

SPECIFICATION

METHOD FOR FABRICATING CRYSTALLINE SEMICONDUCTOR FILM, METHOD FOR CONTROLLING THE HEATING FOR SEMICONDUCTOR FILM AND APPARATUS FOR CRYSTALLIZING THE SEMICONDUCTOR FILM

Technical Field

【0001】 The present invention relates to a method for fabricating a crystalline semiconductor film which consists of irradiating an amorphous semiconductor film with a laser beam and thereby crystallizing the amorphous semiconductor film, a method for controlling the heating to be applied to the semiconductor film, and an apparatus for crystallizing the semiconductor film.

Background Art

【0002】 For methods that may be used for fabricating a crystallized silicon such as the one for the thin film transistor (TFT) which is used in the thin flat panel display such as the liquid crystal display (LCD) device, there are some examples of the methods that are generally used for the above purpose. there are (1) the method known as the laser annealing process which consists of irradiating the amorphous semiconductor film with a laser beam in its pulse forms, and fusing and recrystallizing the amorphous semiconductor film, (2) the method known as the Solid Phase Crystallization (SPC) process which consists of heating a substrate in the heater furnace, and allowing the amorphous semiconductor film to be crystallized and grow in its solid phase without being fused, and (3) the method known as the Chemical Vapor Deposition (DVD) process which consists of allowing the polysilicon film to glow directly on the glass substrate.

【0003】 In addition to the methods mentioned above, there are methods such

as the method which consists of irradiating the poly-silicon grown in its solid phase with the laser beam, and capturing any impurities contained in the poly-silicon by moving them (as disclosed in the below described patent document 1), and the method that consists of irradiating the crystalline silicon film with the laser beam and reducing the crystal defects during the fusing and solidifying process, thereby improving the crystalline quality (as disclosed in the below described patent document 2).

Patent document 1: Japanese patent application now opened for the public examination under No. 2002-373859

Patent document 2: Japanese patent application now opened for the public examination under No. 2006-108136

Disclosure of Invention

Problem to be solved by the Invention

[0004] In the meantime, organic electroluminescent (EL) displays instead of liquid crystal are recently expected to appear as the next generation displays. In the EL display, the screen brightness is increased by the light emitted by the EL elements themselves. The luminescent elements used for the EL display are driven by the electric current, but are not driven by the voltage like LCD. Therefore, requirements for the TFT are different for the EL display. For the TFT based on the amorphous semiconductor film, it is difficult to control any change that may be caused by aging, and the threshold voltage (V_{th}) may drift so largely that the lifetime of the device may be limited. As opposed, polysilicon has a long lifetime because of its stability. For the TFT based on polysilicon, however, its property may present large variations. The variations in the TFT property might easily occur if the boundaries between the crystal grains for the crystallized silicon (crystal grain boundary) exist in the regions in which the channels are formed on the TFT. The variations may occur, depending largely on the crystal grain sizes and the number of crystal grain boundaries found in between the channels on TFT. In addition, as the

grain sizes become larger, the electron field electronic mobility may be generally increased. The TFT used in the organic EL display having high electron field electronic mobility, however, requires the longer channels, and the size of one pixel for each of RGB (red, green, blue) may depend on the channel length on TFT. As such, the high resolution cannot be achieved.

【0005】 For the conventional crystallizing method, however, it is difficult to solve the problems described above. Because the laser annealing method is the process that is used for fusing and recrystallizing the amorphous semiconductor film, So the crystal grain sizes that may be formed using this process are generally large, causing the high electron field electronic mobility to occur to be highly. There are also variations in the crystal grain number that may be formed in several TFT channel regions. Furthermore, there are differences in the random configurations of crystals and orientations of the adjacent crystals. This will largely affect the variations that may occur in the TFT property. The contaminations on the surface may cause the crystal defects.

【0006】 For the solid phase crystallization (SPC) method, on the other hand, it is the crystallizing process that may be used most effectively in solving the problems described above. Because the crystal grain sizes that are thus formed can become smaller and the variations that may thus occur in TFT can become fewer. For the SPC method based on the thermal treatment, however, the crystals thus formed may have the indefinite configurations, and a great number of crystal defects may be found in the crystal grains. Furthermore, it may take a long time for crystallization. For this reason, the SPC process cannot be employed as the mass fabrication method. During the thermal treatment process in which the SPC method can be performed, a batch-type thermal treatment apparatus may be used so that it permits several substrates to be processed thermally at the same time. As a large number of substrates are processed thermally in the SPC, it may take a long time when

the temperature is raised or lowered, and the temperature inside the substrates may tend to be nonuniform. For the SPC method, the glass substrates are heated for a long time at the temperatures higher than the softening point of about 600°C. So the substrate may contract or expand, causing defects to occur in the glass material. When silicon is processed by the SPC process, the crystallizing temperature is set to any temperature higher than the temperature of the glass softening point, and so the glass substrate may have deflections or contractions even within the small temperature distribution range. Although the crystallization may be possible, the consequence of this is that the shallow focus-depth exposure process cannot be performed conveniently, making it difficult to fabricate TFT devices. Generally, the crystallizing speed depends upon the heating temperature. Several ten hours for the treatment would be required at 600°C, several hours would be required at 650°C, and several ten minutes would be required at 700°C. In order to permit the glass material to be processed thermally without causing any damages on the glass substrate, it must be processed for a longer time at the temperatures lower than the temperature of the glass softening point. For the reasons, it is difficult to employ the above process as the mass fabrication method.

[0007] When the polysilicon film is to be formed by using the CVD method, the polysilicon film must be processed at the high temperatures. This would affect the substrate badly. Although the method described in the patent document 1 may allow the impurities to be eliminated, it is difficult to provide the crystalline films having the uniform and small grain sizes. Furthermore, although the method described in the patent document 2 may provide the improved crystalline film by eliminating the crystal defects, it is difficult to provide the crystalline films having the uniform and small grain sizes.

For those recent years, the wiring width is becoming smaller, and the size of the TFT channel region (such as the channel length and channel width)

is also becoming smaller. In order to meet those recent needs, there are demands for a method that allows a crystalline semiconductor film having the uniform and small grain sizes to be formed evenly over the total substrate. Particularly, there are demands for a crystallizing method that allows the differences in the TFT property in the adjacent regions to be minimized.

[0008] The present invention has been made in light of the problems of the prior art described above. Embodiments of the present invention therefore seek to provide a method for fabricating a crystalline semiconductor film having the uniform and small grain sizes in average and in which several crystal grains can reside in the TFT channel regions to provide an apparatus for crystallizing the amorphous semiconductor film, and to provide a method for controlling the heating temperature for the semiconductor film so that the optimal laser beam irradiating condition can be determined easily and the semiconductor film can be heated under such optimal laser beam irradiating condition.

Means for solving problem

[0008a] According to the first aspect of the present invention, there is provided a method for fabricating a crystalline semiconductor film, comprising the steps of: raising the heating temperature of a glass substrate having an amorphous semiconductor film formed on the upper layer thereof and retaining the glass substrate in the raised temperature state; irradiating the amorphous semiconductor film on the glass substrate with a laser beam while the glass substrate is retained in the raised temperature state; heating the amorphous semiconductor film up to a temperature not exceeding the fusing point; and crystallizing the amorphous semiconductor film.

[0008b] According to the second aspect of the present invention, there is provided an apparatus for crystallizing an amorphous semiconductor film, including: a heating laser beam supply source for applying the heating laser beam onto the amorphous semiconductor film formed on the upper layer of a

glass substrate raising the heating temperature up to a temperature not exceeding the fusing point of the semiconductor film with the heating laser beam; a heater for raising the glass substrate; a visible-light diagnostic probe laser beam for applying the diagnostic probe laser beam onto the amorphous semiconductor film; and means for detecting the laser beam reflected back from the amorphous semiconductor film by the diagnostic probe laser beam.

[0009] In the method for fabricating a crystalline semiconductor film of the present invention, specifically, the method according to the first embodiment of the present invention is characterized in the fact that it consists of irradiating an amorphous semiconductor film formed on the upper layer of a glass substrate with a laser beam, heating the amorphous semiconductor film up to the temperature not exceeding the fusing point, and crystallizing the amorphous semiconductor film.

[0010] The method according to the second embodiment of the present invention is characterized in the fact that it consists of raising the temperature of the glass substrate having an amorphous semiconductor film formed on the upper layer thereof and maintaining the glass substrate in the raised temperature state, heating the amorphous semiconductor film on the glass substrate to the temperature not exceeding the fusing point by

irradiating the amorphous semiconductor film with the laser beam while the glass substrate is maintained in the raised temperature state, and crystallizing the amorphous semiconductor film.

【0011】 The method according to the third embodiment of the present invention is provided as a variation of the second embodiment, wherein it is characterized in the fact that the glass substrate is maintained in the heated state by heating the glass substrate up to the temperature not exceeding the softening temperature of the glass substrate.

【0012】 The method according to the fourth embodiment of the present invention is provided as a variation of the second or third embodiment, wherein it is characterized in the fact that the temperature of the glass substrate being heated is raised by heating the glass substrate using a heater.

【0013】 The method according to the fifth embodiment of the present invention is provided as a variation of any of the second, third and fourth embodiments, wherein it is characterized in the fact that the temperature of the glass substrate being heated is raised up to the said maintained heated state in a stepwise fashion, the stepwise raising of the temperature occurring while the glass substrate is maintained raised temperature state.

【0014】 The method according to the sixth embodiment of the present invention is provided as a variation of any of the first, second, third, fourth and fifth embodiment, wherein it is characterized in the fact that the laser beam is supplied as a pulse laser by any of the excimer laser beam generator and YAG laser generator.

【0015】 In accordance with the seventh embodiment of the present invention, the method for controlling the heating temperature for a crystalline semiconductor film is provided, wherein it is characterized in the fact that a visible-light diagnostic probe laser beam is applied onto the surface of a semiconductor film while the semiconductor film is being heated by the heating laser beam, the laser beam reflected back from the semiconductor film

by the diagnostic probe laser beam is detected, the heating laser beam irradiating conditions are determined from the detected diagnostic results, and the semiconductor film is heated up to the temperature not exceeding the fusing point under the heating laser beam irradiating conditions while it is being processed by the heating laser beam.

【0016】 In accordance with the eighth embodiment of the present invention, the apparatus for crystallizing a semiconductor film is provided, wherein the apparatus is characterized in the fact that it includes a heating laser beam supply source for applying a heating laser beam onto the semiconductor film, a diagnostic probe laser beam supply source for applying a visible-light diagnostic probe laser beam onto the semiconductor film, and a reflected light detector for detecting the light reflected back from the semiconductor film by the diagnostic probe laser beam.

【0017】 In the method for fabricating a crystalline semiconductor film in accordance with each of the embodiments described above, when the glass substrate is to be heated, its temperature may be raised without causing any damages on the glass substrate, and the glass substrate may be maintained in the raised temperature state. While the glass substrate is maintained in the raised temperature state, the amorphous semiconductor film formed on the surface of the glass substrate can be crystallized by exposing it to the laser beam and by heating only it at the non-fusing temperature for a short time. In this way, alterations (such as deflections, deformations and internal stress) on the glass substrate is prevented and the high-quality polycrystalline semiconductor substrate having the small and uniform crystal grain sizes can be obtained without causing any physical damages to the glass substrate.. Alternatively, the amorphous semiconductor may also be crystallized at the temperature below the fusing point by irradiating it with the laser beam, without passing the glass substrate through the preliminary heating.

【0018】 Preferably, the temperature of the glass substrate being heated and

maintained should be raised up to the temperature not exceeding the glass softening point, or even if it exceeds the softening point, the temperature should be raised within the small excess temperature range. Further preferably, the temperature should not exceed the glass softening point. In this way, any possible alterations of the glass substrate can be prevented more effectively.

Although the temperature of the glass substrate being heated may be raised by using various types of heating equipments, embodiments of the present invention are not limited to any particular type of heating equipments. Desirably, the glass substrate should be heated through the heat transfer of the heater.

Desirably, the temperature of the glass substrate being heated should be raised in a stepwise fashion, and should be raised up to the stepwise temperature at which the glass substrate is maintained in the raised temperature state. In this way, the glass substrate can be maintained at the uniform temperature, and any possible alterations that may be caused by heating the glass substrate can be minimized.

[0019] In order to avoid that the laser beam will heat the glass substrate excessively, the laser beam should desirably have the characteristic that allows the laser beam to be goodly absorbed by the amorphous semiconductor film. For example, the laser beam having any appropriate wave length range may be chosen. Although embodiments of the present invention are not limited to any particular type of the laser beam supply source, it should be understood that the excimer laser beam generator, YAG laser generator and the like may be employed as the preferred pulse laser beam supply source.

[0020] When the laser beam is irradiating, the glass substrate may be retained the heated temperature state before irradiation with the laser beam. Accordingly, a fluctuating energy range of the laser beam supply source can be more uniformly than it appears, and the variations in the temperature can be kept uniform each time the laser beam is shot. In order to ensure this action,

the glass substrate should desirably be maintained in the properly heated temperature state. Although this may depend upon the type of the material based on the glass substrate, it is generally desirable that the glass substrate should be maintained to be heated at the softening temperature (600°C) or above.

Furthermore, any crystal defects that may exist on the amorphous semiconductor film may be removed by irradiating the amorphous semiconductor film with the laser beam, and any organic substances that may be contained in the amorphous semiconductor film may be decomposed by irradiating the amorphous semiconductor film with the laser beam. In addition, any impurities that may be contained in the amorphous semiconductor film or any contaminations that may be adhere on the surface of the amorphous semiconductor film may also be removed by irradiating the amorphous semiconductor film with the laser beam.

[0021] Furthermore, in accordance with the method for controlling the heating temperature for the semiconductor film and the apparatus for crystallizing the amorphous semiconductor film as described above, the conditions under which the amorphous semiconductor film should be irradiated with the laser beam may be determined from detecting the light reflected back from the amorphous semiconductor film by the probe laser beam.

As it is known in the prior art that irradiating conditions with the laser beam will differ, depending upon the temperature of the substrate being heated, the thickness of the semiconductor film, the amount of impurities contained in the semiconductor film and the like, the optimum energy density (F) at the time when the semiconductor film is to be heated by the laser beam must be determined by varying the value of the energy density, and then by irradiating the semiconductor film with the laser beam at each one shot. Or the optimum number of times (T) that the laser beam irradiation should be

applied must be determined by applying the laser beam successively several times, and the laser beam irradiating conditions (F) or (T) must be determined by checking the substrate using the scan-type electron microscope (SEM) or examining the substrate by the destructive X-ray diffraction method. These methods would require lots of labor to find the optimum laser beam irradiating conditions, and it would be very ineffective.

[0022] In accordance with embodiments of the present invention, the laser beam irradiating conditions can be determined by detecting, in real time, the reflectivity of the light reflected back from the semiconductor surface, without destructive checking. In other words, the heating temperature of the semiconductor substrate can be controlled such that it cannot exceed the fusing point for the semiconductor substrate.

In this way, it is possible to take advantage of the fact that the reflectivity of the fused silicon by the visible light is higher by several 10 percents than the reflectivity of the solid silicon. Therefore, the transfer from the solid phase to the liquid phase or from the liquid phase to the solid phase can be observed easily. More specifically, this method allows the threshold value for the laser beam irradiating energy density (Fth) or number of shots (Tth) at the start of the fusing to be determined easily as the laser beam irradiating condition. In accordance with embodiments of the present invention, the laser beam irradiating condition may be set to satisfy the respective threshold values of both $F < F_{th}$ (the energy density at the start of the fusing) and $T < T_{th}$ (the number of shots at the start of the fusing). Although the reflected light may be detected by using any appropriate photodiode, it should be understood that embodiments of the present invention are not limited to any particular type of the device. Rather, any type of device that allows the amount of reflected light to be measured absolutely or relatively.

Under the laser beam irradiating condition described above, the laser beam supply source can be controlled by permitting the heating laser beam

supply source to reflect the laser beam supply source. For example, the energy density for the laser beam may be controlled by adjusting the laser beam output or by the degree of light collection.

Effect of Invention

【0023】 It may be appreciated from the foregoing description that in accordance with the preferred embodiment of the method for fabricating a crystalline semiconductor thin film, the temperature of the glass substrate having the amorphous semiconductor film formed thereon being heated may be raised, the amorphous semiconductor film may be irradiated with the laser beam while the glass substrate is retained in the raised temperature state, the amorphous semiconductor film may be heated up to the temperature not exceeding the fusing point, and finally the amorphous semiconductor film may be crystallized. The steps described above can proceed without causing any damages on the glass substrate, and the crystalline semiconductor film having the uniform and small crystal grain sizes can thus be obtained.

【0024】 It may also be appreciated from the foregoing description that in accordance with the preferred embodiment of the method for controlling the heating for the semiconductor film, the visible-light diagnostic probe laser beam may be applied onto the surface of the semiconductor film being processed by the laser beam while it is heated by irradiating it with the heating laser beam, the light reflected back from the semiconductor film by the probe laser light may be detected, and according to the result of the detect, the heating laser beam irradiating condition may be determined easily under which the semiconductor film can be heated to the temperature not exceeding the fusing point for the semiconductor film while it is processed by the laser beam. Thus, the optimum laser beam irradiating condition can be determined easily, under which the operation can be performed in the simplified and efficient manner.

【0025】 In addition, it may be appreciated from the foregoing description that

in accordance with the preferred embodiment of the apparatus for crystallizing an amorphous semiconductor film, the apparatus may include the heating laser beam supply source for providing the heating laser beam to be applied onto the semiconductor film, the heating laser beam control part for setting the heating laser beam irradiating condition for the heating laser beam supply source, the diagnostic probe laser beam supply source for providing the visible-light diagnostic probe laser beam to be applied onto the semiconductor film, and the reflected light detector for detecting the light reflected back from the semiconductor film by the diagnostic probe laser beam. Thus, the optimum laser beam irradiating condition can be determined easily from the results detected by the reflected light detector. As the optimum laser beam irradiating condition can be determined to reflect the heating laser beam supply source, the semiconductor film can be crystallized by heating it to the temperature not exceeding the fusing point.

BRIEF DESCRIPTION OF DRAWINGS

【0026】 Fig. 1 is a longitudinal cross sectional view illustrating the excimer laser beam annealing apparatus that may be used in a first embodiment of the present invention;

Fig. 2 illustrates the heater pattern in the first embodiment;

Fig. 3 is a longitudinal cross sectional view illustrating the excimer laser beam annealing apparatus that may be used in other embodiment of the present invention;

Fig. 4 illustrates the heater pattern in the example;

Fig. 5 illustrates the respective scan-type electron microscopic pictures that substitute the drawings, each showing the semiconductor film crystallized according to the example of the present invention and according to the prior art;

Fig. 6 represents a graph that shows the variations in the amount of the reflected light by the diagnostic probe laser beam for each one shot

according to other example of the present invention;

EXPLANATIONS OF NUMERALS

【0027】

- 1: Excimer laser beam annealing apparatus
- 2: Annealing chamber
- 3a: Excimer laser beam generator
- 3b: Excimer laser beam transmission system
- 3c: Laser beam irradiation part
- 4: Substrate placement stage
- 5: Heater
- 6: Reflecting plate
- 8: Substrate
- 9: Amorphous semiconductor thin film
- 10: Laser beam
- 20: Excimer laser beam annealing apparatus
- 22: Annealing chamber
- 23a: Excimer laser beam generator
- 30: Diagnostic probe laser beam generator
- 32: Reflected light detector

BEST MODE OF EMBODYING THE INVENTION

【0028】 (Embodiment 1)

Referring now to Fig. 1, the present invention is described below in accordance with the first embodiment thereof.

In describing the method for fabricating a crystalline semiconductor film in accordance with the first embodiment, it is assumed that the substrate that may be used in the flat panel display TFT device is being processed, and that an amorphous silicon thin film has previously been formed on the substrate. It should be understood, however, that the present invention is not limited to any particular type of the substrate and any particular type of the

amorphous semiconductor substance formed on such substrate.

【0029】 Fig. 1 illustrates the excimer laser beam annealing apparatus 1 that may be used in implementing the method for fabricating a crystalline semiconductor film according to the first embodiment of the present invention. The excimer laser beam annealing apparatus 1 includes an annealing chamber 2 and a KrF excimer laser beam generator 3a located outside the annealing chamber 2. Above the annealing chamber 2, there is a laser beam irradiation part 3c directed inwardly. The KrF excimer laser beam generator (laser beam supply source) 3a and the laser beam irradiation part 3c are interconnected via a laser transmission system 3b. A laser beam irradiation apparatus may thus be constructed by the components described above, that is, the KrF excimer laser beam generator 3a, the laser transmission system 3b and the laser beam irradiation part 3c. The KrF excimer laser beam may be a UV light having a wave length of 248 nm.

【0030】 Inside the annealing chamber 2, there is a substrate placement stage 4 so that the laser beam 10 from the laser beam irradiation part 3c can be directed toward the substrate placement stage 4. The substrate placement stage 4 contains a heater 5 for a heating equipment located beneath it. A thermally insulating cover 7 formed like a framework surrounds the substrate placement stage 4, and a reflecting plate 6 also formed like a framework is provided above the thermally insulating cover 7 by contacting with the thermally insulating cover 7. The inner wall surface of the reflecting plate 6 is inclined inwardly and downwardly so that the inner radiant heat reflected by the reflecting plate 6 can be retained at the high temperature inside the reflecting plate 6.

【0031】 The process of fabricating a thin film using the laser annealing apparatus 1 described above is now described.

A glass substrate 8 has an amorphous silicon thin film 9 of 50 nm thickness previously formed on the surface thereof using the usual method.

The substrate 8 is placed on the substrate placement stage 4. Next, the annealing chamber 2 that is internally placed under the atmospheric pressure may be purged with nitrogen so that it can be placed under the nitrogen atmosphere. Then, the heater 5 may be energized, producing the heat that conducts through the substrate placement stage 4 to the substrate 8 placed thereon. The substrate 8 may be thus heated. In the example shown in Fig. 2, desirably, the temperature of the substrate 8 being heated may be raised in a stepwise fashion and retained isothermally, this temperature may be raised up to the predetermined maintaining temperature. Preferably, this predetermined maintaining temperature may be below the softening temperature of the substrate 8. When the temperature of the substrate 8 is to be raised, the temperature of the amorphous silicon thin film 9 may also be raised by the transfer heat or radiant heat (including the heat reflected from the reflecting plate 6).

【 0032 】 With the substrate 8 being retained at the predetermined temperature, the excimer laser beam emitted from the excimer laser beam generator 3a may be transmitted through the excimer laser beam transmission system 3b to the laser beam irradiation section 3c, from which the excimer laser beam 10 may be applied toward the amorphous silicon thin film 9. Only the amorphous silicon thin film 9 on the substrate 8 will be heated by this laser beam irradiation so that the amorphous silicon can be polycrystallized. The heating temperature for the semiconductor thin film 9 may be any temperature not exceeding its fusing point. In the example shown in Fig. 2, preferably, the temperature of the substrate 8 being heated may be cooled to be lowered in a stepwise fashion and maintained isothermally. The polycrystalline semiconductor thin film thus obtained has the uniform and small grain sizes and the good crystalline quality.

This polycrystalline semiconductor thin film is suited for use on the organic EL displays. It should be understood, however, that the present

invention is not limited to using on the organic EL displays, but may also be applied for other types of crystal liquid displays and electronic materials.

【0033】 (Embodiment 2)

In accordance with the second embodiment shown in Fig. 3, the excimer laser beam annealing apparatus is now described, in which the diagnostic probe laser beam may be provided and detected. In this embodiment 2, components that are similar to those in the embodiment 1 are given similar reference numerals, and the descriptions of those components are omitted or simplified.

The excimer laser beam annealing apparatus 20 includes an annealing chamber 22 and a KrF excimer laser beam generator (heating laser beam supply source) 23a located outside the annealing chamber 22. The excimer laser beam annealing apparatus 20 further includes a first half mirror 23b and a second half mirror 23c located in the direction in which the laser beam from the KrF excimer laser beam generator 23a is directed, wherein the laser beam 10 reflected back from the second half mirror 23c may be transmitted through a lens 23d to a laser beam irradiation section 23e located in the annealing chamber 22. Then, a substrate 8 having an amorphous silicon thin film 9 formed thereon may be placed ahead of the laser irradiating direction from the laser beam irradiation section 23e. An energy meter 25a is provided on the reflecting side of the first half mirror 23b for detecting the output of the KrF excimer laser beam generator 23a. This detected result may be indicated on the output indicator 25b. On the transmission side of the second half mirror 23c, there is a bi-planar phototube 26 for a trigger signal in which the laser beam output of the KrF excimer laser beam generator 23a as detected may be used as a trigger signal for detecting the reflected light.

【0034】 There is a visible-light diagnostic probe laser beam generator (diagnostic probe laser beam supply source) 30 that is located outside the annealing chamber 22 for providing a visible-light diagnostic probe laser

beam. Inside the annealing chamber 22, there is a probe laser beam irradiation section 27a that is located in the direction in which the laser beam is provided by the diagnostic probe laser beam generator 30. The substrate 8 having the semiconductor thin film 9 formed thereon may be placed so that it can be positioned in the laser beam irradiating direction. The light reflected back from the semiconductor thin film 9 goes to a reflected light emitting section 27b within the annealing chamber 22, from which the reflected light may be emitted outside the annealing chamber 22. A mirror 31a and a lens 31b are arranged in the reflected light path, and a phototube-type reflected light detector 32 including a photodiode and the like is arranged forwardly of the reflected light path. The mirror 31a, the lens 31b and the reflected light detector 32 constitute the reflected light detector section.

【0035】 The operation of the excimer laser beam annealing apparatus 20 described above in connection with the above embodiment is now described.

Initially, the substrate 8 having the amorphous silicon thin film 9 formed thereon is placed in position inside the annealing chamber 22 and the annealing chamber 22 is placed under the atmosphere same as described in connection with the embodiment 1. Then, the substrate 8 may be heated by the heat equipment (not shown). The KrF excimer laser beam generator 23a provides an excimer laser beam for heating which may go to the laser beam irradiation section 23e from which it may enter the annealing chamber 22 through the first half mirror 23b, second half mirror 23c and lens 23d. Then, the excimer laser beam may be applied onto the amorphous silicon thin film 9 within the annealing chamber 22. Part of the excimer laser beam for heating may be reflected by the half mirror 23b, and it may be measured energy by the energy meter 25a. The result of the measurement may be indicated on the output indicator 25b. Then, part of the laser beam may be transmitted through the second half mirror 23c, and may be detected by the bi-planar phototube 26 for a trigger signal that provides a trigger signal. This trigger

signal may activate the diagnostic probe laser beam generator 30 so that it can provide the visible-light diagnostic probe laser. The probe laser beam 30a provided by the diagnostic probe laser beam generator 30 may go to the probe laser beam irradiation section 27a through which it may be applied onto the amorphous silicon thin film 9 within the annealing chamber 22. The reflected light 30b reflected back from the amorphous silicon thin film 9 may then go out of the annealing chamber 22 through the reflected light emitting section 27b, while the reflected light 30b may go through the mirror 31a and lens 31b into the reflected light detector 32 where the amount of the light may be detected. The output and detection of the diagnostic probe laser beam may be executed in real time and concurrently with the heating by the heating laser beam 10.

【0036】 By detecting the diagnostic probe laser beam output as described above, it is possible to check any change in the amount of the reflected light that may be executed by varying the energy density or number of shots for the heating laser beam from the KrF excimer laser beam generator 23a. From this checking, it may be determined that the amorphous silicon thin film 9 will transfer from the solid phase to the liquid phase as the amount of light as detected increases remarkably, while it will transfer from the liquid phase to the solid phase as the amount of light as detected decreases remarkably. From this fact, it is possible to determine the conditions under which the heating laser beam 10 should be provided for heating the amorphous silicon thin film 9 up to the temperature not exceeding the fusing point. By processing the amorphous silicon thin film in the sequence described above under the above conditions, the amorphous silicon thin film can be crystallized efficiently under the optimal processing conditions.

Although the present invention has been described above in connection with each of the embodiments, it should be understood that the present invention is not limited to those embodiments, which may be modified or

varied in numerous ways without departing from the scope of the present invention.

(Example 1)

【0037】 An example is presented and described below.

The crystallizing apparatus described above in the embodiment is used, in which an sample of the glass substrate having the amorphous silicon thin film(fusing point of 1200°C) of 50 nm thick formed thereon is provided.

In order to avoid that the glass substrate warp when it is initially heated, as shown in Fig. 4, the temperature of the substrate being heated may be raised within the temperature range between the room temperature and the temperature of 400°C at the heating rate of 100°C/min by the heater, and then the substrate may be retained in the raised temperature state during a period of 5 minutes. Then, the temperature may be raised up to 500°C or 650°C at the heating rate of 50°C/min, and the substrate may be retained at the raised temperature. While the temperature of the substrate 8 is raised up to the temperature of 500°C or 650°C and the substrate 8 is retained in the raised temperature state in 10 minutes, the excimer laser beam 10 in its pulse forms may be shot 30 times from the laser beam irradiation section 3c toward the substrate 8. The amorphous semiconductor thin film on the substrate 8 may be heated to any temperature between 850 and 1000°C, and may thus become poly-crystallized. Following the laser beam irradiation, the substrate 8 may be cooled down to 400°C at the cooling rate of 50°C/min, and may be retained at 400°C for 5 minutes. Then, it may be cooled down to the room temperature at the cooling rate of 100°C/min (see Fig. 4).

【0038】 Next, another example of the experiment is described, in which the temperature of the substrate being heated may be raised from the room temperature up to 350°C at the heating rate of 100°C/min, and then may be retained in the raised temperature state for 10 minutes during which the excimer laser beam 10 in its pulse forms may be applied 30 shots toward the

substrate. The amorphous semiconductor thin film on the substrate 8 has thus been poly-crystallized. Following the laser beam irradiation, the substrate may be cooled down to the room temperature at the cooling rate of 100°C/min. The energy density of the laser beam in each sample may be regulated as shown in Table 1.

【0039】 The measured result of the crystalline grain thus obtained are also presented in Table 1. For the substrate temperature in each sample, it has been observed by the X-ray diffraction that the peak of the crystalline orientation (111) may be obtained when the energy density exceeds a certain value.

When the crystalline grain thus obtained are observed by the scan-type electron microscope (SEM), it is found that when the energy density reaches a certain value, the usual laser annealing crystallization (fusing and re-crystallization) occurs, rather than the solid phase crystallization (SPC). The respective SEM photographs that substitute the drawings and show the solid phase crystallization obtained in this example and the usual laser annealing crystallization by fusing and re-crystallization are presented in Fig. 5.

For each of the polycrystalline semiconductor thin films thus obtained , there are few variations in the grain sizes, which are uniform over the entire surface, although this may depend upon the particular conditions. The polycrystalline semiconductor thin film thus obtained has the good quality as well. Under any of the substrate temperature conditions, the energy margin that is equal to or more than 30mJcm⁻² may be obtained.

【0040】 Since no change is noticed during the etching process (for 21 seconds) that has previously been made (for 21 seconds) by using the Secco solution under the condition in which the amorphous silicon can be dissolved completely, it is also found that the semiconductor film thus obtained exhibits the good crystalline quality. This occurs due to the extremely great difference

in the etching rate by the Secco solution between the amorphous silicon and crystallized silicon. In general, the etching rate for the crystallized silicon is in the order of several angstrom /sec in the direction of the depth, and for the crystallized silicon of 50 nm thick, it would take several minutes until it is fused.

It may be apparent from the foregoing description that the present invention can provide the semiconductor film that presents less variations in the TFT property, since the crystalline semiconductor film having the grain sizes of less than or equal to 100 nm and the uniformity can be obtained.

【0041】 Table 1

Sample No.	Temp (°C)	Retention time (min)	Laser energy density (mJ/cm ²)	Number of shots	X-ray strength (111) (count)	Estimate of crystallization by X-ray	Observation by SEM
1	350	10	75	30	no peaks	×	amorphous
2	350	10	90	30	101	○	solid phase crystallization
3	350	10	105	30	123	○	solid phase crystallization
4	350	10	115	30	120	○	solid phase crystallization
5	350	10	125	30	112	○	solid phase crystallization
6	350	10	138	30	134	○	fusing, re-crystallization
7	500	10	50	30	no peaks	×	amorphous
8	500	10	83	30	130	○	solid phase crystallization
9	500	10	94	30	125	○	solid phase crystallization
10	500	10	108	30	143	○	solid phase crystallization
11	500	10	121	30	142	○	solid phase crystallization
12	500	10	125	30	113	○	fusing, re-crystallization
13	650	10	65	30	127	○	solid phase crystallization
14	650	10	77	30	113	○	solid phase crystallization
15	650	10	89	30	137	○	solid phase crystallization
16	650	10	97	30	109	○	fusing, re-crystallization

【0042】 (Example 2)

Next, another example is described below, in which an amorphous silicon thin film having the film thickness of 50 nm is provided like in the preceding example, and the apparatus described in connection with the second embodiment is used. Then, the temperature of the silicon substrate may be set to 500°C, and the irradiating energy density may be varied at 70, 80, 90 and 100 mJ/cm². The amount of the reflected light may be detected by the reflected light detector for each one shot. The results are shown in Fig. 6.

For the irradiating energy density up to 90 mJ/cm², no changes in the intensity of the reflected light were noticed (except noise level), but for 100 mJ/cm², the change by about 20mV was observed. Specifically, under this condition (substrate), it may be determined that the fusing threshold value (Fth) is in the range of 90mJ/ cm²<Fth<100mJ/ cm², and the optimum energy density (F) is equal to 90mJ/ cm². Thus, the optimum laser beam irradiating condition (irradiating energy density) can be determined easily from the above.

CLAIMS

What is claimed is:

1. A method for fabricating a crystalline semiconductor film, comprising the steps of:

raising the heating temperature of a glass substrate having an amorphous semiconductor film formed on the upper layer thereof and retaining the glass substrate in the raised temperature state;

irradiating the amorphous semiconductor film on the glass substrate with a laser beam while the glass substrate is retained in the raised temperature state;

heating the amorphous semiconductor film up to a temperature not exceeding the fusing point; and

crystallizing the amorphous semiconductor film.

2. The method for fabricating a crystalline semiconductor film as defined in Claim 1, wherein the glass substrate is retained in the raised temperature state by raising the heating temperature up to a temperature not exceeding the melting temperature.

3. The method for fabricating a crystalline semiconductor film as defined in Claims 1 or 2, wherein the heating temperature of the glass substrate is raised by using a heater.

4. The method for fabricating a crystalline semiconductor film as defined in any one of Claims 1 through 3, wherein the glass substrate is raised up to the retaining temperature state by raising the heating temperature of the glass substrate in a stepwise fashion and retaining the raised temperature.

5. The method for fabricating a crystalline semiconductor film as defined in any one of Claims 1 through 3, wherein the laser beam is supplied as a pulse laser by the excimer laser beam generator or YAG laser generator.

6. The method for fabricating a crystalline semiconductor film as defined in Claim 4, wherein the laser beam is supplied as a pulse laser by the excimer laser beam generator or YAG laser generator.

7. The method for fabricating a crystalline semiconductor film as defined in any one of the preceding claims, comprising the steps for controlling the heating temperature of a semiconductor film of:

applying a visible-light diagnostic probe laser beam onto the surface of a semiconductor film being processed by a heating laser beam while the semiconductor film is being heated by irradiating it with the heating laser beam;

detecting the laser beam reflected back from the semiconductor film by the diagnostic probe laser beam; and

determining the heating laser beam irradiating condition from the detected diagnostic results under which the semiconductor film should be heated up to the temperature not exceeding the fusing point while it is being processed by the heating laser beam.

8. An apparatus for crystallizing an amorphous semiconductor film, including:

a heating laser beam supply source for applying the heating laser beam onto the amorphous semiconductor film formed on the upper layer of a

glass substrate raising the heating temperature up to a temperature not exceeding the fusing point of the semiconductor film with the heating laser beam;

a heater for raising the glass substrate;

a visible-light diagnostic probe laser beam for applying the diagnostic

probe laser beam onto the amorphous semiconductor film; and

means for detecting the laser beam reflected back from the amorphous semiconductor film by the diagnostic probe laser beam.

ABSTRACT

A crystalline semiconductor film having a sufficiently small and uniform grain sizes may be provided on a semiconductor substrate.

In a preferred embodiment of the present invention, a glass substrate 8 having an amorphous semiconductor thin film 9 formed on the upper layer thereof may be kept in the heated state by raising the heating temperature of the glass substrate 8. The amorphous semiconductor thin film 9 on the glass substrate 8 may be heated up to the temperature not exceeding the fusing point by irradiating the amorphous semiconductor thin film 9 with a laser beam 20. Thus, the amorphous semiconductor thin film 9 may be crystallized. According to this embodiment, the crystalline semiconductor film having the sufficiently small and uniform grain size can be provided without causing any damages on the glass substrate. According to another embodiment, the glass substrate may be kept in the heated state before it is irradiated with the laser beam, so that the variation in the temperature can be kept consistently upon each shot of the laser beam. Furthermore, any crystalline defects can be eliminated by the laser beam irradiation. Thus, any impurities that may exist inside the amorphous semiconductor film or any contaminations that may adhere on the surface of the amorphous semiconductor film can be removed.