Description

Title of Invention: MANUFACTURING METHOD AND MANUFACTURING APPARATUS OF CRYSTAL SEMICONDUCTOR FILM

Technical Field

[0001] The present invention relates to a manufacturing method and a manufacturing apparatus of a crystal semiconductor film that crystallize an amorphous film and reform a crystal film by moving a pulse laser having a section in a rectangular shape while irradiating a semiconductor film with the pulse laser a plurality of times (overlap irradiation).

Background Art

[0002] Thin film transistors which are generally used in TVs and PC displays are composed of amorphous (noncrystalline) silicon (hereinafter, called a-silicon), and performance as TFTs can be significantly enhanced by using silicon crystallized by some means (hereinafter, called p-silicon). At present, as a Si crystallization process at a low temperature, an excimer laser anneal technique is already put to practical use, is frequently used for applications to compact displays such as smartphones, and is further put to practical use in large screen displays and the like.

[0003] The laser anneal method is designed so that by irradiating a noncrystalline semiconductor film with an excimer laser having high pulse energy, the semiconductor absorbing light energy is brought into a melting or semi-melting state, and is cooled thereafter and is crystallized when solidified. At this time, in order to process a wide region, the pulse laser which is shaped into a line beam shape is applied while the pulse laser is caused to scan relatively in a short axis direction. Usually, scanning of the pulse laser is performed by moving a placement table on which the noncrystalline semiconductor film is placed.

In the scanning of the above described pulse laser, the pulse laser is moved in a scan direction at predetermined pitches so that the pulse laser is applied a plurality of times (overlap irradiation) on the same position of the noncrystalline semiconductor film. Thereby, laser anneal processing for a semiconductor film having a large size is enabled.

[0004] In the conventional laser anneal processing using a line beam, a beam width in the scan direction of a laser pulse is fixed to, for example, around 0.35 to 0.4 mm, a substrate feeding amount at each pulse is set at around 3% to 8% of the beam width, and it is considered to be necessary to increase the number of irradiation times of a laser as many times as the laser can be

applied, in order to ensure uniformity of performance of a plurality of thin film transistors.

For example, in a semiconductor film for a LCD (Liquid Crystal Display), the overlap rate is set at 92 to 95% (the number of irradiation times of 12 to 20, a scanning pitch of 32 to 20 μm in the case of a beam width of 0.4 mm), and in a semiconductor film for an OLED (Organic Light-Emitting Diode), the overlap rate is set at 93.8 to 97% (the number of irradiation times of 16 to 33, a scanning pitch of 25 to 12 μm in the case of a beam width of 0.4 mm).

[0005] In the laser anneal processing as described above, uniformity of processing in the short axis direction and the long axis direction is usually achieved by making the intensity distribution of the beam section have a flat shape. In contrast to this, Patent Literature 1 indicates that a poorly crystallized region is generated in accordance with variation in laser energy, and proposes the method for recrystallizing or reactivating a portion where film quality is degraded due to variation in energy intensity while keeping a portion where sufficient crystallization or activation is achieved, by irradiating with a laser with lower energy after sufficient crystallization processing.

Citation List

Patent Literature

[0006] Patent Literature 1: Japanese Patent Laid-Open No. 10-12548

Summary of Invention

Technical Problem

[0007] The variation in laser energy which is regarded as a problem in Patent Literature 1 is due to variation in the output of a laser light source. The variation in the output of the laser light source has been considerably improved by improvement in an oscillation circuit, improvement in the laser light source itself and the like, and a problem of poor crystallization due to the variation in the output gradually becomes smaller. In addition, by performing overlap many times, a pulse laser is applied on the same irradiation surface many times by being superimposed on one another. Therefore, the poorly crystallized region which is generated due to variation in the output is re-melted and crystallized, and the inferior region can be eliminated.

[0008] However, according to the careful observation by the present inventors, it is found out that irradiation unevenness is recognized in the semiconductors which are crystallized by irradiation of a pulse laser even in the present situation, and this becomes the cause of an influence on performance at the time of the semiconductors being made as devices.

According to the study of the inventors of the present application, it is conceivable that the above described irradiation unevenness is caused by formation of swelling of a polysilicon film at an edge portion (at a rear end side in the scan direction) in the scan direction of the line beam (normally, a short axis direction). This portion corresponds to a boundary between the melting portion of the semiconductor film by laser irradiation and a portion which remains to be a solid without being irradiated with a laser. The swelling is considered to become large proportionally to the intensity of irradiation energy. That is to say, as the irradiation energy becomes larger, melting advances in a film thickness direction of the semiconductor film, and even after the entire film is melted, a temperature of the semiconductor film layer which has become liquid increases. It is conceivable that swelling occurs because when the liquid phase portion is crystallized in conjunction with a drop of temperature, a liquid is solidified while being attracted by an interface of solid and liquid phases where the temperature starts to drop more precedently, that is, a line beam short axis edge portion. Further, an energy fluctuation of a laser, a change in a line beam short axis shape, deviations of the positions of the semiconductor film which moves relatively to the beam and the like become deviations of the height of the aforementioned "swelling portion" and

the intervals, and are recognized as irradiation unevenness.

Accordingly, if the pulse laser is applied by making the irradiation energy density low, the above described irradiation unevenness can be reduced, but for this purpose, it is necessary to apply a laser on the same irradiation surface a larger number of irradiation times, and the production efficiency is declined. Further, if the irradiation pulse energy density becomes too low, there arises a problem that the crystal grain size does not become sufficiently large.

[0009] The present invention is made against the backdrop of the above described circumstances, and one of objects of the invention is to provide a manufacturing method and a manufacturing apparatus of a crystal semiconductor film that can eliminate irradiation unevenness on a semiconductor film by an edge portion in a scan direction of a pulse laser in addition to restraining reduction in productivity as much as possible.

Solution to Problem

[0010] That is to say, in a manufacturing method of a crystal semiconductor film of the present invention, a first present invention is a manufacturing method of a crystal semiconductor film that performs crystallization by applying overlap irradiation while causing a pulse

laser to scan relatively in a short axis direction, onto a non-single-crystal semiconductor film, having,

with an irradiation pulse energy density which is lower than an irradiation pulse energy density with which microcrystallization occurs to the non-single-crystal semiconductor film by irradiation of the pulse laser, and is suitable for crystallization by irradiation of a plurality of times N being set as E0,

a first step of irradiating with the pulse laser having an irradiation pulse energy density E1 which is the same as the irradiation pulse energy density E0, and

a second step of irradiating with the pulse laser having irradiation pulse energy E2 which is lower than the irradiation pulse energy density E1, and is equal to or higher than an irradiation energy density that is necessary for a crystal to be remelted,

wherein the total number of irradiation times to the same irradiation surface in the first step and the second step is equal to or larger than N times.

[0011] The manufacturing method of a crystal semiconductor film of a second present invention is such that in the first present invention, the irradiation pulse energy suitable for crystallization is within a range of E × 0.98 to E × 1.03 where an irradiation pulse energy density with which crystal grain size growth is saturated by irradiation of the plurality of times N is E.

[0012] The manufacturing method of a crystal semiconductor film of a third present invention is such that in the first or the second present invention, the irradiation pulse energy density E2 is equal to or higher than E1 × 0.95.

[0013] The manufacturing method of a crystal semiconductor film of a fourth present invention is such that in any of the first present invention to the third present invention, the total number of irradiation times is equal to or smaller than N × 1.5.

[0014] The manufacturing method of a crystal semiconductor film of a fifth present invention is such that in any of the first present invention to the fourth present invention, irradiation of a plurality of times N1 to the same irradiation surface is sequentially performed while the pulse laser is caused to scan by the first step, thereafter, to the predetermined surface, irradiation of a plurality of times N2 to the same irradiation surface is sequentially performed while the pulse laser is caused to scan by the second step, and the N1 + N2 is set as the total number of irradiation times and is made equal to or larger than N times.

[0015] The manufacturing method of a crystal semiconductor film of a sixth present invention is such that in the fifth present invention, the N1 is made the number of times which is equal to or larger than the N2.

[0016] The manufacturing method of a crystal semiconductor film of a seventh present invention is such that in any of the first present invention to the sixth present invention, in a beam section intensity distribution in a scan direction, the pulse laser has lower intensity at a rear side in the scan direction to a rear end in the scan direction than intensity at a front side in the scan direction, and irradiation of the first step is performed in accordance with the intensity at the front side in the scan direction, whereas irradiation of the second step is performed in accordance with the intensity at the rear side in the scan direction.

[0017] The manufacturing method of a crystal semiconductor film of an eighth present invention is such that in the seventh present invention, a width in the scan direction at the front side in the scan direction is equal to or larger than a width in the scan direction at the rear side in the scan direction.

[0018] The manufacturing method of a crystal semiconductor film of a ninth present invention is such that in any of the first present invention to the eighth present invention, a wavelength of the pulse laser is equal to or shorter than 400 nm.

[0019] The manufacturing method of a crystal semiconductor film of a tenth present invention is such that in any of the first present invention to the ninth

present invention, a full width at half maximum of the pulse laser is equal to or smaller than 200 ns.

[0020] The manufacturing method of a crystal semiconductor film of an eleventh present invention is such that in any of the first present invention to the tenth present invention, the non-single-crystal semiconductor is of silicon.

[0021] A manufacturing apparatus of a crystal semiconductor film of a twelfth present invention includes

one or two or more laser light sources that outputs or output a pulse laser,

an optical system that shapes the pulse laser and guides the pulse laser to a non-single-crystal semiconductor,

an energy regulating section that regulates an irradiation energy density of the pulse laser,

a scanning device that causes the pulse laser to scan relatively to the non-single-crystal semiconductor, and

a control section that controls the laser light source, the energy regulating section and the scanning device,

wherein the control section executes a first step of controlling the energy regulating section to regulate the irradiation pulse energy density to an irradiation pulse energy density E1 which is lower than an irradiation

pulse energy density with which microcrystallization occurs to the non-single-crystal semiconductor film by irradiation of the pulse laser, and is the same as an irradiation pulse energy density E0 which is suitable for crystallization by irradiation of a plurality of times N, and sequentially performing irradiation of a plurality of times N1 (N1 < N) to the non-single-crystal semiconductor while causing the pulse laser to scan by controlling the scanning device, with the irradiation pulse energy density E1, and a second step of controlling the energy regulating section to regulate the irradiation pulse energy density to irradiation pulse energy E2 which is lower than the irradiation pulse energy density E1, and is equal to or higher than an irradiation energy density necessary for a crystal to be remelted, and sequentially performing irradiation of a plurality of times N2 (N2 < N, N1 + N2 ≥ N) to the non-single-crystal semiconductor while causing the pulse laser to scan by controlling the scanning device, with the irradiation pulse energy density E2, to the semiconductor irradiated with the pulse laser in the first step.

[0022] A manufacturing apparatus of a crystal semiconductor film of a thirteenth present invention includes

one or two or more laser light sources that outputs or output a pulse laser,

an optical system that shapes the pulse laser and guides the pulse laser to a non-single-crystal semiconductor,

an intensity regulating section that regulates, in a beam section intensity distribution in a scan direction of the pulse laser, the intensity distribution so that intensity at a rear side in the scan direction to a rear end in the scan direction becomes lower than intensity at a front side in the scan direction, and an irradiation pulse energy density by the intensity at the rear side in the scan direction becomes 0.95 times or more an irradiation pulse energy density by the intensity at the front side in the scan direction,

an energy regulating section that regulates an irradiation energy density of the pulse laser,

a scanning device that causes the pulse laser to scan relatively to the non-single-crystal semiconductor, and

a control section that controls the laser light source, the energy regulating section and the scanning device,

wherein the control section executes a step of controlling the energy regulating section to perform regulation so that in irradiation at the front side in the scan direction of the pulse laser, an irradiation pulse energy density becomes an irradiation pulse energy density E1 which is lower than an irradiation pulse

energy density with which microcrystallization occurs to the non-single-crystal semiconductor film, and is the same as an irradiation pulse energy density E0 which is suitable for crystallization by irradiation of a plurality of times N, and in irradiation at the rear side in the scan direction of the pulse laser, an irradiation pulse energy density becomes an irradiation pulse energy E2 which is lower than the irradiation pulse energy density E1, and is equal to or higher than an irradiation energy density which is necessary for a crystal to be remelted, and sequentially performing irradiation of a plurality of times which is equal to or larger than the N times to the non-single-crystal semiconductor while causing the pulse laser to scan by controlling the scanning device.

[0023] The manufacturing apparatus of a crystal semiconductor film of a fourteenth present invention is such that in the twelfth or the thirteenth present invention, the control section sets the irradiation pulse energy suitable for crystallization to be within a range of $E \times 0.98$ to $E \times 1.03$ where an irradiation pulse energy density with which crystal grain size growth is saturated by irradiation of the plurality of times N is E.

[0024] In the present invention, the non-single-crystal semiconductor film can be favorably crystallized so that a microcrystal is not generated, in the first step and the second step, as in the case of irradiating with a

pulse laser having the irradiation pulse energy density suitable for crystallization by irradiation of N times, to the non-single-crystal semiconductor film. In addition, in the present invention, a height of a swelling portion on the semiconductor film by the edge portion of the pulse laser can be made low. Crystallization can be also the one that makes a crystal semiconductor film of a non-single crystal a single crystal, the one that makes an amorphous semiconductor film a polycrystal semiconductor film, or the one that makes an amorphous semiconductor film a single crystal semiconductor film.

[0025] The irradiation pulse energy density is a pulse energy density on a semiconductor film, and in the first step, irradiation can be performed by making the irradiation pulse energy density the same as the irradiation energy density suitable for crystallization by irradiation of N times. Thereby, in the first step, microcrystallization is avoided. The energy density suitable for crystallization in the first step can be properly selected within a range in which crystallization is intended. For example, the irradiation pulse energy density can be made the irradiation pulse energy density which is the same degree as the irradiation pulse energy density E with which the crystal grain size growth is saturated by irradiation of the plurality of times N. More specifically, the range of $E \times 0.98$ to $E \times 1.03$ is

desirable. When the irradiation pulse energy density of step 1 exceeds E × 1.03, variation due to coarsening of the crystal grain size or the like easily arises. When the irradiation pulse energy density of step 1 becomes less than E × 0.98, the crystal grain growth becomes insufficient, and variation in crystal grain size easily arises.

[0026] Further, in the second step, the irradiation pulse energy density is made equal to or lower than the irradiation pulse energy density E1, and is made equal to or higher than the irradiation energy density that is necessary for a crystal to be remelted, whereby the height of the swelling portion on the semiconductor film by the edge portion of the pulse laser which is generated in the first step is made low, and favorable crystallinity can be kept. Here, the irradiation pulse energy density E2 of the second step needs to satisfy the above described conditions, and is further desirably equal to or higher than E1 × 0.95. Thereby, the crystal grain size after pulse laser irradiation in the first step and the second step can be made uniform and the crystal grain size of sufficiently grown crystal. If the irradiation pulse energy density of the second step is made too low, swelling cannot be reduced unless the irradiation pulse energy density reaches the melt energy density zone, and even if the irradiation pulse energy density reaches the melt energy density zone, sufficient

crystal growth cannot be obtained though a swelling reduction action is obtained, whereby the crystal grain size becomes small.

Further, the irradiation pulse energy density E2 is desirably made lower than E1 × 0.98. If the irradiation pulse energy density E2 is equivalent to the irradiation pulse energy density E1, equivalent swelling is formed again on the semiconductor film, and a swelling reduction action cannot be obtained.

[0027] Further, the total number of irradiation times is made equal to or larger than the N times, and thereby the crystal grain size can be sufficiently grown. The numerical value of N is not specially limited, but in the viewpoint of preventing film quality degradation due to output variation, the certain number of times is desirable, and N can be made equal to or larger than eight, for example.

Furthermore, the total number of irradiation times is desirably made equal to or smaller than N × 1.5. If the total number of irradiation times is made large, reduction in productivity is caused. The total number of irradiation times which is the most desirable from the viewpoint of productivity is N, but the total number of irradiation times can be selected with the state of crystallization taken into consideration.

Further, the irradiation times N1 of the first step is desirably made the same as or larger than the

irradiation times N2 of the second step. Thereby, the total number of irradiation times can be made as small as possible.

[0028] Further, in the invention of the present application, the wavelength of the pulse laser is not limited to a specific wavelength, but a wavelength which is equal to or shorter than 400 nm can be shown, for example.

Furthermore, the full width at half maximum of the pulse laser in the invention of the present application is not limited to a specific full width at half maximum, but a full width at half maximum which is equal to or smaller than 200 ns can be shown, for example.

[0029] Furthermore, as irradiation of the pulse laser in the above described first step and second step, irradiation of different pulse lasers to the non-single-crystal semiconductor film at different times is cited, but pulse laser irradiation in the first step and the second step can be performed with one pulse laser. The pulse laser can be a pulse laser into which two or more pulse lasers are synthesized in a pseudo manner with the non-single-crystal semiconductor film being irradiated with the pulse lasers at the same timing.

That is to say, the pulse laser has lower intensity at the rear side in the scan direction to the rear end in the scan direction than the intensity at the front side in the scan direction, in the beam section intensity

distribution in the scan direction, and irradiation of the first step is performed in accordance with the aforementioned intensity at the front side in the scan direction, whereas irradiation of the second step is performed in accordance with the aforementioned intensity at the rear side in the scan direction.

Advantageous Effect of Invention

[0030] As described above, according to the present invention, a crystal is sufficiently grown by the pulse laser irradiation of the first step and the second step, and the effect of being able to obtain a crystal semiconductor film with a good quality and less irradiation unevenness is provided.

Brief Description of Drawings

[0031]

[Figure 1] Figure 1 is a diagram showing a manufacturing apparatus of a crystal semiconductor film of one embodiment of the present invention.

[Figure 2] Figure 2 is a diagram showing a beam section intensity distribution having a step in beam intensity in a beam section intensity distribution in a scan direction of one embodiment of the present invention.

[Figure 3] Figure 3 is a diagram showing an optical system which shapes a pulse laser having a step in beam intensity in the beam section intensity distribution in

the scan direction of one embodiment of the present invention.

[Figure 4] Figure 4 is a diagram explaining synthesis of pulse lasers having a step in beam intensity in the beam section intensity distribution in the scan direction of one embodiment of the present invention.

[Figure 5] Figure 5 is a diagram showing states of semiconductor film surfaces in examples of one embodiment of the present invention.

[Figure 6] Figure 6 is a diagram showing a result of unevenness evaluation in examples of one embodiment of the present invention.

Description of Embodiment

[0032] Hereinafter a manufacturing apparatus and a manufacturing method of a crystal semiconductor film of one embodiment of the present invention will be described.

A crystal semiconductor film manufacturing apparatus 1 includes a processing chamber 2 and a scanning device 3 which is provided in the processing chamber 2 and is movable in X-Y directions, and a stage 5 is provided at the scanning device 3. At a time of processing, an amorphous silicon film 100 or the like is placed on the stage 5 as a non-single-crystal semiconductor film, and an atmosphere in the processing chamber 2 is regulated by request. The silicon film 100 is formed with a thickness of 40 to 100 nm, for example, on a substrate not shown.

As the present invention, a thickness of the non-single-crystal semiconductor film is not specially limited. Formation of the non-single-crystal semiconductor film can be performed by a usual method, and as the present invention, the method for forming the semiconductor film is not specially limited. Further, the semiconductor film to be a processing target is preferably an amorphous semiconductor film, but is not limited to an amorphous semiconductor film as the present invention, and can be a non-single-crystal film and a film partially including a crystal, and the present apparatus can be also applied to these films as reforming of the crystals.

The scanning device 3 is driven by a motor or the like not shown, the motor has an operation controlled by a control section 8 which will be described later, and a scanning speed of the scanning device 3 is set. Further, in the processing chamber 2, an introduction window 6 through which a pulse laser is introduced from outside is provided.

[0033] Outside the processing chamber 2, a pulse laser oscillation device 10 is installed. The pulse laser oscillation device 10 is constructed of an excimer laser oscillation device. The pulse laser oscillation device 10 is controllably connected to the control section 8. The pulse laser oscillation device 10 outputs a pulse laser with a predetermined output power by an instruction from the control section 8. As the present invention,

the kind of the oscillation device and an oscillation medium are not limited, and any oscillation device and oscillation medium can be adopted as long as a semiconductor film can be irradiated with a desired pulse laser.

[0034] A pulse laser 15 which is oscillated in a pulse form and output in the pulse laser oscillation device 10 is set as a pulse laser with, for example, a wavelength equal to or less than 400 nm and a pulse full width at half maximum equal to or smaller than 200 ns. However, the present invention is not limited to these values.

The pulse laser 15 has a pulse energy density regulated by an attenuator 11. The attenuator 11 is controllably connected to the aforementioned control section 8, and is set at a predetermined attenuation rate by an instruction from the control section 8. In the control section 8, the attenuation rate is regulated so that a predetermined irradiation pulse energy density is obtained on an irradiation surface of a semiconductor film. Preferably, the attenuation rate can be regulated so that the energy density becomes 100 to 500 mJ/cm^2 on the irradiation surface of the silicon film 100.

[0035] The pulse laser 15 which transmits through the attenuator 11 is subjected to beam shaping in an optical system 12 constructed of a lens, a reflection mirror, a homogenizer and the like, and the pulse laser 15 is guided so as to be applied on the silicon film 100 in the

processing chamber 2 through the introduction window 6 provided in the processing chamber 2. In the drawing, as one of the optical system 12, a reflection mirror 12a and a condensing lens 12b are shown. As the present invention, the kind and the number of the optical members included in the optical system are not specially limited.

An irradiation surface shape at the time of irradiation is rectangular in section, and the rectangular shape includes a linear shape.

[0036] Next, the manufacturing method of a crystal semiconductor film using the above described crystal semiconductor film manufacturing apparatus 1 will be described.

With the aforementioned silicon film 100 as a target, an irradiation pulse energy density E0 which is lower than an irradiation pulse energy density with which microcrystallization occurs by irradiation of the pulse laser 15, and is suitable for crystallization by irradiation of a plurality of times N is determined. As the irradiation pulse energy density E0 which is suitable for crystallization, the irradiation pulse energy density which is equivalent to an irradiation pulse energy density E with which crystal grain size growth is saturated by irradiation of N times can be selected. As the equivalent, $E \times 0.98$ to $E \times 1.03$ can be exemplified. In the embodiment, crystallization equivalent to crystallization at a time of irradiating with a pulse

laser with the irradiation pulse energy density E0 by overlap irradiation of N times is obtained.

The above described irradiation pulse energy density E0 is determined as an irradiation pulse energy density E1 of a first step. Further, as an irradiation pulse energy density E2 of a second step, an irradiation pulse energy E2 which is lower than the irradiation pulse energy density E1, and is equal to or higher than an irradiation energy density necessary for a crystal to be remelted is determined, and these irradiation pulse energy densities are set to the control section 8. The irradiation pulse energy density E2 is desirably set as that equal to or higher than E1 × 0.95.

As the above described E0, E1 and E2, numerical values that are empirically obtained can be used.

[0037] Next, irradiation times N1 in overlap in the first step, and irradiation times N2 in overlap in the second step are determined, and are set to the control section 8. A sum of N1 and N2 is equal to or larger than N. $N1 \geq N2$ is desirable, and $N1+N2 \leq 1.5\ N$ is further desirable. The numbers of times N1 and N2 can be empirically fixed.

[0038] Based on the above described settings, under the conditions of the first step, the pulse laser 15 is output from the pulse laser oscillation device 10 while the silicon film 100 is moved in one direction by the scanning device 3, and the silicon film 100 is processed by applying overlap irradiation of the pulse laser 15 to

the silicon film 100 in the processing chamber 2 through the optical system 12 and the introduction window 6. The number of overlap times is determined by the scanning speed of the scanning device 3, a repetition frequency of the pulse laser and a short axis direction width of the pulse. Therefore, the control section 8 determines the scanning speed of the scanning device 3 so that overlap of N1 times is performed with the repetition frequency of the pulse laser as a precondition. The scanning speed can be selected in a range of 6 to 16 mm/sec, for example. As the present invention, the scanning speed is not limited to a specific scanning speed, and can be selected in a range of 1 to 100 mm/sec, for example. Further, the attenuation rate of the attenuator 11 is regulated so that the irradiation pulse energy E1 on the silicon film 100 becomes a set value by the control section 8. A relation between the attenuation rate and the irradiation pulse energy is obtained in advance, and the regulation can be performed in accordance with the relation. Further, the pulse energy density of the pulse laser 15 is measured by a measurement device not shown, and control of the attenuator 11 can be performed so that the pulse energy density has a predetermined value.

[0039] Next, when processing of a predetermined area of the silicon film 100 is completed, the scanning device 3 is operated to move in an opposite direction, and overlap irradiation of the second step is performed. The control

section 8 determines the scanning speed of the scanning device 3 so that overlap of N2 times is performed with the repetition frequency of the pulse laser as a precondition. The scanning speed can be selected in a range of 6 to 16 mm/sec, for example. As the present invention, the scanning speed is not limited to a specific scanning speed, and can be selected in a range of 1 to 100 mm/sec, for example. Further, the attenuation rate of the attenuator 11 is regulated by the control section 8 so that the irradiation pulse energy E2 of the silicon film 100 has a set value. The regulation can be performed similarly to the first step. Further, the number of times by overlap can be changed by using a pulse laser with a different pulse width in the second step, and the desired number of overlap times can be obtained by combining the scanning speed and the like.

[0040] The predetermined area of the silicon film 100 to which the pulse laser irradiation of the first step and the pulse laser irradiation of the second step are applied is crystallized favorably to the same degree as that in the case of performing overlap irradiation of N times with the irradiation pulse energy density E0. Further, in the present embodiment, irradiation of the first step and irradiation of the second step are performed, whereby irradiation unevenness is eliminated by reducing a height of a swelling portion on the semiconductor film by the edge portion of the pulse laser,

and thereby the semiconductor film can be provided to a semiconductor device with higher quality.

[0041] In the above described embodiment, explanation is made on the assumption that after scan irradiation of the first step is performed on a predetermined area, the scan irradiation of the second step is applied to the above described area, but irradiation of the second step can be performed immediately after the irradiation in the first step is performed by using two pulse lasers. In this case, two pulse lasers that are output from two pulse laser light sources can be used, and two pulse lasers can be also obtained by dividing a pulse laser output from one pulse laser light source and performing energy regulation, delay regulation and the like.

The pulse laser can be a pulse laser that is obtained by synthesizing a plurality of pulse lasers and adjusting the pulse width.

[0042] In the above described embodiment, explanation is made on the assumption that after the silicon film in the predetermined area is processed with one pulse laser in the first step, processing is performed with another pulse laser in the second step, but the first step and the second step can be performed at the same timing with one pulse. The one pulse also includes a pulse which can be said as one in a pseudo manner.

That is to say, the pulse laser has lower intensity at a rear side in the scan direction to an rear end in

the scan direction than intensity at a front side in the scan direction, in a beam section intensity distribution in the short axis direction, and the irradiation of the aforementioned first step is performed in accordance with the aforementioned intensity at the aforementioned front side in the scan direction, and the irradiation of the aforementioned second step is performed in accordance with the aforementioned intensity at the aforementioned rear side in the scan direction.

[0043] The beam section intensity distribution in the scan direction of the pulse laser which is used in the embodiment is shown in Figure 2.

A beam section has stepwise beam intensity that has a height of the pulse irradiation energy E1 at the front side in the scanning direction, and has a height of the pulse irradiation energy E2 to the rear end at the rear side in the scanning direction. In the embodiment, pulse laser irradiation of N1 times is performed to the same region of the silicon film 100 with the pulse portion having the height of the pulse irradiation energy E1, and pulse laser irradiation of N2 times is performed to the same region of the silicon film 100 with the pulse portion having the height of the pulse irradiation energy E2. The numbers of times N1 and N2 are fixed by a length L1 of a portion in the scan direction having the height of the pulse irradiation energy E1, a length L2 of a portion in the scan direction having the height of the

pulse irradiation energy E1, and a pitch of each pulse. For example, when L1=L2 (for example, 200 μm) is satisfied, N1 and N2 are basically the same number of times.

That is to say, the number of times of N1 can be increased by making the length L1 relatively long. Therefore, L1≥L2 is desirably satisfied. Accordingly, N1 and N2 depend on values of the lengths L1 and L2, and further depend on the scanning speed and the repetition frequency of the pulse laser similarly to the above described embodiment. By setting these values, N1 and N2 in the embodiment are determined.

[0044] The pulse laser having the beam section intensity distribution in the scan direction in the above described shape can be obtained by various methods.

For example, a member that shields some of laser beams or restrains some of laser beams from being transmitted is disposed at an upstream side or at a downstream side of the optical member on an optical path of the optical system as shown in Figure 3(a), whereby the beam intensity in the scan direction is made partially low as shown in Figure 3 (b), and the pulse laser having a beam section intensity distribution in which the beam intensity becomes stepwise is obtained.

Further, as shown in Figure 4(a), two pulses are synthesized or synthesized in a pseudo manner, whereby as shown in Figure 4(b), a pulse c having the beam section

intensity distribution in which the beam intensity becomes stepwise (widths L1 and L2 in the scan direction) is obtained. For example, a pulse a and a pulse b which are different in beam intensity are synthesized with a time difference provided between the pulse a and the pulse b in the optical system, and the synthesized pulse can be applied on a non-single-crystal semiconductor film. Further, the pulse a and the pulse b which are different in beam intensity are applied on the non-single-crystal semiconductor film by displacing positions of the pulse a and pulse b at the same time, and thereby can be made as one pulse in a pseudo manner.

Example 1

[0045] Next, with use of a pulse laser light source (product number LSX540C), anneal processing was performed by irradiating an amorphous silicon film with a film thickness of 50 nm with an excimer pulse laser in a line beam shape with a wavelength of 308 nm, a pulse width of 70 nm, a repetition frequency of 300 Hz, and a long axis length of 465 mm by a short axis length of 400 μm in a beam section.

As a conventional example, the irradiation energy density E0 (OED (Optimum energy density); 370 mJ/cm^2 in this example) which is suitable for crystallization with an overlap rate of 95% (overlap irradiation of 20 times) was set. At this time, the scanning speed and the

repetition frequency of the pulse laser were set so as to achieve a pitch of 20 μm. The energy density E0 was made the same as the irradiation energy density E with which a microcrystal is not generated, and the crystal grain size is saturated by the aforementioned overlap irradiation.

Further, as an invention example and a reference example, the irradiation energy density E1 (370 mJ/cm^2) which is the same as the irradiation energy density E0 with the overlap rate of 90% (overlap irradiation of 10 times) was set in the first step. At this time, the scanning speed was set so as to achieve a pitch of 40 μm.

[0046] Furthermore, as the invention example, the irradiation energy density E2 (352 mJ/cm^2) which is -5% of the irradiation energy density E1 with the overlap rate of 90% (overlap irradiation of 10 times) was set in the second step. At this time, the scanning speed was set so as to achieve a pitch of 40 μm.

Furthermore, as the reference example, an irradiation energy density which is -10%, -15% or -20% of the irradiation energy density E1 with the overlap rate of 90% (overlap irradiation of 10 times) was set in the second step. At this time also, the scanning speed and the repetition frequency of the pulse laser were set so as to achieve a pitch of 40 μm.

[0047] Under the above described conditions, overlap irradiation of the pulse laser is applied to the amorphous silicon film, and irradiation unevenness and

crystallinity of the crystal silicon film after processing were evaluated. Further, with respect to the conventional example and the invention example, surface irregularities of the crystal silicon films were observed by an AFM (Atomic Force Microscope).

Figure 5 shows schematic diagrams of the surface sections of the crystal silicon film. In the conventional example, relatively large swelling is formed correspondingly to the edge portion by final irradiation of the pulse laser as shown in Figure 5 (b). In the invention example, it is recognized that swelling corresponding to that described above is low and gentle as shown in Figure 5 (a), and it is found out that the swelling is reduced by irradiation of the first step and the second step.

[0048] The irradiation unevenness evaluation of the crystal silicon film was performed according to the following method.

Five spots of the crystal silicon film were irradiated with an inspection light in each of the examples, reflection lights were received and color images were acquired respectively, color components of the color images were detected, and the color images were converted into monochrome images based on the detected color components. Next, data of the monochrome images was convoluted to acquire image date with image shading emphasized, and the image data with image shading

emphasized was subjected to a projection transformation, and the surface unevenness was evaluated based on the image data subjected to the projection transformation. Monochromic conversion can be performed with use of a main color component out of the detected color components, and the main color component can be made a color component having a relatively larger light distribution than those of the other color components.

Monochromic image data is shown by matrix data in which a beam direction of the laser is a row, and the scan direction of the laser is a column, and convolution is performed by multiplying a matrix of a predetermined coefficient by a matrix of monochromic image data.

As for the matrix of the predetermined coefficient, a matrix of the predetermined coefficient which emphasizes the beam direction, and a matrix of the predetermined coefficient which emphasizes the scan direction were respectively used, and image data with image shading emphasized in the beam direction, and image data with image shading emphasized in the scan direction were respectively acquired.

More specifically, the following convolution was performed. The matrixes of the predetermined coefficients are not limited to what is described as follows.

[0049] [Mathematical expression 1]

$$\text{SHOT DIRECTION SHADING EMPHASIS} = \begin{vmatrix} 2 & 2 & 2 \\ 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \\ -2 & -2 & -2 \end{vmatrix} * \text{IMAGE DATA} \quad (1)$$

$$\text{SCAN DIRECTION SHADING EMPHASIS} = \begin{vmatrix} 2 & 1 & 0 & -1 & -2 \\ 2 & 1 & 0 & -1 & -2 \\ 2 & 1 & 0 & -1 & -2 \end{vmatrix} * \text{IMAGE DATA} \quad (2)$$

[0050] With respect to the image data with image shading emphasized, the fact that a large number of streaks appear in the scan direction and the shot direction is used, and projections in the respective directions are obtained.

More specifically, projection transformation is performed in the shot direction and the scan direction respectively according to the expressions shown as follows.

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

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

Note that x represents a position of the image in the shot direction, y represents a position of the image in the scan direction, f(x) represents image data in the position x, f(y) represents image data in the position y, Nx represents the number of images in the shot direction,

and Ny represents the number of images in the scan direction.

[0051] An unevenness score in Figure 6 shows unevenness in the scan direction by numerical values converted from the unevenness. Figure 6 shows that as the numerical value is larger, unevenness is larger.

As is understandable from Figure 6, in the conventional example, the unevenness score is 0.2 to 0.3, and unevenness is large. This is considered to be due to the influence of the surface swelling by the edge of the pulse laser as described above.

In the invention example, unevenness is as large as in the conventional example after the first step, but after the second step, the unevenness score is 0.06 to 0.13, and unevenness is reduced. In the examples in which irradiation in the second step was performed with the irradiation pulse energy of -10% of E0, -15% of E0 and -20% of E0, unevenness was smaller than that in the conventional example, but this was not sufficient from the viewpoint of reduction of unevenness.

[0052] Next, crystallinity of the crystal silicon films of the conventional example, the invention example and the reference example was observed by SEM (Scanning Electron Microscope) photographs.

As a result, uniform crystal grains were equivalently formed in both the conventional example and the invention example. In the reference examples with -

15% of E0, and -20% of E0, sufficient crystal growth was not made, and crystal grain sizes were small. With -10% of E0, the crystal grain size was slightly small, but not so small as those with -15% of E0 and -20% of E0.

[0053] As described above, according to the present invention example, favorable crystal grain growth is obtained, and unevenness can be reduced by reducing swelling by the edge of the pulse laser. Further, the processing can be performed substantially without reducing productivity as compared with the prior art.

[0054] The present invention has been described based on the aforementioned respective embodiment and examples, but the present invention is not limited to the explanation contents, and can be changed properly without departing from the scope of the present invention.

Reference Signs List

[0055]

1 Crystal semiconductor film manufacturing apparatus

2 Processing chamber

3 Scanning device

5 Stage

8 Control section

10 Pulse laser oscillation device

11 Attenuator

Claims

[Claim 1]

A manufacturing method of a crystal semiconductor film that performs crystallization by applying overlap irradiation while causing a pulse laser to scan relatively in a short axis direction, onto a non-single-crystal semiconductor film, comprising:

with an irradiation pulse energy density which is lower than an irradiation pulse energy density with which microcrystallization occurs to the non-single-crystal semiconductor film by irradiation of the pulse laser, and is suitable for crystallization by irradiation of a plurality of times N being set as E0,

a first step of irradiating with the pulse laser having an irradiation pulse energy density E1 which is the same as the irradiation pulse energy density E0; and

a second step of irradiating with the pulse laser having an irradiation pulse energy E2 which is lower than the irradiation pulse energy density E1, and is equal to or higher than an irradiation energy density that is necessary for a crystal to be remelted,

wherein the total number of times of irradiation to the same irradiation surface in the first step and the second step is equal to or larger than N times.

[Claim 2]

The manufacturing method of a crystal semiconductor film according to claim 1,

wherein the irradiation pulse energy suitable for crystallization is within a range of E × 0.98 to E × 1.03 where an irradiation pulse energy density with which crystal grain size growth is saturated by irradiation of the plurality of times N is E.

[Claim 3]

The manufacturing method of a crystal semiconductor film according to claim 1 or 2,

wherein the irradiation pulse energy density E2 is equal to or higher than E1 × 0.95.

[Claim 4]

The manufacturing method of a crystal semiconductor film according to any of claims 1 to 3,

wherein the total number of times of irradiation is equal to or smaller than N × 1.5.

[Claim 5]

The manufacturing method of a crystal semiconductor film according to any of claims 1 to 4,

wherein irradiation of a plurality of times N1 to the same irradiation surface is sequentially performed while the pulse laser is caused to scan by the first step, thereafter, to the predetermined surface, irradiation of

a plurality of times N2 to the same irradiation surface is sequentially performed while the pulse laser is caused to scan by the second step, and the N1 + N2 is set as the total number of irradiation times and is made equal to or larger than N times.

[Claim 6]

The manufacturing method of a crystal semiconductor film according to claim 5,

wherein the N1 is made the number of times which is equal to or larger than the N2.

[Claim 7]

The manufacturing method of a crystal semiconductor film according to any one of claims 1 to 6,

wherein in a beam section intensity distribution in a scan direction, the pulse laser has lower intensity at a rear side in the scan direction to a rear end in the scan direction than intensity at a front side in the scan direction, and irradiation of the first step is performed in accordance with the intensity at the front side in the scan direction, whereas irradiation of the second step is performed in accordance with the intensity at the rear side in the scan direction.

[Claim 8]

The manufacturing method of a crystal semiconductor film according to claim 7,

wherein a width in the scan direction at the front side in the scan direction is equal to or larger than a width in the scan direction at the rear side in the scan direction.

[Claim 9]

The manufacturing method of a crystal semiconductor film according to any of claims 1 to 8,

wherein a wavelength of the pulse laser is equal to or shorter than 400 nm.

[Claim 10]

The manufacturing method of a crystal semiconductor film according to any of claims 1 to 9,

wherein a full width at half maximum of the pulse laser is equal to or smaller than 200 ns.

[Claim 11]

The manufacturing method of a crystal semiconductor film according to any of claims 1 to 10,

wherein the non-single-crystal semiconductor is of silicon.

[Claim 12]

A manufacturing apparatus of a crystal semiconductor film, comprising:

one or two or more laser light sources that outputs or output a pulse laser;

an optical system that shapes the pulse laser and guides the pulse laser to a non-single-crystal semiconductor;

an energy regulating section that regulates an irradiation energy density of the pulse laser;

a scanning device that causes the pulse laser to scan relatively to the non-single-crystal semiconductor; and

a control section that controls the laser light source, the energy regulating section and the scanning device,

wherein the control section executes a first step of controlling the energy regulating section to regulate the irradiation pulse energy density to an irradiation pulse energy density E1 which is lower than an irradiation pulse energy density with which microcrystallization occurs to the non-single-crystal semiconductor film by irradiation of the pulse laser, and is the same as an irradiation pulse energy density E0 which is suitable for crystallization by irradiation of a plurality of times N, and sequentially performing irradiation of a plurality of times N1 (N1 < N) to the non-single crystal semiconductor while causing the pulse laser to scan by controlling the

scanning device with the irradiation pulse energy density E1, and a second step of controlling the energy regulating section to regulate the irradiation pulse energy density to irradiation pulse energy E2 which is lower than the irradiation pulse energy density E1, and is equal to or higher than an irradiation energy density necessary for a crystal to be remelted, and sequentially performing irradiation of a plurality of times N2 ($N2 < N$, $N1 + N2 \geq N$) to the non-single-crystal semiconductor while causing the pulse laser to scan by controlling the scanning device with the irradiation pulse energy density E2, to the semiconductor irradiated with the pulse laser in the first step.

[Claim 13]

A manufacturing apparatus of a crystal semiconductor film, comprising:

one or two or more laser light sources that outputs or output a pulse laser;

an optical system that shapes the pulse laser and guides the pulse laser to a non-single-crystal semiconductor;

an intensity regulating section that regulates, in a beam section intensity distribution in a scan direction of the pulse laser, the intensity distribution so that intensity at a rear side in the scan direction to a rear end in the scan direction becomes lower than intensity at

a front side in the scan direction, and an irradiation pulse energy density by the intensity at the rear side in the scan direction becomes 0.95 times or more an irradiation pulse energy density by the intensity at the front side in the scan direction;

an energy regulating section that regulates an irradiation energy density of the pulse laser;

a scanning device that causes the pulse laser to scan relatively to the non-single-crystal semiconductor; and

a control section that controls the laser light source, the energy regulating section and the scanning device,

wherein the control section executes a step of controlling the energy regulating section to perform regulation so that in irradiation at the front side in the scan direction of the pulse laser, an irradiation pulse energy density becomes an irradiation pulse energy density E1 which is lower than an irradiation pulse energy density with which microcrystallization occurs to the non-single-crystal semiconductor film, and is the same as an irradiation pulse energy density E0 which is suitable for crystallization by irradiation of a plurality of times N, and in irradiation at the rear side in the scan direction of the pulse laser, an irradiation pulse energy density becomes an irradiation pulse energy E2 which is lower than the irradiation pulse energy

density E1, and is equal to or higher than an irradiation energy density which is necessary for a crystal to be remelted, and sequentially performing irradiation of a plurality of times which is equal to or larger than N times to the non-single-crystal-semiconductor while causing the pulse laser to scan by controlling the scanning device.

[Claim 14]

The manufacturing apparatus of a crystal semiconductor film according to claim 12 or 13,

wherein the control section sets the irradiation pulse energy suitable for crystallization to be within a range of E × 0.98 to E × 1.03 where an irradiation pulse energy density with which crystal grain size growth is saturated by irradiation of the plurality of times N is E.