Title: SOLAR RECEIVER AND CONVERSION APPARATUS FOR CONCENTRATED PHOTOVOLTAIC SYSTEMS

Abstract: It is the object of the present invention to provide photovoltaic solar receiver and conversion apparatuses, and methods of their manufacture and use. The apparatuses of the present invention are well suited for use in high concentration photovoltaic systems, and particularly in a system which relies on floatational liquid cooling of the receiver.
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SOLAR RECEIVER AND CONVERSION APPARATUS FOR CONCENTRATED PHOTOVOLTAIC SYSTEMS

Cross-Reference to Related Applications

[0001] The present application claims priority to United States Provisional Application No. 61/682,215 filed August 11, 2012, which is hereby incorporated by reference in its entirety including all tables, figures, and claims.

Background of the Invention

[0002] The following discussion of the background of the invention is merely provided to aid the reader in understanding the invention and is not admitted to describe or constitute prior art to the present invention.

[0003] The photovoltaic effect refers to the production of a voltage from a material as a consequence of the absorption of energy from electromagnetic radiation such as visible or ultraviolet radiation. Conventional photovoltaic cells, such as p-n junction solar cells, directly convert energy from light into an electric current. In commercial scale modules or arrays, conventional photovoltaics typically rely on ambient sunlight as the light source. Photons in sunlight hitting the photovoltaic cells are absorbed by the semiconducting material forming the cell. Electrons are displaced from their atoms, creating an electric potential difference in the material. Current flowing through the material to cancel the potential is captured.

[0004] Unlike conventional photovoltaics, which utilize ambient sunlight, concentrated photovoltaic (CPV) technology uses optics such as lenses to concentrate a large amount of sunlight onto a photovoltaic material to generate electricity. At the commercial scale, CPV systems are often much less expensive to produce than
conventional photovoltaics, because the concentration allows for the production of an equivalent amount of energy from a much smaller array of solar cells. CPV systems are categorized according to the amount of their solar concentration, measured in "suns" (the square of the magnification). Low concentration CPV (LCPV) systems refer to systems having a solar concentration of 2-100 suns. Medium concentration CPV (MCVP) refers to systems having a solar concentration of 100 to 300 suns. Typically, MCVP systems require solar tracking systems and cooling (whether passive or active) for operation. High concentration photovoltaics (HCPV) concentrate sunlight to intensities of 100 suns or more.

[0005] In CPV, there is a tradeoff made between concentration number and what is termed the “acceptance angle.” A useful parameter considered when designing a CPV system is the product of the concentration factor times the acceptance angle, which can be expressed as

\[ \text{CAP} = \frac{(C_g)1}{2\sin\alpha} \]

where \( C_g \) is the geometrical concentration factor and \( \alpha \) is the angle of acceptance (defined as the angle of incidence in which the concentrator collects 90% of the power outside of its optical axis). For a given optical concentrator, the CAP is relatively constant, so as the concentration factor increases, the angle of acceptance must decrease. A typical value for CAP is about 0.85. In HCPV, the acceptance angle can be as low as 1 degree. For this reason, HCPV systems require a multi-angle sun tracking system that provides a high degree of precision.

[0006] Another important parameter in CPV system design is uniformity of illumination. The Fresnel lenses typically employed as a concentrating optic produce a Gaussian light profile on the photovoltaic cell surface. In this case, the lens produces a
concentration factor different from point to point and this causes degradation in the photovoltaic cell power output, because there are some regions of the photovoltaic cell where the photovoltaic current exceeds the peak current of the tunnel diodes. For this reason, secondary optics are often used to improve the uniformity of light at the cell surface.

[0007] Photovoltaic cell efficiency decreases as the temperature of the cell increases. In LCPV systems, the heat flux is low enough that the cells do not need to be actively cooled. Typically, however, MCPV and HCPV systems require cooling systems for practical use. Various liquid cooled cooling systems have been disclosed, for example, in U.S. Patents 8,138,457; 7,299,632; and 5,665,174, each of which is hereby incorporated by reference in its entirety.

[0008] While such systems may provide adequate cooling, the liquid sealing of the components can become compromised over time due to heating (daytime) and cooling (nighttime) cycles, exposure to the elements, etc. Liquid intrusion into the collector electronics due to leaks can reduce the efficiency of such systems and create electrical shorts, corrosion, and ultimately failure of the collector. Collectors for these liquid cooled systems also tend to be produced as a single unit which is not easily repaired, so that a failed collector unit must be discarded in its entirety.

[0009] In addition, heating and cooling cycles and the fact that certain portions of the collector design are actively cooled while others are not each affect the alignment of the concentrating optic relative to the photovoltaic cell due to differences in the coefficient of expansion between the various materials used to manufacture the different components. Given the small acceptance angles of such devices, this can degrade the performance of the system.
[0010] Finally, in cooling systems which rely on floating of the collector in a liquid path (e.g., a pond or pool), the frictional interaction between the collector structure and the cooling liquid can hamper performance of the sun tracking system. This is particularly apparent when the collectors are provided as long arrays. In these arrays, consistent tracking of each module in the array is made increasingly difficult due to torsional forces acting across the length of the array and the small acceptance angles inherent in a high concentration system.

[0011] There remains a need in the art to provide improved systems and components for use in CPV energy production.

**Summary of the Invention**

[0012] It is the object of the present invention to provide photovoltaic solar receiver and conversion apparatuses, and methods of their manufacture and use. The apparatuses of the present invention are well suited for use in high concentration photovoltaic systems, and particularly in a system which relies on floatational liquid cooling of the receiver.

[0013] In a first aspect, the present invention provides solar receiver and conversion apparatuses which comprise:

a photovoltaic cell;

a substantially planar layered substrate assembly providing mechanical support for the photovoltaic cell, comprising:

- a electrically nonconductive ceramic substrate having a coefficient of thermal expansion (CTE) approximately equal to that of the photovoltaic cell, the electrically nonconductive substrate comprising (i) an upper surface having a first
central region having a first electrically conductive surface layer positioned thereon, and a first edge region which is electrically nonconductive, and (ii) a lower surface having a second central region having a second electrically conductive surface layer positioned thereon, and a second edge region which is electrically nonconductive,

wherein the first electrically conductive surface layer is electrically isolated from the second electrically conductive surface layer, and wherein the first electrically conductive surface layer is fabricated to provide a first circuit element in electrical communication with the anode of the photovoltaic cell and a second circuit element in electrical communication with the cathode of the photovoltaic cell, and

a first bus connection tab mechanically supported by the substrate assembly in electrical communication with the first circuit element and a second bus connection tab mechanically supported by the substrate assembly in electrical communication with the second circuit element;

a collection optic held in contact with said photovoltaic cell, wherein an upper surface of the collection optic is configured to receive incident light from a concentrating optic and provide substantially uniform illumination at the photoreactive surface of the photovoltaic cell; and

an electrically nonconductive support assembly which is substantially dimensionally stable at temperatures between 0°C and 120°C, the support assembly comprising:

a first subassembly having a first aperture, and a second subassembly which mates with the first subassembly and having a second aperture,
wherein the support assembly is configured to receive the substrate assembly such that (iii) at least a portion of the first and second edge regions are enclosed within the support assembly to retain the substrate assembly within the support assembly and to prevent undesirable electrical discharge from the substrate assembly, (iv) all or substantially all of the first central region lies within the opening provided by the first aperture, and (v) all or substantially all of the second central region lies within the opening provided by the second aperture.

[0014] As used herein, the term “substantially planar” refers to a substrate assembly having an upper and a lower surface, each defined by a first and second lateral dimension, and a thickness between the upper and lower surface, wherein the thickness of the substrate assembly is no more than 10% of the first and second lateral dimensions. Preferably, the thickness of the substantially planar substrate assembly is less than about 5 mm, more preferably less than about 2.5 mm, and most preferably about 1 mm or less.

[0015] The term “about” as used herein with regard to a numeric value refers to +/- 5% of the numeric value.

[0016] The term “electrically nonconductive” as used herein refers to a material which does not pass current across a 0.1 mm length of the material when measured at an applied voltage of 2500V for a period of 3 minutes. Most preferably, an electrically nonconductive material does not pass current across a 0.025 mm length of material when measured at an applied voltage of 2500V for a period of 3 minutes. A preferred electrically nonconductive material is a ceramic or a high temperature plastic. By way of example only, an electrically nonconductive substrate may be formed of Alumina (Al₂O₃), doped Alumina or aluminum nitride.
[0017] Similarly, an electrically nonconductive support assembly may be molded or machined from a high temperature plastic such as PEEK (polyetheretherketone), PFA (a copolymer of tetrafluoroethylene with a perfluoralkyl vinyl ether), PEI (polyetherimide), PTFE (polytetrafluoroethylene), and FEP (fluorinated ethylene propylene). This list is not meant to be limiting.

[0018] The support assembly is preferably configured such that the substrate is retained within the support assembly, but also “floats” within the frame provided by the support assembly. By “floats” is meant that the force applied to the substrate by the support assembly does not change by more than 10% when measured at 0°C and 120°C. This can act to limit the mechanical forces which might deform the substrate within the support assembly due to temperature changes, thereby improving the functional lifetime of the apparatus.

[0019] The term “electrically isolated” refers to two components of a device which are not made of the same continuous piece of a material, and which do not pass current between the two components when measured at an applied voltage of 2500V for a period of 3 minutes. Similarly, the term “undesirable electrical discharge” as used herein refers to the passage of a current between two components of a device which are designed to be electrically isolated from one another during intended normal use of the device.

[0020] The term “bus connection tab” as used herein refers to a conductive strip of a material which provides electrical communication for interconnection of a solar receiver and conversion apparatus of the present invention in a parallel or series configuration with one or more other solar receiver and conversion apparatuses for purposes of collecting the combined electrical energy generated by the interconnected apparatuses. Preferably, the bus connection is configured such that defective receiver and conversion
apparatuses do not degrade the performance of other receiver and conversion apparatuses on the bus, which means that the overall system is only impacted to the extent that the degraded module(s) affects it.

[0021] A first bus bar may be mated to and in electrical communication with the first bus connection tab, and a second bus bar mated to and in electrical communication with the second bus connection tab, and the bus bars may then be attached to the electrical bus. In certain preferred embodiments, the bus bar, when mated to the bus tab and attached to the electrical bus, provides a spring force onto the upper surface of the electrically nonconductive support assembly.

[0022] The term “collection optic” refers to an optical component configured to receive light collected by a concentrating optic and to transmit the received light to a photovoltaic cell, and to provide an increase in the acceptance angle of the collection system, relative to the same system in the absence of a collection optic. Preferably, one surface of the collection optic is held in contact with a photovoltaic cell, and a second surface of the collection optic is positioned relative to the concentrating optic (e.g., a Fresnel lens) at the focal distance of the concentrating optic such that the concentrated light from the concentrating optic is focused on the second surface. Preferred focal lengths for a concentrating optic are between 390 mm and 420 mm.

[0023] In certain embodiments, the first surface of the collection optic is bonded to the surface of the photovoltaic cell with an adhesive material which is optically transparent. The term “optically transparent” as used herein refers to a material which is at least 90%, more preferably at least 95%, and still more preferably at least 99% transmissive to light at the optimal photon wavelength of the photovoltaic cell. A
silicone-based adhesive between 0.5 and 1.5 mm in thickness is most preferred, and can provide greater than 99% transmission of light from the collection optic to the cell.

[0024] Most preferably, the collection optic provides substantially uniform illumination at the photovoltaic cell. The term “substantially uniform illumination” as used herein refers to illumination which is within 10%, and more preferably within 1%, of uniformity across the illumination beam width.

[0025] The collection optic may be provided in a columnar orientation, such as in the form of an elongate frustum. Suitable materials for the collection optic include glass, …

[0026] The term “substantially dimensionally stable” as used herein refers to a material which changes dimension less than 2% at 120°C relative to its dimensions at 0°C.

[0027] In certain embodiments, the solar receiver and conversion apparatuses of the present invention further comprise a substantially planar heat sink reversibly bonded at a first surface thereof to the lower surface of the electrically nonconductive substrate. The term “reversibly bonded” as used herein with regard to a heat sink refers to the use of a material which is thermally conductive to mate a heat sink to another component, and which permits the heat sink to be removed from the other component without destruction of the other component or the heat sink. Examples of suitable thermally conductive pastes, greases, and adhesives are described hereinafter.

[0028] In certain embodiments, the solar receiver and conversion apparatuses of the present invention further comprise a chamber enclosing the photovoltaic element, substrate assembly, collection optic, and support assembly within an interior thereof, the chamber comprising the concentrating optic. When fully assembled, the
apparatus/chamber combination provides a complete CPV module. The chamber is preferably configured to be partially immersed in water at its lower surface without admitting water into the interior thereof such that the heat sink is configured to dissipate heat into the water during this partial immersion. This is most preferably accomplished by configuring the heat sink in the chamber such that a second surface of the heat sink contacts water during this partial immersion. I certain embodiments, this is accomplished by co-molding the heat sink into the chamber, such that no additional sealing mechanism is required to prevent water ingress around the edges of the heat sink which are in contact with the chamber.

[0029] Preferably, the concentrating optic is provided as the upper surface of the chamber. This concentrating optic may be attached to the chamber by glues; may be attached by fasteners such as screws; may be sealed in a watertight manner to the chamber using a gasket material; may be attached by clips; or by combinations of the foregoing.

[0030] In certain embodiments, the heat sink is copper, aluminum, a copper alloy or an aluminum alloy. This list is not meant to be limiting.

[0031] In certain embodiments, the first electrically conductive layer and the second electrically conductive layer each comprise a layer of gold, copper, or other electrically conductive metal which is less than 1mm in thickness. In preferred embodiments, each electrically conductive layer is provided as a flash layer of gold or copper 0.01 to 0.4 μm in thickness. Additional protection from abrasion, moisture, and other environmental conditions may be optionally provided by sealing the first and/or second conductive layer with a material such as a silicone-based adhesive in one or more regions. In certain
embodiments, this material is the same material used for bonding the collection optic to the photocell.

[0032] In a related aspect, the present invention relates to a method of manufacturing a photovoltaic solar receiver and conversion apparatus as described herein. The methods comprise:

mating a photovoltaic cell to a substantially planar layered substrate assembly, the substrate assembly comprising:

a electrically nonconductive ceramic substrate having a coefficient of thermal expansion (CTE) approximately equal to that of the photovoltaic cell, the electrically nonconductive substrate comprising (i) an upper surface having a first central region having a first electrically conductive surface layer positioned thereon, and a first edge region which is electrically nonconductive, and (ii) a lower surface having a second central region having a second electrically conductive surface layer positioned thereon, and a second edge region which is electrically nonconductive,

wherein the first electrically conductive surface layer is electrically isolated from the second electrically conductive surface layer, and

a first bus connection tab mechanically supported by the substrate assembly and a second bus connection tab mechanically supported by the substrate assembly,

wherein the first electrically conductive surface layer provides circuitry which provides electrical communication between the first bus tab and the anode of the photovoltaic cell and electrical communication between the second bus tab and the cathode of the photovoltaic cell;
mating a collection optic to said photovoltaic cell; and

mating the substrate assembly to an electrically nonconductive support assembly which is substantially dimensionally stable at temperatures between 0°C and 120°C, the support assembly comprising:

- a first subassembly having a first aperture, and a second subassembly which mates with the first subassembly and having a second aperture,

wherein the support assembly is configured to receive the substrate assembly such that:

(iii) at least a portion of the first and second edge regions are enclosed within the support assembly to retain the substrate assembly within the support assembly and to prevent undesirable electrical discharge from the substrate assembly,

(iv) all or substantially all of the first central region lies within the opening provided by the first aperture, and

(v) all or substantially all of the second central region lies within the opening provided by the second aperture.

[0033] In certain embodiments, the methods comprise connecting a first bus bar in electrical communication with the first bus connection tab, and connecting a second bus bar in electrical communication with the second bus connection tab.

[0034] It still other embodiments, the methods comprise reversibly bonding the lower surface of the electrically nonconductive substrate to a substantially planar heat sink. As noted above, the heat sink is preferably provided as a component of a chamber which then encloses the photovoltaic element, substrate assembly, collection optic, and support assembly within an interior thereof.

[0035] In further embodiments, once the chamber encloses the photovoltaic element, substrate assembly, collection optic, and support assembly within an interior thereof, the
methods further comprise placing a concentrating optic at a distance from a light receiving surface of the collection optic which is about equal to the focal length of the concentrating optic, thereby forming a CPV module of the present invention. Preferably, the concentrating optic is sealed to the chamber in a watertight manner.

[0036] In other related embodiments, the present invention comprises methods for generating electrical energy from sunlight. These methods comprise:

positioning a CPV module as described herein relative to incident sunlight such that sunlight received by the concentrating optic is focused on the light receiving surface of the collection optic;

positioning the CPV module relative to a source of cooling fluid such that at least a second surface of the heat sink contacts the fluid and dissipates heat generated by the solar receiver and conversion apparatus; and

collecting the electrical energy generated by the photovoltaic cell.

[0037] Other embodiments of the invention will be apparent from the following detailed description, figures, and claims.

**Brief Description of the Drawings**

[0038] Fig. 1 depicts an exploded view of a solar receiver and conversion apparatus according to the present invention.

[0039] Fig. 2 depicts three views of a solar receiver and conversion apparatus according to the present invention.
Detailed Description of the Invention

[0040] One skilled in the art readily appreciates that the present invention is well adapted to carry out the objects and obtain the ends and advantages mentioned, as well as those inherent therein. The detailed description provided herein are representative of preferred embodiments, are exemplary, and are not intended as limitations on the scope of the invention.

[0041] Fig. 1 depicts various components of a solar receiver and conversion apparatus according to the present invention. A photovoltaic cell package 1 is formed by attaching a photovoltaic cell to a substrate which provides a number of functions to the package. First, while silicon provides almost ideal as a solar cell material, it is mechanically fragile. Thus, the substrate can provide mechanical support for the photovoltaic cell. Second, by providing an edge region which is electrically nonconductive, the substrate can aid in preventing short-circuits by isolating the edge of the photovoltaic cell package. Third, an electrically conductive layer on the upper surface of the substrate can provide electrical interconnects between the anode and cathode of the photovoltaic cell and the electrical energy gathering portions of the solar receiver and conversion apparatus. Finally, the lower surface of the substrate can act to transfer heat energy generated during energy production to an underlying heat sink.

[0042] Advantageously, manufacture of the substrate can be performed using traditional semiconductor package technologies. The main body of the substrate is preferably made of a nonconductive ceramic material commonly used for semiconductor manufacturing such as alumina (Al₂O₃), doped alumina or aluminum nitride. Such substrates will have a CTE approximately equal to that of the photovoltaic cell, thus helping to control stresses on the cell across the range of temperatures typically
encountered during use (e.g., about 0°C to about 125°C). A metal film (e.g., copper) is deposited on both sides of a semiconductor wafer to form the conductive regions of the substrate. A conductive support layer, e.g. gold, is deposited on the upper surface of the metal film layers. A photoresist can be applied over the device side of the substrate to form a designed set of interconnects to the photovoltaic cell on the substrate.

[0043] Conductive wires may be attached near the edge of each device so that the devices are electrically connected to external components. Alternatively, bus tabs 11 may be coupled to the anode and cathode of the photovoltaic cell via conductive pathways on the device side of the substrate. The use of these bus tabs 11 and corresponding bus bars 4, 5 can provide substantially improved resistance characteristics relative to wired connections.

[0044] As noted above, providing an edge region which is electrically nonconductive to the upper and lower surfaces of the substrate can prevent undesirable electrical shunts between the upper and lower surfaces of the substrate. A further improvement in edge isolation can be provided by the inclusion of an electrically nonconductive support assembly which receives the substrate. Typical preferred characteristics for suitable materials include a dielectric strength of > 3kV/mm; operational stability to at least 125°C, a geometric tolerance of ≤ 0.1 mm between 0°C and 125°C; a tensile strength of ≥14,000 psi, a flexure strength of ≥24,000 psi, and a compressive strength of ≥15,000 psi. Materials which may be used to form the support assembly include plastics which are insulating and stable at the operating temperatures of the apparatus. Such materials include PEEK (polyetheretherketone), PFA (a copolymer of tetrafluoroethylene with a perfluoralkyl vinyl ether), PEI (polyetherimide), PTFE (polytetrafluoroethylene), and FEP (fluorinated ethylene propylene). Additives to such plastic materials such as glass-
filling and/or the addition of UV stabilizers may be employed to improve their stability characteristics as desired.

[0045] As shown in Fig. 1, this support assembly is formed by an upper 6 and lower 7 subassembly which forms a sandwich with the substrate 1. The subassemblies are attached to one another with a system of screws or other similar fasteners. These screws do not pass through substrate 1, which is allowed to sit into a recess in the lower subassembly 7, as this permits the substrate to be firmly held within the support assembly, but to “float” in the frame provided to hold substrate 1, thereby preventing strain on the substrate as the screws are firmly seated. A first aperture 13 in the upper subassembly 6 permits access to the photoactive surface of the photoelectric cell. A second aperture 14 in the lower subassembly permits access to the lower surface of substrate 1 for cooling of the apparatus.

[0046] The upper subassembly 6 also can provide for attachment of the bus tabs and bus bars. As depicted, but tabs 11 may be folded into corresponding recesses 12 in upper subassembly 6. Bus bars 4 and 5 are then attached to these bus tabs by a system of screws 9 and threaded inserts 10. Again, these screws do not pass through substrate 1, thereby preventing strain on the substrate as the screws are firmly seated. A force applied to the upper surface of the bus bars can provide a controlled spring force on the support assembly, providing additional mechanical stability to the apparatus as a whole.

[0047] A collection optic 2 may be seated against the photoactive surface of the photoelectric cell in order to provide an increase in the acceptance angle of the collection system, relative to the same system in the absence of a collection optic. Secondary collection optics can provide further concentration relative to the primary concentrating optic, increase acceptance angles by providing a larger target for the concentrated beam from the primary concentrating optic, shape the beam cross-section prior to striking the
photovoltaic cell, and improve beam uniformity to avoid “hot spots” on the photovoltaic
cell. Suitable shapes for collection optics include, but are not limited to frustrums
(truncated cones and truncated pyramids), compound parabolic collectors, kaleidoscopes,
aspheric lenses, prisms, etc. As depicted in Fig. 1, collection optic 2 is positioned to
receive energy through the upper surface thereof, reflect the energy from the interior
surface of the optic, and output the reflected energy to the photovoltaic cell through the
lower surface 3 thereof. BK7, fused silica, crown glass, and fused quart are suitable
materials for the collection optic.

[0048] The collection optic is preferably bonded at its lower surface 3 to the
photovoltaic cell using an optically transparent adhesive. Suitable adhesives include
silicone-based adhesives such as NuSil LS-6941 and LS-6140, Sylgard ® Silicone
Elastomer (Dow Corning), and ELASTOSIL® Solar 2202 (Wacker) adhesives. This list
is not meant to be limiting. Thickness of the adhesive layer may be varied for particular
design criteria, with thicknesses between 0.5 and 1.5 mm preferred. Thinner layers of
adhesive may necessitate the use of a mechanical support for the collection optic. The
adhesive may be applied to the optic surface and allowed to at least partially cure prior to
matting of the collection optic to the photovoltaic cell; may be applied to the photovoltaic
cell and allowed to at least partially cure prior to mating of the collection optic to the
photovoltaic cell; may be applied to the optic surface and the collection optic mated to the
photovoltaic cell prior to curing; may be applied to the photovoltaic cell and the
collection optic mated to the photovoltaic cell prior to curing; or combinations of these
techniques.

[0049] The same adhesive material may optionally be allowed to flow over the
surface of the solar cell and at least part of the substrate in order to provide abrasion and
environmental protection. In this case, it is advantageous to use the support assembly as a mask to prevent adhesive from reaching the edges of the substrate.

[0050] Fig. 2 depicts top (A), side (B) and bottom (C) views of the assembled solar receiver and conversion apparatus. Dimensions indicated (in mm) represent the approximate dimensions suitable for use with a Fresnel primary concentrating optic having a focal length of between 390 mm and 420 mm. These dimensions can provide an excellent tradeoff between size and performance characteristics in fluid-cooled flotation collector structures.

[0051] As shown in Fig. 2C, the lower face of substrate 1 is accessible through aperture 14 of lower subassembly 7. In a liquid-cooled application, this lower face is brought into contact with a heat sink (not shown) for dissipation of heat from the apparatus. A thermally conductive grease, paste, or adhesive is preferably used to improve thermal transfer to the heat sink. Examples of suitable materials include JetArt Nano Diamond Thermal Compound, 3M™ Thermally Conductive Grease 2037, and various Arctic Silver™ (Arctic Silver, Inc.) compounds and adhesives. The heat sink may be made of aluminum alloys, copper, diamonds, copper-tungsten pseudoalloy, AlSiC (silicon carbide in aluminium matrix), Dymalloy (diamond in copper-silver alloy matrix), and E-Material (beryllium oxide in beryllium matrix). Such materials provide a thermal expansion coefficient which can be matched to ceramics and semiconductors.

[0052] The heat sink is preferably provided as part of a chamber which encloses the solar receiver and conversion apparatus within an interior thereof and which comprises the concentrating optic at the top thereof. When fully assembled, the apparatus/chamber combination provides a complete CPV module. The chamber can provide a liquid-sealed enclosure in a liquid-cooled application. In these applications, the heat sink can be sealed within a lower portion of the chamber using adhesives or a fastener and seal system, but
is preferably provided as a co-molded portion of the chamber to minimize leakage, as this lower portion of the chamber is of necessity placed in contact with the cooling fluid.

[0053] It will be readily apparent to a person skilled in the art that varying substitutions and modifications may be made to the invention disclosed herein without departing from the scope and spirit of the invention.

[0054] All patents and publications mentioned in the specification are indicative of the levels of those of ordinary skill in the art to which the invention pertains. All patents and publications are herein incorporated by reference to the same extent as if each individual publication was specifically and individually indicated to be incorporated by reference.

[0055] The invention illustratively described herein suitably may be practiced in the absence of any element or elements, limitation or limitations which is not specifically disclosed herein. Thus, for example, in each instance herein any of the terms “comprising”, “consisting essentially of” and “consisting of” may be replaced with either of the other two terms. The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention that in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention as defined by the appended claims.

[0056] Other embodiments are set forth within the following claims.
We claim:

1. A solar receiver and conversion apparatus, comprising:

   a photovoltaic cell;

   a substantially planar layered substrate assembly providing mechanical support for the photovoltaic cell, comprising:

   a electrically nonconductive ceramic substrate having a coefficient of thermal expansion (CTE) approximately equal to that of the photovoltaic cell, the electrically nonconductive substrate comprising (i) an upper surface having a first central region having a first electrically conductive surface layer positioned thereon, and a first edge region which is electrically nonconductive, and (ii) a lower surface having a second central region having a second electrically conductive surface layer positioned thereon, and a second edge region which is electrically nonconductive,

   wherein the first electrically conductive surface layer is electrically isolated from the second electrically conductive surface layer, and wherein the first electrically conductive surface layer is fabricated to provide a first circuit element in electrical communication with the anode of the photovoltaic cell and a second circuit element in electrical communication with the cathode of the photovoltaic cell, and

   a first bus connection tab mechanically supported by the substrate assembly in electrical communication with the first circuit element and a second bus connection tab mechanically supported by the substrate assembly in electrical communication with the second circuit element;

   a collection optic held in contact with said photovoltaic cell, wherein an upper surface of the collection optic is configured to receive incident light from a concentrating optic and provide substantially uniform illumination at the photoreactive surface of the photovoltaic cell;

   an electrically nonconductive support assembly which is substantially dimensionally stable at temperatures between 0°C and 120°C, the support assembly comprising:
a first subassembly having a first aperture, and a second subassembly which mates with the first subassembly and having a second aperture,

wherein the support assembly is configured to receive the substrate assembly such that (iii) at least a portion of the first and second edge regions are enclosed within the support assembly to retain the substrate assembly within the support assembly and to prevent undesirable electrical discharge from the substrate assembly, (iv) all or substantially all of the first central region lies within the opening provided by the first aperture, and (v) all or substantially all of the second central region lies within the opening provided by the second aperture.

2. A solar receiver and conversion apparatus according to claim 1, further comprising a substantially planar heat sink reversibly bonded at a first surface thereof to the lower surface of the electrically nonconductive substrate using a thermally conductive paste, grease, or adhesive.

3. A solar receiver and conversion apparatus according to claim 2, further comprising a chamber enclosing the photovoltaic element, substrate assembly, collection optic, and support assembly within an interior thereof, the chamber comprising the concentrating optic, the chamber configured to be partially immersed in water at its lower surface without admitting water into the interior thereof, and wherein the heat sink is configured to dissipate heat into the water during said partial immersion.

4. A solar receiver and conversion apparatus according to claim 3, wherein a second surface of the heat sink contacts water during said partial immersion.

5. A solar receiver and conversion apparatus according to claim 4, wherein the heat sink is co-molded into the chamber.

6. A solar receiver and conversion apparatus according to claim 5, wherein the heat sink is copper, aluminum, a copper alloy or an aluminum alloy.

7. A solar receiver and conversion apparatus according to claim 1, wherein the first electrically conductive layer and the second electrically conductive layer each comprise a layer of copper less than 1mm in thickness.
8. A solar receiver and conversion apparatus according to claim 7, wherein the first electrically conductive layer and the second electrically conductive layer further comprise a flash layer of gold, silver or platinum 0.01 to 0.4 µm in thickness.

9. A solar receiver and conversion apparatus according to claim 1, wherein the first conductive layer is sealed with a silicone-based adhesive in one or more regions.

10. A solar receiver and conversion apparatus according to claim 1, wherein the electrically nonconductive ceramic substrate comprises Alumina (Al₂O₃), doped Alumina or aluminum nitride.

11. A solar receiver and conversion apparatus according to claim 1, wherein the support assembly is molded or machined from high temperature plastic.

12. A solar receiver and conversion apparatus according to claim 1, wherein the collection optic is in the form of an elongate frustum.

13. A solar receiver and conversion apparatus according to claim 1, wherein the collection optic is bonded to the photovoltaic cell by a layer of a silicone-based glue which transmits at least 95% of the light from the collection optic to the photovoltaic cell.

14. A solar receiver and conversion apparatus according to claim 1, wherein the layer of the silicone-based glue is between 0.5 and 1.5 mm in thickness.

15. A solar receiver and conversion apparatus according to claim 12, wherein the collection optic is formed from glass.

16. A solar receiver and conversion apparatus according to claim 1, further comprising a first bus bar mated to and in electrical communication with the first bus connection tab, and a second bus bar mated to and in electrical communication with the second bus connection tab.

17. A solar receiver and conversion apparatus according to claim 16, wherein the first and second bus bars are configured to apply a spring force on the support assembly without applying a spring force to the substrate assembly retained within the support assembly.