

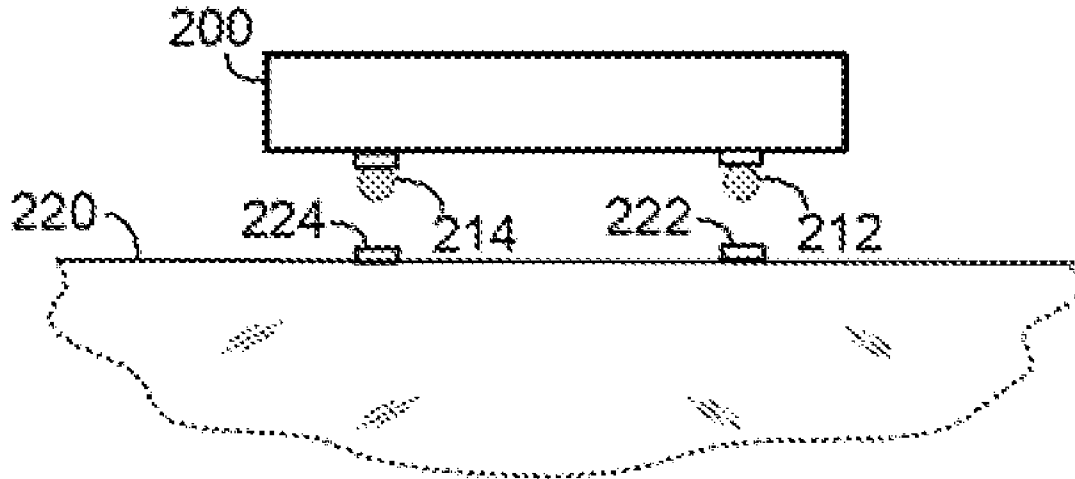


US 20090025789A1

(19) **United States**(12) **Patent Application Publication**
Chan et al.(10) **Pub. No.: US 2009/0025789 A1**(43) **Pub. Date: Jan. 29, 2009**(54) **ALIGNMENT OF OPTICAL ELEMENT AND
SOLAR CELL**(76) Inventors: **Hing Wah Chan**, San Jose, CA
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NEW CANAAN, CT 06840 (US)(21) Appl. No.: **11/782,359**(22) Filed: **Jul. 24, 2007****Related U.S. Application Data**(60) Provisional application No. 60/899,150, filed on Feb.
2, 2007.**Publication Classification**(51) **Int. Cl.****H01L 31/0203** (2006.01)**H01L 31/0232** (2006.01)**B23K 31/02** (2006.01)(52) **U.S. Cl. 136/259; 136/252; 438/127; 228/199**(57) **ABSTRACT**

A system may include a solar cell comprising a first electrical contact, an optical element comprising a second electrical contact, and a solder bump in contact with the first electrical contact and the second electrical contact. The solar cell is to generate charge carriers in response to received photons.

Some aspects provide fabrication of a solder bump on an electrical contact of a solar cell, placement of the solder bump in contact with an electrical contact of an optical element, and melting of the solder bump to couple the electrical contact of the solar cell to the electrical contact of the optical element.



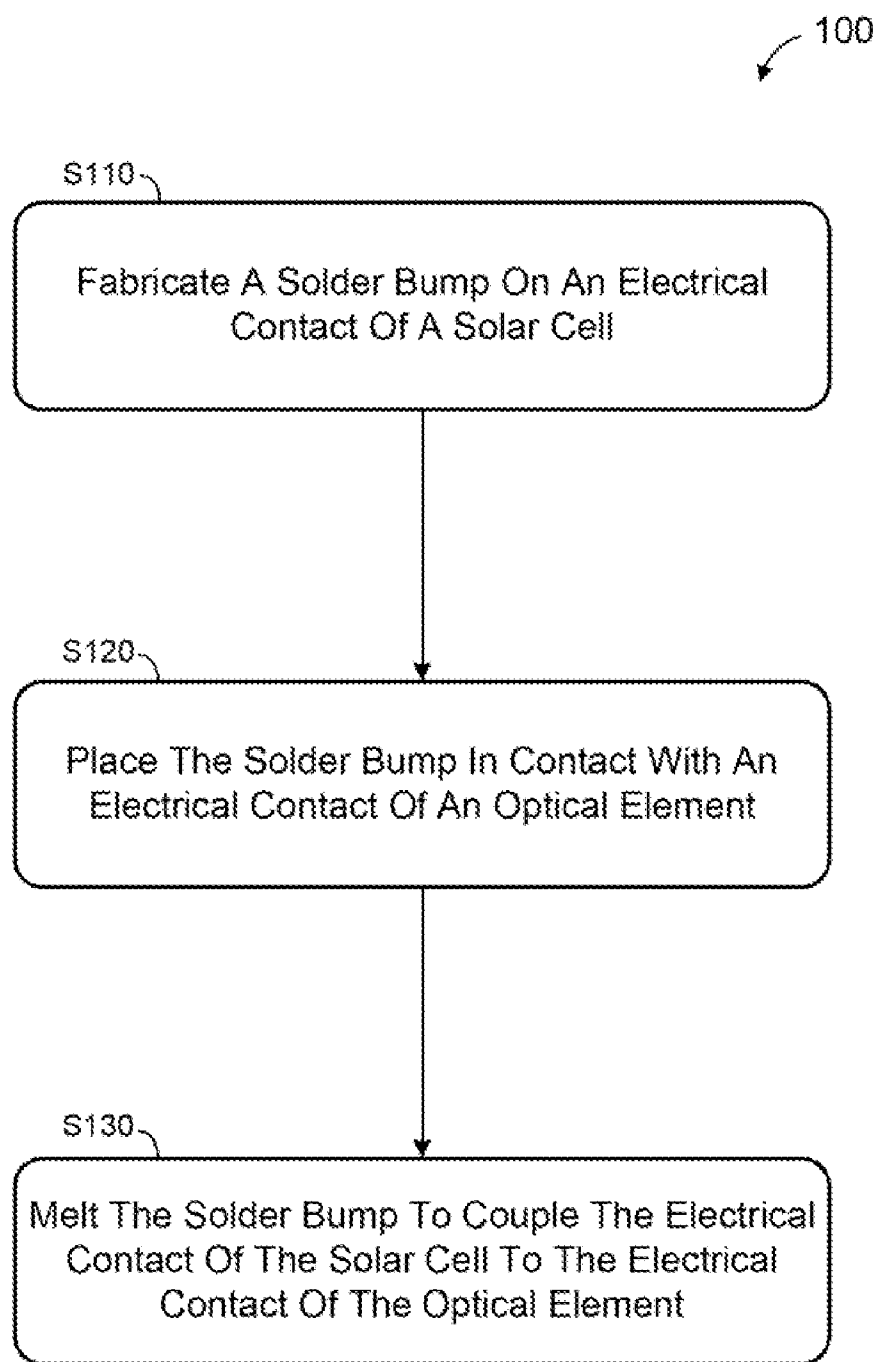


FIG. 1

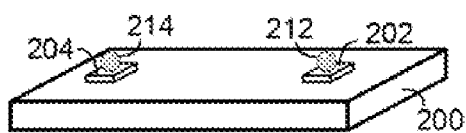


FIG. 2A

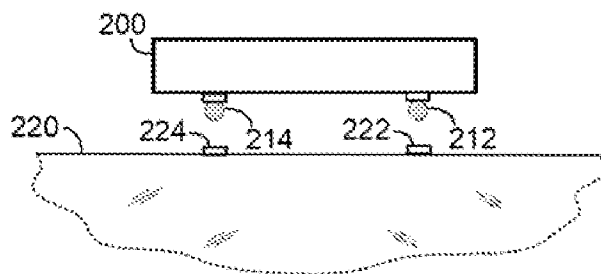


FIG. 2B

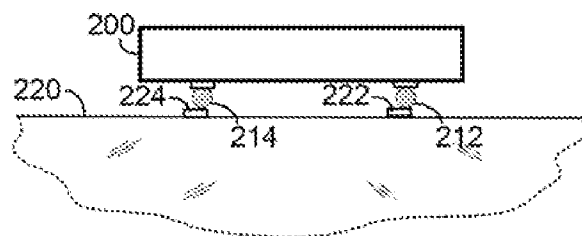


FIG. 2C

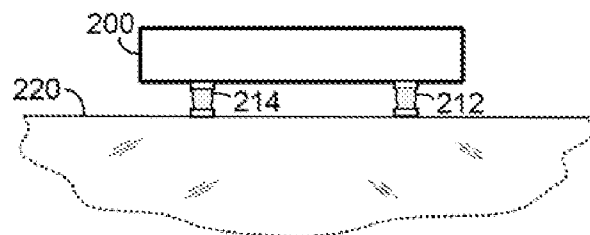


FIG. 2D

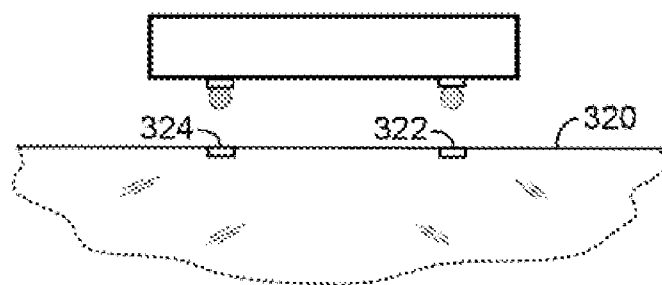


FIG. 3A

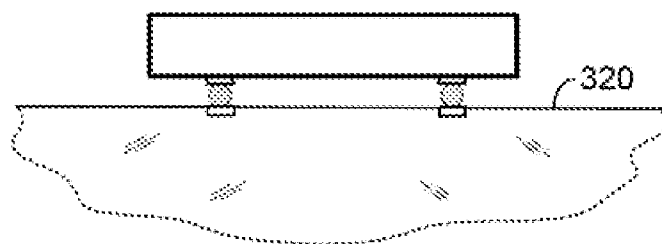


FIG. 3B

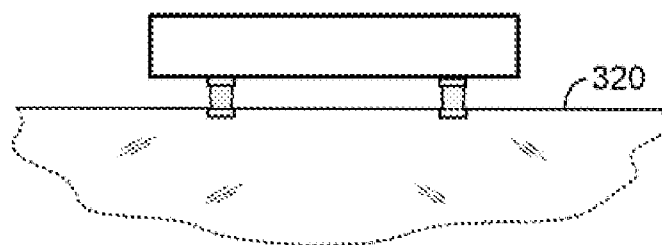


FIG. 3C

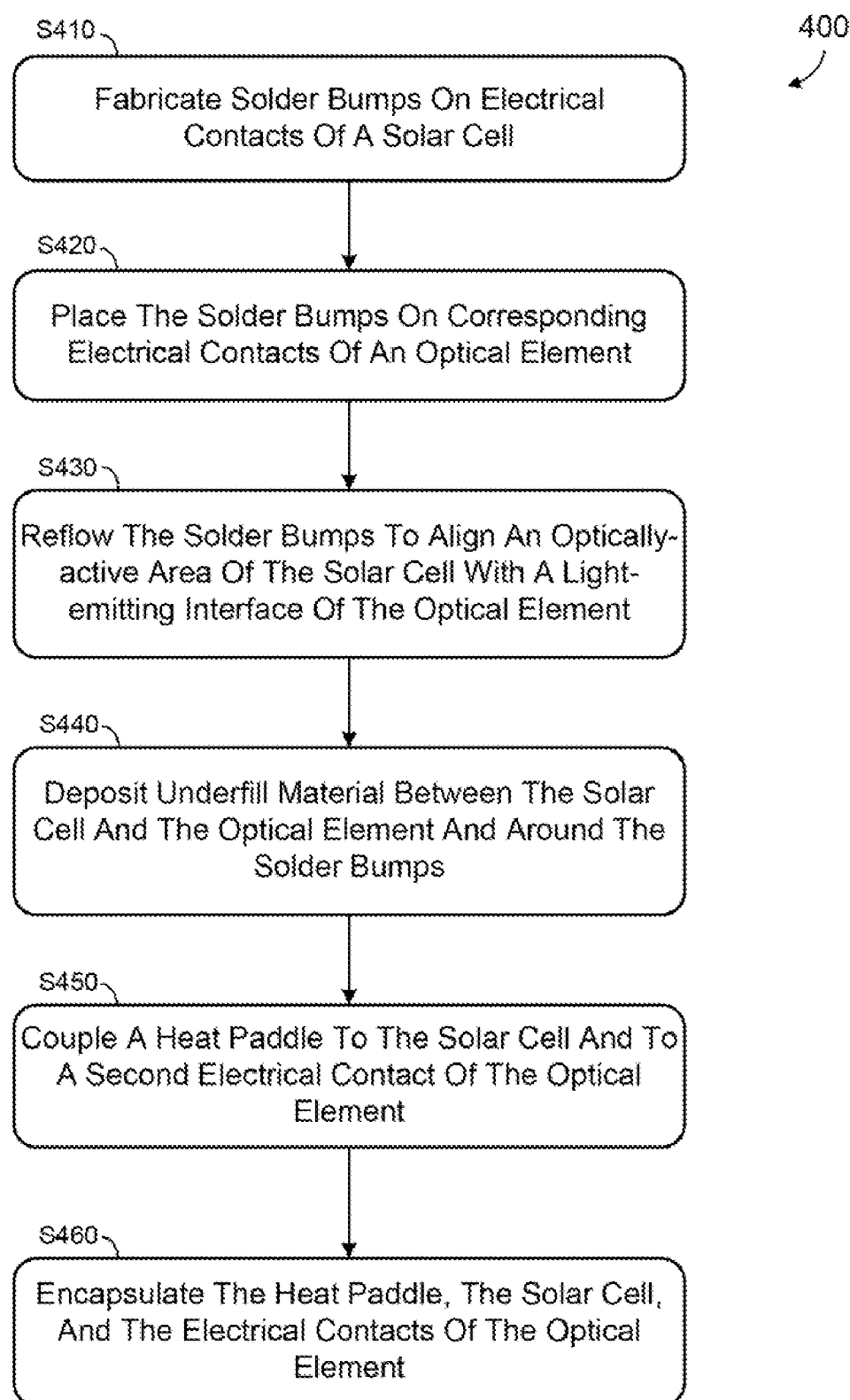


FIG. 4

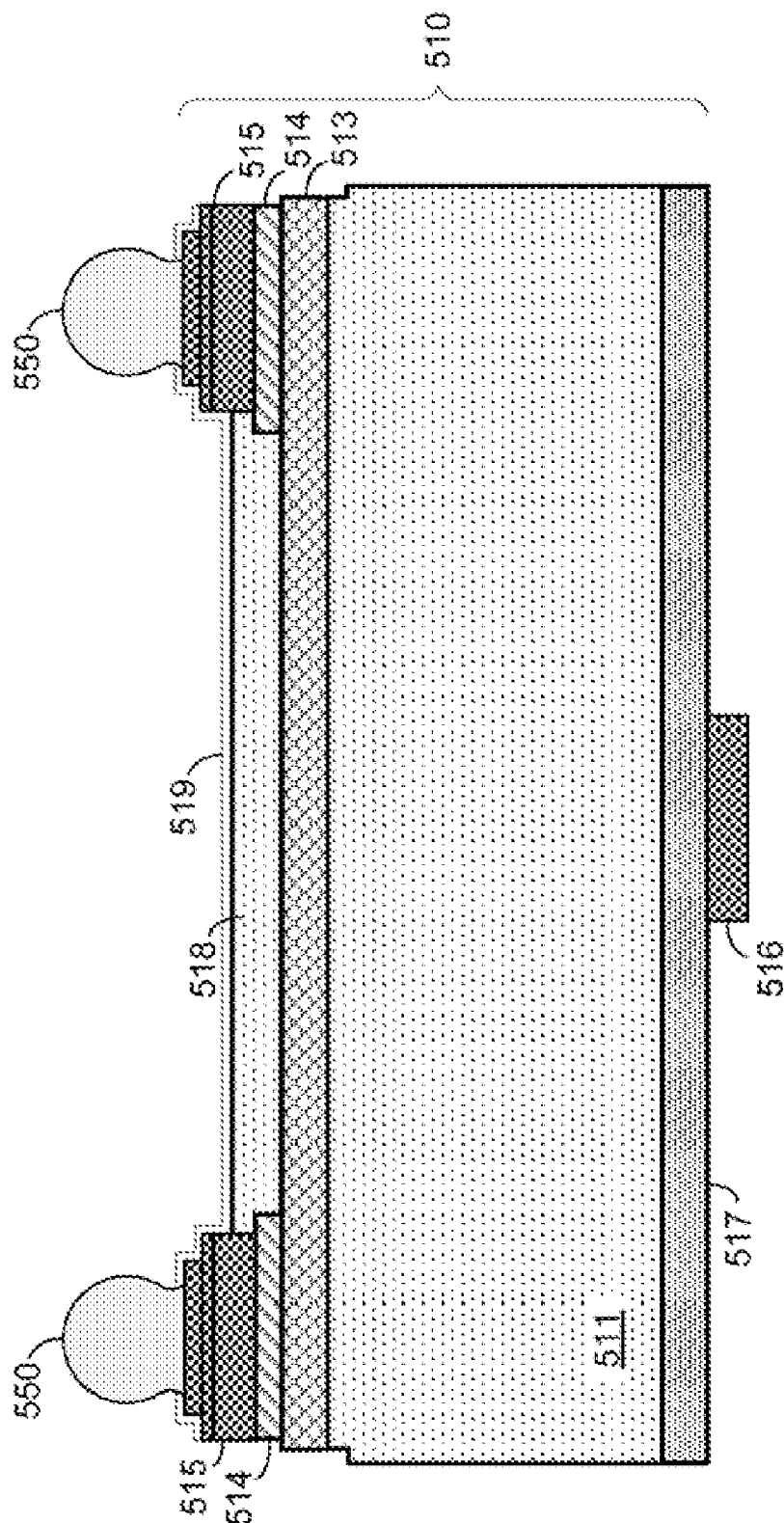


FIG. 5

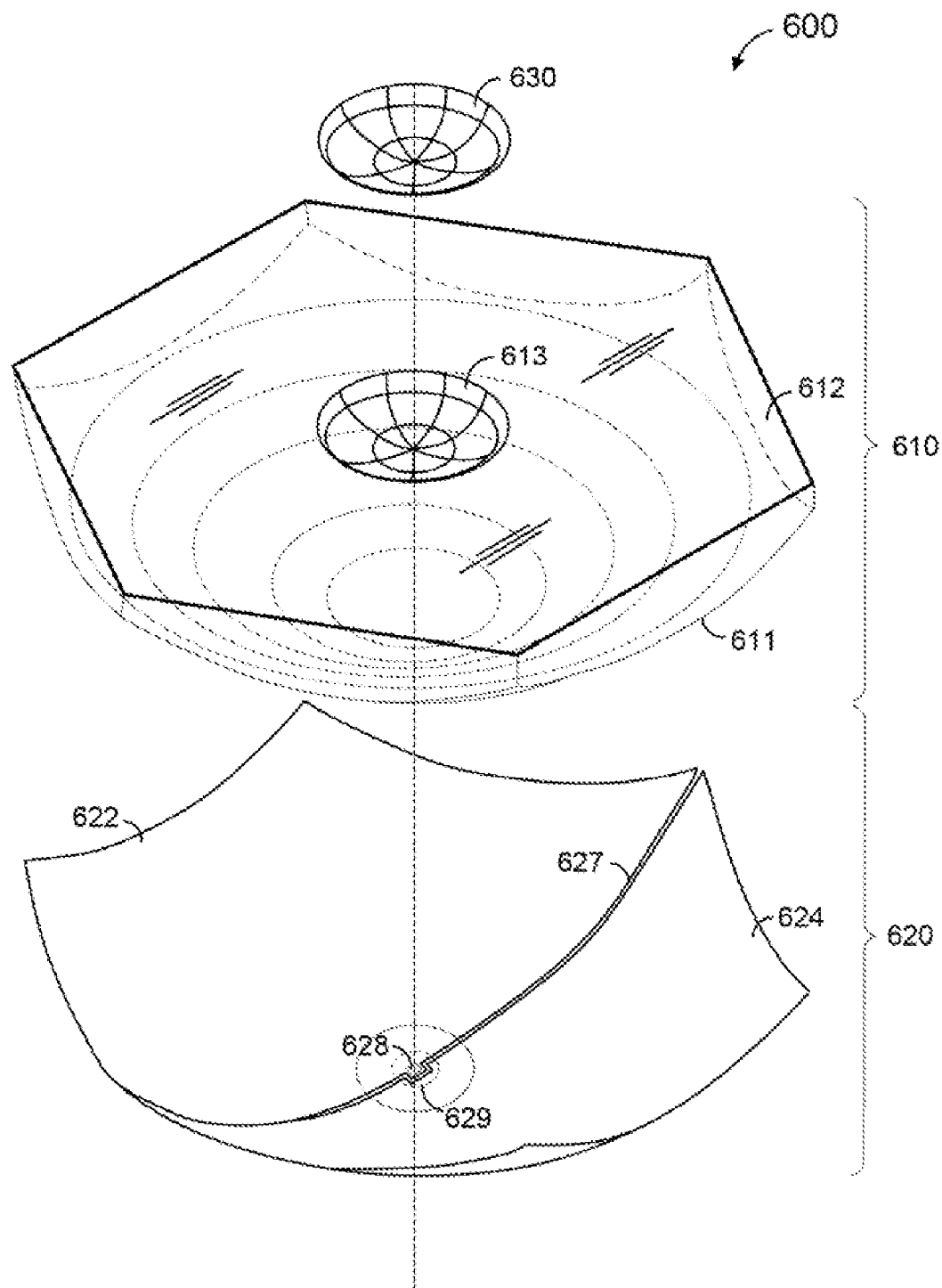


FIG. 6

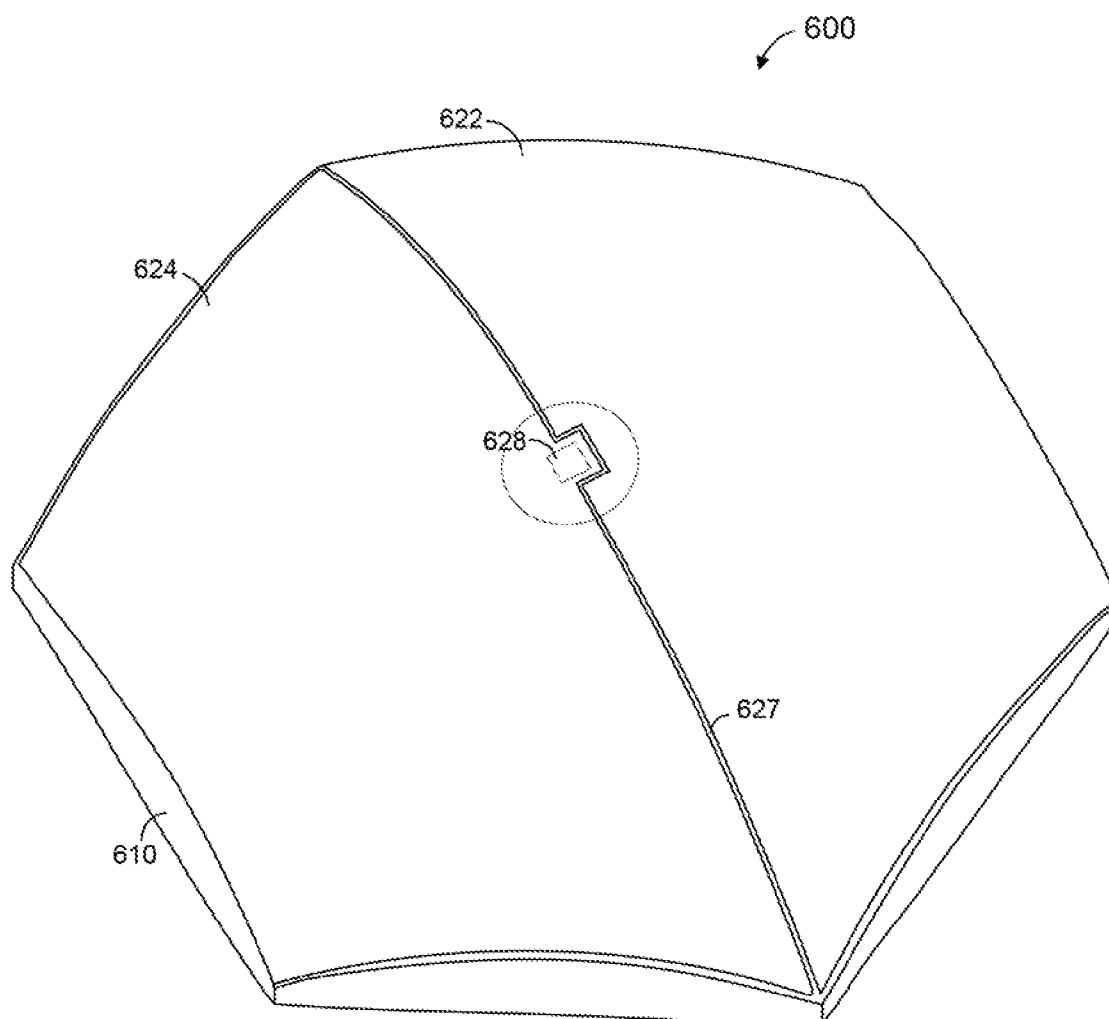


FIG. 7

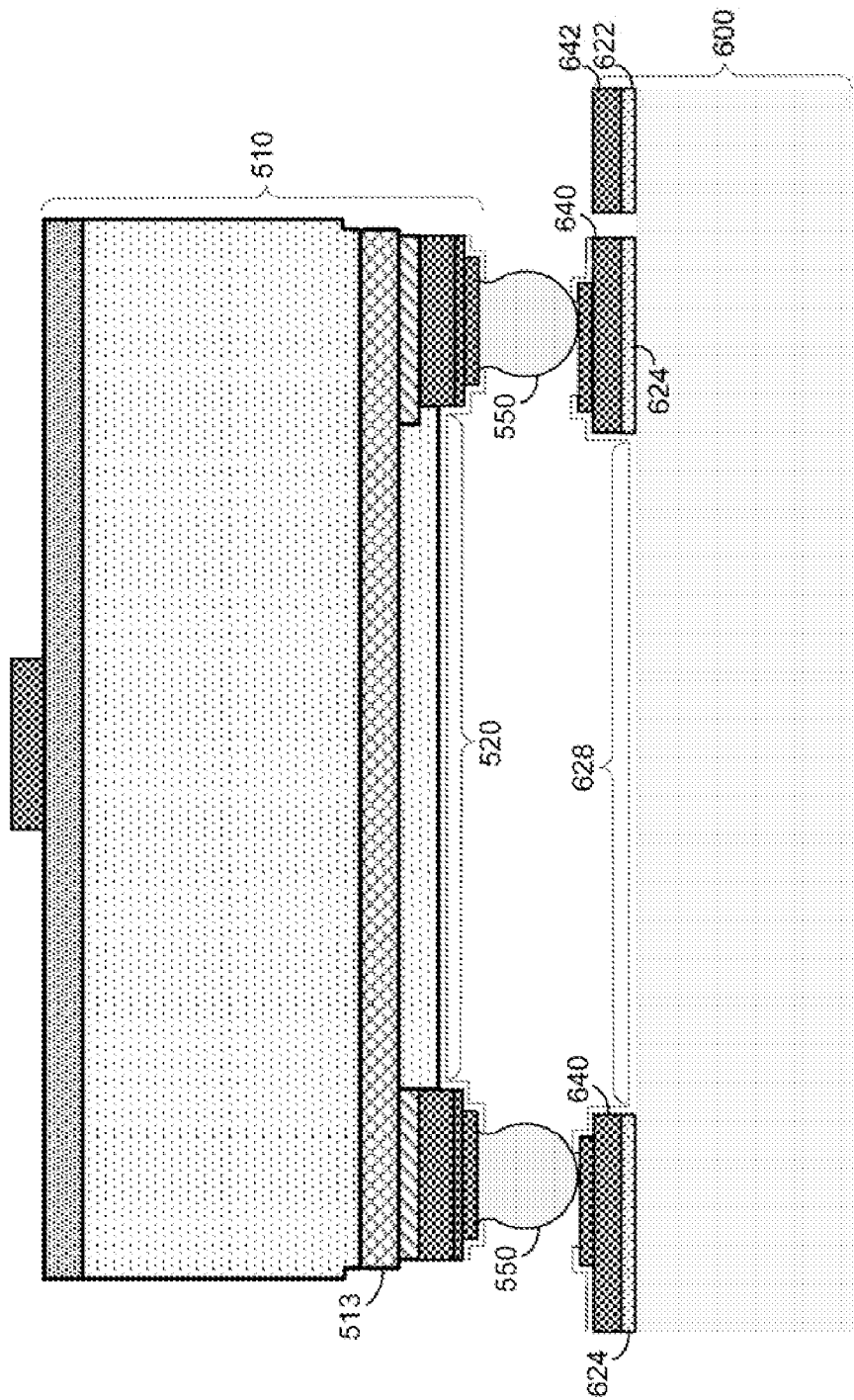


FIG. 8

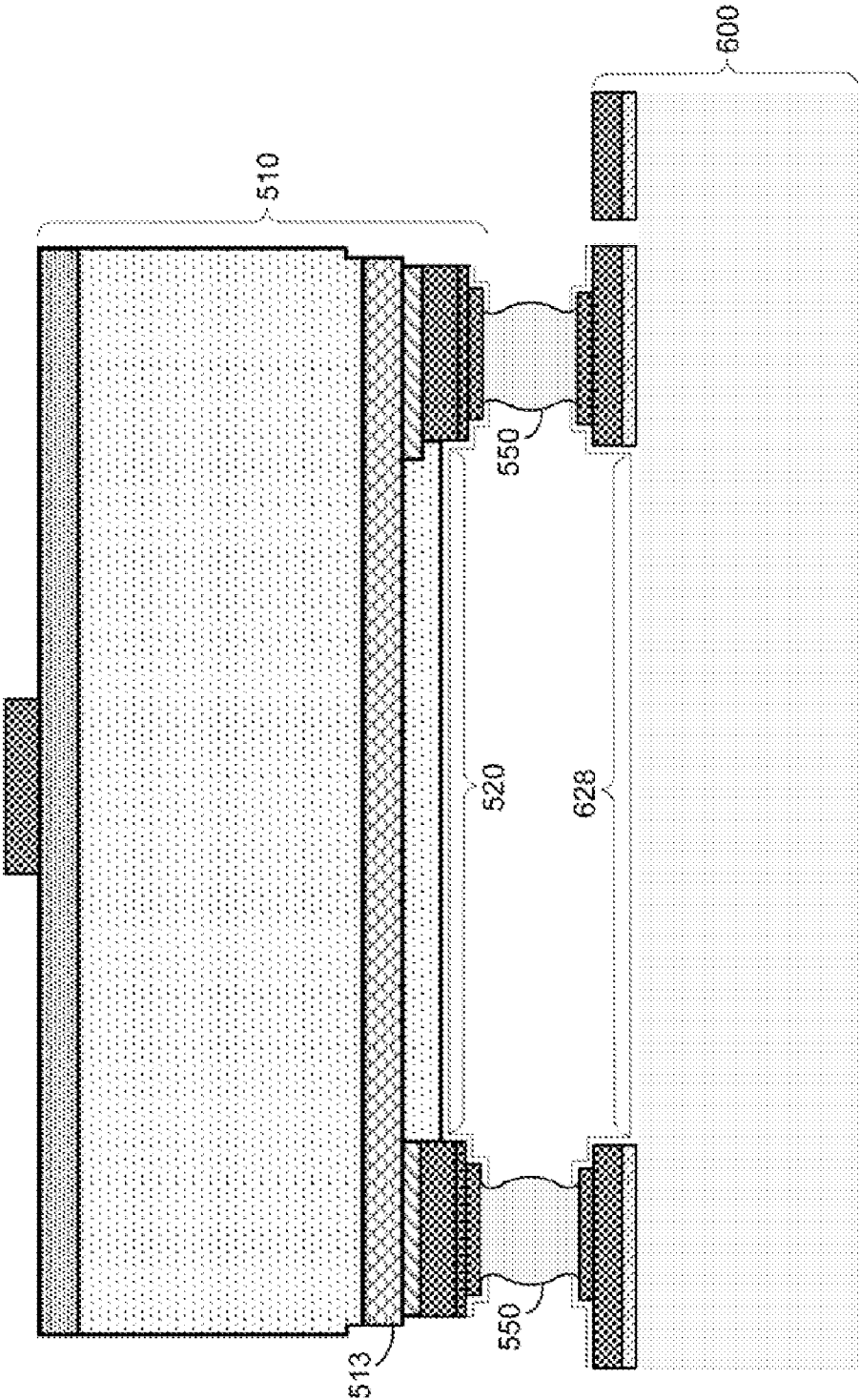


FIG. 9

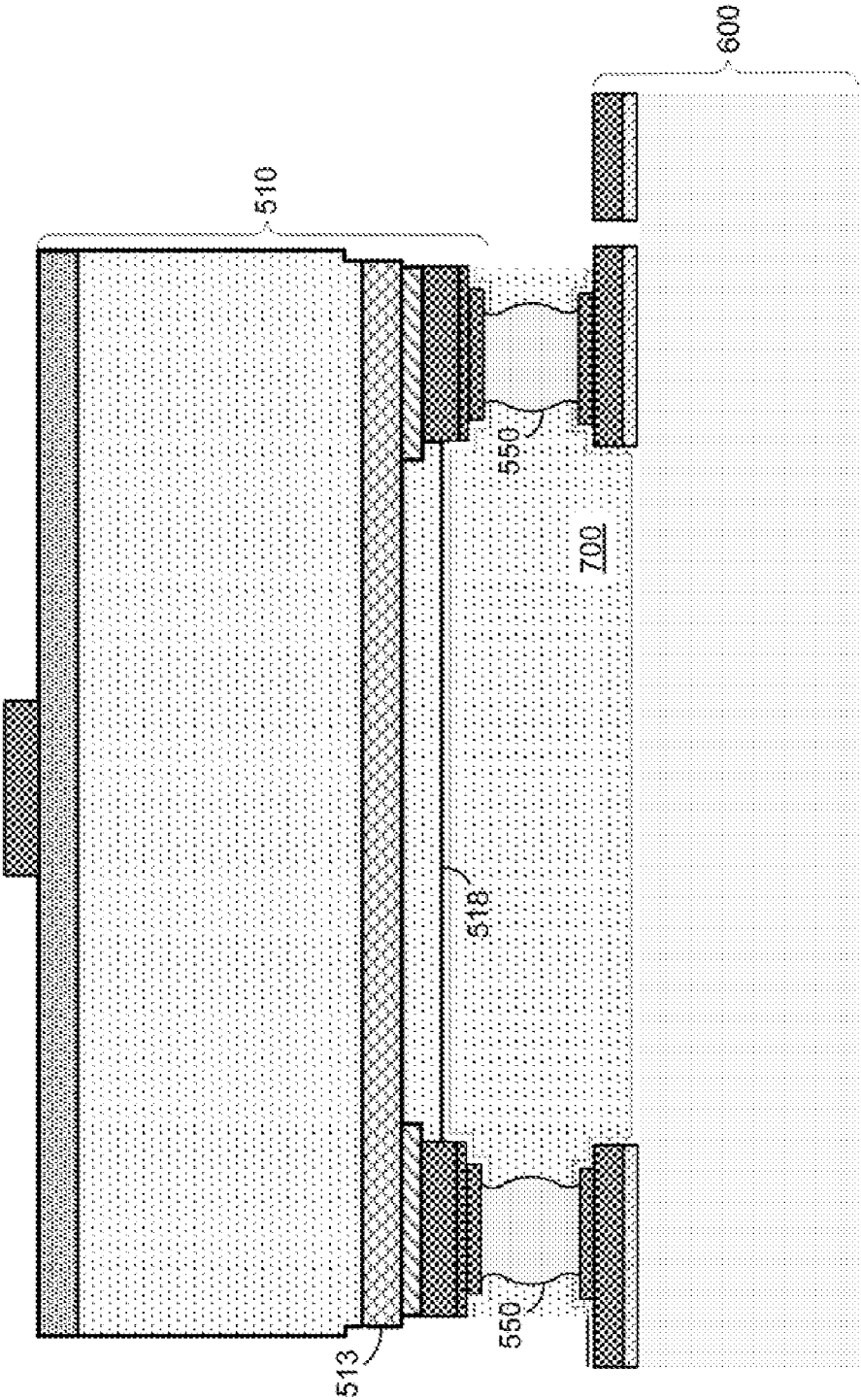


FIG. 10

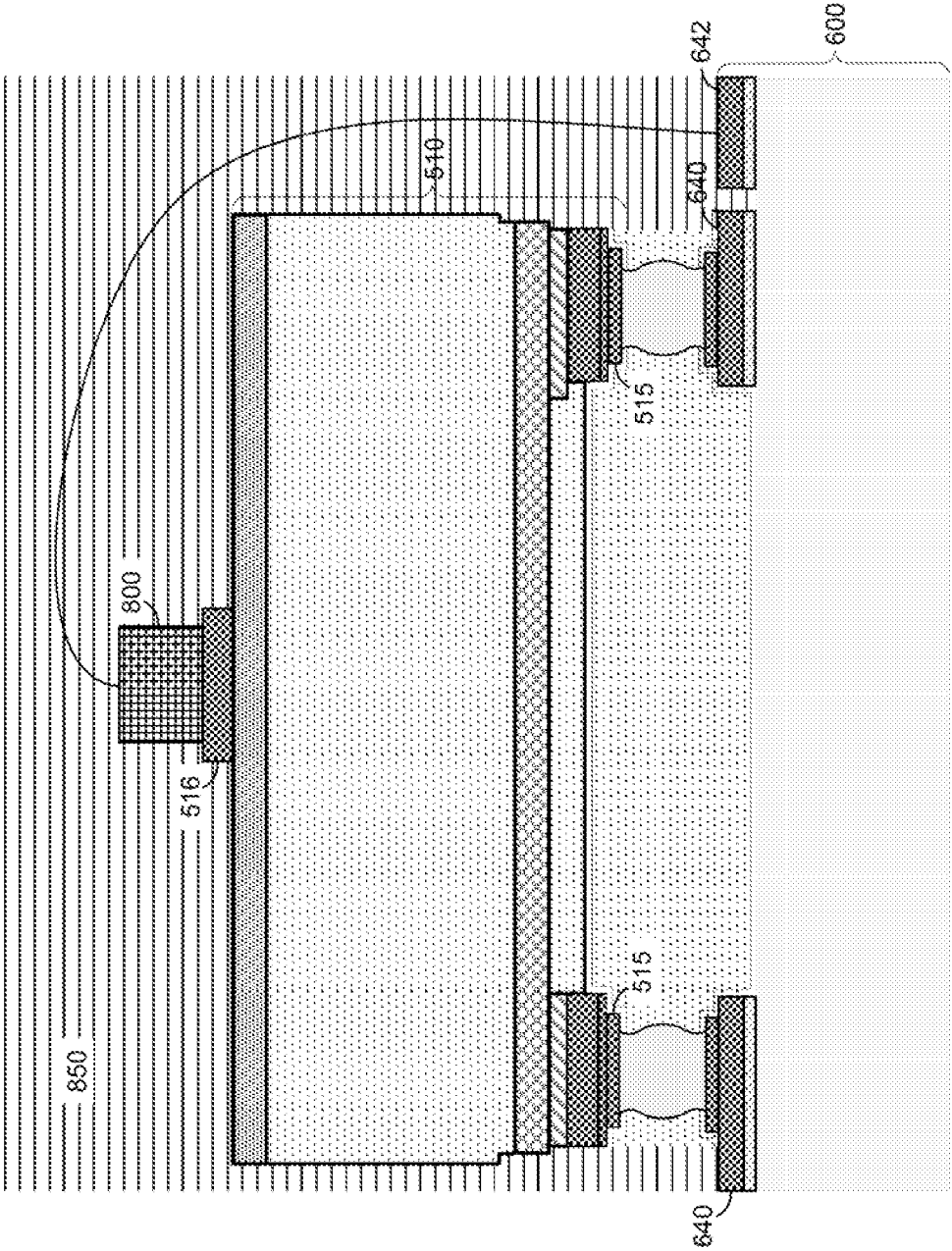


FIG. 11

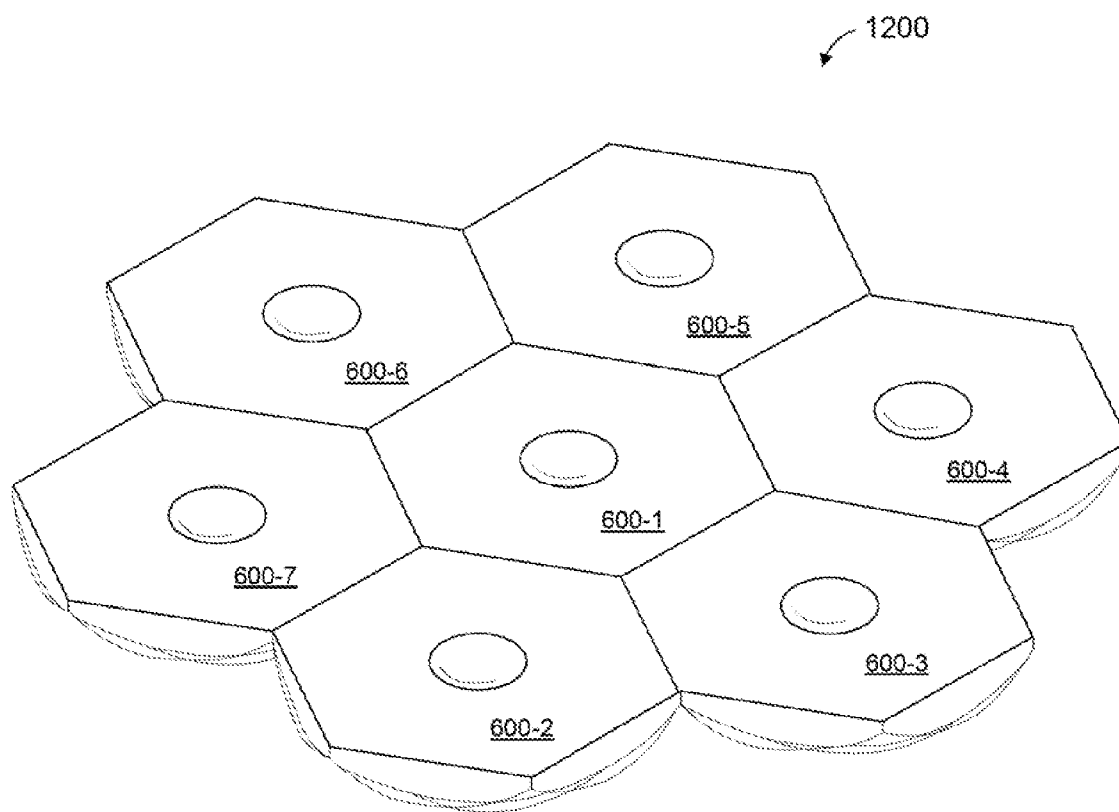


FIG. 12

ALIGNMENT OF OPTICAL ELEMENT AND SOLAR CELL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application Ser. No. 60/899,150, filed on Feb. 2, 2007 and entitled "Concentrated Photovoltaic Energy Designs", the contents of which are incorporated herein by reference for all purposes.

BACKGROUND

[0002] 1. Field

[0003] Some embodiments generally relate to the conversion of solar radiation to electrical energy. More specifically, embodiments may relate to systems to improve the efficiency of manufacture and/or operation of solar radiation collectors.

[0004] 2. Brief Description

[0005] A concentrating solar radiation collector may convert received photons (i.e., sunlight) into a concentrated beam of photons and direct the concentrated beam onto a small photovoltaic cell. The cell, in turn, converts the photons of the concentrated beam into electrical current.

[0006] U.S. Patent Application Publication No. 2006/0231133 describes several types of concentrating solar collectors. As described therein, a photovoltaic cell may be coupled to concentrating optics and electrical contacts of a solar collector using a clear adhesive (e.g., silicone) and wire-bonds, respectively. Alternatively, photovoltaic cell may be incorporated into a surface mount package or a front-side mounting package and connected to optics using clear under-fill material and to electrical contacts using soldered interconnects.

[0007] A photon-receiving surface of a photovoltaic cell must be aligned precisely with respect to the optical path of the solar collector. The alignment is achieved by mechanical means such as industrial pick and place machines and will likely require local fiducial marks to be placed on the optics. The alignment accuracy depends on the mechanical accuracy of the pick and place machine and the placement accuracy of the local fiducial marks.

[0008] The above-described alignment techniques can be inefficient and expensive. For example, accurate alignment (e.g., in the 10-12 micron range) will likely require reduction of the pick and place speed. The combination of reduced pick and place speed and the requirement of local fiducials will slow down the production speed and result in higher production cost.

[0009] What is needed is a system to couple an optically-active semiconductor device to an optical element that addresses one or more of the foregoing and/or other existing concerns.

SUMMARY

[0010] To address at least the foregoing, some aspects provide a system, an apparatus, a method and/or process steps to place a solder bump in contact with an electrical contact of a solar cell, place the solder bump in contact with an electrical contact of an optical element, and melt the solder bump to couple the electrical contact of the solar cell to the electrical contact of the optical element. Some embodiments may melt

the solder bump in order to align an optically active area of the solar cell with a light-emitting interface of the optical element.

[0011] In some aspects, an apparatus includes a solar cell comprising a first electrical contact, the solar cell to generate charge carriers in response to received photons, an optical element comprising a second electrical contact, and a solder bump in contact with the first electrical contact and the second electrical contact. The solar cell may comprise an optically-active area, the optical element may comprise a light-emitting interface, and the optically-active area may be aligned with the light-emitting interface.

[0012] Further to the foregoing aspect, the solar cell may include a semiconductor substrate comprising a majority of a first type of charge carrier, a first semiconductor portion comprising a majority of a second type of charge carrier, and a semiconductor layer disposed between the semiconductor substrate and the first semiconductor portion to generate charge carriers of the first type and of the second type in response to received photons. A third electrical contact may be in contact with the semiconductor substrate and may receive charge carriers of the second type generated by the semiconductor layer. Moreover, the first semiconductor portion may be disposed between the first electrical contact and the semiconductor layer.

[0013] The claims are not limited to the disclosed embodiments, however, as those in the art can readily adapt the description herein to create other embodiments and applications.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The construction and usage of embodiments will become readily apparent from consideration of the following specification as illustrated in the accompanying drawings, in which like reference numerals designate like parts.

[0015] FIG. 1 is a flow diagram of a method according to some embodiments.

[0016] FIGS. 2A through 2D comprise views of a solar cell, solder bumps and an optical element according to some embodiments.

[0017] FIGS. 3A through 3C comprise cross-sectional views of a solar cell, solder bumps and an optical element according to some embodiments.

[0018] FIG. 4 is a flow diagram of a method according to some embodiments.

[0019] FIG. 5 is a cross-sectional view of a solar cell and solder bumps according to some embodiments.

[0020] FIG. 6 is an exploded perspective view of an optical element according to some embodiments.

[0021] FIG. 7 is a rear perspective view of an optical element according to some embodiments.

[0022] FIG. 8 is a cross-sectional view of a solar cell, solder bumps and an optical element according to some embodiments.

[0023] FIG. 9 is a cross-sectional view of a solar cell, solder bumps and an optical element according to some embodiments.

[0024] FIG. 10 is a cross-sectional view of a solar cell, solder bumps and an optical element according to some embodiments.

[0025] FIG. 11 is a cross-sectional view of a solar cell, solder bumps and an optical element according to some embodiments.

[0026] FIG. 12 is a perspective view of an array of optical elements according to some embodiments.

DETAILED DESCRIPTION

[0027] The following description is provided to enable any person in the art to make and use the described embodiments and sets forth the best mode contemplated by for carrying out some embodiments. Various modifications, however, will remain readily apparent to those in the art.

[0028] FIG. 1 is a flow diagram of process 100 according to some embodiments. Process 100 may be performed by any combination of machine, hardware, software and manual means.

[0029] Initially, at S110, a solder bump is fabricated on an electrical contact of a solar cell. The solder bump may be composed of any suitable material and may be fabricated on the electrical contact using any system that is or becomes known. According to some embodiments, the solder bump conforms to the Controlled Collapse Chip Connect (C4) specification, is built up on the electrical contact according to the C4 specification, and is therefore referred to as a C4 solder bump. One or more additional solder bumps may be fabricated on respective ones of one or more additional electrical contacts of the solar cell at S110 in some embodiments. Such fabrication may occur simultaneously or consecutively.

[0030] FIG. 2A illustrates solar cell 200 according to some embodiments. Solar cell 200 may comprise a III-V solar cell, a II-VI solar cell, a silicon solar cell, or any other currently- or hereafter known type of solar cell. Solar cell 200 may comprise any number of active, dielectric and metallization layers, and may be fabricated using any suitable methods that are or become known.

[0031] Solar cell 200 includes electrical contacts 202 and 204, but embodiments are not limited to two electrical contacts. Electrical contacts 202 and 204 may be fabricated during fabrication of solar cell 200, and may comprise solder pads and/or any number of conductive (e.g., metal) layers. Detailed descriptions of electrical contacts 202 and 204 according to some embodiments will be provided below. FIG. 2A also illustrates solder bumps 212 and 214 fabricated on electrical contacts 202 and 204, respectively, according to some embodiments.

[0032] Returning to process 100, the solder bump is placed in contact with an electrical contact of an optical element at S120. The optical element may be composed of any suitable material or combination of materials. The optical element may comprise any number of disparate elements (e.g., lenses, mirrors, etc.) in some embodiments.

[0033] The electrical contact of the optical element may comprise any conductive structure, including but not limited to a solder pad, a metal trace, and a metal surface coating. The electrical contact may have been fabricated on the optical element using any technique. Non-exhaustive examples include sputtering, chemical vapor deposition, and thermal spraying (e.g., twin wire arcing, plasma spraying, powder coating).

[0034] FIGS. 2B and 2C are side views of solar cell 200 and optical element 220 for illustrating S120 according to some embodiments. Any placement system may be used to place solder bumps 212 and 214 in contact with contacts 222 and 224. An adhesive material (not shown) may be applied to contacts 222 and 224 prior to placement in order temporarily bond solder bumps 212 and 214 thereto.

[0035] According to some embodiments, the placement need not be as accurate as the above-mentioned techniques. For example, solder bumps 212 and 214 may be skewed slightly with respect to contacts 222 and 224 as shown in FIG. 2C. The skew can be as great as one half the solder bump diameter, so long as the solder bumps 212 and 214 still make physical contact with the electrical contacts 222 and 224. The placement may therefore be performed by a high speed pick and place machine instead of a flip chip bonder in some embodiments.

[0036] Next, at S130, the solder bump is melted to couple the electrical contact of the solar cell to the electrical contact of the optical element. Any solder reflow process that is or becomes known may be employed at S130. Generally, energy is applied to melt the solder bump and to form a bond between the two electrical contacts. If the energy is in the form of heat, a temperature is determined based on the composition of the solder bump and characteristics of solar cell 200 and element 220. Details of such a determination are known in the art.

[0037] FIG. 2D shows solar cell 200 and optical element 220 after process 100. Surface tension of melted solder bumps 212 and 214 has drawn solar cell 200 into proper alignment with optical element 220. In some embodiments, the use of surface tension may achieve alignment accuracy up to 2 microns. Solder bumps 212 and 214 may subsequently refreeze to maintain the configuration shown in FIG. 2D.

[0038] FIGS. 2B through 2D show only a portion of optical element 220 in order to illustrate that optical element 220 may exhibit any suitable shape or size. Optical element 220 may be configured to manipulate and/or pass desired wavelengths of light. According to some embodiments, optical element 220 is designed to pass wavelengths of light which correspond to the optical characteristics of solar cell 200. For example, solar cell 200 may receive photons from optical element 220 and generate electrical charge carriers in response thereto. Optical element 220 may be deliberately designed to eliminate those photons which cannot generate electrical charge carriers in solar cell 200, thus reducing the temperature and improving the performance of solar cell 200.

[0039] FIGS. 3A through 3C illustrate another embodiment of process 100. FIGS. 3A and 3B illustrate S120 of process 100 and FIG. 3C illustrates S130. In contrast to FIGS. 2A through 2D, electrical contacts 322 and 324 of optical element 320 are recessed below a surface of element 320. Such contacts may be fabricated in any suitable manner, including but not limited to the manner described in U.S. Patent Application No. (Atty. Docket No. SF-P060) filed on even date herewith.

[0040] According to some embodiments, a solder bump is fabricated on an electrical contact of an optical element, and the solder ball is then placed on an electrical contact of a solar cell. In other words, the roles of the optical element and the solar cell are opposite to that described with respect to S110 and S120 of process 100. The solder bump may then be melted as described at S130 to couple the electrical contact of the optical element to the electrical contact of the solar cell.

[0041] FIG. 4 is a flow diagram of process 400 according to some embodiments. Process 400 may be executed during fabrication of a concentrating solar collector, but embodiments are not limited thereto. Process 400 may be performed by any combination of machine, hardware, software and manual means. Although process 400 operates on a solar cell

and an optical element, process 400 may be executed by an entity other than the entity or entities which manufactured the solar cell or optical element.

[0042] Flow begins at S410, at which solder bumps are fabricated on respective electrical contacts of a solar cell. The solder bumps may comprise C4 solder bumps and may be fabricated on the electrical contacts using any system that is or becomes known. FIG. 5 is a detailed cross-sectional view of solar cell 500 and solder bumps 550 after S410 according to some embodiments.

[0043] Device 510 includes semiconductor substrate 511 comprising a majority of a first type of charge carriers. Substrate 511 comprises p+ Ge in some embodiments, but any other suitable substrate material may be used in conjunction with some embodiments. Moreover, the types of charge carriers associated therewith may be reversed from that described herein (i.e., all p regions may be substituted for n regions and vice versa).

[0044] Semiconductor layer 513 is capable of generating charge carriers (i.e., holes and electrons) in response to received photons. According to some embodiments, layer 513 comprises three distinct junctions deposited using any suitable method. According to some embodiments, the junctions are formed using molecular beam epitaxy and/or molecular organic chemical vapor deposition. The junctions may include a Ge junction, a GaAs junction, and a GaInP junction. Each junction exhibits a different band gap energy, which causes each junction to absorb photons of a particular range of energies.

[0045] Semiconductor portions 514 may comprise n++ GaAs and may support metal (e.g., Ag) contacts 515. Metal contacts 515 may comprise any suitable metal contact, and may include a thin adhesion layer (e.g., Ni or Cr), an ohmic metal (e.g., Ag), a diffusion barrier layer (e.g., TiW or TiW:N), a solderable metal (e.g., Ni), and a passivation metal (e.g., Au). Metal contact 516 is coupled to semiconductor region 517 comprising p++ Ge. Semiconductor region 517 may assist in establishing an ohmic contact between contact 516 and substrate 511, and may be omitted in some embodiments. Metal contact 516 exhibits a different polarity than metal contacts 515 by virtue of the illustrated structure. Solar cell 510 also includes anti-reflective coating 518 to allow light from an optical element to reach semiconductor layer 513.

[0046] Solder bumps 550 are attached to metal contacts 515. As shown in FIG. 5, solder bumps 550 have been partially melted and cooled at S410 to form a bond with metal contacts 515. The attachment of solder bumps 550 to metal contacts 515 has consumed any passivation metal that may have existed within metal contacts 515 prior to S410. During the melting process the passivation metal dissolves in the solder, allowing the solder to bond with the solderable metal layer in metal contacts 515.

[0047] Returning to process 400, the solder bumps are placed on corresponding electrical contacts of an optical element at S420. FIG. 6 is an exploded perspective view showing optical element 600 according to some embodiments. Optical element 600 includes substantially light-transparent core 610, primary mirror 620 and secondary mirror 630.

[0048] Core 610 includes relatively large convex surface 611, substantially flat aperture surface 612, and relatively small concave surface 613. Primary mirror 620 and secondary mirror 630 are formed on convex surface 611 and concave surface 613, respectively. An upper periphery of optical element 610 includes six contiguous facets. This six-sided

arrangement may facilitate the formation of large arrays of optical element 600 in a space-efficient manner.

[0049] In some embodiments, core 610 is molded from low-iron glass using known methods. Core 610 may alternatively be formed from a single piece of clear plastic, or separate pieces may be glued or otherwise coupled together to form core 610.

[0050] Primary mirror 620 and secondary mirror 630 may be fabricated by sputtering or otherwise depositing a reflective mirror material (e.g., silver (Ag) or aluminum (Al)) directly onto convex surface 611 and concave surface 613. Primary mirror 620 includes conductive portion 622 disposed on a first half of convex surface 611, and conductive portion 624 disposed on a second half of convex surface 611.

[0051] Gap 627 is defined between conductive portions 622 and 624 to facilitate electrical isolation thereof. Accordingly, conductive portions 622 and 624 of primary mirror 620 may create a conductive path for electrical current generated by photovoltaic cell 510. Conductive portions 622 and 624 may also, as described in above-mentioned U.S. Patent Application Publication No. 2006/0231133, electrically link photovoltaic cells of adjacent collectors in a concentrating solar collector array.

[0052] Primary mirror 620 also includes opening 628 within area 629. In some embodiments, light may pass from core 610 through opening 628 and to solar cell 510. Additional details of the operation of optical element 600 according to some embodiments will be provided below.

[0053] FIG. 7 is a rear perspective view of optical element 600 according to some embodiments. FIG. 7 shows conductive portions 622 and 624 deposited on core 610 and separated by gap 627. Opening 628 is completely surrounded by conductive portion 624 according to the illustrated embodiment.

[0054] Process 400 may operate on an optical element exhibiting any other suitable configuration. Some examples are described in U.S. Patent Application Nos. (Atty. Docket No. SF-P060, Atty. Docket No. SF-P071, and Atty. Docket No. SF-P072) filed on even date herewith.

[0055] According to some embodiments, flux is applied to the solder bumps prior to S420 using known systems. The placement itself may be performed by a fast speed pick and place machine instead of a flip chip bonder in some embodiments. According to some embodiments, the placement need not be as accurate as in conventional flip-chip bonding techniques.

[0056] FIG. 8 is a cross-sectional view of solar cell 510, solder bumps 550 and optical element 600 after S420 according to some embodiments. Unlike the depictions of FIGS. 6 and 7, optical element 600 of FIG. 8 includes electrical contacts 640 and 642 disposed on and electrically coupled to conductive portions 622 and 624, respectively. Electrical contacts 640 and 642 may comprise thick metal, a solderable metal portion and a passivation layer as illustrated.

[0057] Solder bumps 550 are skewed slightly with respect to contacts 640. Accordingly, window 520 of solar cell 510 is slightly mis-aligned with opening 628 of optical element 600. Window 520 comprises an interface into which solar cell 510 receives photons and from which the photons are transmitted to optically-active semiconductor layer 513.

[0058] Next, at S430, the solder bumps are reflowed (i.e., melted) to align an optically-active area of the solar cell with a light-emitting interface of the optical element. S430 may employ any solder reflow system that is or becomes known.

When melted, the surface tension of the solder bumps may move the solar cell so as to align the optically-active area with the light-emitting interface.

[0059] FIG. 9 shows solar cell 510 and optical element 600 after S430 according to some embodiments. In comparison to FIG. 8, window 520 and optically-active area 513 are aligned with window 628. Such alignment may facilitate the transfer of photons from optical element 600 to solar cell 510. Moreover, such alignment is achieved using more efficient placement techniques than conventionally used.

[0060] Underfill material is deposited between the solar cell and the optical element and around the solder bumps at S440. The underfill material may comprise any currently- or hereafter-known underfill material and may be deposited by any suitable system. The underfill material may be optically-transparent to wavelengths of light corresponding to the solar cell. Once cured, the underfill material may protect the solder bumps as well as the optical interfaces of the solar cell and the optical element.

[0061] FIG. 10 is a cross-sectional side view showing underfill material 700 deposited between solar cell 510 and optical element 600 and around solder bumps 550 according to some embodiments. According to some embodiments, underfill material 700 comprises silicone. Underfill material 700 and anti-reflective coating 518 may be selected based at least in part on having substantially similar indexes of refraction.

[0062] A heat paddle may be coupled to the solar cell and to a second electrical contact of the optical element at S450. The heat paddle may dissipate heat from the solar cell and may also conduct current from the solar cell to the second electrical contact. FIG. 11 continues the above example showing silver heat paddle 800 coupled to electrical contact 516 of solar cell 510.

[0063] Heat paddle 800 is also coupled to electrical contact 642 of optical element 600. As noted above, contact 516 is of a different polarity than contacts 515 of solar cell 510 and electrical contact 642 is electrically isolated from electrical contacts 640. Accordingly, electrical contact 642 and electrical contacts 640 may serve to carry generated charge away from solar cell 510 in some embodiments.

[0064] The heat paddle, the solar cell, and the electrical contacts of the optical element are encapsulated at S460. Encapsulation may serve to further protect the encapsulated elements. The encapsulant may comprise a polymer or any other suitable material deposited by any suitable means. FIG. 11 also shows encapsulant 850 surrounding heat paddle 800, solar cell 510, and electrical contacts 640 and 642 according to some embodiments. Encapsulant 850 need not completely cover entire portions of electrical contacts 640 or 642 according to some embodiments.

[0065] The apparatus depicted in FIGS. 5 through 11 may generally operate in accordance with the description of aforementioned U.S. Patent Application Publication No. 2006/0231133. For example, solar rays enter surface 612 and are reflected by primary mirror 620. The rays are reflected toward secondary mirror 630, which in turn reflects the rays toward opening 628. The reflected rays pass through opening 628, underfill material 700 and are received by window 520 of solar cell 510. Those in the art of optics will recognize that combinations of one or more other surface shapes may be utilized to concentrate solar rays onto a solar cell.

[0066] The solar rays may pass through anti-reflective coating 518 before being absorbed by semiconductor layer 513.

Layer 513 generates charge carriers in response to the received light, which pass to metal contacts 515 and 516 and to corresponding ones of electrical contacts 640 and 642. The charge carriers (i.e., electric current) are then conducted to external circuitry (and/or to similar serially-connected apparatuses) to which electrical contacts 640 and 642 are connected.

[0067] FIG. 12 is a perspective view showing a solid, light-transparent optical panel 1200 according to some embodiments. Optical panel 1200 comprises an integrated array of concentrating solar collectors 600-1 to 600-7 arranged in a honeycomb pattern. Each of collectors 600-1 to 600-7 is substantially identical to the apparatus depicted in FIGS. 5 through 11. As such, each of collectors 600-1 to 600-7 includes a solar cell to generate charge carriers in response to received photons and comprising a first electrical contact, an optical element comprising a second electrical contact, and a solder bump in contact with the first electrical contact and the second electrical contact.

[0068] The several embodiments described herein are solely for the purpose of illustration. Embodiments may include any currently or hereafter-known versions of the elements described herein. Therefore, persons in the art will recognize from this description that other embodiments may be practiced with various modifications and alterations.

What is claimed is:

1. A method comprising:

forming a solder bump on an electrical contact of a solar cell;
placing the solder bump in contact with an electrical contact of an optical element; and
melting the solder bump to couple the electrical contact of the solar cell to the electrical contact of the optical element.

2. A method according to claim 1, wherein melting the solder bump comprises:

heating the solar cell, solder bump and optical element in a reflow oven.

3. A method according to claim 1, wherein melting comprises:

melting the solder bump to align an optically active area of the solar cell with a light-emitting interface of the optical element.

4. A method according to claim 1, further comprising:
depositing transparent underfill material between the solar cell and the optical element and around the solder bump.

5. A method according to claim 1, further comprising:
coupling a heat paddle to the solar cell.

6. A method according to claim 5, further comprising:
coupling the heat paddle to a second electrical contact of the optical element; and

encapsulating the heat paddle, the solar cell, the electrical contact of the optical element, and the second electrical contact of the optical element within a polymer.

7. A method according to claim 1,

wherein placing the solder bump in contact with the electrical contact of the optical element comprises placing a second solder bump in contact with a second electrical contact of the optical element, and

wherein melting the solder bump to couple the electrical contact of the solar cell to the electrical contact of the optical element comprises melting the second solder

bump to couple a second electrical contact of the solar cell to the second electrical contact of the optical element.

8. An apparatus comprising:

a solar cell comprising a first electrical contact, the solar cell to generate charge carriers in response to received photons;

an optical element comprising a second electrical contact; and

a solder bump in contact with the first electrical contact and the second electrical contact.

9. An apparatus according to claim **8**, wherein the solder bump has been reflowed while in contact with the first electrical contact and the second electrical contact.

10. An apparatus according to claim **8**, wherein the first electrical contact comprises:

a conductive contact;

a barrier layer in contact with the conductive contact; and a solder pad in contact with the barrier layer.

11. An apparatus according to claim **8**, further comprising: transparent underfill material disposed between the solar cell and the optical element and around the solder bump.

12. An apparatus according to claim **11**, wherein the solar cell comprises an anti-reflective coating exhibiting an index of refraction substantially equal to an index of refraction exhibited by the transparent underfill material.

13. An apparatus according to claim **8**, wherein the solar cell comprises an anti-reflective coating exhibiting an index of refraction substantially equal to 1.0.

14. An apparatus according to claim **8**, wherein the solar cell comprises an optically-active area,

wherein the optical element comprises a light-emitting interface, and

wherein the optically-active area is aligned with the light-emitting interface.

15. An apparatus according to claim **8**, wherein the solar cell comprises:

a semiconductor substrate comprising a majority of a first type of charge carrier;

a first semiconductor portion comprising a majority of a second type of charge carrier;

a semiconductor layer disposed between the semiconductor substrate and the first semiconductor portion to generate charge carriers of the first type and of the second type in response to received photons; and

a third electrical contact in contact with the semiconductor substrate and to receive charge carriers of the second type generated by the semiconductor layer,

wherein the first semiconductor portion is disposed between the first electrical contact and the semiconductor layer.

16. An apparatus according to claim **8**, wherein the solar cell comprises a third electrical contact and wherein the optical element comprises a fourth electrical contact, the apparatus further comprising:

a second solder bump in contact with the third electrical contact and the fourth electrical contact.

17. An apparatus according to claim **8**, wherein the solar cell comprises a heat paddle and wherein the optical element comprises a third electrical contact electrically coupled to the heat paddle, the apparatus further comprising:

a polymer encapsulating the heat paddle, the solar cell, the second electrical contact, and the third electrical contact.

19. An apparatus according to claim **8**, wherein the optical element comprises a solar concentrator.

20. A method comprising:

forming a solder bump on an electrical contact of an optical element;

placing the solder bump in contact with an electrical contact of a solar cell; and

melting the solder bump to couple the electrical contact of the solar cell to the electrical contact of the optical element.

21. A method according to claim **20**, wherein melting the solder bump comprises:

heating the solar cell, solder bump and optical element in a reflow oven.

22. A method according to claim **20**, wherein melting comprises:

melting the solder bump to align an optically active area of the solar cell with a light-emitting interface of the optical element.

23. A method according to claim **20**, further comprising: depositing transparent underfill material between the solar cell and the optical element and around the solder bump.

24. A method according to claim **20**,

wherein placing the solder bump in contact with the electrical contact of the solar cell comprises placing a second solder bump in contact with a second electrical contact of the solar cell, and

wherein melting the solder bump to couple the electrical contact of the solar cell to the electrical contact of the optical element comprises melting the second solder bump to couple the second electrical contact of the solar cell to a second electrical contact of the optical element.

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