Description

Title of Invention: LASER ANNEALING METHOD AND LASER ANNEALING APPARATUS

Technical Field

[0001]

The present invention relates to a laser annealing method and a laser annealing apparatus for crystallizing an amorphous film and modifying a crystal film by scanning a non-single-crystal semiconductor with a pulse laser beam having a linear beam shape to perform overlap irradiation multiple times.

Background Art

[0002]

A thin film transistor used in a TV display and a PC display is typically made of amorphous silicon (hereinafter referred to as a-silicon), and the performance of a TFT can be significantly improved by crystallizing the silicon (hereinafter referred to as p-silicon) by using some means before using the TFT. An excimer laser annealing technology as a low-temperature Si crystallization process has already been put into use and is frequently used at present in applications for compact displays, such as smartphones. Further, the

technology is being put into use in applications for large-screen displays.

[0003]

The laser annealing method is based on a mechanism in which a non-single-crystal semiconductor film is irradiated with an excimer laser beam having high pulse energy, and the semiconductor having absorbed the optical energy is therefore melted or semi-melted, followed by a cooling step that allows the semiconductor to solidify and crystallize. In this process, a large area is scanned with a pulsed laser beam shaped into a linear beam in a minor-axis direction thereof so that the large area is irradiated with the linear laser beam. The pulsed laser beam scanning is typically performed by moving a placement mount on which the non-single-crystal semiconductor film is placed.

In the laser annealing process, an optical system is used to shape the laser beam into a predetermined beam and homogenize the cross-sectional intensity of the beam (top flat: flat portion). Further, the beam is focused as required, and an object to be processed is irradiated with the focused beam.

[0004]

As one type of beam shape, there is a known linear beam shape having a minor-axis width and a major-axis width when viewed in a cross section of the beam. When an object to be processed is scanned and irradiated with

a laser beam having the linear beam shape described above in the minor-axis direction thereof, a large area of the object being processed can be efficiently processed in a single process. It is, however, noted that after the laser beam passes a variety of optical members, even the top-flat linear beam shape has portions located in peripheral areas along the minor-axis direction and the major-axis direction where the energy intensity decreases along the outward direction (also called steepness portions).

[0005]

In Patent Literature 1, since a focused laser beam has peripheral areas where the intensity decreases in accordance with the Gaussian distribution, an unclear boundary at an end portion of a line needs to be solved. To this end, after the laser beam is focused into a spot having a diameter of 100 μm, a mask is disposed in a position away from a surface to be processed, and the shape of a pattern on the mask, for example, having a width of 100 μm × 30 cm can be used to produce a very narrow open-groove pattern having a size of 20 μm × 30 cm with clears edge in peripheral areas of the pattern.

[0006]

Patent Literature 2 describes that the width of a line is defined by using a slit through which a linear beam passes and the linear beam has a flat shape with substantially sharp edges (paragraph [0011]).

Citation List

Patent Literature

[0007]

Patent Literature 1: Japanese Patent Laid-Open No. 5-206558

Patent Literature 2: Japanese Patent Laid-Open No. 9-321310

Summary of Invention

[0007a] According to the first aspect of the invention, there is provided a laser annealing method comprising irradiating a non-single-crystal semiconductor film with a pulsed laser beam having a linear beam cross-sectional shape while scanning the non-single-crystal semiconductor film with the linear beam in a minor-axis direction of the linear beam, wherein

the linear beam has, in the minor-axis direction, a flat portion and steepness portions in a beam intensity profile, the steepness portions located in minor-axis-direction end portions, and the steepness portions are areas having intensities greater than or equal to 10% but smaller than or equal to 90% of a maximum intensity in the beam intensity profile, and

the flat portion has a minor-axis-direction width of an area having intensities at least 96% of the maximum intensity, and the minor-axis-direction width ranges from 100 to 500 μm on the irradiation surface of the non-single-crystal semiconductor film, and a screening is performed in an area outward from a position where the intensity is from 70 to 90% of the maximum intensity at a rear side in a minor-

axis scanning direction of the flat portion such that a minor-axis-direction width of the steepness portion which is one of the steepness portions and which is located on the rear side in the scan direction is 50 μm or smaller on an irradiation surface of the non-single-crystal semiconductor film.

[0007b] According to the second aspect of the invention, there is a laser annealing apparatus comprising:

a laser light source that outputs a pulsed laser beam;

an attenuator that adjusts transmittance at which the attenuator transmits the pulsed laser beam; and

an optical system that shapes the beam cross-sectional shape of the pulsed laser beam and guides the shaped pulsed laser beam to an irradiation surface of a non-single-crystal semiconductor film, wherein

the optical system includes an optical member and a screener, and

the optical member shapes the beam cross-sectional shape of the pulsed laser beam to a linear beam , the linear beam having a high intensity area where the intensity is higher than or equal to a predetermined intensity in a beam intensity profile, the linear beam having, in the minor-axis direction, a flat portion and steepness portions in a beam intensity profile, the steepness portions located in minor-axis-direction end portions and being areas having intensities greater than or equal to 10% but smaller than or equal to 90% of a maximum intensity in the beam intensity profile, the flat portion having a minor-axis-direction width of an area having intensities at least 96% of the maximum intensity, the minor-axis-direction width ranging from 100 to 500 μm on the irradiation surface of the non-single-crystal semiconductor film, and

the screener is disposed in an optical path of the pulsed laser beam and screens a beam cross section of the pulsed laser beam in an area outward from a position where the intensity is from 70 to 90% of the maximum intensity at a rear side in the minor-axis scanning direction of the flat portion in such a way that a minor-axis-direction width of at least a steepness portion which is one of steepness portions located

in minor-axis-direction end portions of the linear beam and which is the steepness portion on the rear side in a scan direction is 50 μm or smaller on the irradiation surface of the non-single-crystal semiconductor film.

Technical Problem

[0008]

It is, however, difficult to completely eliminate the steepness portions even by using a mask, a slit, or a variety of optical systems. The steepness portions can be suppressed, for example, through optical member design, but an attempt of excessive suppression of the steepness portions, for example, through optical member design undesirably results in local formation of intensity impulses 151a, where the intensity steeply increases, at the minor-axis ends of a flat portion 151 in the beam intensity profile of a pulsed laser beam 150, as shown in Figure 8. On the other hand, when a mask or a slit is used, a diffraction phenomenon undesirably similarly causes formation of the intensity impulses 151a, where the intensity steeply increases, at the minor-axis ends of the flat portion 151 in the beam intensity profile of

the laser beam having passed through the mask or the slit. Patent Literature 1 relates to ultraviolet-light-based straight line lithography performed, for example, on a surface of a light transmissive, electrically conductive film to be processed, and the impulses described above are hence not particularly problematic. In laser annealing, however, when a pulsed laser beam having impulses formed at the ends of the flat portion is used, an annealing process is not carried out as expected, for example, because the energy density does not fall within an optimum range.

To avoid the situation, in laser annealing of related art, no mask or slit is used, and the minor-axis-direction width of the steepness portions is reduced to a value ranging from 70 to 100 μm, the range of which is believed to pose no problem in laser beam irradiation, to avoid the formation of the intensity impulses and allow optical members to be readily designed.

[0009]

The present inventors, however, have made careful observation and found that there is irradiation unevenness in a semiconductor crystalized by pulsed laser beam irradiation based even on the state-of-the-art technology, and that the irradiation unevenness affects the performance of a resultant device.

According to studies conducted by the present inventors, it is believed that the irradiation unevenness

described above occurs due to non-uniform formation of raised portions of a polysilicon film in end portions in the linear beam scan direction for each exposure. The raised portions correspond to the boundary between a melted portion of the semiconductor film due to the laser beam irradiation and a portion that is not irradiated with the laser beam having intensity high enough to melt the semiconductor film and hence remains solid. The size of the raised portions is believed to increase in proportion to the intensity of the irradiation energy. That is, higher irradiation energy causes a deeper portion of the semiconductor film in the film thickness direction as to be melted, and even after the entire film is melted, the temperature of the liquid semiconductor film layer keeps increasing. When the liquid-phase portion crystallizes as the temperature decreases, the liquid is attracted to the solid-liquid interface where the temperature starts decreasing before the liquid-phase portion, that is, to each minor-axis edge portion of the linear beam, and the attracted liquid solidifies at the edge portion. It is believed that the raised portions are thus formed. The irradiation unevenness is negligible as long as the raised portions are formed to a uniform height at predetermined intervals.

[0010]

If the output energy of the laser beam varies, however, the inclination of the steepness portions also

varies, and the minor-axis width of an area that affects annealing of the semiconductor film (area where beam intensity is higher than or equal to melting threshold, for example) changes, as shown in Figure 9. In the beam intensity profile shown in Figure 9, which has 100-μm steepness portions, when the beam intensity varies by +10%, the minor-axis width of the melting threshold area undesirably increases by 3% on both sides. As a result, since the width of the melted non-single-crystal semiconductor varies, the height of and intervals between the raised portions described above are not uniform, resulting in irradiation unevenness.

[0011]

The present invention has been made in view of the circumstances described above, and an object of the present invention is to provide a laser annealing method and a laser annealing apparatus capable of reducing an effect of variation in the output energy of a laser beam.

Solution to Problem

[0012]

That is, a first aspect of a laser annealing method according to the present invention is a laser annealing method comprising irradiating a non-single-crystal semiconductor film with a pulsed laser beam having a linear beam cross-sectional shape while scanning the non-

single-crystal semiconductor film with the linear beam in a minor-axis direction of the linear beam, wherein

the linear beam has steepness portions located in minor-axis-direction end portions in a beam intensity profile, and the steepness portions are areas having intensities greater than or equal to 10% but smaller than or equal to 90% of a maximum intensity in the beam intensity profile, and

the irradiation is performed such that a minor-axis-direction width of the steepness portion which is one of the steepness portions and which is located on the rear side in the scan direction is 50 μm or smaller on an irradiation surface of the non-single-crystal semiconductor film.

[0013]

In a laser annealing method according to a second aspect of the present invention, in the first aspect of the present invention, the pulsed laser beam has a wavelength of 400 nm or shorter.

[0014]

In a laser annealing method according to a third aspect of the present invention, in the first or second aspect of the present invention, a pulse of the pulsed laser beam on the irradiation surface has a full width at half maximum of 200 ns or smaller.

[0015]

In a laser annealing method according to a fourth aspect of the present invention, in any of the first to third aspects of the present invention, the pulsed laser beam has a maximum intensity ranging from 250 to 500 mJ/cm^2 in the beam intensity profile on the irradiation surface.

[0016]

In a laser annealing method according to a fifth aspect of the present invention, in any of the first to fourth aspects of the present invention, the non-single-crystal semiconductor is silicon.

[0017]

In a laser annealing method according to a sixth aspect of the present invention, in any of the first to fifth aspects of the present invention, the beam intensity profile of the pulsed laser beam has a flat portion in the minor-axis direction, and the maximum intensity is defined as an average of the intensities across the flat portion.

[0018]

In a laser annealing method according to a seventh aspect of the present invention, in any of the first to sixth aspects of the present invention, when the beam intensity profile of the pulsed laser beam has an intensity impulse where the intensity locally increases at one of the ends or at both ends of the beam intensity

profile, the maximum intensity is defined as a value within a range excluding the intensity impulse.

[0019]

In a laser annealing method according to an eighth aspect of the present invention, in the sixth or seventh aspect of the present invention, the linear beam has a minor-axis-direction width of an area having intensities at least 96% of the maximum intensity, and the minor-axis-direction width ranges from 100 to 500 μm on the irradiation surface of the non-single-crystal semiconductor film.

[0020]

A laser annealing apparatus according to a ninth aspect of the present invention comprises:

a laser light source that outputs a pulsed laser beam;

an attenuator that adjusts transmittance at which the attenuator transmits the pulsed laser beam; and

an optical system that shapes the beam cross-sectional shape of the pulsed laser beam and guides the shaped pulsed laser beam to an irradiation surface of a non-single-crystal semiconductor film, wherein

the optical system includes an optical member that shapes the beam cross-sectional shape of the pulsed laser beam to a linear beam having a high intensity area where the intensity is higher than or equal to a predetermined intensity in a beam intensity profile and an optical

member that steepens at least a steepness portion which is one of steepness portions located in minor-axis-direction end portions of the linear beam and which is the steepness portion on the rear side in a scan direction in such a way that a minor-axis-direction width of the steepness portion is 50 μm or smaller on the irradiation surface of the non-single-crystal semiconductor film.

[0021]

In a laser annealing apparatus according to a tenth aspect of the present invention, in the ninth aspect of the present invention, the optical member that steepens the steepness portion is a screener that is disposed in an optical path of the pulsed laser beam and screens part of a beam cross section of the pulsed laser beam.

[0022]

In a laser annealing apparatus according to an eleventh aspect of the present invention, in the tenth aspect of the present invention, the screener screens part of the beam cross section of the pulsed laser beam in areas outside the minor-axis-direction ends of the high intensity area.

[0023]

In a laser annealing apparatus according to a twelfth aspect of the present invention, in any of the ninth to eleventh aspects of the present invention, the

pulsed laser beam outputted from the laser light source has a wavelength of 400 nm or shorter.

[0024]

In a laser annealing apparatus according to a thirteenth aspect of the present invention, in any of the ninth to twelfth aspects of the present invention, the pulsed laser beam outputted from the laser light source has a full width at half maximum of 200 ns or smaller.

[0025]

In a laser annealing apparatus according to a fourteenth aspect of the present invention, in any of the ninth to thirteenth aspects of the present invention, the optical system includes an optical member that adjusts the intensity in such a way that a beam intensity profile having the high intensity area where the intensity is at least 96% of a maximum intensity and steepness portions located in end portions of the high intensity area is provided.

[0026]

In a laser annealing apparatus according to a fifteenth aspect of the present invention, in any of the ninth to fourteenth aspects of the present invention, the attenuator adjusts the maximum intensity in the beam intensity profile of the pulsed laser beam on the irradiation surface of the non-single-crystal semiconductor film to a value ranging from 250 to 500 mJ/cm^2.

[0027]

That is, according to the present invention, irradiation unevenness due to variation in the output value of the pulsed laser beam is suppressed by steepening the steepness portions. For example, overlap irradiation repeated by a predetermined number is believed to be appropriately performed at a certain irradiation energy density, and the energy density has a certain acceptable range. However, when the steepness portions have a wide width as in related art (70 μm or wider, for example), even a variation within the appropriate irradiation energy density width causes irradiation unevenness.

Each of the steepness portions is not only a portion where the energy intensity decreases along the outward direction but also an area where intensities therein are greater than or equal to 10% but smaller than or equal to 90% of a maximum intensity in the beam intensity profile in the minor-axis direction of the beam.

In the invention of the present application, in which the width of the steepness portions is shortened (50 μm or smaller), an effect of the energy variation is greatly reduced, resulting in a decrease in the irradiation unevenness.

The width of the steepness portions is desirably further smaller, that is, smaller than or equal to 45 μm from the same reason.

[0028]

The annealing in the present invention is directed to a non-single-crystal semiconductor and allows crystallization of an amorphous semiconductor and modification of a crystal semiconductor. The modification includes single crystallization of a polycrystalline semiconductor and improvement in crystal properties. A representative example of a non-single-crystal semiconductor is silicon, but the present invention is not limited to silicon.

[0029]

The pulsed laser is not limited to a specific one in the present invention and can, for example, be a pulsed laser that emits a pulsed laser beam having a wavelength of 400 nm or shorter and a full width at half maximum of 200 ns or narrower. The type of the pulsed laser is also not limited to a specific one and can, for example, be an excimer laser.

[0030]

The pulsed laser beam is shaped into a linear beam by using a variety of optical members, such as a cylindrical lens. The shape of the linear beam is not limited to a specific shape and only needs to be a shape in which the ratio of the length of the major axis to the length of the minor axis has a large value. The ratio is, for example, 10 or greater. The length of the major axis and the length of the minor axis are not limited to

specific values in the present invention. For example, the length of the major axis ranges from 370 to 1300 mm, and the length of the minor axis ranges from 100 to 500 μm. The pulsed laser beam can be so shaped by a homogenizer, a cylindrical lens, or any other optical member that the beam intensity profile has a high intensity area as a primary portion having intensities that are, for example, at least 96% of the maximum intensity (preferably flat portion as a primary area) and steepness portions located at both ends of the high intensity area and having intensities that are 10 to 90% of the maximum intensity. A portion between the high intensity area and each of the steepness portions is a transition portion where the intensity changes, and the width of the transition portion is very small.

Examples of the high intensity area further include a portion where the intensity tends to increase or decrease in the minor-axis direction and a portion where the intensity distribution follows a curve as well as the flat portion described above, and each of the portions has a maximum intensity.

[0031]

The steepness portions can be steepened (width of 50 μm or smaller on the rear side in the scan direction), for example, by using a screener capable of screening end portions of a beam. The screener can be performed by blocking beam passage or lowering light transmittance.

The screener, when disposed in a position close to a non-single-crystal semiconductor film, can narrow the width of the steepness portions, and in this case, a material having higher heat resistance can be used. Further, screeners disposed in multiple stages along the optical path can narrow the minor-axis-direction width of the steepness portions with reduced damage on the screener.

The screener desirably screens part of the beam cross section of the pulsed laser beam in areas outside the minor-axis-direction ends of the high intensity area described above. When part of the pulsed laser beam is screened, the intensity increases at the ends of the transmitted light portion due to diffraction, resulting in the intensity impulses, as described above. In consideration of the phenomenon, the screen is performed in areas which are outside the high intensity area and where the intensity starts decreasing allows the intensity impulses to be eliminated or reduced to a very small value. However, performing the screen in extremely outside areas results in an intensity profile in which the intensity temporarily decreases outside the high intensity area and increases again in a further outside area. It is therefore desirable to perform the screen in a position where the intensity has an appropriate value. For example, the screen is desirably performed in a position where the intensity ranges from 70 to 90% of the maximum intensity.

[0032]

Steepening the steepness portions (width smaller than or equal to 50 μm) can be performed, for example, by adjustment of an optical member. The steepening is achieved, for example, by adjustment of the position of the silicon film relative to the position where an image is formed by a cylindrical lens or use of a unit lens having better image formation performance in place of the cylindrical lens.

[0033]

The pulsed laser beam, although depending on the number of overlaps, can be applied to a non-single-crystal semiconductor, for example, at an energy density ranging from 250 to 500 mJ/cm^2. The number of overlaps can, for example, range from 8 to 50, and the scan speed under the energy density condition described above can, for example, range from 1 to 100 mm/second.

Advantageous Effect of Invention

[0034]

That is, according to the present invention, the steepness portions are steepened, and an effect of variation in energy output is therefore suppressed, whereby irradiation unevenness can be suppressed. As a result, a high-quality semiconductor device can be provided.

Brief Description of Drawings

[0035]

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

[Figure 2] Figure 2 shows the shape of a screener in the embodiment of the present invention.

[Figure 3] Figure 3 shows a change in intensity profile of a beam that occurs when the beam passes through the screener in the embodiment of the present invention.

[Figure 4] Figure 4 shows a beam intensity profile on an irradiation surface in the embodiment of the present invention.

[Figure 5] Figure 5 shows a change in the beam intensity profile on the irradiation surface that occurs when a laser output value varies in the embodiment of the present invention.

[Figure 6] Figure 6 is a schematic view showing a laser annealing apparatus according to another embodiment of the present invention.

[Figure 7] Figure 7 is a photograph that replaces a drawing and shows a result of irradiation unevenness evaluation in an example of the present invention.

[Figure 8] Figure 8 shows a beam intensity profile with impulses formed at the ends of a flat portion in related art.

[Figure 9] Figure 9 shows a beam intensity profile on an irradiation surface in related art.

Description of Embodiments

[0036]

A laser annealing apparatus 1 according to the present invention will be described below with reference to the accompanying drawings.

The laser annealing apparatus 1 includes a processing chamber 2, which accommodates a scan device 3 capable of moving in X-Y directions and a base mount 4 provided on the scan device 3. A substrate placement mount 5 is provided as a stage on the base mount 4. The scan device 3 is driven, for example, by motors that are not shown.

The processing chamber 2 is provided with an introduction window 6, through which a pulsed laser beam is externally introduced.

[0037]

At the time of annealing, an amorphous silicon film 100 or any other film is placed as a semiconductor film made of a non-single-crystal semiconductor on the substrate placement mount 5. The silicon film 100 has been formed to a thickness ranging, for example, from 40 to 100 nm (specifically, to a thickness of, for example, 50 nm) on a substrate that is not shown. The formation can be performed by using an ordinary method, and the

method for forming the semiconductor film is not limited to a specific method in the present invention.

The present embodiment will be described in relation to laser processing in which an amorphous film is crystalized by laser processing, but the laser processing in the present invention is not limited thereto and can, for example, include single crystallization of a non-single-crystal semiconductor film and modification of a crystal semiconductor film.

[0038]

A pulse-oscillation laser light source 10 is provided external to the processing chamber 2. The pulse-oscillation laser light source 10 is formed of an excimer laser oscillator and capable of outputting a pulsed laser beam having a wavelength of 400 nm or shorter and a repetitive oscillation frequency ranging from 1 to 1200 Hz. The pulse-oscillation laser light source 10 can be so controlled that the pulsed laser output is maintained within a predetermined range under feedback control.

[0039]

A pulsed laser beam 15, which is outputted as a pulse-oscillation beam from the pulse-oscillation laser light source 10, is adjusted by an attenuator 11 in terms of energy density and passes through an optical system 12, which is formed of a homogenizer 12a, a reflection mirror 12b, a cylindrical lens 12c, and other optical members,

where the pulsed laser beam 15 undergoes change of the shape thereof to a linear beam shape, deflection, intensity distribution adjustment for providing a beam intensity profile having a flat portion and steepness portions, and other types of operation. A resultant pulsed laser beam 150 passes through the introduction window 6 provided in the processing chamber 2 and is applied to the amorphous silicon film 100 in the processing chamber 2. The optical members that form the optical system 12 are not limited to those described above and can further include a variety of lenses (such as homogenizer and cylindrical lens), a mirror, a waveguide, and other components.

[0040]

A screener 20 is further provided in the processing chamber 2. The screener 20 is disposed in a position where the screener 20 can screen a minor-axis-direction rear end portion of the pulsed laser beam 150 in a relative beam scan direction. The screener 20 can instead be formed of paired two screening plates with a certain amount of gap therebetween, and the two screening plates can be so disposed that they screen both the scan-direction end portions of the pulsed laser beam.

[0041]

A description will next be made of the action of the laser annealing apparatus 1 described above.

The pulsed laser beam 15 outputted as a pulse-oscillation beam from the pulse-oscillation laser light source 10 is, for example, configured to have a wavelength of 400 nm or shorter and a pulse full width at half maximum of 200 ns or shorter. The present invention is, however, not limited thereto.

The pulsed laser beam 15 is adjusted by the attenuator 11 in terms of pulse energy density. The attenuator 11 is set to provide a predetermined attenuation factor, and the attenuation factor is so adjusted that a predetermined irradiation pulse energy density is provided on an irradiation surface of the silicon film 100. For example, to crystallize the amorphous silicon film 100, the adjustment can be so made that the energy density on the irradiation surface of the silicon film 100 ranges from 150 to 500 mJ/cm^2, desirably 250 to 500 mJ/cm^2.

[0042]

The pulsed laser beam 15 having passed through the attenuator 11 is shaped by the optical system 12 into a linear beam and further passes through the cylindrical lens 12c in the optical system 12, where the minor-axis-direction width of the pulsed laser beam is ~~narrowed~~ condensed, and the resultant laser beam is introduced through the introduction window 6 provided in the processing chamber 2.

The pulsed laser beam 150 has a high intensity area which includes a flat portion 151 and where the intensities therein are at least 96% of an maximum energy intensity and steepness portions 152, which are located on opposite sides in the major axis direction, where the energy intensity is lower than that in the flat portion 151 described above, and where the energy intensity gradually decreases along the outward direction, as shown in Figure 3. The steepness portions are areas where the intensities therein fall within a range from 10 to 90% of the maximum intensity.

[0043]

The pulsed laser beam 150 passes through the introduction window 6, is introduced into the processing chamber 2, and further travels and reaches the screener 20. The screener 20 is disposed relative to the pulsed laser beam 150 in a position corresponding to 70 to 90% of the maximum intensity in the beam intensity profile so that the steepness portions 152 on opposite sides in the minor-axis direction of the pulsed laser beam 150 are screened. As a result, intensity impulses formed at the ends of the high intensity area can be reduced in size or eliminated when the pulsed laser beam passes through the screener 20.

[0044]

The pulsed laser beam 150 with the suppressed steepness portion 152 then has a steepness portion 153

due to diffraction and other phenomena at a minor-axis-direction rear end portion in the beam scan direction after passing through the screener 20, as shown in Figures 3 and 4. However, since the steepness portion 153 produced by the screener 20 is formed when the steepness portion 152, which is a steepness portion before passing through the screener 20, is screened, the width of the spread of the steepness portion 153 is considerably smaller than that of the steepness portion 152, which is a steepness portion before passing through the screener 20. The steepness portion 152 in the minor-axis-direction front end portion in the beam scan direction is allowed to remain unchanged with no problem. Figures 3 and 4 show a relative scan direction of the beam (the same holds true for Figure 5 in the following section).

Further, since the screener 20 screens the pulsed laser beam 150 in a position where the intensity is lower than the intensity in the flat portion, the amount of damage of the screener is smaller even when the screener is disposed in a position close to the silicon film 100 than in a case where the screener screens the flat portion. Disposing the screener in a position close to the silicon film 100 allows the degree of spread of the steepness portion 153 to be reduced and the minor-axis width of the steepness portion 153 can be 50 μm or smaller on the irradiation surface. The present

invention differs in this regard from related art in which a mask or a slit is used to screen the flat portion.

[0045]

In the pulsed laser beam 150 having passed through the screener 20, the steepness portion 153 has a reduced degree of spread, and the width of the steepness portion is reduced to 50 μm or smaller, further desirably 45 μm or smaller, as shown in Figures 3 and 4.

[0046]

The scan device 3 is used to move the silicon film 100 in such a way that the silicon film 100 is irradiated with the pulsed laser beam 150 while the silicon film 100 is scanned with the pulsed laser beam 150. The speed of the scanning described above is not limited to a specific value in the present invention. The irradiation intervals can be set at a value ranging from 5 to 65 μm.

The pulsed laser beam 150 is so shaped that the width of the steepness portion 153 is 50 μm or smaller, as described above. Even if the output value of the pulsed laser beam 15 varies, variation in the width of an area where the intensity is greater than or equal to a melting threshold can be suppressed. For example, in a case where the width of the steepness portion 153 is 50 μm or smaller, even when the output energy increases by 10%, the variation in the width of the area where the intensity is greater than or equal to the melting

threshold can be reduced to 0.95% or lower, as shown in Figure 5.

[0047]

Figure 6 shows a laser annealing apparatus 1a according to another embodiment, in which screeners are disposed in multiple stages (two stages in this example). The same configurations as those in the embodiment described above have the same reference characters, and the description thereof will be omitted or simplified.

[0048]

A first screener 21, which corresponds to a first screener, is disposed in a position between the cylindrical lens 12c, which is a collector lens, and the introduction window 6, and a second screener 22, which corresponds to a second screener, is disposed in the processing chamber 2. The first screener 21 is disposed in a position where the first screener 21 can screen the minor-axis-direction rear end portion of the pulsed laser beam 150 in the beam scan direction. The second screener 22 is similarly disposed in a position where the second screener 22 can screen the minor-axis-direction rear end portion of the pulsed laser beam 150 in the beam scan direction.

Each of the first screener 21 and the second screener 22 can instead be so disposed that a paired two screen plates are provided with a certain amount of gap

therebetween and screen the two end portions of the pulsed laser beam in the scan direction.

[0049]

The pulsed laser beam 150 having the steepness portion 152 suppressed by the first screener 21 then has a steepness portion 153 due to diffraction and other phenomena at the minor-axis-direction rear end portion in the scan direction after passing through the first screener 21. However, since the steepness portion 153 is formed when the steepness portion 152 is screened, the width of the spread of the steepness portion 153 is considerably smaller than that of the steepness portion 152.

The first screener 21 desirably screens part of the beam cross section of the pulsed laser beam described above in an area outside the minor-axis-direction end of the high intensity area, and the first screener 21 is further desirably disposed in a position corresponding to 70 to 90% of the maximum intensity in the beam intensity profile.

[0050]

Further, the pulsed laser beam 150 having the steepness portion 153 passes through the introduction window 6, is introduced into the processing chamber 2, and further travels and reaches the second screener 22. The position of the second screener 22 coincides with the position of the steepness portion 153 suppressed by the

first screener 21. The second screener 22 therefore screens a remaining steepness portion excluding part of the inner steepness portion in the minor-axis direction. The pulsed laser beam 150 having passed through the second screener 22 has a steepness portion formed due, for example, to diffraction, but the width of the spread of the steepness portion is further reduced as compared with that of the steepness portion before reaching the second transmitting portion 22, whereby the steepness portion is further suppressed.

The second screener 22 desirably screens part of the beam cross section of the pulsed laser beam described above in an area outside the minor-axis-direction end of the high intensity area, and the second screener 22 is desirably disposed in a position corresponding to 70 to 90% of the maximum intensity in the beam intensity profile after the pulsed laser beam passes the first screener 21.

[0051]

In each of the embodiments described above, the screener or the screeners disposed in the optical path reduce the width of the steepness portion at the minor-axis-direction rear end portion in the scan direction. Instead, the reduction in the width of the steepness portion is achieved, for example, by adjustment of the position of the silicon film relative to the position where an image is formed by the cylindrical lens 12c or

use of a unit lens having better image formation performance in place of the cylindrical lens 12c, or even by a combination with the screener or the screeners.

Example 1

[0052]

An example of the present invention will next be described.

A substrate on which an amorphous silicon film was formed to a thickness of 50 nm was provided. In the laser processing apparatus according to the embodiment shown in Figure 1, an excimer laser oscillator (model name: LSX540C) was used as the pulse-oscillation laser light source, and a pulsed laser beam having a wavelength of 308 nm was outputted at a pulse frequency of 300 Hz.

The optical system was used to shape the beam into a linear beam having a size of 370 mm × 0.4 mm, and a mask was used to set the width of the steepness portion in the minor-axis-direction rear end portion in the beam scan direction at 40 μm. Further, for comparison purposes, a mask was disposed in a high position from the amorphous silicon film, and the width of the steepness portion in the minor-axis direction was set at 70 μm.

[0053]

The number of overlaps was set at 20. Under the conditions described above, an irradiation energy density optimum for crystallization ranged from 310 to 330 mJ/cm^2.

Further, under these conditions, the scan intervals were 20 μm.

Further, the attenuator was used to adjust the irradiation energy density to 310, 320, 330, 340, 350, 360, and 370 mJ/cm^2, and the thus changed irradiation energy densities were used to conduct irradiation tests and resultant crystallization properties were evaluated. Although the optimum energy density range (OED) for the crystallization in this example ranged from 310 to 340 mJ/cm^2, exemplary tests were conducted at 350 mJ/cm^2 in order to emphasize the effect of the variation in the energy density. An optical microscope was then used to observe the surface of each test piece. Figure 7 shows an image of the surface obtained in dark-field observation.

As a result, in the example of the present invention, since the raised portions in end portions of the melted area in the minor-axis direction for each exposure were formed at fixed intervals or 20 μm, the raised portions were not recognized as irradiation unevenness.

In the Comparative Example, although the amount of mechanical movement of the silicon film for each laser exposure was 20 μm, the actual width of the melted portion was increased, and the size of the raised portions in end portions of the melted area in the minor-axis direction was increased. The reason for this is that the pulse energy of the laser beam with which the

portions irradiated changed but remained at a relatively high level, and the portions were recognized as irradiation unevenness.

[0054]

The present invention has been described with reference to the above embodiments, but the present invention is not limited to the contents of the above description, and a variety of changes can be made thereto to the extent that they do not depart from the scope of the present invention.

Reference Signs List

[0055]

1 Laser annealing apparatus

1a Laser annealing apparatus

2 Processing chamber

3 Scan device

5 Substrate placement mount

6 Introduction window

10 Pulse-oscillation laser light source

11 Attenuator

12 Optical system

12c Cylindrical lens

20 Screener

21 First screener

22 Second screener

100 Silicon film

Claims

[Claim 1]

A laser annealing method comprising irradiating a non-single-crystal semiconductor film with a pulsed laser beam having a linear beam cross-sectional shape while scanning the non-single-crystal semiconductor film with the linear beam in a minor-axis direction of the linear beam, wherein

the linear beam has, in the minor-axis direction, a flat portion and steepness portions in a beam intensity profile, the steepness portions located in minor-axis-direction end portions, and the steepness portions are areas having intensities greater than or equal to 10% but smaller than or equal to 90% of a maximum intensity in the beam intensity profile, and the flat portion has a minor-axis-direction width of an area having intensities at least 96% of the maximum intensity, and the minor-axis-direction width ranges from 100 to 500 μm on the irradiation surface of the non-single-crystal semiconductor film, and

a screening is performed in an area outward from a position where the intensity is from 70 to 90% of the maximum intensity at a rear side in a minor-axis scanning direction of the flat portion such that a minor-axis-direction width of the steepness portion which is one of the steepness portions and which is located on the rear side in the scan direction is 50 μm or smaller on an irradiation surface of the non-single-crystal semiconductor film.

[Claim 2]

The laser annealing method according to claim 1, wherein the pulsed laser beam has a wavelength of 400 nm or shorter.

[Claim 3]

The laser annealing method according to claim 1 or 2, wherein a pulse of the pulsed laser beam on the irradiation surface has a full width at half maximum of 200 ns or smaller.

[Claim 4]

The laser annealing method according to any of claims 1 to 3, wherein the pulsed laser beam has a maximum intensity ranging from 250 to 500 mJ/cm^2 in the beam intensity profile on the irradiation surface.

[Claim 5]

The laser annealing method according to any of claims 1 to 4, wherein the non-single-crystal semiconductor is silicon.

[Claim 6]

The laser annealing method according to any of claims 1 to 5, wherein the maximum intensity is defined as an average of the intensities across the flat portion.

[Claim 7]

The laser annealing method according to any of claims 1 to 6, wherein when the beam intensity profile of the pulsed laser beam has an intensity impulse where the intensity locally increases at one of the ends or at both ends of the beam intensity profile, the maximum intensity is defined as a value within a range excluding the intensity impulse.

[Claim 8]

A laser annealing apparatus comprising:

a laser light source that outputs a pulsed laser beam;

an attenuator that adjusts transmittance at which the attenuator transmits the pulsed laser beam; and

an optical system that shapes the beam cross-sectional shape of the pulsed laser beam and guides the shaped pulsed laser beam to an irradiation surface of a non-single-crystal semiconductor film, wherein

the optical system includes an optical member and a screener, and

the optical member shapes the beam cross-sectional shape of the pulsed laser beam to a linear beam , the linear beam having a high intensity area where the intensity is higher than or equal to a predetermined intensity in a beam intensity profile, the linear beam having, in the minor-axis direction, a flat portion and steepness portions in a beam intensity profile, the steepness portions located in minor-axis-direction end portions and being areas having intensities greater than or equal to 10% but smaller than or equal to 90% of a maximum intensity in the beam intensity profile, the flat portion having a minor-axis-direction width of an area having intensities at least 96% of the maximum intensity, the minor-axis-direction width ranging from 100 to 500 μm on the irradiation surface of the non-single-crystal semiconductor film, and

the screener is disposed in an optical path of the pulsed laser beam and screens a beam cross section of the pulsed laser beam in an area outward from a position where the intensity is from 70 to 90% of the maximum intensity at a rear side in the minor-axis scanning direction of the flat portion in such a way that a minor-axis-direction width

of at least a steepness portion which is one of steepness portions located in minor-axis-direction end portions of the linear beam and which is the steepness portion on the rear side in a scan direction is 50 μm or smaller on the irradiation surface of the non-single-crystal semiconductor film.

[Claim 9]

The laser annealing apparatus according to any of claims 8, wherein the pulsed laser beam outputted from the laser light source has a wavelength of 400 nm or shorter.

[Claim 10]

The laser annealing apparatus according to any of claims 8 or 9, wherein the pulsed laser beam outputted from the laser light source has a full width at half maximum of 200 ns or smaller.

[Claim 11]

The laser annealing apparatus according to any of claims 8 to 10, wherein the attenuator adjusts the maximum intensity in the beam intensity profile of the pulsed laser beam on the irradiation surface of the non-single-crystal semiconductor film to a value ranging from 250 to 500 mJ/cm^2.