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Ribbons for use in shingled solar cells

Abstract

A string of solar cells is disclosed. The sides of the solar cells have a corrugated shape which forms an opening when the solar cells are arranged in a shingled manner. The solar cells are electrically connected in series by a ribbon that passes through the opening. A wire mesh used to decrease solar cell resistance is also disclosed.

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Background/Summary

FIELD OF THE INVENTION
(1) The invention relates generally to solar cell modules or panels and the solar cells within the solar cell modules.
BACKGROUND
(2) Alternate sources of energy are needed to satisfy ever increasing world-wide energy demands. Solar energy resources are sufficient in many geographical regions to satisfy such demands, in part, by provision of electric power generated with solar (e.g., photovoltaic) cells.
(3) Generally, solar radiation impinging on the surface of, and entering into, the substrate of a solar cell creates electron and hole pairs in the bulk of the substrate. The electron and hole pairs migrate to p-doped and n-doped regions in the substrate, thereby creating a voltage differential between the doped regions. The doped regions are connected to conductive regions on the solar cell to direct an

electrical current from the cell to an external circuit. When solar cells are combined in an array such as a solar cell module, the electrical energy collected from all of the solar cells can be combined in series and parallel arrangements to provide power with a desired voltage and current.

SUMMARY

(4) This specification discloses a solar module having at least one string of solar cells arranged in a shingled manner. Each solar cell is a crystalline silicon solar cell having a substantially rectangular shape. Each solar cell has a front surface with a metallization pattern and a rear surface with a metallization pattern. Each solar cell has at least one long edge having a corrugated shape, where the corrugated shape comprises protruding portions and recessing portions. The solar cells in the string are arranged in a shingled manner with the protruding portions of one cell overlapping with an adjacent solar cell. The solar cells are shingled so that creates the recessing portions of each cell create openings within the string of solar cell. The shingled solar cells are electrically connected in series by an electrically conductive ribbon which passes through an opening created a recessing portion to electrically connect the rear surface metallization of one cell with the front surface metallization of an adjacent cell.

(5) The solar module disclose may have multiple strings of solar cells with cells within each string electrically connected in series and the strings electrically connected in parallel.

(6) In some embodiments, the front surface metallization pattern of each solar cell comprises a plurality of busbars oriented parallel to a short side of the solar cell and the electrically conductive ribbon is disposed onto a busbar. In some embodiments, the ribbon is soldered onto the busbar. In some embodiments, the portion of the ribbon disposed on or solder on the busbar runs parallel to the short side of the solar cell. In some embodiments, the busbars in one cell are aligned with busbars in an adjacent cell. In some embodiments, the busbars in one cell are not aligned with busbars of an adjacent cell. In some embodiments, the busbars in one cell are not aligned with busbars of an adjacent cell but are aligned with busbars of the cell adjacent to an adjacent cell.

(7) In some embodiments, the busbars of each solar cell are oriented parallel the short side of the solar cell and aligned with a recessing portion of the long side of the solar cell.

(8) In some embodiments, the string of solar cell comprises solar cells having a different alignment of recessing portions. In some embodiments, the recessing portions of one cell is aligned with the protruding portions of an adjacent cell. In some embodiments, the recessing portions of one cell is aligned with the protruding portions of both adjacent cells. In some embodiments, the recessing portions of one cell is not aligned with, e.g. is offset from, the recessing portions of an adjacent cell. In some embodiments, the recessing portions of one cell are not aligned with the recessing portions of both adjacent cells.

(9) In some embodiments, each solar cell has a long side with a corrugated shape and another long side that is straight. In some embodiments, each solar cell has two long sides with corrugated shapes.

(10) This specification discloses a solar module having at least two strings of solar cells electrically connected in parallel. Each string contains solar cells arranged in a shingled manner. Each solar cell is a crystalline silicon solar cell having a substantially rectangular shape. Each solar cell having a long side with a corrugated shape, where the corrugated shape comprises protruding portions and recessing portions, and another long side that is straight. Each solar cell has a front surface with a metallization pattern with busbars oriented parallel to the short side of the solar cell and aligned with a recessing portion of the long side. Each solar cell having a rear surface with a metallization pattern. The solar cells in each string are arranged in a shingled manner with the protruding portions of one cell overlapping with an adjacent solar cell. The solar cells are shingled so that creates the recessing portions of each cell create openings within the string of solar cell. The solar cells are shingled so that recessing portions in adjacent solar cells are offset. The solar cells are shingled so that the busbars in one cell are not aligned with busbars of an adjacent cell but are aligned with busbars of the cell adjacent to an adjacent cell. The shingled solar cells within each

string are electrically connected in series by electrically conductive ribbons which passes through openings created recessing portions to electrically connect the rear surface metallization of one cell with the front surface metallization of an adjacent cell.
(11) This specification discloses a solar cell having a front surface with metallization pattern. The metallization pattern comprises a conductive material, e.g. silver. The metallization pattern has busbars and fingers. The fingers are connected to the busbar, oriented perpendicular to the busbar, and parallel to each other. The solar cell has a wire mesh having wires and ribbons made of a second conductive material, e.g. copper. The wires and ribbons form a grid with the wires parallel to each other and perpendicular to the ribbons. The wire mesh is attached to the metallization by attaching the wires of the wire mesh to the fingers of the metallization. In some embodiments, the wires are soldered onto the fingers of the metallization. In some embodiments, a wire of the wire mesh may connect two fingers of the metallization. In some embodiments, the two fingers connected are connected to different busbars of the metallization. In some embodiments, the ribbons of the wire mesh are aligned with the busbar of the metallization. In some embodiments, the ribbons of the wire mesh are not aligned with the busbars of the metallization.
(12) This specification discloses a method of assembling a solar cell. This method comprises assembling a wire mesh having wires oriented parallel to each other and ribbons attached to the wires where the ribbons oriented perpendicular to the wires. This method further comprises providing a solar cell having a surface metallization pattern with fingers oriented parallel to each other. This method further comprises after assembling the wire mesh, disposing the wire mesh onto the surface metallization of the solar cell so that the wires of the wire mesh are aligned with the fingers of the metallization pattern; and then attaching the wire mesh to the metallization pattern.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The figures described below depict various aspects of the system and methods disclosed herein. Each figure depicts an embodiment of a particular aspect of the disclosed system and methods, and that each of the figures is intended to accord with a possible embodiment thereof. Further, wherever possible, the following description refers to the reference numerals included in the following figures, in which features depicted in multiple figures are designated with consistent reference numerals.
(2) FIG. **1** schematically illustrates a solar module.
(3) FIG. **2** schematically illustrates a cross-sectional view of a string of solar cells.
(4) FIGS. **3**A and **3**B schematically illustrate cross-sectional views of a string of shingled solar cells.
(5) FIGS. **4**A and **4**B schematically illustrate a plan view of the front surface of a solar cell.
(6) FIG. **5** schematically illustrates a plan view of a string of solar cells.
(7) FIG. **6** schematically illustrates a cross-sectional view of the string of solar cells in FIG. **5** viewed from line **6-6**.
(8) FIG. **7** schematically illustrates a plan view of a string of solar cells.
(9) FIG. **8** schematically illustrates a cross-sectional view of the string of solar cells in FIG. **7** viewed from line **8-8**.
(10) FIG. **9** schematically illustrates a plan view of a string of solar cells.
(11) FIG. **10** schematically illustrates a wire mesh.
(12) FIGS. **11** and **12** schematically illustrate solar cells with a wire mesh.
(13) FIG. **13** is a flow chart for a method of assembling a solar cell.
(14) FIG. **14** schematically illustrates a plan view of a solar cell.
(15) FIG. **15** schematically illustrates a plan view of string of solar cells.

(16) FIG. **16** schematically illustrates a cross-sectional view of a string of solar cells.

DETAILED DESCRIPTION

(17) The following detailed description should be read with reference to the drawings, in which identical reference numbers refer to like elements throughout the different figures. The drawings, which are not necessarily to scale, depict selective embodiments and are not intended to limit the scope of the invention. The detailed description illustrates by way of example, not by way of limitation, the principles of the invention. This description will clearly enable one skilled in the art to make and use the invention, and describes several embodiments, adaptations, variations, alternatives and uses of the invention, including what is presently believed to be the best mode of carrying out the invention.

(18) As used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly indicates otherwise. Also, the term "parallel" is intended to mean "substantially parallel" and to encompass minor deviations from parallel geometries. The term "perpendicular" is intended to mean "perpendicular or substantially perpendicular" and to encompass minor deviations from perpendicular geometries rather than to require that any perpendicular arrangement described herein be exactly perpendicular. The term "square" is intended to mean "square or substantially square" and to encompass minor deviations from square shapes, for example substantially square shapes having chamfered (e.g., rounded or otherwise truncated) corners. The term "rectangular" is intended to mean "rectangular or substantially rectangular" and to encompass minor deviations from rectangular shapes, for example substantially rectangular shapes having chamfered (e.g., rounded or otherwise truncated) corners or may have non-linear edges. The term "identical" is intended to mean "identical or substantially identical" and to encompass minor deviations in shape, dimensions, structure, composition, or configuration, for example.

(19) This specification discloses high-efficiency solar modules (also referred to herein as solar panels). FIG. **1** shows a solar module **1000** containing six super cells **100** arranged in parallel rows and electrically connected in parallel. Each super cell **100** in FIG. **1** contains several individual solar cells **10** arranged in a row and electrically connected in series. A solar module may comprise any suitable number of super cells and super cells may comprise any suitable number of solar cells. For example, a solar module may have 480 solar cells arranged in 6 super cells with each super cell containing 80 individual solar cells. The super cells may have lengths spanning essentially the full length or width of the solar module or two or more super cells may be arranged end-to-end in a row.

(20) In the examples described in this specification, each solar cell **10** is a crystalline silicon solar cell having front (sunny side) surface and rear (shaded side). Between the front surface and rear surface are at least one semiconductor layer of p-type conductivity and at least one semiconductor layer of n-type conductivity. The n-type semiconductor layer and the p-type semiconductor layer meet to form an n-p junction. Each solar cell has electrical contacts or metallization on the front surface of the solar cell which makes electrical contact with a semiconductor layer on one side of the n-p junction. Further, each solar cell has electrical contacts on the rear surface of the solar cell which makes electrical contact with a semiconductor layer on the opposite side of the n-p junction. For example, if the front surface electrical contact (metallization) makes an electrical connection with the n-type semiconductor layer, then the rear surface electrical contact makes an electrical contact with the p-type semiconductor layer. However, other material systems, diode structures, physical dimensions, or electrical contact arrangements may be used if suitable.

(21) Resistive effects in solar cells may reduce the efficiency of the solar cell by dissipating power in the resistances. Series resistance in a solar cell may be due to movement of the current through the p-n materials of the solar cell; contact resistance between the metal contact and the silicon; and resistance in the metal contacts or metallization. The design of the metallization (e.g. the metallization pattern) of a solar cell may reduce losses due to resistance. Certain features of the

metallization pattern such as finger and busbar spacing may be optimized to reduce resistance of the metallization.
(22) The solar cells **10** in a super cell may be electrically connected in series. This generally requires an electrical connection from the front surface of one solar cell to the rear surface of an adjacent solar cell. In traditional ribbon-connected solar cells, an electrically conductive ribbons are used to connect the back metal contact of a solar cell with the front metal contact of an adjacent solar cell. This type of connection requires a gap between solar cells to accommodate ribbons used for connecting adjacent solar cells. FIG. **2** shows a cross-sectional view of a string of solar cells **10** connected in series by ribbons **52**. For solar cells **10** having electrical contacts at the front and rear surfaces of the solar cell, the ribbon must connect the front surface of one solar cell with the rear surface of an adjacent cell to make a series connection. For solar cells in FIG. **2**, this series connection requires that the solar cells be spaced apart to allow ribbon **52** to make the required connection. The presence of a space between solar cells reduces the area in a solar module of a given size that can be used to generate electrical power.
(23) Shingling solar cells can eliminate gaps between solar cells as shown in FIGS. **3**A & **3**B. Shingling solar cells **10** can be electrically connected in series by using electrically conductive adhesive to bond the solar cell together as in FIG. **3**A (electrically conductive adhesive not shown). Or shingled solar cells **10** can be electrically connected in series by ribbons **53** as shown in FIG. **3**B.
(24) This specification discloses high-efficiency solar modules where the solar cells within the module are both shingled and use ribbons to electrically connect the solar cells in series. This specification further discloses the use of ribbons or metal wires to decease the resistance of the solar cell.
(25) FIG. **4**A shows a schematic diagram of a front surface view of solar cell **10**. Solar cell **10** is rectangular or substantially rectangular having non-linear long sides. The long sides of solar cell **10** have a corrugated shape with protruding portions **41**, which are portions of the solar cell that protrude or extend away from a center of the solar cell, and recessing portions **42**, which are portions of the solar cell that recess towards the center of the solar cell. Protruding portion **41** protrudes or extends past the imaginary line **45** connecting the corners of the long side of the solar cell to which protruding portion **41** belongs. Recessing portion **42** is a portion of the solar cell that is recessed relative to imaginary line **45**.
(26) The front surface of solar cell **10** has an electrically conducting front surface metallization pattern that collects current generated by the solar cell when the solar cell is illuminated by light. The metallization serves as an electrical contact for the solar cell and may comprise silver. The front surface metallization pattern includes multiple busbars **15** running parallel to the short sides of solar cell **10** and running for substantially the length of the short sides of the solar cell. Multiple fingers **20** are attached substantially perpendicularly to busbars **15** and run parallel to each other. The front surface metallization may not have contact pads at the edge of the front surface which may reduce costs. The rear surface of solar cell **10** may have a similar metallization pattern as the front surface. Busbars **15** are aligned with the recessing portions **42** of the solar cell. For example, busbar **15** in FIG. **4**A starts and ends at a recessing portion **42**.
(27) FIG. **4**B shows a schematic diagram of an alternate embodiment of solar cell **10**. In FIG. **4**B one long side of the solar cell has a corrugated shape whereas the other long side of the solar cell has a straight edge. Busbars **15** in the solar cell of FIG. **4**B have an end point at a recessing portion **42**.
(28) FIG. **5** shows a schematic diagram of a plan (front surface) view of string of series-connected solar cells **10** shown in FIG. **4**A arranged in a shingled manner. This string of solar cells may form a portion of super cell **100**. The solar cells are arranged so that the protruding portion **41** of one solar cell overlaps with the front surface of an adjacent solar cell but recessing portion **42** does not overlap with the front surface of the adjacent solar cell. This arrangement creates an opening

comprising the recessing portions of adjacent solar cells. FIG. **6** shows a cross-sectional view of the string of solar cells through line **6-6** in FIG. **5**. Protruding portions **41** are outlined with dashed lines in FIG. **6** and are behind ribbon **50** in this cross-sectional view.

(29) Solar cells **10** are electrically connected in series to each other using electrically conductive ribbons **50** to connect the front surface metallization (not shown in FIG. **6**) of one solar cell with the rear surface metallization (not shown in FIGS. **5** & **6**) of an adjacent solar cell. Ribbon **50** is made from a conductive metal, for example, copper. Ribbon **50** may also have a conductive metal core, e.g. of copper, coated in silver, lead, tin, lead-tin, or tin-bismuth. The coating may be done by electroplating.

(30) Ribbon **50** may be disposed over and attached to busbar **15** of the front surface metallization as shown in FIG. **5**. Ribbon **50** may be attached to busbar **15** by soldering. Disposing ribbon **50** over the busbar and soldering ribbon **50** to the busbar is advantageous because this eliminates the need for separate contact pads to connect the ribbon. Eliminating contact pads which are generally made from silver reduces the cost of the solar cell. Ribbon **50** may be attached to the rear surface metallization via busbars on the rear surface of the solar cell. Generally, multiple ribbons connect one solar cell to an adjacent solar cell. Ribbon **50** runs from one solar cell to an adjacent solar cell via the opening created by the recessing portions **42** of the solar cells. Ribbon **50** bends slightly as it passes through this opening.

(31) FIG. **7** shows a schematic diagram of a plan (front surface) view of string of series-connected solar cells **10** shown in FIG. **4**B arranged in a shingled manner. The solar cells are arranged so that the protruding portions **41** of one solar cell overlaps with an adjacent solar cell but recessing portion **42** does not overlap with the adjacent solar cell. This arrangement creates an opening comprising the recessing portions of solar cells **10**. FIG. **8** shows a cross-sectional view of the string of solar cells viewed through line **8-8** in FIG. **7**. Protruding portions **41** outlined with dashed lines in FIG. **8** are behind ribbon **50** in this cross-sectional view. Solar cells **10** are electrically connected in series to each other using electrically conductive ribbons **50** to connect the front surface metallization (not shown in FIG. **8**) of one solar cell with the rear surface metallization (not shown in FIGS. **7** & **8**) of an adjacent solar cell. Ribbon **50** may be disposed over and attached to busbar **15** of the front surface metallization as shown in FIG. **7**. Ribbon **50** may be attached to busbar **15** by soldering. Generally, multiple ribbons connect one solar cell to an adjacent solar cell. Ribbon **50** runs from one solar cell to an adjacent solar cell via the opening created by the recessing portions **42** of the solar cells. Ribbon **50** bends slightly as it passes through this opening.

(32) FIG. **16** shows an alternate embodiment of ribbon **50** having two sections: section **51** having a flat rectangular cross-sectional area and section **52** having a triangular cross-sectional area. Section **51** is attached to the rear surface of solar cell **10** and continues to the front side of an adjacent solar cell. The advantage to having a flat cross-sectional area as the ribbon passes through the opening created by the recessing portions is that the corners **1610** of the solar cells may place less stress on a flat ribbon than for example a ribbon with a circular cross-sectional area. The advantage to having triangular cross-sectional area for section **52** is that a triangular cross-sectional area will allow more light to reach the front surface of the solar cell than a ribbon with a flat cross-sectional area. Ribbon **50** in FIG. **16** may be one continuous ribbon with differently shaped cross-sectional area or alternatively, ribbon **50** may comprise two distinct segments joined together or two separate segments attached to a common contact pad (not shown) on the front surface of the solar cell.

(33) There are multiple advantages to the arrangement solar cells shown in FIGS. **5-8** as compared to the arrangement of solar cells shown in FIGS. **2** & **3**. By having the ribbon pass through the opening created by the recessing portions of the solar cells, the solar cells may be brought closer together than is possible in the arrangement of FIG. **2**. Solar cells being closer together more efficiently uses the given space in a solar module and provides for more surface area for electricity generation in the solar module. Further, electrically conductive adhesive (ECA) is not used in the arrangement solar cells shown in FIGS. **5-8**. This simplifies the manufacturing process steps

because a separate step for printing the ECA and another step for oven curing the ECA are not needed. The arrangement solar cells shown in FIGS. **5-8** is also more advantageous than the arrangement shown in FIG. **3**B because the ribbons in FIGS. **5-8** are not sandwiched between two solar cells at any point. For example, at the junction between solar cells in FIG. **3**B, there is a stack of 3 layers that includes solar cell—ribbon—solar cell. This stack puts stress on the portion of the ribbon that is sandwiched between the two solar cells which may lead to fatigue failure. In FIGS. **6** & **8**, this stack of 3 layers does not exist since ribbons **50** are passing through openings. Since ribbons **50** are not sandwiched between two solar cells, much less stress is placed on the portion of the ribbon at the junction between two solar cells.

(34) FIG. **9** shows a schematic diagram of a plan (front surface) view of two types of solar cells **11** & **12** alternately arranged in a shingled manner. The solar cell **11** differs from solar cell **12** in that the protruding portions and the recessing portions of the corrugated sides of the solar cells are offset and complementary. For example, a recessing portion of solar cell **11** is horizontally (e.g. an axis parallel to the short side of the solar cell) aligned with a protruding portion of solar cell **12** and a protruding portion of solar cell **11** is horizontally aligned with a recessing portion of solar cell **12**. As with the embodiments discussed above, ribbons **50** pass through the openings created by the recessing portions of the solar cells. Using two types of solar cells, such as solar cells **11** & **12**, is advantageous because these two types of solar cells can be cut from a silicon wafer with less wastage of silicon material. Since the recessing and protruding portions of solar cells **11** & **12** are complementary, the corrugated sides of these solar cells can be made using a single cut of a silicon wafer.

(35) In some instances, it may be desirable to cut solar cells from industry standard solar cell designs. This may be more cost effective since industry standard solar cells can be made and purchased at a lower price than custom made solar cells. FIG. **14** shows a schematic illustration of the front surface of an industry standard 12 bus bar solar cell, also known as a 12 BB or a MBB (multi busbar) solar cell. It is understood that industry standard MBB solar cells may have more or less than 12 bus bars. MBB solar cell **1410** may be cut along cut line **1401** to produce two solar cells **1411** and **1412** having a corrugated shape. Solar cells **1411** and **1412** have recessing portions that correspond to every other bus bar. In other words, if one bus bar ends in a recessing portion of the corrugated shape, the adjacent bus bars will end in protruding portions of the corrugated side. For example, bus bar **1416** ends in a protruding portion of the corrugated side of solar cell **1412** and adjacent bus bars **1415** end in recessing portions of the corrugated side of solar cell **1412**.

(36) Solar cells **1411** and **1412** cut from industry standard MBB solar cells may be shingled and electrically connected in series as shown in FIG. **15**. Solar cell **1412** is oriented in the same manner as in FIG. **14**, whereas solar cell **1411** is rotated 180 degrees so that its corrugated shaped side is oriented in the same direction as solar cell **1412** corrugated side. Ribbons **50** are attached to the bus bars **1415** that end at a recessing portions. Ribbons **50** of solar cell **1412** pass through the opening created by the recessing portions to connect to the rear surface of adjacent solar cell **1411**. It is understood that more solar cells may be shingled and connected in series to the solar cells **1411** and **1412**. Ribbons (not shown) may also be attached to bus bar **1416** at end in protruding portions to help collect current from the solar cell, but those ribbons would not connect to an adjacent solar cell. In some embodiments, it may be beneficial to use ECA in area **1420** where solar cell **1412** overlaps with solar cell **1411**. The ECA may be placed in this area between solar cells **1411** and **1412** to decrease series resistance and reduce stress on the shingled solar cells since the ECA may act as a cushion against stress placed on the solar cells.

(37) Use of a wire mesh may also reduce the resistances in a solar cell. FIG. **10** shows a schematic diagram of a wire mesh **1001** comprising wires **1002** and ribbons **1050**. Ribbons **1050** and wires **1002** are made from a conductive metal, for example, copper. The ribbons **1050** and wires **1002** may also have a conductive metal core, e.g. of copper, coated in silver, lead, tin, lead-tin, or tin-bismuth. In the wire mesh, ribbons **1050** are oriented substantially parallel to each other, wires

1002 are oriented substantially parallel to each other, and ribbons **1050** are oriented substantially perpendicular to wires **1002**. Ribbons **1050** and wires **1002** may be attached together at junctions **1010** between ribbons **1050** and wires **1002**. Ribbons and wires may be attached to each other by soldering or the use of an adhesive.

(38) Wire mesh **1001** may be disposed on the metallization of a solar cell. For example, FIG. **11** shows wire mesh **1001** disposed on the front surface of solar cell **10** as shown in FIG. **4**B. Wire mesh **1001** may be disposed on other types of solar cells and other types of metallization patterns. Wire mesh **1001** may be disposed on the rear surface metallization of a solar cell. In FIG. **11**, wires **1002** are disposed over and attached to the fingers of the metallization. Wires **1002** may be attached to the fingers by soldering. In FIG. **11**, ribbons **1010** are aligned with busbars **15** of the metallization pattern. FIG. **12** shows a schematic diagram of an alternative embodiment of wire mesh **1001** where ribbons **1010** are not aligned with, e.g. offset from, and not disposed over busbars **15**. Disposing wire mesh **1001** onto the metallization of a solar cell will decrease the series resistance of the solar cell and improve the solar cell's efficiency.

(39) FIG. **13** is a flow chart showing steps for attaching a wire mesh onto a solar cell. In step **1301**, the wire mesh is assembled e.g. by attaching the ribbons to the wires of the mesh. In step **1302**, after assembling the wire mesh, the wire mesh is disposed onto the metallization of the solar cell. In some embodiments, the wire mesh is disposed onto the metallization so that wires **1002** of the wire mesh are disposed onto the fingers of the metallization. In step **1303**, the wire mesh is attached to the metallization, e.g. by soldering wires **1002** of the wire mesh onto the fingers of the metallization. One advantage of assembling the wire mesh before attaching the wire mesh to the solar cell is that the attachment step can be done as a single step. The alternative to this is to first solder the wires onto the fingers of the metallization which is a time-consuming process when multiple individual wires need to be soldered for each solar cell. In the method of FIG. **13**, only one wire mesh needs to be soldered onto the solar cell metallization.

(40) This disclosure is illustrative and not limiting. Further modifications will be apparent to one skilled in the art in light of this disclosure and are intended to fall within the scope of the appended claims. For example, where methods and steps described above indicate certain events occurring in certain order, those of ordinary skill in the art will recognize that the ordering of certain steps may be modified, and that some steps may be omitted or additional steps added, and that such modifications are in accordance with the variations of the invention.

Claims

1. A device comprising: a string of solar cells comprising at least first and second substantially rectangular crystalline silicon solar cells electrically connected in series, each solar cell comprising front and rear surfaces each having a metallization pattern, a first long side having a corrugated shape with protruding portions and recessing portions, and a second long side; the first and second solar cells arranged in a shingled manner with the protruding portions of the first long side of the second solar cell overlapping with the second long side of the first solar cell; an opening comprising one of the recessing portions of the first long side of the second solar cell; and an electrically conductive ribbon passing through the opening connecting the front surface metallization pattern of the second solar cell with the rear surface metallization pattern of the first solar cell.
2. The device of claim 1, wherein the front surface metallization pattern of each solar cell comprises a plurality of busbars oriented parallel to a short side of the solar cell; and the electrically conductive ribbon is disposed on one of the busbars of the second solar cell.
3. The device of claim 1, wherein the electrically conductive ribbon comprises a first portion with a flat rectangular cross-sectional area and second portion with a triangular cross-sectional area.
4. The device of claim 2, wherein a portion of the electrically conductive ribbon runs substantially

parallel to the short side of the second solar cell and wherein the portion is disposed on and attached to one of the busbars of the second solar cell.
5. The device of claim 1, wherein the front surface metallization pattern of each solar cell comprises a busbar oriented parallel to a short side of the solar cell and wherein the busbar is aligned with one of the recessing portions of the first long side of each solar cell.
6. The device of claim 1, wherein the recessing portions of the first solar cell are not aligned with the recessing portions of the second solar cell.
7. The device of claim 1, wherein the second long side of each solar cell is straight.
8. The device of claim 1, wherein the second long side has a corrugated shape with protruding portions and recessing portions.
9. The device of claim 1, comprising a third substantially rectangular crystalline silicon solar cell, the second and third solar cells arranged in a shingled manner with the protruding portions of the first long side of the third solar cell overlapping with the second long side of the second solar cell.
10. The device of claim 9, wherein the recessing portions of the first solar cell are aligned with the recessing portion of the third solar cell and not aligned with the recessing portions of the second solar cell.
11. The device of claim 10, wherein the front surface metallization pattern of each solar cell comprises a busbar oriented parallel to a short side of the solar cell and wherein the busbar is aligned with one of the recessing portions of the first long side of each solar cell.
12. The device of claim 11, wherein the second long side of each solar cell is straight.
13. The device of claim 1, comprising a second opening comprising another one of the recessing portions of the first long side of the second solar cell; and a second electrically conductive ribbon passing through the second opening connecting the front surface metallization pattern of the second solar cell with the rear surface metallization pattern of the first solar cell.