

DESCRIPTION

Title of Invention: CRYSTALLINE SEMICONDUCTOR MANUFACTURING METHOD AND CRYSTALLINE SEMICONDUCTOR MANUFACTURING APPARATUS

Technical Field

[0001]

The present invention relates to a crystalline semiconductor manufacturing method and a crystalline semiconductor manufacturing apparatus for obtaining a crystalline semiconductor by emitting a pulsed laser beam onto an amorphous semiconductor and crystallizing the amorphous semiconductor.

Background Art

[0002]

The process of manufacturing a thin-film transistor for use in a pixel switch and a drive circuit for a liquid crystal display and an organic electro-luminescence (EL) display includes a process of obtaining a crystalline semiconductor using a laser beam as part of a low-temperature process. This process is such that a laser beam is emitted onto a non-single-crystal semiconductor film formed on a substrate so as to locally heat the non-single-crystal semiconductor film and in the cooling step, the semiconductor thin film is crystallized into a polycrystalline or single crystal semiconductor thin film. In the crystallized semiconductor thin film, the carrier mobility is increased, and hence allows the thin-film transistor can achieve high performance.

The laser beam irradiation requires homogeneous processing to be performed on the semiconductor thin film, and hence control is generally performed so as to maintain a constant energy density of pulsed laser beams to be emitted onto an amorphous film.

[0003]

For example, Patent Literature 1 proposes a laser irradiation apparatus that can maintain maximum peak heights of the pulsed laser beams constant, thereby to allow good crystallization.

In addition, Patent Literature 2 proposes a laser irradiation apparatus that generates pulse waveforms by controlling the operation timing of a plurality of laser beams by a method of bundling by combining the plurality of laser beams outputted from a laser light source.

Citation List

Patent Literature

[0004]

Patent Literature 1: Japanese Patent No. 3293136

Patent Literature 2: Japanese Patent Laid-Open No. 2002-176006

Summary of Invention

Technical Problem

[0005]

The above pulsed laser light source using gas such as excimer gas oscillates the laser beams by an electric discharge method. Then, after the first discharge by high voltage, a plurality of discharges occur by residual voltage.

As a result, a laser beam having a plurality of peak groups occur. When a plurality of pulsed laser beams outputted from such a pulsed laser light source are used, a difference in peak shape may produce a different result due to laser beam irradiation even if an object is irradiated with the pulsed laser beams at the same energy density.

[0006]

Note that a prior art laser irradiation apparatus is generally configured to use an energy monitor to control the output of laser beams, and hence can operate by maintaining the same energy density of the laser beams. However, even if the pulsed laser light source maintains a constant energy density, a change in peak shape occurs over time by a change in gas mixing ratio or the like. For this reason, there is a problem in that when an amorphous semiconductor is crystallized by irradiation with laser beams, a change in crystallization action occurs, and hence it is difficult to obtain the equivalent crystals with good quality.

[0007]

In view of the above circumstances, the present invention has been made, and embodiments of the present invention are to provide a crystalline semiconductor manufacturing method and a crystalline semiconductor manufacturing apparatus capable of more uniformly crystallizing an amorphous semiconductor.

According to a first aspect of the invention, a crystalline semiconductor manufacturing method of crystallizing an amorphous semiconductor by irradiating the amorphous semiconductor with a plurality of pulsed laser beams guided through different paths is provided, wherein the plurality of pulsed laser beams are emitted onto the

amorphous semiconductor at the same energy density include, in one pulse in a temporal intensity change, at least a first peak group appearing and a second peak group later appearing, and a maximum peak intensity of the first peak group is a maximum height in the one pulse, and

assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a previously determined reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the plurality of pulsed laser beams is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio and the plurality of pulsed laser beams are set such that between any of each pulsed laser beam, assuming that a maximum peak intensity ratio of one of the pulsed laser beams is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the other of the pulsed laser beams has a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

According to a second aspect of the invention, a crystalline semiconductor manufacturing apparatus is provided. The apparatus comprises

one or two or more laser light sources; and

an optical system guiding a plurality of pulsed laser beams to an amorphous semiconductor, the plurality of pulsed laser beams being outputted from the laser light sources, the plurality of pulsed laser beams are emitted onto the amorphous semiconductor at the same energy density and including, in one pulse in a temporal intensity change, at

least a first peak group appearing and a second peak group later appearing, a maximum peak intensity of the first peak group being a maximum height in the one pulse, and the plurality of pulsed laser beams being guided through different paths, wherein

the plurality of pulsed laser beams are set for each pulsed laser beam such that assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a previously determined reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio and the plurality of pulsed laser beams are set such that between any of each pulsed laser beam, assuming that a maximum peak intensity ratio of one of the pulsed laser beams is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the other of the pulsed laser beams has a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

Solution to Problem

[0008]

Specifically, a first aspect of the present invention according to a crystalline semiconductor manufacturing method

of the present invention is a crystalline semiconductor manufacturing method of crystallizing an amorphous semiconductor by irradiating the amorphous semiconductor with a plurality of pulsed laser beams guided through different paths, in which

the plurality of pulsed laser beams include, in one pulse in a temporal intensity change, at least a first peak group appearing and a second peak group later appearing, and a maximum peak intensity of the first peak group is a maximum height in the one pulse, and

assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the plurality of pulsed laser beams is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

[0009]

In the crystalline semiconductor manufacturing method of a second aspect of the present invention according to the first aspect of the present invention, the plurality of pulsed laser beams are emitted onto the amorphous semiconductor at mutually different pulse generation timings.

[0010]

In the crystalline semiconductor manufacturing method of a third aspect of the present invention according to the first or second aspect of the present invention, the

plurality of pulsed laser beams are outputted from a plurality of laser light sources.

[0011]

In the crystalline semiconductor manufacturing method of a fourth aspect of the present invention according to any one of the first to the third aspects of the present invention, the plurality of pulsed laser beams are emitted onto the amorphous semiconductor at the same energy density.

[0012]

In the crystalline semiconductor manufacturing method of a fifth aspect of the present invention according to any one of the first to the fourth aspects of the present invention, the maximum peak intensity ratio of the plurality of pulsed laser beams are within a preset predetermined range.

[0013]

In the crystalline semiconductor manufacturing method of a sixth aspect of the present invention according to any one of the first to the fifth aspects of the present invention, the reference maximum peak intensity ratio is a maximum peak intensity ratio of one pulsed laser beam of the plurality of pulsed laser beams.

[0014]

In the crystalline semiconductor manufacturing method of a seventh aspect of the present invention according to any one of the first to the sixth aspects of the present invention, the plurality of pulsed laser beams are set such that between any of each pulsed laser beam, assuming that a maximum peak intensity ratio of one of the pulsed laser beams is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the other of the pulsed laser

beams has a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

[0015]

In the crystalline semiconductor manufacturing method of an eighth aspect of the present invention according to any one of the first to the seventh aspects of the present invention, the amorphous semiconductor is an amorphous silicon thin film formed on a substrate.

[0016]

A crystalline semiconductor manufacturing apparatus of a ninth aspect of the present invention comprises: one or two or more laser light sources; and

an optical system guiding a plurality of pulsed laser beams to an amorphous semiconductor, the plurality of pulsed laser beams being outputted from the laser light sources, the plurality of pulsed laser beams including, in one pulse in a temporal intensity change, at least a first peak group appearing and a second peak group later appearing, a maximum peak intensity of the first peak group being a maximum height in the one pulse, and the plurality of pulsed laser beams being guided through different paths, wherein

the plurality of pulsed laser beams are set for each pulsed laser beam such that assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio is set to have a difference of less than or

equal to 4% with respect to the reference maximum peak intensity ratio.

[0017]

In the crystalline semiconductor manufacturing apparatus of a tenth aspect of the present invention according to the ninth aspect of the present invention, the plurality of pulsed laser beams are emitted onto the amorphous semiconductor at different pulse generation timings.

[0018]

In the crystalline semiconductor manufacturing apparatus of an eleventh aspect of the present invention according to the ninth or the tenth aspect of the present invention, the different pulse generation timings are given by the laser light sources and/or the optical system.

[0019]

In the crystalline semiconductor manufacturing apparatus of an eleventh aspect of the present invention according to any one of the ninth to the eleventh aspects of the present invention, the crystalline semiconductor manufacturing apparatus comprises a peak intensity ratio adjusting unit adjusting the maximum peak intensity ratio outputted from the laser light sources.

[0020]

In the crystalline semiconductor manufacturing apparatus of a thirteenth aspect of the present invention according to any one of the ninth to the twelfth aspects of the present invention, the crystalline semiconductor manufacturing apparatus comprises an energy density setting unit setting the energy density for emitting the plurality of pulsed laser

beams onto the amorphous semiconductor at the same energy density.

[0021]

In the crystalline semiconductor manufacturing apparatus of a fourteenth aspect of the present invention according to any one of the ninth to the thirteenth aspects of the present invention, the crystalline semiconductor manufacturing apparatus comprises a scanning apparatus relatively scanning and emitting the plurality of pulsed laser beams to the amorphous semiconductor.

[0022]

According to the present invention, when a plurality of pulsed laser beams guided through different paths are emitted onto an amorphous semiconductor to crystallize the amorphous semiconductor, each pulsed laser beam has, in one pulse in a temporal intensity change, a plurality of peak groups including a first peak group appearing and a second peak group later appearing, and a maximum peak intensity of the first peak group is a maximum height in the one pulse. Note that the present invention can allow three or more peak groups to appear in one pulse.

[0023]

The peak group in a pulsed laser beam refers to a group including one or more peaks appearing in close temporal proximity in one pulse, and at least two peak groups appear in one pulse. There is a minimum energy intensity between the peak groups.

[0024]

The plurality of pulsed laser beams can be pulsed laser beams outputted from a plurality of laser light sources, can

be pulsed laser beams obtained by splitting a pulsed laser beam outputted from a single laser light source, or a combination thereof. The path through which the plurality of pulsed laser beams are guided can be at least a partially different path including the light source and the optical system, and it is not excluded that the path has a common path.

[0025]

A study of the present inventors has revealed that a difference in 2nd/1st maximum peak intensity ratio correlates with a difference in irradiation energy density optimum for crystallization of an amorphous semiconductor.

Figures 6 to 8 are photographs (contrast emphasized) by an irregularity monitor of a polycrystalline silicon thin film obtained by crystallizing an amorphous silicon thin film by irradiation with pulsed laser beams with different energy density for each case of a 2nd/1st maximum peak intensity ratio of 18.2%, 23.0%, and 26.2%. It can be confirmed from these photographs that an optimum energy density is shifted.

[0026]

As illustrated in Figure 6, in a case of a 2nd/1st maximum peak intensity ratio of 18.2%, the least uneven polycrystalline silicon thin film surface is obtained at an irradiation energy density of 440 mJ/cm² among the irradiation energy densities of 430 mJ/cm², 440 mJ/cm², and 450 mJ/cm², so it is understood that 440 mJ/cm² is the optimum irradiation energy density.

In addition, as illustrated in Figure 7, in a case of a 2nd/1st maximum peak intensity ratio of 23.0%, the least uneven polycrystalline silicon thin film surface is obtained

at an irradiation energy density of 450 mJ/cm^2 among the irradiation energy densities of 440 mJ/cm^2 , 450 mJ/cm^2 , and 460 mJ/cm^2 , so it is understood that 450 mJ/cm^2 is the optimum irradiation energy density.

Further, as illustrated in Figure 8, in a case of a 2nd/1st maximum peak intensity ratio of 26.2%, the least uneven polycrystalline silicon thin film surface is obtained at an irradiation energy density of 460 mJ/cm^2 among the irradiation energy densities of 450 mJ/cm^2 , 460 mJ/cm^2 , and 470 mJ/cm^2 , so it is understood that 460 mJ/cm^2 is the optimum irradiation energy density.

[0027]

Note that irradiation irregularities of a crystal silicon film were evaluated by the following method.

Inspection light was emitted at five points on a crystal silicon film for each example. Reflected light was received from each point to acquire a color image. Color components of the color image were detected. Based on the detected color components, the color image was monochromatized. Then, data of the monochromatized image was convoluted to acquire image data with image shading emphasized, whereby the surface irregularities were evaluated.

Monochromatization can be performed using major color components of the detected color components. The major color components can have relatively larger light distribution than that of other color components.

The monochromatized image data is expressed as a matrix where each row indicates a laser beam direction and each column indicates a laser scanning direction. Convolution was

performed by multiplying a matrix of predetermined coefficients by a matrix of monochromatized image data.

The matrix of predetermined coefficients includes one for emphasizing the beam direction and one for emphasizing the scanning direction, each of which is used to acquire image data with emphasized image shading in the beam direction and image data with emphasized image shading in the scanning direction respectively as an irregularity monitor.

Specifically, the following convolution was performed. Note that the matrix of predetermined coefficients is not limited to the following.

[0028]

[Expression 1]

$$\begin{array}{l} \text{SHOT DIRECTION} \\ \text{SHADING EMPHASIS} \end{array} = \begin{array}{c} \left| \begin{array}{ccc} 2 & 2 & 2 \\ 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \\ -2 & -2 & -2 \end{array} \right| \end{array} * \text{IMAGE DATA} \quad (1)$$

$$\begin{array}{l} \text{SCAN DIRECTION} \\ \text{SHADING EMPHASIS} \end{array} = \begin{array}{c} \left| \begin{array}{ccccc} 2 & 1 & 0 & -1 & -2 \\ 2 & 1 & 0 & -1 & -2 \\ 2 & 1 & 0 & -1 & -2 \end{array} \right| \end{array} * \text{IMAGE DATA} \quad (2)$$

[0029]

Figure 9 is a graph illustrating the association between the thus obtained optimum energy density and the 2nd/1st maximum peak intensity ratio. Note that the graph also illustrates data other than the above described measurement results. As is apparent from the graph in Figure 9, the irradiation energy density optimum for crystallization increases as the 2nd/1st maximum peak intensity ratio increases.

[0030]

As described above, a difference in 2nd/1st maximum peak intensity ratio correlates with a difference in irradiation energy density optimum for crystallization of an amorphous semiconductor.

Accordingly, in the present invention, assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the plurality of pulsed laser beams is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

[0031]

It is difficult to adjust the maximum peak intensity ratio after it is outputted from the laser light source, and hence the maximum peak intensity ratio is usually set when it is outputted from the laser light source. The maximum peak intensity ratio can be set by the adjustment of the output from the laser light source, the setting of an output circuit, adjustment of the mixing ratio of a gas serving as a medium, and other adjustments.

[0032]

Note that the reference maximum peak intensity ratio can be set using an initial maximum peak intensity ratio in one pulsed laser beam of a plurality of pulsed laser beams or can be previously determined experimentally. Alternatively, the maximum peak intensity ratio of a pulsed laser beam in an

immediately preceding irradiation can be set as the reference maximum peak intensity ratio. Further, the maximum peak intensity ratio of one pulsed laser beam between any of a plurality of pulsed laser beams is defined as a reference maximum peak intensity ratio, and the maximum peak intensity ratio of the other of the pulsed laser beams can be set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

[0033]

As described above, the maximum peak intensity ratio is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio. The reason for this follows.

As illustrated in Figure 10, the energy density can be expressed as a sum of the time-integrated energy intensity in a first peak group in one pulse and the time-integrated energy intensity in a second peak group. Note also that the energy density optimum for crystallization of an amorphous semiconductor is constant on the same substrate. The optimum energy density is affected by a laser pulse waveform, specifically the maximum peak intensity ratio. The area of a pulse waveform corresponds to the associated energy density. The optimum energy density on a normal amorphous silicon thin film has an allowable width of about 10 mJ/cm² (OED range: optimum energy density range). Crystallization by laser processing is equally performed within the allowable width. In order to satisfy the allowable width, the maximum peak intensity ratio needs to have a difference within 4%. Therefore, the difference is set to less than or equal to 4%.

[0034]

For example, assuming that the peak intensity is expressed as arbitrary units, in the case where the 2nd/1st maximum peak intensity ratio is 18.2%, when the relative numeric value of the maximum peak intensity in the first peak group is 100 and the relative numeric value of the maximum peak intensity of the second peak group is 18.2, the optimum energy density is 439.5 mJ/cm². In the case where the 2nd/1st maximum peak intensity ratio is 23.1%, when the relative numeric value of the maximum peak intensity in the first peak group is 93 and the relative numeric value of the maximum peak intensity of the second peak group is 21.5, the optimum energy density is 451.3 mJ/cm². In the case where the 2nd/1st maximum peak intensity ratio is 26.2%, when the relative numeric value of the maximum peak intensity in the first peak group is 89 and the relative numeric value of the maximum peak intensity of the second peak group is 23.5, the optimum energy density is 459.2 mJ/cm².

From these relationships, when linear regression by least squares method is performed, a line A in Figure 9 is obtained. Based on the line A, for example, in the case the 2nd/1st maximum peak intensity ratio is 22.4%, the optimum energy density width (10 mJ/cm²) is within a range from 455 mJ/cm² to 445 mJ/cm². The 2nd/1st maximum peak intensity ratio corresponding to the optimum energy density 445 mJ/cm² is 20.44%, and the 2nd/1st maximum peak intensity ratio corresponding to the optimum energy density 455 mJ/cm² is 24.49%. When the width is expressed as a difference between the maximum peak intensity ratios, 24.49% - 20.44% = 4.05%. Thus, if the difference between the maximum peak intensity

ratios is less than or equal to 4%, the energy density can be within the allowable range in the optimum energy density.

[0035]

Note that a plurality of pulsed laser beams can be emitted onto the amorphous semiconductor at mutually different pulse generation timings thereby to increase the number of pulses emitted onto the amorphous semiconductor per unit time and enlarge the pulse width in a pseudo manner.

The mutually different pulse generation timings can be obtained at output from the laser light source, or can be obtained by a phase difference given in the middle of the path. The phase difference can be given by splitting, but the means of splitting the pulsed laser beam is not particularly limited and a beam splitter or the like can be used as needed.

When the pulsed laser beams are emitted onto the amorphous semiconductor at different pulse generation timings, the pulses can be not be overlapped with each other or the pulses can be partially overlapped.

[0036]

In addition, a variable attenuator capable of adjusting the transmittance of the pulsed laser beams can be provided in the pulsed laser beam path. The pulsed laser beams can be emitted onto the amorphous semiconductor at a desired energy density by the variable attenuator. Further, the plurality of pulsed laser beams can be emitted onto the amorphous semiconductor at a common energy density.

Note that the energy density of the pulsed laser beams can be performed by one or both of the output control of the pulsed laser light source and the variable attenuator.

Advantageous Effects of Invention

[0037]

As described above, the present invention is a crystalline semiconductor manufacturing method of irradiating an amorphous semiconductor with a plurality of pulsed laser beams guided through different paths and thereby crystallizing the amorphous semiconductor, in which

the plurality of pulsed laser beams include, in one pulse in a temporal intensity change, at least a first peak group appearing and a second peak group later appearing, and a maximum peak intensity of the first peak group is a maximum height in the one pulse,

assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the plurality of pulsed laser beams is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio. Thus, the present invention can more uniformly crystallize an amorphous semiconductor.

Brief Description of Drawings

[0038]

[Figure 1] Figure 1 is a schematic view illustrating a laser annealing apparatus according to an embodiment of the present invention.

[Figure 2] Figure 2 is a schematic view illustrating a measurement configuration of pulsed laser beams according to the embodiment of the present invention.

[Figure 3] Figure 3 is a graph illustrating an example of a pulse waveform of the pulsed laser beam according to the embodiment of the present invention.

[Figure 4] Figure 4 is an explanatory drawing describing maximum peak intensity ratio of the pulsed laser beams outputted from two pulsed laser light sources according to the embodiment of the present invention.

[Figure 5] Figure 5 is an explanatory drawing describing superposition of the pulsed laser beams outputted from two pulsed laser light sources according to the embodiment of the present invention.

[Figure 6] Figure 6 is a drawing substitute photograph by an irregularity monitor of a polycrystalline silicon thin film obtained by crystallizing an amorphous silicon thin film by irradiation with the pulsed laser beams with the energy density changed at a maximum peak intensity ratio of 18.2% according to the embodiment of the present invention.

[Figure 7] Figure 7 is a drawing substitute photograph by the irregularity monitor of the polycrystalline silicon thin film obtained by crystallizing the amorphous silicon thin film by irradiation with the pulsed laser beams with the energy density changed at a maximum peak intensity ratio of 23.0% according to the embodiment of the present invention.

[Figure 8] Figure 8 is a drawing substitute photograph by the irregularity monitor of the polycrystalline silicon thin film obtained by crystallizing the amorphous silicon thin film by irradiation with the pulsed laser beams with the energy

density changed at a maximum peak intensity ratio of 26.2% according to the embodiment of the present invention.

[Figure 9] Figure 9 is a graph illustrating a relationship between the ratio of the maximum peak intensity of the first peak group in the pulsed laser beams to the maximum peak intensity of a second peak group and the irradiation energy density optimum for crystallization according to the embodiment of the present invention.

[Figure 10] Figure 10 is an explanatory drawing describing the reason why the maximum peak intensity ratio of the other pulsed laser beams other than the reference pulsed laser beam is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio according to the embodiment of the present invention.

Description of Embodiments

[0039]

An embodiment of the present invention will be described based on the accompanying drawings.

First, a crystalline semiconductor manufacturing apparatus according to the present embodiment will be described with reference to Figures 1 and 2.

As illustrated in Figure 1, a laser annealing apparatus 1 corresponding to the crystalline semiconductor manufacturing apparatus includes two pulsed laser light sources 2 and 3 that output pulsed laser beams.

Each of the pulsed laser light sources 2 and 3 is, for example, an excimer laser oscillation light source that outputs a pulsed laser beam with a wavelength of 308 nm and a pulse frequency of 1 to 600 Hz.

[0040]

There is disposed, on an output side of the pulsed laser light source 2, a variable attenuator 4 which can adjust the attenuation rate of the pulsed laser beam outputted from the pulsed laser light source 2. In addition, there is disposed, on an output side of the pulsed laser light source 3, a variable attenuator 5 which can adjust the attenuation rate of the pulsed laser beam outputted from the pulsed laser light source 3.

[0041]

There is disposed, on an output side of the variable attenuator 4, a one-way mirror 6 which transmits a part of the pulsed laser beam outputted from the variable attenuator 4 for measurement and reflects the remaining part thereof for processing.

As illustrated in Figure 2, there can be disposed, on the transmission side of the one-way mirror 6, a light-receiving unit 7a of a measurement instrument 7 that measures a waveform of the pulsed laser beam. The measurement instrument 7 is electrically connected to a control unit 8. The measurement result of the measurement instrument 7 is outputted to the control unit 8.

[0042]

There is disposed, on an output side of the variable attenuator 5, a mirror 9, one surface of which reflects the pulsed laser beam reflected from the one-way mirror 6 toward an optical system 12, and the other surface of which reflects the pulsed laser beam outputted from the variable attenuator 5.

There is disposed, on the other surface reflection side of the mirror 9, a one-way mirror 10 which transmits a part of the pulsed laser beam reflected from the mirror 9 for measurement and reflects the remaining part thereof to the optical system 12 for processing.

[0043]

As illustrated in Figure 2, there can be disposed, on the transmission side of the one-way mirror 10, a light-receiving unit 11a of a measurement instrument 11 that measures a waveform of the pulsed laser beam. The measurement instrument 11 is electrically connected to the control unit 8. The measurement result of the measurement instrument 11 is outputted to the control unit 8.

[0044]

The optical system 12 is configured to guide two pulsed laser beams: a pulsed laser beam reflected from one reflection surface of the mirror 9 and a pulsed laser beam reflected from the one-way mirror 10, so as to perform processing such as shaping of the beam shape and output them to the same path. The optical system 12 includes, for example, a mirror, a lens, and a homogenizer.

In the present invention, the configuration of the optical system is not particularly limited and a plurality of optical systems can be provided according to the number of pulsed laser beams.

[0045]

The pulsed laser light sources 2 and 3, and the variable attenuators 4 and 5 are controllably connected to the control unit 8. The control unit 8 performs entire control of the laser annealing apparatus 1 such as output adjustment and

setting of the pulse start timing for the pulsed laser light sources 2 and 3, and control of the attenuation rate for the variable attenuators 4 and 5.

The control unit 8 can include a CPU, programs for operating the CPU, a ROM for storing the programs etc., a RAM for work area, a flash memory for holding data in a nonvolatile manner, and the like.

The control unit 8 can adjust the maximum peak intensity ratio of the pulsed laser beam by output adjustment of the pulsed laser light sources 2 and 3. Alternatively, the control unit 8 can perform control so as to adjust the gas mixing ratio of the pulsed laser light sources 2 and 3, thereby to resultantly adjust the maximum peak intensity ratio of the pulsed laser beam. In terms of these controls, the control unit 8 corresponds to a peak intensity ratio adjusting unit.

[0046]

Note that the energy density of the pulsed laser beam on the amorphous semiconductor can be set by the output adjustment of the pulsed laser light sources 2 and 3 by the control unit 8 and the adjustment of the attenuation rate by the variable attenuators 4 and 5. In other words, the control unit 8 and the variable attenuators 4 and 5 correspond to an energy density setting unit.

[0047]

There is disposed, on an output side of the optical system 12, a one-way mirror 13 which transmits a part of the plurality of pulsed laser beams for measurement and reflects the remaining part thereof for processing.

There is disposed, on the transmission side of the one-way mirror 13, a light-receiving unit 14a of a measurement instrument 14 that measures an energy density of each pulsed laser beam. The measurement instrument 14 is electrically connected to a control unit 8. The measurement result of the measurement instrument 14 is outputted to the control unit 8.

[0048]

There is disposed, on a reflecting side of the one-way mirror 13, a stage 16 which holds a substrate 15 on which an amorphous semiconductor film 15a is formed. The substrate 15 is, for example, a glass substrate. The amorphous semiconductor film 15a is, for example, an amorphous silicon thin film.

[0049]

The stage 16 can move along a surface direction (XY direction) of the stage 16. The stage 16 includes a moving apparatus 17 that fast moves the stage 16 along the surface direction.

[0050]

Now, the description focuses on a method of manufacturing a semiconductor using the amorphous semiconductor film 15a as a raw material by the laser annealing apparatus 1.

The substrate 15 is placed and held on the stage 16. A non-crystalline semiconductor film 15a to be crystallized is formed on an upper layer of the substrate 15.

According to the present invention, an amorphous silicon thin film formed on the substrate is suitably used for the amorphous semiconductor. A polycrystalline silicon thin film can be obtained by crystallizing the amorphous silicon thin

film. The amorphous silicon thin film is usually formed to have a thickness of 45 to 55 nm, but the present invention is not particularly limited to this thickness.

Note that a glass substrate is usually used for the substrate, but the present invention is not particularly limited to this material and the other materials can be used for the substrate.

[0051]

Then, the control unit 8 controls the pulsed laser light sources 2 and 3 to output each pulsed laser beam from the pulsed laser light sources 2 and 3. Each pulsed laser beam has the same wavelength and the same repetition frequency but a different pulse start timing thereby to have a phase difference on the amorphous semiconductor film. The pulse start timing of each pulsed laser beam is set so as to have a phase difference with respect to the repetition frequency between the different pulsed laser beams, and then each pulsed laser beam is emitted onto the amorphous semiconductor film 15a at mutually different pulse generation timings.

[0052]

As illustrated in Figure 3, the pulsed laser beam outputted from the pulsed laser light sources 2 and 3 such as excimer laser oscillators has, in one pulse in a temporal change, a first peak group P1 appearing and a second peak group P2 later appearing. In addition, the maximum peak intensity a of the first peak group P1 is greater than the maximum peak intensity b of the second peak group P2 and the maximum peak intensity a is the maximum height in one pulse.

[0053]

Figure 3 illustrates a pulse waveform in a case where the same excimer laser oscillator is used and the output energy thereof is set to 850 mJ, 950 mJ, and 1050 mJ. The higher the output energy, the larger the maximum peak intensity ratio b/a (hereinafter referred to as "2nd/1st maximum peak intensity ratio" as needed), and the lower the output energy, the smaller the maximum peak intensity ratio b/a .

[0054]

Each pulsed laser beam outputted from the pulsed laser light sources 2 and 3 reaches the variable attenuators 4 and 5 respectively, through which each pulsed laser beam is attenuated at a predetermined attenuation rate. The control unit 8 controls the attenuation rate such that each pulsed laser beam outputted from the pulsed laser light sources 2 and 3 is adjusted to have the same energy density on the amorphous semiconductor film 15a.

A part of the pulsed laser beam attenuated and outputted by the variable attenuator 4 is transmitted and the remaining part thereof is reflected by the one-way mirror 6. The pulsed laser beam transmitted through the one-way mirror 6 is received by the light-receiving unit 7a, and then the pulse waveform is measured by the measurement instrument 7. The measurement result of the pulse waveform by the measurement instrument 7 is sent to the control unit 8.

The remaining part of the pulsed laser beam reflected by the one-way mirror 6 is reflected on one reflection surface of a total reflection mirror 9 and introduced into the optical system 12.

[0055]

The pulsed laser beam attenuated and outputted by the variable attenuator 5 is reflected by the other reflection surface of the mirror 9 and enters the one-way mirror 10. A part of the pulsed laser beam entering the one-way mirror 10 is transmitted through the one-way mirror 10 and received by the light-receiving unit 11a, and the remaining part thereof is reflected and enters the optical system 12. The pulse waveform of the pulsed laser beam received by the light-receiving unit 11a is measured by the measurement instrument 11. The measurement result of the pulse waveform by the measurement instrument 11 is sent to the control unit 8.

[0056]

Based on the measurement results of the pulse waveforms obtained by the measurement instruments 7 and 11, the control unit 8 calculates the ratio between the maximum peak intensity of the first peak group and the maximum peak intensity of the second peak group as the maximum peak intensity ratio.

More specifically, as illustrated in Figure 4, regarding the pulsed laser beam outputted from the pulsed laser light source 2, the 2nd/1st maximum peak intensity ratio $R1$ is expressed as a ratio $b1/a1$ of the maximum peak intensity $b1$ of the second peak group to the maximum peak intensity $a1$ of the first peak group. Meanwhile, regarding the pulsed laser beam outputted from the other pulsed laser light source 3, the 2nd/1st maximum peak intensity ratio $R2$ is expressed as a ratio $b2/a2$ of the maximum peak intensity $b2$ of the second peak group to the maximum peak intensity $a2$ of the first peak group.

The present embodiment controls such that assuming that the initial value of the maximum peak intensity ratio R_1 is a reference maximum peak intensity ratio R_0 , the subsequent maximum peak intensity ratio R_1 and the maximum peak intensity ratio R_2 have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio R_0 .

[0057]

The control method is such that the variation in maximum peak intensity ratio can be adjusted to less than or equal to 4% by adjusting the output of the pulsed laser light sources 2 and 3. It is apparent from Figure 3 that an output change in pulsed laser beam appears as the maximum peak intensity ratio.

The variation in energy density due to the output adjustment of the pulsed laser light sources 2 and 3 is canceled by adjusting the attenuation rate of the variable attenuators 4 and 5. The adjustment of the attenuation rate by the variable attenuators 4 and 5 hardly affects the maximum peak intensity ratio, and hence the attenuation rate can be adjusted for the purpose of only adjusting the energy density.

[0058]

Each pulsed laser beam whose maximum peak intensity ratio has a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio is subjected to desired shaping by the optical system 12 and then guided out onto the same optical path. A part of the plurality of pulsed laser beams outputted from the optical system 12 is transmitted through the one-way mirror 13 and

received by the light-receiving unit 14a, and the remaining part thereof is reflected by the one-way mirror 13 and emitted onto the amorphous semiconductor film 15a. As the amorphous semiconductor film 15a moves together with the stage 16 moved by the moving apparatus 17, the pulsed laser beams are emitted while being relatively scanned.

In addition, regarding each pulsed laser beam received by the light-receiving unit 14a, the attenuation rates of the variable attenuators 4 and 5 are set so that each pulsed laser beam has the same energy density in the measurement result by the measurement instrument 14. The light receiving position of the light-receiving unit 14a is set to a position assuming the irradiation surface on the amorphous semiconductor film 15a.

[0059]

The same energy density is maintained on the amorphous semiconductor film 15a and the maximum peak intensity ratio is maintained thereon to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio, whereby the amorphous film is uniformly and satisfactorily crystallized. The above adjustment of the maximum peak intensity ratio can reduce the difference in the maximum peak intensity ratio between the pulsed laser beams outputted from the different pulsed laser light sources 2 and 3 and can also reduce the temporal change.

[0060]

The pulsed laser light sources 2 and 3 preferably output the pulsed laser beams at mutually different pulse generation timings so that each pulsed laser beam is not overlapped with

each other and has a predetermined phase difference with respect to the repetition frequency.

More specifically, for example, as illustrated in Figure 5, in a case where both the pulsed laser light sources 2 and 3 output the pulsed laser beams at a pulse frequency of 600 Hz, the pulsed laser light source 3 outputs the pulsed laser beams at a pulse generation timing with a half cycle delay to the pulsed laser light source 2. As a result, the amorphous semiconductor film 15a is substantially irradiated with the pulsed laser beams at a pulse frequency of 1200 Hz, which is twice that of the pulsed laser light sources 2 and 3.

By irradiating the amorphous semiconductor with the pulsed laser beams at mutually different pulse generation timings, the pulse frequency can be substantially increased and irradiation with pulsed laser beams can be performed with high productivity.

[0061]

Note that the above description has focused on the embodiment using two pulsed laser light sources 2 and 3, but more than two pulsed laser light sources can be used.

Note also that the above embodiment relatively scans the pulsed laser beam by moving the stage 16, but can relatively scan the pulsed laser beam by fast moving the optical system guiding the pulsed laser beam.

Note also that the above description has focused on the embodiment in which the amorphous semiconductor film is irradiated with a plurality of pulsed laser beams at the same energy density, but the amorphous semiconductor film can be set to be irradiated with the plurality of pulsed laser beams at different energy densities.

[0062]

Hereinbefore, the present invention has been described based on the above embodiment, but the present invention is not limited to the content of the above embodiment, and appropriate modifications can be made without departing from the scope of the present invention.

Reference Signs List

[0063]

- 1 laser annealing apparatus
- 2 pulsed laser light source
- 3 pulsed laser light source
- 4 variable attenuator
- 5 variable attenuator
- 6 one-way mirror
- 7 measurement instrument
- 7a light-receiving unit
- 8 control unit
- 9 total reflection mirror
- 10 one-way mirror
- 11 measurement instrument
- 11a light-receiving unit
- 12 optical system
- 13 one-way mirror
- 14 measurement instrument
- 14a light-receiving unit
- 15 substrate
- 15a amorphous semiconductor film
- 16 stage
- 17 moving apparatus

Claims

[Claim 1]

A crystalline semiconductor manufacturing method of crystallizing an amorphous semiconductor by irradiating the amorphous semiconductor with a plurality of pulsed laser beams guided through different paths, wherein

the plurality of pulsed laser beams are emitted onto the amorphous semiconductor at the same energy density, include, in one pulse in a temporal intensity change, at least a first peak group appearing and a second peak group later appearing, and a maximum peak intensity of the first peak group is a maximum height in the one pulse, and

assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a previously determined reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the plurality of pulsed laser beams is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio, and

the plurality of pulsed laser beams are set such that between any of each pulsed laser beam, assuming that a maximum peak intensity ratio of one of the pulsed laser beams is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the other of the pulsed laser beams has a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

[Claim 2]

The crystalline semiconductor manufacturing method according to claim 1, wherein the plurality of pulsed laser beams are emitted onto the amorphous semiconductor at mutually different pulse generation timings.

[Claim 3]

The crystalline semiconductor manufacturing method according to claim 1 or 2, wherein the plurality of pulsed

laser beams are outputted from a plurality of laser light sources.

[Claim 4]

The crystalline semiconductor manufacturing method according to any one of claims 1 to 3, wherein the maximum peak intensity ratio of the plurality of pulsed laser beams are within a preset predetermined range.

[Claim 5]

The crystalline semiconductor manufacturing method according to any one of claims 1 to 4, wherein the amorphous semiconductor is an amorphous silicon thin film formed on a substrate.

[Claim 6]

A crystalline semiconductor manufacturing apparatus comprising:

one or two or more laser light sources; and

an optical system guiding a plurality of pulsed laser beams to an amorphous semiconductor, the plurality of pulsed laser beams being outputted from the laser light sources, the plurality of pulsed laser beams are emitted onto the amorphous semiconductor at the same energy density, including, in one pulse in a temporal intensity change, at least a first peak group appearing and a second peak group later appearing, a maximum peak intensity of the first peak group being a maximum height in the one pulse, and the plurality of pulsed laser beams being guided through different paths, wherein

the plurality of pulsed laser beams are set for each pulsed laser beam such that assuming that a maximum peak intensity ratio is defined as a ratio b/a between the maximum peak intensity a of the first peak group and the maximum peak intensity b of the second peak group, and the maximum peak intensity ratio serving as a previously determined reference is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio is set to have a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio, and

the plurality of pulsed laser beams are set such that between any of each pulsed laser beam, assuming that a maximum peak intensity ratio of one of the pulsed laser beams is defined as a reference maximum peak intensity ratio, the maximum peak intensity ratio of the other of the pulsed laser beams has a difference of less than or equal to 4% with respect to the reference maximum peak intensity ratio.

[Claim 7]

The crystalline semiconductor manufacturing apparatus according to claim 6, wherein the plurality of pulsed laser

beams are emitted onto the amorphous semiconductor at different pulse generation timings.

[Claim 8]

The crystalline semiconductor manufacturing apparatus according to claim 6 or 7, wherein the different pulse generation timings are given by the laser light sources and/or the optical system.

[Claim 9]

The crystalline semiconductor manufacturing apparatus according to any one of claims 6 to 8, comprising a peak intensity ratio adjusting unit adjusting the maximum peak intensity ratio outputted from the laser light sources.

[Claim 10]

The crystalline semiconductor manufacturing apparatus according to any one of claims 6 to 9, comprising an energy density setting unit setting the energy density for emitting the plurality of pulsed laser beams onto the amorphous semiconductor at the same energy density.

[Claim 11]

A crystalline semiconductor manufacturing apparatus according to any one of claims 6 to 10, comprising a scanning apparatus relatively scanning and emitting the plurality of pulsed laser beams to the amorphous semiconductor.