PRODUCTION LINE MODULE FOR FORMING MULTIPLE SIZED PHOTOVOLTAIC DEVICES

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] Embodiments of the present invention generally relate to a module of a production line used to form multiple sized solar cell devices.

Description of the Related Art

[0002] Photovoltaic (PV) devices or solar cells are devices which convert sunlight into direct current (DC) electrical power. Typical thin film type PV devices, or thin film solar cells, have one or more p-i-n junctions. Each p-i-n junction comprises a p-type layer, an intrinsic type layer, and an n-type layer. When the p-i-n junction of the solar cell is exposed to sunlight (consisting of energy from photons), the sunlight is converted to electricity through the PV effect. Solar cells may be tiled into larger solar arrays. The solar arrays are created by connecting a number of solar cells and joining them into panels with specific frames and connectors.

[0003] Typically, a thin film solar cell includes active regions, or photoelectric conversion units, and a transparent conductive oxide (TCO) film disposed as a front electrode and/or as a back electrode. The photoelectric conversion unit includes a p-type silicon layer, an n-type silicon layer, and an intrinsic type (i-type) silicon layer sandwiched between the p-type and n-type silicon layers. Several types of silicon films including microcrystalline silicon film (μc-Si), amorphous silicon film (a-Si), polycrystalline silicon film (poly-Si), and the like may be utilized to form the p-type, n-type, and/or i-type layers of the photoelectric conversion unit. The backside electrode may contain one or more conductive layers. There is a need for an improved process of forming a solar cell that has good interfacial contact, low contact resistance and provides a high overall electrical device performance.

[0004] With traditional energy source prices on the rise, there is a need for a low cost way of producing electricity using a low cost solar cell device. Conventional solar cell manufacturing processes are highly labor intensive and have numerous

interruptions that can affect the production line throughput, solar cell cost, and device yield. For instance, particular solar cell device sizes are needed for particular applications. Conventional solar cell lines are either capable of producing only a single sized solar cell device or require significant downtime to manually convert the solar cell production line processes to accommodate a different substrate size and produce a different sized solar cell device. Thus, there is a need for a production line that is able to perform all phases of the fabrication process for producing multiple sized solar cell devices from a single large substrate.

SUMMARY OF THE INVENTION

[0005] In one embodiment of the present invention, a module for sectioning a solar cell device comprises an inlet conveyor configured to receive commands from a system controller and transfer a solar cell device into a scribing station of the module, a scribing mechanism configured to receive commands from the system controller and scribe a pattern into a first surface of the solar cell device, a first positioning mechanism configured to receive commands from the system controller and accurately position the scribed solar cell device over a first break mechanism, and a first actuator configured to receive commands from the system controller and raise the first break mechanism.

[0006] In another embodiment of the present invention, a method for sectioning a partially processed solar cell device comprises receiving a substrate having a processing surface, forming a silicon layer on the processing surface, sectioning the substrate into a first and second section after forming the silicon layer on the processing surface, and transferring the first section into a next station for further processing.

[0007] In another embodiment of the present invention, a system for fabricating solar cell devices comprises a substrate receiving module that is adapted to receive a substrate, a cluster tool having a processing chamber that is adapted to deposit a silicon-containing layer on a surface of the substrate, a back contact deposition chamber configured to deposit a back contact layer on a surface of the substrate, a

substrate sectioning module configured to section the substrate into two or more sections, and a system controller for controlling and coordinating functions of each of the substrate receiving module, the cluster tool, the processing chamber, the back contact deposition chamber, and the substrate sectioning module.

[0008] In yet another embodiment of the present invention, a method of processing a solar cell device comprises cleaning a substrate to remove one or more contaminants from a surface of the substrate, depositing a photoabsorbing layer on the surface of the substrate, removing at least a portion of the photoabsorbing layer from a region on a surface of the substrate, depositing a back contact layer on the surface of the substrate, sectioning the substrate into two or more sections, performing an edge deletion process on a surface of one of the sections bonding a back glass substrate to the surface of one of the sections to form a composite structure, and attaching a junction box to the composite structure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0010] Figure 1 illustrates a process sequence for forming a solar cell device according to one embodiment described herein.

[0011] Figure 2 illustrates a plan view of a solar cell production line according to one embodiment described herein.

[0012] Figure 3A is a side cross-sectional view of a thin film solar cell device according to one embodiment described herein.

[0013] Figure 3B is a side cross-sectional view of a thin film solar cell device according to one embodiment described herein.

[0014] Figure 3C is a plan view of a composite solar cell structure according to one embodiment described herein.

[0015] Figure 3D is a cross-sectional view of along Section A-A of Figure 3C.

[0016] Figure 3E is a side cross-sectional view of a thin film solar cell device according to one embodiment described herein.

[0017] Figures 4A-4E are schematic plan views illustrating the sequencing of a sectioning module according to one embodiment of the present invention.

[0018] Figures 5A-5C are schematic side views of portions of the sectioning module illustrating a sequence of sectioning a substrate according to one embodiment of the present invention.

DETAILED DESCRIPTION

[0019] Embodiments of the present invention generally relate to a system used to form solar cell devices using processing modules adapted to perform one or more processes in the formation of the solar cell devices. In one embodiment, the system is adapted to form thin film solar cell devices by accepting a large unprocessed substrate and performing multiple deposition, material removal, cleaning, sectioning, bonding, and testing processes to form multiple complete, functional, and tested solar cell devices that can then be shipped to an end user for installation in a desired location to generate electricity. In one embodiment, the system is capable of accepting a single large unprocessed substrate and producing multiple smaller solar cell devices. In one embodiment, the system is capable of changing the sizes of the solar cell devices produced from the single large substrate without manually moving or altering any of the system modules. While the discussion below primarily describes the formation of silicon thin film solar cell devices, this configuration is not intended to be limiting as to the scope of the invention since the apparatus and methods disclosed herein can also be used to form, test, and analyze other types of solar cell devices, such as III-V type solar cells, thin film chalcogenide solar cells

(*e.g.*, CIGS, CdTe cells), amorphous or nanocrystalline silicon solar cells, photochemical type solar cells (*e.g.*, dye sensitized), crystalline silicon solar cells, organic type solar cells, or other similar solar cell devices.

[0020] The system is generally an arrangement of automated processing modules and automation equipment used to form solar cell devices that are interconnected by an automated material handling system. In one embodiment, the system is a fully automated solar cell device production line that is designed to reduce and/or remove the need for human interaction and/or labor intensive processing steps to improve the device reliability, process repeatability, and the cost of ownership of the formation process. In one configuration, the system is adapted to form multiple silicon thin film solar cell devices from a single large substrate and generally comprises a substrate receiving module that is adapted to accept an incoming substrate, one or more absorbing layer deposition cluster tools having at least one processing chamber that is adapted to deposit a silicon-containing layer on a processing surface of the substrate, one or more back contact deposition chambers that is adapted to deposit a back contact layer on the processing surface of the substrate, one or more material removal chambers that are adapted to remove material from the processing surface of each substrate, one or more sectioning modules used to section the processed substrate into multiple smaller processed substrates, a solar cell encapsulation device, an autoclave module that is adapted to heat and expose a composite solar cell structure to a pressure greater than atmospheric pressure, a junction box attaching region to attach a connection element that allows the solar cells to be connected to external components, and one or more quality assurance modules adapted to test and qualify each completely formed solar cell device. The one or more quality assurance modules generally include a solar simulator, a parametric testing module, and a shunt bust and qualification module.

[0021] Figure 1 illustrates one embodiment of a process sequence 100 that contains a plurality of steps (*i.e.*, steps 102-142) that are each used to form a solar cell device using a novel solar cell production line 200 described herein. The configuration, number of processing steps, and order of the processing steps in the

process sequence 100 is not intended to be limiting to the scope of the invention described herein. Figure 2 is a plan view of one embodiment of the production line 200, which is intended to illustrate some of the typical processing modules and process flows through the system and other related aspects of the system design, and is thus not intended to be limiting to the scope of the invention described herein.

[0022] In general, a system controller 290 may be used to control one or more components found in the solar cell production line 200. The system controller 290 is generally designed to facilitate the control and automation of the overall solar cell production line 200 and typically includes a central processing unit (CPU) (not shown), memory (not shown), and support circuits (or I/O) (not shown). The CPU may be one of any form of computer processors that are used in industrial settings for controlling various system functions, substrate movement, chamber processes, and support hardware (*e.g.*, sensors, robots, motors, lamps, etc.), and monitor the processes (*e.g.*, substrate support temperature, power supply variables, chamber process time, I/O signals, etc.). The memory is connected to the CPU, and may be one or more of a readily available memory, such as random access memory (RAM), read only memory (ROM), floppy disk, hard disk, or any other form of digital storage, local or remote. Software instructions and data can be coded and stored within the memory for instructing the CPU. The support circuits are also connected to the CPU for supporting the processor in a conventional manner. The support circuits may include cache, power supplies, clock circuits, input/output circuitry, subsystems, and the like. A program (or computer instructions) readable by the system controller 290 determines which tasks are performable on a substrate. Preferably, the program is software readable by the system controller 290 that includes code to perform tasks relating to monitoring, execution and control of the movement, support, and/or positioning of a substrate along with the various process recipe tasks and various chamber process recipe steps being performed in the solar cell production line 200. In one embodiment, the system controller 290 also contains a plurality of programmable logic controllers (PLC's) that are used to locally control one or more modules in the solar cell production, and a material handling system controller (*e.g.*, PLC or standard computer) that deals with the higher level strategic movement,

scheduling and running of the complete solar cell production line. An example of a system controller, distributed control architecture, and other system control structure that may be useful for one or more of the embodiments described herein can be found in the United States Provisional Patent Application Serial No. 60/967,077, which has been incorporated by reference.

[0023] Examples of a solar cell 300 that can be formed using the process sequence(s) illustrated in Figure 1 and the components illustrated in the solar cell production line 200 are illustrated in Figures 3A-3E. Figure 3A is a simplified schematic diagram of a single junction amorphous or micro-crystalline silicon solar cell 300 that can be formed and analyzed in the system described below. As shown in Figure 3A, the single junction amorphous or micro-crystalline silicon solar cell 300 is oriented toward a light source or solar radiation 301. The solar cell 300 generally comprises a substrate 302, such as a glass substrate, polymer substrate, metal substrate, or other suitable substrate, with thin films formed thereover. In one embodiment, the substrate 302 is a glass substrate that is about 2200mm x 2600mm x 3mm in size. The solar cell 300 further comprises a first transparent conducting oxide (TCO) layer 310 (*e.g.*, zinc oxide (ZnO), tin oxide (SnO)) formed over the substrate 302, a first p-i-n junction 320 formed over the first TCO layer 310, a second TCO layer 340 formed over the first p-i-n junction 320, and a back contact layer 350 formed over the second TCO layer 340. To improve light absorption by enhancing light trapping, the substrate and/or one or more of the thin films formed thereover may be optionally textured by wet, plasma, ion, and/or mechanical processes. For example, in the embodiment shown in Figure 3A, the first TCO layer 310 is textured, and the subsequent thin films deposited thereover generally follow the topography of the surface below it. In one configuration, the first p-i-n junction 320 may comprise a p-type amorphous silicon layer 322, an intrinsic type amorphous silicon layer 324 formed over the p-type amorphous silicon layer 322, and an n-type microcrystalline silicon layer 326 formed over the intrinsic type amorphous silicon layer 324. In one example, the p-type amorphous silicon layer 322 may be formed to a thickness between about 60Å and about 300Å, the intrinsic type amorphous silicon layer 324 may be formed to a thickness between about

1,500Å and about 3,500Å, and the n-type microcrystalline semiconductor layer 326 may be formed to a thickness between about 100Å and about 400Å. The back contact layer 350 may include, but is not limited to a material selected from the group consisting of Al, Ag, Ti, Cr, Au, Cu, Pt, alloys thereof, and combinations thereof.

[0024] Figure 3B is a schematic diagram of an embodiment of a solar cell 300, which is a multi-junction solar cell that is oriented toward the light or solar radiation 301. The solar cell 300 comprises a substrate 302, such as a glass substrate, polymer substrate, metal substrate, or other suitable substrate, with thin films formed thereover. The solar cell 300 may further comprise a first transparent conducting oxide (TCO) layer 310 formed over the substrate 302, a first p-i-n junction 320 formed over the first TCO layer 310, a second p-i-n junction 330 formed over the first p-i-n junction 320, a second TCO layer 340 formed over the second p-i-n junction 330, and a back contact layer 350 formed over the second TCO layer 340. In the embodiment shown in Figure 3B, the first TCO layer 310 is textured, and the subsequent thin films deposited thereover generally follow the topography of the surface below it. The first p-i-n junction 320 may comprise a p-type amorphous silicon layer 322, an intrinsic type amorphous silicon layer 324 formed over the p-type amorphous silicon layer 322, and an n-type microcrystalline silicon layer 326 formed over the intrinsic type amorphous silicon layer 324. In one example, the p-type amorphous silicon layer 322 may be formed to a thickness between about 60Å and about 300Å, the intrinsic type amorphous silicon layer 324 may be formed to a thickness between about 1,500Å and about 3,500Å, and the n-type microcrystalline semiconductor layer 326 may be formed to a thickness between about 100Å and about 400Å. The second p-i-n junction 330 may comprise a p-type microcrystalline silicon layer 332, an intrinsic type microcrystalline silicon layer 334 formed over the p-type microcrystalline silicon layer 332, and an n-type amorphous silicon layer 336 formed over the intrinsic type microcrystalline silicon layer 334. In one example, the p-type microcrystalline silicon layer 332 may be formed to a thickness between about 100Å and about 400Å, the intrinsic type microcrystalline silicon layer 334 may be formed to a thickness between about 10,000Å and about 30,000Å, and the n-type

amorphous silicon layer 336 may be formed to a thickness between about 100Å and about 500Å. The back contact layer 350 may include, but is not limited to a material selected from the group consisting of Al, Ag, Ti, Cr, Au, Cu, Pt, alloys thereof, and combinations thereof.

[0025] Figure 3C is a plan view that schematically illustrates an example of the rear surface of a formed solar cell 300 that has been produced in the production line 200. Figure 3D is a side cross-sectional view of portion of the solar cell 300 illustrated in Figure 3C (see section A-A). While Figure 3D illustrates the cross-section of a single junction cell similar to the configuration described in Figure 3A, this is not intended to be limiting as to the scope of the invention described herein.

[0026] As shown in Figures 3C and 3D, the solar cell 300 may contain a substrate 302, the solar cell device elements (*e.g.*, reference numerals 310-350), one or more internal electrical connections (*e.g.*, side buss 355, cross-buss 356), a layer of bonding material 360, a back glass substrate 361, and a junction box 370. The junction box 370 may generally contain two connection points 371, 372 that are electrically connected to portions of the solar cell 300 through the side buss 355 and the cross-buss 356, which are in electrical communication with the back contact layer 350 and active regions of the solar cell 300. To avoid confusion relating to the actions specifically performed on the substrates 302 in the discussion below, a substrate 302 having one or more of the deposited layers (*e.g.*, reference numerals 310-350) and/or one or more internal electrical connections (*e.g.*, side buss 355, cross-buss 356) disposed thereon is generally referred to as a device substrate 303. Similarly, a device substrate 303 that has been bonded to a back glass substrate 361 using a bonding layer 360 is referred to as a composite solar cell structure 304.

[0100] Figure 3E is a schematic cross-section of a solar cell 300 illustrating various scribed regions used to form the individual cells 382A-382B within the solar cell 300. As illustrated in Figure 3E, the solar cell 300 includes a transparent substrate 302, a first TCO layer 310, a first p-i-n junction 320, and a back contact layer 350. Three laser scribing steps may be performed to produce trenches 381A, 381B, and 381C, which are generally required to form a high efficiency solar cell

device. Although formed together on the substrate 302, the individual cells 382A and 382B are isolated from each other by the insulating trench 381C formed in the back contact layer 350 and the first p-i-n junction 320. In addition, the trench 381B is formed in the first p-i-n junction 320 so that the back contact layer 350 is in electrical contact with the first TCO layer 310. In one embodiment, the insulating trench 381A is formed by the laser scribe removal of a portion of the first TCO layer 310 prior to the deposition of the first p-i-n junction 320 and the back contact layer 350. Similarly, in one embodiment, the trench 381B is formed in the first p-i-n junction 320 by the laser scribe removal of a portion of the first p-i-n junction 320 prior to the deposition of the back contact layer 350. While a single junction type solar cell is illustrated in Figure 3E this configuration is not intended to be limiting to the scope of the invention described herein.

General Solar Cell Formation Process Sequence

[0027] Referring to Figures 1 and 2, the process sequence 100 generally starts at step 102 in which a substrate 302 is loaded into the loading module 202 found in the solar cell production line 200. In one embodiment, the substrates 302 are received in a "raw" state where the edges, overall size, and/or cleanliness of the substrates 302 are not well controlled. Receiving "raw" substrates 302 reduces the cost to prepare and store substrates 302 prior to forming a solar device and thus reduces the solar cell device cost, facilities costs, and production costs of the finally formed solar cell device. However, typically, it is advantageous to receive "raw" substrates 302 that have a transparent conducting oxide (TCO) layer (*e.g.*, first TCO layer 310) already deposited on a surface of the substrate 302 before it is received into the system in step 102. If a conductive layer, such as TCO layer, is not deposited on the surface of the "raw" substrates then a front contact deposition step (step 107), which is discussed below, needs to be performed on a surface of the substrate 302.

[0028] In one embodiment, the substrates 302 or 303 are loaded into the solar cell production line 200 in a sequential fashion, and thus do not use a cassette or batch style substrate loading system. A cassette style and/or batch loading type system that requires the substrates to be un-loaded from the cassette, processed,

and then returned to the cassette before moving to the next step in the process sequence can be time consuming and decrease the solar cell production line throughput. The use of batch processing does not facilitate certain embodiments of the present invention, such as fabricating multiple solar cell devices from a single substrate. Additionally, the use of a batch style process sequence generally prevents the use of an asynchronous flow of substrates through the production line, which is believed to provide improved substrate throughput during steady state processing and when one or more modules are brought down for maintenance or due to a fault condition. Generally, batch or cassette based schemes are not able to achieve the throughput of the production line described herein, when one or more processing modules are brought down for maintenance, or even during normal operation, since the queuing and loading of substrates can require a significant amount of overhead time.

[0029] In the next step, step 104, the surfaces of the substrate 302 are prepared to prevent yield issues later on in the process. In one embodiment of step 104, the substrate is inserted into a front end substrate seaming module 204 that is used to prepare the edges of the substrate 302 or 303 to reduce the likelihood of damage, such as chipping or particle generation from occurring during the subsequent processes. Damage to the substrate 302 or 303 can affect device yield and the cost to produce a usable solar cell device. In one embodiment, the front end seaming module 204 is used to round or bevel the edges of the substrate 302 or 303. In one embodiment, a diamond impregnated belt or disc is used to grind the material from the edges of the substrate 302 or 303. In another embodiment, a grinding wheel, grit blasting, or laser ablation technique is used to remove the material from the edges of the substrate 302 or 303.

[0030] Next the substrate 302 or 303 is transported to the cleaning module 206, in which step 106, or a substrate cleaning step, is performed on the substrate 302 or 303 to remove any contaminants found on the surface of thereof. Common contaminants may include materials deposited on the substrate 302 or 303 during the substrate forming process (*e.g.*, glass manufacturing process) and/or during shipping or storing of the substrates 302 or 303. Typically, the cleaning module 206

uses wet chemical scrubbing and rinsing steps to remove any undesirable contaminants.

[0031] In one example, the process of cleaning the substrate 302 or 303 may occur as follows. First, the substrate 302 or 303 enters a contaminant removal section of the cleaning module 206 from either a transfer table or an automation device 281. In general, the system controller 290 establishes the timing for each substrate 302 or 303 that enters the cleaning module 206. The contaminant removal section may utilize dry cylindrical brushes in conjunction with a vacuum system to dislodge and extract contaminants from the surface of the substrate 302. Next, a conveyor within the cleaning module 206 transfers the substrate 302 or 303 to a pre-rinse section, where spray tubes dispense hot DI water at a temperature, for example, of 50° C from a DI water heater onto a surface of the substrate 302 or 303. Commonly, since the device substrate 303 has a TCO layer disposed thereon, and since TCO layers are generally electron absorbing materials, DI water is used to avoid any traces of possible contamination and ionizing of the TCO layer. Next, the rinsed substrate 302, 303 enters a wash section. In the wash section, the substrate 302 or 303 is wet-cleaned with a brush (*e.g.*, perlon) and hot water. In some cases a detergent (*e.g.*, Alconox™, Citrajet™, Detojet™, Transene™, and Basic H™), surfactant, pH adjusting agent, and other cleaning chemistries are used to clean and remove unwanted contaminants and particles from the substrate surface. A water re-circulation system recycles the hot water flow. Next, in a final rinse section of the cleaning module 206, the substrate 302 or 303 is rinsed with water at ambient temperature to remove any traces of contaminants. Finally, in a drying section, an air blower is used to dry the substrate 302 or 303 with hot air. In one configuration a deionization bar is used to remove the electrical charge from the substrate 302 or 303 at the completion of the drying process.

[0032] In the next step, or step 108, separate cells are electrically isolated from one another via scribing processes. Contamination particles on the TCO surface and/or on the bare glass surface can interfere with the scribing procedure. In laser scribing, for example, if the laser beam runs across a particle, it may be unable to scribe a continuous line, and a short circuit between cells will result. In addition, any

particulate debris present in the scribed pattern and/or on the TCO of the cells after scribing can cause shunting and non-uniformities between layers. Therefore, a well-defined and well-maintained process is generally needed to ensure that contamination is removed throughout the production process. In one embodiment, the cleaning module 206 is available from the Energy and Environment Solutions division of Applied Materials in Santa Clara, California.

[0033] Referring to Figures 1 and 2, in one embodiment, prior to performing step 108 the substrates 302 are transported to a front end processing module (not illustrated in Figure 2) in which a front contact formation process, or step 107, is performed on the substrate 302. In one embodiment, the front end processing module is similar to the processing module 218 discussed below. In step 107, the one or more substrate front contact formation steps may include one or more preparation, etching and/or material deposition steps that are used to form the front contact regions on a bare solar cell substrate 302. In one embodiment, step 107 generally comprises one or more PVD steps that are used to form the front contact region on a surface of the substrate 302. In one embodiment, the front contact region contains a transparent conducting oxide (TCO) layer that may contain metal element selected from a group consisting of zinc (Zn), aluminum (Al), indium (In), and tin (Sn). In one example, a zinc oxide (ZnO) is used to form at least a portion of the front contact layer. In one embodiment, the front end processing module is an ATON™ PVD 5.7 tool available from Applied Materials in Santa Clara, California in which one or more processing steps are performed to deposit the front contact formation steps. In another embodiment, one or more CVD steps are used to form the front contact region on a surface of the substrate 302.

[0034] Next the device substrate 303 is transported to the scribe module 208 in which step 108, or a front contact isolation step, is performed on the device substrate 303 to electrically isolate different regions of the device substrate 303 surface from each other. In step 108, material is removed from the device substrate 303 surface by use of a material removal step, such as a laser ablation process. The success criteria for step 108 are to achieve good cell-to-cell and cell-to-edge isolation while minimizing the scribe area. In one embodiment, a Nd:vanadate

($Nd:YVO_4$) laser source is used ablate material from the device substrate 303 surface to form lines that electrically isolate one region of the device substrate 303 from the next. In one embodiment, the laser scribe process performed during step 108 uses a 1064 nm wavelength pulsed laser to pattern the material disposed on the substrate 302 to isolate each of the individual cells (*e.g.*, reference cells 382A and 382B) that make up the solar cell 300. In one embodiment, a 5.7 m^2 substrate laser scribe module available from Applied Materials, Inc. of Santa Clara, California is used to provide simple reliable optics and substrate motion for accurate electrical isolation of regions of the device substrate 303 surface. In another embodiment, a water jet cutting tool or diamond scribe is used to isolate the various regions on the surface of the device substrate 303. In one aspect, it is desirable to assure that the temperature of the device substrates 303 entering the scribe module 208 are at a temperature in a range between about 20°C and about 26°C by use of an active temperature control hardware assembly that may contain a resistive heater and/or chiller components (*e.g.*, heat exchanger, thermoelectric device). In one embodiment, it is desirable to control the device substrate 303 temperature to about 25 +/- 0.5°C.

[0035] Next the device substrate 303 is transported to the cleaning module 210 in which step 110, or a pre-deposition substrate cleaning step, is performed on the device substrate 303 to remove any contaminants found on the surface of the device substrate 303 after performing the cell isolation step (step 108). Typically, the cleaning module 210 uses wet chemical scrubbing and rinsing steps to remove any undesirable contaminants found on the device substrate 303 surface after performing the cell isolation step. In one embodiment, a cleaning process similar to the processes described in step 106 above is performed on the device substrate 303 to remove any contaminants on the surface(s) of the device substrate 303.

[0036] Next, the device substrate 303 is transported to the processing module 212 in which step 112, which comprises one or more photoabsorber deposition steps, is performed on the device substrate 303. In step 112, the one or more photoabsorber deposition steps may include one or more preparation, etching, and/or material deposition steps that are used to form the various regions of the

solar cell device. Step 112 generally comprises a series of sub-processing steps that are used to form one or more p-i-n junctions. In one embodiment, the one or more p-i-n junctions comprise amorphous silicon and/or microcrystalline silicon materials. In general, the one or more processing steps are performed in one or more cluster tools (*e.g.*, cluster tools 212A-212D) found in the processing module 212 to form one or more layers in the solar cell device formed on the device substrate 303. In one embodiment, the device substrate 303 is transferred to an accumulator 211A prior to being transferred to one or more of the cluster tools 212A-212D. In one embodiment, in cases where the solar cell device is formed to include multiple junctions, such as the tandem junction solar cell 300 illustrated in Figure 3B, the cluster tool 212A in the processing module 212 is adapted to form the first p-i-n junction 320 and cluster tools 212B-212D are configured to form the second p-i-n junction 330. Information regarding the hardware and processing methods used to deposit one or more layers in the p-i-n junctions is further described in United States Patent Application Serial No. 12/178,289 [Attorney docket # APPM 11709.P3], filed July 23, 2008, and United States Patent Application Serial No. 12/170,387 [Attorney docket # APPM 11710], filed July 9, 2008, which are both herein incorporated by reference.

[0037] In one embodiment of the process sequence 100, a cool down step, or step 113, is performed after step 112 has been performed. The cool down step is generally used to stabilize the temperature of the device substrate 303 to assure that the processing conditions seen by each device substrate 303 in the subsequent processing steps are repeatable. Generally, the temperature of the device substrate 303 exiting the processing module 212 could vary by many degrees Celsius and exceed a temperature of 50°C, which can cause variability in the subsequent processing steps and solar cell performance.

[0038] In one embodiment, the cool down step 113 is performed in one or more of the substrate supporting positions found in one or more accumulators 211. In one configuration of the production line, as shown in Figure 2, the processed device substrates 303 may be positioned in one of the accumulators 211B for a desired period of time to control the temperature of the device substrate 303. In one

embodiment, the system controller 290 is used to control the positioning, timing, and movement of the device substrates 303 through the accumulator(s) 211 to control the temperature of the device substrates 303 before proceeding down stream through the production line.

[0039] Next, the device substrate 303 is transported to the scribe module 214 in which step 114, or the interconnect formation step, is performed on the device substrate 303 to electrically isolate various regions of the device substrate 303 surface from each other. In step 114, material is removed from the device substrate 303 surface by use of a material removal step, such as a laser ablation process. In one embodiment, an Nd:vanadate ($Nd:YVO_4$) laser source is used ablate material from the substrate surface to form lines that electrically isolate one solar cell from the next. In one embodiment, a $5.7m^2$ substrate laser scribe module available from Applied Materials, Inc. is used to perform the accurate scribing process. In one embodiment, the laser scribe process performed during step 108 uses a 532 nm wavelength pulsed laser to pattern the material disposed on the device substrate 303 to isolate the individual cells that make up the solar cell 300. As shown in Figure 3E, in one embodiment, the trench 381B is formed in the first p-i-n junction 320 layers by used of a laser scribing process. In another embodiment, a water jet cutting tool or diamond scribe is used to isolate the various regions on the surface of the solar cell. In one aspect, it is desirable to assure that the temperature of the device substrates 303 entering the scribe module 214 are at a temperature in a range between about 20°C and about 26°C by use of an active temperature control hardware assembly that may contain a resistive heater and/or chiller components (*e.g.*, heat exchanger, thermoelectric device). In one embodiment, it is desirable to control the substrate temperature to about 25 +/- 0.5°C.

[0040] In one embodiment, the solar cell production line 200 has at least one accumulator 211 positioned after the scribe module(s) 214. During production accumulators 211C may be used to provide a ready supply of substrates to a contact deposition chamber 218, and/or provide a collection area where substrates coming from the processing module 212 can be stored if the contact deposition chamber 218 goes down or can not keep up with the throughput of the scribe

module(s) 214. In one embodiment it is generally desirable to monitor and/or actively control the temperature of the substrates exiting the accumulators 211C to assure that the results of the back contact formation step 120 are repeatable. In one aspect, it is desirable to assure that the temperature of the substrates exiting the accumulators 211C or arriving at the contact deposition chamber 218 are at a temperature in a range between about 20°C and about 26°C. In one embodiment, it is desirable to control the substrate temperature to about 25 +/- 0.5°C. In one embodiment, it is desirable to position one or more accumulators 211C that are able to retain at least about 80 substrates.

[0041] Next, the device substrate 303 is transported to the processing module 218 in which one or more substrate back contact formation steps, or step 118, are performed on the device substrate 303. In step 118, the one or more substrate back contact formation steps may include one or more preparation, etching, and/or material deposition steps that are used to form the back contact regions of the solar cell device. In one embodiment, step 118 generally comprises one or more PVD steps that are used to form the back contact layer 350 on the surface of the device substrate 303. In one embodiment, the one or more PVD steps are used to form a back contact region that contains a metal layer selected from a group consisting of zinc (Zn), tin (Sn), aluminum (Al), copper (Cu), silver (Ag), nickel (Ni), and vanadium (V). In one example, a zinc oxide (ZnO) or nickel vanadium alloy (NiV) is used to form at least a portion of the back contact layer 305. In one embodiment, the one or more processing steps are performed using an ATON™ PVD 5.7 tool available from Applied Materials in Santa Clara, California. In another embodiment, one or more CVD steps are used to form the back contact layer 350 on the surface of the device substrate 303.

[0042] In one embodiment, the solar cell production line 200 has at least one accumulator 211 positioned after the processing module 218. During production, the accumulators 211D may be used to provide a ready supply of substrates to the scribe modules 220, and/or provide a collection area where substrates coming from the processing module 218 can be stored if the scribe modules 220 go down or can not keep up with the throughput of the processing module 218. In one embodiment

it is generally desirable to monitor and/or actively control the temperature of the substrates exiting the accumulators 211D to assure that the results of the back contact formation step 120 are repeatable. In one aspect, it is desirable to assure that the temperature of the substrates exiting the accumulators 211D or arriving at the scribe module 220 are at a temperature in a range between about 20°C and about 26°C. In one embodiment, it is desirable to control the substrate temperature to about 25 +/- 0.5°C. In one embodiment, it is desirable to position one or more accumulators 211C that are able to retain at least about 80 substrates.

[0043] Next, the device substrate 303 is transported to the scribe module 220 in which step 120, or a back contact isolation step, is performed on the device substrate 303 to electrically isolate the plurality of solar cells contained on the substrate surface from each other. In step 120, material is removed from the substrate surface by use of a material removal step, such as a laser ablation process. In one embodiment, a Nd:vanadate ($Nd:YVO_4$) laser source is used ablate material from the device substrate 303 surface to form lines that electrically isolate one solar cell from the next. In one embodiment, a $5.7m^2$ substrate laser scribe module, available from Applied Materials, Inc., is used to accurately scribe the desired regions of the device substrate 303. In one embodiment, the laser scribe process performed during step 120 uses a 532 nm wavelength pulsed laser to pattern the material disposed on the device substrate 303 to isolate the individual cells that make up the solar cell 300. As shown in Figure 3E, in one embodiment, the trench 381C is formed in the first p-i-n junction 320 and back contact layer 350 by use of a laser scribing process. In one aspect, it is desirable to assure that the temperature of the device substrates 303 entering the scribe module 220 are at a temperature in a range between about 20°C and about 26°C by use of an active temperature control hardware assembly that may contain a resistive heater and/or chiller components (*e.g.*, heat exchanger, thermoelectric device). In one embodiment, it is desirable to control the substrate temperature to about 25 +/- 0.5°C.

[0044] Next, the device substrate 303 is transported to the quality assurance module 222 in which step 122, or quality assurance and/or shunt removal steps, are

performed on the device substrate 303 to assure that the devices formed on the substrate surface meet a desired quality standard and in some cases correct defects in the formed device. In step 122, a probing device is used to measure the quality and material properties of the formed solar cell device by use of one or more substrate contacting probes. In one embodiment, the quality assurance module 222 projects a low level of light at the p-i-n junction(s) of the solar cell and uses the one more probes to measure the output of the cell to determine the electrical characteristics of the formed solar cell device(s). If the module detects a defect in the formed device, it can take corrective actions to fix the defects in the formed solar cells on the device substrate 303. In one embodiment, if a short or other similar defect is found, it may be desirable to create a reverse bias between regions on the substrate surface to control and or correct one or more of the defectively formed regions of the solar cell device. During the correction process the reverse bias generally delivers a voltage high enough to cause the defects in the solar cells to be corrected. In one example, if a short is found between supposedly isolated regions of the device substrate 303 the magnitude of the reverse bias may be raised to a level that causes the conductive elements in areas between the isolated regions to change phase, decompose, or become altered in some way to eliminate or reduce the magnitude of the electrical short. In one embodiment of the process sequence 100, the quality assurance module 222 and factory automation system are used together to resolve quality issues found in a formed device substrate 303 during the quality assurance testing. In one case, a device substrate 303 may be sent back upstream in the processing sequence to allow one or more of the fabrication steps to be re-performed on the device substrate 303 (*e.g.*, back contact isolation step (step 120)) to correct one or more quality issues with the processed device substrate 303.

[0045] Next, the device substrate 303 is optionally transported to the substrate sectioning module 224 in which a substrate sectioning step 124 is used to cut the device substrate 303 into a plurality of smaller device substrates 303 to form a plurality of smaller solar cell devices. In one embodiment of step 124, the device substrate 303 is inserted into substrate sectioning module 224 that uses a CNC glass cutting tool to accurately cut and section the device substrate 303 to form solar

cell devices that are a desired size. In one embodiment, the device substrate 303 is inserted into the cutting module 224 that uses a glass scribing tool to accurately score the surface of the device substrate 303. The device substrate 303 is then broken along the scored lines to produce the desired size and number of sections needed for the completion of the solar cell devices.

[0046] In one embodiment, the solar cell production line 200 is adapted to accept (step 102) and process substrate 302 or device substrates 303 that are 5.7 m^2 or larger. In one embodiment, these large area substrates 302 are partially processed and then sectioned into four 1.4 m^2 device substrates 303 during step 124. In one embodiment, the system is designed to process large device substrates 303 (*e.g.*, TCO coated 2200mm x 2600mm x 3mm glass) and produce various sized solar cell devices without additional equipment or processing steps. Currently amorphous silicon (a-Si) thin film factories must have one product line for each different size solar cell device. In the present invention, the manufacturing line is able to quickly switch to manufacture different solar cell device sizes. In one aspect of the invention, the manufacturing line is able to provide a high solar cell device throughput, which is typically measured in Mega-Watts per year, by forming solar cell devices on a single large substrate and then sectioning the substrate to form solar cells of a more preferable size.

[0047] In one embodiment of the production line 200, the front end of the line (FEOL) (*e.g.*, steps 102- 122) is designed to process a large area device substrate 303 (*e.g.*, 2200mm x 2600mm), and the back end of the line (BEOL) is designed to further process the large area device substrate 303 or multiple smaller device substrates 303 formed by use of the sectioning process. In this configuration, the remainder of the manufacturing line accepts and further processes the various sizes. The flexibility in output with a single input is unique in the solar thin film industry and offers significant savings in capital expenditure. The material cost for the input glass is also lower since solar cell device manufacturers can purchase a larger quantity of a single glass size to produce the various size modules.

[0048] In one embodiment, steps 102-122 can be configured to use equipment that is adapted to perform process steps on large device substrates 303, such as 2200mm x 2600mm x 3mm glass device substrates 303, and steps 124 onward can be adapted to fabricate various smaller sized solar cell devices with no additional equipment required. In another embodiment, step 124 is positioned in the process sequence 200 prior to step 122 so that the initially large device substrate 303 can be sectioned to form multiple individual solar cells that are then tested and characterized one at a time or as a group (*i.e.*, two or more at a time). In this case, steps 102-121 are configured to use equipment that is adapted to perform process steps on large device substrates 303, such as 2200mm x 2600mm x 3mm glass substrates, and steps 124 and 122 onward are adapted to fabricate various smaller sized modules with no additional equipment required. A more detailed description of an exemplary substrate sectioning module 224 is presented below in the section entitled, "Substrate Sectioning Module and Processes."

[0049] Referring back to Figures 1 and 2, the device substrate 303 is next transported to the seamer/edge deletion module 226 in which a substrate surface and edge preparation step 126 is used to prepare various surfaces of the device substrate 303 to prevent yield issues later on in the process. In one embodiment of step 126, the device substrate 303 is inserted into seamer/edge deletion module 226 to prepare the edges of the device substrate 303 to shape and prepare the edges of the device substrate 303. Damage to the device substrate 303 edge can affect the device yield and the cost to produce a usable solar cell device. In another embodiment, the seamer/edge deletion module 226 is used to remove deposited material from the edge of the device substrate 303 (*e.g.*, 10 mm) to provide a region that can be used to form a reliable seal between the device substrate 303 and the backside glass (*i.e.*, steps 134-136 discussed below). Material removal from the edge of the device substrate 303 may also be useful to prevent electrical shorts in the final formed solar cell.

[0050] In one embodiment, a diamond impregnated belt is used to grind the deposited material from the edge regions of the device substrate 303. In another embodiment, a grinding wheel is used to grind the deposited material from the edge

regions of the device substrate 303. In another embodiment, dual grinding wheels are used to remove the deposited material from the edge of the device substrate 303. In yet another embodiment, grit blasting or laser ablation techniques are used to remove the deposited material from the edge of the device substrate 303. In one aspect, the seamer/edge deletion module 226 is used to round or bevel the edges of the device substrate 303 by use of shaped grinding wheels, angled and aligned belt sanders, and/or abrasive wheels.

[0051] Next the device substrate 303 is transported to the pre-screen module 228 in which optional pre-screen steps 128 are performed on the device substrate 303 to assure that the devices formed on the substrate surface meet a desired quality standard. In step 128, a light emitting source and probing device are used to measure the output of the formed solar cell device by use of one or more substrate contacting probes. If the module 228 detects a defect in the formed device it can take corrective actions or the solar cell can be scrapped.

[0052] Next the device substrate 303 is transported to the cleaning module 230 in which step 130, or a pre-lamination substrate cleaning step, is performed on the device substrate 303 to remove any contaminants found on the surface of the substrates 303 after performing steps 122-128. Typically, the cleaning module 230 uses wet chemical scrubbing and rinsing steps to remove any undesirable contaminants found on the substrate surface after performing the cell isolation step. In one embodiment, a cleaning process similar to the processes described in step 106 is performed on the substrate 303 to remove any contaminants on the surface(s) of the substrate 303.

[0053] Next the substrate 303 is transported to a bonding wire attach module 231 in which step 131, or a bonding wire attach step, is performed on the substrate 303. Step 131 is used to attach the various wires/leads required to connect the various external electrical components to the formed solar cell device. Typically, the bonding wire attach module 231 is an automated wire bonding tool that is advantageously used to reliably and quickly form the numerous interconnects that are often required to form the large solar cells formed in the production line 200. In

one embodiment, the bonding wire attach module 231 is used to form the side-buss 355 (Figure 3C) and cross-buss 356 on the formed back contact region (step 118). In this configuration the side-buss 355 may be a conductive material that can be affixed, bonded, and/or fused to the back contact layer 350 found in the back contact region to form a good electrical contact. In one embodiment, the side-buss 355 and cross-buss 356 each comprise a metal strip, such as copper tape, a nickel coated silver ribbon, a silver coated nickel ribbon, a tin coated copper ribbon, a nickel coated copper ribbon, or other conductive material that can carry the current delivered by the solar cell and be reliably bonded to the metal layer in the back contact region. In one embodiment, the metal strip is between about 2mm and about 10 mm wide and between about 1 mm and about 3 mm thick. The cross-buss 356, which is electrically connected to the side-buss 355 at the junctions, can be electrically isolated from the back contact layer(s) of the solar cell by use of an insulating material 357, such as an insulating tape. The ends of each of the cross-busses 356 generally have one or more leads that are used to connect the side-buss 355 and the cross-buss 356 to the electrical connections found in a junction box 370, which is used to connect the formed solar cell to the other external electrical components. Further information on soldering bus wire to thin film solar modules is disclosed in United States Provisional Patent Application Serial No. 60/967,077, United States Provisional Patent Application Serial No. 61/023,810, and United States Provisional Patent Application Serial No. 61/032,005, which are incorporated by reference herein.

[0054] In the next step, step 132, a bonding material 360 (Figure 3D) and "back glass" substrate 361 are prepared for delivery into the solar cell formation process (*i.e.*, process sequence 100). The preparation process is generally performed in the glass lay-up module 232, which generally comprises a material preparation module 232A, a glass loading module 232B and a glass cleaning module 232C. The back glass substrate 361 is bonded onto the device substrate 303 formed in steps 102-130 above by use of a laminating process (step 134 discussed below). In general, step 132 requires the preparation of a polymeric material that is to be placed between the back glass substrate 361 and the deposited layers on the device

substrate 303 to form a hermetic seal to prevent the environment from attacking the solar cell during its life. Referring to Figure 2, step 132 generally comprises a series of sub-steps in which a bonding material 360 is prepared in the material preparation module 232A, the bonding material 360 is then placed over the device substrate 303, the back glass substrate 361 is loaded into the loading module 232B and is washed by use of the cleaning module 232C, and the back glass substrate 361 is placed over the bonding material 360 and the device substrate 303.

[0055] In one embodiment, the material preparation module 232A is adapted to receive the bonding material 360 in a sheet form and perform one or more cutting operations to provide a bonding material, such as Polyvinyl Butyral (PVB) or Ethylene Vinyl Acetate (EVA) that is sized to form a reliable seal between the backside glass and the solar cells formed on the device substrate 303. In general, when using bonding materials 360 that are polymeric, it is desirable to control the temperature (*e.g.*, 16-18°C) and relative humidity (*e.g.*, RH 20-22%) of the solar cell production line 200 where the bonding material 360 is stored and integrated into the solar cell device to assure that the attributes of the bond formed in the bonding module 234 are repeatable and the dimensions of the polymeric material is stable. It is generally desirable to store the bonding material prior to use in temperature and humidity controlled area (*e.g.*, T= 6-8°C; RH = 20-22%). The tolerance stack up of the various components in the bonded device (Step 134) can be an issue when forming large solar cells, therefore accurate control of the bonding material properties and tolerances of the cutting process are required to assure that a reliable hermetic seal is formed. In one embodiment, PVB may be used to advantage due to its UV stability, moisture resistance, thermal cycling, good US fire rating, compliance with Intl Building Code, low cost, and reworkable thermo-plastic properties. In one part of step 132, the bonding material 360 is transported and positioned over the back contact layer 350, the side-buss 355 (Figure 3C), and the cross-buss 356 (Figure 3C) elements of the device substrate 303 using an automated robotic device. The device substrate 303 and bonding material 360 are then positioned to receive a back glass substrate 361, which can be placed thereon by use of the same

automated robotic device used to position the bonding material 360, or a second automated robotic device.

[0056] In one embodiment, prior to positioning the back glass substrate 361 over the bonding material 360, one or more preparation steps are performed to the back glass substrate 361 to assure that subsequent sealing processes and final solar product are desirably formed. In one case, the back glass substrate 361 is received in a "raw" state where the edges, overall size, and/or cleanliness of the substrate 361 are not well controlled. Receiving "raw" substrates reduces the cost to prepare and store substrates prior to forming a solar device and thus reduces the solar cell device cost, facilities costs, and production costs of the finally formed solar cell device. In one embodiment of step 132, the back glass substrate 361 surfaces and edges are prepared in a seaming module (*e.g.*, seamer 204) prior to performing the back glass substrate cleaning step. In the next sub-step of step 232 the back glass substrate 361 is transported to the cleaning module 232B in which a substrate cleaning step, is performed on the substrate 361 to remove any contaminants found on the surface of the substrate 361. Common contaminants may include materials deposited on the substrate 361 during the substrate forming process (*e.g.*, glass manufacturing process) and/or during shipping of the substrates 361. Typically, the cleaning module 232B uses wet chemical scrubbing and rinsing steps to remove any undesirable contaminants as discussed above. The prepared back glass substrate 361 is then positioned over the bonding material and partially device substrate 303 by use of an automated robotic device.

[0057] Next the device substrate 303, the back glass substrate 361, and the bonding material 360 are transported to the bonding module 234 in which step 134, or lamination steps are performed to bond the backside glass substrate 361 to the device substrate formed in steps 102-130 discussed above. In step 134, a bonding material 360, such as Polyvinyl Butyral (PVB) or Ethylene Vinyl Acetate (EVA), is sandwiched between the backside glass substrate 361 and the device substrate 303. Heat and pressure are applied to the structure to form a bonded and sealed device using various heating elements and other devices found in the bonding module 234. The device substrate 303, the back glass substrate 361 and bonding

material 360 thus form a composite solar cell structure 304 (Figure 3D) that at least partially encapsulates the active regions of the solar cell device. In one embodiment, at least one hole formed in the back glass substrate 361 remains at least partially uncovered by the bonding material 360 to allow portions of the cross-buss 356 or the side buss 355 to remain exposed so that electrical connections can be made to these regions of the solar cell structure 304 in future steps (*i.e.*, step 138).

[0058] Next the composite solar cell structure 304 is transported to the autoclave module 236 in which step 136, or autoclave steps are performed on the composite solar cell structure 304 to remove trapped gasses in the bonded structure and assure that a good bond is formed during step 134. In step 134, a bonded solar cell structure 304 is inserted in the processing region of the autoclave module where heat and high pressure gases are delivered to reduce the amount of trapped gas and improve the properties of the bond between the device substrate 303, back glass substrate, and bonding material 360. The processes performed in the autoclave are also useful to assure that the stress in the glass and bonding layer (*e.g.*, PVB layer) are more controlled to prevent future failures of the hermetic seal or failure of the glass due to the stress induced during the bonding/lamination process. In one embodiment, it may be desirable to heat the device substrate 303, back glass substrate 361, and bonding material 360 to a temperature that causes stress relaxation in one or more of the components in the formed solar cell structure 304.

[0059] Next the solar cell structure 304 is transported to the junction box attachment module 238 in which junction box attachment steps 138 are performed on the formed solar cell structure 304. The junction box attachment module 238, used during step 138, is used to install a junction box 370 (Figure 3C) on a partially formed solar cell. The installed junction box 370 acts as an interface between the external electrical components that will connect to the formed solar cell, such as other solar cells or a power grid, and the internal electrical connections points, such as the leads, formed during step 131. In one embodiment, the junction box 370 contains one or more connection points 371, 372 so that the formed solar cell can

be easily and systematically connected to other external devices to deliver the generated electrical power.

[0060] Next the solar cell structure 304 is transported to the device testing module 240 in which device screening and analysis steps 140 are performed on the solar cell structure 304 to assure that the devices formed on the solar cell structure 304 surface meet desired quality standards. In one embodiment, the device testing module 240 is a solar simulator module that is used to qualify and test the output of the one or more formed solar cells. In step 140, a light emitting source and probing device are used to measure the output of the formed solar cell device by use of one or more automated components that are adapted to make electrical contact with terminals in the junction box 370. If the module detects a defect in the formed device it can take corrective actions or the solar cell can be scrapped.

[0061] Next the solar cell structure 304 is transported to the support structure module 241 in which support structure mounting steps 141 are performed on the solar cell structure 304 to provide a complete solar cell device that has one or more mounting elements attached to the solar cell structure 304 formed using steps 102-140 to a complete solar cell device that can easily be mounted and rapidly installed at a customer's site.

[0062] Next the solar cell structure 304 is transported to the unload module 242 in which step 142, or device unload steps are performed on the substrate to remove the formed solar cells from the solar cell production line 200.

[0063] In one embodiment of the solar cell production line 200, one or more regions in the production line are positioned in a clean room environment to reduce or prevent contamination from affecting the solar cell device yield and useable lifetime. In one embodiment, as shown in Figure 2, a class 10,000 clean room space 250 is placed around the modules used to perform steps 108-118 and steps 130-134.

Substrate Sectioning Module and Processes

[0064] The substrate sectioning module 224 and processing sequence performed during the substrate sectioning step 124 are used to section a large, partially processed device substrate 303 (*i.e.*, a substrate having one or more thin silicon films deposited thereon) into two or more device substrates 303 for further processing into a solar module. In one embodiment, the substrate sectioning module receives a 2600 mm x 2200 mm device substrate 303 and sections it into two 1300mm x 2200 mm device substrates 303 for further processing. In one embodiment, the substrate sectioning module receives a 2600 mm x 2200 mm device substrate 303 and sections it into two 2600 mm x 1100 mm device substrates 303 for further processing. In one embodiment, the substrate sectioning module receives a 2600 mm x 2200 mm device substrate 303 and sections it into four 1300 mm x 1100 mm device substrates 303 for further processing.

[0065] In one embodiment, the system controller 290 (Figure 2) controls the number and size of the sections of the device substrates 303 produced by the substrate sectioning module 224. Accordingly, the system controller 290 sends commands to all downstream processes in the sequence 100 (Figure 1) for coordinating both the processes and adjustments to the downstream modules to accommodate and further process sections of the device substrate 303 produced by the substrate sectioning module regardless of the size of the sections produced.

[0066] Figures 4A-4E are top plan, schematic views illustrating a sequence of sectioning a device substrate 303 according to one embodiment of the substrate sectioning module 224. Referring to Figure 4A, an inlet conveyor 410 transports the device substrate 303 into a scribing station 420. In one embodiment, the side of the device substrate 303 having thin films deposited thereover is facing upward. A scribing conveyor 422 positions the device substrate in the scribing station 420 for scribing. In the scribing station 420, as shown in Figure 4B, a pattern is scribed on the upper surface of the device substrate 303 via a scribing mechanism 424 according to the programmed sectioning of the device substrate 303. In one embodiment, the inlet conveyor 410, the scribing conveyor 422, and the scribing

mechanism 424 are controlled and coordinated with each other as well as other operations in the sequence 100 (Figure 1) via the system controller 290 (Figure 2).

[0067] In one embodiment, the scribing mechanism 424 is a mechanical scribing mechanism, such as a mechanical scribing wheel. In one embodiment, the scribing mechanism 424 is an optical scribing mechanism, such a laser scribing mechanism. Regardless of the type of scribing mechanism 424 employed, it should be noted that the scribing mechanism must cut completely through any films deposited on the processing surface of the device substrate 303 and cleanly score the upper surface of the underlying glass.

[0068] The scored device substrate 303 is then transported via the scribing station conveyor 422 partially onto a cross transfer station 430 as shown in Figure 4C. A first transfer station conveyor 432 is coordinated with the scribing station conveyor 422 via the system controller 290 to properly position the device substrate 303. Figures 5A-5C schematically illustrate a process for breaking the scored device substrate 303 according to one embodiment of the present invention. Referring to Figures 4C and 5A, the scored device substrate 303 is positioned over a roller 426 such that a line scribed along the X-axis is located directly above the roller 426. The roller 426 is then raised and placed in contact with the lower surface of the device substrate 303 as schematically shown in Figure 5B. As schematically depicted in Figure 5C, the roller 426 is raised exerting a lifting force on the lower surface of the device substrate 303 along the scribed line and perpendicular to the plane of the device substrate 303 resulting in a clean break along the scribed line.

[0069] In one embodiment, the roller 426 is a padded cylindrical roller extending the length of the device substrate 303. The roller 426 is raised by an actuator 428. In one embodiment, the actuator 428 may be an electric, hydraulic, or pneumatic motor. In one embodiment, the actuator 428 may be a hydraulic or pneumatic cylinder. In one embodiment, the actuator 428 is controlled and coordinated by the system controller 290.

[0070] Next, shown in Figure 4D, a first section 303A of the substrate device 303 is fully loaded into the cross transfer station 430 via the first transfer conveyor 432.

Next, a second transfer conveyor 434, in conjunction with an exit conveyor 440, transfers the first section 303A partially onto the exit conveyor 440 as shown in Figure 4E. The second transfer station conveyor 434 is coordinated with the exit conveyor 440 via the system controller 290 to properly position the device substrate section 303A. Referring to Figures 4E and 5A, the scored sectioned device substrate 303A is positioned over the roller 426 such that a line scribed along the Y-axis is located directly above the roller 426. The roller 426 is then raised and placed in contact with the lower surface of the sectioned device substrate 303A as schematically shown in Figure 5B. As schematically depicted in Figure 5C, the roller 426 is raised to exert a lifting force on the lower surface of the device substrate section 303A along the scribed line and perpendicular to the plane of the device substrate section 303A resulting in a clean break along the scribed line. As a result the substrate section 303A is sectioned into two smaller device substrate sections 303C and 303D. Each of the substrate sections 303C and 303D are then transferred via the second transfer conveyor 434 and the exit conveyor 440 into a subsequent module for further processing. The above processes are then repeated for the device substrate section 303B.

[0071] Although the above-described embodiment illustrates processes and apparatus for sectioning a single substrate device 303 into four smaller sections, it should be evident that the embodiment works equally well for sectioning a single substrate device 303 into two smaller sections by adjusting the scribing mechanism 424 to scribe only a single line on either the X-axis or the Y-axis and performing only a single break process.

[0072] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims:

1. A module for sectioning a solar cell device, comprising:

an inlet conveyor configured to receive commands from a system controller and transfer a solar cell device into a scribing station of the module;

a scribing mechanism configured to receive commands from the system controller and scribe a pattern into a first surface of the solar cell device;

a first positioning mechanism configured to receive commands from the system controller and accurately position the scribed solar cell device over a first break mechanism; and

a first actuator configured to receive commands from the system controller and raise the first break mechanism.

2. The module of claim 1, further comprising:

a cross transfer station having a conveyor and a second positioning mechanism, wherein the conveyor is positioned to receive a section of the solar cell device from the first positioning mechanism, and wherein the second positioning mechanism is configured to receive commands from the system controller and accurately position the section of the solar cell device over a second break mechanism;

a second actuator configured to receive commands from the system controller and raise the second break mechanism; and

an exit conveyor positioned to receive a portion of the section of the solar cell device.

3. The module of claim 2, wherein the first and second break mechanisms are elongated rollers.

4. The module of claim 3, wherein the first break mechanism extends along a first axis and the second break mechanism extends along a second axis, and wherein the first and second axes are substantially perpendicular to one another.

5. The module of claim 1, wherein the scribing mechanism is a mechanical scribing wheel.

6. The module of claim 1, wherein the scribing mechanism is a laser scribing device.

7. A method for sectioning a partially processed solar cell device, comprising:

receiving a substrate having a processing surface;

forming a silicon layer on the processing surface;

sectioning the substrate into a first and a second section after forming the silicon layer on the processing surface; and

transferring the first section into a next station for further processing.

8. The method of claim 7, wherein sectioning the substrate comprises:

scribing a first line into a surface of the substrate after forming the silicon layer on the processing surface; and

actuating a break mechanism to break the substrate along the first line.

9. The method of claim 8, wherein the scribing a first line comprises scribing a line completely through the silicon layer and into the processing surface.

10. The method of claim 8, further comprising scribing a second line into the processing surface, wherein the second line is substantially perpendicular to the first line.

11. The method of claim 10, further comprising positioning the first section of the substrate adjacent a second break mechanism such that the second scribed line is substantially in line with an axis of the second break mechanism.

12. The method of claim 11, further comprising actuating the second break mechanism to break the first section along the second scribed line.

13. The method of claim 11, wherein the processing surface has a surface area greater than about 1.4 m^2.

14. A system for fabricating solar cell devices, comprising:

a substrate receiving module that is adapted to receive a substrate;

a cluster tool having a processing chamber that is adapted to deposit a silicon-containing layer on a surface of the substrate;

a back contact deposition chamber configured to deposit a back contact layer on a surface of the substrate;

a substrate sectioning module configured to section the substrate into two or more sections; and

a system controller for controlling and coordinating functions of each of the substrate receiving module, the cluster tool, the processing chamber, the back contact deposition chamber, and the substrate sectioning module.

15. The system of claim 14, wherein the substrate sectioning module comprises a CNC glass cutter.

16. The system of claim 14, wherein the substrate sectioning module comprises a scribing station configured to scribe a line into a surface of the substrate, a breaking station configured to break the substrate along the line, and a positioning mechanism for positioning the substrate such that the line scribed into the substrate is substantially aligned with the breaking mechanism.

17. The system of claim 16, wherein the substrate sectioning module further comprises a second positioning mechanism for positioning one of the sections of the substrate adjacent a second breaking mechanism, such that the second breaking mechanism is substantially aligned with a second line scribed into the substrate.

18. A method of processing a solar cell device, comprising:

cleaning a substrate to remove one or more contaminants from a surface of the substrate;

depositing a photoabsorbing layer on the surface of the substrate;

removing at least a portion of the photoabsorbing layer from a region on the surface of the substrate;

depositing a back contact layer on the surface of the substrate;

sectioning the substrate into two or more sections;

performing an edge deletion process on a surface of one of the sections;

bonding a back glass substrate to the surface of one of the sections to form a composite structure; and

attaching a junction box to the composite structure.

19. The method of claim 18, wherein sectioning the substrate comprises scribing a first line into the substrate, aligning the first line with a first break mechanism, and breaking the substrate along the first line.

20. The method of claim 19, wherein sectioning the substrate further comprises scribing a second line into the substrate, aligning the second line with a second break mechanism, and breaking the substrate along the second line, wherein the first line is substantially perpendicular to the second line.