs measurement of prescribed items of the object to be processed, compares the measurement values with target values, and determines whether or not additional laser processing is necessary. Logic circuit 18 receives the Q-switch frequency pulse and the determination results of measurement comparison/decision unit 17, and transmits the Q-switch frequency pulse to programmable timer circuit 14 in cases in which measurement comparison/decision unit 17 has determined that additional laser processing is necessary. Logic circuit 18 prevents the transmission of the Q-switch frequency pulse to programmable timer circuit 14 in cases in which measurement comparison/decision unit 17 does not determine that additional laser processing is necessary.

Thus, in cases in which measurement comparison/decision

unit 17 determines that additional laser processing is necessary, each part of the device operates according to the Q-switch control pulse and optical switch pulse shown in Fig. 9 and in accordance with the process described with reference to Fig. 9. In this way, giant pulses for processing are generated.

In cases in which measurement comparison/decision unit 17 does not determine that additional laser processing is necessary, the Q-switch frequency pulse is not transmitted to programmable timer circuit 14. The Q-switch control pulse is therefore not generated in the Q-switch period to which the Q-switch frequency pulse that was not transmitted belongs. As a result, the optical switch pulse of that period is also not generated. Thus, periods in which measurement comparison/decision unit 17 does not determine that additional laser processing is necessary become periods of suspended laser processing.

It is to be understood, however, that although the characteristics and advantages of the present invention have been set forth in the foregoing description, the disclosure is illustrative only, and changes may be made in the arrangement of the parts within the scope of the appended claims.

CLAIMS:

1. A laser processing device, comprising:

a laser oscillator having an optical resonator provided with a Q-switch unit the operation of which is controlled by a Q-switch control pulse, said laser oscillator being checked
5 from oscillation and storing optical energy through pumping when the Q-switch unit is turned ON, and performing oscillation as normal when the Q-switch unit is turned OFF under the control of the Q-switch control pulse;

10 an optical switch unit for transmitting or blocking laser light under the control of an optical switch pulse, said optical switch unit being arranged on the optical path between said laser oscillator and an object to undergo laser-processing by laser pulses emitted from said
15 laser oscillator;

a computer for supplying I/O data that designate: the start timing of laser processing; after said start timing of laser processing, the frequency of repetition at which said Q-switch unit is caused to operate periodically;
20 and the period in which said Q-switch unit is turned ON to designate a pumping period;

a control unit for generating: Q-switch frequency pulses having said frequency of repetition designated by said I/O data; Q-switch control pulse each having a first
25 logic level to cause said Q-switch unit to turn ON and a second logic level to cause said Q-switch unit to turn OFF, and having a leading edge that exhibits a transition from

said second logic level to said first logic level, a trailing edge that exhibits a transition from said first logic level to said second logic level wherein said leading edge of said Q-switch control pulses synchronized with the trailing edges of said Q-switch frequency pulse in the period of each of said Q-switch frequency pulses, and a pulse width, i.e., the time duration between said leading edge and said trailing edge, that is equal to the period designated as a pumping period by said I/O data; and optical switch pulses, each having a first logic level to cause optical switch unit to transmit laser light and a second logic level to cause said optical switch to block said laser light, and having the leading edge that exhibits a transition from said second logic level to said first logic level and a pulse width predetermined to be equal to the time duration of passing the laser light, said leading edge of said optical switch pulse being synchronized with the trailing edges of said Q-switch control pulses in the period of each of said Q-switch frequency pulses;

a Q-switch driver that receives said Q-switch control pulse for controlling said Q-switch unit in response to said Q-switch control pulse; and

an optical switch driver that receives said optical switch pulse for controlling said optical switch unit in response to said optical switch pulse.

2. A device according to claim 1, wherein said

control unit comprises a laser control unit, said laser

control unit comprising:

a decoder for decoding I/O data supplied from said computer;

5 a reference clock oscillator for generating reference clock signals;

a programmable frequency divider circuit for frequency-dividing said reference clock signals to generate Q-switch frequency pulses having a frequency of repetition

10 designated by said decoded I/O data;

a first timer circuit that receives the Q-switch frequency pulse, reference clock signals, and I/O data that have been decoded, for generating a Q-switch control pulse synchronized with said Q-switch frequency pulse using said

reference clock signals as timing signals; and

a second timer circuit that receives said Q-switch control pulse provided from said first timer circuit and said reference clock signals, for generating optical switch pulses synchronized with said Q-switch control pulses using
5 said reference clock signals as timing signals.

3. A device according to claim 2, wherein the leading edge of said Q-switch control pulse is synchronized with the
10 trailing edge of the Q-switch frequency pulse, and the trailing edge of the Q-switch control pulse is synchronized with the leading edge of the optical switch pulse.

4. A device according to claim 2, wherein the pulse
15 width of the Q-switch control pulse generated by said first timer circuit is programmable.

5. A device according to claim 1, wherein said Q-switch control pulse has a second logic level before the
20 start timing of processing or while processing is suspended.

6. A device according to claim 2, wherein:
said control unit further includes a measurement comparison/decision unit for measuring prescribed items of
25 the object to be processed, comparing the measured values with target values, and determining whether or not additional laser processing is necessary; and

said laser control unit is further provided with a logic circuit arranged between said programmable frequency divider circuit and said first timer circuit and that receives said Q-switch frequency pulse and the determination results of

5 said measurement comparison/decision unit;

said logic circuit transmitting the Q-switch frequency pulse to the first timer circuit in cases in which said measurement comparison/decision unit has determined that additional laser processing is necessary and preventing the

10 transmission of the Q-switch frequency pulse to the first timer circuit in cases in which said measurement comparison/decision unit does not determine that additional laser processing is necessary.

Laser Processing Device

Abstract

Laser oscillator (6) includes a Q-switch unit controlled by a Q-switch control pulse and an optical resonator (7). Oscillation is checked when the Q-switch unit is turned ON under the control of the Q-switch control pulse but proceeds normally when the Q-switch unit is OFF. Optical switch unit (9) is arranged in the optical path between a laser oscillator and an object to be processed and either transmits or blocks laser light under the control of an optical switch pulse. Control unit (2) generates a Q-switch frequency pulse of repetition frequency designated by computer (1) and a Q-switch control pulse synchronized with the Q-switch frequency pulse. The Q-switch control pulse has a width corresponding to a period designated as pumping interval by computer (1) and generates an optical switch pulse synchronized with the Q-switch control pulse that has a pulse width corresponding to a predetermined interval of laser light transmission.

FIG 7.