

Single Laser System For Manufacture Of Thin Film Solar Cell

Field of Invention

[0001] The present invention relates to a method and apparatus for annealing and scribing of thin film amorphous silicon film by using only one single laser and optics system and controller in the manufacture of thin film solar cells.

Background

[0002] Solar cells convert sunlight to electricity. The active photoelectric material of a solar cell is made up of a PIN semiconductor junction or dual (or tandem) PIN semiconductor junctions. Each PIN semiconductor junction typically consists of an n-doped layer formed on a p-doped substrate and an intermediate i-layer. When light is incident on the semiconductor junction and due to migration of electrons and holes across the junction, the i-layer acts like a diode and a voltage is generated across the i-layer. By providing a transparent front electrode and a rear electrode, electrons are allowed to flow from the n-doped layer through an external load circuit to the p-doped layer. The voltage across the electrodes of a single photoelectric cell is insufficient for most applications. To achieve a useful power level, individual photoelectric cells are connected in series to form a solar cell module. In addition, some solar cell modules may comprise of two or more PIN semiconductor junctions formed in tandem with each other in a photoelectric cell.

[0003] US Patent No. 4,892,592, assigned to Solarex Corp., describes thin film amorphous silicon photoelectric cell arrays and a method of making such a solar cell module. However, this approach requires directing a laser beam through a glass substrate and front electrodes to break the rear metal film to form the rear electrode.

[0004] In another approach, US Patent No. 6,288,325, assigned to BP Corp. North America Inc., describes a solar cell module with photoelectric cells having multi-junctions and dual rear contacts. This document highlights the advantages of using

crystalline silicon. However, such polycrystalline silicon is formed by a hydrogen plasma process.

[0005] Solar spectrum ranges from about 300 nm to about 2200 nm. Conventional amorphous silicon solar cells convert sunlight from about 400 nm to about 900 nm to electricity.

[0006] Despite development in the art of this invention, it can thus be seen that there exists a need for another method and system for manufacturing solar cell modules that can overcome the shortcoming of the existing prior art.

Summary

[0007] The following presents a simplified summary to provide a basic understanding of the present invention. This summary is not an extensive overview of the invention, and is not intended to identify key features of the invention. Rather, it is to present some of the inventive concepts of this invention in a generalised form as a prelude to the detailed description that is to follow.

[0008] In another embodiment, the present invention provides a laser and optics system for annealing and scribing thin films in the manufacture of solar cell modules. The laser and optics system and controller comprise: a laser source and its controller for generating a laser beam; an attenuator and its driver; a laser beam shaping and focusing system; means for sweeping the laser beam on a target; and a system controller for synchronizing the laser controller, attenuator driver and sweeping means so that the laser beam intensity is set to a predetermined level according to the process of material annealing or scribing.

[0009] In one embodiment of the laser and optics system, the laser beam intensity is set at a high level for scribing and a low level for annealing during a single pass of the laser beam across a rear face of a PIN amorphous silicon semiconductor junction. In another embodiment, the laser beam intensity is separately set at a low level for annealing during a pass of the laser beam across a rear face of a PIN amorphous silicon

semiconductor junction, and the laser beam intensity is set to a high level for scribing during a return pass of the laser beam after the annealing process is performed.

[0010] In one embodiment, the present invention provides a method for annealing and scribing of thin films in the manufacture of solar cell modules. The method comprises: annealing a rear most face of an n-doped amorphous silicon junction to convert it into a crystalline structure; and scribing the silicon junction into parallel stripes, so that forming a conductive layer over stripes of the silicon junction and filing the scribed lines lead to forming rear electrodes of the solar cell module.

Brief Description of the Drawings

[0011] This invention will be described by way of non-limiting embodiments of the present invention, with reference to the accompanying drawings, in which:

[0012] FIGs. 1a-1e illustrate the processes involved in the manufacture of thin film solar cells according to an embodiment of the present invention;

[0013] FIG. 2 illustrates a laser and optics system and controller for use with the processes shown in FIG. 1 according to another embodiment of the present invention;

[0014] FIG. 3 illustrates scribing of the PIN semiconductor structure into separate photoelectric cells according to another embodiment of the present invention;

[0015] FIG. 4 illustrates a single pass output pulse string of the laser and optics system according to another embodiment of the present invention; and

[0016] FIG. 5 illustrates separate laser pulse trains for annealing and scribing according to another embodiment of the present invention.

Detailed Description

[0017] One or more specific and alternative embodiments of the present invention will now be described with reference to the attached drawings. It shall be apparent to one skilled in the art, however that this invention may be practised without such specific details. Some of the details may not be described at length so as not to obscure the invention. For ease of reference, common reference numerals or series of numerals will be used throughout the figures when referring to the same or similar features common to the figures.

[0018] FIGs. 1a-1e illustrate the process flow in the manufacture of thin film solar cell modules according to an embodiment of the present invention. FIG. 1a shows a substrate 1 of a solar cell module. The substrate 1 may be a glass or the like. As shown in FIG. 1b, a transparent conductive oxide (TCO) layer 5, such as tin oxide, is deposited on the glass substrate 1 and is laser scribed to form parallel stripes, as shown in FIG. 1c. Active amorphous semiconductor layers 6 are then deposited on and filled in the TCO layer 5. These active amorphous semiconductor layers 6 may be a single PIN junction or a dual or tandem PIN junction, as shown in FIG. 1d. The top layer of the active amorphous semiconductor layers 6, such as the n-layer in the tandem amorphous silicon photoelectric cell, is then annealed by a laser beam to form a microcrystalline structure; the n- top layer correspond to the rear most active amorphous semiconductor junction with respect to front glass substrate 1. The laser annealing process is followed by a laser scribing process or is combined with the laser scribing process. The laser annealing and scribing process uses the same laser source. A result of the laser scribing process is shown in FIG. 1e, and this forms the basis for forming photoelectric cells connected in series to form the solar cell module.

[0019] FIG. 2 illustrates a single laser and optics system 9 for use with the processes of manufacturing the solar cell module shown in FIGs. 1a-1e. The laser and optics system 9 includes a laser system, an optics system and a stage 17. The laser system includes a laser source 10, a laser controller 20 and a system controller 21. The optics system includes an attenuator 11 disposed in line with an output beam of the laser source 10. Optically in series with the attenuator are a homogenizer 12, a field lens 13, a mirror 14

and a cylindrical lens 15. A target 1a (such as, target shown in FIG. 1b or target shown in FIG. 1d) is mounted on a stage 17.

[0020] In one embodiment, the laser source 10 is a UV laser, such as, a KrF, XeCl, ArF or KrCl excimer laser; in another, it is a solid state frequency tripled UV laser; in yet another, it is a solid state frequency doubled green laser. The laser controller 20 controls firing of the laser source 10 to give a laser beam of predetermined intensity and pulse rate. The attenuator 11 is used to attenuate the laser beam from the laser source 10 and therefore additionally control the intensity of the laser beam on the target. The homogenizer 12 is used to make the laser beam homogenized in the far field region of the beam. The laser beam is then passed through the field lens 13 to expand the laser beam into a rectangular profile. The mirror 14 after the field lens 13 directs the laser beam to the cylinder lens 15, which focuses the laser beam into a line on the target 1a. The stage 17 has movements in the X, Y, Z and Θ directions and its stage controller 18 moves the target 1a according to each process recipe settings to perform the annealing and/or scribing tasks by sweeping the focused laser beam over the entire solar cell module. The system controller 21 handles the entire laser and optics system 9 and synchronises the laser controller 20, an attenuator driver 19 and the stage controller 18.

[0021] To perform laser annealing and/or scribing by a single sweep action, the laser beam needs to be regulated in real-time mode in its intensity according to the annealing and/or scribing process settings. For example, for the UV laser with wavelength of 248 nm, the intensity of the laser beam for annealing thin-film amorphous silicon is set to about $0.5\text{J}/\text{cm}^2$, whilst the intensity for scribing is set to about $2\text{J}/\text{cm}^2$. As shown in FIG. 3, when the laser beam sweeps across photoelectric cell areas A1, A2, A3,...An, the intensity of the laser beam is set to the annealing energy level via the attenuator and driver; when the laser beam sweeps across the scribing line or separation areas S1, S2, S3,...Sn, the intensity of the laser beam is set to the scribing energy level.

[0022] FIG. 4 shows variations in intensity of the laser beam at a particular pulse rate for each single sweeping motion across a solar cell module. As shown in FIG. 4, the laser source 10 operates at the scribing energy level when the laser beam is incident on

the scribing areas S1, S2, S3....Sn, but switches to the annealing energy level when the laser beam is incident on the photoelectric area A1, A2, A3... An. In other words, the target 1a need only to move one time from a starting point to an end point to perform annealing and scribing a section of the solar cell module with a width according to the length of the laser beam at the target. Alternatively, each annealing and scribing process is performed during separate motions in another embodiment. For example, as shown in FIG. 5, a first pass is to perform annealing at the annealing energy intensity level for the entire module or panel; a return pass is for scribing the target at the scribing energy intensity level only in the separating areas S1, S2, S3...Sn. These two pass laser pulse trains are indicated in FIG. 5.

[0023] In one embodiment of operation of the laser and optics system 9, the power setting of the laser source is kept at constant value for the two processes of annealing and scribing. To vary the laser beam energy intensity on the target solar cell module, the attenuator 11 is provided. Such attenuator may be selected from an electro-optical device like a liquid crystal device or motorized variable attenuators changing an angle of their optical window/filter to regulate the energy density or fluence of the laser beam striking the target 1a. In another embodiment, the pulse rate of the laser source is set by the system controller 21.

[0024] An advantage of the present invention is that a laser system and associated optics is used in the manufacture of thin film solar cell modules. This laser and optics system is simpler and more cost effective than conventional solar panel processing machines. In addition, converting the n-layer of the rear most PIN tandem amorphous semiconductor into crystalline structure, which has a bandgap of about 1.1eV, allows sunlight in the remaining 900 – 1400 nm spectrum to be converted to electricity.

[0025] While specific embodiments have been described and illustrated, it is understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the invention. For example, the mirror 14 may be pivoted and oscillated so as to sweep the focused laser beam on the target 1a instead of mounting the target 1a on the moveable stage17.

CLAIMS:

1. A laser and optical system for material annealing and scribing in the manufacture of thin film solar cell modules, the system comprising:
 - a laser source and its controller for generating a laser beam;
 - an attenuator and its driver;
 - a laser beam shaping and focusing system;
 - means for sweeping the laser beam on a target; and
 - a system controller for synchronizing the laser controller, attenuator driver and sweeping means so that the laser beam intensity is set to a predetermined level according to the process of material annealing or scribing.
2. A system according to claim 1, wherein the laser beam intensity is set at a high level for scribing and a low level for annealing during a single pass of the laser beam across a rear face of a PIN amorphous silicon semiconductor junction.
3. A system according to claim 1, wherein the laser beam intensity is separately set at a low level for annealing during a pass of the laser beam across a rear face of a PIN amorphous silicon semiconductor junction.
4. A system according to claim 3, wherein the laser beam intensity is set to a high level for scribing during a return pass of the laser beam after the annealing process is performed.
5. A system according to claim 1, wherein the laser beam intensity is separately set at a high level for scribing during a pass of the laser beam across a rear face of a PIN amorphous silicon semiconductor junction.
6. A system according to claim 5, wherein the laser beam intensity is set to a low level for annealing during a return pass of the laser beam after the scribing process is performed.

7. A system according to any one of claims 2-6, wherein the low energy intensity for annealing is substantially about 0.5 J/cm^2 .
8. A system according to any one of claims 2-6, wherein the high energy intensity for scribing is substantially about 2 J/cm^2 .
9. A system according to any one of the preceding claims, wherein the sweeping means comprises a stage and its controller and the target is mounted on said stage.
10. A system according to any one of claims 1-8, wherein the sweeping means comprises a pivot and oscillation unit mounted on the mirror to sweep the laser beam on the target.
11. A system according to any one of the preceding claims, wherein the laser source is selected from one of the following lasers: KrF, XeCl, ArF or KrCl excimer lasers; Ar^+ laser; and solid state lasers.
12. A system according to any one of the preceding claims, wherein the attenuator is an electro-optical device.
13. A system according to claim 12, wherein the electro-optical device is a liquid crystal device.
14. A system according to any one of claims 1-11, wherein the attenuator comprises a window or filter that is motorized to adjust an angle of the window/filter.
15. A single laser and optical system for material processing for thin-film solar cell fabrication processes of annealing and scribing, the system comprising:
 - a laser source and its controller;
 - an attenuator system and its controller synchronized with processing motion stages;
 - a laser beam shaping, guiding and focusing system; and

a centralized system control computer.

16. A single laser and optical system according to claim 15, wherein the system is operable to perform the two processes of annealing and scribing during thin-film solar cell fabrication in single travel mode or multi-pass travel mode for the laser beam sweeping over the target solar panel surface.

17. A single laser and optical system according to claim 15 or 16, wherein the laser source is selected from the lasers of KrF, XeCl, ArF or KrCl excimer lasers; Ar⁺ laser; and solid state lasers.

18. A single laser and optical system according to any one of claims 15-17, wherein the optical system produces a focused laser beam having an a line-shaped cross section, with an energy controllable attenuator, changing the working energy level on work piece in real time mode without compromising laser tube output stability, to perform annealing and scribing requirements on a thin film solar cell panel, so that the lower pulse energy is employed for annealing and a higher pulse energy is employed for scribing, and the timing and power levels are controlled by the centralized system controller.

19. A single laser and optical system according to any one of claims 15-18, wherein the attenuator system is an electro-optical device, which includes a liquid crystal device, or motorized variable attenuators for changing an angle of light optical window/filter to adjust an energy level of the laser beam.

20. A method for the manufacture of a solar cell module, the method comprising:
sweeping a focused laser beam from a laser on a rear most face of an n-doped amorphous silicon junction to convert it into a crystalline structure; and
scribing the silicon junction with the laser beam from said laser source into parallel stripes, so that forming a conductive layer over stripes of the silicon junction and filing the scribed lines lead to forming rear electrodes of the solar cell module.

21. The method according to claim 20, wherein converting the amorphous silicon into crystalline silicon and scribing the silicon junction into parallel stripes are performed in a single sweep of the laser beam.

22. The method according to claim 20, wherein converting the amorphous silicon into crystalline silicon and scribing the silicon junction into parallel stripes are performed in separate sweeps of the laser beam.