

PV Cell

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SPECIFICATION

BACKGROUND OF THE INVENTION

[0001] The present invention is in the field of photovoltaics (PV). More particularly, the invention is in the technical field of PV cell.

[0002] One of the known PV module construction method is referred to as the shingling process. This is done by dividing a full PV cell into smaller segmented pieces and electrically connecting these cells together by partially overlapping them. During the shingling process, the front cell busbar of one PV cell makes physical and electrical contact with the rear cell busbar of an adjacent PV cell. Intermediary conductive materials such as Electrically Conductive Adhesives (ECA) is sometimes dispensed onto the busbar surface to bond the PV cells together and improve the electrical interconnectivity between shingled PV cells. This process is repeated multiple times until the desired PV module specification is achieved. This shingling process involves high precision

pick and place techniques to ensure the accuracy of the PV cells overlapped placement and is often accomplished by sophisticated equipment.

[0003] In a conventional PV module, the PV cells are connected electrically via interconnecting conductive ribbons. In a conventional PV cell design, the busbars of the PV cells are designed to have a flat or non-profiled surface. This allows the largest effective contact area between PV cell busbars and interconnecting conductive ribbons. Where else in a shingled PV module, an electrical connection is established between the PV cells by means of shingling two or more PV cells such that the busbars are physically in contact with each other.

[0004] When a conventional PV cell design with non-profiled busbar surface is used in a shingled PV module, multiple setbacks and challenges are faced. Firstly, the PV cells with a flat or non-profiled busbar surface tends to slip and misalign during the shingling process due to process equipment contribution, such as equipment vibration, placement offset, etc. Secondly, the ECA which is dispensed onto the flat or non-profiled busbar surface tends to squeeze out of the overlapping region as a result of compression between two flat busbar surfaces during shingling process. This leads to PV cell shunting, hotspot failures and other reliability issues. Thirdly, the effective contact area between the busbars are limited by the length and width of the flat or non-profiled busbars. This increases the resistivity and contributes to the overall electrical performance drop of a PV module.

SUMMARY OF THE INVENTION

[0005] Embodiments of the present disclosure generally relate to solve the shortcomings of prior art. In the present invention, a PV cell with profiled busbar surface incorporated into the PV cell busbar is used specifically in a shingled PV module. As compared to a conventional PV cell with flat or non-profiled busbars, the PV cell in the present invention has busbars which are profiled with opposing structures, namely height protrusions and cavities, such that it fits and hold onto each other during the shingling process.

[0006] The PV cell of the present invention comprises a Silicon semiconductor structure comprising a front metallization surface disposed with electrically conducting grid fingers which is connected to the front busbar of the PV cell. An electrically conducting back surface metallization is disposed on the back surface. The back metallization surface is disposed with Al-BSF layer and rear busbars. In another variation, the back metallization surface is disposed with electrically conducting grid fingers which is connected to the rear busbars of the PV cell. The busbars on the front and rear surface of the PV cell is made from electrically conductive materials, which are profiled with different height profiles, shapes and textures.

[0007] The busbars of the PV cell of the present invention are profiled with multiple methods which includes, but not limited to; 1) single layer printing using overlaid stencil design; 2) multi stage layered printing using single overlaid or multiple designed stencils; 3) 2D or 3D printing; 4) single or multiple sputtering process; 4) chemical or physical deposition process or any combination thereof.

[0008] The present invention introduces a PV cell with profiled busbars, namely protrusions and cavities, which are designed in a way such that during the shingling process, these PV cells are capable of self-aligning and interlocking with each other via the protrusion and cavity profiles. With this in-built self-aligning and interlocking mechanism incorporated into the PV cells, the capability of the shingling process is greatly improved, as it does not have to rely completely on

the process equipment for placement accuracy and process control. The self-aligning interlocking mechanism now allows the PV cells to fit into the designed profiles and secure its position.

[0009] In another variation of the present invention, the PV cell with profiled busbar surface comprise additional cavities to hold the intermediary conductive materials. When intermediary conductive materials such as ECA is dispensed onto the busbars, the void that is created by the profiled busbars are able to hold and contain the ECA within the busbar region and prevents ECA squeeze out due to compression during the shingling process. This eliminates the shunting issue and improves the reliability of the PV module.

[0010] The PV cell with profiled busbar surface in the present invention also comprise a depth profile from protrusions and cavities. This increases the effective contact surface area between the shingled busbars, thus improves the electrical performance of the entire PV module.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 shows a top and bottom plan view of an example of a PV cell;

[0012] FIG. 2 shows a top and bottom plan view of an example of a PV cell in FIG. 1 divided into five smaller pieces;

[0013] FIG. 3 shows a top and bottom plan view of an example of separated PV cells in FIG. 2;

[0014] FIG. 4 shows a perspective view of an example of separated PV cell in FIG. 3;

[0015] FIG. 5 shows a close up side view of an example of two rectangular PV cells in FIG. 4;

[0016] FIG. 6 shows a close up side view of an example of PV cells electrically connected via the profiled busbars;

[0017] FIG. 7 shows a top plan view of an example of a plurality of shingled PV cells in FIG. 6 electrically connected to each other;

[0018] FIG. 8 shows a side view of an example in FIG. 7;

[0019] FIG. 9 shows a close up side view of an example of PV cells electrically connected with conductive intermediary materials;

[0020] FIG. 10 shows a close up side view of an example of PV cells electrically connected with non-conductive bonding materials.

DETAILED DESCRIPTION

[0021] Certain terminology may also be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as "top", "bottom", "upper", "lower", "above", and "below" refer to internally consistent directions in the drawings to which reference is made. Terms such as "front", "back", "rear", "side" may describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import.

[0022] "Photovoltaic" – Photovoltaic, or PV in short, may refer to the conversion of light into electricity using semiconductor materials that exhibit photovoltaic effect. Photovoltaic cells and photovoltaic modules can also be regarded as solar cells and solar modules.

[0023] "Photovoltaic Cell" – Photovoltaic cell, or PV cell in short, may refer to the semiconductor material that exhibit photovoltaic effect that converts light into electricity. Photovoltaic cells can also be regarded as solar cells.

[0024] "Photovoltaic Module" – Photovoltaic module, or PV module in short, may constitute PV cells which are interconnected and are encapsulated into an assembly that generates solar electricity. Photovoltaic modules can also be regarded as solar modules or solar panels.

[0025] "Shingled" – Shingled may refer to Photovoltaic cells which are shingled together. Shingled may refer to a PV cell which is partially overlapped onto another PV cell. During shingling process, the back busbar contact area of a PV cell comes into contact with the front busbar contact area of another PV cell.

[0026] "String" – String may refer to two or more Photovoltaic cells that are connected in series to form a chain or a string of PV cells.

[0027] “Busbar” – Busbar or bus bar may refer to a conductive element or electrode which is printed on the front and rear of a PV cell. The purpose of a busbar is to conduct the direct current produced by the PV cell from the incoming photons. Busbars are used to conduct electric current from grid fingers, neighboring PV cells and/or external circuitry.

[0028] FIG. 1a shows a top and bottom plan view of an example of a single facial PV cell. On the front side, the PV cell 100 includes front cell busbars 101, along with electrically conducting grid fingers 103 disposed on the top surface of a silicon substrate 104. The grid fingers are electrically connected to the front busbar of the PV cell. In FIG. 1a, the rear surface of the single facial PV cell includes rear cell busbars 102, and an Al-BSF conductive layer 105 disposed on the back surface of a silicone substrate 104. The busbars on the front and rear surface of the PV cell is made from electrically conductive materials, which are profiled with different height profiles, shapes and textures.

[0029] In another variation, FIG. 1b shows a top and bottom plan view of an example of a bi-facial PV cell. On the front side, the PV cell 100 includes front cell busbars 101, along with electrically conducting grid fingers 103 disposed on the top surface of a silicon substrate 104. The grid fingers are electrically connected to the front busbar of the PV cell. In FIG. 1b, the rear surface of the bi-facial PV cell includes rear cell busbars 102, along with electrically conducting grid fingers 103 disposed on the back surface of a silicon substrate 104. The busbars on the front and rear surface of the PV cell is made from electrically conductive materials, which are profiled with different height profiles, shapes and textures.

[0030] FIG. 2 shows a top and bottom plan view of an example of a PV cell in FIG. 1a divided and physically separated into five smaller pieces. It is shown three rectangular cells 210 along with two chamfered cells 211. Multiple techniques can be used to physically separate a PV cell into multiple smaller pieces. Methods such as wire cut, diamond saw and laser cut are examples of separation techniques that can be used. With these examples of methods mentioned above, careful consideration must be made on the process selection to ensure separation accuracy, electrical and mechanical properties of the PV cell is not affected.

[0031] FIG. 3 shows a top and bottom plan view of an example of separated rectangular PV cells 210. It is shown a front cell busbar 101 and rear cell busbar 102 design which is continuous. In another example, the front cell busbar 106 and rear cell busbar 107 are segmented into multiple segments.

[0032] FIG. 4a shows a perspective view of an example of a separated rectangular PV cell 210. It is shown a front cell busbar 101 and rear cell busbar 102. Compared to a conventional PV cell which has flat or non-profiled surface busbars, the busbars in FIG. 4 of the present invention features busbar surfaces which are profiled into a non-flat surface. The front cell busbar 101 is profiled in such a way that part of the busbar surface is produced with a lower height, thus creating a cavity profile 109. In contrast to the front cell busbar with cavity profile, the rear cell busbar 102 is profiled in such a way that part of the busbar surface is produced with an additional height, thus creating a protrusion profile 108.

[0033] FIG. 4b shows another variation of an example of a profiled front cell busbar 101 and its corresponding rear busbar 102. The examples in FIG. 4b shows various busbar shapes, both protrusion and cavities. Depending on the type of application and available busbar profiling and printing technology, the most suitable busbar shape can be selected to suit for unique application types.

[0034] The busbars of the PV cell of the present invention are profiled with multiple methods which includes, but not limited to; 1) single layer printing using overlaid stencil design; 2) multi stage layered printing using single overlaid or multiple designed stencils; 3) 2D or 3D printing; 4) single or multiple sputtering process; 4) chemical or physical deposition process or any combination thereof.

[0035] FIG. 5 shows a close up side view of an example of two rectangular PV cells 210 in FIG. 4a placed above each other in such a way that the front busbar 101 of the bottom PV cell is aligned to the rear busbar 102 of the top PV cell. The respective busbar structures of these two adjacent PV cells fits into each other during shingling process, whereby the protrusion profile 108 of the top PV cell fits into the cavity profile 109 of the bottom PV cell. During the engagement process,

electrical connectivity is established between the two PV cells. Furthermore, the busbars profiles itself permits PV cell to PV cell mechanical interlocking mechanism to be established, thus securing the shingled PV cells in its position. The profiled busbar also covers a larger busbar surface contact area between the shingled busbars when the PV cells are shingled together. A larger busbar surface contact area improves the electrical connectivity between the PV cells which are shingled together within a PV module.

[0036] Also shown in FIG. 5 are five different examples of busbar profiles, shown as a, b, c, d and e. Profile “a” has a “U” shaped busbar appearance, profile “b” has a “triangle” shaped busbar appearance, profile “c” has a “dome” shaped busbar appearance and profile “d” has a “ladder” shaped busbar appearance. Examples a, b and c are designed to have a single profile matching pair, whereby there is only one type of profile incorporated in any one of the busbars. Where else in example “d”, multi profile matching pair can be established as each busbar features both protrusion and cavity profile incorporated into it. In example “e”, one part of the busbar is profiled flat and the other part has a cavity profile. The examples shown in FIG. 5 are not limited to the six examples which are shown and can have various types of profiles, designs and appearances that best suits the application.

[0037] Compared to known conventional busbar designs which has a flat surface, the profiled busbar in FIG. 5, when connected together, provides multiple added benefits, which includes but not limited to; 1) improved mechanical reliability; 2) improved overall electrical performance; 3) reduce the reliance on high precision process equipment; 4) improved product reliability; 5) reduced cost from bill-of-material (BOM) reduction.

[0038] When PV cells are shingled via the profiled busbar, the busbar profiles provides an interlocking interface whereby the PV cells could be held securely together with limited slippage factor as compared to a conventional flat or non-profiled busbar. This improves the mechanical load handling capability of the PV cell joint, which in turn improves the PV string, followed by the entire PV module.

[0039] FIG. 6a shows a close up side view of an example of PV cells electrically connected via the profiled busbars. It is shown two rectangular PV cells 210 electrically connected to each other via the busbars. The rear busbar of the top cell 102 and front busbar of the bottom cell 101 features a “U” shaped busbar profile and are placed directly above each other in a partial overlapping manner during shingling process.

[0040] FIG. 6b shows a close up side view of an example of PV cells electrically connected via the profiled busbars. It is shown two rectangular PV cells 210 electrically connected to each other via the busbars. The rear busbar of the top cell 102 and front busbar of the bottom cell 101 features a “U” shaped busbar profile and are placed directly above each other in a partial overlapping manner during shingling process. Conductive intermediary material 301 is applied on the busbar surface of the overlapping region during shingling process.

[0041] FIG. 7 shows a top plan view of an example of a plurality of shingled PV cells in FIG. 6 electrically connected to each other to be formed into a PV string 220. It is shown five rectangular PV cells 210 electrically connected to each other via shingling process. During the shingling process, the rear cell busbar 102 of a PV cell makes direct contact with the front cell busbar 101 of another PV cell.

[0042] FIG. 8 shows a side view of an example of PV cells electrically connected to each other as shown in the example of FIG. 7. In both of the examples in FIGS. 7-8, the profiled busbars 101,102 is used to establish electrical connection between the PV cells 210. The profiled busbar is also used to establish an interlocking mechanism between the five PV cells which are shingled together.

[0043] The number of PV cells that are electrically connected to each other to construct a PV string are determined based on system needs and requirements set by the PV module designer. The method of electrically connecting the PV cells is subjected to the technology availability and equipment capability.

[0044] The process of shingling may be performed by manual human intervention, standalone equipment, fully automatic equipment or any combination thereof. Most commonly, a fully

automated precision equipment is used to accomplish this task due to the high process capability requirement.

[0045] FIG. 9 shows a close up side view of an example of PV cells electrically connected via the profiled busbars with conductive intermediary materials applied at the interfacing joints. Prior to the shingling process, the conductive intermediary material 301 is applied within the cavity of the rear busbar 102 of the rectangular PV cells 210. This is followed by the shingling process. Once the PV cells are shingled, the chamber 110 which is formed between the shingled busbars serves as a container to hold the intermediary materials within the busbar region. Certain type of conductive intermediary materials such as Electrically Conductive Adhesives (ECA) and solder paste have semi-solid state properties. This would allow the material to fill up the chamber between the busbars to further increase the joint strength and electrical connectivity.

[0046] Intermediary materials such as Electrically Conductive Adhesives (ECA), solder paste and conductive ribbons are commonly used to bond PV cells together during shingling process. The application volume of these intermediary materials need to be optimized to ensure product performance and reliability is not compromised. If volume is insufficient, the shingled joint may suffer from increased resistive loss which leads to overall power drop in a module. On the other hand, excessive application leads to material squeeze out, which can cause electrical shorting and catastrophic failure. The introduction of intermediary materials also adds cost to the bill-of-material (BOM) of the PV module. When PV cells with hollow busbar profile is used for this application, the usage of intermediary materials can be optimized. This mitigates the reliability impact and lowers the module's BOM cost.

[0047] FIG. 10 shows a close up side view of an example of PV cells electrically connected via the profiled busbar with non-conductive bonding materials applied on the overlapping regions. It is shown two rectangular PV cells 210 electrically connected to each other via the busbars. The rear busbar of the top cell 102 and front busbar of the bottom cell 101 features a "U" shaped appearance interlocking busbar profile and are placed directly above each other. Non-conductive bonding material 401 is applied on the PV cell such that it is contained within the overlapping region. The non-conductive bonding material can also be applied on the edges of the cells, such

that it forms a fillet 402. The bonding material can be applied on any location within the PV cell, irrespective of front surface of PV cell, rear surface of PV cell, edges of PV cell, or any combination thereof.

[0048] The non-conductive bonding material that is used for this application should have adequate adhesion to mechanically hold the PV cells together and has properties to ensure it is compatible with the fabrication process, chemically inert to the other components in contact, and stable over time and operation temperature to meet the reliability requirements of PV modules. The choices of bonding material type includes, but not limited to; epoxy based, gel based and can be in the form of paste, liquid, tape, film, etc. It is critical to ensure that the bonding material properties are electrically non-conductive. This is to prevent electrical shorting.

[0049] While the foregoing written description of the invention enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific embodiments, method, and examples herein. The invention should therefore not be limited by the above described embodiments, method, and examples, but by all embodiments and methods within the scope and spirit of the invention.

WHAT IS CLAIMED IS:

1. A PV cell comprising of a substrate, a front and back surface, a profiled front busbar, a profiled rear busbar and a plurality of grid fingers that is disposed on the front surface or rear surface or both surface of the PV cell, wherein the plurality of grid fingers are connected to the profiled busbars.
2. The PV cell of claim 1, wherein the profiled front busbar and profiled rear busbar are profiled with opposing structures, namely protrusions and cavities, which when shingled together, the profiled busbars allows electrical connectivity to be established and further creates an interlocking mechanism between a plurality of PV cells during shingling process.
3. The profiled front busbar and profiled rear busbar of claim 2, wherein the opposing structures of the PV cell busbars are profiled to fit or almost fit into each other during shingling process.
4. The profiled front busbar and profiled rear busbar of claim 2, wherein the opposing structures of the PV cell busbars are profiled to create a chamber in between the two opposing busbar structures, once it is shingled.
5. The profiled front busbar and profiled rear busbar of claim 2, wherein the front side of the PV cell has at least one height protrusion profile incorporated onto the busbar and the rear side of the same PV cell has at least one cavity profile incorporated onto the busbar.
6. The profiled front busbar and profiled rear busbar of claim 2, wherein the rear side of the PV cell has at least one height protrusion profile incorporated onto the busbar and the front side of the same PV cell has at least one cavity profile incorporated onto the busbar.
7. The profiled front busbar and profiled rear busbar of claim 2, wherein the front side of the PV cell has at least one combination of both height protrusion and cavity profile incorporated onto the busbar and the rear side of the same PV cell has at least one opposing combination of both height protrusion and cavity profile incorporated onto the busbar.
8. The profiled front busbar and profiled rear busbar of claim 2, wherein the front side of the PV cell has at least one cavity profile incorporated onto the busbar and the rear side of the same PV cell has a flat or almost flat profile incorporated onto the busbar.

9. The profiled front busbar and profiled rear busbar of claim 2, wherein the rear side of the PV cell has at least one cavity profile incorporated onto the busbar and the front side of the same PV cell has a flat or almost flat profile incorporated onto the busbar.