

## **METHOD AND APPARATUS FOR SEPARATING A COMPONENT FROM A THERMOSET POLYMER ADHERED TO THE COMPONENT**

### **TECHNICAL FIELD**

[0001] Various aspects of this disclosure relate to methods and apparatuses for separating components from thermoset polymer adhered to the components.

### **BACKGROUND**

[0002] A typical photovoltaic (PV) module has a technical lifetime of 20-25 years. At the end of this lifetime, the module becomes waste. With the enormous numbers of PV modules already installed, and the continued growth of the industry, effective measures need to be established to deal with the upcoming enormous volumes of waste in an environmentally responsible manner.

[0003] A typical PV module includes glass, encapsulating material, silicon solar cells, backsheet, and a frame around the outer edge. This construction provides rigidity to the PV module while protecting the cells from harsh environments. To recycle the silicon solar cell material, the encapsulant layer needs to be separated from the silicon solar cells. Currently, there's no sustainable and cost effective process for separating the encapsulant layer from the silicon solar cells.

### **SUMMARY**

[0004] Various aspects of this disclosure provide a method of separating a component from a thermoset polymer adhered to the component according to various embodiments. The method may include providing the component and the thermoset polymer adhered to the component. The method may further include providing radio frequency electromagnetic waves to induce a current in an electrically conductive surface of the component. The current may generate heat to reduce a bonding force adhering the thermoset polymer to the component so that the component is separated from the thermoset polymer.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

FIG. 1 is a schematic showing a perspective view of a completed photovoltaic (PV) module.

FIG. 2A is a schematic showing a cross sectional view of a conventional thermal treatment apparatus in the process of thermally decomposing the encapsulant layer of a photovoltaic (PV) module.

FIG. 2B is a schematic showing the remaining solar cells and the glass panel after decomposition.

FIG. 3 is a schematic illustrating a method of separating a component from a thermoset polymer adhered to the component according to various embodiments.

FIG. 4 is a schematic illustrating a radio frequency electromagnetic wave emitter according to various embodiments.

FIG. 5 is a schematic showing a perspective view of a radio frequency (RF) coil radio frequency coil (RF) coil according to various embodiments with a photovoltaic module (PV) module positioned within the radio frequency coil radio frequency coil (RF) coil.

FIG. 6A is a schematic showing a cross sectional side view of a winding radio frequency (RF) coil according to various embodiments with a photovoltaic module (PV) positioned within the radio frequency coil radio frequency coil (RF) coil.

FIG. 6B is a schematic showing a cross sectional side view of the photovoltaic module (PV) after undergoing debonding according to various embodiments.

FIG. 7 is a schematic showing a perspective view of a flat RF coil according to various embodiments.

FIG. 8A is a schematic showing a cross-sectional side view of a radio frequency (RF) electromagnetic wave emitter according to various embodiments positioned over a photovoltaic (PV) module.

FIG. 8B is a schematic showing a cross sectional side view of the photovoltaic module (PV) after undergoing debonding according to various embodiments in which an array of solar cells is separated from the cross-linked Ethyl Vinyl Acetate (EVA) layers.

FIG. 9A is a schematic showing a cross-sectional side view of a radio frequency (RF) electromagnetic wave emitter according to various embodiments positioned over a photovoltaic (PV) module.

FIG. 9B is a schematic showing a cross sectional side view of the photovoltaic module (PV) after undergoing debonding according to various embodiments in which only one solar cell is separated from the cross-linked Ethyl Vinyl Acetate (EVA) layers.

FIG. 10A a cross-sectional side view of a radio frequency (RF) electromagnetic wave emitter according to various embodiments positioned over a photovoltaic (PV) module immersed in a liquid coolant.

FIG. 10B is a schematic showing a cross sectional side view of the photovoltaic module (PV) after undergoing debonding according to various embodiments.

FIG. 11 is a flow diagram illustrating a process of recycling a photovoltaic (PV) module according to various embodiments.

### **DETAILED DESCRIPTION**

[0006] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, and logical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0007] FIG. 1 is a schematic showing a perspective view of a completed photovoltaic (PV) module 100. PV module 100 includes solar cells 104, which may be silicon solar cells. A glass panel 102 may be located over the solar cells 104 and a backsheet 106 may be located below the cells 104. A first cross-linked Ethyl Vinyl Acetate (EVA) layer 108 may be located between glass panel 102 and cells 104. A second cross-linked Ethyl Vinyl Acetate (EVA) layer 110 may be located between cells 104 and backsheet 106. The cross-linked Ethyl Vinyl Acetate (EVA) layers 108, 110 may provide encapsulation for the solar cells 104 within the PV module 100.

[0008] The encapsulating material, which provides physical isolation and protection for the solar cell assembly, is a critical component of the PV module. The encapsulant layer may

include Ethyl Vinyl Acetate (EVA). The pure EVA without crosslinking is a thermoplastic polymer. However, the low elastic property, low heat resistance and solvent resistance make pure EVA unstable and unsuitable for use as encapsulant for PV module directly.

[0009] A curing agent may therefore be added for curing (crosslinking) EVA to form a thermoset encapsulant for PV modules. The encapsulating material may further include ultraviolet light stabilizer and antioxidant. This is described in U.S. Patent No. 6,093,757, which is incorporated herein for reference in its entirety. The EVA encapsulating material may include EVA polymer (91~99%, having VA content of 25~35%), curing agent (0.05~5%), UV stabilizer (0.01~2%) and antioxidant (0.01~2%). The total percentage of the constituents adds up to 100%. The encapsulating material may be referred herein as a cross-linked EVA layer.

[0010] The encapsulation of the cells involves melting and cross-linking of the EVA encapsulant at about 140°C to about 150°C, and is a non-reversible chemical process. Accordingly, once the encapsulation of the cells is completed, it is not possible to delaminate the encapsulant by reheating the PV module to 140-150°C. In fact, the cross-linked EVA shows excellent stability. More complicated methods such as thermal treatment and chemical treatment have been explored for the removal of the encapsulant layer.

[0011] Thermal treatment requires the transfer of energy through heat conduction and convection. These cause a lot of unwanted energy loss, which lowers the energy and cost efficiencies of the process. For example, the entire photovoltaic module is exposed to high temperature in a thermal chamber. As such, much energy is lost to the redundant thermal conduction and convection processes. Also, harmful gases such as NO<sub>x</sub> are emitted. The cell may become defective due to temperatures greater than 450°C. Furthermore, the need of high temperature requires the installation of large furnaces, which may be impractical to be realized in large-scale commercialization.

[0012] FIG. 2A is a schematic showing a cross sectional view of a conventional thermal treatment apparatus 212 in the process of thermally decomposing the encapsulant layer of a photovoltaic (PV) module 200. The PV module 200 may include glass panel 202, a first cross-linked EVA layer 208, solar cells 204, a second cross-linked EVA layer 210 and backsheet 206. The PV module 200 may be arranged inside a thermal chamber 212 for thermal treatment with temperatures above 450°C in atmospheric air or inert gas. After the thermal treatment, the cross-linked EVA layers 208, 210 and backsheet 206 may be

decomposed. FIG. 2B is a schematic showing the remaining solar cells 204 and the glass panel 202 after decomposition. Typically, a PV module 200 with power of 255-300 Watts may measure have a length of 1956 mm, a width of 990 mm, and a height of 50mm. As can be seen from FIG. 2A, the thermal chamber 212 may be required to be large enough to host the whole size of the PV module 200. As such, a single furnace with thermal chamber 212 may have a length of 3000 mm, a width of 2000 mm and a height of 1000 mm. Further, the furnace may require constant temperature profiling throughout. The decomposition process in such a furnace may require an average of 120 minutes for each module. The furnaces may remain continuously powered and may be continuously purged with nitrogen or another inert gas, leading to significant operating costs. Additionally, the harmful gases produced (e.g.  $\text{NO}_x$ ) may be required to be treated before their emission into the atmosphere. Also, cell degradation may occur due to the diffusion of electrode metals at high temperatures.

[0013] On the other hand, chemical treatment involves the utilization of highly toxic chemicals (e.g. concentrated acids or organic solvents) to dissolve the cross-linked EVA layer. These chemicals are environmentally harmful and have to be carefully disposed of and may prove to be practically inhibitory to any large scale commercialization due to the unimaginable amount required as well as safety concerns. Furthermore, the efficiency of chemical treatment is low. The whole process takes more than 7 days.

[0014] The conventional processes of using thermal treatment or chemical treatment are time consuming, expensive and environmental hazardous.

[0015] Various embodiments seek to address the shortcomings of the conventional processes. Various embodiments seek to provide a sustainable and cost effective process for separating the encapsulant layer from the silicon solar cells.

[0016] Various embodiments seek to reduce the process time and costs for debonding operation. Various embodiments seek to eliminate the need for large, expensive conventional furnace in the cross-linked EVA removal or separation process. Various embodiments seek to reduce the energy and purging gas requirements for removal or separation of cross-linked EVA from solar cells. Various embodiments seek to achieve high debonding efficiency. Various embodiments seek to prevent overheating of the cross-linked EVA and solar cells. Various embodiments seek to be environmental friendly and significantly reduce toxic gas release.

[0017] Various embodiments seek to provide a method of repairing the PV modules by replacing individual Si solar cells. Various embodiments provide a highly scalable method of removing or separating cross-linked EVA from solar cells.

[0018] Induction heating is a method of raising the temperature of an electrically conductive material. The electrically conductive material may be heated by subjecting said electrically conductive material to an alternating electromagnetic field based on the discoveries of Michael Faraday in 1831. The electrical currents induced in the conductive material dissipate power in the form of heat. A water filled coil, or inductor, acts as the primary winding of a transformer and surrounds the material to be heated which acts as the secondary winding. Alternating currents flowing in the primary coil induce eddy currents in the electrically conductive material, causing it to be heated. The depth to which the eddy currents penetrate the conductive material depends on a complex relationship between the frequency of the alternating current in the inductor, the material dimensions, and the magnetic permeability and resistivity of the conductive material.

[0019] In various embodiments, a method of separating a component from a thermoset polymer adhered to the component may be provided. FIG. 3 is a schematic 300 illustrating a method of separating a component from a thermoset polymer adhered to the component according to various embodiments. The method may include, in 302, providing the component and the thermoset polymer adhered to the component. The method may further include, in 304, providing radio frequency electromagnetic waves to induce a current in an electrically conductive surface of the component. The current may generate heat to reduce a bonding force adhering the thermoset polymer to the component so that the component is separated from the thermoset polymer.

[0020] In other words, the method may include debonding a component from a thermoset polymer, which acts as an adhesive. The method may include using radio frequency waves to generate currents in the electrically conductive portions of the component. The induced heat caused by the currents may soften the thermoset, allowing the component to be debonded from the thermoset polymer.

[0021] A thermoset is a material that cures or hardens into a given shape, generally through the application of heat. Curing is an irreversible chemical reaction in which permanent connections (known as cross-links) are made between the material's molecular

chains. These cross-links give the cured polymer a three-dimensional structure, as well as a higher degree of rigidity than it possessed prior to curing.

[0022] A cured, thermoset material would not regain the processibility it had before being cured. Curing changes the material forever. Thermoset polymers outperform other materials (such as thermoplastics) in a number of areas, including mechanical properties, chemical resistance, thermal stability, and overall durability. As such, thermoset parts tend to make more effective seals.

[0023] The bonding force may be reduced by deforming the thermoset polymer. Deforming the thermoset polymer may generate one or more gaps between the thermoset polymer and the component to reduce the bonding force. In other words, the one or more gaps may be generated along an interface of the thermoset polymer and the component. Various embodiments may provide a convenient, relatively inexpensive method for separating components adhered to thermoset polymers. Further, various embodiments may not generate harmful byproducts. The gaps may include air, gases generated from the debonding/deforming process, partial vacuum, or any combination thereof.

[0024] In various embodiments, only a portion of the thermoset polymer in contact or near the metallic surface of the component may be deformed. The portion of the thermoset polymer that is deformed may be within a predetermined distance from the interface or the metallic surface. The remaining portion of the thermoset polymer may remain undeformed or unchanged. In various embodiments, the deformation of the thermoset polymer may be localized. Various embodiments may have the benefit of requiring less energy and/or reduce time for debonding.

[0025] In various embodiments, the induced current may heat up the electrically conductive surface, which may in turn heat up the thermoset polymer. In other words, heat generated by the induced current may be transferred from the conductive surface to the thermoset polymer to deform the thermoset polymer.

[0026] Various embodiments may relate to debonding one or more solar cells from a photovoltaic module. In various embodiments, the component may be a solar cell, or a solar cell array including a plurality of solar cells. In various embodiments, the thermoset polymer may be or may include cross-linked ethyl vinyl acetate (EVA). In various other embodiments, thermoset polymer may be one-part thermosetting epoxy resin, threebond UV-curing sealant 3025, or threebond thermosetting type sealant 3025B.

[0027] Various other embodiments may relate to debonding a screen display (e.g. a plasma display, a liquid crystal display (LCD) or a thin-film transistor (TFT) display) or one or more cells from the screen display from a display set. The component may be the screen display or one or more cells of the screen display. The radio frequency waves may generate a current on the electrically conductive surface, e.g. aluminum frame, of the screen display. The induced current may generate heat to reduce a bonding force adhering the thermoset polymer to the component so that the component is separated from the thermoset polymer.

[0028] The component and the thermoset polymer adhered to the component may be included in a photovoltaic (PV) module. The PV module may include cross-linked EVA adhered to a solar cell or a solar cell array. Radio frequency (RF) waves may be used to induce heat on the solar cell or solar cell array through induction heating, and the heat may subsequently deform the cross-linked EVA, enabling the solar cell or solar cell array to be separated from the cross-linked EVA easily. A solar cell may be a semiconductor-based solar cell, such as a silicon-based solar cell or a III-V semiconductor based solar cell, e.g. a GaAs-based solar cell.

[0029] The radio frequency (RF) electromagnetic waves may be of a frequency above 20 kHz. The radio frequency (RF) electromagnetic waves may be of a frequency selected from a range between about 50 kHz to about 10 MHz. In other words, an alternating electromagnetic field in the RF spectrum of above 20 kHz, e.g. between 50 kHz to 10 MHz, may be suitable. The radio frequency electromagnetic waves are provided by a radio frequency (RF) coil coupled to a radio frequency generator. The RF generator may be coupled to a power source.

[0030] In various other embodiments, the RF electromagnetic waves may be provided by electrically conductive wires in the shape of a spiral or a helix.

[0031] In various embodiments, the RF coil used as an inductor may produce very shallow eddy current depths (about 0.02 mm to about 0.2 mm) and localized heating at fast rates. The eddy current may become shallower and the heating effect may become more localized with increasing RF frequency. The RF coil may be oriented to localize an induced current at the periphery of a solar cell or a solar cell array.

[0032] In various embodiments, the method may include providing the component and the thermoset polymer adhered to the component within the frequency coil so that the frequency coil surrounds the component and the thermoset polymer. In various other embodiments, the method may include providing the radio frequency coil over or above the component and the

thermoset polymer adhered to the component. The radio frequency coil or wire may include a suitable metal such as copper.

[0033] The electrically conductive surface may be a metallic surface, such as a metallic back surface field or a metallic electrode.

[0034] The component and a further component, such as glass or a backsheet, may be held together by the thermoset polymer so that separating the component from the thermoset polymer also separates the component from the further component. The component, the further component, and the thermoset polymer adhered to the component may be included in a photovoltaic (PV) module. The PV module may include a solar cell or a solar cell array attached to a further component, such as a glass layer or a backsheet via cross-linked EVA, which acts as an adhesive joining further component to the solar cell or to the solar cell array. Deforming the cross-linked EVA between the two components may allow the two components to be separated from each other.

[0035] The method may further include providing a concentrator. The concentrator may be a magnetic flux concentrator. The method may also include directing the electromagnetic waves to the concentrator so that the concentrator focuses the electromagnetic waves to the electrically conductive surface of the component. The concentrator may include one or more selected from a group consisting of a ferrite material, a permalloy, a nickel-iron-molybdenum (NiFeMo) alloy, Supermalloy, a nickel-based alloy, an iron-based alloy, a cobalt-based alloy, and a manganese-based alloy. The concentrator may improve the process of debonding or separation by increasing the heating efficiency and providing uniform heating.

[0036] In various embodiments, the concentrator may surround the RF coil. In various embodiments, the concentrator may cover the entire or part of the RF coil. In various embodiments, the concentrator may be on or above the RF coil.

[0037] The RF coil and/or concentrator may be connected to a power source, e.g. a RF power source, or a RF generator.

[0038] In various embodiments, the component may be separated from the thermoset polymer in a suitable liquid coolant. The suitable liquid coolant may be selected from a group consisting of water, ethanol, isopropyl alcohol (IPA), tetrahydrofuran, trichloroethylene, toluene, benzene, o-dichlorobenzene, and oil. The liquid coolant may be contained in a liquid tank. The liquid tank may be a plastic liquid tank including polypropylene (PP), polyethylene

(PE), acrylonitrile butadiene styrene (ABS), polystyrene (PS), EVA or any combination thereof.

[0039] In various embodiments, an apparatus for separating a component from a thermoset polymer adhered to the component may be provided. The apparatus may be or may include a radio frequency electromagnetic wave emitter configured to generate or emit radio frequency electromagnetic waves to induce a current in an electrically conductive surface of the component. The current may generate heat to reduce a bonding force adhering the thermoset polymer to the component so that the component is separated from the thermoset polymer. In various embodiments, the apparatus may be referred to as a RF debonding apparatus.

[0040] FIG. 4 is a schematic illustrating a radio frequency electromagnetic wave emitter 414 according to various embodiments. The radio frequency electromagnetic wave emitter 414 may include a frequency generator 416. The radio frequency electromagnetic wave emitter 414 may further include a radio frequency coil (RF) coil 418 coupled to the frequency generator 416.

[0041] In various embodiments, the frequency generator 416 may be configured to generate signals of a frequency selected from a range between about 50 kHz to about 10 MHz. In various embodiments, the frequency generator 416 may be configured to generate signals of a frequency above 20 kHz.

[0042] The apparatus may further include a concentrator. The concentrator may be configured to focus the electromagnetic waves onto the electrically conductive surface of the component.

[0043] The apparatus may be constructed in a stationary assembly, which may include an RF coil for providing the induction heating effect. The components of the assembly may be mounted on a rigid tool frame to form a panel underneath which the debonding process may take place. The assembly or apparatus may further include a tank of liquid coolant. The PV module may be immersed in the liquid coolant and the tank may be arranged under the RF coil. The RF coil may be energized and may generate an electromagnetic field, which induces a current in an electrically conductive surface of a silicon solar cell. The cross-linked EVA may be deformed by the heated metallic back surface filed as well as the solar cell, which may result in highly localized gaps that may be visible within a few seconds. When the deformation temperature of the cross-linked EVA is reached, the RF coil may be turned off.

The debonded PV module may be removed from the assembly or apparatus within a few seconds. As such, the silicon solar cells may be separated from glass and EVA with relative ease.

[0044] FIG. 5 is a schematic showing a perspective view of a radio frequency (RF) coil radio frequency coil (RF) coil 518 according to various embodiments with a photovoltaic module (PV) module 500 positioned within the radio frequency coil radio frequency coil (RF) coil 518. The PV module 500 may include glass panel 502, a first cross-linked EVA layer 508, solar cells 504, a second cross-linked EVA layer 510 and backsheet 506. The RF coil 518 may include a metallic tubing, such as a copper tubing 522. The RF coil 518 may also include coupling elements, such as flare nuts 520, for coupling or connecting the RF coil 514 to output of RF generator (not shown in FIG. 5). The PV module 500 may be arranged or positioned within the RF coil 518 for debonding. The coil 518 may surround the PV module 500. The metallic tubing 522 may allow water or other coolant to flow through, which may prevent the RF coil 518 from overheating and melting.

[0045] FIG. 6A is a schematic showing a cross sectional side view of a winding radio frequency (RF) coil 618 according to various embodiments with a photovoltaic module (PV) 600 positioned within the radio frequency coil radio frequency coil (RF) coil 618. The PV module 600 may correspond to the PV module 500 shown in FIG. 5 and the RF coil 618 may correspond to the RF coil 518 shown in FIG. 5. The entire PV module 600 may be surrounded by the RF coil 618. The induction heating effect caused by the RF waves generated by the coil 618 may be used on the metallic layer coated solar cell 604. The heat generated by the current induced in the metallic layer of solar cell 604 may be conducted to the cross-linked EVA layers 608, 610 and the cross-linked EVA layers 608, 610 may reach their deforming temperature within a few seconds. Due to the short time of heating, only the surfaces of the cross-linked EVA layers 608, 610 in contact with solar cells 604 may deform, while the other opposing surfaces of the cross-linked EVA layers 608, 610 may remain unchanged (i.e. the surface of the cross-linked EVA layer 608 in contact with glass layer 602 and the surface of the cross-linked EVA layer 610 in contact with backsheet 606), resulting in highly-localized gaps visible between the solar cells 604 and cross-linked EVA layers 608, 610. The solar cells 604 may therefore debond from the cross-linked EVA layers 608, 610 for recycling. FIG. 6B is a schematic showing a cross sectional side view of the photovoltaic module (PV) 600 after undergoing debonding according to various embodiments. As shown

in FIG. 6B, the solar cells 604 may be separated from the cross-linked EVA layers 608, 610 to be reclaimed or recycled.

[0046] FIG. 7 is a schematic showing a perspective view of a flat RF coil 718 according to various embodiments. The RF coil 718 illustrated in FIG. 7 may include a single turn coil made of or including copper tubing 722. The coil 718 may further include coupling elements such as flare nuts 720 for coupling to a RF generator or an RF matching transformer. An RF matching transformer may be required for coupling to the single turn coil 718 to the RF generator (not shown in FIG. 7). In various other embodiments, a multiple turn coil may alternatively be used and may have an added advantage of not requiring the RF matching transformer. The tubing 722 may allow water or other coolant to flow, which may prevent or reduce the likelihood of the RF coil 718 from overheating and melting.

[0047] FIG. 8A is a schematic showing a cross-sectional side view of a radio frequency (RF) electromagnetic wave emitter 814 according to various embodiments positioned over a photovoltaic (PV) module 800. The radio frequency (RF) electromagnetic wave emitter 814 may include a RF coil 818. The flat RF coil 818 may be a single turn coil or a multiple turn coil, and may be placed over the PV module 800 during operation. The flat RF coil 818 may cover one entire array of solar cells 804. The RF coil may enclose an area substantially equal to or greater than the area of the array of solar cells 808. Coupling elements, such as flare nuts 820, may connect the RF coil 818 to an output of a RF generator (not shown in FIGS. 8A-B). The radio frequency (RF) electromagnetic wave emitter 814 may further include a magnetic flux concentrator 824. The concentrator 824 may be placed over the flat RF coil 818. The concentrator 824 may focus the RF waves onto the metallic layer of the solar cells 804 for uniform heating. Without the concentrator 824, the magnetic field may be more dispersed, resulting in low heating efficiency. The debonding process may be carried out one array at a time. Heat may be generated by the current induced in the metallic layer of the array of solar cells 804. The metallic layer may conduct the heat generated to the cross-linked EVA layers 808, 810 so that the cross-linked EVA layers may be able to reach deforming temperature within a few seconds. Because of the relatively short period of heating time, only portions of the cross-linked EVA layers 808, 810 in contact with and/or near the solar cells 804 may deform, while the other portions (e.g. the surface of the cross-linked EVA layer 808 in contact with glass layer 802 and the surface of the cross-linked EVA layer 810 in contact with backsheet 806) may remain unchanged or undeformed, resulting in visible, highly-

localized gaps between solar cells 804 and cross-linked EVA layers 808, 810. The array of solar cells 804 may therefore debond from the cross-linked EVA layers 808, 810 and be recycled. FIG. 8B is a schematic showing a cross sectional side view of the photovoltaic module (PV) 800 after undergoing debonding according to various embodiments in which an array of solar cells is separated from the cross-linked EVA layers 808, 810. Then the radio frequency (RF) electromagnetic wave emitter 814 may be moved to over another array of solar cells 806 until the whole PV module 800 is debonded and all the solar cells are extracted out to be reclaimed or recycled.

[0048] FIG. 9A is a schematic showing a cross-sectional side view of a radio frequency (RF) electromagnetic wave emitter 914 according to various embodiments positioned over a photovoltaic (PV) module 900. The radio frequency (RF) electromagnetic wave emitter 914 may include a RF coil 918. The flat RF coil 918 may be a single turn coil or a multiple turn coil, and may be placed over the PV module 900 during operation. The flat RF coil 918 may cover a single solar cell 904a of an array of solar cells 904. Coupling elements, such as flare nuts 920 may connect the RF 918 coil to an output of an RF generator (not shown in FIGS. 9A-B). The radio frequency (RF) electromagnetic wave emitter 914 may further include a magnetic flux concentrator 924. The concentrator 924 may be placed over the flat RF coil 918. The concentrator 924 may focus the RF waves onto the metallic layer of the solar cells 904 for uniform heating. Without the concentrator 924, the magnetic field may be more dispersed, resulting in low heating efficiency. FIG. 9B is a schematic showing a cross sectional side view of the photovoltaic module (PV) 900 after undergoing debonding according to various embodiments in which only one solar cell is separated from the cross-linked EVA layers 908, 910. As shown in FIG. 9B, only one solar cell may be separated from the cross-linked EVA layers 908, 910. The debonding process may be for repair of the PV module 900 repair extract a single faulty Si solar cell 904a. The faulty solar cell 904a may be debonded and replaced by a new solar cell. Heat may be generated by the current induced in the metallic layer of the single solar cell 904a. The heat may be conducted to the cross-linked EVA layers 908, 910 until they reach their deforming temperature within a few seconds. Due to the short duration of heating, only portions of surfaces of the cross-linked EVA layers 908, 910 in contact with and/or near solar cell 904a may deform, while the other portions of the cross-linked EVA layers 908, 910 (e.g. the surface of the cross-linked EVA layer 908 in contact with glass layer 902, the surface of the cross-linked EVA layer 910 in contact with

backsheet 906, the portions of the crosslinked EVA layers 908, 910 in contact with and/or near other solar cells of the solar cell array 904) may remain unchanged or undeformed, resulting in visible, highly-localized gaps between solar cell 904a and crosslinked EVA layers 908, 910. The single Si solar cell 904a may therefore debond from the crosslinked EVA layers 908, 910 and be replaced by new Si solar cell.

[0049] It may also be envisioned that the RF coil may be used to extract a few solar cells instead of a single solar cell 904a. The RF coil 918 may cover the few solar cells to be extracted and the portions of the crosslinked EVA layers 908, 910 near or in contact with the few solar cells may be deformed to extract the few solar cells.

[0050] FIG. 10A a cross-sectional side view of a radio frequency (RF) electromagnetic wave emitter 1014 according to various embodiments positioned over a photovoltaic (PV) module 1000 immersed in a liquid coolant 1026. The PV module 1000 may be placed in a liquid tank 1028 containing liquid coolant 1026. The radio frequency (RF) electromagnetic wave emitter 1014 may include a RF coil 1018. The flat RF coil 1018 may be a single turn coil or a multiple turn coil, and may be placed above the PV module 1000. The flat RF coil 1018 covers an array of solar cells 1004. Coupling elements, such as flare nuts 1020, may connect the RF coil 1018 to an output of a RF generator. A magnetic flux concentrator 1024 may be placed over the flat RF coil 1018. The concentrator 1024 may focus the RF waves onto the metallic layer of the solar cells for uniform heating. Without the concentrator 1024, the magnetic field may be more dispersed, resulting in low heating efficiency. The debonding process may be done one array at a time. Heat may be generated by the current induced in the metallic layer of the array of solar cells 1004. The heat may be conducted to the cross-linked EVA layers 1008, 1010 so that they reach their deforming temperature within a few seconds. Due to the short duration of heating, only the cross-linked EVA layers 1008, 1010 in contact with or near the array of solar cells 1004 may deform, while the opposing surfaces of the cross-linked EVA layers 1008, 1010 (e.g. the surface of the cross-linked EVA layer 1008 in contact with glass layer 1002 and the surface of the cross-linked EVA layer 1010 in contact with backsheet 1006) may remain unchanged or undeformed, resulting in highly-localized gaps visible between the array of solar cells 1004 and crosslinked EVA layers 1008, 1010. The liquid coolant 1026 may fill into the gaps to prevent the solar cells 1004 from rebonding with the cross-linked EVA layers 1008, 1010. The array of solar cells 1004 may therefore debond from the 1008, 1010 and be recycled. FIG. 10B is a schematic showing a cross

sectional side view of the photovoltaic module (PV) 1000 after undergoing debonding according to various embodiments. The flat RF coil 1018 may then be moved to the next array of solar cells until the whole PV module 1000 is debonded and all solar cells are recycled or reclaimed.

[0051] It may also be envisioned that the debonding may be done one solar cell at a time or a few solar cells at a time. The RF coil 1018 may cover a single solar cell or a few solar cells. The RF waves may then be concentrated on the metallic layers of the solar cell or the few solar cells to deform portions of the cross-linked EVA layers in the vicinity of the solar cell or the few solar cells.

[0052] FIG. 11 is a flow diagram 1100 illustrating a process of recycling a photovoltaic (PV) module according to various embodiments. The process may begin in step 1102 by disassembly of PV module. The junction box and aluminum frame may be reclaimed in 1104. The solar cells may be debonded from the PV module in 1106, and the silicon (Si) solar cells may be reclaimed in 1110. The glass panels and the copper (Cu) ribbons may be reclaimed in 1108. In step 1112, chemical leaching and recovery of metal from Si solar cells may be carried out. Silicon (Si), silver (Ag) and aluminum (Al) may be reclaimed in step 1114.

[0053] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

**CLAIMS**

1. A method of separating a component from a thermoset polymer adhered to the component, wherein the component is a solar cell or a solar cell array comprising a plurality of solar cells, the method including:
  - providing the component and the thermoset polymer adhered to the component;
  - providing radio frequency electromagnetic waves selected from a range between about 50 kHz to about 10 MHz to induce a current in an electrically conductive surface of the component;
  - wherein the current generates heat to reduce a bonding force adhering the thermoset polymer to the component so that the component is separated from the thermoset polymer.
2. The method according to claim 1,
  - wherein the bonding force is reduced by deforming the thermoset polymer.
3. The method according to claim 2,
  - wherein deforming the thermoset polymer generates one or more gaps between the thermoset polymer and the component to reduce the bonding force.
4. The method according to claim 1,
  - wherein the thermoset polymer comprises cross-linked ethyl vinyl acetate.
5. The method according to claim 1,
  - wherein the electrically conductive surface is a metallic surface.
6. The method according to claim 1,
  - wherein the component and a further component is held together by the thermoset polymer so that separating the component from the thermoset polymer also separates the component from the further component.

7. The method according to claim 6,  
wherein the further component is glass.
8. The method according to claim 1, further comprising:  
providing a concentrator; and  
directing the electromagnetic waves to the concentrator so that the  
concentrator focuses the electromagnetic waves to the electrically conductive  
surface of the component.
9. The method according to claim 8,  
wherein the concentrator comprises one or more selected from a group  
consisting of a ferrite material, a permalloy, a nickel-iron- molybdenum  
(NiFeMo) alloy, an iron-based alloy, a cobalt-based alloy, and a manganese-  
based alloy.
10. The method according to claim 1,  
wherein the component is separated from the thermoset polymer in a suitable  
liquid coolant.
11. The method according to claim 10,  
wherein the suitable liquid coolant is selected from a group consisting of  
water, ethanol, isopropyl alcohol (IPA), tetrahydrofuran, trichloroethylene,  
toluene, benzene, o-dichlorobenzene, and oil.
12. The method according to claim 10,  
wherein the liquid coolant is contained in a liquid tank.
13. The method according to claim 1,  
wherein the radio frequency electromagnetic waves are provided by a radio  
frequency coil coupled to a radio frequency generator.
14. The method according to claim 13, the method further comprising:

providing the component and the thermoset polymer adhered to the component within the frequency coil so that the frequency coil surrounds the component and the thermoset polymer.

15. The method according to claim 13, the method further comprising:  
providing the radio frequency coil over the component and the thermoset polymer adhered to the component.
16. The method according to claim 13,  
wherein the radio frequency coil comprises copper.
17. The method according to claim 1,  
wherein the component and the thermoset polymer adhered to the component are comprised in a photovoltaic module.