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(54) Title: SOLAR ROOF TILES AND MODULES WITH HEAT EXCHANGE

(57) Abstract: A photovoltaic tile and module with photovoltaic cell and a heat sink. The heat sink is attached on a side of the cell opposite to the light-receiving side of the photovoltaic cell and can remove heat caused by light absorbed by the photovoltaic cell but not converted to electricity as well as heat generated by electrical resistance. A photovoltaic tile or module formed of such cells can exhibit greater energy conversion efficiency as a result of the ability to dissipate the heat. The tiles can be arranged on a roof to protect the roof structure and generate electricity. Photovoltaic tiles comprising interlocking mechanical and electrical connections for ease of installation are described. The modules can be designed to place over an existing finished roof. Methods of making photovoltaic tiles and modules involve e.g., laminating a heat sink to a photovoltaic cell and/or injection molding.



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SOLAR ROOF TILES AND MODULES WITH HEAT EXCHANGE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority benefit of United States Provisional Application No.60/874,313, entitled “Modular Solar Roof Tiles And Solar Panels With Heat Exchange” filed December 11, 2006; US Application No. 11/788, 456, entitled “Modular Solar Panels With Heat Exchange” filed April 19, 2007; US Application No. 11/804,656, entitled “Solar Roof Tiles With Heat Exchange and Methods of Making Thereof” filed May 18, 2007; US Application No. 11/788,703 entitled “Modular Solar Panels With Heat Exchange and Methods of Making Thereof” filed April 19, 2007; US Application No. 11/804,695 entitled “Interlocking Solar Roof Tiles With Heat Sink Exchange” filed May 18, 2007; US Application No. 11/804,657 entitled “Solar Roof Tiles With Heat Exchange” filed May 18, 2007; US Application No. 11/804,399 entitled “Photovoltaic Roof Tiles and Methods of Making Same” filed May 18, 2007; and US Provisional Application No.60/964,301 entitled “Cost Effective Heat Exchanger For Solar Panels and Roof Tiles” filed August 9, 2007. The content of these applications is hereby incorporated by reference in its entirety as if it was put forth in full below.

BACKGROUND OF THE INVENTION

[0002] Solar energy is a renewable energy source that has gained significant worldwide popularity due to the recognized limitations of fossil fuels and safety concerns of nuclear fuels. The photovoltaic (PV) solar energy demand has grown at least 25% per annum over the past 15 years. Worldwide photovoltaic installations increased by 1460 MW (Megawatt) in 2005, up from 1,086 MW installed during the previous year (representing a 34% yearly increase) and compared to 21 MW in 1985.

[0003] Growth in the field of solar energy has focused on solar modules fixed on top of an existing roof. Rooftops provide direct exposure of solar radiation to a solar cell and structural support for photovoltaic devices. Despite increased growth, the widespread use of conventional roof-mounted solar modules has been limited by their difficulty and cost of installation, lack of aesthetic appeal, and especially their low conversion efficiency.

[0004] Many conventional roof-mounted solar modules are constructed largely of glass enclosures designed to protect the fragile silicon solar cells. These modules are complex

systems comprising separate mechanical and electrical interconnections that are then mounted into existing rooftops, requiring significant installation time and skill. Additionally, because existing modules do not provide weather protection to roof tops, homeowners are subjected to material and labor costs for both the modules and the protective roofing material to which they are mounted. Modules are also invasive in the aesthetics of homes and commercial buildings, resulting in limited use. A few manufacturers have fabricated more aesthetically pleasing and less obstructive solutions, but the systems are not price competitive largely due to installation difficulties and poor total area efficiency. Lower module efficiency levels are correlated to higher photovoltaic system costs because a greater module area is required for a given energy demand.

[0005] The efficiency of converting light into electricity for a typical crystalline-silicon roof-mounted solar cell is approximately 13%. Some systems have seen efficiency increases (up to 18-20%) by modifications such as the use of anti-reflective glass on the cell surface to decrease optical reflection, use of textured glass on the cell surface to increase light trapping, and the use of improved materials like thin film silicon or germanium alloy. Despite these improvements, solar cell conversion efficiency remains limited, in part, by high solar cell temperatures. The efficiency of a photovoltaic device decreases as the temperature increases. Part of the energy radiated onto the cell is converted to heat, which limits the electrical energy output and overall conversion efficiency of the cell. Fabrication of a system capable of removing heat from the photovoltaic cell would greatly increase total efficiency.

[0006] There is significant interest in and need for a photovoltaic tiles that addresses the above problems.

BRIEF SUMMARY OF THE INVENTION

[0007] Described herein are various solar modules and solar roof tiles that produce energy from the sun's radiation as well as various methods employed in fabrication of those solar modules and tiles. Some of the tiles have increased efficiency in converting solar energy to electricity, are aesthetically attractive, and well suited for installation on unfinished rooftops. Some tiles minimize or prevent weather from reaching the underlying materials of a rooftop and together form a finished roof of a house. Some of the tiles are configured for attachment directly to battens or purlins for ease of installation. Some solar modules are aesthetically attractive, and well suited for installation over top of conventional roofs.

[0008] In one instance, a photovoltaic module has photovoltaic cells, a frame retaining the photovoltaic cells and adapted to mount on a finished rooftop, and a heat sink to remove heat from the photovoltaic cells. The heat sink has fins positioned parallel along a heat sink base and parallel to each other. The heat sink base has a thickness of between 0.05'' and 0.5'', and the fins each have a height between 0.25'' and 7'', a center to center spacing between 0.05'' and 1'', and a width between 0.001'' and 0.25'', and the center to center spacing is sufficient to provide a channel between said fins for cooling air to enter. In another instance, the heat sink base has a thickness of between 0.1'' and 0.25'', and the fins each have a height between 0.75'' and 5'', a center to center spacing between 0.2'' and 0.5'', and a width between 0.007'' and 0.1''. In another instance, the heat sink base has a thickness of between 0.1'' and 0.2'', and the fins each have a height between 0.9'' and 2'', a center to center spacing between 0.3'' and 0.4'', and a width between 0.02'' and 0.05''.

[0009] In other instances, the photovoltaic module has a thermal interface layer between the heat sink and photovoltaic cells to improve heat dissipation. In other instances, the module has a conformal coating on the photovoltaic cells.

[0010] In other instances, the frame of the module does not extend beyond the base of the heat sink, allowing unimpeded access of ambient air to fins of the heat sink.

[0011] In other instances, the heat sink has a length, thickness, fin height, fin spacing and fin width to maintain the photovoltaic cell at a temperature below about 150°F in quiescent ambient air at a temperature of 70°F.

[0012] In other instances, the heat sink has of fins positioned substantially parallel to a long axis of the heat sink. In other instances, the fins are positioned substantially perpendicular to a long axis of the heat sink.

[0013] In other instances, the heat sink is positioned substantially parallel to a long axis of the photovoltaic module. In other instances, the heat sink is positioned substantially perpendicular to a long axis of the module. In other instances, the heat sink has a length sufficient to span greater than $\frac{3}{4}$ the width of the module. In other instances, the heat sink has a length sufficient to span greater than $\frac{3}{4}$ the length of the module.

[0014] In other instances, the heat sink is constructed of extruded aluminum. In other instances, the heat sink is constructed of black anodized aluminum. In other instances, heat sink base is constructed of a thermally conductive polymer. In other instances, the heat sink base is constructed of elastomer.

[0015] In other instances, the fins are discontinuous along a long axis of the heat sink base to form air escape and entry channels. In other instances, the channels are herringbone shape.

[0016] In one instance, a method of fabricating a photovoltaic module has the steps of: (a) placing a heat sink in a jig such that a lower surface of said heat sink is in contact with said jig and an upper surface of said heat sink is exposed; (b) placing a photovoltaic cell on the upper surface; (c) joining the photovoltaic cell and the heat sink; and (d) removing the heat sink from the jig.

[0017] In another instance, the method includes lamination to attach the heat sink. In another instance, the method includes lamination of an intervening layer between the heat sink and the photovoltaic cell. In another instance, the intervening layer is a thermally conductive polymer. In another instance, the polymer is an elastomer.

[0018] In another instance, the method includes decreasing the air pressure between the heat sink and the photovoltaic cell, preferably for between 5 to 30 minutes. In another instance, the method includes increasing the temperature between the heat sink and the photovoltaic cell, preferably to between 125 °C and 175 °C. In another instance, the method includes increasing the temperature for between 5 to 30 minutes. In another instance, the method includes increasing the pressure between the heat sink and the photovoltaic cell, preferably between 0.5 and 5 atmospheres. In another instance, the method includes increasing the pressure between the heat sink and the photovoltaic cell between 5 to 30 minutes.

[0019] In another instance, the method includes attaching a protective layer on the photovoltaic cell. In another instance, the protective layer is a conformal coating.

[0020] In one instance, the method includes attaching a frame surrounding the photovoltaic cell wherein the frame does not extend beyond said upper surface, allowing unimpeded access of ambient air to the heat sink.

[0021] In another instance the heat sink of the method is constructed of extruded aluminum. In another instance the heat sink is constructed of a conductive polymer. In another instance, the heat sink has a plurality of fins substantially parallel to each other and said jig comprises a plurality of depressions complementary to said plurality of fins.

[0022] In one instance, the photovoltaic tile has a photovoltaic cell, a housing adapted to mount on a rooftop and retain the photovoltaic cell while exposing light-receiving surfaces of the photovoltaic cell along a first surface of the housing, and a heat sink in thermal

communication with an unexposed surface of said photovoltaic cell. The heat sink has a base positioned substantially parallel to the unexposed surface, and a plurality of fins attached to said base positioned substantially parallel to each other. The base has a thickness between 0.05" and 0.5"; and the fins each independently have a height between 0.25" and 7", a center to center spacing between 0.05" and 1", a width between 0.001" and 0.25", and where the center to center spacing is sufficient to provide a channel between said fins for cooling air to enter.

[0023] In another instance, the photovoltaic tile has a thermal interface layer between the heat sink and the unexposed surface to improve heat dissipation.

[0024] In another instance, the heat sink has a length, thickness, fin height, fin spacing and fin width to maintain the photovoltaic cell at a temperature below about 150°F in ambient air at a temperature of 70°F.

[0025] In another instance, the photovoltaic tile has an overhang along said first surface of said housing substantially parallel to a ridgeline of the rooftop.

[0026] In another instance, the photovoltaic tile has an overhang along said first surface of said housing substantially perpendicular to a ridgeline of the rooftop.

[0027] In another instance, the plurality of fins is positioned in a direction substantially parallel to a ridgeline of the rooftop.

[0028] In another instance, the plurality of fins is positioned in a direction substantially perpendicular to a ridgeline of the rooftop.

[0029] In another instance, the heat sink is constructed of extruded aluminum.

[0030] In another instance, the heat sink is constructed of black anodized aluminum.

[0031] In another instance, the base is constructed of a conductive polymer. In another instance the conductive polymer is an elastomer.

[0032] In another instance, the fins are discontinuous along a long axis of said base to form air escape and entry channels. In another instance, the channels are herringbone shape.

[0033] In another instance, the base has a thickness between 0.1" and 0.25"; and the fins each independently have a height between 0.75" and 5", a center to center spacing between 0.2" and 0.5", and a width between 0.007" and 0.1". In another instance, the photovoltaic tile has a thermal interface layer between the heat sink and the unexposed surface to improve heat dissipation. In another instance, the plurality of fins is positioned in a direction substantially perpendicular to a ridgeline of the rooftop. In another instance, the heat sink is constructed of extruded aluminum.

[0034] In another instance, the photovoltaic tile has a thickness between 0.1" and 0.2"; and the fins each independently have a height between 0.9" and 2", a center to center spacing between 0.3" and 0.4", and a width between 0.02" and 0.05". In another instance, the photovoltaic tile has a thermal interface layer between the heat sink and said unexposed surface to improve heat dissipation. In another instance, the plurality of fins is positioned in a direction substantially perpendicular to a ridgeline of the rooftop. In another instance, the heat sink is constructed of extruded aluminum.

[0035] In one instance, a plurality of photovoltaic tiles includes:

a first photovoltaic tile having a photovoltaic cell, a housing adapted to mount on a rooftop and retaining the photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell along a first surface of the housing, a heat sink in thermal communication with a surface opposite said light-receiving surfaces of said photovoltaic cell, and a first electrical connector and a second electrical connector attached to the first photovoltaic tile,

a second photovoltaic tile having a photovoltaic cell, a housing adapted to mount on a rooftop and retaining the photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell along a first surface of the housing, a heat sink in thermal communication with a surface opposite said light-receiving surfaces of said photovoltaic cell, and a first electrical connector and a second electrical connector attached to the second photovoltaic tile,

where the first electrical connector of the first tile mates with the second electrical connector of the second tile, and the first electrical connector of the first tile and the second electrical connector of the second tile are, upon mating, configured to prevent the first tile from being rotated independently of the second tile.

[0036] In another instance, the first photovoltaic tile and the second photovoltaic tile are identical.

[0037] In another instance, each electrical connector is independently a male or female connector. In another instance, each electrical connector is independently a projection or socket connector.

[0038] In another instance the first electrical connector of the first tile is configured to mate with the second electrical connector of the second tile in a direction substantially parallel to a ridgeline of the rooftop.

[0039] In another instance, the first electrical connector of the first tile is configured to mate with the second electrical connector of the second tile in a direction substantially perpendicular to a ridgeline of the rooftop.

[0040] In another instance, each photovoltaic cell is a thin film photovoltaic cell.

[0041] In another instance, each photovoltaic tile has a thermal interface layer between said heat sink and said unexposed surface to improve heat dissipation.

[0042] In another instance, each heat sink is configured to maintain its corresponding photovoltaic cell at a temperature below about 150°F in ambient air at a temperature of 70°F.

[0043] In another instance, each photovoltaic tile comprises an overhang along the first surface of the housing substantially parallel to a ridgeline of the rooftop.

[0044] In another instance, each photovoltaic tile has an overhang along the first surface of the housing substantially perpendicular to a ridgeline of the rooftop.

[0045] In another instance, each heat sink has a base positioned substantially parallel to the surface opposite the light-receiving surfaces, and a plurality of fins attached to the base positioned substantially parallel to each other. In another instance, the fins are positioned in a direction substantially parallel to a ridgeline of the rooftop. In another instance, the fins are positioned in a direction substantially perpendicular to a ridgeline of the rooftop. In another instance the fins are discontinuous along a long axis of the associated base to form air escape and entry channels. In another instance, the channels are herringbone shape.

[0046] In another instance, each heat sink is constructed of metal. In another instance, the metal is extruded aluminum. In another instance, the metal is black anodized aluminum.

[0047] In another instance, each heat sink is constructed of a conductive polymer. In another instance, the conductive polymer is an elastomer.

[0048] In one instance, the photovoltaic tile has a photovoltaic cell, a housing retaining the cell and exposing light-receiving surfaces of the photovoltaic cell, and a first electrical connector and a second electrical connector attached to the photovoltaic tile. The housing is adapted to mount on a rooftop, and the housing has a thermally conductive polymer in thermal communication with an unexposed surface of said photovoltaic cell.

[0049] In another instance, the housing the photovoltaic cell has a second polymer adjoining the first polymer.

[0050] In another instance, the first electrical connector of the photovoltaic tile mates with an electrical connector of a second photovoltaic tile. The first electrical connector of the first tile and the electrical connector of the second tile are, upon mating, configured to prevent the first tile from being rotated independently of the second tile. In other instance, the first photovoltaic tile and the second photovoltaic tile are identical. In another instance, each electrical connector is independently a male or female connector. In another instance, each electrical connector is independently a projection or socket connector.

[0051] In another instance, the first electrical connector of the tile is configured to mate with the electrical connector of the adjacent tile in a direction substantially parallel to a ridgeline of the rooftop.

[0052] In another instance, the first electrical connector of the tile is configured to mate with the electrical connector of the adjacent tile in a direction substantially perpendicular to a ridgeline of the rooftop.

[0053] In another instance, the photovoltaic tile has an overhang along the first surface of the housing substantially parallel to a ridgeline of the rooftop.

[0054] In another instance, the photovoltaic tile has an overhang along the first surface of the housing substantially perpendicular to a ridgeline of the rooftop.

[0055] In another instance, the photovoltaic cell is a thin film photovoltaic cell.

[0056] In another instance, the thermally conductive polymer is shaped as a plurality of fins positioned substantially parallel to each other. In another instance, the fins are discontinuous

along a long axis of said base to form air escape and entry channels. In another instance, the channels are herringbone shape.

[0057] In another instance, the photovoltaic tile is fabricated by the method of: placing a photovoltaic cell in a mold; injecting a first polymer into the mold; and removing the polymer and the cell from the mold.

[0058] In another instance, the first polymer of the method is a thermally conductive polymer.

[0059] In another instance, the method includes injecting a second polymer into the mold.

[0060] In another instance, upon injecting the first polymer into the mold, the first polymer is in thermal communication with a surface opposite of light-receiving surfaces of the photovoltaic cell.

[0061] In another instance, the first polymer of the method forms a housing retaining the photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell, wherein the housing is adapted to mount on a rooftop.

[0062] In another instance, the second polymer of the method forms a housing retaining the photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell, wherein the housing is adapted to mount on a rooftop.

[0063] In another instance, the photovoltaic cell of the method has a metal heat sink attached to a surface opposite of light-receiving surfaces.

[0064] In another instance, the photovoltaic tile of the method has an electrical connector, wherein the electrical connector of the photovoltaic tile and an electrical connector of a second tile are, upon mating, configured to prevent the photovoltaic tile from being rotated independently of the second tile.

[0065] In another instance, sufficient heat and pressure are used when injecting the first polymer to allow intimate thermal contact between the first polymer and the photovoltaic cell.

[0066] In another instance, the method includes cooling the mold.

[0067] In one instance, a photovoltaic tile is fabricated by the method of: placing a heat sink in a jig such that a lower surface of the heat sink is in contact with the jig and an upper surface of the heat sink is exposed; placing a photovoltaic cell adjacent said upper surface;

joining the photovoltaic cell and the heat sink; removing the heat sink from the jig; and forming a housing around the photovoltaic cell.

[0068] In another instance, the step of joining the photovoltaic cell and the heat sink comprises laminating.

[0069] In another instance, the step of laminating comprises providing a thermal interface layer between said upper surface and said photovoltaic cell. In another instance, the step of laminating comprises laminating the heat sink, intervening layer, and photovoltaic cell together. In another instance, the intervening layer is a thermally conductive polymer. In another instance, the thermally conductive polymer is an elastomer.

[0070] In another instance, the step of laminating comprising decreasing ambient pressure between the upper surface and the photovoltaic cell. In another instance, the ambient pressure is decreased for between 5 to 30 minutes.

[0071] In another instance, the step of laminating comprising increasing the temperature between said upper surface and said photovoltaic cell. In another instance, the temperature is increased to between 125°C and 175°C. In another instance, the temperature is increased for between 5 to 30 minutes.

[0072] In another instance, the step of laminating comprises increasing the pressure between said upper surface and the photovoltaic cell. In another instance, the pressure is increased to between 0.5 and 5 atmospheres. In another instance, the pressure is increased for between 5 to 30 minutes.

[0073] In another instance, the heat sink is constructed of extruded aluminum.

[0074] In another instance, the heat sink is constructed of a conductive polymer.

[0075] In another instance, the method includes attaching a protective layer on the photovoltaic cell. In another instance, the protective layer is a conformal coating.

[0076] In another instance, the heat sink has fins positioned substantially parallel to each other and the jig comprises depressions complementary to the fins.

[0077] The present invention is better understood upon consideration of the detailed description below in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0078] Figure 1A is a perspective view of a photovoltaic module with multiple heat sinks.
- [0079] Figure 1B is a perspective view of a photovoltaic tile with a heat sink.
- [0080] Figure 2A is a partial cross-sectional view of a photovoltaic tile or module with a heat sink containing fins.
- [0081] Figure 2B is a partial cross-sectional view of a photovoltaic tile or module with a heat sink containing frustum cones.
- [0082] Figure 2C is a bottom view of a heat sink.
- [0083] Figure 3 is a top view of an array of overlapping tiles.
- [0084] Figure 4 is a cross-sectional view of an array of overlapping tiles on a rooftop.
- [0085] Figure 5A is a perspective view of an interlocking photovoltaic tile with a heat sink.
- [0086] Figure 5B is a partial perspective view of photovoltaic tiles with various mechanical and electrical configurations.
- [0087] Figure 5C is a side view of an additional variation of an interlocking photovoltaic tile.
- [0088] Figure 5D is a perspective view of an additional variation of an interlocking photovoltaic tile.
- [0089] Figure 6 is a top view and side view of an interlocking roof tile comprising a thin photovoltaic film.
- [0090] Figure 7 is a perspective view of interlocking shaped tiles each comprising a thin film.
- [0091] Figure 8A-1 is a cross-sectional view of an upper jig and a lower jig used to attach photovoltaic cell(s) to a heat sink for use in a tile or module.
- [0092] Figure 8A-2 is a bottom view of an upper jig.
- [0093] Figure 8B is the view shown in Figure 8A-1 with a photovoltaic cells and a heat sink.
- [0094] Figures 8C is the view shown in Figure 8B with an interface layer.

[0095] Figure 8D illustrates the apparatus shown in Figure 8C where the upper jig and lower jig are compressed.

[0096] Figure 8E shows photovoltaic cell(s) attached to a heat sink by the described process.

[0097] Figure 8F is a cross-sectional view of an upper jig and a lower jig used to attach photovoltaic cell(s) to a heat sink containing frustum cones.

[0098] Figure 8G shows photovoltaic cell(s) attached to a heat sink containing frustum cones by the described process.

[0099] Figure 9 is a flow chart of a method of installing a photovoltaic tile.

[00100] Figure 10 is a flow chart of an alternative method of installing a photovoltaic tile.

[00101] Figure 11 shows a heat sink comprising one variation of hollow frustum cones.

[00102] Figure 12 shows a heat sink comprising another variation of hollow frustum cones.

DETAILED DESCRIPTION

[00103] The following description is presented to enable a person of ordinary skill in the art to make and use the invention. Descriptions of specific materials, techniques, and applications are provided only as examples. Various modifications to the examples described herein will be readily apparent to those of ordinary skill in the art, and the general principles defined herein may be applied to other examples and applications without departing from the spirit and scope of the invention. Thus, the present invention is not intended to be limited to the examples described and shown, but is to be accorded the scope consistent with the appended claims.

[00104] Photovoltaic (PV) modules are often packaged interconnected solar cells surrounded by a frame, backing and protective covering. Modules may be relatively large in size and designed for many applications, such as installation over existing rooftops, without necessarily providing primary protection of the roof, as well as other non-rooftop applications such as trackers in fields. Photovoltaic (PV) tiles are often smaller photovoltaic devices designed to mimic and/or replace roofing tiles, providing energy conversion and environmental protection to rooftops.

[00105] Figures 1A illustrates an example of a photovoltaic (PV) module **100-M** of the present invention. The photovoltaic module **100-M** comprises a photovoltaic array of interconnected photovoltaic cells **110-M** positioned within a frame **120-M**, which may be adapted to mount the module on a finished rooftop. Each photovoltaic cell is positioned within the frame **120-M** to allow exposure of a cell's light-receiving surface to solar radiation.

[00106] Figure 1B illustrates an example of a photovoltaic (PV) tile **100** of the present invention. The photovoltaic tile **100** comprises one or more photovoltaic cells **110** positioned in a housing **120**. The housing may lie on an unfinished roof surface horizontally with respect to the length of the roof. Each photovoltaic cell is positioned within the housing **120** to allow exposure of a light-receiving surface to solar radiation. When more than one photovoltaic cell is housed in or on the tile, each cell may be electrically connected to an adjacent cell.

[00107] Each photovoltaic cell of a module or tile may be any currently used in the art or developed in the future, such as a silicon-based wafer photovoltaic cell, a thin film photovoltaic cell, or a conductive polymer that converts photons to electricity. Such cells are well-known and include wafer-based cells formed on a monocrystalline silicon, poly- or multicrystalline silicon, or ribbon silicon substrate. A thin-film photovoltaic cell may comprise amorphous silicon, poly-crystalline silicon, nano-crystalline silicon, micro-crystalline silicon, cadmium telluride, copper indium selenide/sulfide (CIS), copper indium gallium selenide (CIGS), an organic semiconductor, or a light absorbing dye.

[00108] Each photovoltaic cell may be of any shape (e.g., square, rectangular, hexagonal, octagonal, triangular, circular, or diamond) and located in or on a surface of a modules or tile. A photovoltaic cell in a module or tile is one recessed within the frame with essentially only the top surface of the cell exposed to the light source. A photovoltaic cell on a module or tile is one placed directly on top of the frame with essentially only the bottom surface not exposed to the light source.

Photovoltaic Modules and Tiles with Heat Sink

[00109] The photovoltaic module and tile (as shown in Figures 1A and 1B, respectively) may optionally comprise one or more heat sinks **130-M** and **130** in thermal communication with the unexposed surface of the photovoltaic cells **110M** and **110** to dissipate the waste heat from the cells. Figure 2A shows a detailed partial view of an attached heat sink wherein the heat sink has fins. Each heat sink may comprise a base **200** attached to the flat surface of

the unexposed surface of the solar cells and a plurality of fins **210** extending substantially perpendicular to a large surface of the base. Each fin may project from the base parallel to an adjacent fin. The base and fins may be constructed separately and later joined, or constructed as one unit from the same material source. Figure 2B shows a similar detailed partial view of an attached heat sink wherein the heat sink has frustum cones. Each heat sink may comprise a base **200** attached to the flat surface of the unexposed surface of the solar cells and a plurality of frustum cones **211** extending substantially perpendicular to a large surface of the base.

[00110] The heat sink may be in direct physical contact with the solar cells or may have one or more intervening layers. An example of an intervening layer is an intervening thermal interface layer **220**, which can be made of any material used in the art, such as thermally conductive grease or adhesive (e.g., conductive epoxy, silicone, or ceramic) or an intervening conductive polymer (such as a thermally conductive polymer available from Cool Polymers, Inc., nylon 6-6, and/or a polyphenylene sulfide, optional mixed with one or more metallic fillers). The thermal interface layer may be of any material commonly used in the art (e.g., ethyl-vinyl-acetate (EVA), polyester, Tedlar®, EPT). The thermal interface layer may be constructed of material that is both electrically isolative and thermally conductive. The thermal interface layer may be a thin layer of polymer that is not intrinsically thermally conductive but, due to its thinness, conducts heat at a sufficient rate that it is considered thermally conductive. Other layers may be present separately or in addition to an intervening thermal interface layer, such as one or more electrically insulating layers. The intervening layer may be in simultaneous contact with both the solar cell(s) and the heat sink.

[00111] The base **200** and fins **210** (or cones **211**) of each heat sink can be independently constructed of one or more thermally conductive materials, such as aluminum or aluminum alloy (e.g., 6063 aluminum alloy, 6061 aluminum alloy, and 6005 aluminum alloy), copper, graphite, or conductive polymer (such as conductive elastomer as available from, e.g., Cool Polymers, Inc.), and may be of any color, such as blue, black, gray, or brown. Dark colors may improve heat sink performance. A heat sink constructed of metal may be anodized or plated. Heat sinks may be constructed by common manufacturing techniques such as extrusion, casting, or injection molding, or may be constructed using a combination of manufacturing techniques to construct hybrid heat sinks (e.g., aluminum fins molded into a conductive polymer base).

[00112] In some instances, the efficiency of the heat sink in lowering the temperature of the photovoltaic cell(s) may depend on the thermal conductivity properties of the heat sink and

the amount of contact made between the surface of the heat sink and the photovoltaic cell(s). In other instances, the efficiency of the heat sink in lowering the temperature of the photovoltaic cell(s) may depend on the surface geometry of the heat sink and the amount of convection.

[00113] Figures 2A and 2B illustrate dimensions of a heat sink **130** attached to a photovoltaic module or photovoltaic tile. The base **200** has a thickness designated as t . The fins **210** or frustum cones **211** independently have a height designated h , a center to center spacing designated as s , and a width (in the case of fins) or inner diameter (in the case of frustum cones) designated as w . The width w of any fin may be independently less than 1 inch, or less than 0.75'', or less than 0.5'', or less than 0.3'', or less than 0.2'', or less than 0.15'', or less than 0.1'', or less than 0.05'', or less than 0.025'', or less than 0.01'', or less than 0.005'', or less than 0.0025'', or less than 0.001'', or between 0.001'' and 0.25'', or between 0.002'' and 0.1'', or between 0.005'' and 0.075'', or between 0.01'' and 0.06'', or between 0.02'' and 0.05'', or 0.02''. The height h of any fin may be independently greater than 0.1'', or greater than 0.25'', or greater than 0.5'', or greater than 0.75'', or greater than 1'', or greater than 2'', or greater than 3.5'', or between 0.25'' and 7'', or between 0.5'' and 6'', or between 0.75'' and 5'', or between 0.8'' and 2.5'', or between 0.9'' and 2'', or between 0.9'' and 1.25'', or 1''. The center to center spacing s between fins may be independently between 0.05'' and 1'', or between 0.075'' and 0.9'', or between 0.1'' and 0.8'', or between 0.2'' and 0.7'', or between 0.2'' and 0.5'', or between 0.25'' and 0.45'', or between 0.25'' and 0.4'' or between 0.3'' and 0.4'', or between 0.3'' and 0.45'', or between 0.35'' and 0.4''. The thickness t of the base of each heat sink may be independently less than 1'', or less than 0.75'' or less than 0.5'', or less than 0.4'', or less than 0.3'', or less than 0.2'', or less than 0.15'', or less than 0.1'', or less than 0.05'', or between 0.05'' and 0.5'', or between 0.075'' and 0.35'', or between 0.1'' and 0.25'', or between 0.1'' and 0.2'', or 0.1'', or 0.15'', or 0.2''. The ratio of center to center spacing (s) to the fin height (h) (i.e. s/h) may be independently 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.5, 0.6, 0.65, 0.7, or between 0.1 and 0.7, or between 0.15 and 0.5, or between 0.2 and 0.4, or between 0.2 and 0.35, or between 0.25 and 0.3. The dimensions of any fin may be identical or different from the dimensions of other fins on the same heat sink. The dimensions of any fin or base may be identical or different from the dimensions on other heat sinks. The dimensions of all heat sink bases on a tile or module may be the same. The dimensions of all heat sink fins of all heat sinks on a tile or module may be the same. The dimensions of all heat sink fins of an

individual heat sink may be the same. The height of all fins of a heat sink may be the same. The height of all fins of a heat sink may be different. The average height of all fins of a heat sink may be of any dimension described above. The average center to center spacing of all fins of a heat sink may be of any dimension described above. The average width of all fins of a heat sink may be of any dimension described above.

[00114] The dimensions of each heat sink may independently be any combination of the dimensions described above, such as w between 0.002'' and 0.1'', h between 0.75'' and 5'', s between 0.2'' and 0.5'', and t between 0.1'' and 0.25''; w between 0.001'' and 0.25'', h between 0.75'' and 5'', s between 0.2'' and 0.5'', and t between 0.1'' and 0.25''; w between 0.02'' and 0.05'', h between 0.75'' and 5'', s between 0.2'' and 0.5'', and t between 0.1'' and 0.25''; w between 0.002'' and 0.1'', h between 0.25'' and 7'', s between 0.2'' and 0.5'', and t between 0.1'' and 0.25''; w between 0.002'' and 0.1'', h between 0.9'' and 2'', s between 0.2'' and 0.5'', and t between 0.1'' and 0.25''; w between 0.002'' and 0.1'', h between 0.75'' and 5'', s between 0.05'' and 1'', and t between 0.1'' and 0.25''; w between 0.002'' and 0.1'', h between 0.75'' and 5'', s between 0.3'' and 0.4'', and t between 0.1'' and 0.25''; w between 0.002'' and 0.1'', h between 0.75'' and 5'', s between 0.2'' and 0.5'', and t between 0.05'' and 0.5''; and w between 0.002'' and 0.1'', h between 0.75'' and 5'', s between 0.2'' and 0.5'', and t between 0.1'' and 0.2''.

[00115] A heat sink may be designed such that a first volume (defined as a volume of a heat sink including its associated heat sink base) is a percentage of a second volume (defined as a volume from a top-down projected surface area of the heat sink base and a third dimension, wherein the third dimension is defined by the least squares determination from the heights of each protrusion on the heat sink base (such as cones, fins, etc.)). For example, if all protrusions of a heat sink are of equal dimensions then the first volume would be the heat sink base volume added to the product of the volume of each protrusion and the number of protrusions; and the second volume would be the top-down projected surface area of the heat sink base (e.g., width x length, if the heat sink base were rectangular) multiplied by the protrusion height (i.e. the third dimension). If the heights of protrusions within a heat sink are different, then the least squares determination of all protrusion heights would determine the third dimension used in the example above. The percent volume is the first volume divided by the second volume x 100. The percent volume may be, for example, between 10% and 50%, between 15% and 45%, between 20% and 40%, between 25% and 35%, between 20% and 30%, between 25% and 30%, between 30% and 35%, between 35% and 40%, between

40% and 45%, between 45% and 50%, between 20% and 25%, between 15% and 20%, between 10% and 15%, between 10% and 20%, between 15% and 25%, between 25% and 35%, between 30% and 40%, between 35% and 45%, between 40% and 50%, between 10% and 25%, between 15% and 30%, between 20% and 35%, between 25% and 40%, between 30% and 45%, between 35% and 50%, between 10% and 12.5%, between 12.5% and 15%, between 15% and 17.5%, between 17.5% and 20%, between 20% and 22.5%, between 22.5% and 25%, between 25% and 27.5%, between 27.5% and 30%, between 30% and 32.5%, between 32.5% and 35%, between 35% and 37.5%, between 37.5% and 40%, between 40% and 42.5%, between 42.5% and 45%, between 45% and 47.5%, or between 47.5% and 50%.

[00116] A long axis of fins may be substantially parallel or substantially perpendicular to a long axis of the base, for instance. Substantially parallel is when two referenced axes form an angle of less than 10°. Substantially perpendicular is when two referenced axes form an angle between 85° and 95°. A long axis is an axis parallel to the longest straight edge of the object referenced. A long axis is implied if no axis is referenced. The fins may run continuously along most or all of the length of the base. Fins may not all form the same angle with respect to the long axis of the heat sink (e.g., a fan orientation), so that air may pass freely through many of the channels formed by adjacent fins regardless of wind direction. Surfaces of fins may also have features such as ridges or bumps that help induce eddies in air flowing past the fins to help convection.

[00117] One or more heat sinks may, for instance, be positioned substantially parallel or substantially perpendicular to the long axis of the tile or module and may span portions of or the entire length or width of the tile or module. Likewise, multiple heat sinks may be aligned in tandem, with or without intervening space, to span the portions of or the entire length or width of the tile or module, if desired. In one variation a heat sink has sufficient length to span greater than $\frac{3}{4}$ of the length of the tile or module. In another variation a heat sink has sufficient length to span greater than $\frac{3}{4}$ of the width of the tile or module. In some variations different heat sinks on the tile will be positioned substantially perpendicular to one another. In another variation a single heat sink is oriented to cover most of the unexposed surface of the photovoltaic cell(s). The heat sink may also be located on the sides and/or top of the tile to increase convection and cooling efficiency.

[00118] A heat sink may be of various designs to provide increased heat transfer. For example, as shown in Figure 2C, fins may contain breaks in their length, such as to create channels across fins (or equivalent), to provide additional openings to the interior of the heat

sink and increased airflow to the internal fins. Channels may be of any pattern, such as general cross-cut, herringbone, or undulating. The fins may also be replaced with other heat dissipating shapes attached to the base, such as pyramids (including frustum pyramids), cylinders, square pegs, or cones (including frustum cones).

[00119] Other shapes (such as frustum cones) may be aligned in parallel rows and columns across the length and width of the heat sink, respectively; or in staggered parallel rows and columns across the length and width of the heat sink, respectively. The use of frustum cones may allow wind current from any direction to contribute to the convection of the heat sink and increase cooling of the photovoltaic tile or module. The heat dissipating shapes (such as frustum cones) may be hollow (as shown in Figs 11 and 12). Hollow heat dissipating shapes may allow efficient heat transfer of the heat sink while reducing the amount of polymer, thermally conductive polymer, and/or additive to reduce production costs. The heat dissipating shapes (such as hollow frustum cones) may be combined with one or more UV stabilizers, one or more heat stabilizers, and/or thermally conductive particles (such as metallic fillers described herein).

[00120] Figure 11 depicts one exemplary embodiment of a heat sink comprising frustum cones **11-1**. The frustum cones may have a height (h), a width (w), a wall thickness (wt), a bottom width (bw), a center to center spacing (s), and may be attached to a base **11-2** having a thickness (t). As depicted in figure 11, the frustum cones may be hollow from the bottom width of each cone to the top of each cone (and optionally hollow completely through the top of each cone) to decrease production cost. In one instance of the embodiment exemplified in figure 11, the heat sink comprises a base with a thickness (t) of about 3 mm; hollow frustum cones having a height (h) of about 18 mm to about 25 mm, a width (w) of about 2.5 mm to about 3 mm, a bottom width (bw) of about 3.8 mm to about 5 mm, a wall thickness (wt) of about 3 mm, and a center to center spacing (s) of about 6mm; and wherein the frustum cones are aligned in staggered parallel rows and columns. In some instances, the base **11-2** may have surface dimensions of about 15" by about 15". The heat sink may be made of, for example, Nylon 1020, Nylon 1040, Nylon 1240, Froton 6165A, Froton 6165D, or polyphenylene sulfide, or any other polymer described herein, and may comprise one or more UV stabilizers and/or one or more heat stabilizers. The frustum cones may comprise channels across the width of one or more cones to allow increased ambient air access. The heat sink may comprise any thermally conductive material (such as metallic fillers describe herein). In some instances, the height (h), width (w), wall thickness (wt), bottom width (bw), center to

center spacing (s), thickness (t), amount of conductive material, and/or type of polymer may be selected to maintain sufficient heat dissipation of the frustum cones relative to non-hollow frustum cones.

[00121] Figure 12 depicts another exemplary embodiment of a heat sink comprising frustum cones **12-1**. The frustum cones may have a height (h), a width (w), a bottom width (bw), a center to center spacing (s), and may be attached to a base **12-2** having a thickness (t). As depicted in figure 12, the frustum cones may be hollow from the top of each cone down through the center of each cone to decrease production cost. The hollow bore arrangement may allow increased surface area of the frustum cones to promote heat dissipation from the heat sink. The hollow bore **12-3** depicted in figure 12 may be a constant bore diameter (bd), or may be varying diameter (such as decreasing in diameter as the bore is closer to the heat sink base). In one instance of the embodiment exemplified in figure 12, the heat sink comprises a base with a thickness (t) of about 3 mm; hollow frustum cones having a height (h) of about 18 mm to about 25 mm, a width (w) of about 2.5 mm to about 3 mm, a bottom width (bw) of about 3.8 mm to about 5 mm, and a center to center spacing (s) of about 6mm; and wherein the frustum cones are aligned in staggered parallel rows and columns. In some instances, the base **12-2** may have surface dimensions of about 15" by about 15". The heat sink may be made of, for example, Nylon 1020, Nylon 1040, Nylon 1240, Froton 6165A, Froton 6165D, or polyphenylene sulfide, or any other polymer described herein, and may comprise one or more UV stabilizers and/or one or more heat stabilizers. The frustum cones may comprise channels across the width of one or more cones to allow increased ambient air access. The heat sink may comprise any thermally conductive material (such as metallic fillers describe herein). In some instances, the height (h), width (w), bore diameter (bd), bottom width (bw), center to center spacing (s), thickness (t), amount of conductive material, and/or type of polymer may be selected to maintain sufficient heat dissipation of the frustum cones relative to non-hollow frustum cones.

[00122] The heat sinks described in figures 11 and 12 may be used with any photovoltaic tile or module described herein.

[00123] The heat sink may be configured to reduce temperature of a photovoltaic cell in ambient quiescent air that is at standard temperature and pressure and an irradiance (E) by white light individually or in any combination of $800 \text{ W} \cdot \text{m}^{-2}$, $1000 \text{ W} \cdot \text{m}^{-2}$, or $1200 \text{ W} \cdot \text{m}^{-2}$ by at least 1°C ; or by at least 2°C ; or by at least 5°C ; or by at least 7°C ; or by at least 10°C ; or by at least 12°C ; or by at least 15°C ; or by at least 20°C as compared to an identical cell

lacking the heat sink. The size, number, and spacing of fins, the size of the base portion, and the materials of construction of the heat sink may be selected based on the desired decrease in temperature over the comparative PV cell.

[00124] The heat sink may be configured to maintain the photovoltaic cell at a temperature below about 175°F, or below about 160°F, or below about 150°F, or below about 140°F, or below about 130°F, or below about 120°F, or below about 110°F, or below about 100°F, or below about 90°F, or below about 80°F in ambient air at a temperature of 70°F.

[00125] The heat sink may be configured to increase the energy conversion efficiency (defined by the equation: $\eta = (P_m / (E \times A_c))$, where P_m is maximum electrical power in watts, E is the input light irradiance in $W \cdot m^{-2}$ and A_c is the surface area of the solar cell in m^2) or total-area efficiency of a photovoltaic cell (which may be defined by the relative change in current (I) and/or voltage (V) or relative change in the product of I and V) in ambient quiescent air that is at standard temperature and pressure and an irradiance (E) by white light individually or in any combination of $800 W \cdot m^{-2}$, $1000 W \cdot m^{-2}$, or $1200 W \cdot m^{-2}$ by at least 0.5%; or by at least 1%; or by at least 1.5%; or by at least 2%; or by at least 2.5%; or by at least 3%; or by at least 3.5%; or by at least 4%; or by at least 4.5%; or by at least 5%; or by at least 5.5%; or by at least 6%; or by at least 6.5%; or by at least 7%; or by at least 7.5%; or by at least 8%; or by at least 8.5%; or by at least 9%; or by at least 9.5%; or by at least 10% as compared to an identical cell lacking the heat sink.

[00126] If desired, the heat sink may be subjected to forced airflow provided by any means, e.g., one or more fans, to increase airflow over the heat sink and increase cooling effectiveness of the photovoltaic cell. A fan may deliver the forced air to the heat sink by direct exposure or remotely through a duct system.

[00127] As shown in figure 1A, a photovoltaic module may have a frame **120-M** with mounting fixtures such as screw holes, tabs, and/or electrical connections that are suitable to mount the module in framework that is attached to a finished roof-top so that heat from the solar cells may be dissipated into ambient air. The frame may surround the photovoltaic cells and, optionally, may surround additional layers that may be present adjacent to cells. It is preferable for roof-top mounting that little or none of the frame of the module blocks access to the heat sinks **130-M** so that relatively cool air may flow freely through the cooling fins. In one experiment, blocking access to the heat sink via a frame resulted in decreased photovoltaic efficiency. Figure 1A illustrates how the fins and channels there between are

free of the frame so that air may travel through the channels unimpeded by the frame (e.g., allowing horizontal access to the heat sink).

[00128] The frame may comprise a flange or lip **102-M** (straight or curved) as shown in figure 1A oriented to direct air flowing through the heat sink upward upon exiting the module. This feature may prevent hot air generated from a heat sink from entering an adjacent module. Likewise, a flange or lip may be oriented to force fresh cold air flowing above a module or adjacent module into a heat sink. A feature of this orientation may be particularly useful to permit cool air to enter the underside of a module when multiple modules are arranged with minimal intervening space. Multiple flanges and/or lips may be incorporated into a single frame to direct cool air into a heat sink and to direct hot air away from a heat sink.

[00129] Optionally, legs **140-M** may be provided to permit the module to be set upon a flat surface during handling and prior to installation, thus supporting the weight of the module **100-M** and preventing compression of the fins. Legs **140-M** may also be used to mount the module to a surface such as a rooftop. Legs may be sufficiently long that they elevate the module a sufficient distance from the surface to which they are mounted that air flows freely beneath and through channels through and past the fins to provide improved energy conversion efficiency over a similar construction in which the fins touch the surface of the roof top.

[00130] The frame **120-M** and legs **140-M** may be independently constructed of one or more materials capable of supporting the photovoltaic module, such as metal (e.g., aluminum), ceramic, cement, composite, or polymer (e.g., conductive polymer). The frame and heat sink may be constructed as one mold from a conductive polymer, if desired. The frame may have an extended configuration to cover the heat sink wherein the frame may also include a screen or perforations along the sides to allow air flow to the heat sinks.

[00131] The framework into which modules may be inserted typically has footers especially adapted to mount to common roofing materials such as composite roofing or wood battens forming part of the roof structure. Often, the framework has a height such that fins of the module's heat sink just touch or are just above the surface (e.g., rooftop) on which the framework is mounted. Alternatively, the framework may elevate the module over the rooftop a sufficient distance that air may flow sufficiently freely beneath and through the

channels between fins to provide improved efficiency over a similar construction in which the fins touch the rooftop.

[00132] A photovoltaic module may be formed in standard lengths of approximately *e.g.*, 3 feet, 4 feet, 5 feet, 6 feet, 7 feet, 8 feet, 9 feet, 10 feet, or 1 meter, 1.5 meter, 2 meter, 2.5 meter, 3 meter, 3.5 meter, or 4 meter. The photovoltaic module may be formed in standard widths of approximately *e.g.*, 1 foot, 1.5 feet, 2 feet, 2.5 feet, 3 feet, 3.5 feet, 4 feet, 4.5 feet, 5 feet, or 0.25 meter, 0.5 meter, 0.75 meter, 1 meter, 1.25 meter, 1.5 meter, 1.75 meter, or 2 meter.

[00133] Photovoltaic modules typically contain 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 20, 24, 28, 32, 36, 40, 25, 36, 45, 50, 42, 48, 54, 60, or 72 PV cells arranged in rows and columns. PV cells may be arranged, for instance, 4 x 9, 6 x 8, 6 x 9, 6 x 12, or 8 x 12. A module may, for example, have from five to ten heat sinks in instances where a single heat sink is in contact with cells across an entire row of PV cells in the module.

[00134] A typical photovoltaic module may have an overall width of between 35" and 40", an overall length of between 50" and 60", photovoltaic cells in a 6 x 9 configuration, and 9 heat sinks each spanning a column of photovoltaic cells across the width of the module. When viewing the solar-cell side of the module in which light receiving surfaces of the cells are visible ("top-down") the width of a module is the minor axis or the shortest distance between opposite walls of the frame. Columns span the module width, while rows span the module length. In another configuration, a photovoltaic module may have an overall width of between 35" and 40", an overall length of between 45" and 55", photovoltaic cells in a 6 x 8 configuration, and 8 heat sinks each spanning a column of photovoltaic cells across the width of the module. In another configuration, a photovoltaic module may have an overall width of between 20" and 30", an overall length of between 50" and 60", photovoltaic cells in a 4 x 9 configuration, and 8 heat sinks each spanning a column of photovoltaic cells across the width of the module. In another configuration, a photovoltaic module may have an overall width of between 30" and 40", an overall length of between 50" and 55", photovoltaic cells in an 8 x 12 configuration, and 12 heat sinks each spanning a column of photovoltaic cells across the width of the module. Other module configurations described within (such as heat sinks spanning the length of the module) may be applied to the examples above.

[00135] In one example, a module was constructed containing 36 photovoltaic cells in a 4 x 9 configuration of monocrystalline silicon (225 μm thickness). The cells were laminated with

glass using an SPI-laminator (Spire, Inc.) and heat sinks attached using omegabond® 101 epoxy cement. Heat sinks contained fins with the following dimensions: $w = 0.06''$, $h = 0.9375''$, $s = 0.3''$, and $t = 0.1''$. Each heat sink contained eight fins and had an overall width of 2.5". Two heat sinks were abutted such that the overall width of the joined heat sinks was 5" in order to cover the width of each photovoltaic cell.

[00136] Often anywhere from 4 to 20 modules are installed in a solar module on the roof-top of a house, depending on the amount of south-facing (in the northern hemisphere) rooftop that is available. Many more solar modules may be installed on the larger roofs of commercial buildings, for instance.

[00137] The photovoltaic modules described herein may be linked together by any method and/or using any apparatus known in the art. Photovoltaic modules may also be designed to interlock mechanically and/or electronically, as described in U.S. Provisional Application No.60/874,313, entitled "Modular Solar Roof Tiles And Solar Panels With Heat Exchange" filed December 11, 2006, which is incorporated by reference in its entirety. Modules may also be separated from one another with sufficient space to allow increased airflow between the modules to improve cooling of photovoltaic cells.

[00138] As described for modules, photovoltaic tile may comprise a flange or lip (straight or curved) on a housing oriented to direct air flowing through the heat sink underneath a tile upward upon exiting the tile. This feature may prevent hot air generated from a heat sink from entering an adjacent tile. Likewise, a flange or lip may be oriented to force fresh cold air flowing above a tile or adjacent tile into a heat sink. A feature of this orientation may be particularly useful to prevent trapping a layer of warm air underneath an array of tiles and permit cool air to enter the underside to promote efficient heat transfer. Multiple flanges and/or lips may be incorporated into a single tile to direct cool air into a heat sink and to direct hot air away from a heat sink.

[00139] Tiles and modules may be configured to provide air-flow channels that allow air to circulate via natural convection or forced convection caused by wind past heat sinks to cool photovoltaic cells. Air-flow channels of individual tiles or modules may be aligned with air flow channels of one or more adjacent tiles or modules to provide continuous air flow through the heat sinks of multiple tiles or modules. The channels may be oriented such that air may flow parallel or perpendicular to the roof line through the heat sinks of individual

tiles or continuously through the heat sinks of multiple tiles or modules. Ducts or plenums (not shown for sake of clarity) may be provided along the edges of tile or module arrays.

[00140] Tiles may be designed to partially overlay one another such that a collection of tiles protects an unfinished rooftop from weather exposure. To aid in weather protection, tiles may have one or more projections (such as **140** in figure 1B) which complement one or more depressions (such as **150** in figure 1B) in an adjacent tile. The tiles may be arranged such that a projection **140** when located on the lower end of a tile overlaps a depression **150** located on the upper end of an adjacent tile as shown in figures 3 and 4. When placed on a sloped rooftop **400** the projections may prevent rainfall from reaching the underlying roof (figure 4) and/or add structural integrity to the tile array. The tiles may have one or more overhangs (such as **180** and **190** in figures 1B and 4) which do not have corresponding depressions in adjacent tiles. These features add additional weather protection since no vertical seams are exposed to the outside surface when adjacent tiles are joined. The arrangement of overhangs and depressions may be of any combination and used e.g., on the sides of a tile, individually or in addition to the upper and lower ends, to prevent exposure of electrical connections, fasteners, and the roof surface. A sealant may be used at seams between joined tiles (e.g., those underneath a projection/overhang) to provide additional weather protection.

[00141] Mounting holes (**160** in figure 1B) may be included in the base to fasten the tiles to a rooftop (**400** of figure 4) before placement of an overlapping adjacent tile. These holes are preferably located along or near the edge opposite the photovoltaic cell such that the adjacent row of tiles may overlap the mounting holes when installed on a roof to prevent exposing fasteners to weather. The tiles may additionally or alternatively have tabs with holes attached to the base along the edge near holes **160** so that e.g., nails or screws may be inserted into them to affix the tile to portions of a roof structure such as framing and wood panels that lie under the tiles.

[00142] The electrical configurations between individual photovoltaic cells as well as the electrical connections between individual tiles or modules may be independently configured as series, parallel, or mixed series-parallel as is well known in the art to achieve the desired operating current and voltage. For example, individual photovoltaic cells within a tile or modules may be connected in series to increase the total operating voltage of the tile or module. If the voltage produced by each individual photovoltaic cell within a tile or module is sufficient, then the cells may be connected to adjacent cells in parallel to maintain voltage,

increase current, and/or so that failure of one cell does not inactivate all cells of the tile or module.

[00143] The tile or module may contain a protective layer (such as **170** shown in figures 1B, 2A, and 2B) adjacent to the light-receiving surface of each photovoltaic cell to protect the photovoltaic cells from damage (caused, for example, from moisture, dust, chemicals, and temperatures changes), while allowing the transmission of sunlight. The protective layer may conform to the surface shape of the photovoltaic cells and may be made of any suitable material, such as glass (*e.g.*, low-lead tempered glass) or polymer (*e.g.*, polymerized para-xylene, vapor phase deposited para-xylene, or ethylene vinyl-acetate). The protective layer may be a film (clear or colored) and be made of *e.g.*, acrylics, epoxies, urethanes, and silicones. The protective layer may optionally be an antireflective coating, such as silicon nitride.

[00144] A photovoltaic tile may be formed in standard lengths of approximately *e.g.*, 6 inches, 12 inches, 18 inches, 24 inches, 30 inches, 36 inches, 42 inches, or 48 inches, with any combination of standard widths of approximately *e.g.*, 4 inches, 8 inches, 12 inches, 18 inches, 22 inches, 26 inches, 30 inches, or 38 inches.

[00145] Photovoltaic tiles typically contain 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 18, 21, 24, 27, 30, 20, 24, 28, 32, 36, 40, 25, 36, 45, 50, 42, 48, 54, 60, or 72 PV cells arranged in rows and columns. PV cells may be arranged, for instance, 1 x 2, 1 x 3, 1, x 4, 2 x 2, 2 x 3, 2 x 4, 2 x 6, 2 x 8, 3 x 3, 3 x 4, 3 x 5, 3 x 6, 3 x 7, 3 x 8, 3 x 9, 3 x 10, 4 x 4, 4 x 5, 4 x 6, 4 x 7, 4 x 8, 4 x 9, 4 x 10, 5 x 5, 5 x 6, 5 x 7, 5 x 8, 5 x 9, 5 x 10, 5 x 12, 6 x 6, 6 x 8, 6 x 10, 6 x 12, or 8 x 12. A tile may, for example, have one, two, three, four, five, six, seven, eight, nine, or ten or more heat sinks in instances where a single heat sink is in contact with cells across an entire row of PV cells or in the tile.

[00146] Polymers may be used to allow increased design flexibility in making the tile, module and/or heat sink. In one variation, a photovoltaic tile or module may comprise photovoltaic cell(s) within an integrated thermally conductive polymeric housing such that the housing itself acts as a heat sink. The polymer may be a thermally conductive polymeric material (*e.g.*, CoolPoly® thermally conductive plastics, nylon 6-6, and/or a polyphenylene sulfide, optional mixed with one or more metallic fillers) so that the entire housing may support the photovoltaic cell(s) (and any integrated components) while also transferring heat away from the photovoltaic cells. This arrangement may decrease the number of components

and interfaces between the photovoltaic cell(s) and increase the overall surface area of the heat sink. The housing may be comprised of multiple types of polymers (e.g., 2 or 3) to form different components of the tile or module where each component may have different polymeric properties. For example, one polymer may be a thermally conductive polymer attached to a photovoltaic cell and acting as a heat sink, while another polymer may surround the photovoltaic cell and/or photovoltaic cell/heat sink interface to provide e.g., structural integrity, aesthetic appeal, weather resistance, and/or a roof-mounting surface. In another variation, one or more polymers may be used to form the tile or module housing (and/or a portion of the heat sink), while metal may be used to form the heat sink (or a portion of the heat sink).

Interlocking Photovoltaic Tiles

[00147] Figure 5A illustrates a photovoltaic roofing tile as also comprising a rigid interconnect system. As with other photovoltaic tiles described, the interlocking photovoltaic tile **500** comprises a housing **120** and one or more photovoltaic cells **110** disposed in or on the tile to allow exposure to direct solar radiation from the top surface of the tile. The tile may also comprise a heat sink **130** in any variation described herein. Both the left and right sides of the tile may comprise either a male base connector **510** or a female base connector **520** configured as part of the tile housing. A base connector of each tile is designed to partially overlap a base connector of an adjacent tile. The male base connector may be of any design such that material generally extends outside of the housing **120** (e.g., a tab or shelf), while the female base connector may be any design such that material is generally removed from the housing **120** (e.g., a rabbet or mitered edge). The base connectors may be of any shape or orientation (e.g., occupy the entire length of one side of a tile, or occupy only a portion of one side of a tile) to complement the base connector of an adjacent tile.

[00148] Upon each base connector may be one or more electrical projections **530** and/or electrical sockets **540**, where an electrical projection and an electrical socket are designed to complement one another and permit continuity of current. Thus, each electrical connector may comprise a base component and an integrated electrical component in one of at least four combinations: (1) a male base connector **510** containing an electrical projection **530**, (2) a male base connector **510** containing an electrical socket **540**, (3) a female base connector **520** containing an electrical projection **530**, and (4) a female base connector **520** containing an electrical socket **540**.

[00149] The interlocking tiles are designed such that a connector on one tile is designed to complement an adjacent tile connector to form a substantially rigid connection between adjacent tiles while maintaining continuity of electrical current, thus limiting the complexity of installation and reducing installation costs. Once two tiles are connected by the connector, the tiles are essentially movable as a unit. There may be little to no relative movement between tiles when they are individually twisted about an axis of the tiles.

[00150] The electrical sockets and projections may be oriented in any direction (e.g., perpendicular or parallel) to the orientation of a base connector and may be of any combination (such as a mixture of projections and sockets) to complement an adjacent tile. The electrical sockets and projections may be arranged asymmetrically and opposite relative the position of the photovoltaic cell(s) such that when one row of tiles overlaps an adjacent row of tiles each electrical connection is disposed directly underneath a row of overlapping tiles to prevent exposure to weather.

[00151] A plug and socket connection or a hermaphroditic electrical connection may be used in lieu of a projection and socket electrical connection. Projections or plugs include any connector extending out from its surface, including mechanical springs, pins or prongs. The electrical connections are not limited to the projection-socket arrangement and may include any device that allows continuity of electrical current while maintaining a substantially rigid mechanical connection. For example, an electrical connection may comprise two electrodes disposed as a film on the surface of two complementary and interlocking adjacent tiles. Pins used as electrical connectors may have springs that help lock the pins into receptacles, providing a stronger connection between tiles.

[00152] Some roof tiles are designed to be laid on a roof such that the longitudinal or major axis of each tile is parallel to the roofline to provide overlapping rows of tiles that parallel the roof-line. Rectangularly-shaped roof tiles are commonly installed in this manner. Connectors on this or other roof tiles as described herein may be positioned at the ends of a major or longitudinal axis of a roof-tile so that adjacent tiles may be interconnected along a row parallel to the roofline. An alternative to this configuration is for the connectors to be positioned at the ends of a minor or latitudinal axis of the roof-tile so that adjacent tiles may be interconnected generally in columns toward the roofline so that adjacent tiles are interconnected in a direction toward or away from the roofline. The connectors may be positioned in a combination of longitudinal and latitudinal axis.

[00153] Figure 5B illustrates various electrical/mechanical configurations for one side of a tile that may be used with the present invention. Each tile may have a complementary electrical/mechanical connector on the opposite side of the tile (not shown). Tile A shows a male base connector **510** with electrical projections **530**. This configuration is designed to match a complementary adjacent tile having a female base connector **520** and an electrical socket **540** (such as the mirror image of the connector shown in tile D). The connector in tile A in the variation shown is placed along an edge such that when two identical tiles are laid parallel with respect to the roof line the electrical insertion is horizontal (or parallel) with respect to the roof surface and parallel with respect to the roof line. Tile B shows a similar connector configuration to tile A, but the electrical projections have been replaced with electrical sockets. Tile E shows a similar connector configuration to that shown in figure 5A wherein the sockets and projections have been replaced with projections and sockets, respectively. The tile in figure 5A and tiles E-G of figure 5B are examples wherein insertion of the connectors is made perpendicular with respect to the roof surface. Tiles F and G of figure 5B show similar socket configurations to the tile of figure 5A where the female base connector extends through the entire edge of the tile. Other connector variations are within the scope of the present invention. For example, connectors may be mixed socket/projection (as shown in tile H) and/or on a surface perpendicular to the roof line (also shown in tile H) or on more than one surface of the tile (such as a long edge and a short edge).

[00154] Figure 5C illustrates a side view of an additional aspect of the invention. The tile may be shaped to allow substantial overlap of an adjacent tile when installed. The overlap also helps protect the electrical and mechanical connector. Heat sink fins of one tile **210** may touch the fin-receiving surface **550** of an adjacent tile and can be adhered to the surface using e.g., epoxy cement or bitumen. The overhang **180** may overlay an adjacent tile and can be adhered or waterproofed to prevent water from getting between tiles. An additional mechanical connector **560** may be provided in this instance to provide extra strength to the installation and help guard against wind-lift of tiles that can occur during severe storms.

[00155] Figure 5D depicts a rectangular roof tile having a solar cell **110** (or multiple solar cells, e.g., 3-5) in which the tile will be installed with its longitudinal axis parallel to the roofline. Connectors may be on opposite long sides of the tile (e.g., **580** as shown in figure 5D) or on the central portion of the joint (e.g., **570**) to permit tiles to be connected to adjacent tiles in a direction that is generally perpendicular to or intersects at an angle the roof-line on which the tile will be installed. Sections of tiles can therefore be laid by placing one tile with

projection **589** in the vicinity of the roof-line and then inserting two tiles (in this instance) in the adjacent row next furthest from the roof-line, then repeating the procedure until the photovoltaic tiles extend close to the edge of the roof closest to ground level toward the roof-line. Assembling the roof in thin vertical sections in this manner leaves a major surface of the roof accessible to ease further tile installation. Upon installation, the projection **589** overlaps a portion of an adjacent tile (at **590**). Projections similar to **589** may be formed on one or more sides of each tile such that all sides of each tile are either overlapping or being overlapped by an adjacent tile.

[00156] The tile in figure 5D additionally comprise a metal frame (e.g., aluminum) and may be used in combination with any heat sink design (such as an aluminum heat sink of folded sheet metal fins 0.01"-0.02" in thickness and 1"-2" in height). The tile may also contain a protective surface or coating (e.g., glass) and mounting holes to secure the tile to the roof-top (or on top of an existing roof).

[00157] Thin film photovoltaic cells may be utilized in any aspect of the described invention. Figure 6 illustrates a composite roofing shingle **600** with a thin film solar cell **610** applied on the upper surface of a composite shingle. A male base connector **620** and a female base connector **630** having e.g., pins **640** and corresponding receptacles **650** are provided at each end of the shingle to interface with complimentary connectors on adjacent shingles. When two or more composite shingles are connected to one another via corresponding connectors, their relative locations are established to one another such that one may not be rotated to a different direction from the other relative to a rooftop. The two shingles may be installed parallel to one another or along the same line in this instance. The rigidity of connections between tiles that removes degrees of freedom of movement of one tile relative to its adjacent tile helps assure installation in parallel rows and therefore helps ease installation. Figure 6 also shows an optionally present heat sink **130**.

[00158] A thin film solar cell may be positioned on e.g., ceramic or concrete tiles as well. Figure 7 illustrates ceramic shaped tiles **700** that have photovoltaic cells (PV) or thin-films **610** in or on surfaces of tiles. The thin-film may be adhered to a copper sheet, which is then adhered to the tile or may be printed directly onto the module. The thin-film may be of any material, size, or configuration and may be any color or combination of colors. The tile bases may be made of any material e.g., ceramic, cement, metal, composite, or polymer, and act as a frame to house additional components of the tile. The tiles may have a heat sink **130** that is embedded in and contacts the respective cells. Interlocking connectors **710** may provide the

mechanical and electrical connections that lock tiles in place as well as conduct electricity from one tile to the next. The curved configurations of the tiles provide large surface areas for their respective cells to occupy, increasing electrical output for a given square footage of roof-top, and the curved configurations also provide large fluid-conducting channels into which fins of heat sinks may extend. Air or other cooling medium may therefore pass with less resistance and aid in cooling the photovoltaic cells more effectively. Channels may be used in this or any other tile configuration herein so that liquid coolant may be pumped through the channels to decrease the photovoltaic cell operating temperature.

[00159] The thin film variations described above may also be applied to photovoltaic modules described herein.

Method of Fabrication

[00160] A tile may be formed a number of ways. For instance, a tile may be formed of a polymer or composite mix in a mold. Housing portions of male and female polymeric connectors are placed in the mold, as are e.g., tubes to carry wiring from the connectors to the photovoltaic cell or wiring itself or to a printed circuit board (PCB) with conductive lines to conduct electricity. If wires or a PCB are placed in the mold, electrical connections are made to the connector portions of the connectors. Next, the polymer or composite mixture is poured into the mold and cured to form a solid tile. The mold may be shaped to provide openings in the cured product top and bottom so that a solar cell can be inserted in the top hole and wired or soldered via e.g., solder-balls to connections on the PCB or to wires in the tile. The heat sink and/or bottom of the solar cell may then be coated with thermally conductive adhesive, the heat sink inserted into the bottom hole and into thermal contact with the solar cell, and the adhesive cured to complete the tile. Alternatively, the heat sink may be fixed to the photovoltaic cell using a lamination procedure described herein.

[00161] A tile formed of terra cotta may be likewise formed in a mold. Ceramic housings for male and female connectors are placed in the mold, as are metal tubes as conduits for wiring from the connectors to the photovoltaic cell. A clay mixture as is typically used in forming tiles is placed in the mold and fired to form the tile. The tile may have an opening from top to bottom and interfacing with the tubes. The photovoltaic cell edges are covered with a weatherproof adhesive such as silicone as are inner walls of the opening, and the cell having an anti-reflective coating is inserted into the top of the tile such that bottom edges of the cell

engage a shelf formed in the tile by the mold. Excess adhesive is removed from the surface of the tile and anti-reflection coating, and the tile is set aside to give the adhesive time to set.

[00162] Wires are inserted through the tubes and out ends of the ceramic connector housings. The wires are connected to an electrical pin or receptacle assembly, and each assembly is then inserted into the corresponding ceramic connector housing with which the electrical pin assembly engages to be locked into place and form the completed connector. Wires are connected to the cell and wires running to the second connector of the tile to provide the desired electrical connection (series, parallel, or series-parallel). Once all wire connections have been made and the electrical pin assemblies seated in their respective ceramic connectors, a heat sink is coated with a thermally conductive adhesive such as thermally conductive epoxy or silicone and inserted through the hole in the bottom of the tile so that the adhesive and heat sink engage the exposed bottom of the photovoltaic cell. Once the adhesive cures, the tile comprising a roof tile, photovoltaic cell, and heat sink is ready for installation as a roof tile on a roof.

Method of Attaching Heat Sink

[00163] Another feature of the present invention is a method of attaching a heat sink to a photovoltaic tile or module. Figures 8A-8E are different views during the described fabrication process of a photovoltaic tile or module.

[00164] Figure 8A-1 illustrates a cross-sectional view of a system used to construct, in whole or in part, a photovoltaic tile or module. An upper jig **800** comprises an optionally present depression **810** designed to complement one or more photovoltaic cells. The depression may have a depth **820** roughly the thickness of the photovoltaic cell(s), or less than the thickness of the cell or cells. Vacuum channels **887** in any shape, number, and configuration may be present to allow a vacuum source through the upper jig to the photovoltaic cell(s). A vacuum source may allow the photovoltaic cells(s) to be temporarily held within the depression **810** during the manufacturing process. Figure 8A-2 shows the upper jig **800** from a bottom view. Each depression **810** is shown with its corresponding width **882** and length **884**. The width and length can collectively or independently have roughly the same dimensions as the largest surface of the cell or cells, or have slightly larger dimensions. The number of depressions **810** may be united or separated and any number desired for the tile or module, such as 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18,

19, 20, or 25. The shape of a depression may be of any shape of photovoltaic cell or cells, such as square, rectangular, hexagonal, octagonal, triangular, circular, or diamond.

[00165] A lower jig **840** shown in Figure 8A-1 may comprise a base depression **850** and a number of fin depressions **860**. The base depression **850** and fin depressions **860** may be designed to collectively compliment a heat sink such that the heat sink may be inserted into the lower jig and is incapable of substantial horizontal movement following insertion. The base depression may have a depth **870** roughly the thickness of a heat sink base or slightly less than the thickness of a heat sink base, and a width roughly the same as the heat sink base or slightly larger than the heat sink base. The base depression may be optionally present. Each fin depression **860** may have roughly the same dimensions as the heat sink fins or slightly larger dimensions to allow uninhibited insertion of the heat sink. The lower jig **840** may also be designed to complement any number of heat sink designs describe herein, such as pyramids (including frustum pyramids), cylinders, square pegs, or cones (including frustum cones). Vacuum channels (not shown) may be present to provide a vacuum source through the lower jig to the heat sink, as described for the upper jig.

[00166] The material of the upper and lower jig may be independently any material known in the art, such as aluminum, copper, ceramic, and polymer. The upper jig and the lower jig may be in reverse orientation, such that the upper jig is below the lower jig.

[00167] The photovoltaic tile or module manufacturing process may begin by placing the photovoltaic cell(s) and the heat sink into their respective jigs, as illustrated in Figure 8B. The upper jig **800** houses one or more photovoltaic cells **886** inserted into each depression **810** such that a flat surface of each cell **888** is exposed while most of the remaining surface area of each cell is housed within depression. Each cell may be made of any material described herein or known in the art, such as wafer-based cells formed on a monocrystalline silicon, poly- or multicrystalline silicon, or ribbon silicon substrate, and may be of any shape, such as square, rectangular, hexagonal, octagonal, triangular, circular, or diamond. The cell(s) may be temporarily fixed to the upper jig **800** by gravity, vacuum (using e.g., optionally present vacuum channels **887**), or any common adherent. The lower jig **840** houses the heat sink **890** such that a flat surface of the heat sink **892** is exposed while most of the remaining surface area, such as the fins, is housed within depression. The heat sink may be made of any thermally conductive material known in the art and/or described herein, such as aluminum or aluminum alloy (e.g., 6063 aluminum alloy, 6061 aluminum alloy, and 6005 aluminum alloy), copper, graphite, or conductive polymer (such as conductive elastomer), may be of

any color (e.g., blue, black, gray, or brown) and may comprise cooling surfaces configured of any geometry, such as pyramids (including frustum pyramids), cylinders, square pegs, or cones (including frustum cones). The heat sink may be temporarily fixed to the lower jig **840** by gravity, vacuum, or any common adherent.

[00168] Figure 8C illustrates how an intervening layer **894** may be added to the exposed surface of the heat sink **892** or to the exposed surface(s) of the cell(s). The intervening layer may be a thermal interface layer, such as thermally conductive grease (e.g., conductive epoxy, silicone, or ceramic) or an intervening thermally conductive polymer. The intervening layer may be of any material that is both electrically isolative and thermally conductive and may be a compound or mixture of compounds that chemically react when exposed to air, heat, and/or pressure. The thermal interface layer may be, for example, constructed of any material that is both electrically isolative and thermally conductive and may be a compound or mixture of compounds that chemically react when exposed to air, heat, and/or pressure. The intervening layer may comprise multiple layers, such as an electrically isolating layer next to PV cells and a thermally conductive layer next to a heat sink, or may be absent. The layer may be in simultaneous contact with both the photovoltaic cell(s) and the heat sink.

[00169] As illustrated in Figure 8D, both jigs house the heat sink **890**, optionally present intervening layer **894**, and photovoltaic cell(s) **886** are sandwiched together to allow simultaneous contact of the optionally present intervening layer **894** with the heat sink and the photovoltaic cell(s). Sufficient pressure may be applied to either the upper jig **800**, lower jig **840**, or both, in a direction toward the photovoltaic components to allow pressure between the cell(s) and the heat sink, and force intimate contact of their surfaces. Because the upper jig is complementary to the housed cell(s) **886**, the resulting applied pressure is distributed across the area of a cell-upper jig interface, thus preventing the likelihood of damage to the cell(s). Likewise, because the lower jig is complementary to the housed heat sink, the applied pressure may be less likely to damage the heat sink fins (e.g., crushing or warping the fins). Sufficient heat may also be applied during the process, separately or in conjunction with sufficient pressure, to intimately join the heat sink to the photovoltaic cell(s). This process of temporarily applying pressure and/or heat to unite two or more materials together, also known as laminating, may allow the surface(s) of the cell(s) to more closely contact an adjacent material at a microscopic level and allow increased conductive heat transfer away from the cell(s). A vacuum may be applied to decrease air pressure before, during, and/or after applying pressure and/or heat to aid in removing pockets of air between layers.

Removing trapped air may allow a more intimate contact between layers resulting in increased thermal transfer.

[00170] Conditions during lamination may vary depending on the photovoltaic tile or module configuration. In one instance the lamination temperature is approximately 155 °C, decreased air pressure is applied for five minutes, and one additional atmosphere of pressure is applied by the jigs to force the heat sink for seven minutes. In another instance, the lamination temperature is between 100 °C and 200 °C, or between 125 °C and 175 °C, or between 135 °C and 155 °C. In another instance 1.25, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, or greater than 5 additional atmospheres of pressure is applied by the jigs to force the heat sink and the photovoltaic cell(s) between the jigs together. In another instance pressure is applied for 1 to 30 minutes, 2 to 20 minutes, 5 to 15 minutes, or greater than 30 minutes. In another instance decreased air pressure is applied for 1 to 30 minutes, 2 to 20 minutes, 5 to 15 minutes, or greater than 30 minutes.

[00171] Figure 8E illustrates a photovoltaic tile or module following removal of the upper jig and the lower jig. At this stage the laminated heat sink **890** and photovoltaic cell(s) **886** may have a housing fabricated and attached as described above.

[0100] The process may comprise additional layers known in the art (e.g., ethyl-vinyl-acetate (EVA), polyester, Tedlar®, EPT) on or within the tile or module, such as a protective layer (e.g., conformal coating), as described herein.

[0101] As used for a module, the process may further comprise the addition of a frame, with or without legs, as described herein, to permit airflow through direct horizontal access to the heat sink.

[0102] A vacuum may be used during the process to remove trapped air between the described layers.

[0103] Figures 8F illustrates a variation of figure 8A-1 used to construct a photovoltaic tile or module. The lower jig **840** shown in Figure 8F may comprise a base depression **850** and a number of frustum cone depressions **861**. As with figure 8A-1, the base depression **850** and frustum cone depressions **861** may be designed to collectively compliment a heat sink such that the heat sink may be inserted into the lower jig and is incapable of substantial horizontal movement following insertion. The base depression may have a depth **870** roughly the thickness of a heat sink base or slightly less than the thickness of a heat sink base, and a width roughly the same as the heat sink base or slightly larger than the heat sink base. The

base depression may be optionally present. Each frustum cone depression **861** may have roughly the same dimensions as the heat sink frustum cone or slightly larger dimensions to allow uninhibited insertion of the heat sink. Vacuum channels (not shown) may be present to provide a vacuum source through the lower jig to the heat sink, as described for the upper jig.

[0104] The lamination process for a heat sink comprising frustum cones **891** may be as described above and resulting in a photovoltaic tile or module as shown in figure 8G.

Methods Using Injection Molding

[0105] Injection molding techniques commonly known in the field (e.g., screw injection molding) to form a polymeric housing may be used to fabricate a photovoltaic tile. Although the methods described below exemplify injection molding for tile construction, the described methods may also be used for construction of a photovoltaic module.

[0106] One advantage of injection molding is that a tile may comprise a conductive polymeric housing also acting as a heat sink. Another advantage is that multiple polymeric injections can be made to form different components of the tile or module where each component may have different polymeric properties. Additionally, injection molding may allow formation of a heat sink that acts as “skin” to coat desired regions of the photovoltaic tile(s) as well as allowing the formation of geometries otherwise not available with traditional fabrication techniques that permit increased convection and cooling.

[0107] One or more molds may be generated from e.g., standard machining or electrical discharge machining using any common mold material (e.g., hardened steel, pre-hardened steel, aluminum, or beryllium-copper alloy) to complement the photovoltaic tile design. Photovoltaic cell(s) and wiring may then be positioned within the mold(s) as described above such that one surface of the photovoltaic cell(s) will be ultimately exposed and the remaining surfaces of the photovoltaic cell(s) will be in thermal contact with the polymeric housing upon injection. The mold apparatus is then closed and a heated polymer (e.g., thermally conductive polymer, such as nylon 6-6, and/or a polyphenylene sulfide, optional mixed with one or more metallic fillers; resin; or a fluid-like raw material for injection molding) is channeled into the mold by pressure from e.g., an electric motor or hydraulic source, followed by cooling (e.g., water-channels within the mold) to solidify the tile housing/heat sink. The injected material may be a polymer, mixture of polymers, unpolymerized monomer, mixture of unpolymerized monomers, or any mixture of polymer(s) and unpolymerized monomers(s). The polymer and/or monomer may have a coefficient of thermal expansion that

is similar or identical to the coefficient of thermal expansion of the photovoltaic cell(s) to insure intimate contact of the injected material with the photovoltaic cell(s) during temperature changes. High pressure (e.g., 5-6000 tons) and heat applied during the injection process may allow intimate contact between the injection polymer (which may ultimately form the heat sink) and the photovoltaic cell(s), resulting in increased heat dissipation during operation of the tiles or modules. The mold may then be opened and the tile ejected with assistance of ejector pins within the mold, followed by any necessary machining. The tile or module is then ready for installation on a roof.

Methods of Tile Installation

[0108] One method of installation is illustrated in figure 9. Roof tiles are attached to purlins or battens that retain and support the tiles. Tiles are laid by e.g., nailing the first tile to lowest purlin or batten, engaging male connector of one tile with female connector of a second tile and locking into place by e.g., pushing the two tiles together, nailing the second tile to this purlin or batten, and repeating this across a portion of the roof. The next course of tiles is formed by placing one tile on the next highest purlin or batten so that it partially overlies the tile on the lower purlin or batten, snapping tiles together using the connectors, and nailing tiles to the purlin or batten. The overlapping portions of tiles may be adhered to one another using e.g., bitumen or adhesive to provide a watertight seal and/or prevent the tiles from being lifted by wind.

[0109] This process is depicted in the flow chart of figure 9. In a step **900**, a first photovoltaic tile is provided. In a step **902**, a second photovoltaic tile is provided. In a step **904**, the first photovoltaic tile is attached to a roof. In a step **906**, an electrical connector of the first photovoltaic tile is engaged with an electrical connector of the second photovoltaic tile to form a substantially rigid mechanical connection between the photovoltaic tile and to form an electrical connection between a photovoltaic cell of the first photovoltaic tile and a photovoltaic cell of the second photovoltaic tile. In an optional step **908**, the second photovoltaic tile is attached to the roof.

[0110] Figure **10** is a flow chart of a second method for installing a photovoltaic tile. In a step **1000**, a first photovoltaic tile is provided. In a step **1002**, a second photovoltaic tile is provided. In a step **1004**, an electrical connector of the first photovoltaic tile is engaged with an electrical connector of the second photovoltaic tile to form a substantially rigid mechanical connection between the photovoltaic tiles and to form an electrical connection between a

photovoltaic cell of the first photovoltaic tile and a photovoltaic cell of the second photovoltaic tile. In a step **1006**, the first photovoltaic tile is attached to a roof. In an optional step **708**, the second photovoltaic tile is attached to the roof.

[0111] In one method of installing photovoltaic roof tiles, plural roof tiles are joined together horizontally through their connectors, parallel to the roofline, and attached on the rooftop at the furthest point from the roofline (closest to ground level). The tiles joined together in this step does not span the entire horizontal length of the rooftop but spans only a portion of the rooftop to provide access on one or both sides of the joined roof tiles. The next vertically adjacent row of roof tiles is then installed, again leaving access on one side or both. This process is repeated until roof tiles cover a section of the roof from the lowest area of the roofline to essentially the highest area of the roofline. The entire process may be repeated to build additional sections of tiles on one or both sides of the completed section. Thus, the horizontal length of individual sections may be short compared to the horizontal length of the rooftop, or the horizontal length of a section may be almost the entire horizontal length of the rooftop. Once all sections of photovoltaic roof tiles have been installed, conventional roof-tiles may be installed along one or both edges of the roof from lowest area of the roofline to highest area to provide areas people may access the rooftop without damaging photovoltaic roof-tiles. In this manner access may be provided to e.g., chimneys and ducts or pipes that penetrate the roof-top. Conventional tiles may be provided near the roofline and near gutters as well if desired.

[0112] A tile may be attached individually to the rooftop immediately after it is connected via connectors to an adjacent tile previously secured to the rooftop. Alternatively, multiple tiles may be connected via their connectors, and the assembled tiles may then be secured to the rooftop. For instance, the installer may interconnect many tiles, center the interconnected tiles along the horizontal length of the rooftop, assure the interconnected tiles are also parallel to the roofline, and then secure this first row (furthest from the rooftop) to underlying purlins or battens. The installer may then add tiles individually as described above to finish a section, or the installer may interconnect multiple tiles and connect or overlay them to form the adjacent row of tiles in that section.

[0113] The tiles may therefore be installed to complete all or most of a first row of tiles before progressing to form an adjacent row of tiles and so forth until the roof is covered, or the tiles may be installed to form sections that run partially across the horizontal length of the roof and partially or fully to the roofline from near or at the baseline of the roof.

[0114] In another instance, a roof may be formed by placing a roofing tile at the baseline of the roof and connecting adjacent tiles by the connectors in a direction toward the roofline. Strips of tiles are formed that can have e.g., a sealing strip or bitumen placed in and/or across the vertically-rising seam formed with adjacent tiles on the left or right of a strip.

[0115] The installation process may be performed by placing a roof tile nearest the roofline and then placing rows adjacent in the direction toward the ground in any of the methods discussed above. Any of the tiles described herein may be configured for installation from roofline toward ground or from the portion of the roof closest to ground and toward the roofline. An entire row may be formed or only a portion of a row in either method.

CLAIMS

What is claimed is:

1. A photovoltaic module comprising:
 - A. a plurality of photovoltaic cells,
 - B. a frame retaining the plurality of photovoltaic cells and exposing light-receiving surfaces of the plurality of photovoltaic cells along a first surface of the frame,
 - C. said frame being adapted to mount on a finished rooftop,
 - D. a heat sink in thermal communication with an unexposed surface of said plurality of photovoltaic cells,
 - E. said heat sink comprising
 - i) a base positioned substantially parallel to said unexposed surface, and
 - ii) a plurality of fins attached to the base positioned substantially parallel to each other,wherein said base has a thickness between 0.05" and 0.5";
and wherein said fins each independently have a height between 0.25" and 7", a center to center spacing between 0.05" and 1", and a width between 0.001" and 0.25";
wherein the center to center spacing is sufficient to provide a channel between said fins for cooling air to enter.
2. The photovoltaic module of Claim 1, further comprising a thermal interface layer between the heat sink and said unexposed surface to improve heat dissipation.
3. The photovoltaic module of Claim 1, further comprising a conformal coating on said light-receiving surfaces substantially transparent to visible light.
4. The photovoltaic module of Claim 1, wherein said frame does not extend beyond a base of said heat sink, allowing unimpeded access of ambient air to fins of the heat sink.
5. The photovoltaic module of Claim 1, wherein the heat sink has a length, thickness, fin height, fin spacing and fin width to maintain the photovoltaic cell at a temperature below about 150°F in quiescent ambient air at a temperature of 70°F.

6. The photovoltaic module of Claim 1, wherein a long axis of each fin of the plurality of fins is positioned substantially parallel to a long axis of the heat sink.
7. The photovoltaic module of Claim 1, wherein a long axis of each fin of the plurality of fins is positioned substantially perpendicular to a long axis of the heat sink.
8. The photovoltaic module of Claim 1, wherein a long axis of the heat sink is positioned substantially parallel to a long axis of the photovoltaic module.
9. The photovoltaic module of Claim 1, wherein a long axis of the heat sink is positioned substantially perpendicular to a long axis of the photovoltaic module.
10. The photovoltaic module of Claim 1, wherein the heat sink has a length sufficient to span greater than $\frac{3}{4}$ the width of the photovoltaic module.
11. The photovoltaic module of Claim 1, wherein the heat sink has a length sufficient to span greater than $\frac{3}{4}$ the length of the photovoltaic module.
12. The photovoltaic module of Claim 1, wherein the heat sink is constructed of extruded aluminum.
13. The photovoltaic module of Claim 1, wherein the heat sink is constructed of black anodized aluminum.
14. The photovoltaic module of Claim 1, wherein the base is constructed of a conductive polymer.
15. The photovoltaic module of Claim 14, wherein the conductive polymer is an elastomer.
16. The photovoltaic module of Claim 1, wherein said fins are discontinuous along a long axis of said base to form air escape and entry channels.

17. The photovoltaic module of Claim 16, wherein the channels are herringbone shape.
18. The photovoltaic module of Claim 1, wherein said base has a thickness between 0.1" and 0.25"; and wherein said fins each independently have a height between 0.75" and 5", a center to center spacing between 0.2" and 0.5", and a width between 0.007" and 0.1".
19. The photovoltaic module of Claim 18, further comprising a thermal interface layer between the heat sink and said unexposed surface to improve heat dissipation.
20. The photovoltaic module of Claim 18, wherein a long axis of the heat sink is positioned substantially perpendicular to a long axis of the photovoltaic module.
21. The photovoltaic module of Claim 18, wherein the heat sink is constructed of extruded aluminum.
22. The photovoltaic module of Claim 18, wherein said base has a thickness between 0.1" and 0.2"; and wherein said fins each independently have a height between 0.9" and 2", a center to center spacing between 0.3" and 0.4", and a width between 0.02" and 0.05".
23. The photovoltaic module of Claim 22, further comprising a thermal interface layer between the heat sink and said unexposed surface to improve heat dissipation.
24. The photovoltaic module of Claim 22, wherein a long axis of the heat sink is positioned substantially perpendicular to a long axis of the photovoltaic module.
25. The photovoltaic module of Claim 22, wherein the heat sink is constructed of extruded aluminum.
26. A method of fabricating a photovoltaic module comprising the steps of:

placing a heat sink in a jig such that a lower surface of said heat sink is in contact with said jig and an upper surface of said heat sink is exposed;
placing a photovoltaic cell adjacent said upper surface;
joining said photovoltaic cell and said heat sink; and
removing said heat sink from said jig.

27. The method according to claim 26, wherein the step of joining said photovoltaic cell and said heat sink comprises laminating.
28. The method according to claim 27, wherein the step of laminating comprises providing a thermal interface layer between said upper surface and said photovoltaic cell.
29. The method according to claim 28, wherein the step of laminating comprises laminating the heat sink, intervening layer, and photovoltaic cell together.
30. The method according to claim 29, wherein said intervening layer is a thermally conductive polymer.
31. The method according to claim 30, wherein said thermally conductive polymer is an elastomer.
32. The method according to claim 27, wherein the step of laminating comprising decreasing ambient pressure between said upper surface and said photovoltaic cell.
33. The method according to claim 32, wherein the ambient pressure is decreased for between 5 to 30 minutes.
34. The method according to claim 27, wherein the step of laminating comprising increasing the temperature between said upper surface and said photovoltaic cell.
35. The method according to claim 34, wherein the temperature is increased to between 125 °C and 175 °C.

36. The method according to claim 34, wherein the temperature is increased for between 5 to 30 minutes.
37. The method according to claim 27, wherein the step of laminating comprises increasing the pressure between said upper surface and said photovoltaic cell.
38. The method according to claim 37, wherein the pressure is increased to between 0.5 and 5 atmospheres.
39. The method according to claim 37, wherein the pressure is increased for between 5 to 30 minutes.
40. The method according to claim 26, comprising attaching a protective layer on the photovoltaic cell.
41. The method according to claim 40, wherein said protective layer is a conformal coating.
42. The method according to claim 26, comprising attaching a frame surrounding the one or more photovoltaic cells wherein the frame does not extend beyond said upper surface, allowing unimpeded access of ambient air to the heat sink.
43. The method according to claim 26, wherein the heat sink is constructed of extruded aluminum.
44. The method according to claim 26, wherein the heat sink is constructed of a conductive polymer.
45. The method according to claim 26, wherein the heat sink comprises a plurality of fins positioned substantially parallel to each other and wherein said jig comprises a plurality of depressions complementary to said plurality of fins.
46. A photovoltaic tile comprising:
 - A. a photovoltaic cell,

- B. a housing retaining the photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell along a first surface of the housing,
 - C. said housing being adapted to mount on a rooftop,
 - D. a heat sink in thermal communication with an unexposed surface of said photovoltaic cell,
 - E. said heat sink comprising
 - i) a base positioned substantially parallel to said unexposed surface, and
 - ii) a plurality of fins attached to said base positioned substantially parallel to each other,
 - wherein said base has a thickness between 0.05" and 0.5";
 - wherein said fins each independently have a height between 0.25" and 7", a center to center spacing between 0.05" and 1", and a width between 0.001" and 0.25";
 - and wherein the center to center spacing is sufficient to provide a channel between said fins for cooling air to enter.
47. The photovoltaic tile of Claim 46, further comprising a thermal interface layer between the heat sink and said unexposed surface to improve heat dissipation.
48. The photovoltaic tile of Claim 46, wherein the heat sink has a length, thickness, fin height, fin spacing and fin width to maintain the photovoltaic cell at a temperature below about 150°F in ambient air at a temperature of 70°F.
49. The photovoltaic tile of Claim 46, further comprising an overhang along said first surface of said housing substantially parallel to a ridgeline of the rooftop.
50. The photovoltaic tile of Claim 46, further comprising an overhang along said first surface of said housing substantially perpendicular to a ridgeline of the rooftop.
51. The photovoltaic tile of Claim 46, wherein the plurality of fins is positioned in a direction substantially parallel to a ridgeline of the rooftop.

52. The photovoltaic tile of Claim 46, wherein the plurality of fins is positioned in a direction substantially perpendicular to a ridgeline of the rooftop.
53. The photovoltaic tile of Claim 46, wherein the heat sink is constructed of extruded aluminum.
54. The photovoltaic tile of Claim 46, wherein the heat sink is constructed of black anodized aluminum.
55. The photovoltaic tile of Claim 46, wherein the base is constructed of a conductive polymer.
56. The photovoltaic tile of Claim 53, wherein the conductive polymer is an elastomer.
57. The photovoltaic tile of Claim 46, wherein said fins are discontinuous along a long axis of said base to form air escape and entry channels.
58. The photovoltaic tile of Claim 57, wherein the channels are herringbone shape.
59. The photovoltaic tile of Claim 46, wherein said base has a thickness between 0.1" and 0.25"; and wherein said fins each independently have a height between 0.75" and 5", a center to center spacing between 0.2" and 0.5", and a width between 0.007" and 0.1".
60. The photovoltaic tile of Claim 59, further comprising a thermal interface layer between the heat sink and said unexposed surface to improve heat dissipation.
61. The photovoltaic tile of Claim 59, wherein the plurality of fins is positioned in a direction substantially perpendicular to a ridgeline of the rooftop.
62. The photovoltaic tile of Claim 59, wherein the heat sink is constructed of extruded aluminum.

63. The photovoltaic tile of Claim 59, wherein said base has a thickness between 0.1'' and 0.2''; and wherein said fins each independently have a height between 0.9'' and 2'', a center to center spacing between 0.3'' and 0.4'', and a width between 0.02'' and 0.05''.
64. The photovoltaic tile of Claim 63, further comprising a thermal interface layer between the heat sink and said unexposed surface to improve heat dissipation.
65. The photovoltaic tile of Claim 63, wherein the plurality of fins is positioned in a direction substantially perpendicular to a ridgeline of the rooftop.
66. The photovoltaic tile of Claim 63, wherein the heat sink is constructed of extruded aluminum.
67. A plurality of photovoltaic tiles comprising:
 - A. a first photovoltaic tile comprising
 - i. a photovoltaic cell,
 - ii. a housing retaining the photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell along a first surface of the housing,
 - iii. said housing being adapted to mount on a rooftop,
 - iv. a heat sink in thermal communication with a surface opposite said light- receiving surfaces of said photovoltaic cell, and
 - v. a first electrical connector and a second electrical connector attached to the first photovoltaic tile,
 - B. a second photovoltaic tile comprising
 - i. a photovoltaic cell
 - ii. a housing retaining the photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell along a first surface of the housing,
 - iii. said housing being adapted to mount on a rooftop,
 - iv. a heat sink in thermal communication with a surface opposite said light- receiving surfaces of said photovoltaic cell, and
 - v. a first electrical connector and a second electrical connector attached to the second photovoltaic tile,

wherein the first electrical connector of the first tile mates with the second electrical connector of the second tile, and
wherein the first electrical connector of the first tile and the second electrical connector of the second tile are, upon mating, configured to prevent the first tile from being rotated independently of the second tile.

68. The plurality of photovoltaic tiles of Claim 67, wherein the first photovoltaic tile and the second photovoltaic tile are identical.
69. The plurality of photovoltaic tiles of Claim 67, wherein each electrical connector is independently a male or female connector.
70. The plurality of photovoltaic tiles of Claim 69, wherein each electrical connector is independently a projection or socket connector.
71. The plurality of photovoltaic tiles of Claim 67, wherein the first electrical connector of the first tile is configured to mate with the second electrical connector of the second tile in a direction substantially parallel to a ridgeline of the rooftop.
72. The plurality of photovoltaic tiles of Claim 67, wherein the first electrical connector of the first tile is configured to mate with the second electrical connector of the second tile in a direction substantially perpendicular to a ridgeline of the rooftop.
73. The plurality of photovoltaic tiles of Claim 67, wherein each photovoltaic cell is a thin film photovoltaic cell.
74. The plurality of photovoltaic tiles of Claim 67, wherein each photovoltaic tile comprises a thermal interface layer between said heat sink and said unexposed surface to improve heat dissipation.

75. The plurality of photovoltaic tiles of Claim 67, wherein each heat sink is configured to maintain its corresponding photovoltaic cell at a temperature below about 150°F in ambient air at a temperature of 70°F.
76. The plurality of photovoltaic tiles of Claim 67, wherein each photovoltaic tile comprises an overhang along said first surface of said housing substantially parallel to a ridgeline of the rooftop.
77. The plurality of photovoltaic tiles of Claim 67, wherein each photovoltaic tile comprises an overhang along said first surface of said housing substantially perpendicular to a ridgeline of the rooftop.
78. The plurality of photovoltaic tiles of Claim 67, wherein each heat sink comprises
- i) a base positioned substantially parallel to said surface opposite said light-receiving surfaces, and
 - ii) a plurality of fins attached to the base positioned substantially parallel to each other.
79. The plurality of photovoltaic tiles of Claim 78, wherein each plurality of fins is positioned in a direction substantially parallel to a ridgeline of the rooftop.
80. The plurality of photovoltaic tiles of Claim 78, wherein each plurality of fins is positioned in a direction substantially perpendicular to a ridgeline of the rooftop.
81. The plurality of photovoltaic tiles of Claim 78, wherein each plurality of fins is discontinuous along a long axis of the associated base to form air escape and entry channels.
82. The plurality of photovoltaic tiles of Claim 81, wherein the channels are herringbone shape.
83. The plurality of photovoltaic tiles of Claim 67, wherein each heat sink is constructed of metal.

84. The plurality of photovoltaic tiles of Claim 83, wherein the metal is extruded aluminum.
85. The plurality of photovoltaic tiles of Claim 83, wherein the metal is black anodized aluminum.
86. The plurality of photovoltaic tiles of Claim 67, wherein each heat sink is constructed of a conductive polymer.
87. The plurality of photovoltaic tiles of Claim 86, wherein the conductive polymer is an elastomer.
88. A photovoltaic tile comprising:
a) a photovoltaic cell,
b) a housing retaining the cell and exposing light-receiving surfaces of the photovoltaic cell, and
c) a first electrical connector and a second electrical connector attached to the photovoltaic tile,
wherein said housing is adapted to mount on a rooftop, and
wherein said housing comprises a thermally conductive polymer in thermal communication with an unexposed surface of said photovoltaic cell.
89. The photovoltaic tile of Claim 88, wherein said housing further comprises a second polymer adjoining the first polymer.
90. The photovoltaic tile of Claim 88, wherein the first electrical connector mates with an electrical connector of a second photovoltaic tile, and
wherein the first electrical connector of the first tile and the electrical connector of the second tile are, upon mating, configured to prevent the first tile from being rotated independently of the second tile.
91. The photovoltaic tile of Claim 90, wherein the photovoltaic tile and the second photovoltaic tile are identical.

92. The photovoltaic tile of Claim 90, wherein each electrical connector is independently a male or female connector.
93. The photovoltaic tile of Claim 91, wherein each electrical connector is independently a projection or socket connector.
94. The photovoltaic tile of Claim 88, wherein the first electrical connector of the tile is configured to mate with the electrical connector of the adjacent tile in a direction substantially parallel to a ridgeline of the rooftop.
95. The photovoltaic tile of Claim 88, wherein the first electrical connector of the tile is configured to mate with the electrical connector of the adjacent tile in a direction substantially perpendicular to a ridgeline of the rooftop.
96. The photovoltaic tile of Claim 88, further comprising a overhang along said first surface of said housing substantially parallel to a ridgeline of the rooftop.
97. The photovoltaic tile of Claim 88, further comprising a overhang along said first surface of said housing substantially perpendicular to a ridgeline of the rooftop.
98. The photovoltaic tile of Claim 88, wherein the photovoltaic cell is a thin film photovoltaic cell.
99. The photovoltaic tile of Claim 88, wherein the thermally conductive polymer is shaped as a plurality of fins positioned substantially parallel to each other.
100. The photovoltaic tile of Claim 99, wherein the fins are discontinuous along a long axis of said base to form air escape and entry channels.
101. The photovoltaic tile of Claim 100, wherein the channels are herringbone shape.
102. A method of fabricating a photovoltaic tile comprising the steps of:
placing a photovoltaic cell in a mold;
injecting a first polymer into said mold;

removing said polymer and said cell from said mold.

103. The method according to claim 102, wherein said first polymer is a thermally conductive polymer.
104. The method according to claim 103, further comprising injecting a second polymer into said mold.
105. The method according to claim 103, wherein upon injecting said first polymer into said mold, said first polymer is in thermal communication with a surface opposite of light-receiving surfaces of said photovoltaic cell.
106. The method according to claim 103, wherein said first polymer forms a housing retaining said photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell, wherein said housing is adapted to mount on a rooftop.
107. The method according to claim 104, wherein said second polymer forms a housing retaining said photovoltaic cell and exposing light-receiving surfaces of the photovoltaic cell, wherein said housing is adapted to mount on a rooftop.
108. The method according to claim 102, wherein the photovoltaic cell comprises a metal heat sink attached to a surface opposite of light-receiving surfaces.
109. The method according to claim 102, wherein the photovoltaic tile comprises an electrical connector, wherein said electrical connector of said photovoltaic tile and an electrical connector of a second tile are, upon mating, configured to prevent said photovoltaic tile from being rotated independently of said second tile.
110. The method according to claim 102, wherein injecting said first polymer comprises increased heat and pressure sufficient to allow intimate thermal contact between said first polymer and said photovoltaic cell.
111. The method according to claim 102, further comprising cooling said mold.

112. A method of fabricating a photovoltaic tile comprising the steps of:
placing a heat sink in a jig such that a lower surface of said heat sink is in contact with said jig and an upper surface of said heat sink is exposed;
placing a photovoltaic cell adjacent said upper surface;
joining said photovoltaic cell and said heat sink; and
removing said heat sink from said jig;
forming a tile housing around said photovoltaic cell.
113. The method according to claim 112, wherein the step of joining said photovoltaic cell and said heat sink comprises laminating.
114. The method according to claim 113, wherein the step of laminating comprises providing a thermal interface layer between said upper surface and said photovoltaic cell.
115. The method according to claim 114, wherein the step of laminating comprises laminating the heat sink, intervening layer, and photovoltaic cell together.
116. The method according to claim 115, wherein said intervening layer is a thermally conductive polymer.
117. The method according to claim 116, wherein said thermally conductive polymer is an elastomer.
118. The method according to claim 113, wherein the step of laminating comprising decreasing ambient pressure between said upper surface and said photovoltaic cell.
119. The method according to claim 118, wherein the ambient pressure is decreased for between 5 to 30 minutes.
120. The method according to claim 113, wherein the step of laminating comprising increasing the temperature between said upper surface and said photovoltaic cell.

121. The method according to claim 120, wherein the temperature is increased to between 125°C and 175°C.
122. The method according to claim 120, wherein the temperature is increased for between 5 to 30 minutes.
123. The method according to claim 113, wherein the step of laminating comprises increasing the pressure between said upper surface and said photovoltaic cell.
124. The method according to claim 123, wherein the pressure is increased to between 0.5 and 5 atmospheres.
125. The method according to claim 123, wherein the pressure is increased for between 5 to 30 minutes.
126. The method according to claim 112, wherein the heat sink is constructed of extruded aluminum.
127. The method according to claim 112, wherein the heat sink is constructed of a conductive polymer.
128. The method according to claim 112, comprising attaching a protective layer on the photovoltaic cell.
129. The method according to claim 128, wherein said protective layer is a conformal coating.
130. The method according to claim 112, wherein the heat sink comprises a plurality of fins positioned substantially parallel to each other and wherein said jig comprises a plurality of depressions complementary to said plurality of fins.

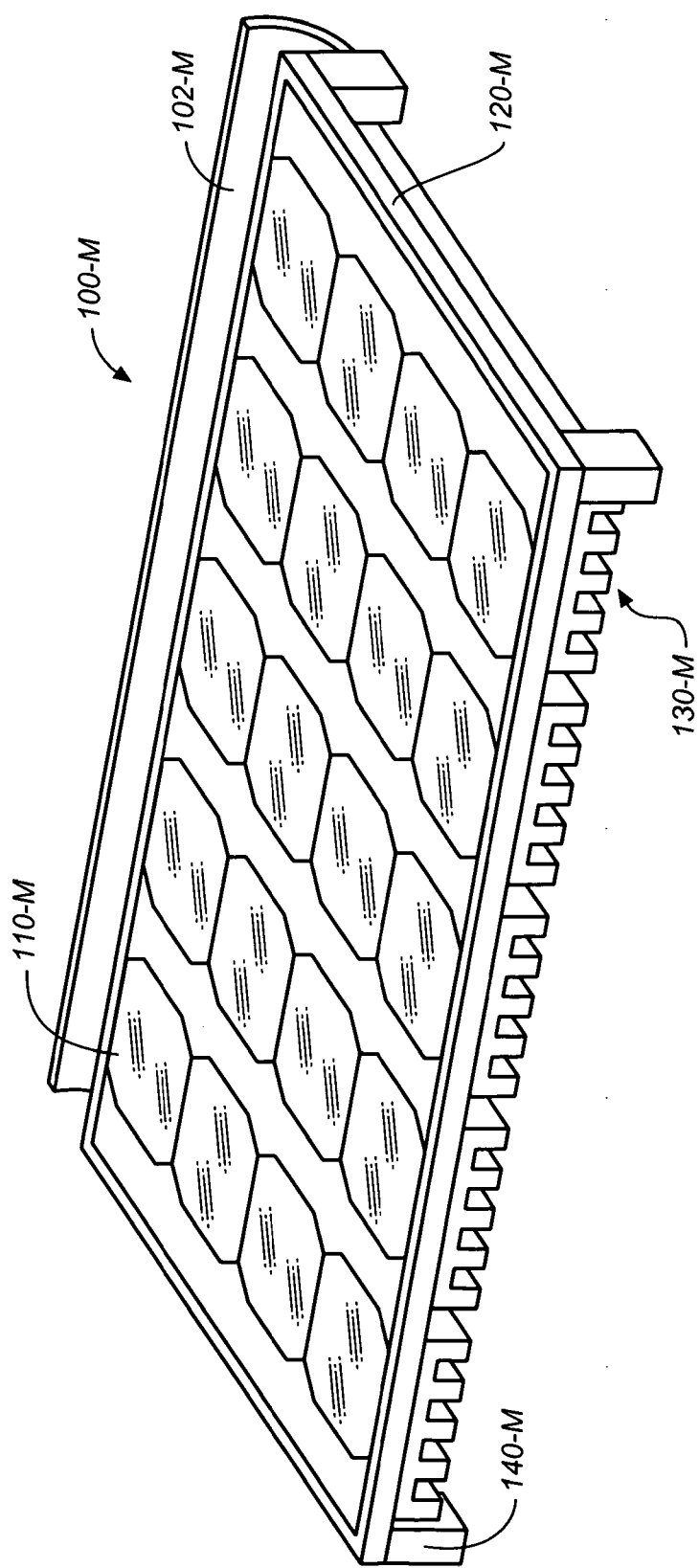


FIG. 1A

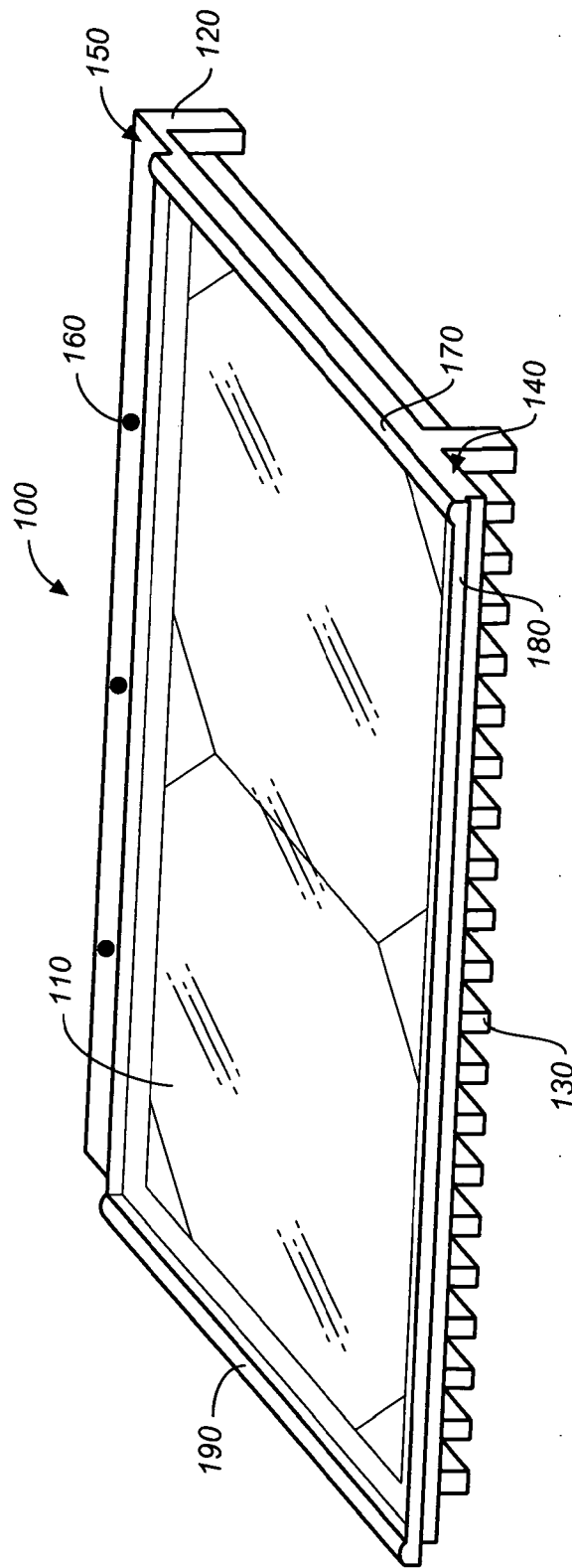
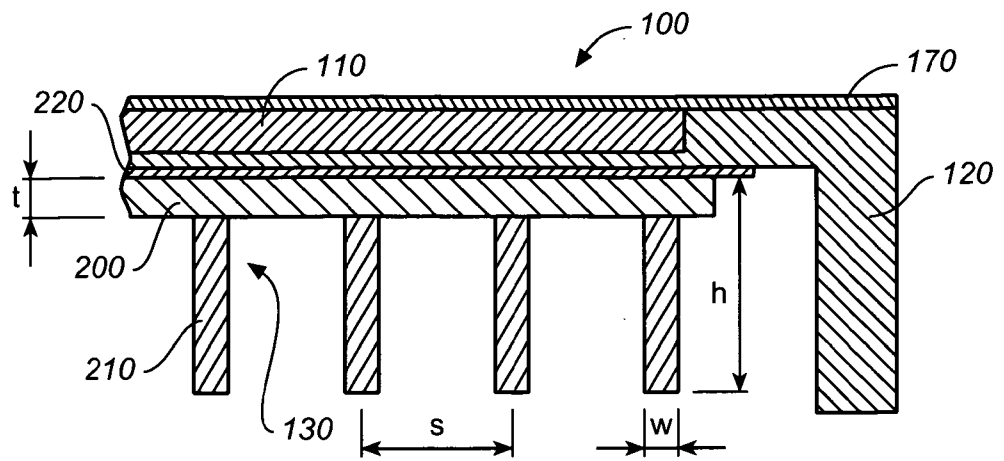
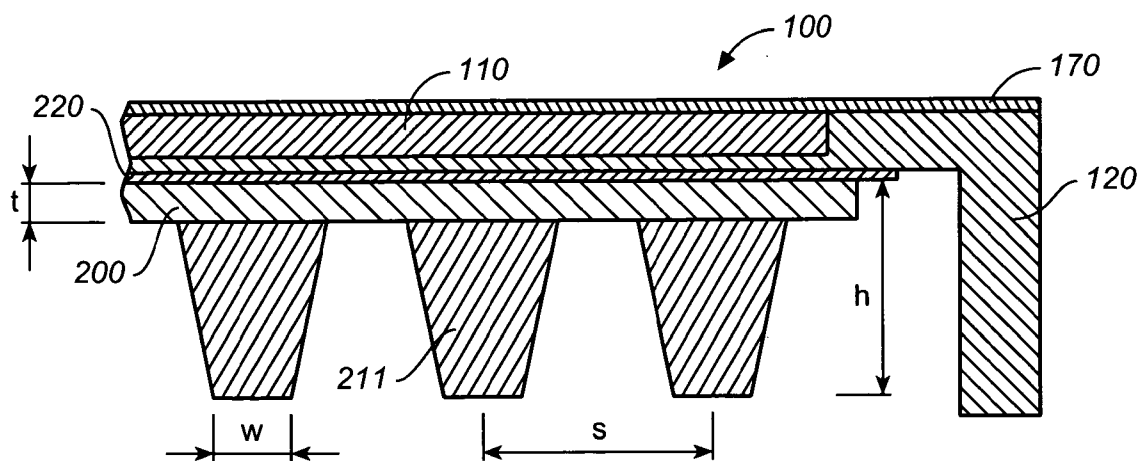


FIG. 1B

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**FIG. 2A****FIG. 2B**

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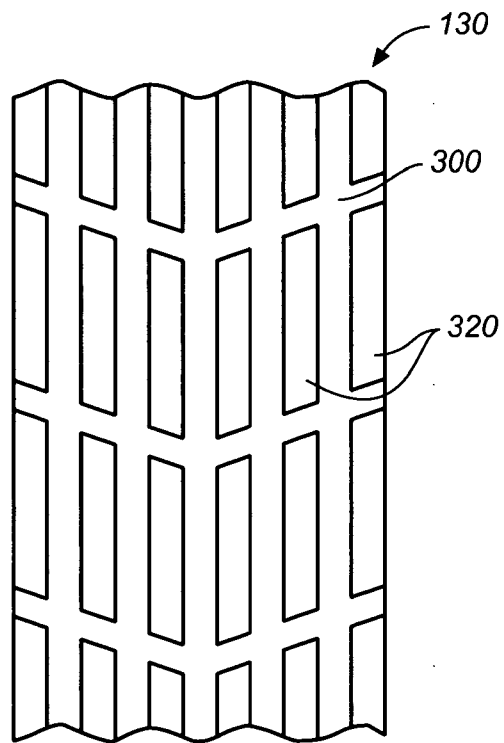


FIG. 2C

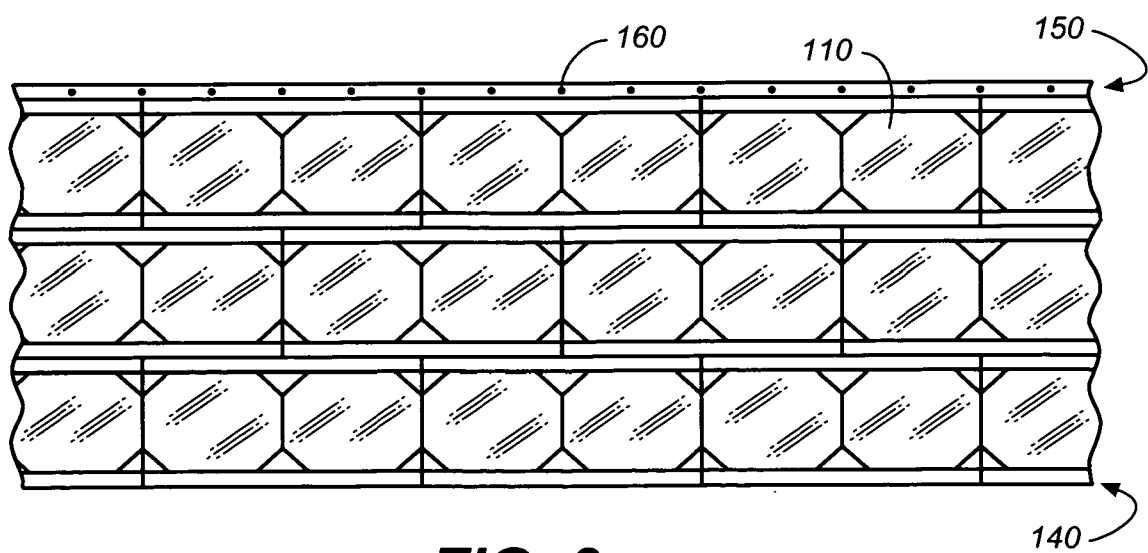


FIG. 3

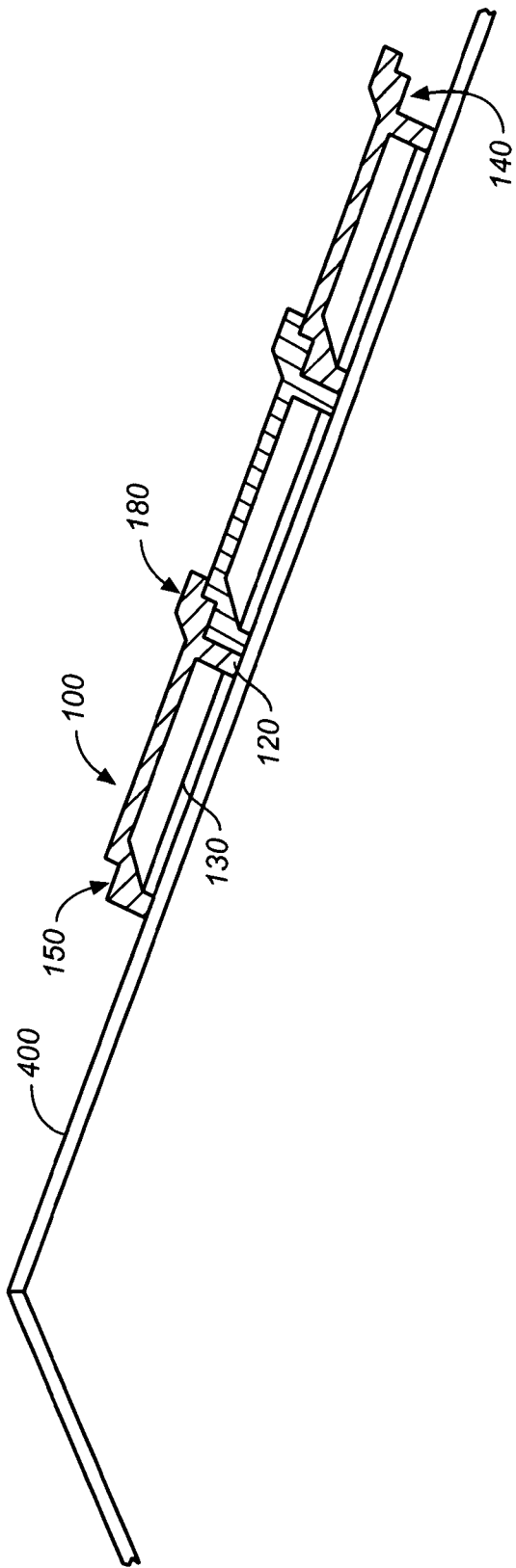


FIG. 4

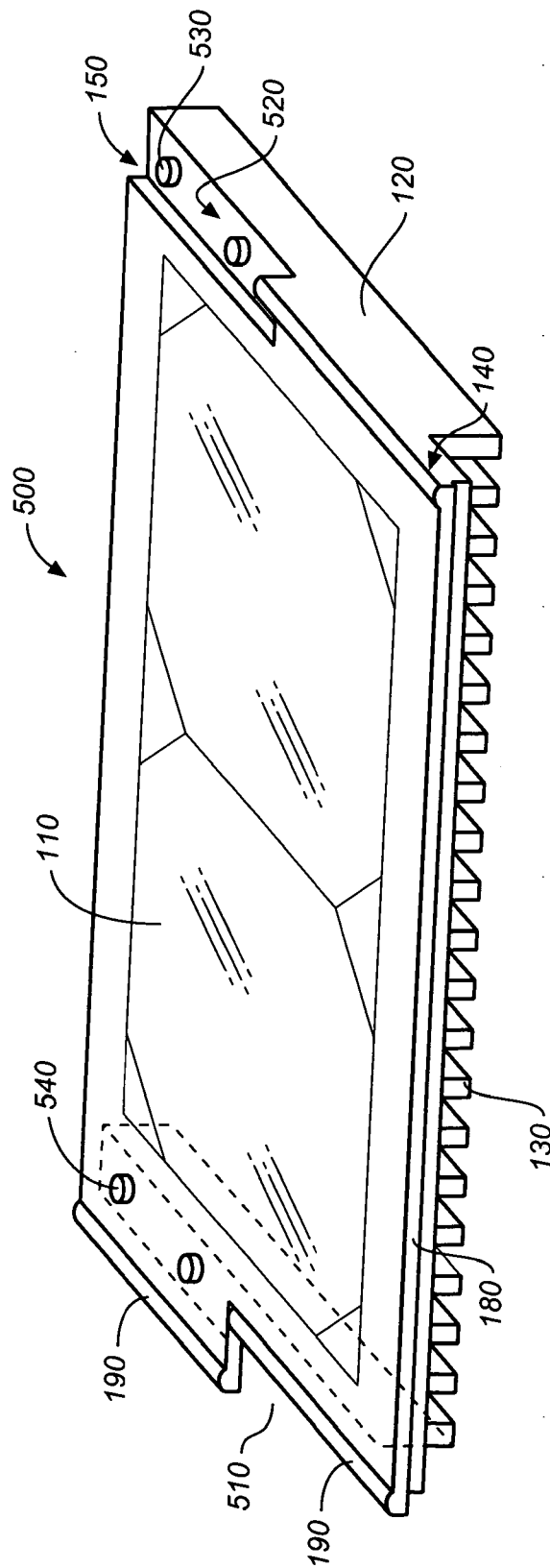


FIG. 5A

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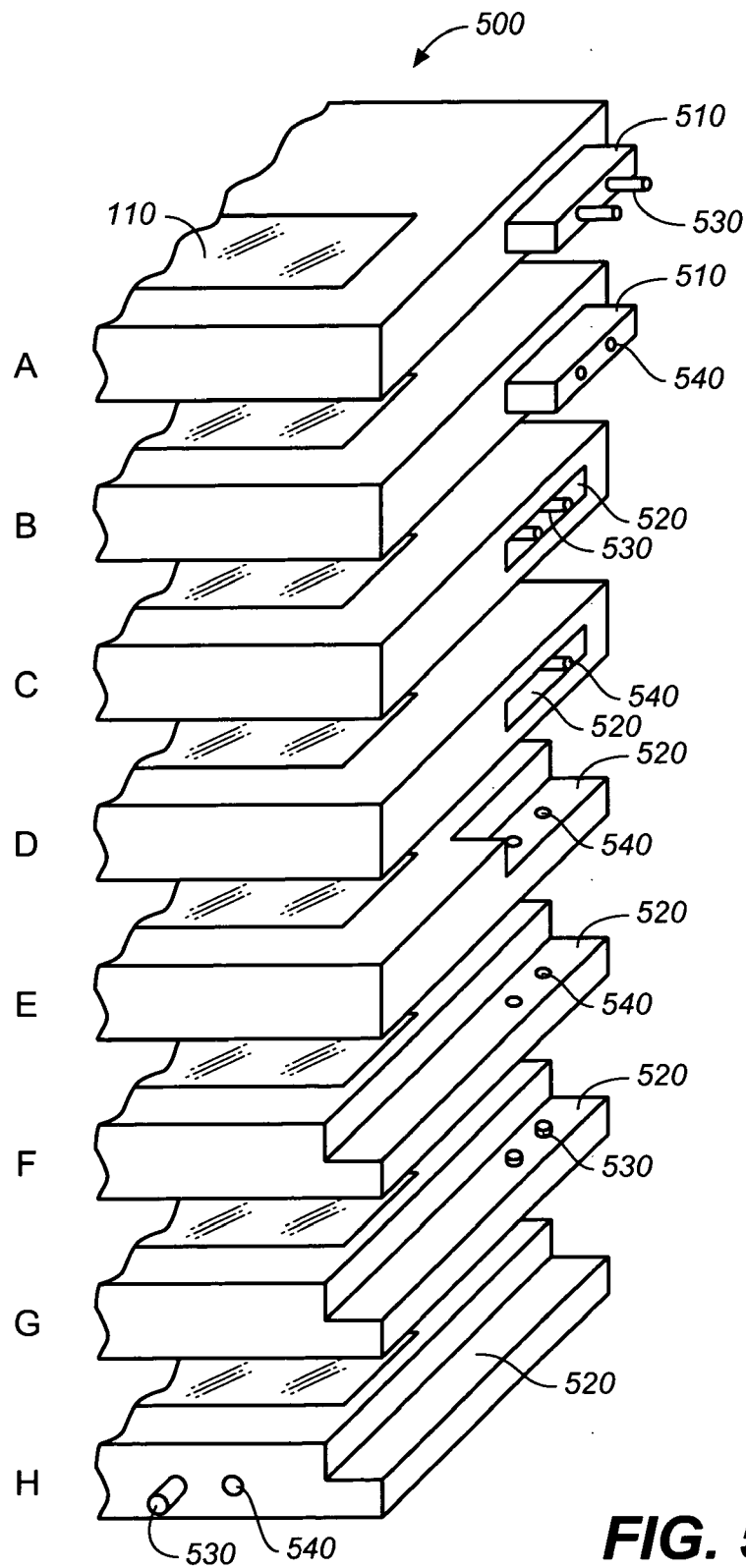


FIG. 5B

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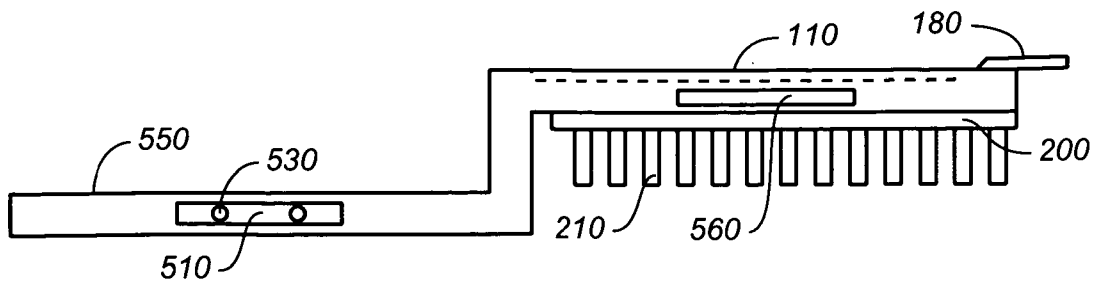


FIG. 5C

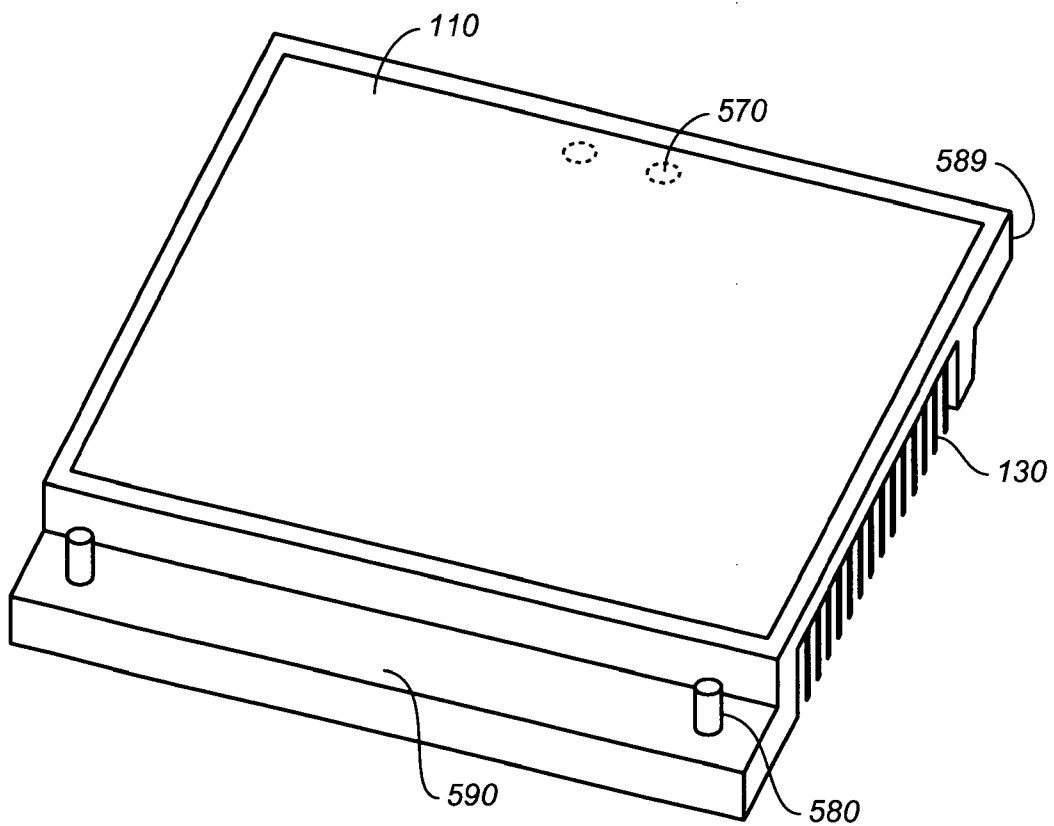
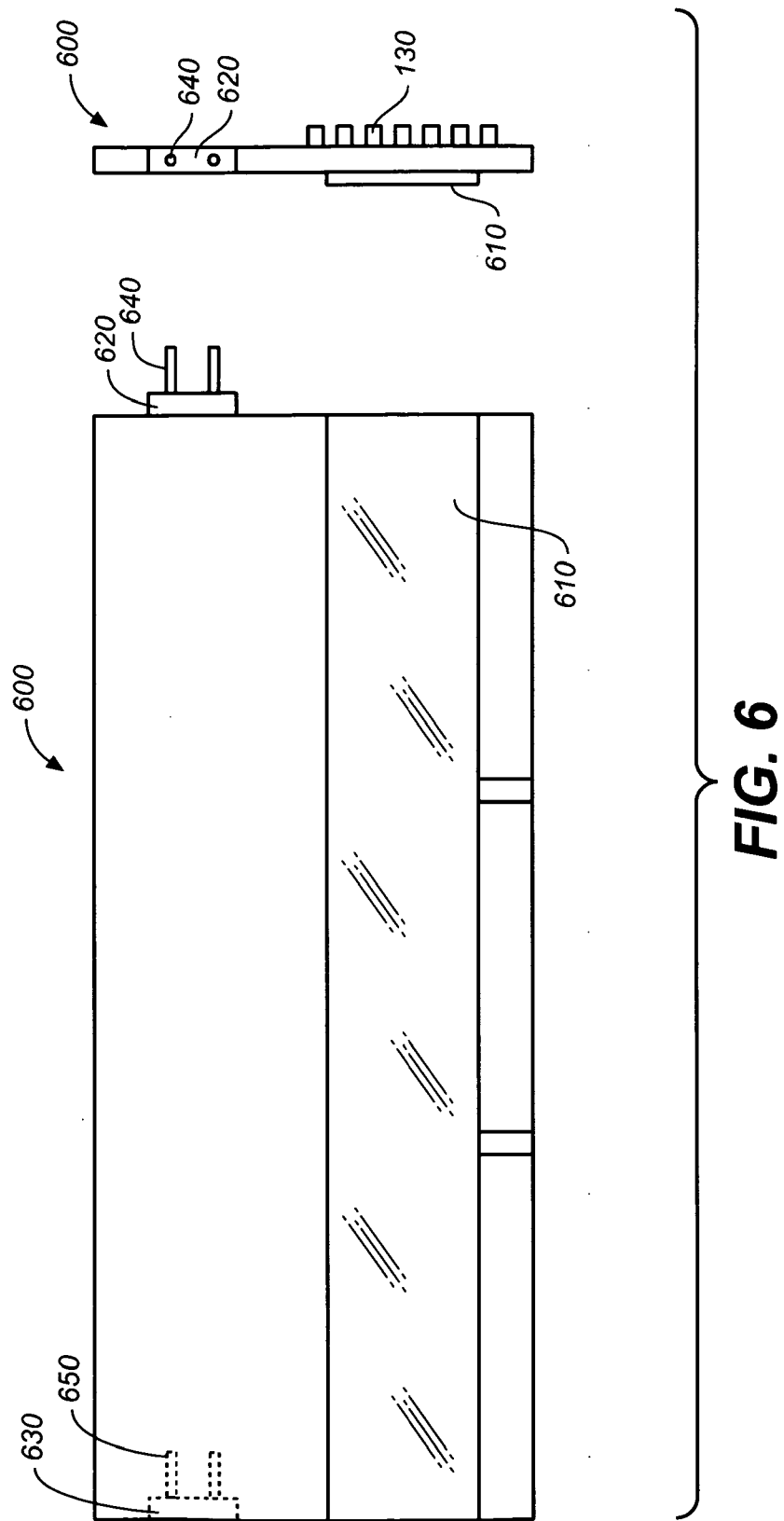


FIG. 5D



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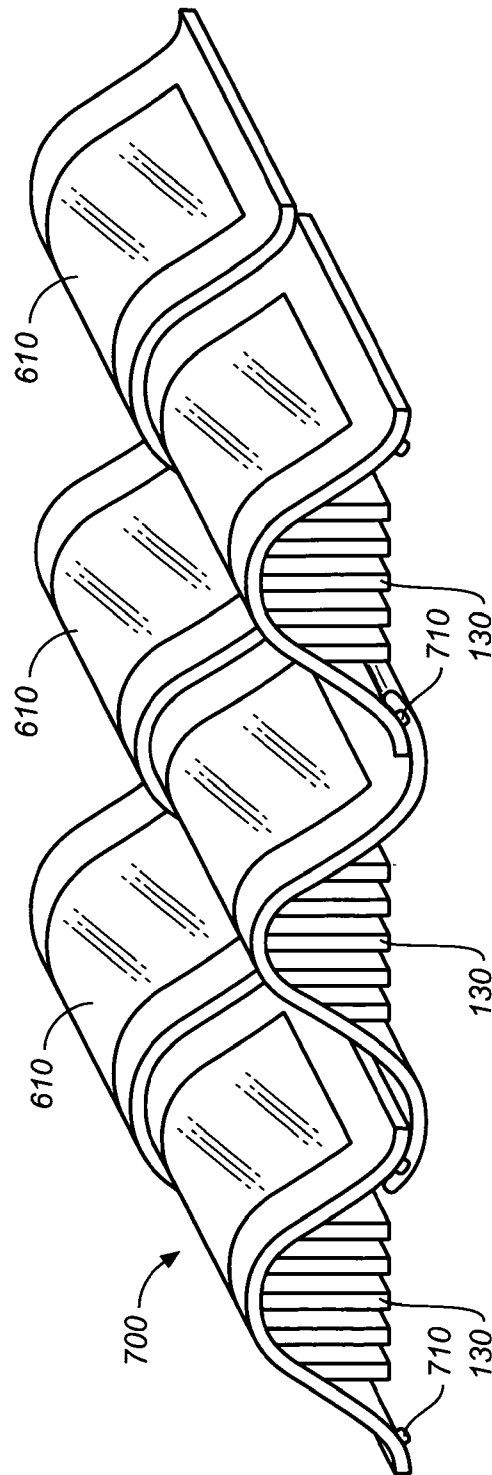


FIG. 7

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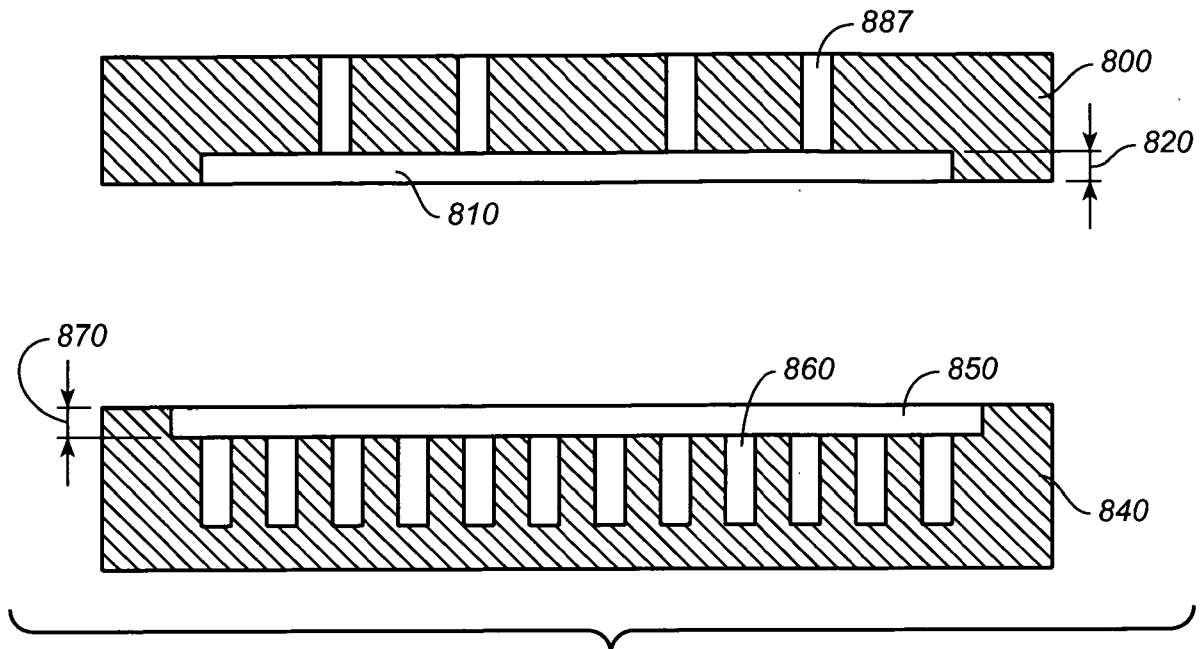


FIG. 8A-1

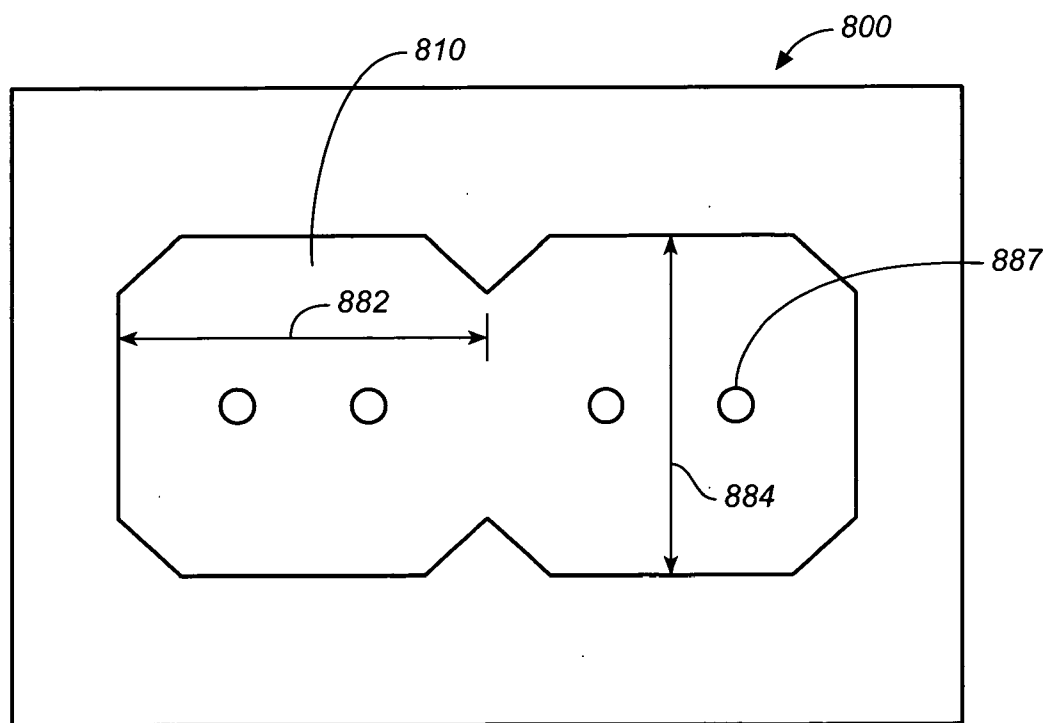
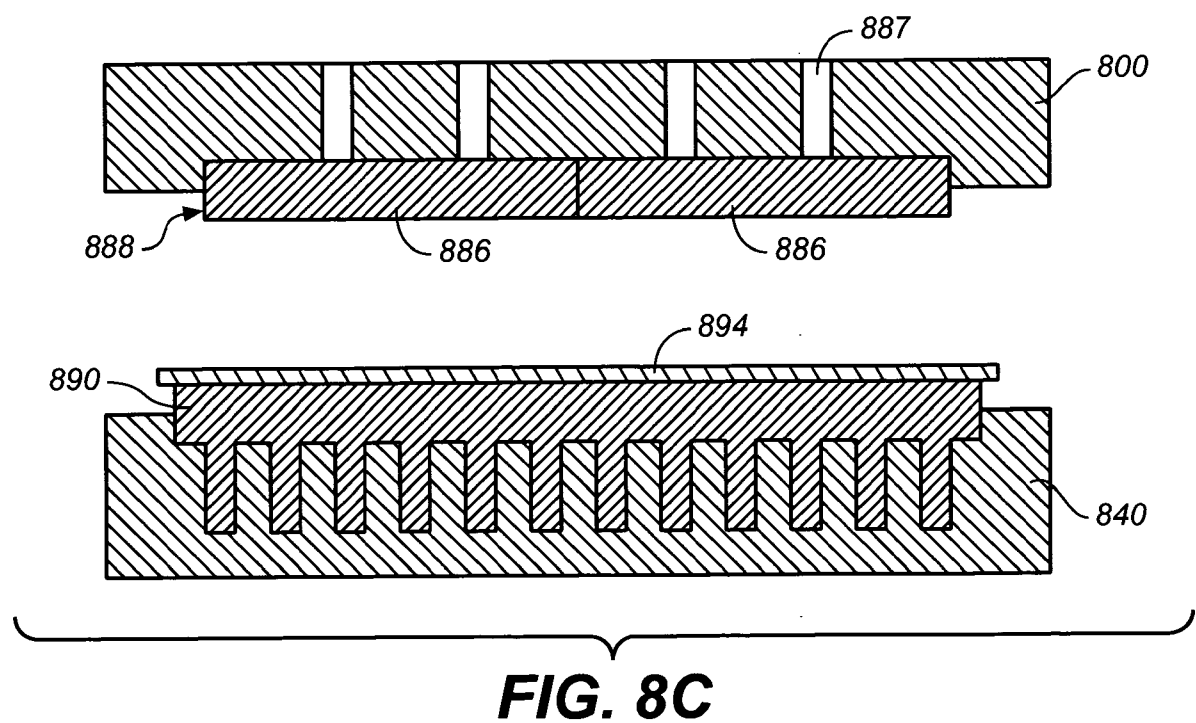
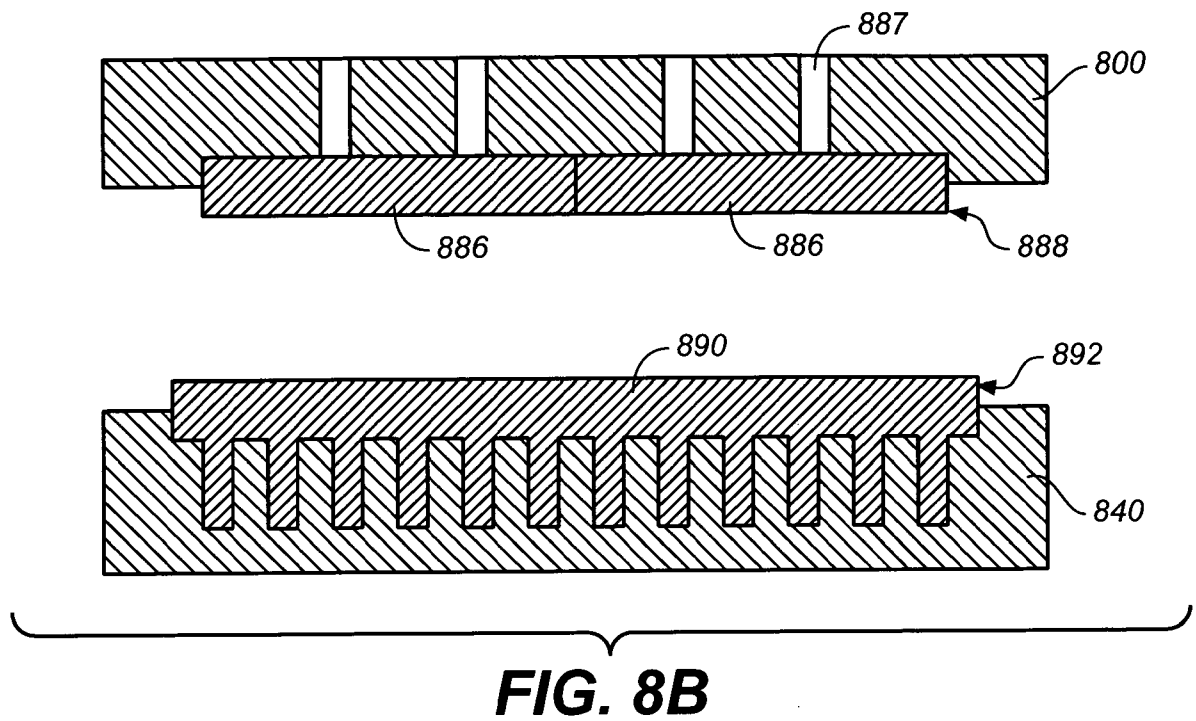


FIG. 8A-2

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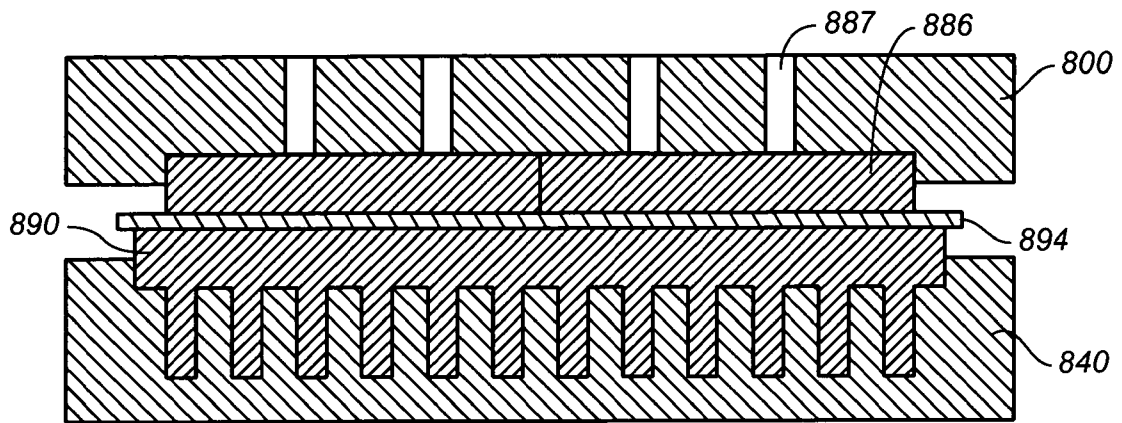


FIG. 8D

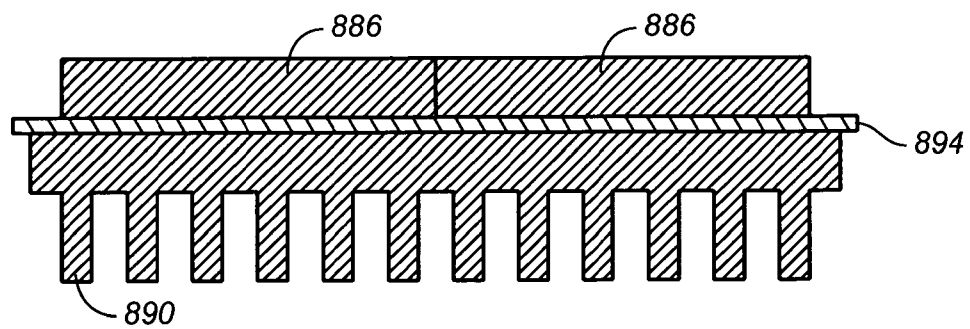
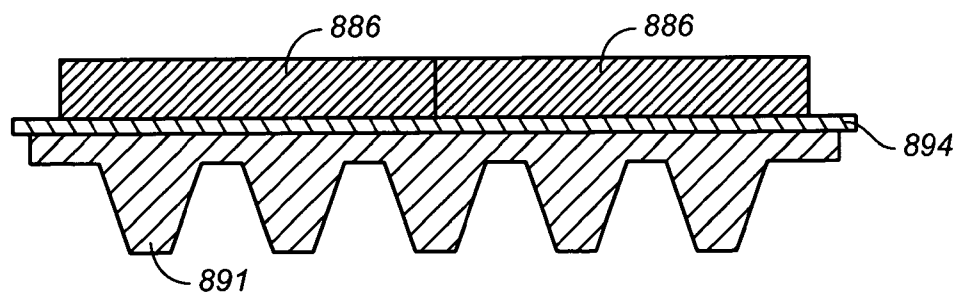
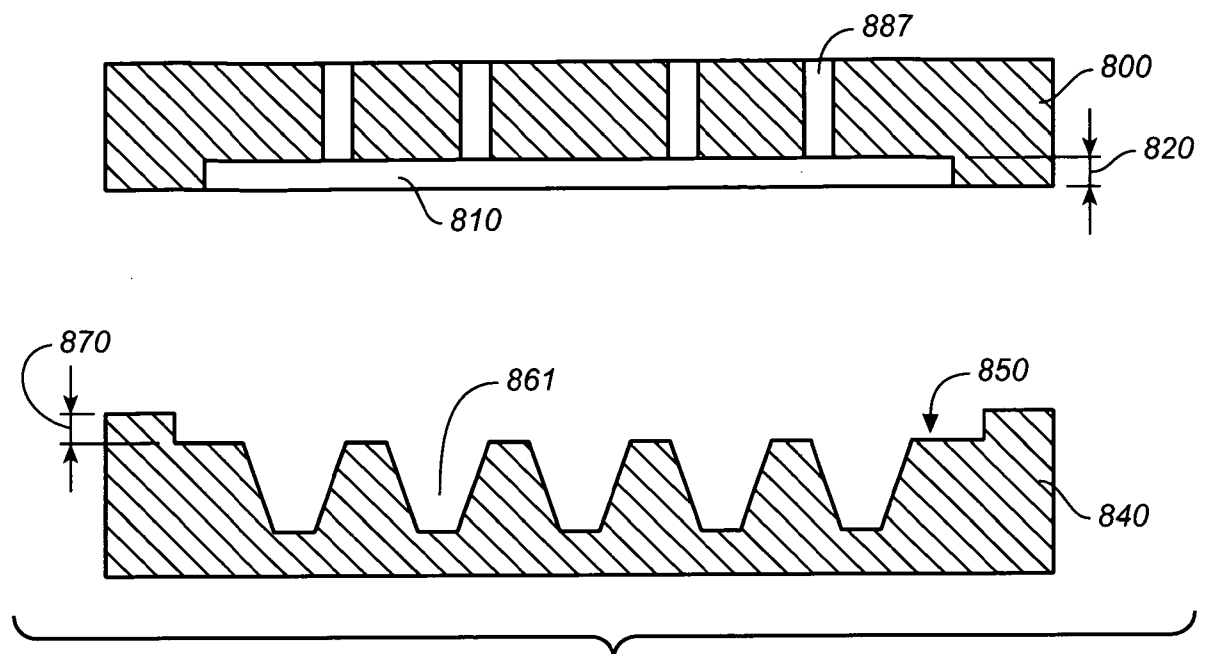
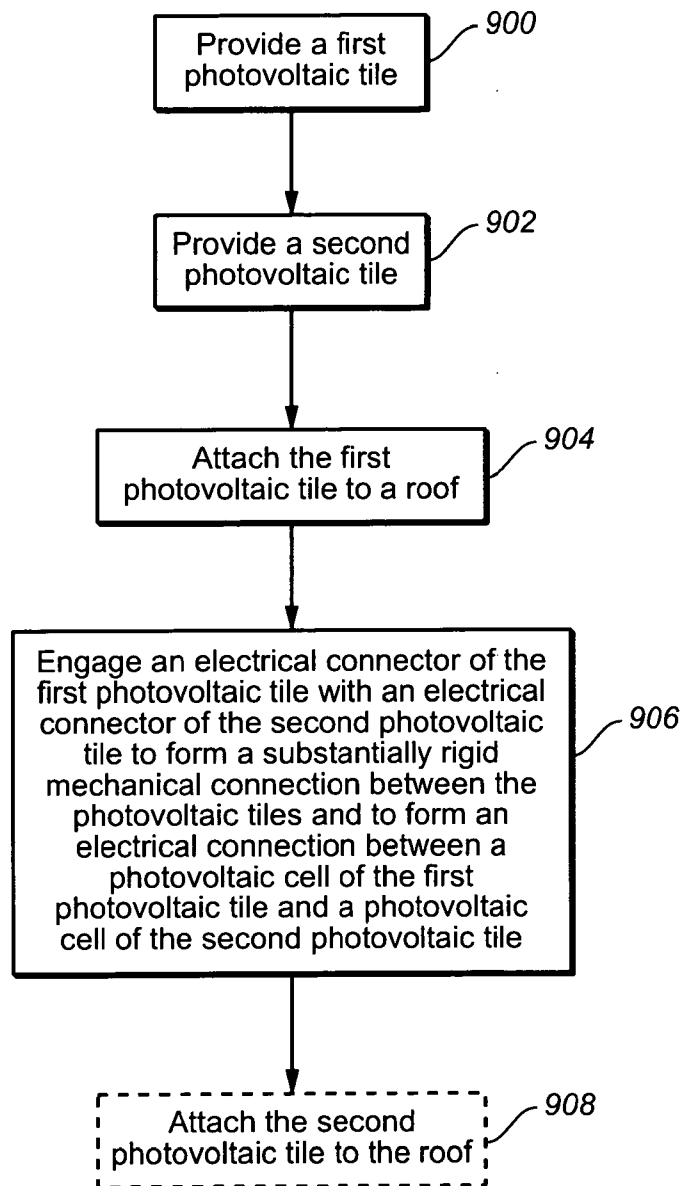


FIG. 8E

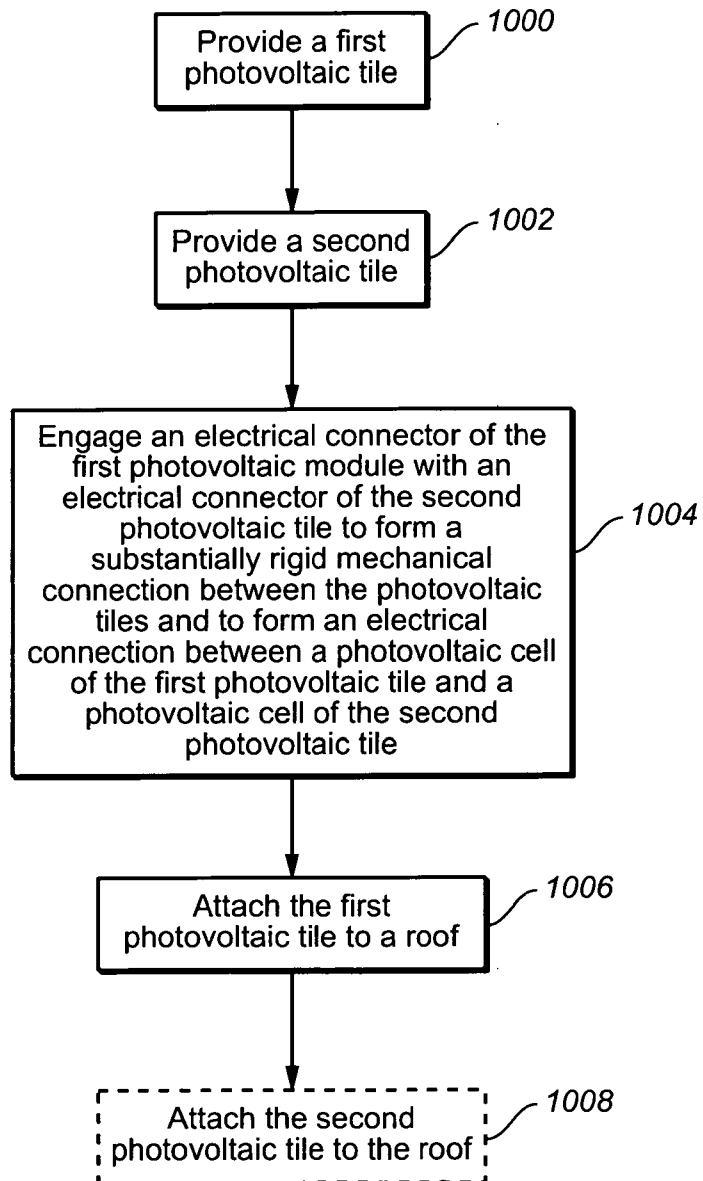
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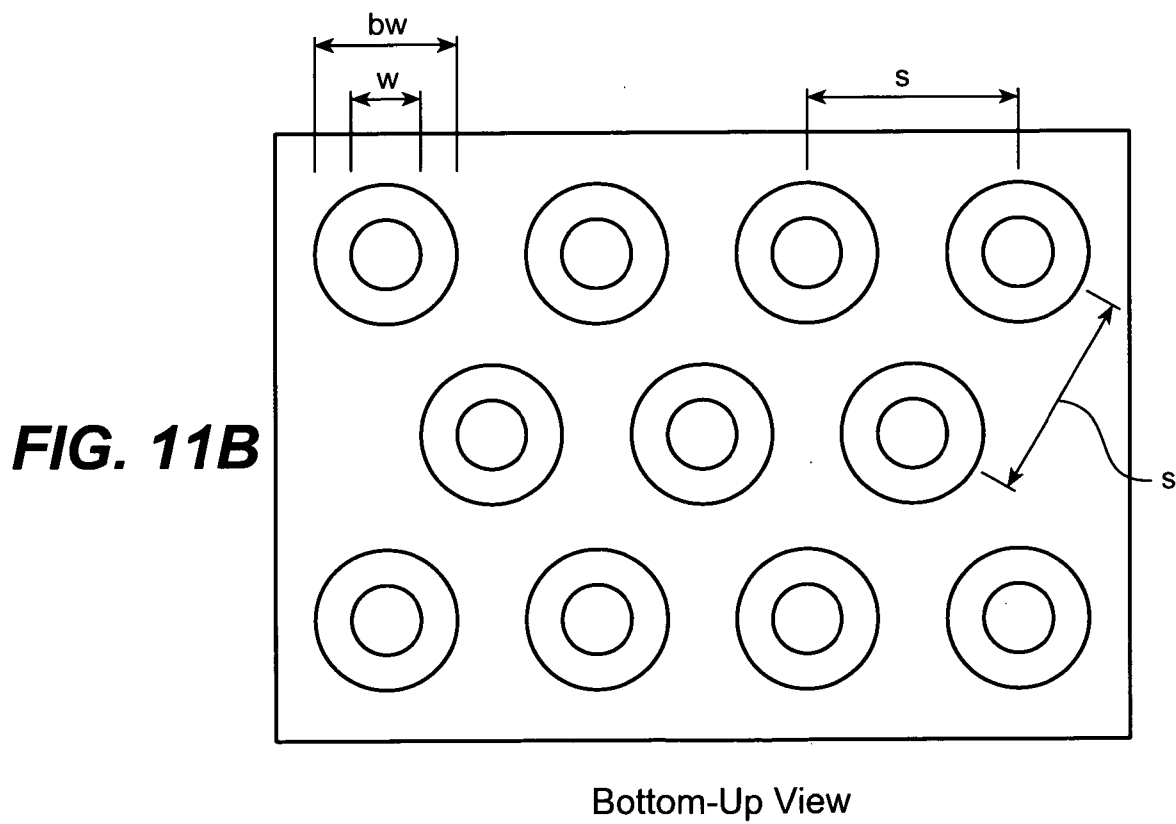
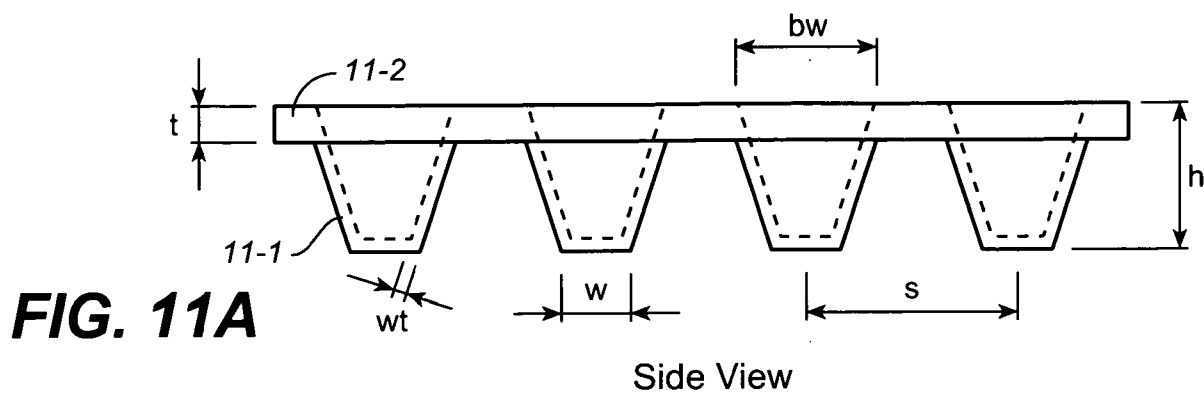
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**FIG. 9**

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**FIG. 10**

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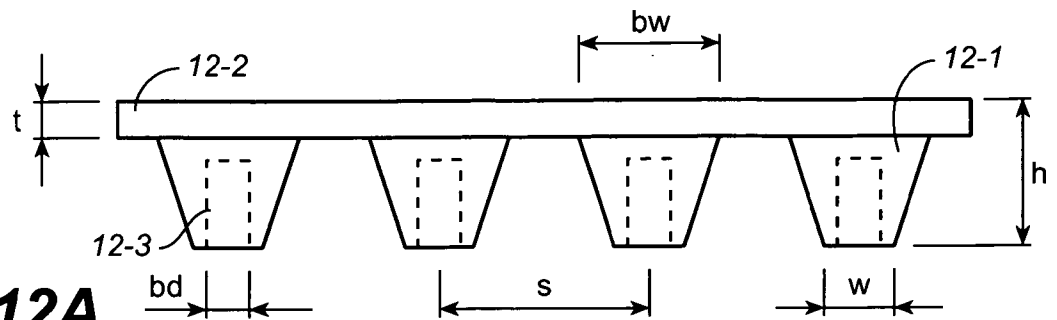


FIG. 12A

Side View

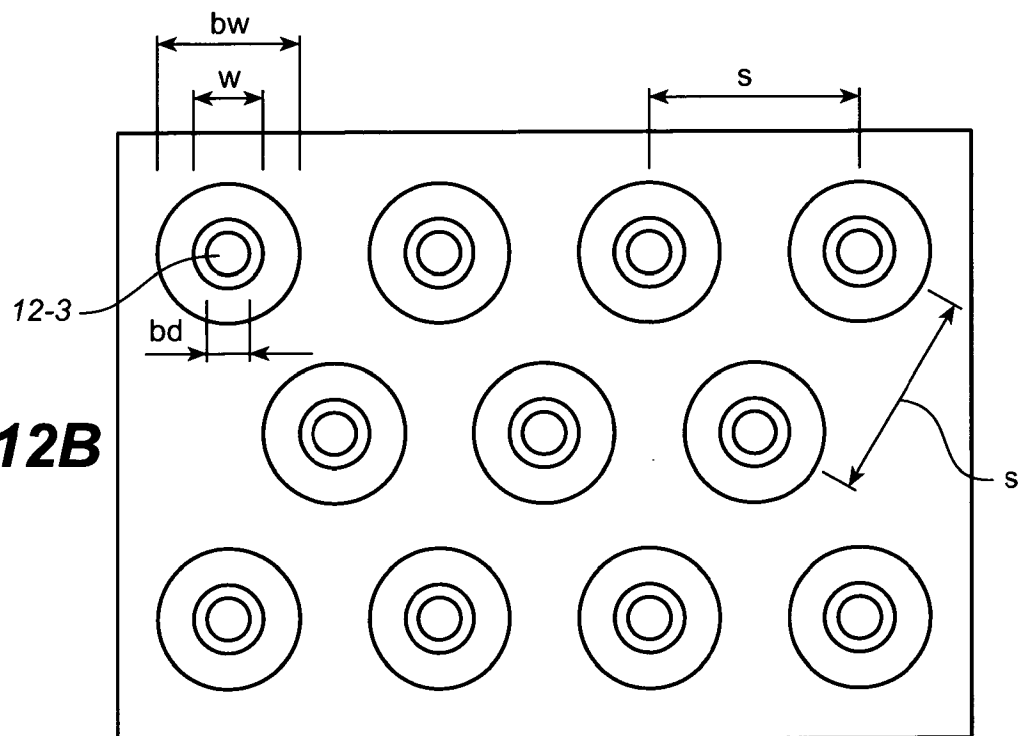


FIG. 12B

Bottom-Up View