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(54) METHOD OF MANUFACTURING FLEXIBLE, LIGHTWEIGHT PHOTOVOLTAIC ARRAY

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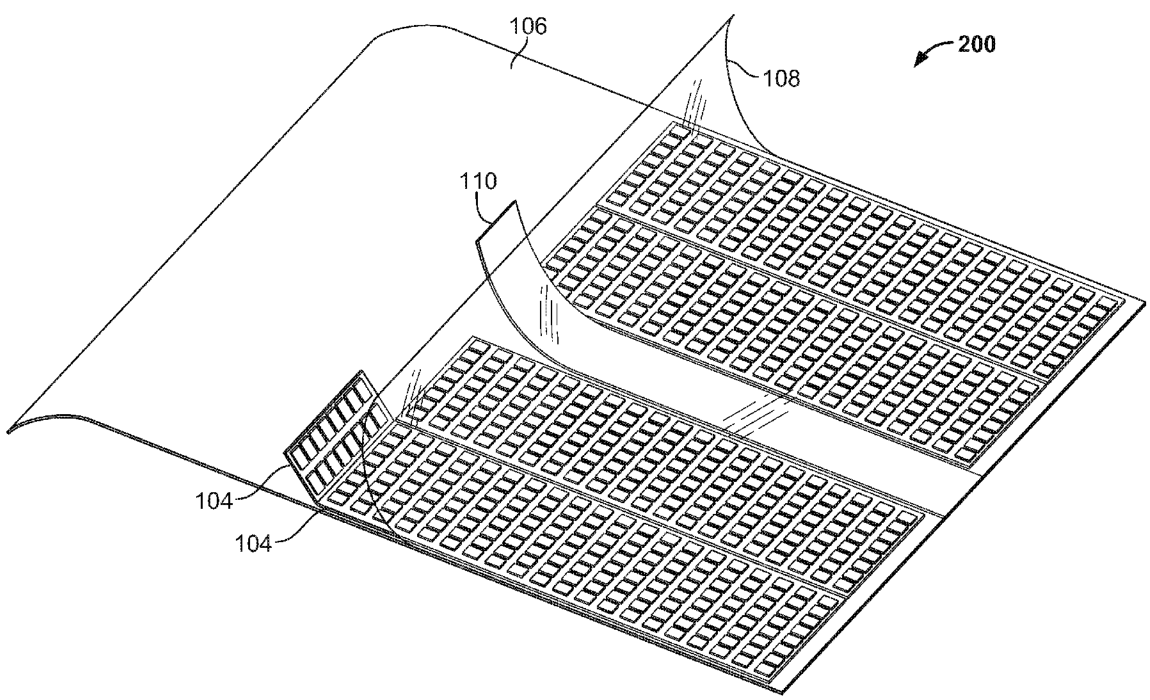
(57) **ABSTRACT**

A flexible, lightweight photovoltaic cell array includes one or more individual photovoltaic cell strings attached to a polyimide film substrate and covered with a polyvinyl fluoride film. Each photovoltaic cell string includes one or more photovoltaic cells attached to a flexible printed circuit board. The photovoltaic cell array may be manufactured by a method that includes bonding at least one photovoltaic cell to a flexible printed circuit board, mounting the flexible printed circuit board on a polyimide film substrate, and covering the flexible printed circuit board with a substantially transparent polyvinyl fluoride film.



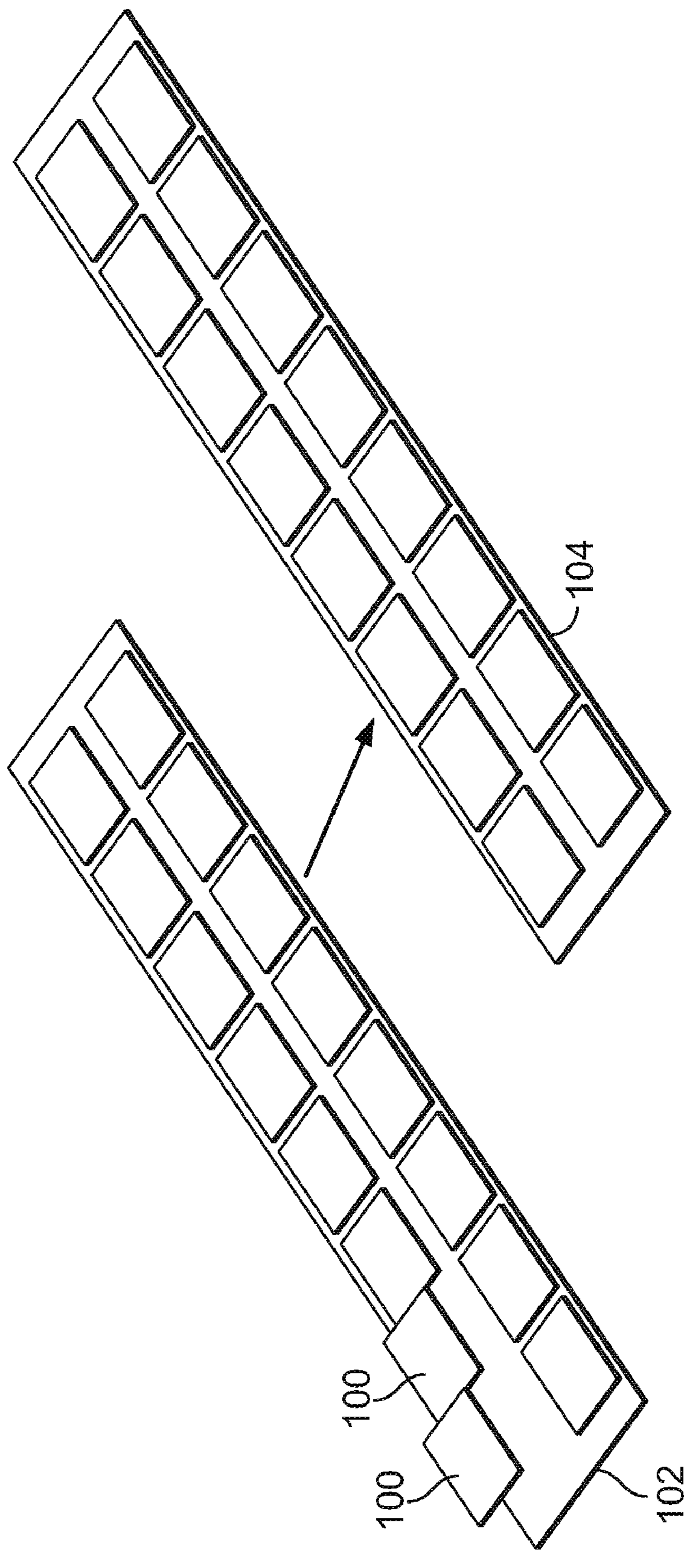


FIG. 1

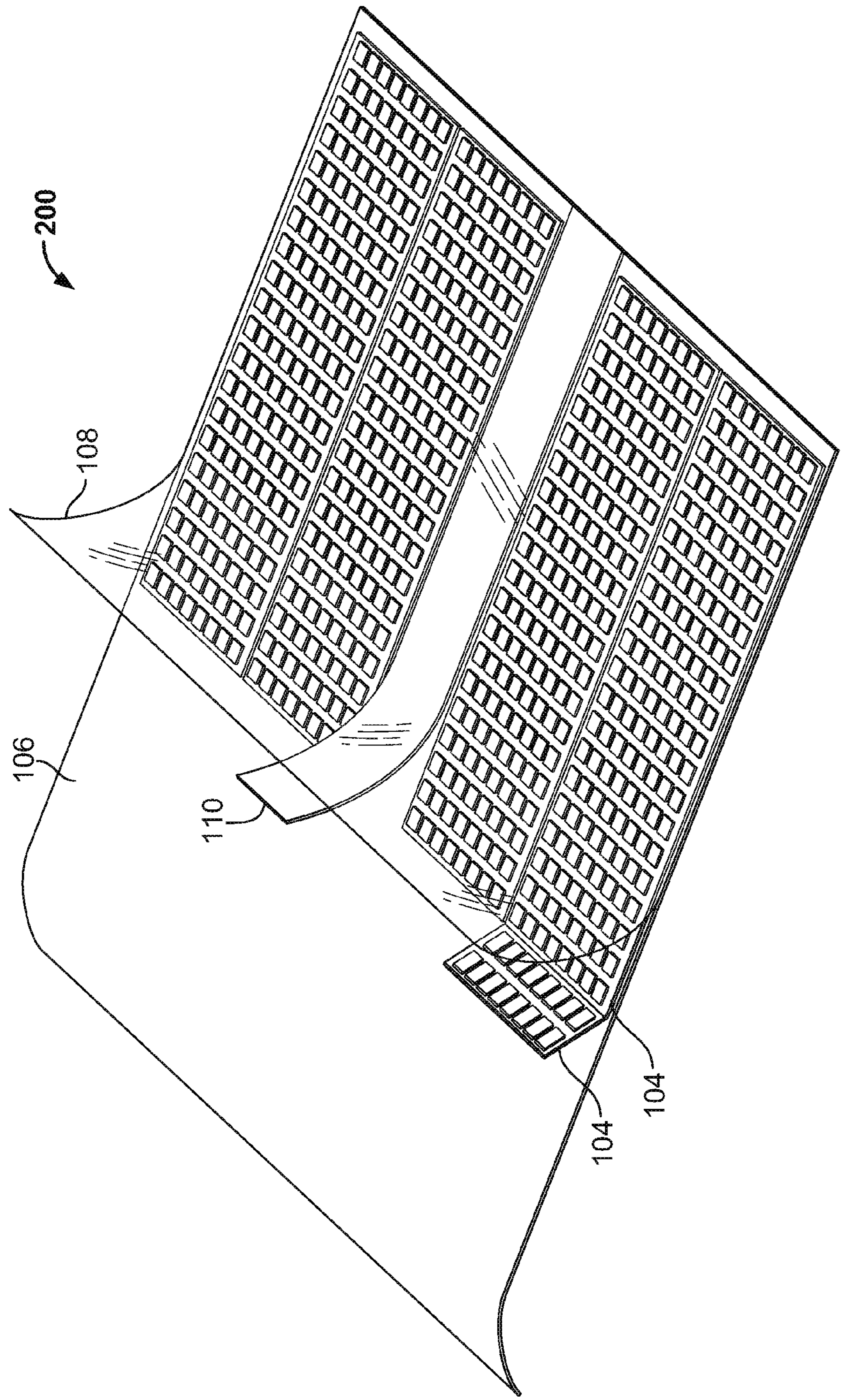


FIG. 2

Fig. 3

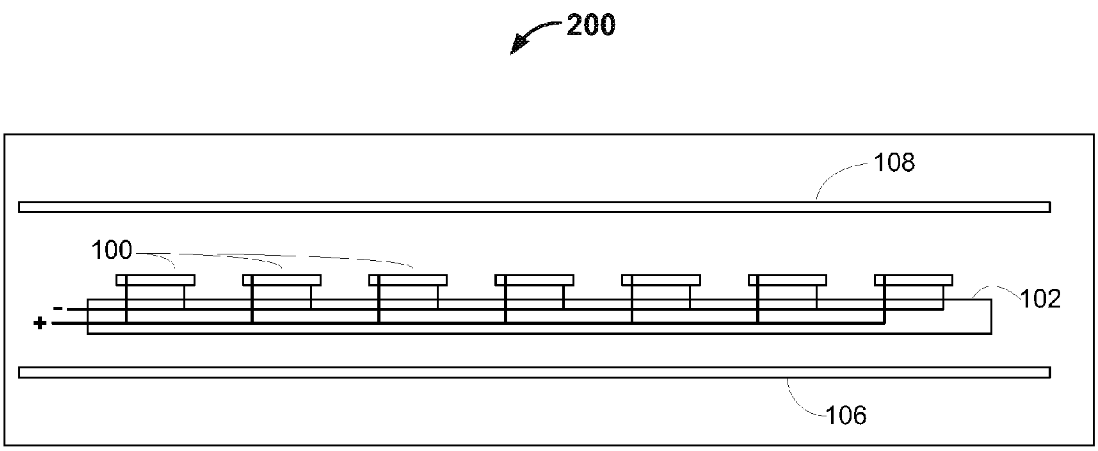
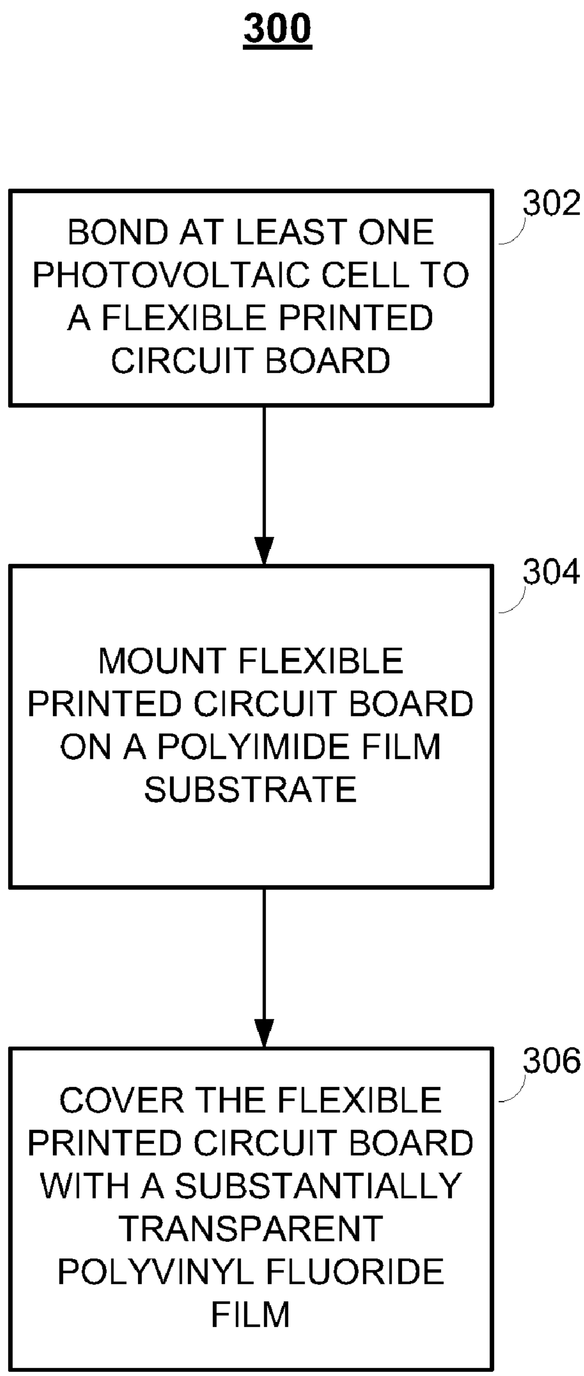


Fig. 4


300
BOND AT LEAST ONE PHOTOVOLTAIC CELL TO A FLEXIBLE PRINTED CIRCUIT BOARD
302
MOUNT FLEXIBLE PRINTED CIRCUIT BOARD ON A POLYIMIDE FILM SUBSTRATE
304
COVER THE FLEXIBLE PRINTED CIRCUIT BOARD WITH A SUBSTANTIALLY TRANSPARENT POLYVINYL FLUORIDE FILM
306

METHOD OF MANUFACTURING FLEXIBLE, LIGHTWEIGHT PHOTOVOLTAIC ARRAY

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation-in-part of U.S. application Ser. No. 12/471,094 filed May 22, 2009, which claims the benefit of U.S. Provisional Application No. 61/128,510 filed May 22, 2008, and U.S. Provisional Application No. 61/130,148 filed May 27, 2008, the entirety of each of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The invention relates to photovoltaic arrays. More particularly, the invention relates to flexible, lightweight photovoltaic arrays suitable for mounting directly on a surface of, or being deployed from, a spacecraft or an airplane.

[0003] Photovoltaic cell strings include individual photovoltaic cells connected in series so as to obtain a desired voltage, according to characteristics of the photovoltaic cells. The photovoltaic cell strings are then connected in parallel so as to obtain a desired output capacity or current, thus creating a photovoltaic cell array.

[0004] Traditionally, photovoltaic arrays have been fabricated on a graphite panel. Typically, this panel is the thickest member of an array of photovoltaic cells and contributes most of the weight to the array. In spacecraft or certain consumer applications, it is desirable to minimize the weight of the photovoltaic array.

[0005] Additionally, traditional photovoltaic array manufacturing methods involve extensive manual labor, which gives rise to relatively high manufacturing costs.

SUMMARY OF THE INVENTION

[0006] The invention relates to a method of manufacturing a low-cost, flexible, lightweight photovoltaic array.

[0007] According to one aspect, the invention relates to a photovoltaic array that includes at least one photovoltaic cell bonded to a flexible printed circuit board. The flexible printed circuit board is mounted on a substrate of a polyimide film, such as that sold by E.I. du Pont de Nemours and Company under the trademark KAPTON®, reinforced with aramid fiber such as that sold by E.I. du Pont de Nemours and Company under the trademark KEVLAR®. The flexible printed circuit board may then be covered by a substantially transparent abrasion-resistant film (e.g., a polyvinyl fluoride film, such as that sold by E.I. du Pont de Nemours and Company under the trademark TEDLAR®). In one embodiment, the photovoltaic array is suitable for mounting directly on a surface of, or being deployed from, a spacecraft or an airplane.

[0008] In one embodiment, a bladder sleeve is attached to the polyimide film substrate to facilitate inflatable deployment. The bladder sleeve preferably is applied prior to covering the polyimide film substrate with the abrasion-resistant transparent film. Additionally, the bladder sleeve may also be used for mechanical boom deployment.

[0009] In one embodiment, a substantial reduction in manufacturing costs is achieved by bonding the one or more photovoltaic cells to the printed circuit board using automated assembly equipment such as for example, surface-mount technology placement systems (e.g., pick-and-place machines).

[0010] In one embodiment, one side of the polyimide film substrate, to which the photovoltaic cells are to be applied is coated with an adhesive, while the other side of the polyimide film substrate is coated with a high-emissivity coating (e.g., high-emissivity paint) to facilitate dissipation of waste heat. The adhesive preferably is a silicone-based adhesive, such as CV10-2568, available from NuSil Technology, of Carpinteria, Calif.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The above and other features of the present invention, its nature and various advantages will be more apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters represent like parts throughout and in which:

[0012] FIG. **1** is a diagram illustrating the process of assembling a string carrier, according to an illustrative embodiment of the invention;

[0013] FIG. **2** is a diagram illustrating the process of assembling a flexible lightweight photovoltaic array, according to an illustrative embodiment of the invention;

[0014] FIG. **3** is a schematic diagram of the flexible lightweight photovoltaic array manufactured according to the process of FIG. **2**; and

[0015] FIG. **4** is a flow chart of a method of manufacturing the flexible lightweight photovoltaic array of FIG. **3**, according to an illustrative embodiment of the invention.

DETAILED DESCRIPTION

[0016] To provide an overall understanding of the invention, certain illustrative embodiments will now be described, including a flexible lightweight photovoltaic array and a method for manufacturing the photovoltaic array. However, it will be understood by one of ordinary skill in the art that the systems and methods described herein may be adapted and modified as is appropriate for the application being addressed and that the systems and methods described herein may be employed in other suitable applications, and that such other additions and modifications will not depart from the scope hereof.

[0017] Individual photovoltaic cells are connected in series so as to obtain a desired voltage, according to characteristics of the photovoltaic cells, to create photovoltaic cell strings. The photovoltaic cell strings are then connected in parallel so as to obtain a desired output capacity, thus creating a photovoltaic cell array. FIG. **1** shows the assembly of individual photovoltaic cell strings **104** in accordance with an illustrative embodiment of the present invention. As shown in FIG. **1**, one or more photovoltaic cells **100** are bonded onto a printed circuit board (PCB) **102** to create a photovoltaic cell string **104**. PCB **102** is preferably a flexible PCB, but alternatively may be a rigid PCB. Photovoltaic cells **100** preferably are bonded to PCB **102** using automated assembly equipment such as, for example, surface-mount technology placement systems. In one embodiment, photovoltaic cells **100** may be soldered to PCB **102** using pick-and-place machines.

[0018] Photovoltaic cells **100** may soldered to PCB **102** using, for example, wave soldering. A solder mask is applied to areas of the photovoltaic cells **100** and the PCB **102** on which solder is not desired. Photovoltaic cells **100** are then glued to PCB **102** using pick-and-place machines, and PCB **102** is then run through a wave of molten solder. The solder wets metal surfaces not coated with the solder mask to form electrical connections between the photovoltaic cells **100** and the PCB **102**. The use of automated assembly equipment reduces labor costs and improves the rate at which photovoltaic cell strings are assembled.

[0019] The photovoltaic cells **100**, within a photovoltaic cell string **104** are wired in series to generate a fixed voltage for each photovoltaic cell string **104**. The number of photovoltaic cells **100** in a particular photovoltaic cell string **104** is determined by the voltage requirement of the specific application. Preferably, the return trace is routed on the mounting surface of the PCB **102**. In at least one embodiment, PCB **102** is a multi-layer PCB, and the return trace is routed underneath the photovoltaic cell string to reduce the magnetic moment and the associated loop area. A multi-layer PCB also allows for proper separation, thus reducing breakdown potential between layers which would result in string loss.

[0020] In at least one embodiment, string blocking diodes (not shown) are also installed onto PCB **102** using automated assembly equipment. Blocking diodes are used to prevent current from flowing back into one or more photovoltaic cell strings **104** which are not exposed to sunlight (e.g., in shaded areas or at nighttime). Additionally, blocking diodes may be installed between photovoltaic array **200** and the battery (not shown). Once a photovoltaic cell string **104** is assembled, individual photovoltaic cell strings **104** are wired together in parallel to generate the necessary capacity, thus creating a photovoltaic array **200**.

[0021] FIG. **2** shows the assembly of a photovoltaic array **200** in accordance with an illustrative embodiment of the present invention. As shown in FIG. **2**, one or more individual photovoltaic cell strings **104** are mounted onto a polyimide film substrate **106**. The polyimide film substrate **106** preferably is reinforced with aramid fiber. In addition to photovoltaic cell strings **104**, a bladder sleeve **110** may also be mounted onto polyimide film substrate **106** to facilitate inflatable deployment in spacecraft or other applications. Photovoltaic cell strings **104** and bladder sleeve **110** are mounted onto polyimide film substrate **106** using, for example, a silicone-based adhesive. In at least one embodiment, the adhesive is applied to the front face of polyimide film substrate **106** where photovoltaic cell strings **104** and bladder sleeve **110** are mounted. The back side of polyimide film substrate may be coated with a high-emissivity coating (e.g., high-emissivity paint) to facilitate dissipation of waste heat. In at least one embodiment, one or more wire harnesses (not shown) are also mounted on the front face of polyimide film substrate **106**.

[0022] Once the appropriate number of photovoltaic cell strings **104** are mounted to polyimide film substrate **106**, the entire assembly including photovoltaic cell strings **104**, film substrate **106** and bladder sleeve **110**, may be covered with a substantially transparent film **108**. Film **108** may be, for example, a polyvinyl fluoride film to provide abrasion resistance for photovoltaic cells **102** (FIG. **1**).

[0023] FIG. **3** is a schematic diagram of photovoltaic array **200** in accordance with an illustrative embodiment of the present invention. Photovoltaic array **200** includes photovoltaic cells **100** bonded onto PCB **102**. PCB **102** is mounted onto film substrate **106**, and photovoltaic cells **100** are then covered with film **108**. Photovoltaic array **200** is suitable for mounting directly on a surface of, or being deployed from, a spacecraft or an airplane.

[0024] FIG. **4** is a flow chart of a method **300** of manufacturing the flexible lightweight photovoltaic array **200** of FIG. **3**, in accordance with an illustrative embodiment of the present invention. In step **302**, one or more photovoltaic cells are bonded to a flexible printed circuit board (PCB) using, for example, automated assembly equipment. The photovoltaic cells may be soldered onto the flexible PCB using a pick-and-place machine. In some embodiments, in addition to photovoltaic cells, blocking diodes also may be soldered onto the PCB using a pick-and-place machine.

[0025] Photovoltaic cells (and blocking diodes) are soldered to the PCB using, for example, wave soldering. A solder mask is applied to areas of the photovoltaic cells **100** and the PCB **102** on which solder is not desired. Photovoltaic cells **100** (and blocking diodes) are then glued to PCB **102** using pick-and-place machines, and PCB **102** is then run through a wave of molten solder. The solder wets metal surfaces not coated with the solder mask to form electrical connections between the photovoltaic cells **100** and the PCB **102**.

[0026] The flexible PCB including photovoltaic cells (and blocking diodes) may then be mounted on a polyimide film substrate (step **304**). The polyimide film substrate may be, for example, a 1 mil sheet of polyimide film reinforced with aramid fibers.

[0027] The flexible PCB preferably is attached to the polyimide film substrate preferably using a silicone-based adhesive. In at least one embodiment, one or more wire harnesses and/or one or more inflatable bladder sleeves are also mounted on the polyimide film substrate using a silicone-based adhesive. The adhesive is applied to the front face of the polyimide film substrate, on which the flexible PCB, one or more wire harnesses, and/or one or more bladder sleeves are mounted. The back side of the polyimide film substrate may be coated with a high-emissivity coating (e.g., high-emissivity paint) to facilitate dissipation of waste heat. In step **306**, the entire assembly including photovoltaic cells bonded to the flexible PCB, which is attached to the film substrate is encapsulated by a substantially transparent film. The substantially transparent film may be, for example, a polyvinyl fluoride film. The assembled photovoltaic array is suitable for mounting directly on a surface of, or being deployed from, a spacecraft or an airplane.

[0028] The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects illustrative, rather than limiting of the invention. The present invention is limited only by the claims which follow.

What is claimed is:

1. A method of manufacturing a flexible photovoltaic array, the method comprising:

bonding at least one photovoltaic cell to a flexible printed circuit board;

mounting said flexible printed circuit board on a first side of a polyimide film substrate; and

covering said flexible printed circuit board with a substantially transparent film.

2. The method of claim **1**, further comprising:

coating said first side of said polyimide film substrate with an adhesive; and

coating a second side of said polyimide film substrate with a high-emissivity coating.

3. The method of claim **2**, wherein coating the second side of said polyimide film substrate with the high-emissivity coating comprises coating the second side of said polyimide film substrate with high-emissivity paint.

4. The method of claim **1**, further comprising:
attaching a bladder sleeve to said polyimide film substrate prior to covering said flexible printed circuit board with said film.

5. The method of claim **4** wherein said attaching is performed prior to covering said flexible printed circuit board with said film.

6. The method of claim **1**, wherein mounting said flexible printed circuit board comprises mounting said flexible printed circuit board on said polyimide film substrate reinforced with aramid fibers.

7. The method of claim **1**, wherein covering said flexible printed circuit board comprises covering said flexible printed circuit board with a substantially transparent polyvinyl fluoride film.

8. The method of claim **1**, further comprising:
mounting said film substrate directly to a surface of a spacecraft or an airplane.

9. A flexible photovoltaic array comprising:
at least one photovoltaic cell bonded to a flexible printed circuit board;
a polyimide film substrate on which said flexible printed circuit board is mounted; and
a substantially transparent film covering said flexible printed circuit board.

10. The flexible photovoltaic array of claim **9**, wherein:
a first side of said polyimide film substrate is coated with an adhesive; and
a second side of said polyimide film substrate is coated with a high-emissivity coating.

11. The flexible photovoltaic array of claim **10**, wherein said flexible printed circuit board is mounted on said first side of said polyimide film substrate.

12. The flexible photovoltaic array of claim **10**, wherein said high-emissivity coating is high-emissivity paint.

13. The flexible photovoltaic array of claim **9**, further comprising:
a bladder sleeve attached thereto.

14. The flexible photovoltaic array of claim **13** wherein said bladder sleeve is attached to said polyimide film substrate and is covered by said substantially transparent film.

15. The flexible photovoltaic array of claim **9**, wherein said polyimide film substrate is reinforced with aramid fibers.

16. The flexible photovoltaic array of claim **9**, wherein said substantially transparent film is a polyvinyl fluoride film.

17. The flexible photovoltaic array of claim **9**, wherein said polyimide film substrate is mounted directly to a surface of a spacecraft or an airplane.

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