DESCRIPTION

TITLE OF INVENTION

LASER ANNEALING APPARATUS AND LASER ANNEALING METHOD

TECHNICAL FIELD

[0001]

The present invention relates to a laser annealing apparatus for irradiating a semiconductor film with a pulsed laser beam to thereby perform laser annealing and a laser annealing method for the same.

BACKGROUND ART

[0002]

In recent years, high resolution, high frame rate driving, 3D capability, etc., have been sought after as the key words for liquid crystal displays, thereby creating a need for thin film transistors that have adequate performance to achieve the key-word capabilities. To enhance the performance of the thin film transistors, silicon semiconductor films should be crystallized by means of laser annealing.

Conventionally, laser annealing apparatuses are apparatuses to crystallize amorphous silicon (a-Si), in which the annealing technology by means of an excimer laser is employed. Since a beam of the excimer laser is of low quality, it is not possible to narrow the beam into a fine beam. For this reason, an optical system is arranged to form a beam with respect to X and Y directions into a top flat shape and the top-flat beam is used. Typically used excimer lasers are XeCl lasers (having an wavelength of 308 nm), which are characterized in a high level of absorption into a-Si, a shallow depth of penetration into amorphous silicon that is

approximately 7 nm, and the occurrence of a temperature gradient along a direction of film thickness. In the annealing technology using the excimer lasers, the temperature gradient is utilized to output a laser with which an amorphous silicon film is not completely molten as a whole, but molten to the extent of leaving nuclei of crystal growth unmelted on a bottom region of the film, to thereby induce crystal growth using the nuclei as the origin of the growth. FIG. 8 shows a schematic diagram of the thus-induced crystallization.

Specifically, an amorphous silicon film 31 formed on a glass substrate 30 is irradiated by a pulsed laser beam 40, to produce a molten silicon film 32. The molten silicon film 32 is crystallized in the course of recrystallization and solidification, leading to formation of a crystalline silicon film 33.

[0003]

In addition to the above technology, a laser annealing method using an absorption layer (Patent Literature 1), a laser annealing apparatus using a second harmonic of YAG laser (the wavelength of 532 nm) (Patent Literature 2), and a apparatus using a continuous oscillation laser (Patent Literature 3) have been suggested.

Moreover, a method for laser annealing has been known in which a complicated process is employed in order to achieve uniform crystallization without irregularities, and a method using a heating stage, for example, is suggested in Patent Literature 4. Furthermore, a method for performing laser irradiation in two separate steps (Patent Literatures 5 and 6). There is another example of attempting to address the above problem by means of a laser having a wavelength other than those described above. As such an example, the use of an

Mo film absorption layer and a laser diode has been reported (Non-Patent Literature 1). In addition, a method using a blue semiconductor laser based on GaN has been suggested (Patent Literature 7).

CITATION LIST

PATENT LITERATURE

[0004]

Patent Literature 1: Japan Patent Laid-Open Publication No. S62-1323311

Patent Literature 2: Japan Patent Laid-Open Publication No. 2005-294493

Patent Literature 3: Japan Patent Laid-Open Publication No. 2010-118409

Patent Literature 4: Japan Patent Laid-Open Publication No. 2008-147487

Patent Literature 5: Japan Patent Laid-Open Publication No. 2010-103485

Patent Literature 6: Japan Patent Laid-Open Publication No. 2001-338873

Patent Literature 7: Japan Patent Laid-Open Publication No. 2009-111206

NON-PATENT LITERATURE

[0005]

Non-Patent Literature 1: E. P. Donovan, "Calorimetric studies of crystallization and relaxation of amorphous Si and Ge prepared by ion implantation", J. Appl. Phys., Vol. 57, pp. 1795-1804, 1985

SUMMARY OF INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0006]

In conventional XeCl excimer laser annealing apparatuses that employ the methods as described above, although good crystallization can be achieved, it is yet necessary to perform a dehydrogenation process for the purpose of preventing ablation that results from instantaneous heating to the melting point, and precisely control the laser output and focus. Further, a jointed portion between beams along the long axis suffers from a problem of property degradation due to a fact that a melting is caused, and substrates are not scalable beyond a G4 substrate size (730 mm × 920 mm) under present circumstances because of limitations of a beam size, which is problematic in that large-area processing is difficult. Because a crystalline state is changed depending on the amplitude of laser output in a laser annealing process, Patent Literature 1 also discloses a method for changing the laser output in view of the aforesaid problem, yet fails to solve the problem associated with the jointed portion along the long axis.

[0007]

Because the apparatus using the continuous oscillation laser disclosed in Patent Literature 3 needs an optical system for converging a plurality of laser beams, the energy that laser oscillators respectively possess exhibits variations in strength and undergoes interference, whereby it becomes difficult to provide an improvement in uniformity with a high degree of accuracy.

On the other hand, the method using the heating stage as in the case of Patent Literature 4 is suffering from a great loss in takt time associated with a heating-cooling process, and accordingly unsuitable for practical applications. Further, the method disclosed in Patent Literatures 5 and 6 in which laser is irradiated in the two separate steps has a

problem of a deterioration in throughputs. Moreover, a way to address the above-described problem using the laser having the another wavelength as disclosed in Non-Patent Literature 1 is not unsuitable for practical applications because the number of process steps is increased by a process such as separation of the absorption layer.

Still further, the method using the blue semiconductor laser based on GaN in Patent Literature 7 is essentially the same as a melt process, and unsuitable for industrial applications in terms of extremely low output resulting from limitation to the use of the blue semiconductor laser based on GaN in the process.

[0008]

The present invention is directed to overcome the problems of the conventional techniques as described above, and provide a laser annealing apparatus and a laser annealing method with which a large-area semiconductor film can be evenly and uniformly crystallized through the use of a laser beam that is absorbed in the semiconductor film and composed so as to have an effective power density defined in this application in a specific range without requiring any complicated process.

MEANS FOR SOLVING BY THE INVENTION

[0009]

A laser annealing apparatus according to a first aspect of the present invention irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to perform crystallization of the amorphous semiconductor film. The laser annealing apparatus comprises a pulsed laser oscillator that outputs a pulsed laser beam, and

an optical transmission means that transmits the pulsed laser beam output from the pulsed laser oscillator to irradiate a semiconductor film with the pulsed laser beam, in which the pulsed laser beam is irradiated onto the semiconductor film

in a condition where the pulsed laser beam has an energy density of from 100 to 400 mJ/cm^2 and an effective power density calculated by the following formula falls within a range of from 2.7×10^{12} to 1.5×10^{12} on an irradiation surface of the semiconductor film.

effective power density $(J/(sec \cdot cm^3))$ = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

[0010]

The laser annealing apparatus according to a second aspect of the present invention irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to carry out crystallization of the amorphous semiconductor film. The laser annealing apparatus comprises a continuous laser oscillator that outputs a continuous laser beam, an optical transmission means that transmits the continuous laser beam output from the continuous laser oscillator and a pulsed laser beam split from the continuous laser beam to irradiate a semiconductor film with the pulsed laser beam, and a pulsed laser beam generating means that splits the continuous laser beam during the transmission into a pseudo pulsed shape to thereby generate a pulsed laser beam. In the laser annealing device, the pulsed laser beam is irradiated onto the semiconductor film in the condition where the effective power density calculated by the following formula falls within a range of from 2.7×10^{12} to 1.5×10^{12} on the irradiation surface of the semiconductor film.

effective power density $(J/(sec \cdot cm^3))$ = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

[0011]

The laser annealing apparatus according to an embodiment further comprises, in the first or second invention, an energy adjusting means that adjusts an energy density of the pulsed laser beam. In the energy adjusting means, the energy density is defined in such a manner that the effective power density calculated by the

above-described formula falls within the range of from 3×10^{12} to 1.5×10^{12}.

[0012]

The laser annealing apparatus according to another embodiment comprises, as the energy adjusting means in one of the above embodiments, an attenuator that attenuates the pulsed laser beam at a predetermined attenuation rate and an output adjusting means that adjusts an output of the laser oscillator. In the attenuator and the output adjusting means, the attenuation rate and the output are defined in such a manner that the effective power density calculated by the above-described formula falls within the range of from 2.7×10^{12} to 1.5×10^{12}.

[0013]

The laser annealing apparatus according to another embodiment further comprises, in any one of the above embodiments, a pulse width adjusting means that adjusts a pulse width of the pulsed laser beam. Further, the pulse width adjusting means adjusts the pulse width of the pulsed laser beam in such a manner that the effective power density calculated by the above formula falls within the range of from 2.7×10^{12} to 1.5×10^{12}.

[0014]

The laser annealing apparatus according to one embodiment has characteristic features that the semiconductor film is a silicon semiconductor film, the energy density is from 100 to 500 mJ/cm^2, and the pulse width is from 50 to 500 nsec in any one of the above embodiments.

[0015]

A laser annealing method according to a third aspect of the present invention irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the

amorphous semiconductor film is not completely molten to perform crystallization of the semiconductor film. The method comprises the laser

annealing method for irradiating a semiconductor film with a pulsed laser beam to perform laser annealing of the semiconductor film, setting a pulse energy density and a pulse width of the pulsed laser beam in such a manner that the pulsed laser beam has an energy density of from 100 to 400 mJ/cm^2 and an effective power density calculated by the following formula within a range of from 2.7×10^{12} to 1.5×10^{12} on an irradiated surface, and irradiating the thus-set pulsed laser beam onto the semiconductor film with the pulsed laser beam having the defined pulse energy density and pulse width, the effective power density being calculated by a formula of:

effective power density $(J/(sec \cdot cm^3))$ = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

[0016]

According to embodiments of the present invention, the pulsed laser beam is produced to satisfy an appropriate relationship among the energy density, the pulse width, and the absorption coefficient, and irradiated onto the semiconductor film, to thereby rapidly heat up the semiconductor film for application of heat at which the semiconductor film is not completely molten. In this way, it is possible to obtain uniform crystalswith small variability in grain size, with a technique different from conventional complete melt/recrystallization methods. Conventional melt crystallization methods or SPC (solid phase crystallization) by means of a heating furnace result in the presence of a wide range of variations in crystal grains.

Next, conditions defined in the present invention will be described below.

[0017]

Effective Power Density: within the range of from 3×10^{12} to 1.5×10^{12}

When the effective power density calculated by the following formula is set to fall within an appropriate range, a uniform crystalline semiconductor film with small variability can be obtained by annealing a semiconductor film. When the effective power density is smaller than the lower limit, it is not possible to sufficiently heat the semiconductor film, which can often result in uneven crystallization. On the other hand, when the effective power density exceeds the upper limit, melting of the semiconductor film is caused to occur, which produces non-uniformity in crystals.

effective power density ($J/(sec \cdot cm^3)$) = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

Note that the above-described effective power density is defined as a specific value in the present invention, and should not be regarded as a value that represents any general physical property.

[0018]

Wavelength Range of Pulsed Laser Beam

In the present invention, the pulsed laser beam to be irradiated onto the semiconductor film is not limited to those having a wavelength in a specific wavelength range. However, when the pulsed laser beam, which is set to have a wavelength in the range where the wavelength is well absorbed by the semiconductor film, in particular, an amorphous silicon film, is irradiated onto the semiconductor film, the semiconductor film can be directly heated. This ensures efficient heating of the semiconductor film, and eliminates the necessity to install a laser absorption layer in an indirect manner on an upper layer of the semiconductor film. When the pulsed laser beam has a wavelength that is not only

absorbed by the semiconductor film, in particular, the amorphous silicon film but also transmitted therethrough, a light absorption rate of the semiconductor film exhibits a wide range of deviation (variation) depending on the thickness of a lower layer compose of silicon due to multiple reflection from the lower layer. In this respect, it is preferable that the wavelength range lies in an ultraviolet region from 308 to 358 nm.

[0019]

Energy Density

The semiconductor film, which is irradiated with the pulsed laser beam having an appropriate energy density, undergoes a change in a state where it is not completely molten, so that fine crystals can be produced. When the energy density is lower, the effective power density is decreased to the extent of resulting in insufficient crystallization or leading to difficulty in crystallization. On the other hand, when the energy density is higher, the effective power density is excessively increased to the extent of forming molten crystals or causing ablation to occur. In the present invention, the energy density is not limited to any specific value as long as the value can yield the effective power density that falls within the appropriate range. Still, a range of from 100 to 500 mJ/cm^2 may be presented as a preferable range for the energy density.

[0020]

Pulse Width

The pulse width is one of important factors needed to obtain the appropriate effective power density for heating the semiconductor film as appropriate, and when the pulse width is excessively smaller, the effective power density is increased to the extent that the semiconductor film is heated

to a temperature at which it is completely molten. This makes it difficult to achieve uniform crystallization. On the other hand, when the pulse width is excessively greater, the effective power density is decreased to the extent that the semiconductor film may not be heated to the temperature at which it is crystallized in some cases. In the present invention, although the pulse width is not limited to any specific width as long as the width can yield the effective power density that falls within the appropriate range, a range of from 50 to 500 nsec may be presented as a preferable range for the pulse width.

[0021]

The shape of the pulsed laser beam on the irradiation surface is not limited to any specific shape, and the semiconductor film may be irradiated with the pulsed laser beam formed in a shape of a spot or a line, for example.

When the pulsed laser beam is formed in the shape of a line, a short axis width of the pulsed laser beam is preferably defined to be 0.5 mm or smaller. When the pulsed laser beam is relatively scanned along a direction of the short axis width, crystallization of a large area can be achieved while partially irradiating and heating the semiconductor film. However, an excessively greater short axis width requires an increased scan rate for effective crystallization, which leads to an increase in cost of the apparatus.

[0022]

The relative scan of the pulsed laser beam with respect to the amorphous film allows the semiconductor film to be crystallized along a plane direction. The scan may be performed while moving the pulsed laser beam, moving the amorphous film, or moving both the pulsed laser beam and the

amorphous film.

[0023]

Further, in the present invention, a solid laser beam source for outputting pulsed laser beams may be used to output the pulsed laser beam in a desired wavelength range, and uniform crystals can be produced by means of the laser beam source which is superior in maintainability. It should be noted that the pulsed laser beam may be a beam in a pseudo pulsed shape formed by splitting a continuous laser beam. The splitting may be carried out using a shutter, which is mechanically rotated at high velocity or driven otherwise, an optical modulator, or the like.

[0024]

The pulsed laser beam may be irradiated onto the semiconductor film after the energy density of the pulsed laser beam is adjusted as appropriate by a energy adjusting means in order to create uniform fine crystals using the proper effective power density. In the energy adjusting means, a predetermined energy density may be obtained by adjusting the output of the laser oscillator, or the energy density may be adjusted by controlling the attenuation rate of the laser beam output from the laser oscillator in the attenuator or the like. Regarding the energy density condition of the pulsed laser beam in a case of using the pseudo pulsed laser beam, the energy adjustment may be made before the laser beam is split into the pulsed shape.

[0025]

Still further, the pulsed laser beam may be irradiated onto the semiconductor film after the pulse width of the pulsed laser beam is adjusted as appropriate by a pulse width adjusting means in order to create uniform fine crystals using the proper effective power density.

The pulse width adjusting means may be composed of a beam splitting means that splits the pulsed laser beam into a plurality of beams, a delaying means that delays each of the split beams, and a beam synthesizing means that synthesizes each of the split beams. A pulse waveform can be formed in an appropriate shape by setting the amount of delay defined in the delaying means. The delaying means is capable of changing the amount of delay by adjusting an optical path length.

For example, the laser beams split by the above-described beam splitting means are directed to optical systems, each of which has a different optical path length. The split and delayed beams may be redirected to a single optical path, to thereby extend a temporal pulse width and accordingly adjust the pulse waveform. In particular, a temporal pulse waveform can be changed as appropriate by adjusting a ratio of intensities of the beams to be split and respectively defining the optical path length of the split beams after the beam split.

[0026]

The pulse width may be adjusted by overlapping the pulsed laser beams output from a plurality of laser beam source. A desired pulse waveform can be obtained as a result of irradiating a plurality of pulsed laser beams onto the semiconductor. When the plurality of pulsed laser beams are overlapped, a pulse output phase may be adjusted, and/or the pulse width may be adjusted via the delaying means to a desired width. Such components for making the adjustments constitute the pulse width adjusting means.

[0027]

The pulsed laser beam may be relatively scanned with respect to the semiconductor film by a scanning device, to thereby obtain fine and uniform crystals in a large area of

the semiconductor film. A pulse frequency, the short axis width of the pulsed laser beam, and the scan rate are established in such a manner that the number of shots taken by the scan in the same area on the semiconductor film matches a predetermined number of, for example, from 1 to 10.

The scanning device may be a scanning device that moves an optical system into which the pulsed laser beam is directed, to thereby move the pulsed laser beam, or that moves a base on which the semiconductor film is placed.

EFFECTS OF THE INVENTION

[0028]

As has been described above, according to the present invention, the semiconductor film is irradiated with the pulsed laser beam with setting the effective power density expressed by the following formula within the range of from 3×10^{12} to 1.5×10^{12}. As a result, the semiconductor film can be crystallized without inducing abnormal grain growth, which makes it possible to obtain uniform crystals with small variability.

BRIEF DESCRIPTION OF DRAWINGS

[0029]

FIG. 1 is a schematic diagram showing an embodiment of a laser annealing apparatus according to the present invention.

FIG. 2 is a schematic diagram showing an example of pulse width adjusting means in the embodiment of the present invention.

FIG. 3 is a schematic diagram showing the laser annealing apparatus according to another embodiment.

FIG. 4 shows SEM photographs of crystals obtained after laser annealing in an example according to the present

invention.

FIG. 5 shows SEM photographs of crystals obtained after laser annealing in the example of the present invention.

FIG. 6 shows SEM photographs of crystals obtained after laser annealing in the example of the present invention.

FIG. 7 is a diagram showing an effective power density in the example of the present invention.

FIG. 8 is an explanatory diagram showing crystallization states in conventional laser annealing.

MODE FOR CARRYING OUT THE INVENTION

[0030]

Hereinafter, an embodiment of the present invention will be described.

FIG. 1 is a diagram schematically showing a laser annealing apparatus 1 of the present invention.

The laser annealing apparatus 1 includes a processing chamber 2, a scanning device 3 capable of moving in X and Y directions inside the processing chamber 2, and a base 4 mounted on the top of the scanning device 3. On the base 4, a substrate mounting table 5 is installed as a stage. When an annealing process is performed, an amorphous silicon film 100 or the like, as a semiconductor film, is placed on the substrate mounting table 5. The silicon film 100 is formed with a thickness of 50 nm on a substrate, which is not illustrated. The formation of the silicon film 100 may be performed in an ordinary method, and the present invention is not intended to be limit to any specific method for forming the semiconductor film. Further, although a semiconductor film of an amorphous type is preferably used for the semiconductor film to be annealed, the semiconductor film is not limited to those of the amorphous type in the present

invention. The semiconductor film may be those of a crystalline type or those partially including crystals, and the laser annealing may be also applied to those semiconductor films for modifying the crystals.

It should be noted that the scanning device 3 is driven by a not-illustrated motor or other devices, and operation of the motor is controlled by a control unit 8, which will be described below, to set a scan rate. In addition, the processing chamber 2 is equipped with an introduction window 6 into which the pulsed laser beam is introduced from the outside.

[0031]

Outside the processing chamber 2, a pulsed laser oscillator 10 is installed. The pulsed laser oscillator 10 is composed of an excimer laser oscillator. The pulsed laser oscillator 10 is connected to a laser power source 9 for supplying a drive voltage, and the laser power source 9 is controllably connected to the control unit 8. In response to a command from the control unit 8, the laser power source 9 supplies a required drive voltage to the pulsed laser oscillator 10, and a pulsed laser beam is output at a predetermined output power from the pulsed laser oscillator 10.

[0032]

A pulsed laser beam 15 generated and output as pulses from the pulsed laser oscillator 10 has an energy density, which is adjusted in an attenuator 11 when needed. In the attenuator 11 controllably connected to the control unit 8, a predetermined attenuation rate is set in accordance with the command from the control unit 8. Namely, the laser power source 9, the control unit 8, and the attenuator 11 described above constitute the energy adjusting means of the present

invention. In the energy adjusting means, an energy density can be preferably adjusted to be 100 ~ 500 mJ/cm^2 on an irradiation surface of the silicon film 100.

The pulsed laser beam 15 transmitted through the attenuator 11 is subjected to beam shaping and/or deflected in an optical transmission means 12 composed of a lens, a reflecting mirror, a homogenizer, and others, and irradiated onto the silicon film 100 through the introduction window 6 installed in the processing chamber 2. The shape on the irradiation surface obtained at the irradiation is not specifically limited, and may be formed, for example, into a spot shape, a circular shape, a rectangular shape, an elongated shape, etc. by the optical transmission means 12.

[0033]

Further, the optical transmission means 12 may be equipped with a pulse width adjusting means 13. An overview of the pulse width adjusting means 13 will be explained with reference to FIG. 2.

In the pulse width adjusting means 13, a beam splitter 130 composed of a half mirror is installed on an optical path to split the beam 15 into a partial beam 15a to be reflected at 90 degrees and the other remaining beam 15b to be transmitted. Namely, the beam splitter 130 corresponds to the beam splitting means of the present invention. In addition, a total reflection mirror 131 is placed in a reflection direction of the beam splitter 130 so as to establish an angle of incidence of 45 degrees, a total reflection mirror 132 is placed in a reflection direction of the total reflection mirror 131 so as to establish the angle of incidence of 45 degrees, a total reflection mirror 133 is placed in a reflection direction of the total reflection mirror 132 so as to establish the angle of incidence of 45

degrees, and a total reflection mirror 134 is placed in a reflection direction of the total reflection mirror 133 so as to establish the angle of incidence of 45 degrees.

A reflection direction of the total reflection mirror 134 is situated on a back surface side of the beam splitter 130 onto which, and the beam is irradiated at the angle of incident of 45 degrees on the back surface side.

[0034]

The beam 15a reflected at 90 degrees on the beam splitter 130 is sequentially reflected at 90 degrees on each of the total reflection mirrors 131, 132, 133, and 134, and directed to reach, as a delayed beam 15c, the back surface side of the beam splitter 130 where the delayed beam 15c is partially reflected at 90 degrees and overlapped on the beam 15b in a delayed form. The other remaining beam is transmitted through the beam splitter 130, and again subjected to the total reflections and the split in the beam splitter 130 repetitively. The resultant beam overlapped on the beam 15b travels on the optical path as a pulsed laser beam 150 whose pulse waveform has been shaped and whose pulse width has been adjusted by the overlapping of the delayed beam.

Note that an amount of delay can be changed by moving the position of each total reflection mirror so that the optical path length is adjusted. In this way, the pulse width of the overlapped pulsed laser beam can be changed to any desired width. Alternatively or additionally, the intensities of the split pulsed laser beams may be independently adjusted.

Preferably, the pulse width may be set to fall within a range of from 50 to 500 ns by the pulse width adjusting means. It should be noted that the present invention may be embodied, without including the pulse width adjusting means, by

irradiating the silicon film 100 with a pulsed laser beam whose pulse width remains unchanged from that of the output pulsed laser beam.

[0035]

The pulsed laser beam 150 is introduced through the introduction window 6 into the processing chamber 2 and irradiated onto the silicon film 100 placed on the substrate mounting table 5. At this time, the substrate mounting table 5 is moved together with the base 4 by the scanning device 3, thereby relatively scanning the pulsed laser beam 150 on the silicon film 100 while irradiating the silicon film 100.

At the time of irradiation, the pulsed laser beam 150 is formed so as to have the effective power density suitable for crystallization. Specifically, the output power of the pulsed laser oscillator 10, the attenuation rate in the attenuator 11, the pulse width, and a cross-sectional area of the pulsed laser beam to be irradiated are established in such a manner that the effective power density calculated by the above-described formula falls within the range of from 3×10^{12} to 1.5×10^{12}. Irradiation of the thus-formed pulsed laser beam 150 causes the silicon film 100 to be uniformly crystallized. Note that the coefficient of laser beam absorption in the silicon film 100 is determined by the wavelength of the pulsed laser beam, and can be found using known information.

The silicon film 100, which has been crystallized through irradiation of the pulsed laser beam 150, exhibits superior crystalline properties, in which crystals have a uniform grain size.

[0036]

It has been described that the pulse width adjustment is performed in the pulse width adjusting means 13 in which the pulsed laser beam is split and delayed to adjust the pulse

width. However, the pulsed laser beams output from a plurality of pulsed laser oscillators may be brought out of synchronization with each other and irradiated onto the silicon film 100 to adjust the pulse width.

FIG. 3 is a diagram showing components of the thus-configured apparatus, which will be described below. It should be noted that components similar to those in the above-described embodiment are identified by identical reference numerals to those in the above-described embodiment.

The laser annealing apparatus includes, as shown in FIG. 3, the processing chamber 2, the scanning device 3 capable of moving in the X and Y directions within the processing chamber 2, and the base 4 mounted on the top of the scanning device 3. The substrate mounting table 5 is disposed on the base 4. When the annealing process is performed, the silicon film 100 to be processed is placed on the substrate mounting table 5. Note that the scanning device 3 is driven by the not-illustrated motor or other devices, and controlled by the control unit 8.

The pulsed laser oscillator 10 is installed outside the processing chamber 2. The pulsed laser beam 15 oscillated as pulses in the pulsed laser oscillator 10 and output therefrom is directed, after the energy density of the pulsed laser beam 15 is adjusted in the attenuator 11 when needed, to the optical transmission means 12 composed of a lens, a reflection mirror, a homogenizer, and others, in which beam shaping and deflection is performed on the pulsed laser beam 15, and irradiated onto the silicon film 100 in the processing chamber 2.

[0037]

Further, outside the processing chamber 2, a pulsed laser oscillator 20 that also generates a pulsed laser beam

25 is installed. The pulsed laser beam 25 oscillated as pulses in the pulsed laser oscillator 20 and output therefrom is directed, after the energy density of the pulsed laser beam 25 is adjusted in an attenuator 21 when needed, to an optical transmission means 22 composed of a lens, a reflection mirror, a homogenizer, and others, in which beam shaping and deflection is performed on the pulsed laser beam 25, and irradiated onto the silicon film 100 in the processing chamber 2.

In the above-described apparatus, the control unit 8 is used for controlling the entire apparatus, and controllably connected to both the laser power source 9 for driving the pulsed laser oscillator 10 and a laser power source 19 for driving the pulsed laser oscillator 20 for setting each output of the pulsed laser oscillators 10 and 20. In addition, the control unit 8 is also controllably connected to the attenuator 11 and the attenuator 21 for respectively setting their attenuation rates. Accordingly, the laser power sources 9 and 19, the attenuators 11 and 21, and the control unit 8 constitute the a energy adjusting means of the present invention.

[0038]

In the above laser annealing apparatus, the pulsed laser beam 15 and the pulsed laser beam 25 are output as shown in FIG. 3, and combined on the silicon film 100 to irradiate the silicon film 100. At this time, the pulsed laser beams to be irradiated together are brought out of synchronization with each other, so that the pulse width of the resultant pulsed laser beam to be irradiated onto the silicon film 100 can be accordingly adjusted.

In the pulsed laser beam whose pulse width has been adjusted, the effective power density is set to a value

within the range of from 3×10^{12} to 1.5×10^{12}. Then, the pulsed laser beam having the thus-set effective power density is irradiated onto the silicon film 100.

[0039]

Although the pulsed laser beam has been explained as being output from the pulsed laser oscillator in the above embodiments, it is also possible to use a laser beam in a pseudo pulsed shape formed by splitting a continuous laser beam output from a continuous laser oscillator.

Example 1

[0040]

Next, the inventive examples and comparative examples will be described in comparison.

The laser annealing apparatus (FIG. 1) according to the above-described embodiment was used to conduct an experiment to irradiate a pulsed laser beam onto an amorphous silicon thin film of 50 nm formed on a surface of a glass substrate in an ordinary method.

In the experiment, the pulsed laser beam was shaped so as to be rectangular on a processing surface by the optical transmission means, composed to have the energy density in a range of from 8 to 400 mJ/cm^2 and the pulse width in the range of from 20 to 600 ns on the irradiation surface, and irradiated onto amorphous silicon on a substrate. Here, the absorption coefficient of the amorphous silicon film is defined as follows:

absorption coefficient = 4pk / wavelength.

(k: attenuation coefficient, refer to Non-Patent Literature: D. E. Aspnes and J. B. Theeten, J. Electrochem, Soc. 127, 1359 (1980))

[0041]

The amorphous silicon was heated by the irradiation of the pulsed laser beam, and modified to crystalline silicon. The thus-irradiated thin film was evaluated by means of a microscope and SEM photographs. The SEM photographs (substitute photograph for a drawing) are shown in FIGS. 4 to 6.

Note that the effective power density, which will be described below, was calculated by the formula indicated below. Further, calculation results are shown in FIG. 7. FIG. 7 also shows effective power densities in conventional laser annealing as reference data. In the diagram, circle marks correspond to examples explained below, while cross marks correspond to comparative examples explained below.

Effective power density ($J/(sec \cdot cm^3)$) = pulse energy density (J/cm^2)) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

[0042]

(Example 1)

A XeCl excimer laser was used for the laser oscillator, and the effective power density was set to 2.0×10^{12} to perform irradiation of the pulsed laser beam. Through the irradiation, uniform crystals containing no irregularity were obtained as shown in photograph 1.

(Example 2)

The XeCl excimer laser was used for the laser oscillator, and the effective power density was set to 2.7×10^{12} to perform irradiation of the pulsed laser beam. Through the irradiation, uniform crystals containing no irregularity were obtained as shown in photograph 2.

(Example 3)

A third harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to

1.8×10^{12} to perform irradiation of the pulsed laser beam. Through the irradiation, uniform crystals containing no irregularity were obtained as shown in photograph 3.

(Example 4)

The third harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 2.5×10^{12} to perform irradiation of the pulsed laser beam. Through the irradiation, uniform crystals containing no irregularity were obtained as shown in photograph 4.

(Example 5)

A second harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 1.6×10^{12} to perform irradiation of the pulsed laser beam. Through the irradiation, uniform crystals containing no irregularity were obtained as shown in photograph 5.

(Example 6)

The second harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 2.4×10^{12} to perform irradiation of the pulsed laser beam. Through the irradiation, uniform crystals containing no irregularity were obtained as shown in photograph 6.

[0043]

(Comparative Example 1)

The XeCl excimer laser was used for the laser oscillator, and the effective power density was set to 2.0×10^{13} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of uneven crystals varying in their crystalline states on overlapped portions along the long axis as shown in photograph 7. A surface analysis conducted with XRD (X-Ray Diffraction) revealed that almost all regions were molten.

(Comparative Example 2)

The XeCl excimer laser was used for the laser oscillator, and the effective power density was set to 3.5×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of uneven crystals varying in their crystalline states on overlapped portions along the long axis as shown in photograph 8. The surface analysis conducted with XRD revealed that the surface layer was molten to a depth of approximately 3 nm.

(Comparative Example 3)

The third harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 3.1×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of uneven crystals varying in their crystalline states on overlapped portions along the long axis as shown in photograph 9. The surface analysis conducted with XRD revealed that the surface layer was molten to a depth of approximately 8 nm.

(Comparative Example 4)

The third harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 3.5×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of uneven crystals varying in their crystalline states on overlapped portions along the long axis as shown in photograph 10. The surface analysis conducted with XRD revealed that the surface layer was molten to a depth of approximately 9 nm.

(Comparative Example 5)

The second harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 3.2×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of uneven crystals varying in their crystalline states on overlapped portions

along the long axis as shown in photograph 11.

(Comparative Example 6)

The XeCl excimer laser was used for the laser oscillator, and the effective power density was set to 1.4×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of crystals, which were uneven on the whole as shown in photograph 12.

(Comparative Example 7)

The XeCl excimer laser was used for the laser oscillator, and the effective power density was set to 1.3×10^{12} to perform irradiation of the pulsed laser beam. The irradiation of the pulsed laser beam resulted in creation of totally uneven crystals as shown in photograph 13.

(Comparative Example 8)

The third harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 1.4×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of crystals, which were uneven on the whole as shown in photograph 14.

(Comparative Example 9)

The third harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 0.9×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of crystals, which were uneven on the whole as shown in photograph 15.

(Comparative Example 10)

The second harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 0.6×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of crystals, which were uneven on the whole as shown in photograph 16.

(Comparative Example 11)

The second harmonic of YAG solid laser was used for the laser oscillator, and the effective power density was set to 1.4×10^{12} to perform irradiation of the pulsed laser beam. The irradiation resulted in creation of crystals, which were uneven on the whole as shown in photograph 17.

[0044]

In the above description, the present invention has been explained based on the embodiments and the examples. However, the present invention is not limited to any contents of the above description, and may be changed as appropriate without departing from the scope of the present invention.

DESCRIPTION OF SYMBOLS

[0045]

1 laser annealing apparatus
2 processing chamber
3 scanning device
5 substrate mounting table
8 control unit
9 laser power source
10 pulsed laser oscillator
11 attenuator
12 optical transmission means
13 pulse width adjusting means
15 pulsed laser beam
19 laser power source
20 pulsed laser oscillator
21 attenuator
22 optical transmission means
25 pulsed laser beam
100 silicon film
150 pulsed laser beam

CLAIMS

1. A laser annealing apparatus which irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to perform crystallization of the amorphous semiconductor film comprising:

a pulsed laser oscillator to output a pulsed laser beam, and

an optical transmission means to transmit the pulsed laser beam output from the pulsed laser oscillator to irradiate a semiconductor film with the pulsed laser beam, wherein

the pulsed laser beam is irradiated on the semiconductor film in a condition where the pulsed laser beam has an energy density of from 100 to 400 mJ/cm^2 and an effective power density calculated by the following formula within a range of from 2.7×10^{12} to 1.5×10^{12} on an irradiation surface of the semiconductor film.

effective power density $(J/(sec \cdot cm^3))$ = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

2. A laser annealing apparatus which irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to carry out crystallization of the amorphous semiconductor film comprising:

a continuous laser oscillator to output a continuous laser beam;

an optical transmission mean to transmit the continuous laser beam output from the continuous laser oscillator and a pulsed laser beam split from the continuous laser beam to

irradiate a semiconductor film with the pulsed laser beam; and

pulsed laser beam generating means to split the continuous laser beam during the transmission into a pseudo pulsed shape to thereby generate the pulsed laser beam; wherein

the pulsed laser beam is irradiated on the semiconductor film in a condition where an effective power density of the pulsed laser beam calculated by the following formula within a range of from 2.7×10^{12} to 1.5×10^{12} on an irradiation surface of the semiconductor film.

effective power density $(J/(sec \cdot cm^3))$ = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

3. The laser annealing apparatus according to Claim 1 or 2, further comprising:

an energy adjusting means to adjust an energy density of the pulsed laser beam, wherein the energy density is defined in the energy adjusting means in such a manner that the effective power density calculated by the formula falls within the range of from 2.7×10^{12} to 1.5×10^{12}.

4. The laser annealing apparatus according to Claim 3, comprising, as the energy adjusting means, an attenuator to transmit the pulsed laser beam attenuated at a predetermined attenuation rate and an output adjusting means to adjust an output of the laser oscillator, wherein the attenuation rate and the output are defined in the attenuator and the output adjusting means in such a manner that the effective power density calculated by the formula falls within the range of from 2.7×10^{12} to 1.5×10^{12}.

5. The laser annealing apparatus according to any one of Claims 1 to 4, further comprising a pulse width adjusting means to adjust a pulse width of the pulsed laser beam, wherein the pulse width adjusting means adjusts the pulse width in such a manner that the effective power density calculated by the formula falls within the range of from 2.7×10^{12} to 1.5×10^{12}.

6. The laser annealing apparatus according to any one of Claims 1 to 5, wherein the semiconductor film is a silicon semiconductor film, and the pulse width is from 50 to 500 nsec.

7. A laser annealing method for irradiating an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to perform crystallization of the semiconductor film, the method comprising:

defining a pulse energy density and a pulse width of the pulsed laser beam in such a manner that the pulsed laser beam has an energy density of from 100 to 400 mJ/cm^2 and an effective power density calculated by the following formula within a range of from 2.7×10^{12} to 1.5×10^{12} on an irradiated surface, and irradiating the semiconductor film with the pulsed laser beam having the defined pulse energy density and pulse width.

effective power density $(J/(sec \cdot cm^3))$ = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)