# Description

[Title of the invention]

A crystalline film production method and production apparatus

[Technical field]

[0001]

This invention relates to a crystalline film production method comprising irradiation of an amorphous film with a laser beam to microcrystallize it to form a crystalline film, and a production apparatus therefor.

[Background art]

[0002]

To produce crystalline silicon for thin film transistors (TFTs) to be used in the flat panel displays of thin-type display units such as liquid crystal display devices, either of the following two methods is generally used: preparing a substrate provided with a upper layer of amorphous silicon film, and irradiating said amorphous silicon film with a pulsed laser beam to melt and recrystallize it (laser annealing); or preparing a substrate provided with a upper layer of amorphous silicon film, and heating it in a preheating furnace to cause the silicon film to crystallize and grow in a solid phase without melting (SPC: solid phase crystallization).

[0003]

The present inventors have verified that a fine polycrystalline film can be produced by a solid phase growth process in which a noncrystalline film is irradiated with a pulsed laser beam while maintaining the substrate in a heated state, and proposed this process (see Patent document 1).

[Prior art references]

[Patent documents]

[0004]

Patent document 1: Japanese Unexamined Patent Publication No. 2008-147487

[Summary of the invention]

[Problems to be solved by the invention]

[0005]

In recent years, there is an increasing demand for methods that serve for low cost production of large sized uniform fine polycrystalline silicon films to be used for manufacturing of OLED (organic light-emitting diode) panels and LCD (liquid crystal display) panels for large TV sets.

In the organic EL display panel, which is recently regarded as likely to be the next generation product to replace liquid crystal displays, the organic EL element emit light itself to achieve a high screen brightness. The luminescent material of organic EL elements is driven by the current drive mechanism, instead of the voltage drive mechanism used in LCDs, and there are different requirements for TFTs. For TFTs formed from amorphous silicon, it is difficult to depress its deterioration with age and a large drift of the threshold voltage (Vth) occurs to shorten the device life. Polysilicon, on the other hand, is a stable material with a long life. However, the variation in TFT characteristics is large in the case of TFTs formed from the polysilicon film. Such a variation in TFT characteristics can take place if there is a significant variation in the crystal grain diameter or if the interfaces of crystal grains of crystalline silicon (crystal grain boundaries) exist in the TFT channel regions. The variation in TFT characteristics tends to depend mainly on the size of the crystal grains and the number of the crystal grain boundaries existing between the channels. Furthermore, the electron mobility tends to increase with an increasing crystal grain diameter. In the case of TFTs for organic EL displays, however, as the electron mobility of field electrons increases, the channel length of the TFT will have to be longer, and the size of each RGB (red,

green, blue) pixel will depend on the TFT's channel length, making it impossible to achieve a high resolution. This is why there is such an increasing demand for fine crystal films with a decreased variation in crystal grain diameter.

[0006]

It is difficult, however, for the conventional crystallization methods to solve these problems. The reason is that in the laser annealing process, which is one of the conventional ones, amorphous silicon is once melted and then recrystallized, and the formed crystal grains tend to large in diameter. Accordingly, the electron mobility of field electrons will be high as described above, and there will be a significant variation in the number of crystal grains in those TFT channel regions. In addition, these crystal grains will have random shapes and adjacent crystals will have significantly different crystal orientations. As a result, these will have large influence on the variation in TFT characteristics. In particular, differences in crystallinity are likely to take place in regions where laser irradiation overlaps, and these crystallinity differences can ha large influence on the variation in TFT characteristics. In addition, another problem can take place due to crystal defects caused by surface contamination (impurities).

[0007]

The crystals produced by the solid phase crystallization process (SPC process) are small in grain diameter and also small in TFT variation, indicating that it is the most effective crystallization method to solve the aforementioned problem. However, it requires a long crystallization time, and it is difficult to apply to mass production. A batch-type heat treatment apparatus for simultaneous processing of two or more substrates is used in the heat treatment step that can perform the solid phase crystallization (SPC) process. If many substrates are heated simultaneously, the temperature will be ununiform in the substrates as the heating and cooling time increases. If heating is continued for a long period of time at a high temperature above the strain point temperature of the glass substrates in the solid phase growth

process, the glass substrates themselves will suffer shrinkage or expansion to cause damage to the glass substrates. In the SPC process, as the crystallization temperature is higher than the glass transition point, a small temperature distribution can lead to significant deflection and shrinkage distribution in the glass substrates. As a result, even if crystallization is possible, troubles can take place in exposure step and other steps, making it difficult to prepare devices. A higher temperature uniformity is required with an increasing processing temperature. In general, the crystallization speed depends on the heating temperature, and a processing time of 10 to 15 hours at 600°C, 2 to 3 hours at 650°C, and several tens of minutes at 700°C are required, respectively. A long processing time is necessary to perform processing without causing damage to the glass substrates, making it difficult to use this method for mass production.

[0008]

The invention is achieved in such background circumstances with the aim of providing a crystalline film production method and production apparatus in which a fine crystalline film with a limited variation in crystal grains diameter is produced efficiently from the amorphous film without causing damage to the substrates.

[Means of solving the problems]

[0009]

Specifically, the crystalline film production method according to an aspect of the invention comprises irradiation of an amorphous film layer that is an amorphous silicon film formed on a substrate with a continuous-wave laser beam having a linear beam shape with a wavelength of 510 to 540 nm in the visible range without preheating of the substrate, the laser beam being relatively scanned in a direction of a short axis of the laser beam, to heat the amorphous film so that said amorphous film is heated up to a temperature not in excess of the melting point in order to crystallize said amorphous film.

[0010]

The crystalline film production apparatus according to another aspect of the invention comprises a laser

oscillator to emit a continuous-wave laser beam with a wavelength of 510 to 540 nm in the visible range, an optical system to shape a laser beam emitted from said laser oscillator into a linear beam shape and lead it to an amorphous silicon film and is not subjected to preheating, a scanning apparatus to cause a relative movement of said amorphous film to said laser beam in the direction of the amorphous film surface and in the direction of a short axis of the laser beam, and an attenuator to adjust the power density of said laser beam so that the amorphous film is heated and crystallized at a temperature not in excess of the melting point as the laser beam is being scanned by said scanning apparatus and irradiated / applied to said amorphous film.

[0011]

According to the invention, a continuous-wave laser beam in the visible range is applied to an amorphous film so that said laser beam is absorbed effectively by the amorphous film to heat the amorphous film rapidly up to a temperature not in excess of the melting point, making it possible to allow uniform fine crystals, such as those of 50 nm or less, with little grain size variation to be produced by a process that is different from the conventional melting and recrystallization process. When using the conventional melting and crystallization process and the SPC (Solid Phase Crystallization) process incorporating a preheating furnace, the resulting crystal grains will inevitably have a large variation in grain size. In the process of the invention, preheating is not necessary in addition to the heating of the amorphous film by applying the continuous-wave laser beam, and the amorphous film can be processed efficiently while controlling the heating of the substrate on which the amorphous film is formed.

According to the invention, furthermore, the same level of crystallinity is achieved also in those regions where the laser beam overlaps, leading to an improved uniformity. In the case of the conventional laser annealing process, crystals of a different structure are formed in those regions where the laser beam overlaps, leading to a decreased uniformity in crystallinity.

When processing an amorphous film, in particular amorphous silicon, the

underlying substrate will not be easily damaged at an increased temperature if a continuous-wave laser beam is adjusted to have a short axis length of 100 μm or less and moved in the direction of the short axis to achieve quick heating. In particular, damage to the substrate can be avoided almost completely if the laser beam is scanned relative to the substrate at a high speed to shorten the irradiation time. Though preheating of the substrate is not necessary for the invention, the invention does not deny the incorporation of a step for heating the substrate.

In addition, because of direct heating of an amorphous film, in particular amorphous silicon, by applying a laser beam that is easily absorbed, it is not necessary to indirectly provide a laser absorbed layer on the amorphous film.

[0012]

It is preferable that the amorphous film is an amorphous silicon film with a thickness of 50 to 200 nm. A beam in said wavelength range is absorbed at a high rate by an amorphous silicon film to serve for efficient microcrystallization. The amorphous silicon film should preferably be in said thickness range because the heating can easily influence the substrate if the thickness is less than 50 nm, whereas sufficient crystallization will not achieved over the entire film if it is more than 200 nm.

However, the absorption rate of amorphous silicon for visible light changes with the film thickness, and therefore, an appropriate film thickness for efficient absorption should be identified.

[0013]

When irradiating an amorphous film with a continuous-wave laser beam in said wavelength range, the power density of said laser beam is preferably in the range of 55 to 290kW/cm$^2$ at the irradiated surface. The amorphous film will not be sufficiently heated, making crystallization difficult, if the power density is lower. If the power density is too high, on the other hand, the amorphous film can be heated up to a temperature above the melting point, and this, together with other factors,

makes it difficult to produce fine crystal grains. Thus the power density of the laser beam is preferably in said range.

[0014]

When performing laser beam irradiation, the laser beam preferably has short axis length of 100 μm or less. By irradiating partial regions of the amorphous film, the amorphous film can be partially heated rapidly without allowing the substrate to be affected by the heat. Crystallization can take place in large regions of the amorphous film if the laser beam is relatively moved in the direction of said short axis. If the short axis length is very large, however, the scanning speed need to be increased to proceed the crystallization efficiently, leading to an increased equipment cost.

[0015]

Relative scanning of the laser beam to the amorphous film allows said amorphous film to crystallize in the direction of the amorphous film surface. Said scanning may be achieved by moving the laser beam, moving the amorphous film, or moving both. This scanning is preferably performed at a speed of 50 to 1000 mm/sec.

If the scanning speed is too small, the irradiation duration will increase to cause the amorphous film heating up to a temperature above the crystalline melting point, possibly causing melting or ablation. If the scanning speed is too large, the irradiation duration will decrease, possibly failing to achieve heating up to a temperature where solid phase crystallization can take place.

[Effect of the invention]

[0016]

Thus, as described above, the crystalline film production method of the invention serves to irradiate an amorphous film formed on a substrate with a continuous-wave laser beam with a wavelength of 510 to 540 nm in the visible

range to heat said amorphous film so that said amorphous film is crystallized at a temperature not in excess of the melting point. Thus, it is possible to perform processing at a temperature not in excess of the transition point of the substrate, or at a considerably low temperature even in cases where it is above the transition point, allowing only the amorphous film to be crystallized by applying a laser beam to heat it up to a high temperature. Concurrently, it also serves to produce crystallites of 50 nm or less in a short time. In addition, fine crystallites of 50 nm or less can be produced in regions where laser irradiation overlaps (effective for production of large sized crystals). Moreover, it works to shorten the irradiation duration to minimize the shape changes in the substrate (deflection, deformation, internal stress). The glass substrate is slightly heated at the same time, serving to remove impurities existing in the amorphous silicon film and contamination on its surface. Furthermore, the invention serves to reduce the equipment cost and maintenance cost and perform processing at a high operating rate, leading to an increased productivity.

[Brief description of the drawings]

[0017]

[Figure 1] This shows a longitudinal section of a continuous-wave solid-state laser type annealing unit that is used in an embodiment and in a production method in the embodiment of the invention.

[Figure 2] Similarly, this shows SEM photographs of thin films irradiated with a laser beam in Example.

[Figure 3] Similarly, this shows SEM photographs of thin films irradiated with a laser beam in Example.

[Best mode for carrying out the invention]

[0018]

An embodiment of the present invention is described below with reference to Figure 1.

The crystalline film production method of this embodiment focuses on the substrate 6 to be used in the TFT device in a flat panel display, and as said amorphous film, a thin amorphous silicon film 6a has been formed on said substrate 6. This description, however, is not intended to limit the properties of the substrate or amorphous film used for the invention. The thin amorphous silicon film 6a has been formed with a common method on the substrate 6.

[0019]

Figure 1 shows a continuous-wave solid-state laser type annealing unit 10 used for the crystalline film production method in an embodiment of the invention. The continuous-wave solid-state laser type annealing unit 10 works as a crystalline film production apparatus of the invention.

The continuous-wave solid-state laser type annealing unit 10 comprises a visible continuous-wave laser oscillator 1, that is, a continuous-wave solid-state laser that emits a laser beam with a wavelength of 510 to 540 nm, installed on a vibration-free base 8

[0020]

A laser shutter 2, which switches between to permit or shut the passage of a laser beam 1a is provided on the output side of the visible continuous-wave laser oscillator 1, and an attenuator (attenuation unit) 3 is provided subsequent to said laser shutter 2. For the invention, there are no specific limitations on the attenuator 3 if it can attenuate the laser beam at a required attenuation rate.

Total reflection mirrors 40a, 40b, and 40c are provided on the output side of the attenuator 3, and condenser lenses 41a and 41b are provided in the deflected direction of the total reflection mirror 40c. These total reflection mirrors 40a to 40c and the condenser lenses 41a and 41b constitute an optical system 4, and said optical system 4 further contains beam homogenizers etc, that are not included in

Figure. Thus, said optical system 4 can make the laser beam 1a to be shaped into a rectangular, linear, or other prescribed beam shape with a short axis of 5 to 100 μm. On the outgoing side of the optical system 4, a substrate placing table 7 is installed to place the substrate 6 on it. The substrate placing table 7 is movable in the plane direction (X-Y direction) of said placing table, and provided with a scanning apparatus (not included in Figures) for high speed movement of said substrate placing table 7 in said plane direction.

[0021]

A description of a crystallization method for thin amorphous silicon film using said continuous-wave solid-state laser type annealing unit 10 is given below.

First, a substrate 6 on which a layer of thin amorphous silicon film 6a is formed is placed on the substrate placing table 7. In this embodiment, heating of said substrate 6 with a heater etc. is not performed.

A continuous-wave laser beam with a wavelength of 510 to 540 nm is emitted from the visible continuous-wave laser oscillator 1, and the laser shutter 2 is opened to permit the laser beam 1a to pass through.

[0022]

The continuous-wave laser beam 1a emitted from the visible continuous-wave laser oscillator 1 reaches the attenuator 3 via the laser shutter 2, and is attenuated at a predetermined attenuation rate while passing through it. Said attenuation rate is adjusted so that the laser beam will have a power density required for the invention at the processing plane. The attenuator 3 may be of a variable attenuation rate type so that the power density can be changed. For the invention, however, the output adjustment may be achieved by controlling the power density of the laser beam source without using an attenuator.

The continuous-wave laser beam 1a with an adjusted power density is deflected as it is reflected by the total reflection mirrors 40a, 40b, and 40c in the optical system

4, and then it is condensed by the condenser lenses 41a and 41b. During this step, it passes through a beam homogenizer etc. that are not included in Figure. In said optical system 4, the continuous-wave laser beam 1a is shaped into a rectangular or linear laser beam with a short axis of 100μm or less, and then the continuous-wave laser beam 1a is emitted toward the substrate 6 with a power density of 55 to 290 $kW/cm^2$ at the irradiation surface.

[0023]

Said substrate placing table 7 is scanned by the scanning apparatus in the short axis direction of said laser beam along the surface of the thin amorphous silicon film 6a. As a result, a large region of the surface of the said thin amorphous silicon film 6a is irradiated with said continuous-wave laser beam , with being scanned relatively. Here, the scanning speed of the continuous-wave laser beam is adjusted to 50 to 1,000 mm/sec so that the continuous-wave laser beam is irradiated to the thin amorphous silicon film 6a with being scanned at a high speed on the thin amorphous silicon film 6a.

[0024]

Said irradiation with the continuous-wave laser beam 1a serves to heat only the thin amorphous silicon film 6a on the substrate 6 to achieve quick production of a polycrystalline film. During this step, the thin amorphous silicon film 6a is heated at a temperature not in excess of its melting point (for instance, 1,000°C to 1,200°C). The thin crystalline film produced by said irradiation contains uniform, fine, high-quality crystals with a crystal grain size of 50 nm or less, and is free of protrusions such as those resulting from the conventional solid phase crystal growth process.

This thin crystalline film can be used effectively as material for organic EL displays. The invention, however, is not limited to these uses and can be useful for other liquid crystal displays and electronic devices.

The substrate placing table in said embodiment moves relatively in order to

perform scanning-like pulsed laser beam movement, but instead, the optical system that collimates the pulsed laser beam may be moved relatively at a high speed to perform such scanning-like pulsed laser beam movement.

Example 1

[0025]

Described below is Example for the invention.

An experiment is carried out, in which a thin amorphous silicon film with a thickness of 50 nm formed on the surface of a glass substrate with a common method is irradiated with a continuous-wave laser beam using a continuous-wave solid-state laser type annealing unit 10 as used in said embodiment.

The continuous-wave laser beam used in said experiment have a wavelength of 532 nm in the visible range, and is shaped in the optical system to produce a beam with a rectangular cross section of 7 μm x 2 mm or 65 μm x 2 mm at the processing surface. The laser beam is also adjusted by the attenuator 3 to have a power density as shown in Table 1 at the processing plane.

The laser beam is irradiated to said amorphous silicon film with relatively scanning to said amorphous silicon film by moving the substrate placing table at different scanning speeds (stage speeds) as shown in Table 1.

[0026]

SEM photographs of thin films (No. a to j) irradiated with a laser beam under various conditions are shown in Figures 2 and 3.

Of the thin films, the specimens of No. b, c, d, f, g, h, and i are small in the variation in the crystal grain diameter and polycrystallized uniformly over the entire surface, and indicating that a high-quality thin polycrystalline silicon films are obtained. The crystal grains were small, in the diameter range of 50 nm or less, and free of protrusions. Furthermore, uniform crystallites aree produced in those regions subjected to overlapping irradiation. No changes are seen when the films were

subjected in advance to etching (for 21 sec) in a Secco solution, which was intended for complete dissolution of the amorphous silicon, indicating that all silicon films obtained have crystallinity.

As compared to these, the specimen of No. a has been heated up to a temperature above the melting point because of increased power densities. In the specimens of No. e and j, solid phase crystallization did not take place in many regions over the irradiated surface because of decreased power densities.

Thus, it is found that the method of the invention successfully produce uniform crystalline silicon films and can provide silicon films with little variation in TFT characteristics.

[0027]

[Table 1]

| | (a) | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | (j) |
|---|---|---|---|---|---|---|---|---|---|---|
| Power density ($kW/cm^2$) | 273 | 257 | 242 | 210 | 195 | 80 | 78 | 76 | 73 | 71 |
| Beam size | 2 mm x 7 μm | 2 mm x 7 μm | 2 mm x 7 μm | 2 mm x 7 μm | 2 mm x 7 μm | 2 mm x 65 μm | 2 mm x 65 μm | 2 mm x 65 μm | 2 mm x 65 μm | 2 mm x 65 μm |
| Stage speed | 900 mm/s | 900 mm/s | 900 mm/s | 900 mm/s | 900 mm/s | 750 mm/s | 750 mm/s | 750 mm/s | 750 mm/s | 750 mm/s |
| Irradiation duration | 7.8 μsec | 7.8 μsec | 7.8 μsec | 7.8 μsec | 7.8 μsec | 86 μsec | 86 μsec | 86 μsec | 86 μsec | 86 μsec |
| State | melted | SPC | SPC | SPC | a-Si/ SPC mixed | SPC | SPC | SPC | SPC | a-Si/ SPC mixed |

[0028]

Thus, the invention has been described with reference to said embodiment and Examples, but the invention is not limited to the scope of said description. It is naturally possible to make appropriate changes as long as they do not deviate from the scope of the invention.

Explanation of numerals

[0029]

| | |
|---|---|
| 1 | laser oscillator |
| 2 | laser shutter |
| 3 | attenuator |
| 4 | optical system |
| 40a | total reflection mirror |
| 40b | total reflection mirror |
| 40c | total reflection mirror |
| 41a | condenser lens |
| 41b | condenser lens |
| 6 | substrate |
| 6a | thin amorphous silicon film |
| 7 | substrate mounting table |
| 8 | vibration-free base |
| 10 | continuous-wave solid-state laser type annealing unit |

Claims

[Claim 1]

A crystalline film production method comprising irradiation of an amorphous film that is an amorphous silicon film formed on a substrate with a continuous-wave laser beam having a linear beam shape with a wavelength of 510 to 540 nm in the visible range without preheating of the substrate, the laser beam being relatively scanned in a direction of a short axis of the laser beam, to heat the amorphous film so that the amorphous film is crystallized at a temperature not in excess of the melting point.

[Claim 2]

A crystalline film production method as claimed in Claim 1 wherein said amorphous film is an amorphous silicon film with a thickness of 50 to 200 nm.

[Claim 3]

A crystalline film production method as claimed in either Claim 1 or 2 wherein the power density of said laser beam is 55 to 290 kW/cm$^2$ at the irradiated surface of said amorphous film.

[Claim 4]

A crystalline film production method as claimed in any of Claims 1 to 3 wherein the short axis of the laser beam used for irradiation of said amorphous film is 100 μm or less.

[Claim 5]

A crystalline film production method as claimed in any of Claims 1 to 4

wherein said irradiation is performed with scanning the laser beam relative to said amorphous film at a scanning speed of 50 to 1,000 mm/sec.

[Claim 6]

A crystalline film production method as claimed in Claim 5 wherein said laser beam is shaped in the optical system into the linear beam shape and said scanning is achieved by moving said substrate at a high speed.

[Claim 7]

A crystalline film production method as claimed in any of Claims 1 to 6 wherein crystallites with a size of 50 nm or less are obtained by said crystallization.

[Claim 8]

A crystalline film production apparatus comprising a laser oscillator to emit a continuous-wave laser beam with a wavelength of 510 to 540 nm in the visible range, an optical system to shape a laser beam emitted from said laser oscillator into a linear beam shape and lead it to an amorphous film that is an amorphous silicon film and is not subjected to preheating, a scanning apparatus to cause a relative movement of said amorphous film to said laser beam in the direction of the amorphous film surface and in the direction of a short axis of the laser beam, and an attenuator to adjust the power density of said laser beam so that the amorphous film is heated and crystallized at a temperature not in excess of the melting point as the laser beam is scanned by said scanning apparatus and irradiated to said amorphous film.

[Claim 9]

A crystalline film production apparatus as claimed in Claim 8 wherein said optical system shapes the laser beam so that the shaped laser beam has a short axis in the direction of scanning, said short axis being in the range of 5 to 100 μm.

[Claim 10]

A crystalline film production apparatus as claimed in either Claim 8 or 9

wherein said scanning apparatus moves said amorphous film relative to said laser beam at a speed of 50 to 1,000 mm/sec..

[Claim 11]

A crystalline film production apparatus as claimed in any of Claims 8 to 10 wherein said attenuator adjusts the power density of said laser beam to 55 to 290 $kW/cm^2$ at the irradiated surface of said amorphous film.

[Claim 12]

A crystalline film production apparatus as claimed in any of Claims 8 to 11 wherein said laser beam heats said amorphous film to 1,000 to 1,200°C when irradiated to said amorphous film.

A crystalline film production method and production apparatus

Abstract

Uniform and fine crystals can be efficiently formed during crystallization of an amorphous film.

An amorphous film layer (amorphous silicon film 6a) formed on a substrate 6 is irradiated with a continuous-wave laser beam 1a with a wavelength of 510 to 540 nm in the visible range so that said amorphous film is heated up to a temperature not in excess of the melting point to crystallize said amorphous film. It is preferable that the continuous-wave laser beam laser beam has a power density of 55 to 290 $kW/cm^2$ and a short axis of 100 μm or less. It is also preferable that the continuous-wave laser beam is relatively scanned at a speed of 50 to 1,000 mm/sec. A fine crystalline film with little variation in the crystal grain diameter can be produced efficiently from an amorphous film without causing damage to the substrate.

Fig. 1