

Description

Title of Invention: LASER PROCESSING METHOD AND LASER
PROCESSING APPARATUS

Technical Field

[0001]

This invention relates to a laser annealing method and a laser annealing apparatus that perform a plurality of times of overlap irradiation while scanning a non-single crystal semiconductor with a pulsed laser in a line beam shape to crystallize an amorphous film or to modify a crystal film.

Background Art

[0002]

In general, a thin-film transistor used in a TV or a PC display is made of amorphous (non-crystalline) silicon (hereinafter, called a-silicon), and the silicon can be crystallized (hereinafter, called p-silicon) by some means to significantly improve the performance of the TFT. Currently, an excimer laser annealing technique is already implemented as a Si crystallization process at low temperature. The technique is frequently used for small displays of smartphones and the like and is also implemented in large-screen displays and the like.

[0003]

In the laser annealing method, an excimer laser with high pulse energy is directed to a non-single crystal semiconductor film. The semiconductor that has absorbed the light energy is molten or half-molten and is later crystallized when the semiconductor is cooled and solidified. In this case, to process a wide area, a pulsed laser formed into a line beam shape is directed while relatively scanning the film in a minor axis direction, for example. Usually, an installation board provided with the non-single crystal semiconductor film is moved to perform the scan with the pulsed laser.

In the scan with the pulsed laser, the pulsed laser is moved in the scanning direction at a predetermined scanning pitch so that the pulsed laser is directed for a plurality of times (overlap irradiation) to the same position of the non-single crystal semiconductor film. This enables a laser annealing process of a large-sized semiconductor film.

[0004]

In the laser annealing process using a conventional line beam, the beam width in the scanning direction of the laser pulse is fixed to about 0.35 to 0.4 mm, and the substrate feed amount of each pulse for ensuring uniformity of the performance of a plurality of thin-film transistors is set to about 5% to 8% of the beam width. The production efficiency is taken into account to

determine the number of times of irradiation with the laser.

[0005]

In an intensity distribution of a beam cross section of a pulsed laser, there is an area at a scanning direction end section in which the intensity gradually decreases to 0. Patent Literature 1 addresses an issue that in the overlap irradiation of the pulsed laser with the intensity distribution, there is a difference in mobility when transistors are formed in irradiation areas irradiated for a plurality of times with different intensity areas (paragraphs 0015 to 0019). To solve the problem, proposed is a method of setting the scanning pitch equal to or smaller than a predetermined value according to the intensity area. Patent Literature 1 states that the method allows manufacturing thin-film transistors with significantly small variations in mobility (paragraph 0026).

Citation List

Patent Literature

[0006]

Patent Literature 1: Japanese Patent Laid-Open No. 9-45926

Summary of Invention

According to the first aspect of the invention, a laser processing method of forming a crystal semiconductor film by performing overlap irradiation at a predetermined scanning pitch while scanning a non-single crystal semiconductor film by a pulsed laser with a predetermined beam cross section profile is provided, wherein

the overlap irradiation of the pulsed laser is performed by setting the scanning pitch in a range satisfying the following Formula (1), wherein

b denotes a length in a scanning direction of a base of a rising section formed by the irradiation of the semiconductor film with the pulsed laser, formed on a back end side in the scanning direction of a pulsed laser beam directed to the semiconductor film, and p denotes the scanning pitch.

$$0.75b \geq p \geq 0.25b \quad \dots (1)$$

According to the second aspect of the invention, A laser processing apparatus comprising:

a pulse oscillation laser light source that outputs a pulsed laser at a predetermined repetition frequency;

an optical system that adjusts a beam cross section profile of the pulsed laser and guides the pulsed laser to a non-single crystal semiconductor film;

an attenuator that adjusts an energy density of the pulsed laser;

a scanning apparatus that relatively scans the non-single crystal semiconductor film with the pulsed laser at a predetermined scanning speed; and

a control unit that controls the laser light source, the attenuator, and the scanning apparatus, wherein

the control unit acquires a length b in a scanning direction of a base of a rising section formed by irradiation of a semiconductor film with the pulsed laser, formed on a back end side in the scanning direction of a pulsed laser beam directed to the semiconductor film, and determines the repetition frequency in the laser light source and the scanning speed of the scanning apparatus according to the length in the scanning direction so that a scanning pitch p at the irradiation of the non-single crystal semiconductor film with the pulsed laser satisfies the following Formula (1).

$$0.75b \geq p \geq 0.25b \quad \dots (1)$$

Technical Problem

[0007]

Patent Literature 1 is intended to solve a problem caused by an intensity distribution in which the intensity gradually decreases on the front side in the scanning direction of the laser beam, and the scanning pitch is 1 mm in a specific example.

However, according to studies of the inventors of the present invention, it is clear that the scanning pitch indicated in Patent Literature 1 affects the performance of the semiconductor due to an area (hereinafter, called steepness section) in which the intensity gradually decreases at a back end section in the scanning direction of the laser beam.

[0008]

More specifically, as shown in Figure 6, a rising section 102 of a polysilicon film is formed by each pulse irradiation according to an end section of a line beam minor axis, on a silicon film 101 irradiated with a pulsed laser, for example. This section is equivalent to a boundary between a molten section of the semiconductor film after the laser irradiation and a part that is still solid because a laser with intensity enough to melt the semiconductor film is not applied. It is considered that the rise increases in proportion to the intensity of the irradiation energy. More specifically, the melting advances in the film thickness direction of the semiconductor film along with an increase in the

irradiation energy, and the temperature of the liquid semiconductor film layer rises even after the entire film is molten. When the liquid-phase part is crystallized with a reduction in the temperature, the liquid is solidified while being attracted to a solid-liquid interface where the temperature starts to drop earlier, that is, an edge section of the line beam minor axis, and this generates the rise.

[0009]

At the rising sections, the height and the intervals of the rising sections are disordered due to energy variation of the laser, change in the profile of the line beam minor axis, disorder in the position of the semiconductor film moved relative to the laser beam, and the like. The disorder is recognized as uneven irradiation, leading to variations in the characteristics when the semiconductor films are used as devices.

[0010]

The present invention has been made in view of the circumstances, and an object of the present invention is to provide a laser processing method and a laser processing apparatus that can reduce influence of steepness sections at an end section in a scanning direction of a beam to manufacture crystal semiconductor films with little uneven irradiation.

Solution to Problem

[0011]

More specifically, a first invention of a laser processing method of the present invention is a laser processing method of forming a crystal semiconductor film by performing overlap irradiation at a predetermined scanning pitch while scanning a non-single crystal semiconductor film by a pulsed laser with a predetermined beam cross section profile, wherein

the overlap irradiation of the pulsed laser is performed by setting the scanning pitch in a range satisfying the following Formula (1), wherein

b denotes a length in a scanning direction of a base of a rising section formed by the irradiation of the semiconductor film with the pulsed laser, formed on a back end side in the scanning direction of a pulsed laser beam directed to the semiconductor film, and p denotes the scanning pitch.

$$0.75b \geq p \geq 0.25b \quad \dots (1)$$

[0012]

A second invention provides the laser processing method according to the first invention, wherein the irradiation of the semiconductor film with the pulsed laser is performed at an irradiation energy density optimal for crystallization on the semiconductor film.

[0013]

A third invention provides the laser processing method according to the first or second invention,

wherein a wavelength of the pulsed laser is 400 nm or less.

[0014]

A fourth invention provides the laser processing method according to any of the first to third inventions, wherein a pulse half value width of the pulsed laser is 200 ns or less.

[0015]

A fifth invention provides the laser processing method according to any of the first to fourth inventions, wherein the non-single crystal semiconductor is silicon.

[0016]

A sixth invention provides the laser processing method according to any of the first to fifth inventions, wherein the scanning pitch is 5 to 20 μm .

[0017]

A seventh invention provides the laser processing method according to any of the first to six inventions, wherein the length in the scanning direction of the base of the rising section formed on the back end side in the scanning direction of the pulsed laser beam directed to the semiconductor film by the irradiation of the semiconductor film with the pulsed laser is measured, and the scanning pitch is determined based on a result of the measurement.

[0018]

An eighth invention provides a laser processing apparatus including:

a pulse oscillation laser light source that outputs a pulsed laser at a predetermined repetition frequency;

an optical system that adjusts a beam cross section profile of the pulsed laser and guides the pulsed laser to a non-single crystal semiconductor film;

an attenuator that adjusts an energy density of the pulsed laser;

a scanning apparatus that relatively scans the non-single crystal semiconductor film with the pulsed laser at a predetermined scanning speed; and

a control unit that controls the laser light source, the attenuator, and the scanning apparatus, wherein

the control unit acquires a length b in a scanning direction of a base of a rising section formed by irradiation of a semiconductor film with the pulsed laser, formed on a back end side in the scanning direction of a pulsed laser beam directed to the semiconductor film, and determines the repetition frequency in the laser light source and the scanning speed of the scanning apparatus according to the length in the scanning direction so that a scanning pitch p at the irradiation of the non-single crystal semiconductor film with the pulsed laser satisfies the following Formula (1).

$$0.75b \geq p \geq 0.25b \quad \dots (1)$$

[0019]

A ninth invention provides the laser processing apparatus according to the eighth invention, further including a film surface profile measurement apparatus that measures the length b in the scanning direction of the base of the rising section formed by the irradiation of the semiconductor film with the pulsed laser, formed on the back end side in the scanning direction of the pulsed laser beam directed to the semiconductor film.

[0020]

In the present invention, the scanning pitch is set in an appropriate range, and the rising sections formed by steepness sections at the back end side in the scanning direction of the laser beam cross section are closely formed. The reason that the scanning pitch is defined will be described here.

The base of the rising section is b , and the scanning pitch p can be reduced to reduce the difference in elevation between the rising sections. If p is greater than $0.75b$, the effect of reducing the difference in elevation cannot be sufficiently obtained. If p is smaller than $0.25b$, the number of times of overlap increases, and the production efficiency is reduced. Therefore, the scanning pitch p is set to $0.75b$ or less and $0.25b$ or more. For the same reason, it is desirable to set the scanning pitch p to less than $0.7b$ and $0.5b$ or more.

Although the absolute numerical value of the scanning pitch p is not limited, the value can be, for example, 5 to 20 μm .

[0021]

Although the size of the base of the rising section is not particularly limited in the present invention, the size can be in a range of, for example, 10 to 30 μm .

The rising section is from a boundary between a molten section of the semiconductor film after the irradiation with the back end side in the scanning direction of the laser beam and a part that is still solid because a laser with intensity enough to melt the semiconductor film is not applied, to a point where the decreasing trend of the height of the rise of the semiconductor film ends, through a position where the height is maximum. The increasing and decreasing trends of the height of the rising section can be clearly indicated by using an approximate line (such as a polynomial approximate line) of the height of the rise section.

[0022]

The size of the base of the rising section is affected by the size of the width of the steepness section at the back end in the scanning direction of the pulsed laser. The steepness section can be indicated as an area with an intensity that is 10% or more and 90% or less of the maximum intensity in the beam intensity

profile. The width of the steepness section on the back end side in the scanning direction in the pulsed laser of the present invention can be, for example, 100 μm or less. The width of the steepness section can be adjusted by design of optical members, arrangement of slits on an optical path, and the like. However, if the steepness section is excessively narrowed down, a projection with a rapid increase in intensity is formed at an end in the minor axis direction of a flat section in the beam intensity profile. Therefore, the width of the steepness section is adjusted to, for example, 30 μm or more.

[0023]

It is desirable that the pulsed laser is directed to the semiconductor film at an irradiation energy density optimal for crystallization on the semiconductor film. The irradiation energy density optimal for the crystallization can be determined by an appropriate standard, and for example, the irradiation pulse energy density can be about the same as an irradiation pulse energy density E at which the crystal grain growth is saturated by N times of irradiation. Specifically, a range of $E \times 0.98$ to $E \times 1.03$ is desirable. The optimal irradiation energy density varies depending on the number of times of irradiation and the like. Although the density is not limited to a specific numerical value in the present invention, the density can be, for example, 250 to 500 mJ/cm^2 .

[0024]

Although the pulsed laser used in the present invention is not limited to a specific pulsed laser, the wavelength can be 400 nm or less, and the half value width can be 200 ns or less, for example. Although the type of pulsed laser is not particularly limited, an example of the pulsed laser includes an excimer laser.

[0025]

Although the non-single crystal semiconductor film formed into the crystal semiconductor film by the pulsed laser is not limited to a specific material in the present invention, an example of the material includes silicon. The present invention can attain an advantageous effect regardless of the material.

[0026]

The pulsed laser is output at a predetermined repetition frequency in the laser processing apparatus of the present invention. Although the repetition frequency is not particularly limited in the present invention, the repetition frequency can be, for example, 1 to 1200 Hz. The repetition frequency can be set in the laser light source based on the control by the control unit.

[0027]

Various optical members, such as a cylindrical lens, are used to form the pulsed laser into an appropriate shape, such as a rectangular shape and a line beam shape. The shape of the line beam is not limited to a specific

shape, and it is only necessary that the major axis be greater than the minor axis. For example, the ratio of the major axis to the minor axis can be 10 or more. Although the length of the major axis side and the length of the minor axis side are not limited to specific lengths in the present invention, the length of the major axis side can be 370 to 1300 mm, and the length of the minor axis side can be 100 μm to 500 μm , for example. Optical members, such as a homogenizer and a cylindrical lens, can adjust the pulsed laser so that the beam intensity profile includes, for example, a flat section with an intensity that is 96% or more of the maximum intensity and steepness sections, positioned at the end section, with an intensity that is 10 to 90% of the maximum intensity.

[0028]

The attenuator adjusts the transmittance of the pulsed laser so that the pulsed laser light can have a predetermined energy density on the non-single crystal semiconductor film, and the transmittance can be adjusted based on the control by the control unit.

[0029]

An example of the apparatus that relatively scans the non-single crystal semiconductor film with the pulsed laser includes a movement apparatus that moves one or both of the pulsed laser and the non-single crystal semiconductor film. The pulsed laser can be moved in a

horizontal direction, and a mechanism using a polygon mirror or a galvano mirror can also move the pulsed laser. A mechanism that moves a stage or the like for holding the non-single crystal semiconductor film can move the non-single crystal semiconductor film.

Although the scanning speed is not particularly limited in the present invention, the scanning speed can be, for example, 1 to 100 mm/second. The scanning apparatus can set the scanning speed based on the control by the control unit.

[0030]

The control unit can acquire the length in the scanning direction of the base of the rising section to determine the scanning pitch, and the film surface profile measurement apparatus can measure the length of the rising section. The film surface profile measurement apparatus is not limited to a specific apparatus as long as the film surface profile of the semiconductor film irradiated with the pulsed laser can be measured, and examples of the film surface profile measurement apparatus include an atomic force microscope (AFM) and a stylus-type surface profile measurement device. The control unit determines the scanning pitch based on the length in the scanning direction and controls the laser light source, the attenuator, and the scanning apparatus to execute processes. The scanning pitch is determined by the repetition frequency of the laser light source and

the scanning speed of the scanning apparatus, and the control unit can set one or both of these to set the scanning pitch. The control unit includes a CPU, a program for operating the CPU, a storage unit storing operation parameters, and the like.

Advantageous Effects of Invention

[0031]

As described, according to the present invention, there is an advantageous effect that the rising sections formed by the steepness sections on the back end side in the scanning direction of the laser beam cross section are closely formed to reduce the difference in elevation between the rising sections and to reduce the uneven irradiation.

Brief Description of Drawings

[0032]

[Figure 1] Figure 1 is a diagram showing an outline of a laser processing apparatus according to an embodiment of the present invention.

[Figure 2] Figure 2 is a diagram showing a beam intensity profile in a minor axis direction of an adjusted pulsed laser according to the embodiment of the present invention.

[Figure 3] Figure 3 is a diagram describing formation of rises when the pulsed laser is directed at a scanning

pitch of the present invention according to the embodiment of the present invention.

[Figure 4] Figure 4 is a graph of an example of an experiment in which uneven irradiation is digitized according to the embodiment of the present invention.

[Figure 5] Figure 5 illustrates images of the example of the experiment in which the uneven irradiation is emphasized according to the embodiment of the present invention.

[Figure 6] Figure 6 is a diagram describing formation of rises when a pulsed laser is directed at a conventional scanning pitch.

Description of Embodiments

[0033]

Hereinafter, a laser processing apparatus 1 of an embodiment of the present invention will be described with reference to the attached drawings.

The laser processing apparatus 1 includes a processing chamber 2, includes a scanning apparatus 3 that can move in an X-Y direction in the processing chamber 2, and includes a base 4 above the scanning apparatus 3. A substrate arrangement board 5 as a stage is provided on the base 4. The scanning apparatus 3 is driven by a motor or the like not shown.

An introduction window 6 for introducing a pulsed laser from the outside is provided on the processing chamber 2.

[0034]

During an annealing process, a substrate 100 or the like provided with an amorphous silicon film 101 as a semiconductor film that is a non-single crystal semiconductor is installed on the substrate arrangement board 5. The silicon film 101 is formed on a substrate not shown, with a thickness of, for example, 40 to 100 nm (specifically, thickness of 50 nm for example). The formation can be performed by an ordinary method, and the formation method of the semiconductor film of the present invention is not particularly limited.

Although laser processing of crystallizing the amorphous film by laser processing is described in the present embodiment, the details of the laser processing are not limited to this in the present invention. For example, single crystallization of a non-single crystal semiconductor film can be performed, or a crystal semiconductor film can be modified.

[0035]

A pulse oscillation laser light source 10 is installed outside of the processing chamber 2. The pulse oscillation laser light source 10 includes an excimer laser oscillator, and a pulsed laser with a wavelength of 400 nm or less and a repeated oscillation frequency of 1

to 1200 Hz can be output. In the pulse oscillation laser light source 10, feedback control can control and maintain the output of the pulsed laser within a predetermined range. A control unit 7 that can control the pulse oscillation laser light source 10 is connected to the pulse oscillation laser light source 10, and the control unit 7 can adjust the repetition frequency and the output of the pulsed laser output by the pulse oscillation laser light source 10.

The control unit can mainly include a CPU and a program for operating the CPU and can also include a non-volatile memory, a RAM, and the like.

[0036]

An attenuator 11 adjusts the energy density of a pulsed laser 15 oscillated and output by the pulse oscillation laser light source 10. The control unit 7 that can control the attenuator 11 is connected to the attenuator 11, and the control unit 7 can adjust the transmittance of the pulsed laser 15 transmitted through the attenuator 11.

[0037]

The pulsed laser 15 transmitted through the attenuator 11 reaches an optical system 12. The optical system 12 includes optical members, such as a homogenizer 12a, a reflection mirror 12b, and a cylindrical lens 12c. The optical system 12 forms the pulsed laser 15 into a line beam shape, deflects the pulsed laser 15, or forms a

beam intensity profile including a flat section and steepness sections. A pulsed laser 150 is directed to the amorphous silicon film 101 in the processing chamber 2 through the introduction window 6 provided on the processing chamber 2. The optical members included in the optical system 12 are not limited to the ones described above, and various lenses (such as a homogenizer and a cylindrical lens), mirrors, waveguide portions, and the like can be included.

[0038]

Next, operation of the laser processing apparatus 1 will be described.

The pulse oscillation laser light source 10 performs pulse oscillation at a predetermined repetition frequency by the control of the control unit 7 and outputs the pulsed laser 15 at a predetermined output. The wavelength of the pulsed laser 15 is 400 nm or less, and the pulse half value width is 200 n seconds or less, for example. However, the present invention is not limited to these.

The attenuator 11 controlled by the control unit 7 adjusts the pulse energy density of the pulsed laser 15. The attenuator 11 is set at a predetermined attenuation factor, and the attenuator factor is adjusted to obtain optimal irradiation pulse energy density for the crystallization on the irradiation surface of the silicon film 101. For example, when the amorphous silicon film

101 is to be crystallized, the attenuation factor can be adjusted so that the energy density is 250 to 500 mJ/cm² on the irradiation surface.

[0039]

The optical system 12 forms the pulsed laser 15 transmitted through the attenuator 11 into a line beam shape. The minor axis width is condensed through the cylindrical lens 12c of the optical system 12, and the pulsed laser 15 is introduced to the introduction window 6 provided on the processing chamber 2.

The line beam is adjusted so that, for example, the length on the major axis side is 370 to 1300 mm, and the length on the minor axis side is 100 μ m to 500 μ m.

[0040]

As shown in Figure 2, the line beam 150 includes: a flat section 151 with an energy intensity that is 96% or more of the maximum energy intensity; and steepness sections 152 positioned at both end sections in the major axis direction and having an energy intensity smaller than that of the flat section 151, wherein the energy intensity gradually decreases toward the outside. The steepness section is an area in a range of 10% to 90% of the maximum intensity.

The width of the steepness sections 152 on the silicon film 101 of the line beam 150 is, for example, 40 to 100 μ m.

[0041]

The scanning apparatus 3 controlled by the control unit 7 can move the silicon film 101 at a predetermined scanning speed to direct the line beam 150 to the silicon film 101 while relatively scanning the silicon film 101. The scanning speed in this case is in a range of, for example, 1 to 100 mm/second. However, the scanning speed is not limited to a specific speed in the present invention.

To determine the scanning speed and the repetition frequency, a scanning pitch p is set to satisfy the following formula as shown in Figure 3, wherein b is a length in the scanning direction of a base of a rising section 102 formed on the silicon film 101 by the irradiation with the pulsed laser 15.

$$0.75b \geq p \geq 0.25b \quad \dots (1)$$

[0042]

The scanning pitch needs to satisfy the condition of Formula (1). Although the scanning pitch is not limited to a specific numerical value, an example of the scanning pitch includes a range of 5 to 15 μm .

The control unit 7 can acquire in advance the length in the scanning direction of the base of the rising section 120 to thereby determine the scanning pitch.

[0043]

A film surface profile measurement apparatus 20, such as an atomic force microscope and a stylus-type surface profile measurement device, can measure the

length in the scanning direction of the base of the rising section 102. Specifically, the laser pulse is directed at an energy density optimal for the crystallization according to a predicted number of times of overlap, and the base length of the rising section formed by the irradiation with the end section in the minor axis direction of the beam is measured. The measurement can be performed in advance for reference, or the measurement can be performed in a processed silicon film.

When the measurement is performed in advance, the length in the scanning direction can also be measured in one shot of the pulsed laser. The scanning pitch can be determined when the base length of the rising section is obtained, and the determination of the scanning pitch defines the number of times of irradiation in a predetermined beam profile. The optimal energy density in the number of times of irradiation is different from the energy density in the measurement of the base length of the rising section 102 in some cases. In this case, when the optimal energy density is changed by a change in the number of times of irradiation, the length in the scanning direction of the base of the rising section 102 can be measured at the changed optimal energy density, and the scanning pitch can be determined according to the result.

[0044]

As a result of an appropriate scanning pitch, the rising sections 102 are closely formed as shown in Figure 3, and the difference in elevation between the rising sections 102 is small. In this way, even if there is energy variation in the laser, change in the profile of the line beam minor axis, disorder in the position of the semiconductor film moved relative to the laser beam, or the like, the influence can be reduced.

Example 1

[0045]

Next, the laser processing apparatus illustrated in the embodiment is used to conduct an experiment for evaluation. The condition of the experiment is as follows.

a-Si (non-single crystal semiconductor)

film thickness: 50 nm

Pulse oscillation laser light source

LSX315C (Coherent, Inc.) /
wavelength 308 nm, repetition
frequency 300 Hz

Beam size 370 mm × 0.4 mm

Laser pulse half value width 50 ns

Irradiation energy density

optimal energy density for
crystallization: 370 mJ/cm² (on
semiconductor film)

Base length b of rising section

18 μm (one-shot measurement)

Scanning pitch p 15 μm , 10 μm , 5 μm (15 μm is a comparative example)

Rising section base length measurement apparatus

manufactured by SII NanoTechnology
Inc., scanning probe microscope unit,
trade name "S-image"

[0046]

The pulsed laser is applied under the condition, and uneven irradiation in obtained polysilicon is evaluated. The uneven irradiation is evaluated by the following standard.

Inspection light is directed to a plurality of spots on the crystal silicon film, and the reflected light is received to acquire a color image. Color components of the color image are detected, and the color image is converted into a monochrome image based on the detected color components. Next, data of the monochrome image is convoluted to acquire image data with emphasized image concentration difference, and projective transformation of the image data with emphasized image concentration difference is performed to evaluate the surface unevenness based on the image data after the projective transformation. Main color components of the detected color components can be used to perform the conversion into the monochrome image, and the main color component

can be a color component in which the light distribution is larger than the other color components.

The monochrome image data is indicated by matrix data, wherein the row is the beam direction of the laser, and the column is the scanning direction of the laser. Matrices of predetermined coefficients are multiplied by the matrix of the monochrome image data to perform the convolution.

A matrix emphasizing the beam direction and a matrix emphasizing the scanning direction are used for the matrices of the predetermined coefficients, and image data in which the image concentration difference in the beam direction is emphasized and image data in which the image concentration difference in the scanning direction is emphasized are acquired.

Specifically, the following convolution is performed. The matrices of the predetermined coefficients are not limited to the following.

[0047]

[Expression 1]

$$\begin{array}{l} \text{CONCENTRATION DIFFERENCE} \\ \text{EMPHASIZED IN SHOT DIRECTION} = \end{array} \left| \begin{array}{ccc} 2 & 2 & 2 \\ 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \\ -2 & -2 & -2 \end{array} \right| * \text{IMAGE DATA} \quad (1)$$

$$\begin{array}{l} \text{CONCENTRATION DIFFERENCE} \\ \text{EMPHASIZED IN SCANNING DIRECTION} = \end{array} \left| \begin{array}{cccc} 2 & 1 & 0 & -1 & -2 \\ 2 & 1 & 0 & -1 & -2 \\ 2 & 1 & 0 & -1 & -2 \end{array} \right| * \text{IMAGE DATA} \quad (2)$$

[0048]

For the image data in which the concentration difference of image is emphasized, the appearance of organized lines in the scanning direction and the shot direction is used to obtain projection in each direction.

Specifically, the following formulas are used to perform projective transformation in the shot direction and the scanning direction.

Shot direction = $(\text{Max } (\Sigma f(x)/N_x) - \text{Min } (\Sigma f(x)/N_x)) / \text{average}$

Scanning direction = $(\text{Max } (\Sigma f(y)/N_y) - \text{Min } (\Sigma f(y)/N_y)) / \text{average}$

In the formulas, x denotes a position of image in the shot direction, y denotes a position of image in the scanning direction, f(x) denotes image data at the position x, f(y) denotes image data at the position y, N_x denotes the number of images in the shot direction, and N_y denotes the number of images in the scanning direction.

[0049]

Since the projection is a total sum in each direction, the projection has resistance to noise, and random values are cancelled. More specifically, the difference between projections in the shot direction can be calculated to express the uneven shot by numerical values. The difference between projections in the shot direction is large in an image with high uneven shot, and the difference between projections is small in an image

with low uneven shot. Similarly, the difference between projections in the scanning direction can be calculated to express the uneven scan by numerical values. The difference between projections in the scanning direction is large in an image with high uneven scan, and the difference between projections is small in an image with low uneven scan. In this way, the uneven shot and the uneven scan can be digitized based on the difference between projections.

[0050]

Figure 4 is a graph with digitized uneven shot when the experiment is performed by changing the scanning pitch.

In a comparative example, the degree of uneven irradiation indicates 0.22 to 0.27.

On the other hand, scanning pitches 10 μm and 5 μm satisfy conditional expression (1) of the present invention. The uneven shot indicates 0.13 to 0.18 at the scanning pitch of 10 μm , and the uneven shot indicates 0.081 to 0.11 at 5 μm . The uneven irradiation is significantly alleviated.

[0051]

Drawing substitute photographs (magnification of 6) of Figure 5 illustrate screens in which the concentration difference is emphasized in the evaluation. It can be recognized that while the unevenness is conspicuous in the comparative example with the scanning pitch of 15 μm ,

the unevenness is small at the scanning pitches of 10 μm and 5 μm .

[0052]

Although the present invention has been described based on the embodiment, the present invention is not limited to the details of the embodiment, and appropriate changes can be made without departing from the scope of the present invention.

Reference Signs List

[0053]

- 1 laser annealing apparatus
- 2 processing chamber
- 3 scanning apparatus
- 5 substrate arrangement board
- 6 introduction window
- 7 control unit
- 10 pulse oscillation laser light source
- 11 attenuator
- 12 optical system
- 20 film surface profile measurement apparatus
- 100 substrate
- 101 silicon film
- 102 rising section

[Claim 1]

A laser processing method of forming a crystal semiconductor film by performing overlap irradiation at a predetermined scanning pitch while scanning a non-single crystal semiconductor film by a pulsed laser with a predetermined beam cross section profile, wherein

the overlap irradiation of the pulsed laser is performed by setting the scanning pitch in a range satisfying the following Formula (1), wherein

b denotes a length in a scanning direction of a base of a rising section formed by the irradiation of the semiconductor film with the pulsed laser, formed on a back end side in the scanning direction of a pulsed laser beam directed to the semiconductor film, and p denotes the scanning pitch.

$$0.75b \geq p \geq 0.25b \quad \dots (1)$$

[Claim 2]

The laser processing method according to claim 1, wherein

the irradiation of the semiconductor film with the pulsed laser is performed at an irradiation energy density optimal for crystallization on the semiconductor film.

[Claim 3]

The laser processing method according to claim 1 or 2, wherein a wavelength of the pulsed laser is 400 nm or less.

[Claim 4]

The laser processing method according to any of claims 1 to 3,
wherein

a pulse half value width of the pulsed laser is 200 ns or less.

[Claim 5]

The laser processing method according to any of claims 1 to 4,
wherein

the non-single crystal semiconductor is silicon.

[Claim 6]

The laser processing method according to any of claims 1 to 5,
wherein

the scanning pitch is 5 to 20 μm .

[Claim 7]

The laser processing method according to any of claims 1 to 6,
wherein

the length in the scanning direction of the base of the rising section formed on the back end side in the scanning direction of the pulsed laser beam directed to the semiconductor film by the irradiation of the semiconductor film with the pulsed laser is measured , and the scanning pitch is determined based on a result of the measurement.

[Claim 8]

A laser processing apparatus comprising:

a pulse oscillation laser light source that outputs a pulsed laser at a predetermined repetition frequency;

an optical system that adjusts a beam cross section profile of the pulsed laser and guides the pulsed laser to a non-single crystal semiconductor film;

an attenuator that adjusts an energy density of the pulsed laser;

a scanning apparatus that relatively scans the non-single crystal semiconductor film with the pulsed laser at a predetermined scanning speed; and

a control unit that controls the laser light source, the attenuator, and the scanning apparatus, wherein

the control unit acquires a length b in a scanning direction of a base of a rising section formed by irradiation of a semiconductor film with the pulsed laser, formed on a back end side in the scanning direction of a pulsed laser beam directed to the semiconductor film, and determines the repetition frequency in the laser light source and the scanning speed of the scanning apparatus according to the length in the scanning direction so that a scanning pitch p at the irradiation of the non-single crystal semiconductor film with the pulsed laser satisfies the following Formula (1).

$$0.75b \geq p \geq 0.25b \quad \dots (1)$$

[Claim 9]

The laser processing apparatus according to claim 8, further comprising

a film surface profile measurement apparatus that measures the length b in the scanning direction of the base of the rising section formed by the irradiation of the semiconductor film with

the pulsed laser, formed on the back end side in the scanning direction of the pulsed laser beam directed to the semiconductor film.