Apparatuses and methods for recovering recyclable components of photovoltaic modules

Technical Field

[0001] This disclosure generally relates to apparatuses and methods for recycling photovoltaic modules.

Background

[0002] This background description is provided for the purpose of generally presenting the context of the disclosure. Contents of this background section are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0003] Photovoltaic (PV) modules form part of solar energy harvesting systems or solar farms. Solar farms comprise a large collection of photovoltaic (PV) solar panels that absorb energy from the sun, convert it into electricity and transmit that electricity to the power grid for distribution and consumption. A PV module comprises several interconnected solar cell units. Each solar cell unit comprises solar cells and the circuitry and associated components to enable the operation of the solar cell unit. The solar cells are encapsulated between a sun-facing glass layer and a back sheet (or another glass layer). The former is known as glass-back sheet PV module, while the latter is known as glass-glass PV module. The glass layer protects the solar cells and ensures the robustness of the entire photovoltaic module while maintaining a high degree of transparency. The back sheet is often made from a plastic material that electrically isolates, protects and shields the PV cells from weather and moisture. The back sheet, solar cell and glass layer are bound together using layers of encapsulating material. The entire PV module is secured at its periphery using a frame that is often fabricated using aluminium or an aluminium alloy. The frame ensures robustness and a practical and safe coupling to the photovoltaic module. A layer of sealant may be deposited around the parts of the PV module contacting the frame as a moisture barrier. A junction box is provided for housing the electrical connections of the PV module. The junction box is often provided on a side of the PV module opposite of the side intended to be directed towards the sun.

[0004] PV modules are provided outdoors and are continuously subjected to harsh weather conditions. Over time PV modules degrade and require replacement. PV modules comprise valuable materials such as Si wafers and metals such as aluminium frames, copper cables, silver etc. Given the premise of the use of PV energy generation is to generate energy in a more sustainable manner, it is imperative that after the degradation of PV modules, valuable components from the PV modules are efficiently recovered and made available for reuse. Known PV module recycling processes suffer from poor rates of recovery of recyclable materials and the need for complex machinery requiring a significant degree of intervention and maintenance. Known PV module recycling processes may also not provide a more holistic recovery lifecycle and may only recover certain materials that are easy to recover. Improper recovery of materials from PV modules may also lead to the improper disposal of hazardous materials resulting in undesirable environmental impact.

[0005] There is a need to provide more efficient apparatuses and methods for recovering recyclable materials from PV modules or at least provide a useful alternative to any existing apparatuses and methods.

Summary

[0006] Some embodiments relate to an apparatus for recovering recyclable components of photovoltaic (PV) modules, the apparatus comprising:

a loading station;

a frame removal station;

a PV module dismantling station;

a furnace station;

a component separation station;

an etching station comprising a plurality of etching receptacles; and

one or more conveyor elements configured to convey the PV modules through the stations;

wherein the apparatus is configured to:

receive at least one PV module on one end of one of the conveyor elements;

loading one PV module onto the frame removal station by the loading station;

separate a frame from the PV module by the frame removal station to recover the frame and obtain a frameless PV module;

separate one or more parts selected from the group consisting of a junction box, a back sheet and one or more glass panels, from the frameless PV module by the PV module dismantling station to obtain an encapsulated solar cell unit;

heat the encapsulated solar cell unit in the furnace station to obtain a solar cell unit;

separate one or more remnant parts selected from the group consisting of metallic bus bars and glass cullets from the solar cell unit by the component separation station to obtain solar cells; and

perform etching of the solar cells by the etching station to obtain the Al compound, Ag, and Si wafers from the solar cells.

[0007] In some embodiments, the PV modules are selected from the group consisting of glass-back sheet PV modules, glass-glass PV modules or combinations thereof.

[0008] In some embodiments, the frame removal station comprises a frame removal tool mounted beneath a roof of the frame removal station to separate the frame from the PV module.

[0009] In some embodiments, the frame removal tool comprises a retractable holding jig to secure at least a part of the frame and apply pressure outwards with respect to a centre of the PV module onto the part of the frame for removal.

[0010] In some embodiments, the PV module is rectangular with a frame element attached on each side of the rectangular PV module; and

the frame removal tool comprises a plurality of holding jigs, each jig being positioned to secure and apply pressure outwards onto the frame element.

[0011] In some embodiments, the frame removal station comprises one or more hydraulic presses to operate the frame removal tool.

[0012] In some embodiments, the frame removal station comprises one or more holding arms and one or more guards to retain the recovered frames.

[0013] In some embodiments, the PV module dismantling station subjects the PV module to heat at a temperature in the range of 100°C to 300°C to soften an adhesive material around the junction box before removing the junction box from the PV module.

[0014] In some embodiments, the PV module dismantling station comprises a multi-axis motion system with a scraper provided at one end to separate the junction box from the frameless PV module; and

a cutting tool being configured to cut through the back sheet for the glass-back sheet PV module.

[0015] In some embodiments, the multi-axis motion system comprises a picking tool provided at another end to pick up and peel off the back sheet that has been cut through by the cutting tool.

[0016] In some embodiments, the apparatus further comprises a cutting station configured to cut the PV module into fragments after processing by the PV module dismantling station;

wherein the cutting is performed on the PV module with cracked glass panel.

[0017] In some embodiments, the furnace station comprises three zones through which the encapsulated solar cell units are propagated: a pre-heat zone, a heating zone and a cooling zone; and

wherein the temperature of the heating zone is in the range of 400°C to 800°C.

[0018] In some embodiments, the encapsulated solar cell units are subjected to heat in the heating zone for a duration of 20 min to 40 min.

[0019] In some embodiments, the component separation station comprises a vibrating sieve and an eddy current-based separator to separate the metallic bus bars, and glass cullet from the solar cell unit.

[0020] In some embodiments, the metallic bus bars comprise of copper wirings.

[0021] The etching station of some embodiments comprises:

a first etching receptacle containing a first specified etchant for removing Al back surface field (Al-BSF) layer from the solar cells to obtain Al compound;

a second etching receptacle containing a second specified etchant for removing an Ag electrode layer to obtain Ag;

a third etching receptacle containing a third specified etchant for removing an anti-reflection layer from the solar cells to obtain Si wafers from the solar cells; and

at least one rinsing receptacle to wash the solar cells before transitioning from the first etching receptacle to the second etching receptacle or before transitioning from the second etching receptacle to the third etching receptacle or after exiting the third etching receptacle.

[0022] In some embodiments, the etching station comprises a holding receptacle for receiving the solar cells before commencement of etching;

wherein a weight sensor is provided in the etching station to sense weight of the received solar cells in the holding receptacle; and

the etching process is initiated after the weight of the received solar cells in the holding receptacle reaches a predefined value.

[0023] In some embodiments, the etching station comprises at least one dryer to dry the Si wafers after etching.

[0024] In some embodiments, the etching station comprises at least one dosing tank to replenish respective etching receptacle with at least one of: the first specified etchant, the second specified etchant or the third specified etchant.

[0025] In some embodiments, the etching station further comprises recovery tanks to recover the Al compound and Ag from the first specified etchant and second specified etchant respectively.

[0026] Some embodiments relate to a method of recovering recyclable components of photovoltaic (PV) modules using an apparatus according to one of the apparatus embodiments, the method comprising:

receiving at least one PV module on one end of one of the conveyor elements;

loading one PV module onto the frame removal station by the loading station;

separating a frame from the PV module by the frame removal station to recover the frame and obtain a frameless PV module;

separating one or more parts selected from the group consisting of a junction box, a back sheet and one or more glass panels, from the frameless PV module by the PV module dismantling station to obtain an encapsulated solar cell unit;

heating the encapsulated solar cell unit in the furnace station to obtain a solar cell unit;

separating one or more remnant parts selected from the group consisting of metallic bus bars, and glass cullets from the solar cell unit by the component separation station to obtain solar cells; and

etching of the solar cells by the etching station to obtain the Al compound, Ag, and Si wafers from the solar cells.

Brief Description of the Drawings

[0027] Some embodiments of apparatuses and methods for recovering recyclable components of PV modules, in accordance with the present disclosure, will now be described, by way of non-limiting example only, with reference to the accompanying drawings in which:

[0028] Figure 1 illustrates a perspective view of an apparatus for recycling components of a PV module;

[0029] Figure 2 illustrates a flowchart of an overall method of recycling components from a glass-back sheet PV module;

[0030] Figure 3 illustrates a flowchart of a method of recycling components of a glass-back sheet PV module with an intact glass panel;

[0031] Figure 4 illustrates a flowchart of a method of recycling components of a glass-back sheet PV module with a shattered glass panel;

[0032] Figure 5 illustrates a subset of stations of the apparatus for recycling components of a PV module;

[0033] Figure 6 illustrates a cutting station of the apparatus;

[0034] Figure 7A illustrates a side cross-section view of a furnace station of the apparatus;

[0035] Figure 7B illustrates a perspective view of a furnace station of the apparatus;

[0036] Figure 8 illustrates separation stations of the apparatus;

[0037] Figure 9A illustrates a perspective view of an etching and recovery station of the apparatus;

[0038] Figure 9B illustrates another perspective view of an etching and recovery station of the apparatus;

[0039] Figure 9C illustrates a top view of an etching and recovery station of the apparatus;

[0040] Figure 10 illustrates an inside view of the etching and recovery station of the apparatus;

[0041] Figure 11 illustrates an alternative implementation of a part of a PV module dismantling station;

[0042] Figures 12 to 15 illustrate parts of a frame removal station of an apparatus.

Detailed Description

[0043] The apparatus for recovering recyclable components of photovoltaic (PV) modules comprise a frame removal station (station 2 of Figure 1), a PV module dismantling station (stations 3 and/or 4 of Figure 1), a furnace station (station 5 of Figure 1), a component separation station (stations 6 and/or 7 of Figure 1), an etching and recovery station (station 8 of Figure 1) comprising a plurality of etching receptacles, one or more conveyor elements configured to convey PV modules through the stations. The apparatus may also comprise other stations for ancillary functions such as conveying or collecting recovered materials etc. The method of recycling components from a glass-back sheet PV module is illustrated in the flowchart of Figure 2.

[0044] Broadly, the apparatus receives a PV module on one end of the conveyor elements and separates a frame of the PV module by the frame removal station to recover the PV module frame. Subsequently, the junction box, back sheet and the glass panel are separated by the PV module dismantling station. After the removal of the junction box, back sheet and glass panel, the solar cell units of the PV module are isolated. These isolated solar cell units comprise of encapsulated solar cells and associated circuitry. The solar cell units are subjected to heat in the furnace station to separate the encapsulating material from the solar cells. At the component separation station, the solar cells are separated from the solar cell units while recovering the remaining constituents of the solar cell units such as copper ribbons, etc. After the solar cells are isolated, they are subjected to etching by the etching station to obtain the Al compound, Ag and Si wafers from the solar cells.

[0045] The disclosed apparatuses and methods allow for continuous end-to-end recycling of valuable materials from silicon-based photovoltaic (PV) modules. Advantageously, some embodiments process PV modules of various sizes, configurations (e.g., glass-back sheet or glass-glass, and regardless of the number and positions of the junction boxes), and conditions (i.e., regardless of whether the glass is intact or broken). The apparatuses are designed with small footprints and operate with minimal human intervention. The embodiments are capable of processing PV modules with both intact and cracked or shattered glass panels. This ability improves the overall efficiency of recovery of materials from PV modules and makes redundant the need for recycling PV modules with and without shattered glass panels on different processing lines. Conventional PV module recycling processes often grind intact glass panels of the PV modules, resulting in greater waste and lower degree of recovery of useful material from PV modules. The embodiments also improve the purity of the recovered materials enabling a more efficient reuse of the recovered materials.

[0046] Starting from a full-sized PV module, a method of recovery of materials may comprise the following steps: (a) disassembly and reclaiming of aluminium (Al) frames, (b) removal of junction box, back sheet and encapsulating materials (i.e., ethylene-vinyl acetate (EVA)), in order to reclaim the tempered glass and copper ribbons, (c) leaching and recovery of silver (Ag) and aluminium (Al), and (d) leaching of anti-reflection layer in order to recover the substrate silicon (Si) wafers. The recycling process for PV modules allows the reusing of most of the PV module components, which are the Si wafers, Ag, copper, Al, and glass.

[0047] An apparatus for the recovery process is illustrated in Figure 1. While the apparatus can treat glass-back sheet PV modules of different conditions (i.e., intact glass or shattered glass), the method for treating these PV modules in different conditions varies as illustrated in the flow charts of Figure 3 (intended for PV modules with intact glass panels) and Figure 4 (intended for PV modules with shattered glass panels). By modifying the PV module dismantling station (station 3), this method of treating glass-back sheet PV modules (with various glass conditions) is also applicable to glass-glass PV modules.

Loading Station (Station 1)

[0048] PV modules of the same size, configuration and condition may be sorted into distinct batches. Based on Figure 5, approximately ten PV modules may be stacked one on top of another with the glass side facing down onto a trolley (500), to prepare a batch of PV modules for processing in the loading station (521). The PV modules may be transferred between the loading station (station 1, 521) and the conveyer element of the frame removal station (station 2, 522) using a suction arm (501) provided above station 1. After the suction arm moves one PV module from station 1 (521) to station 2 (522), a scissors lift (502) provided underneath the trolley of station 1 moves up to prepare the next PV module for transfer.

Frame Removal Station (Station 2)

[0049] After the PV module is deposited on the work surface of the frame removal station (station 2, 522), a scissors lift (503) provided beneath the work surface rise to bring the PV module (504) close to the holding jigs provided beneath the roof (505) of station 2 (522). The holding jigs extend outwards to dismantle the Al frames of the PV modules. The dismantled Al frames then drop onto holders attached to the sides of the scissors lift. Next, the holding jigs retract, and the scissors lift lowers back into position for the suction arm to transfer the PV module without frames to the PV module dismantling station (station 3, 523).

[0050] Based on Figure 15, the frame removal tool may comprise a retractable holding jig (1612) to secure at least a part of the frame (1610) and apply pressure outwards onto the part of the frame for removal. The arrow (1616) indicates the direction in which force is applied by the retractable holding jig (1612) with respect to the PV module (1614). In some embodiments, the PV module (1614) is rectangular with a frame element provided

on each side of the rectangular PV module. The frame removal tool may comprise a plurality of holding jigs, each jig is positioned to secure and apply pressure directed towards each frame element. The frame removal station also comprises one or more holding elements to collect separated frames. The holding element may be in the form of a rack or a collection container provided to collect the frames as they are separated from the PV module.

[0051] The frame removal station of some embodiments comprise one or more hydraulic presses to hold down or secure the PV module while the frames are removed. The hydraulic presses may be provided in a roof region of the frame removal station. By securing the PV module during frame dismantling, the hydraulic presses reduce the likelihood of movement of the PV module which may result in incomplete removal of frames, thereby improving the efficiency of the apparatuses.

[0052] In some embodiments, holding arms and clear guards may be provided on a periphery of the frame removal station to enhance collection of dismantled frames. The holding arms provide additional support along the periphery of the PV module to reduce the movement of the PV module during dismantling, while the clear guards are attached to the holding arms to securely retain the recovered frames on the holding arms. The collected frames may be deposited on a material recovery conveyer belt for subsequent recovery and transport. Figure 12 illustrates an inside roof view of the frame removal station. Figure 13 illustrates a pneumatic hydraulic cylinder (1401) provided in the frame removal station to move the holding jigs. Figure 14 illustrates the holding jigs (1501) provided in the frame removal station.

PV Module Dismantling Station (Station 3)

[0053] The PV module dismantling station (station 3) removes the junction box and back sheet from the PV module. Separation of the frame allows the recovery of the back sheet and the junction box. The embodiments implement different methods for PV modules depending on the status of the glass panel.

[0054] The surface of station 3 is heated to a temperature of about 100°C to about 300°C, about 150°C to about 300°C, about 200°C to about 300°C, about 250°C to about 300°C, about 100°C to about 150°C, about 100°C to about 200°C, about 100°C to about 250°C, about 150°C to about 200°C, about 150°C to about 250°C, or about 200°C to about 250°C, to soften the adhesive applied to the surroundings of the junction box.

Based on Figure 5, a robot arm (506) provided in station 3 (523) comprising a scrapper extension would subsequently remove the junction box and drops it into a collection box adjacent to the station. A line of wheel cutters (507) then move from one end of the panel to the other to cut through the back sheet of the PV module. The robot arm then picks up and peels off the strips of back sheet and drop them into another collection box. For PV modules with intact glass panels, after the back sheets are removed, the robot arm scrapes off the EVA-solar cell units from the glass panel and transfers the EVA-solar cell units onto a separate conveyor (508), while the whole glass panels are removed from station 3 (523) into a collection trolley (509) intended for whole glass panels.

[0055] Based on Figure 5, PV modules with shattered glass panels are transferred to the cutting station (station 4, 510) after removal of the junction boxes at station 3 (523). PV modules with intact glass panels are not processed in station 4 and proceed to station 5 after passing through station 3.

Cutting Station (Station 4)

[0056] Based on Figure 6, the conveyor (508) adjacent to the cutting station (station 4) transfers the input materials (PV modules with frame, back sheet and junction box removed) to station 4. Station 4 only processes PV modules with shattered glass panels. Based on Figures 7A and 7B, the output materials of station 4 are transferred by a conveyor element (700) to the furnace station (station 5, 701).

[0057] PV modules with intact glass panels that were removed in station 3 would by-pass station 4 to be transferred directly to the furnace station (station 5). The PV modules with shattered glass panels are cut into small square or rectangular shapes at station 4 for purpose of improving the efficiency of materials recovery at subsequent stages. After cutting, the fragments of PV panels are then transferred to station 5 via a conveyor element.

Furnace Station (Station 5)

[0058] Based on Figures 7A and 7B, the output materials (i.e., EVA-solar cell units from station 3 or small fragments of PV panels from station 4) are loaded into the trays (702) of the furnace station (station 5). Station 5 may be implemented as a conveyor-type furnace with customized trays to collect and process the materials. The furnace may comprise three zones: (i) a pre-heat zone, (ii) heating zone, and (iii) cooling zone. The

temperature of the heating zone may be approximately 600°C. In some embodiments, the temperature of the heating zone may be in the range of about 400°C to about 800°C, about 500°C to about 800°C, about 600°C to about 800°C, about 700°C to about 800°C, about 400°C to about 500°C, about 400°C to about 600°C, about 400°C to about 700°C, about 500°C to about 600°C, about 500°C to about 700°C, or about 600°C to about 700°C. The flue gas generated from the heating process is treated before being released to the environment. Heating of the solar cell units removes the EVA component from the solar cell units. The EVA-solar cell units may be subjected to heat for approximately 30 mins. In some embodiments, the EVA-solar cell units may be subjected to heat for about 20 mins to about 40 mins, about 25 mins to about 40 mins, about 30 mins to about 40 mins, about 35 mins to about 40 mins, about 20 mins to about 25 mins, about 20 mins to about 30 mins, about 20 mins to about 35 mins, about 25 mins to about 30 mins, about 25 mins to about 35 mins, or about 30 mins to about 35 mins. Subsequently, the trays comprising the heated solar cell units are moved to the cool zone. Based on Figure 8, after adequate cooling, the remnants of the solar cell units are deposited on a conveyor element (800) exiting the furnace station to carry the remnants of the solar cell units to the separation station.

Separation Station (Vibrating sieve station 6)

[0059] After removal of the EVA component from the EVA-solar cell units, the constitute components of the solar cell units are exposed and become more amenable to separation by mechanical or electrical separation processes. The output of the furnace station may comprise solar cells, copper or other metal deposits used in wiring and potentially any glass material remaining from glass panel not removed during the earlier recovery operations.

[0060] Figure 8 illustrates separation stations of the apparatus. A separation station (station 6) with a separation apparatus (801) separates the input materials (solar cells and copper ribbons) into 2 output streams. In some embodiments, the separation apparatus may be a vibrating sieve. The separation station of some embodiments may comprise a series of separation apparatuses (for example a series of sieves or vibrating sieves) arranged to perform separation at a higher separation rate. The output streams (802) may be vertically displaced from each other, and the separated materials may be collected in separate receptacles (803). In some embodiments, a receptacle collecting copper ribbons may be positioned above a receptacle collecting the solar cells. If the input

material to the separation station also comprises remnant glass material, then the solar cells and remnant glass material may be collected in a lower receptacle.

Separation Station (Eddy current separator station 7)

[0061] Based on Figure 8, an eddy current separator (804) (station 7) processes the output of station 6 wherein remnant glass material is collected with solar cells. Separation of the solar cells and remnant glass material is performed based on the different electrical conductivities of the solar cells and remnant glass material. A permanent magnet in station 7 produces a strong magnetic field which generates an eddy current in the solar cell when it passes through the magnetic field. This eddy current in the solar cell in turn generates a magnetic field that is opposite to that generated by the magnet, creating a repulsive force on the solar cell and propelling it further away from the conveyor element (805), while the remnant glass material just drops into a collection bin provided underneath station 7 once it reaches the end of the conveyor element (805). Once separated, the solar cells are transferred to the etching and recovery station (station 8) via an exiting conveyor element.

Etching and recovery station (Station 8)

[0062] Figure 9A illustrates a perspective view of an etching and recovery station of the apparatus. Figure 9B illustrates another perspective view of an etching and recovery station of the apparatus. Figure 9C illustrates a top view of an etching and recovery station of the apparatus. Figure 10 illustrates an inside region of the etching station. Based on Figures 9A and 9B, a conveyor belt between stations 7 and 8 transports the solar cells directly into an etching drum/receptacle (900), located at one end of the etching and recovery station (station 8). After the weight of the material inside the etching drum reaches a pre-determined value, the door to the etching drum closes and the etching drum is moved to an inner region of station 8. Based on Figure 10, the etching drum is placed inside a first tank (901) by a transporter arm (902) provided in station 8. The first tank (901) contains an etchant for the removal of the Al BSF layer from the solar cells. After the Al BSF layer is removed, the transporter arm (902) moves the etching drum (900) into the next tank to rinse off the Al etchant. Subsequently, the next tank contains an etchant for the removal of the Ag electrode layer from the solar cells. Similarly, after the Ag layer is removed, the etching drum (900) is moved to another rinsing tank. This is followed by the step of anti-reflection layer removal from the solar cells. Lastly, the contents of the etching drum may be dried in a dryer (903) after going through the final

rinse tank (904) to obtain Si wafers. After drying, the etching drum (900) is transported outside of station 8 for the recovered Si wafers to be removed from the etching drum (900). The sequence of the etching and recovery may be varied by alternative embodiments without departing from the spirit of the disclosure. For example, the etching of the Ag layer may be performed first followed by the anti-reflection layer and Al BSF. Alternatively, etching of the anti-reflection layer may be performed first followed by Ag layer and then the Al BSF layer. The various etching operations may be performed using suitable etchants known to the skilled person. The etchants may include acids such as nitric acid, phosphoric acid, HCl, HF, and H_2SO_4, alkai such as NaOH and KOH, commercial extractants such as LIX-84-I, and LIX 622N, and complexing agents such as cyanide, thiosulfate, hydantoin, dimethylhydantoin, niacin, ammonia, chloride, iodide, bromide, iodobromide, chlorobromide, ethylenedinitrilotetraacetic acid disodium, etc.

[0063] Based on Figure 10, a fixture (905) provided in station 8 may open the etching drum (900), before rotating the drum to pour out the recovered Si wafers into a collection tray. The transporter arm (902) may then move the empty etching drum (900) back to the front end of station 8 to repeat the etching process. In some embodiments, there may be a total of 7 tanks used for the etching process, with 3 dosing tanks (906) (for chemical replenishment) and 2 recovery tanks (907) (for the recovery process) at the back of station 8. The chemicals in the etching tanks can be used for several batches of etching before replenishment is required. Once the concentration of the Al and Ag in their respective chemical etch tanks is sufficient for recovery, they are transferred to the 2 recovery tanks at the back of station 8 for further processing.

[0064] In some embodiments, the loading suction arm of the apparatus can be replaced by conveyors to transfer PV modules between stations 1 to 4. In some embodiments, the removal of the junction box can be performed by the frame removal station (station 2) during the removal of the Al frames. In embodiments where the junction box is removed at the frame removal station, PV modules with shattered glass panels may bypass station 3 and move directly to the cutting station (station 4). The robot arm system used in the PV module dismantling station (station 3) can be replaced by an XYZ 3-axis system as illustrated in Figure 11. The junction box scraper, wheel cutter and back sheet pick-up tool may be installed on the multi-axis system and be operated in a desired sequence. In some embodiments, the multi-axis system may be a 3-axis system.

[0065] Some embodiments are directed to a method of recovering recyclable components of photovoltaic (PV) modules using the described apparatuses. The flowcharts of Figures 2, 3 and 4 illustrate at least part of the methods of some embodiments. The method may generally comprise receiving a PV module on one end of one of the conveyor elements (station 1), separating a frame of the PV module by the frame removal station to recover the frame (station 2), separating a junction box, a back sheet and glass panel of the PV module by the PV module dismantling station (station 3). This may be followed by heating the solar cell units in the furnace station (station 5), separating the solar cells from the solar cell units by the component separation station (station 6 or station 7 or both stations 6 and 7) and etching of the solar cells by the etching station (station 8) to obtain the Al compound, Ag, and Si wafers from the solar cells.

[0066] Some embodiments relate to an apparatus with a frame removal station to separate a frame from a PV module to recover the frame and obtain a frameless PV module. Such embodiments comprise a frame removal tool mounted beneath a roof of the frame removal station to separate the frame from the PV module. The frame removal tool may comprise a retractable holding jig to secure at least a part of the frame and apply pressure outwards with respect to a centre of the PV module onto the part of the frame for removal. The PV module may be rectangular with a frame element attached on each side of the rectangular PV module; and the frame removal tool may comprise a plurality of holding jigs, each jig being positioned to secure and apply pressure outwards onto the frame element.

[0067] Some embodiments relate to an apparatus with a PV module dismantling station to dismantle a frameless PV module. The PV module dismantling station may subject the PV module to heat at a temperature in the range of 100°C to 300°C to soften adhesive material around the junction box before removing the junction box from the PV module. In such embodiments, the PV module dismantling station may comprises a multi-axis motion system with a scraper provided at one end to separate the junction box from the frameless PV module; and a cutting tool being configured to cut through the back sheet for the glass-back sheet PV module. The PV module dismantling station may comprise a multi-axis motion system with a scraper provided at one end to separate the junction box from the frameless PV module; and a cutting tool being configured to cut through the back sheet for the glass-back sheet PV module. The multi-axis motion system may comprise a picking tool provided at another end to pick up and peel off the back sheet that has been cut through by the cutting tool.

[0068] Some embodiments relate to an etching station comprising a plurality of etching receptacles to perform etching of the solar cells to obtain the Al compound, Ag, and Si wafers from the solar cells. The etching station may comprise: a first etching receptacle containing a first specified etchant for removing Al back surface field (Al-BSF) layer from the solar cells; a second etching receptacle containing a second specified etchant for removing an Ag electrode layer; a third etching receptacle containing a third specified etchant for removing an anti-reflection layer from the solar cells to obtain Al compound, Ag, and Si wafers, from the solar cells; and at least one rinsing receptacle to wash the solar cells before transitioning from the first etching receptacle to the second etching receptacle or before transitioning from the second etching receptacle to the third etching receptacle or after exiting the third etching receptacle. In some embodiments, the etching station comprises a holding receptacle for receiving the solar cells before commencement of etching; wherein a weight sensor is provided in the etching station to sense a weight of the received solar cells in the holding receptacle; and the etching process is initiated after the weight of the received solar cells in the holding receptacle reaches a predefined value. In some embodiments, the etching station further comprises recovery tanks to recover the Al compound and Ag from the first specified etchant and second specified etchant respectively.

[0069] The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavor to which this specification relates.

[0070] As used herein, the term “about” typically means +/- 5% of the stated value, more typically +/- 4% of the stated value, more typically means +/- 3% of the stated value, more typically means +/- 2% of the stated value, even more typically means +/- 1% of the stated value, and even more typically +/- 0.5% of the stated value.

[0071] Throughout this specification, certain embodiments may be disclosed in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to

6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6, etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

[0072] Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

[0073] The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, feature, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Although this disclosure describes or illustrates particular embodiments as providing particular advantages, particular embodiments may provide none, some, or all of these advantages.

Claims

1. An apparatus for recovering recyclable components of photovoltaic (PV) modules, the apparatus comprising:

a loading station;

a frame removal station;

a PV module dismantling station;

a furnace station;

a component separation station;

an etching station comprising a plurality of etching receptacles; and

one or more conveyor elements configured to convey the PV modules through the stations;

wherein the apparatus is configured to:

receive at least one PV module on one end of one of the conveyor elements;

loading one PV module onto the frame removal station by the loading station;

separate a frame from the PV module by the frame removal station to recover the frame and obtain a frameless PV module;

separate one or more parts selected from the group consisting of a junction box, a back sheet and one or more glass panels, from the frameless PV module by the PV module dismantling station to obtain an encapsulated solar cell unit;

heat the encapsulated solar cell unit in the furnace station to obtain a solar cell unit;

separate one or more remnant parts selected from the group consisting of metallic bus bars and glass cullets from the solar cell unit by the component separation station to obtain solar cells; and

perform etching of the solar cells by the etching station to obtain the Al compound, Ag, and Si wafers from the solar cells.

2. The apparatus of claim 1, wherein the PV modules are selected from the group consisting of glass-back sheet PV modules, glass-glass PV modules or combinations thereof.
3. The apparatus of claim 1 or claim 2, wherein the frame removal station comprises a frame removal tool mounted beneath a roof of the frame removal station to separate the frame from the PV module.
4. The apparatus of claim 3, wherein the frame removal tool comprises a retractable holding jig to secure at least a part of the frame and apply pressure outwards with respect to a centre of the PV module onto the part of the frame for removal.
5. The apparatus of any one of claims 1 to 4, wherein the PV module is rectangular with a frame element attached on each side of the rectangular PV module; and
the frame removal tool comprises a plurality of holding jigs, each jig being positioned to secure and apply pressure outwards onto the frame element.
6. The apparatus of claim 3, wherein the frame removal station comprises one or more hydraulic presses to operate the frame removal tool.
7. The apparatus of any one of claims 1 to 6, wherein the frame removal station comprises one or more holding arms and one or more guards to retain the recovered frames.
8. The apparatus of any one of claims 1 to 7, wherein the PV module dismantling station subjects the PV module to heat at a temperature in the range of 100°C to 300°C to soften an adhesive material around the junction box before removing the junction box from the PV module.
9. The apparatus of any one of claims 1 to 8, wherein the PV module dismantling station comprises a multi-axis motion system with a scraper provided at one end to separate the junction box from the frameless PV module; and

a cutting tool being configured to cut through the back sheet for the glass-back sheet PV module.

10. The apparatus of claim 9, wherein the multi-axis motion system comprises a picking tool provided at another end to pick up and peel off the back sheet that has been cut through by the cutting tool.

11. The apparatus of any one of claims 1 to 10, wherein the apparatus further comprises a cutting station configured to cut the PV module into fragments after processing by the PV module dismantling station;

wherein the cutting is performed on the PV module with cracked glass panel.

12. The apparatus of any one of claims 1 to 11, wherein the furnace station comprises three zones through which the encapsulated solar cell units are propagated: a pre-heat zone, a heating zone and a cooling zone; and

wherein the temperature of the heating zone is in the range of 400°C to 800°C.

13. The apparatus of claim 12, wherein the encapsulated solar cell units are subjected to heat in the heating zone for a duration of 20 min to 40 min.

14. The apparatus of any one of claims 1 to 13, wherein the component separation station comprises a vibrating sieve and an eddy current-based separator to separate the metallic bus bars, and glass cullet from the solar cell unit.

15. The apparatus of claim 14, wherein the metallic bus bars comprise of copper wirings.

16. The apparatus of any one of claims 1 to 15, wherein the etching station comprises:

a first etching receptacle containing a first specified etchant for removing Al back surface field (Al-BSF) layer from the solar cells to obtain Al compound;

a second etching receptacle containing a second specified etchant for removing an Ag electrode layer to obtain Ag;

a third etching receptacle containing a third specified etchant for removing an anti-reflection layer from the solar cells to obtain Si wafers from the solar cells; and

at least one rinsing receptacle to wash the solar cells before transitioning from the first etching receptacle to the second etching receptacle or before transitioning from the second etching receptacle to the third etching receptacle or after exiting the third etching receptacle.

17. The apparatus of any one of claim 1 to 16, wherein the etching station comprises a holding receptacle for receiving the solar cells before commencement of etching;

wherein a weight sensor is provided in the etching station to sense a weight of the received solar cells in the holding receptacle; and

the etching process is initiated after the weight of the received solar cells in the holding receptacle reaches a predefined value.

18. The apparatus of any one of claims 1 to 17, wherein the etching station comprises at least one dryer to dry the Si wafers after etching.

19. The apparatus of claim 16, wherein the etching station comprises at least one dosing tank to replenish a respective etching receptacle with at least one of: the first specified etchant, the second specified etchant or the third specified etchant.

20. The apparatus of any one of claims 1 to 19, wherein the etching station further comprises recovery tanks to recover the Al compound and Ag from the first specified etchant and second specified etchant respectively.

21. A method of recovering recyclable components of photovoltaic (PV) modules using the apparatus of any one of claims 1 to 20,

the method comprising:

receiving at least one PV module on one end of one of the conveyor elements;

loading one PV module onto the frame removal station by the loading station;

separating a frame from the PV module by the frame removal station to recover the frame and obtain a frameless PV module;

separating one or more parts selected from the group consisting of a junction box, a back sheet and one or more glass panels, from the frameless PV module by the PV module dismantling station to obtain an encapsulated solar cell unit;

heating the encapsulated solar cell unit in the furnace station to obtain a solar cell unit;

separating one or more remnant parts selected from the group consisting of metallic bus bars, and glass cullets from the solar cell unit by the component separation station to obtain solar cells; and

etching of the solar cells by the etching station to obtain the Al compound, Ag, and Si wafers from the solar cells.

22. The method of claim 21, wherein the PV modules are selected from the group consisting of glass-back sheet PV modules, glass-glass PV modules or combinations thereof.