

Laser Scribing OF Thin-film Solar Cell Panel

Field of Invention

[0001] The present invention relates to apparatuses and methods for laser scribing of thin-film solar cell panels.

Background

[0002] A thin-film solar cell panel or module typically includes a transparent front electrode disposed on a glass substrate, a photovoltaically active layer containing a PN or PIN junction and a rear electrode. The front electrode is usually a transparent metal oxide such as tin oxide or zinc oxide. The simplest PIN junction includes a layer of a semiconductor material doped with a p-type dopant to form a P-layer, an undoped layer of a semiconductor material that forms an intrinsic or I-layer, and a layer of a semiconductor material doped with an n-type dopant to form an N-layer. Light incident on the substrate passes through the substrate, the front electrode and the photovoltaic layer, and a voltage is generated across the front and rear electrodes.

[0003] Typical methods for the manufacture of such thin-film solar cell panels use a laser to form a series of generally parallel grooves or scribes in the above-mentioned front electrode, semiconductor layer and rear electrode to divide the panel into a collection of individual, series connected cells. In one approach, as described in US 2008/0105303, laser beams are scanned across the panels to form parallel scribed lines. In another approach, the scribed lines were formed by moving the substrate containing the photovoltaic layer and electrodes under the laser beam. These known scribing processes tend to be slow.

[0004] Despite development in the art of forming parallel scribed lines on thin-film solar panels, there is a need for a new apparatus to meet volume production requirements of such solar panels and methods of use.

Summary

[0005] 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.

[0006] The present invention seeks to provide a system and method for laser scribing of thin-films in the manufacture of solar cell panels.

[0007] In one embodiment, the present invention provides a system comprising: an input section; an output section; a processing section between the input and output sections; grippers associated with a linear drive operable to grip on a workpiece, wherein the linear drive is operable to translate the workpiece between the input and output sections; and two or more laser sources disposed in a lower part of the processing section such that each laser source is operable to fire a laser beam upwardly through a transparent substrate of the workpiece to scribe the relevant layer of the thin-film solar panel as the workpiece is being translated between the input and output sections, with each laser source being independently indexable after each scribed line is formed so that the relevant thin-film layer is divided into substantively parallel strips, which are electrically isolated one from another.

[0008] In another embodiment, the present invention provides a method comprising: loading a workpiece with the transparent substrate facing downwards in an input station of a first machine; biasing a reference edge of the workpiece against a front and rear stopper associated with a linear drive, wherein the linear drive is operable to translate the workpiece between the input station and an output station; translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a first frequency substantially vertically through a space between the input and output stations to pass through the transparent substrate of the workpiece to scribe parallel lines on the front electrodes with reference to the edge of the workpiece in contact with the front and rear stoppers, wherein each said laser beam is outputted from a separate laser source; and indexing the two or more laser sources and repeating the back

and forth translation of the work piece between the input and output stations until the entire front electrode is divided into parallel strips that are electrically isolated one from another.

[0009] The method of the present invention further comprising: loading the workpiece formed with parallel strips of front electrodes in an input station of a second machine; biasing the workpiece against a front stopper and a rear adjustable stopper associated with a linear drive similar to that of the first machine, wherein the linear drive is operable to translate the workpiece between the input station and an output station; aligning a scribed line Lp1 on the front electrode with the linear drive by using a camera disposed at the front edge of the workpiece and another camera disposed near the rear adjustable stopper to determine the correction required to achieve parallelism; translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a second frequency substantially vertically through a space between the input and output stations to pass through the transparent substrate of the workpiece to scribe parallel lines (Lp2, Lp3) on the semiconductor layer or rear electrode with reference to the scribed lines (Lp1) on the front electrode, wherein each said laser beam is outputted from a separate laser source; and indexing the two or more laser sources and repeating the back and forth translation of the work piece between the input and output stations until the entire semiconductor layer or rear electrode is divided into parallel strips that are electrically isolated one from another.

[0010] In another embodiment of the present invention, the method comprises: loading a workpiece with the transparent substrate facing downwards in an input station of a machine; biasing the workpiece against a front stopper and a rear adjustable stopper associated with a linear drive; wherein the linear drive is operable to translate the workpiece between the input station and an output station; aligning a reference line on a reference edge of the workpiece with the linear drive by using a camera (C1-C4) disposed near the front edge of the workpiece and another camera (C5) disposed near the rear adjustable stopper to determine the correction required to achieve parallelism between the reference line and the linear drive; translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a first frequency substantially vertically, through a space between the input and output stations,

through the transparent substrate of the workpiece to scribe parallel lines on the front electrode; wherein each said laser beam is outputted from a separate laser source; indexing the two or more laser sources and repeating the back and forth translation of the work piece between the input and output stations until the entire front electrode is divided into parallel strips that are electrically isolated one from another; aligning a scribed line (Lp1) on the front electrode with the linear drive by using the camera (C1-C4) disposed near the front edge of the workpiece and the another camera (C5) disposed near the rear adjustable stopper to determine the correction required to achieve parallelism; translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a second frequency substantially vertically, through a space between the input and output stations, through the transparent substrate of the workpiece to scribe parallel lines (Lp2,Lp3) on the semiconductor layer or rear electrode; wherein each said laser beam is outputted from a separate laser source; and indexing the two or more laser sources and repeating the back and forth translation of the work piece between the input and output stations until the entire semiconductor layer or rear electrode is divided into parallel strips that are electrically isolated one from another.

[0011] In one embodiment, each laser source is independently indexable by separate ballscrew and associated motor. In another embodiment, the rear stopper is adjustable through a ballscrew and an associated motor. In another embodiment, workpiece parallelism alignment is carried out manually with a dummy workpiece; in another, the camera or cameras are mounted on independently motorized axes disposed transverse to the scribed lines and workpiece parallelism alignment is carried out automatically. In yet another embodiment, workpiece parallelism alignment and laser source/camera alignment are carried out with a precision jig.

Brief Description of the Drawings

[0012] This invention will be described by way of non-limiting embodiments of the present invention, with reference to the accompanying drawings, in which:

[0013] FIG. 1A shows an apparatus for laser scribing of the front electrodes according to an embodiment of the present invention; FIG. 1B illustrates an end view of the apparatus shown in FIG. 1A;

[0014] FIG. 2A shows block diagrams of the apparatus shown in FIG. 1A, whilst FIG. 2B shows block diagrams of the first laser scribing process; FIG. 2C shows a substrate after the first laser scribing process;

[0015] FIG. 3A shows an apparatus for laser scribing of the semiconductor layer and rear electrode according to another embodiment of the present invention, whilst FIG. 3B illustrates an end view of the apparatus shown in FIG. 3A;

[0016] FIG. 4A shows block diagrams of the apparatus shown in FIG. 3; FIGs. 4B and 4C show block diagrams of the second laser scribing process;

[0017] FIGs. 5A-5B show block diagrams of the third laser scribing process; and

[0018] FIG. 6A shows the process flow for laser scribing of the front electrode; and FIG. 6B shows the process flow for laser scribing of the semiconductor layer and rear electrode.

Detailed Description

[0019] 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.

[0020] FIG. 1A shows a top perspective view of a laser scribing apparatus **100** according to an embodiment of the present invention. As shown in FIGs. 1A-1B, the laser scribing apparatus **100** includes a frame **110**. The frame **110** has an upper platform **112**, a lower platform **114** and a number of columns **116** joining the upper platform **112** to the lower platform **114**. As seen in FIGs. 1A and 1B, the left hand side of the apparatus **100** is an input section **102**, to which an external conveyor may dock with; the right hand side is an output section **104** of the apparatus. In each of the input and output sections **102,104**, there are two rows of respective air bearings **122,124**. Preferably, the input air bearings **122** are in line with the output air bearings **124** such that a workpiece **W**, for example the glass substrate **S** of 635 mm x 1400 mm, is moveable on air cushions between the substrate and the input/output air bearings **122,124**. In between the two input air bearings **122**, there is an input puller **132**; in between the output air bearings **124**, there is an output pusher **134**. The input puller **132** and output pusher **134** are operable to travel linearly in the respective section to pull or push the workpiece **W** along the respective air bearings. On the far side of the apparatus **100** as seen in FIG. 1A, i.e. the left hand side of the workpiece **W**, there is a linear drive **140**. The linear drive **140** extends from the input section **102** to the output section **104** in an x-direction as indicated by the right hand coordinate system shown in FIG. 1A such that the linear drive **140** is substantially parallel to the input puller **132** and output pusher **134**. The linear drive **140** has at least two spaced apart grippers **144** connected thereto. The grippers **144** are operable to grip the left hand edge of the workpiece **W** and to transfer the workpiece to and forth between the input and output sections **102,104** whilst the workpiece is floating on the input and output air bearings **122,124**. Above the upper platform **112** and in between the input and output sections **102,104**, there is a gantry **160**. The gantry **160** has a span to allow the workpiece **W** to move unobstructively between the input and output sections **102,104**. Substantively below the gantry **160** and on the lower platform **114**, there are four laser sources **150**. Each laser source **150** emits a laser beam upwards through a space between the input and output sections **102,104** to scribe the workpiece **W**. The laser sources **150** are individually operable to index at predetermined pitches **di** transversely with respect to the left hand edge of the workpiece **W**, i.e in the negative y-direction as shown in FIG. 1A, so that substantially parallel scribed lines **Lp1,Lp2,Lp3** can be formed in four bands **B1-B4** on the workpiece **W** with respect to the first, second and third laser scribing

processes **P1,P2,P3** on the three respective major layers on a solar cell panel. On the gantry **160**, four suction nozzles **162** associated with the four laser sources **150** are provided to remove any debris that may be generated during the laser scribing process.

[0021] Associated with the linear drive **140**, there are two fixed stoppers **142** against which the far side, as seen in FIG. 1A, or left hand side of the workpiece **W** is referenced to. In order to ensure that the workpiece **W** is always in contact with the fixed stoppers **142**, two spring-loaded rollers **146** are provided on the right hand side of the input section **102** to bias the workpiece against the fixed stoppers **142**. Once the workpiece is biased against the fixed stoppers **142**, the grippers **144** are operable to grip the left hand edge of the workpiece **W** to translate the workpiece at constant speed between the input and output sections **102,104** for laser scribing of parallel lines **Lp1,Lp2,Lp3** thereon. After parallel lines **Lp1** are formed on the workpiece, front and rear isolation lines **Lf,Lr** are separately formed transversely to the parallel scribed lines **Lp1**. Strip of the isolated front electrodes are checked by a resistance tester **190** at the output section **104** to ensure that each of the strips is electrically isolated one from another. After each of the laser scribing process **P1,P2,P3** is performed, each workpiece **W** is removed from the output section **104** for cleaning or further processing.

[0022] For clarity, FIGs. 2A-2B show block diagrams of some parts of the apparatus **100** in its plan view with respect to the first laser scribing process **P1** on the front electrode. As shown in FIG. 2A, when the substrate **S**, with the top side formed with the front electrode and orientated to face the gantry **160**, is received at the input section **102** of the apparatus **100**, the input puller **132**, such as a gripper being operable to extend from a retracted position to grip the substrate **S**, engages the leading end of the substrate **S** and pulls the substrate into the input section **102** to an input stop position **133**. The input stop position **133** is defined by activation of a position sensor, such as, a photoelectric sensor. When the substrate **S** reaches the input stop position **133**, the substrate **S** is biased by the spring-loaded rollers **146** against the fixed stoppers **142**. Whilst the leading edge of the substrate **S** is at the input stop position **133**, the grip on the substrate **S** changes over from the input puller **132** to the grippers **144** on the linear drive **140**. Once the grippers **144** on the linear drive **140** are clamped on the substrate **S**, the input puller **132** releases its grip and the input puller **132** is retracted, for example, pneumatically; the corresponding

position of the linear drive **140** is denoted as a home **H** position by the servomotor **141** (not shown in the figures) associated with the linear drive **140**. Once the substrate **S** is clamped firmly by the grippers **144**, the substrate **S** is operable to translate between the input and output sections **102,104** whilst the substrate **S** is supported by the air bearings **122,124**. From the home **H** position, the grippers **144** and linear drive **140** index the substrate **S** to a process start **Ps** position. The stroke of movement of the substrate **S** is defined by the process start **Ps** position and a process end **Pe** position. The **Ps** and **Pe** positions are set/encoded in the servomotor **141**. Once a scribed line **Lp1** in each of the four bands **B1-B4** is formed on the front electrode, i.e. between the process start **Ps** position and the process end **Pe** position, the laser sources **150** are indexed at a pitch of **di**, in the negative y-direction as indicated by the coordinate system shown in FIGs. 1A and 2A, and a new scribed line **Lp1** in each of the four bands **B1-B4** is then formed parallel to the respective earlier scribed line **Lp1**. By indexing the laser sources **150** after forming a laser scribed line and repeating the process **P1**, the entire substrate **S** is scribed with lines **Lp1** disposed at a uniform pitch **di** so that the front electrode is isolated, physically and electrically, into substantively parallel strips of uniform widths.

[0023] In one embodiment, the pitch **di** is about 10 mm and the width of the **Lp1** scribed lines is about 40-50 microns. In an example, when the substrate is 635mm wide by 1.4m long, each band **B1-B4** is 150 mm wide and has 15 **Lp1** scribed lines. In another example, when the substrate is 1.1m wide by 1.4m long, each band **B1-B4** is 270 mm wide and has 27 **Lp1** scribed lines.

[0024] In one embodiment of the apparatus shown in FIGs. 2A-2B, the linear drive **140** moves the grippers **144** back to the process start **Ps** position after every laser scribing process **P1** and scribing is carried out from right to left as seen in FIG. 2A; in another embodiment, the laser scribing process **P1** starts from one end and restarts from the opposite end of the substrate, i.e. scribing is carried out in both right and left directions.

[0025] In yet another embodiment of the apparatus shown in FIGs. 1A and 2A, the left hand side stopper **142a** is made adjustable. The adjustable left hand side stopper **142a**, is driven, for example, by a motor **142b** and ballscrew **142c**; in one embodiment, the motor **142b** is a servomotor. A camera **C1** is provided near the leading edge of the substrate **S**

to monitor the left hand edge of each substrate, a pre-marked reference line or a fiducial near the left hand edge of each substrate S. Another camera C5 is provided near the adjustable left hand side stopper 142a to monitor the left hand, rear edge of the substrate S, the pre-marked reference line or a fiducials near the rear, left hand edge of the substrate S. Parallelism of the left hand edge of the substrate S, pre-marked reference line or pair of fiducials near the left hand edge of the substrate S with respect to the linear drive 140 is determined by measuring the deviation of the left hand edge/left hand reference line/pair of fiducials by means of the cameras C1, C5. If the left hand edge/reference line/pair of fiducials is not parallel to the linear drive 140, this is corrected by adjusting the position of the adjustable left hand stopper 142a with reference to the right hand stopper 142. To correct the position of the adjustable left hand stopper 142a, the motor 142b is programmed to rotate the associated ballscrew 142c an appropriate number of turns so that the edge of the substrate/pre-marked reference line/pair of fiducials on the substrate S is parallel to the linear drive 140 and thus the Lp1 lines to be scribed are parallel to the left hand edge/left hand reference line/pair of fiducials on each substrate S. Such parallelism correction may be carried out regularly. Alternatively, such parallelism determination and correction may be carried out for each batch of substrates S.

[0026] In another embodiment, the motor 142b is a stepper motor. In yet another embodiment, the motor 142b is a piezoelectric motor; the piezoelectric motor may be connected directly to the adjustable stopper 142a.

[0027] As described, the laser sources 150 are operable to index at pitch di transversely from the direction of a scribed line Lp1,Lp2 but independently of each other. In another method to scribe straight lines parallel to the edge of the substrate/pre-marked reference line/pair of fiducials on the substrate, a laser source 150 may be indexed at a predetermined rate, for example, to compensate for any error in setting the two fixed stoppers 142; such error is determined by the cameras C1,C5 and parallelism correction is carried out dynamically during the P1,P2,P3 scribing process. The laser sources 150 may be mounted on a platform, which is moveable on linear guides; this allows the laser sources 150 and associated platform to be moved out of their positions, for example, for ease of maintenance. In another embodiment, there are two or more such platforms so

that one or more laser sources **150** may be moved in different directions from the other laser sources for more ease of maintenance.

[0028] FIG. 2C shows a substrate **S** with the front electrode being divided into substantively parallel strips of uniform widths after undergoing the **P1** scribing process with the laser sources **150** irradiating laser beams of about 1064 nm wavelength. At the end of **P1** process, if grippers **144** end up at the process start **Ps** position, the linear drive **140** indexes the grippers **144** and the substrate **S** to a front isolation **Pf** position. The front isolation **Pf** position is a predetermined distance, for example 10mm, short of the process start **Ps** position. With the substrate **S** in the **Pf** position, each of the lasers sources **150** is indexed to its respective left hand travel position. The lasers sources **150** are then operated to fire the respective laser beams on the substrate whilst the laser sources **150** are indexing at a constant speed in a left to right hand direction according to the arrows shown in FIG. 2C such that a continuous isolation line **Lf** is formed near the leading edge of the substrate **S**, as shown in FIG. 2C. After the front isolation line **Lf** is formed, the linear drive **140** indexes the grippers **144** and the substrate **S** to a rear isolation **Pr** position. The rear isolation **Pr** position is a predetermined distance, for example 10mm, short of the process end **Pe** position. The laser sources **150** are then operated to fire the respective laser beams on the substrate **S** whilst the laser sources **150** are indexing in a left to right hand direction so that a continuous rear isolation line **Lr** is formed near the rear end of the substrate **S**.

[0029] Alternatively, at the end of the **P1** process, laser sources **150** remain at their respective right hand travel positions and if substrate **S** is at the front isolation **Pf** position, the laser sources **150** are fired and indexed at a constant speed in a right to left hand direction as seen in FIG. 2C. After the front isolation line **Lf** is scribed, the linear drive **140** indexes the grippers **144** to the rear isolation **Pr** position and the laser sources **150** are then fired and indexed at a constant speed from the left to right hand direction. Alternatively, the laser sources **150** are moved back to the respective home positions and they are indexed in a left to right hand direction when scribing the **Lf** and **Lr** isolation lines.

[0030] FIG. 3A shows a laser scribing apparatus **100a** according to another embodiment of the present invention. FIG. 3B shows an end view of the apparatus **100a**. As shown in FIGs. 3A and 3B, the laser scribing apparatus **100a** is similar to the first scribing apparatus **100** with rear, adjustable stopper **142a** except that the laser scribing apparatus **100a** has additional cameras **C1-C4** mounted on the gantry **160**. The cameras **C1-C4** are associated with the four respective laser sources **150**. The laser scribing apparatus **100a** may be suitable for the **P2** and **P3** scribing processes and is advantageous if parallelism of to-be-scribed lines need to be monitored and corrected with reference to a previously scribed line. For example, after the front electrodes are divided into parallel strips and the PN junction/semiconductor layer is formed over the strips of front electrodes, the partially processed workpiece **W** is transferred onto the input section **102** of apparatus **100a**. The input puller **132** then pulls the workpiece **W** to the input stop **133** position and the spring-loaded rollers **146** then push the workpiece **W** against the left hand side stoppers **142,142a**. When the leading edge of the workpiece is at the input stop position **133**, the grip on the workpiece changes over from the input puller **132** to the grippers **144**. Once the grippers **144** on the linear drive **140** are clamped on the workpiece **W**, the input puller **132** releases its grip and the input puller **132** is retracted. Parallelism setting is first conducted to align the scribed lines **Lp1** previously formed on the front electrode with the linear drive **140**. In the parallelism setting, the grippers **144** translate the workpiece **W** along the linear drive **140** and the cameras **C1** and **C5** determines the amount and side of deviations, if any, of the scribed line **Lp1** at the leading edge of the workpiece from the rear edge. Once the deviation is determined, the workpiece **W** is translated to the process start **Ps** position and the position of the rear, adjustable stopper **142a** is corrected to ensure parallelism of the scribed lines **Lp1** with the linear drive **140** before the **P2** scribing of the PN junction/semiconductor layer is carried out. Similarly, a parallelism setting is conducted to align the scribed lines **Lp2** with the linear drive **140** before the **P3** scribing process is started. By carrying out these parallelism settings, parallelism of the to-be-scribed lines **Lp2,Lp3** with the relevant previously scribed lines **Lp1,Lp2** is substantively certain. After the parallelism settings, the positions of the laser sources **150** with respect to the previously scribed lines are also corrected, when necessary, by offsetting the relevant laser sources **150** with the respective deviations obtained from the cameras **C1-C4** so that the desired pitch **di** is maintained.

[0031] Alternative to the above parallelism determination and correction, a dummy substrate or workpiece is used for manual calibration of the scribed lines **Lp1,Lp2**. The dummy substrate is transferred onto the input section **102,102a**. The left hand edge of the dummy substrate is then clamped by the grippers **144** and moved to the process start **Ps** position. All the four laser sources **150** are fired while the linear drive **140** translates the dummy plate to the process end **Pe** position. The four scribed lines **Lp1,Lp2** are then measured for parallelism with the left hand edge/left hand reference line/pair of fiducials and the pitch is determined. To correct parallelism with the linear drive **140**, the position of the adjustable stopper **142a** is adjusted by rotating the servomotor **142b** by an appropriate number of turns. Similarly, the positions of each laser source **150** is adjusted to correct any errors in the line pitch **di**. Such manual calibration may be carried out for each batch of solar cell panels.

[0032] In yet another embodiment, automatic line pitch determination and correction is provided. For automatic line pitch determination and correction, each of the cameras **C1-C4** is mounted on individual motorized y-axis. For initial setting of the cameras **C1-C5** so that a workpiece is parallel to the linear drive **140** and the cameras **C1-C5** are in their respective positions, a precision jig plate is used. On the precision jig plate, there is a line in each of the four bands **B1-B4** that correspond to each of the laser sources **150** and cameras **C1-C4**. The four lines are substantively parallel to each other and with the left hand edge/reference line/pair of fiducials. During calibration, a camera **C1-C4** captures an image of an associated scribed line **Lp1,Lp2** and travels to capture an image of an adjacent scribed line to determine the line pitch **di**. If there is an error in the line pitch **di**, the position of the motor connected to the relevant camera is corrected by rotating it an appropriate number of turn.

[0033] FIG. 4A shows block diagrams of some of the parts of the apparatus **100a** in its plan view. FIG. 4B shows alignment of the laser sources **150** with the respective scribed lines **Lp1** on the front electrode, whilst FIG. 4C shows the **P2** scribing of the semiconductor layer by the laser beams going through the substrate **S** and front electrode with the respective laser sources **150** being offset **doff** from the **Lp1** scribed lines. In one embodiment, the offset **doff** is about 100 microns when the **P2** scribed lines are about 60-80 microns wide. During the **P2** scribing process, the laser beams are modulated to

shorter wavelengths, for example from about 500 to about 600 nm, so that the laser beams pass through both the substrate and front electrodes but are absorbed by the semiconductor layer. As a result of absorption of the laser energy by the semiconductor layer, the semiconductor layer is ablated and **Lp2** scribed lines are formed, thereby dividing the semiconductor layer into strips of uniform widths parallel to the strips of the front electrodes.

[0034] In addition or alternative to the above calibration at the start of each scribing process **P2,P3**, calibration of a new scribe line against a previously scribed line is carried out dynamically during the relevant scribing process.

[0035] The apparatus **100a** is also used to scribe lines **Lp3** on the rear electrode with reference to the scribed lines **Lp2** on the PN junction/semiconductor layer. In this process **P3**, scribing of the rear electrode is by firing laser beams through the substrate **S** and front electrode such that the laser beam is absorbed by the semiconductor layer. Due to the explosive ablation of the semiconductor layer, both the semiconductor layer and rear electrode are ablated, thereby forming a scribed line **Lp3**. Operation of the scribed lines **Lp3** on the rear electrode with reference to the scribed lines **Lp2** on the PN junction/semiconductor layer is similar to the above description for **P2** scribing the semiconductor layer and therefore no further description is provided. In one embodiment, the **Lp3** scribed lines are offset **d_{off}** about 100 microns from the **Lp2** lines when the width of the **Lp3** lines are about 60-80 microns. FIG. 5A shows alignment of the laser sources **150** with respect to the scribed lines **Lp2** on the semiconductor layer, whilst FIG. 5B shows the scribing **P3** of the rear electrodes by laser beams going through the substrate **S** and front electrode and ablating both the semiconductor layer and rear electrode.

[0036] In the above laser scribing **P2,P3** of the semiconductor layer and semiconductor layer/rear electrodes, after the first scribed line **Lp2,Lp3** is formed in each of the four bands **B1-B4**, the linear drive **140** and grippers **144** moves the partially processed workpiece to the start process **Ps** position and laser scribing **P2,P3** is carried out from right to left as seen in FIG. 4A. In another embodiment, the laser scribing process **P2,P3** is carried out in both right and left directions. After an entire workpiece is processed, the

workpiece W is translated into the output section **104** for removal from the apparatus **100a**.

[0037] FIG. 6A illustrates the process flow 200 of apparatus 100 according to another embodiment of the present invention. As shown in FIG. 6A, the process flow 200 starts at step 201. In the next step 202, the apparatus 100 requests a workpiece. In step 204, an input conveyor (connected to the input section 102 of apparatus 100) responds by feeding the workpiece into the input section 102. The input puller 132 then grips the workpiece and pulls it to the input stop position 133, in step 206. The input puller gripper 132 releases its grip and retracts, and at the same time, in step 208, the spring loaded rollers 146 are activated to bias the workpiece against the stoppers 142, 142a. Next, in step 209, the grippers 144 on the linear drive 140 grip the workpiece. The cameras C1, C5 are then activated, in step 210, to capture any parallelism deviation of the workpiece with the linear drive. If parallelism correction is required, the grippers 144 are then released whilst the motor 142b adjusts the adjustable stopper 142a. The grippers 144 are activated again and the cameras C1, C5 again capture any parallelism deviation of the workpiece with the linear drive; such parallelism deviation and correction may be repeated, in step 210, until the workpiece is aligned with the linear drive 140. Once the workpiece is aligned with the linear drive 140, the grippers 144 on the linear drive 140 then grip the aligned workpiece. Next, in step 217, the spring loaded rollers 146 retract, and in step 218, the linear drive indexes from its home position to the process start Ps position.

[0038] At the process start position, the laser sources 150 are activated to fire the respective laser beams on the workpiece; at the same time, the linear drive 140 is activated to move at a constant speed, in step 220. In step 222, the linear drive reaches the process end Pe position and the laser sources are deactivated. In the next step at 224, the laser sources 150 are indexed to the next pitch by a distance of d_i . In the following step at 226, the laser sources are reactivated whilst the linear drive 140 indexes the workpiece back at a constant speed to the process start Ps position to scribe another Lp1 line parallel to the earlier one. The scribing process P1 is repeated in step 230 until the entire workpiece is scribed with uniform and parallel lines Lp1. Following process P1, the linear drive 140 indexes, in step 232, the workpiece to the front isolation Pf position. At the Pf position, the laser sources are activated whilst the laser sources are respectively

indexed at a constant speed in the negative y-direction to scribe the front isolation line Lf. Next, in step 240, the linear drive indexes the workpiece to the rear isolation Pr position and the laser sources are activated to scribe the rear isolation line Lr. Following these steps, the P1 laser scribing process is completed in step 245. In the next step at 250, the linear drive indexes the workpiece into the output section 104 and the gang resistance tester 190 is activated in step 252. A decision in step 260 is then made whether the strips of the front electrodes divided after process P1 are electrically isolated one from another. If the decision is negative, an alarm is activated in step 262 before the linear drive moves the workpiece to its output position in step 264. If the decision in step 260 is positive, the workpiece is move, in step 264, to its output position.

[0039] Once the workpiece is at the output position, the output pusher 134 is activated in step 270 to grip the workpiece and the grippers 144 release their grip in step 272. At the same time, a decision in step 274 is made whether the offload conveyor (not shown in the figures) connected to the output section 104 is available. If the decision in step 274 is negative, the process 200 waits for the offload conveyor to be available. If the decision in step 274 is positive, the output pusher 134 pushes the process workpiece onto the offload conveyor and repeats, in step 285, the process 200 on another workpiece. Before a new workpiece is processed, the linear drive 140 indexes the grippers 144 to their home positions in the input section, in step 280. Once all the workpieces are scribed with Lp1 lines on the front electrode, the process ends at step 290.

[0040] FIG. 6B illustrates the process flow 200a of apparatus 100a according to yet another embodiment of the present invention. The process flow 200a is similar to that of process 200 except the cameras C1-C4 perform additional line alignment process and there is no gang resistance test. For purposes of description, similar process steps are identified by similar reference numerals and only the different steps in FIG. 6B are described. As shown in FIG. 6B, in step 210a, the cameras C1-C5 are activated to capture any parallelism deviation of the workpiece with the linear drive 140. Once workpiece parallelism deviation and correction are made, the grippers 144 grip the workpiece. A decision is then made in step 211 whether the laser sources 150 are aligned with a previously scribed line. If the decision is negative, the motor 150a connected to each laser source 150 corrects line alignment with a previously scribed line P1,P2 and

the motor 150a then offsets doff the respective laser source from the relevant previously P1,P2 scribed line. Once this line alignment correction and laser offset are carried out, spring loaded rollers 146 retract and process 200a continues. In step 230a, scribing of all the P2 and/or P3 lines are repeated, and the process 200a is repeated in step 285a until all the workpieces are laser scribed before the process 200a ends in step 290a.

[0041] 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, a leadscrew may be used instead of a ballscrew, a stepper motor may be used instead of a servomotor, and a linear motor may be used instead of a linear drive. In addition, the laser sources may produce laser beams that are longitudinal with respect to the long dimensions of the laser sources and mirrors are used to bend the laser beams upwardly through the space between the input and output sections. Although four laser sources 150 have been described, it is not so limited; two or more laser sources may be employed in order to achieve a reasonable throughput. In addition, the apparatus 100,100a is described for handling 635 mm x 1400 mm panels; to handle larger panels such as 1100mm x 1400mm panels or bigger panels, more than two rows of air bearings in each of the input and output sections would be required and the width and/or length of the machine is/are changed accordingly; in addition, another linear drive acting as a slave is provided parallel to the linear drive 140. The slave linear drive also has grippers to ensure that the workpieces do not shift during the laser scribing process.

CLAIMS:

1. A laser scribing system for manufacture of thin-film solar panel, said system comprising:

an input section;

an output section;

a processing section between the input and output sections;

grippers associated with a linear drive operable to grip on a workpiece, wherein the linear drive is operable to translate the workpiece between the input and output sections; and

two or more laser sources disposed in a lower part of the processing section such that each laser source is operable to fire a laser beam upwardly through a transparent substrate of the workpiece to scribe the relevant layer of the thin-film solar panel as the workpiece is being translated between the input and output sections, with each laser source being independently operable to index at predetermined pitches after each scribed line is formed so that the relevant thin-film layer is divided into substantively parallel strips, which are electrically isolated one from another,

wherein each laser source is mounted on an independently motorized axes, which allows scribed lines to be calibrated accordingly.

2. A laser scribing system according to claim 1, wherein each laser source is independently indexable by separate ballscrew and associated motor.

3. A laser scribing system according to claim 1 or 2, wherein the input section further comprising:

an input puller and an associated input stop sensor; and

a front stopper and rear stopper, in respect of translation of the workpiece, being associated with the linear drive, and a spring loaded roller operable to bias the workpiece against the front and rear stoppers such that scribed lines formed on the workpiece are parallel to the edge of the workpiece that is in contact with the front and rear stoppers.

4. A laser scribing system according to claim 3, wherein the rear stopper is adjustable through a ballscrew and an associated motor.

5. A laser scribing system according to claim 4, further comprising a camera to monitor the position of the rear stopper.
6. A laser scribing system according to any one of the preceding claims, further comprising a gantry disposed across both the linear drive and workpiece such that the gantry is substantially above the processing section.
7. A laser scribing system according to claim 6, wherein the gantry further comprising a camera and a suction nozzle associated with each laser source.
8. A laser scribing system according to any one of claims 5-7, wherein each camera is mounted on an independent motorized axis disposed transverse to the scribed lines.
9. A laser scribing system according to any one of the preceding claims, wherein the laser sources are mounted on linear guides such that one or more laser sources are slidable during maintenance.
10. A laser scribing process in the manufacture of thin-film solar panel, the process comprising:
 - loading a workpiece with the transparent substrate facing downwards in an input station of a first machine;
 - biasing a reference edge of the workpiece against a front and rear stopper associated with a linear drive, wherein the linear drive is operable to translate the workpiece between the input station and an output station;
 - translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a first frequency substantially vertically through a space between the input and output stations to pass through the transparent substrate of the workpiece to scribe parallel lines on the front electrodes with reference to the edge of the workpiece in contact with the front and rear stoppers, wherein each said laser beam is outputted from a separate laser source that is mounted on an independently motorized axes, which allows scribed lines to be calibrated accordingly;
 - and

indexing the two or more laser sources at predetermined pitches and repeating the back and forth translation of the work piece between the input and output stations until the entire front electrode is divided into parallel strips that are electrically isolated one from another.

11. A laser scribing process according to claim 10, further comprising:

loading the workpiece formed with parallel strips of front electrodes in an input station of a second machine;

biasing the workpiece against a front stopper and a rear adjustable stopper associated with a linear drive similar to that of the first machine, wherein the linear drive is operable to translate the workpiece between the input station and an output station;

aligning a scribed line Lp1 on the front electrode with the linear drive by using a camera disposed at the front edge of the workpiece and another camera disposed near the rear adjustable stopper to determine the correction required to achieve parallelism;

translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a second frequency substantially vertically through a space between the input and output stations to pass through the transparent substrate of the workpiece to scribe parallel lines (Lp2, Lp3) on the semiconductor layer or rear electrode with reference to the scribed lines (Lp1) on the front electrode, wherein each said laser beam is outputted from a separate laser source; and

indexing the two or more laser sources and repeating the back and forth translation of the work piece between the input and output stations until the entire semiconductor layer or rear electrode is divided into parallel strips that are electrically isolated one from another.

12. A laser scribing process in the manufacture of thin-film solar panel, the process comprising:

loading a workpiece with the transparent substrate facing downwards in an input station of a machine;

biasing the workpiece against a front stopper and a rear adjustable stopper associated with a linear drive; wherein the linear drive is operable to translate the workpiece between the input station and an output station;

aligning a reference line on a reference edge of the workpiece with the linear drive by using a camera (C1-C4) disposed near the front edge of the workpiece and another camera (C5) disposed near the rear adjustable stopper to determine the correction required to achieve parallelism between the reference line and the linear drive;

translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a first frequency substantially vertically, through a space between the input and output stations, through the transparent substrate of the workpiece to scribe parallel lines on the front electrode; wherein each said laser beam is outputted from a separate laser source that is mounted on an independently motorized axes, which allows scribed lines to be calibrated accordingly;

indexing the two or more laser sources at predetermined pitches and repeating the back and forth translation of the work piece between the input and output stations until the entire front electrode is divided into parallel strips that are electrically isolated one from another;

aligning a scribed line (Lp1) on the front electrode with the linear drive by using the camera (C1-C4) disposed near the front edge of the workpiece and the another camera (C5) disposed near the rear adjustable stopper to determine the correction required to achieve parallelism;

translating the workpiece back and forth between the input station and output station and firing two or more laser beams at a second frequency substantially vertically, through a space between the input and output stations, through the transparent substrate of the workpiece to scribe parallel lines (Lp2,Lp3) on the semiconductor layer or rear electrode; wherein each said laser beam is outputted from a separate laser source; and

indexing the two or more laser sources and repeating the back and forth translation of the work piece between the input and output stations until the entire semiconductor layer or rear electrode is divided into parallel strips that are electrically isolated one from another.

13. A laser scribing process according to any one of claims 10-12, wherein parallelism alignment is carried out manually with a dummy workpiece.

14. A laser scribing process according to any one of claims 10-12, wherein the camera or cameras are mounted on independently motorized axes disposed transverse to the scribed lines and workpiece parallelism alignment is carried out automatically.
15. A laser scribing process according to claim 14, wherein workpiece parallelism alignment and laser source/camera alignment are carried out with a precision jig.