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(54) Title: EDGE PASSIVATION OF SHINGLED SOLAR CELLS

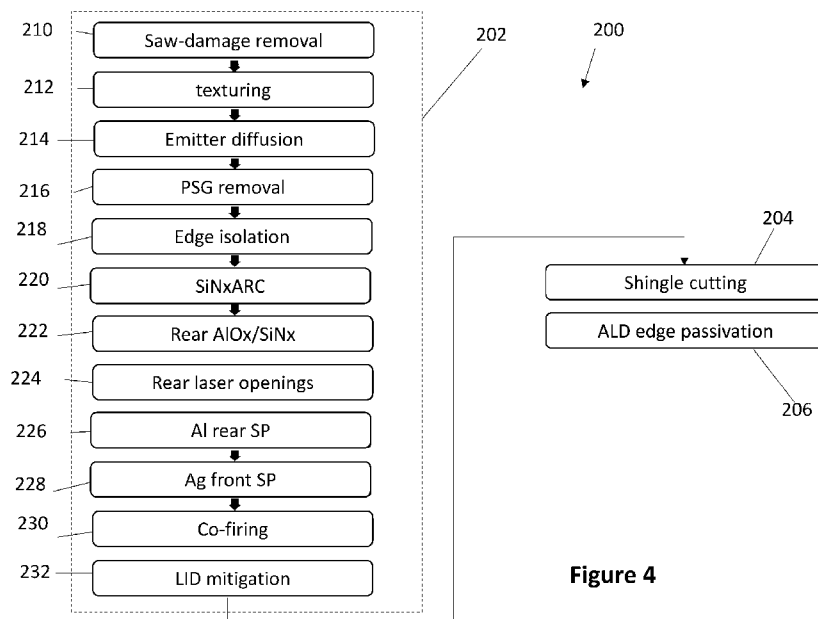


Figure 4

(57) Abstract: Disclosed is a method of forming a solar cell shingle, comprising the steps of: providing a solar cell structure; forming at least one least one solar cell shingle using the solar cell structure; and passivating an edge portion of the formed solar cell shingle.

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
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EDGE PASSIVATION OF SHINGLED SOLAR CELLS**TECHNICAL FIELD**

This disclosure relates to photovoltaic devices. In particular, it relates to shingled
5 solar cell modules.

BACKGROUND ART

Shingled interconnection of solar cells, although it was already introduced in
1956, is now drawing more attention within the industry market, as an emerging
solar module fabrication technique. This concept can be used to maximise the
10 device power conversion efficiency on a module level, as it increases the effective
working area of a module while simultaneously reducing the shading and
interconnection losses. Recent development of the shingled interconnection of
solar cells, involving a 72-cell solar module, reached an output of 442 W with an
full area efficiency of 21.7%, using silicon hetero-junction (SHJ) bifacial solar
15 cells.

It is to be understood that, if any prior art is referred to herein, such reference does
not constitute an admission that the prior art forms a part of the common general
knowledge in the art, in Australia or any other country.

SUMMARY

20 In a first aspect, the invention provides a method of providing a solar cell shingle,
comprising the steps of providing a solar cell structure; forming at least one solar
cell shingle using the solar cell structure, and passivating an edge portion of the
solar cell shingle, at a location where the solar cell shingle is separated from
another portion of the solar cell structure.

In a second aspect, the invention provides a method of providing a passivated solar cell shingle, including applying a passivating material to at least one edge of a solar cell shingle.

5 In the above aspects, forming the solar cell shingle from the solar cell structure can include scribing the solar cell structure, and mechanical separation of the solar cell structure at a location of the scribing. The scribing can be laser scribing.

Forming the solar cell shingle from the solar cell structure can include cleaving the solar cell shingle from the solar cell structure.

10 Also, the step of applying a passivating material to the solar cell structure can be a final step in the manufacture of the solar cell shingle.

In the methods mentioned, the passivating material can be applied the solar cell shingle by deposition. Particularly, the passivating material can be deposited onto the solar cell shingle by plasma-enhanced chemical vapor or by atomic layer deposition.

15 The passivating material can be deposited in a layer of a thickness of approximately 5 nm.

The passivating material can provides surface passivation on silicon.

The passivating material can be a metal oxide. The metal oxide can be AlO_x , particularly Al_2O_3 .

20 Alternatively, the passivating material can be one of: amorphous silicon, or a material having a chemical formulation expressed as one of SiO_x , SiN_x , SiO_xN_y , AlO_xN_y , AlN_x , TiO_x , SiC_x .

The method can include removal of silicon damage before the application of the passivating material.

In a further aspect, the present invention provides a solar cell shingle provided using any method as mentioned above.

In a further aspect, the present invention provides a shingled solar cell module including a plurality of the solar cell shingles mentioned above, the plurality of
5 solar cell shingles being arranged in a stacked fashion, wherein each solar cell shingle overlaps a portion of an adjacent solar cell shingle.

The passivating material can be applied before the plurality of solar cell shingles are stacked together. Alternatively, the passivating material can be applied after the plurality of solar cell shingles are stacked together.

10 **BRIEF DESCRIPTION OF THE DRAWINGS**

Embodiments will now be described by way of example only, with reference to the accompanying drawings in which

Figure 1 is a schematic drawing of a solar cell;

Figure 2 is a schematic drawing of four of the solar cell of Figure 1, scribed and
15 cleaved into separate strips;

Figure 3 is a schematic drawing of five solar cell strips being arranged together to form a shingled module;

Figure 4 is a flow chart depicting a production process for providing a passivated emitter and rear cell (PERC) solar cell shingle, in accordance with one
20 embodiment of the present invention;

Figure 5 is a flow chart depicting a production process for providing a PERC solar cell shingle, in accordance with another embodiment of the present invention;

Figure 6-1 depicts the results of electrical simulation applied to a passivated solar
25 cell shingle in accordance with present invention;

Figure 6-2 depicts the results of electrical simulation applied to a prior art solar cell shingle, which does not have edge passivation; and

Figure 7 depicts simulation results showing the effect of shingle size on the efficiency of the shingled solar module, for both prior art solar cell shingles and
5 solar cell shingles provided in accordance with the present invention.

DETAILED DESCRIPTION

In the following detailed description, reference is made to accompanying drawings which form a part of the detailed description. The illustrative
10 embodiments described in the detailed description, depicted in the drawings and defined in the claims, are not intended to be limiting. Other embodiments may be utilised and other changes may be made without departing from the spirit or scope of the subject matter presented. It will be readily understood that the aspects of the present disclosure, as generally described herein and illustrated in the
15 drawings can be arranged, substituted, combined, separated and designed in a wide variety of different configurations, all of which are contemplated in this disclosure.

In a shingled photovoltaic module, instead of interconnecting the solar cells using ribbons, wires or strings, the interconnection of the solar cells is achieved by
20 “overlapping” neighbouring solar cells. The arrangement of solar cell “shingles” in this way is similar to the laying of roof shingles. It maximises the area of the photovoltaic module that is covered with the solar cells, i.e. the packing density of the photovoltaic module. The solar cells are interconnected using, for example, soldering or an electrically conductive adhesive.

25 Figure 1 and Figure 2 depict an example of preparing a solar cell for shingled interconnection. Figure 1 shows a solar cell 100 having electrodes including fingers (not shown) and busbars 102, 104, 106, 108, 110. The solar cell 100, for

example of a length of about 156 to 160 millimetres (mm), is cut along the edges of the busbars 102, 104, 106, 108, 110. The arrows in Figure 1 indicate the separation lines. Figure 2 shows the four middle strips 122, 124, 126, 128 which result from the separation. Each strip 122, 124, 126, 128 includes a busbar 110, 1008, 106, 104. A plurality of the solar cell strips thus formed from the solar cell(s) are arranged together where each strip overlaps with a portion of an adjacent solar cell strip, i.e., in a shingled manner, as shown in Figure 3.

In one embodiment, the cell cutting process is performed using a technique known as laser scribe. Cells are firstly scribed by a laser and then separated mechanically. The separation is done by cleaving, sawing, or another technique. The laser scribing helps to reduce the loss of power due to increased recombination current at the strip edges, resulting from the cleaving damage.

A residual recombination current is detected after the mechanical separation, which is assumed to be caused by defects at the edge of the silicon solar cell, causing higher recombination at the edge. A possible way to reduce this recombination current is to passivate the newly formed surfaces at the edges.

The current invention, in one embodiment, involves the deposition of a passivating material on the separation (e.g., cleaved) edge or edges of the shingled cell strip, after the laser scribing and mechanical separation. An example of the passivating material is AlO_x , such as Al_2O_3 , for c-Si type solar cells. As an example, the passivating material is deposited as a layer having a thickness of about 5 nanometers (nm). In some embodiments, after the deposition, a thermal process, or annealing, at about 400°C is applied to improve the passivation effect.

Other materials, e.g., metal oxides, with passivating qualities for the solar cell type of concern may be used. Potential materials include, but are not limited to, amorphous-Si, or a material having a chemical formulation expressed as one of SiO_x , SiN_x , SiO_xN_y , AlN_x , TiO_x , SiC_x . Factors to consider in the selection of passivating material, include but are not limited to, the bandgap of the material (a

higher bandgap reduces the likelihood of parasitic absorption), its level of surface passivation and in particular its level of chemical passivation, and how readily available the materials needed are. Given the material properties of the aforementioned materials and the selection requirements, another choice which
5 the skilled person may consider is AlO_xN_y .

The edge passivation for shingled solar cell increases the cell efficiency, by reducing the recombination current at the edge. The deposition method is preferably atomic layer deposition (ALD). Figure 4 is a schematic flow chart of the manufacturing process 200 of a shingled Passivated Emitter and Rear Cell
10 (PERC) in accordance one embodiment of the invention. Steps 210 to 232 in the flow chart are the fabrication steps 202 for making the PERC solar cell, prior to the scribing and cleaving step to cut the cell into shingles or strips. In step 210, the saw damage resulted from wafer cutting is removed. In this step, concentrated sodium hydroxide, typically at 30% weight/volume (w/v), is typically used in a
15 chemical bath maintained at 90 °C, to remove (i.e. “etch”) the damaged regions from both surfaces of the wafer. The removal occurs at a rate of approximately 2 micrometers (μm) per minute. Surface texturing 212 is next performed on the etched wafer. In this step, the wafer is immersed in a chemical bath of sodium or potassium hydroxide, typically of about 2% w/v concentration. The chemical bath
20 may be maintained at 80 to 90 °C to ensure a high pyramid nucleation rate. It can also have additives such as isopropanol at 5%(w/v). A cleaning step may be applied to the wafer, using 2% (w/v) each of hydrogen fluoride (HF) and hydrochloric acid (HCl), at room temperature. Steps 210 and 212 may be performed in one equipment in a production line. Next is the emitter diffusion step
25 214. Typically, n-type layers are produced by phosphorus solid state diffusion, from a phosphorus glass (PSG) layer grown on the wafer surface, at temperatures generally in the range of 800 to 900 °C. The phosphorus glass is then removed in step 216. This is done by immersing wafers in a room-temperature solution of 1% to 5% (w/v) hydrofluoric acid (HF), and then rinsing in deionised water.

After the removal of the phosphorous glass in step 216, an edge isolation step 218 is performed. Typically, a cooled solution of hydrofluoric acid (HF) and nitric acid (HNO₃) is used. Again, steps 216 and 218 can be and generally are combined in one equipment in a production line. An anti-reflection coating is applied to the front side of the wafer in step 220 and to the rear side of the wafer in step 222. The front coating can be a SiN_x material. The rear coating can be an AlO_x/ SiN_x stack. The coating steps utilises deposition, such as plasma enhanced chemical vapor deposition (PECVD) and ALD, to provide a thin and smooth layer of the coating material onto the existing layer(s).

In the fabrication process 202 (before cutting the solar cell into shingles), no further deposition steps occur after the deposition of the coating materials in steps 220 and 222. After the coating deposition, metallisation steps are applied to provide openings in the cell in step 224, and to apply rear and front contacts (e.g. silver (Ag) contacts) in steps 226, 228. The layers are co-fired in step 230. As PERC cells are susceptible to light induced degradation, a degradation mitigation process, as can be identified from existing teachings in mitigation techniques, is applied at step 232.

The specific fabrication process 202 involved for forming the uncut PERC solar cell is not taken to be comprise essential limiting features of the present invention.

The present invention can be applied to any types of solar cells suitable for forming shingled solar cell modules.

According to an embodiment of the present invention, after a PERC solar cell has been fabricated 202, it is separated (e.g., cut) into solar cell shingles or strips in step 204, and an ALD edge passivation step 206 is then applied.

In the prior art, dielectric films are normally used to improve optics (antireflection coating), c-Si surface and bulk passivation. For these functionalities, the layers should be present before metallisation and co-firing. Therefore, in the currently available solar cell production, dielectric depositions steps are only applied prior

to the metallisation step. However, in accordance with the present invention, a dielectric deposition step 206 is further included as the final step in the fabrication process. The deposition steps in the manufacture provided in accordance with the present invention are coloured in grey.

5 Figure 5 depicts a different embodiment of the fabrication process for the solar cell shingle. It is similar to that shown in Figure 4, except that after the shingle separation step 204, a silicon damage removal step 208 is performed (e.g. by chemical etching), prior to the ALD edge passivation 206, to remove the damaged
10 208 further maximises the effectiveness of the technology, by reducing the roughness of the edge surface to which the ALD is applied. The silicon damage removal step 208 is performed in the same or a similar manner as the saw damage removal step 210.

Advanced two-dimensional simulations have revealed that when the edges are
15 adequately passivated, the recombination currents J_{01} and J_{02} at the edges located at the line of separation are significantly reduced, and the efficiency of a solar cell “shingle” can increase by more than 0.7% absolute, from 20.05% to 20.8%, as shown in Figure 6-1 and Figure 6-2. Figure 6-1 shows the simulation results of a solar cell shingle in accordance with the present invention (i.e. with edge
20 passivation). Figure 6-2 shows the simulation results of a prior art solar cell shingle. The light-coloured shapes 300, 302 in Figure 6-1 and Figure 6-2 correspond with the solar cell shingle, in plan view. It can be seen from Figure 6-1 and Figure 6-2, that the simulation indicates one side edge 306 of the prior art shingle 304 would have a more voltage loss as a result of the leakage current (as
25 can be seen from the darker coloured portions along the side edge 306), compared with the same edge 308 in the passivated shingle 302 provided in accordance with an embodiment of the present invention.

The improvement in the efficiency of a shingled solar cell, which can be achieved by the invention, will depend on the size of the solar cell “shingles” into which the

solar cell is separated. Given a particular solar cell size, it is expected that the smaller the “shingles” are, the more cutting or cleaving would have occurred. More cuts or cleaved edges and hence possible leakage current locations would be present in the overall module. Thus, the application of edge passivation is expected to result in a larger efficiency improvement, in a smaller solar cell shingle, and thus in the solar cell module made from the smaller “shingles”.

Figure 7 demonstrates the above described effect. The horizontal axis is the number of shingles produced from a solar cell of the same size. Thus, the numbers 2, 3, 4, and 5 along the axis would correspond with progressively smaller solar cell shingles, being $1/2$, $1/3$, $1/4$, and $1/5$ of the original size of a solar cell. The vertical axis shows the simulated efficiency of the solar cell shingle module comprising the number of shingles as indicated by the position along the horizontal axis. As the shingle size becomes smaller (i.e., the solar cell is cut into more shingles), the efficiency of the overall shingled module increases, for both the prior art shingled module (square data points) and the shingled module according to the present invention (round data points). However, the shingled module according to the present invention achieves a higher efficiency for all simulated cases.

Therefore, a related advantage is that using the herein described invention, it is possible to produce solar cell shingles of a smaller size compared to existing solar cell shingles, without any or significant compromise in the conversion efficiency. The smaller shingle size allows for a potential reduction in the resistive loss in the module. It also allows a potential increase in the packing density of in the shingled solar cell module, which increases the power output of the module.

In the invention, the passivating material can be applied to the edges of the solar cell shingles, after the shingles are stacked together into the “shingled” module (see Figure 3). The stacking can thus simplify the edge passivating process. Alternatively, the passivating material can be applied prior to the stacking.

Variations and modifications may be made to the parts previously described without departing from the spirit or ambit of the disclosure. Some possible variations of embodiments are described above. Furthermore, the application of the passivating material, after the metallization and cleaving steps in the
5 production of the solar cell, is not limited to the edges of the solar cell shingles.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or
“comprising” is used in an inclusive sense, i.e. to specify the presence of the
10 stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

CLAIMS

1. A method of forming a solar cell shingle, comprising the steps of:
 providing a solar cell structure;
 forming at least one solar cell shingle using the solar cell structure;
 and
 passivating an edge portion of the solar cell shingle, at a location where the solar cell shingle is separated from another portion of the solar cell structure.
2. A method of providing a passivated solar cell shingle, including applying a passivating material to at least one edge of a solar cell shingle.
3. A method as claimed in claim 1 or claim 2, wherein forming the solar cell shingle from the solar cell structure includes scribing the solar cell structure, and mechanical separation of the solar cell structure at a location of the scribing.
4. The method of claim 3, wherein the scribing is laser scribing.
5. The method of any preceding claim, wherein forming the solar cell shingle from the solar cell structure includes cleaving the solar cell shingle from the solar cell structure.
6. The method of any preceding claim, wherein applying a passivating material to the solar cell shingle is a final step in a manufacture of the solar cell shingle.
7. The method of any preceding claim, wherein the passivating material is applied to the solar cell shingle by deposition.
8. The method of claim 7, wherein the passivating material is deposited onto the solar cell shingle by plasma enhanced chemical vapor deposition or by atomic layer deposition.

9. The method of claim 8, wherein the passivating material is deposited in a layer of a thickness of approximately 5 nm.
10. The method of any preceding claim, wherein the passivating material provides surface passivation on silicon.
11. The method of any preceding claim, wherein the passivating material is a metal oxide.
12. The method of claim 11, wherein the metal oxide is AlO_x .
13. The method of claim 12, wherein the metal oxide is Al_2O_3 .
14. The method of any one of claims 1 to 9, wherein the passivating material is one of: amorphous silicon, or a material having a chemical formulation expressed as one of SiO_x , SiN_x , SiO_xN_y , AlN_x , AlO_xN_y , TiO_x , SiC_x .
15. The method of any preceding claim, including removal of silicon damage, before application of the passivating material.
16. A solar cell shingle provided using a method as claimed in any one of claims 1 to 15.
17. A shingled solar cell module including a plurality of solar cell shingles, each as claimed in claim 16, the plurality of solar cell shingles being arranged in a stacked fashion, wherein each solar cell shingle overlaps a portion of an adjacent solar cell shingle.
18. The shingled solar cell module of claim 17, wherein the passivating material is applied before the plurality of solar cell shingles are stacked together.

19. The shingled solar cell module of claim 17, wherein the passivating material is applied after the plurality of solar cell shingles are stacked together.

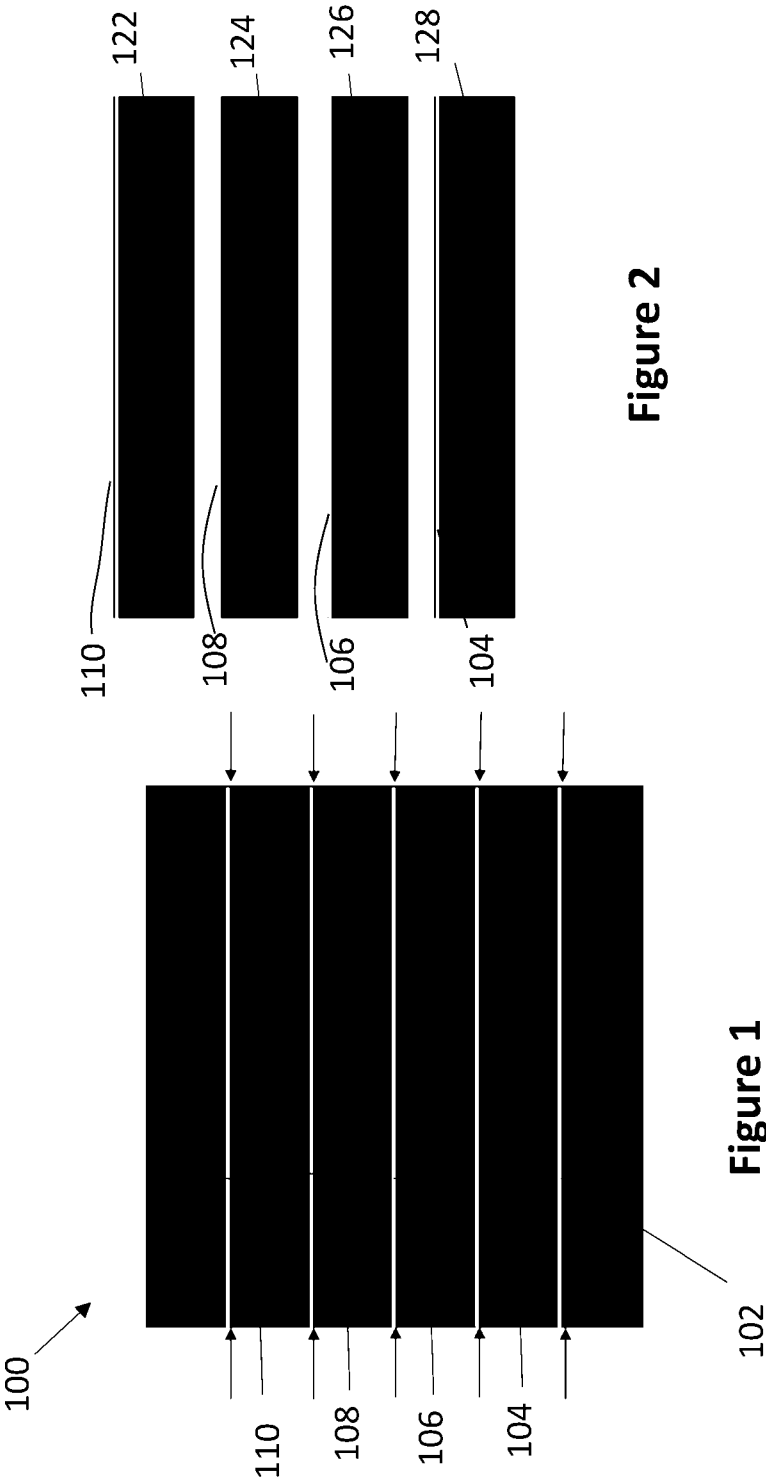


Figure 2



Figure 3

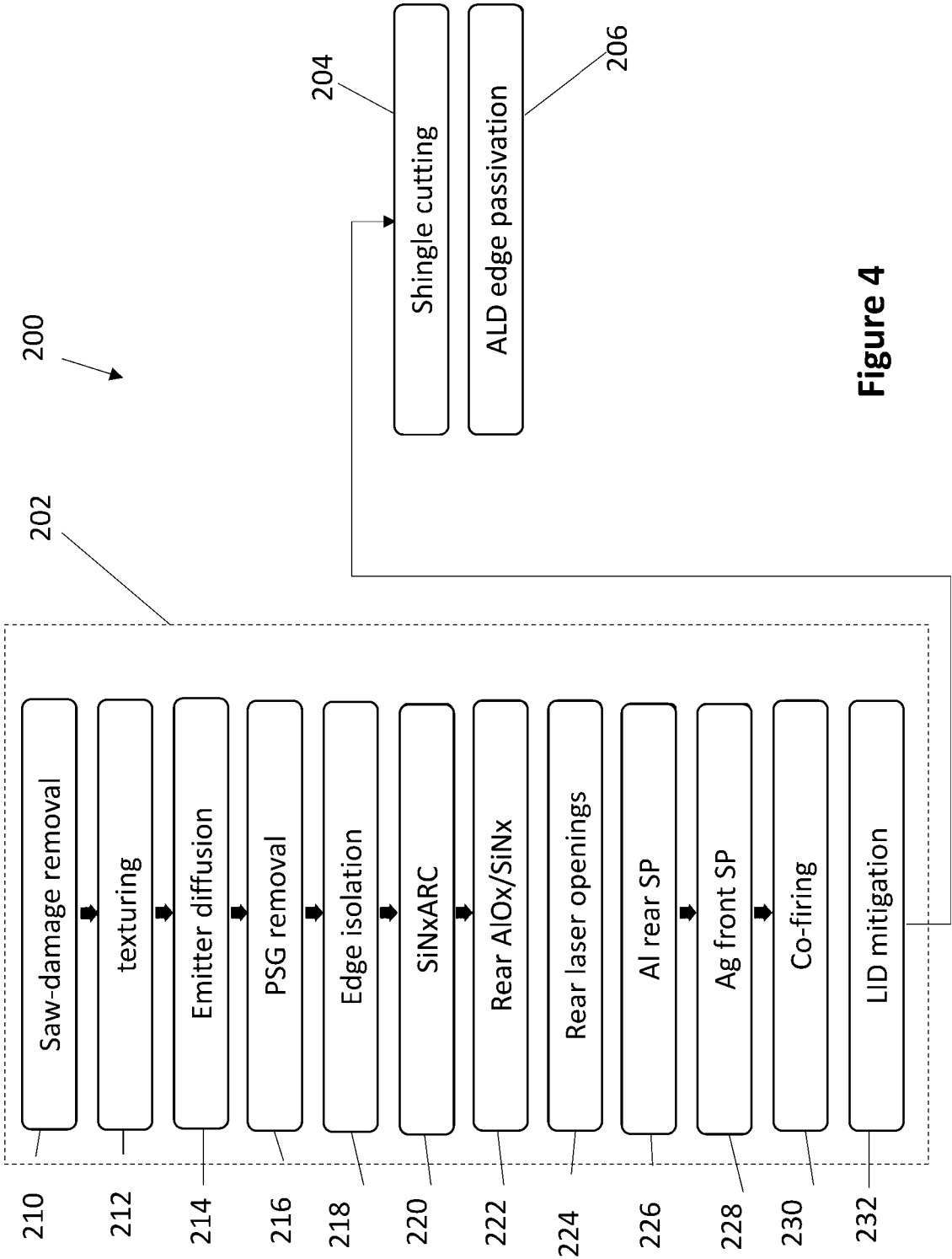


Figure 4

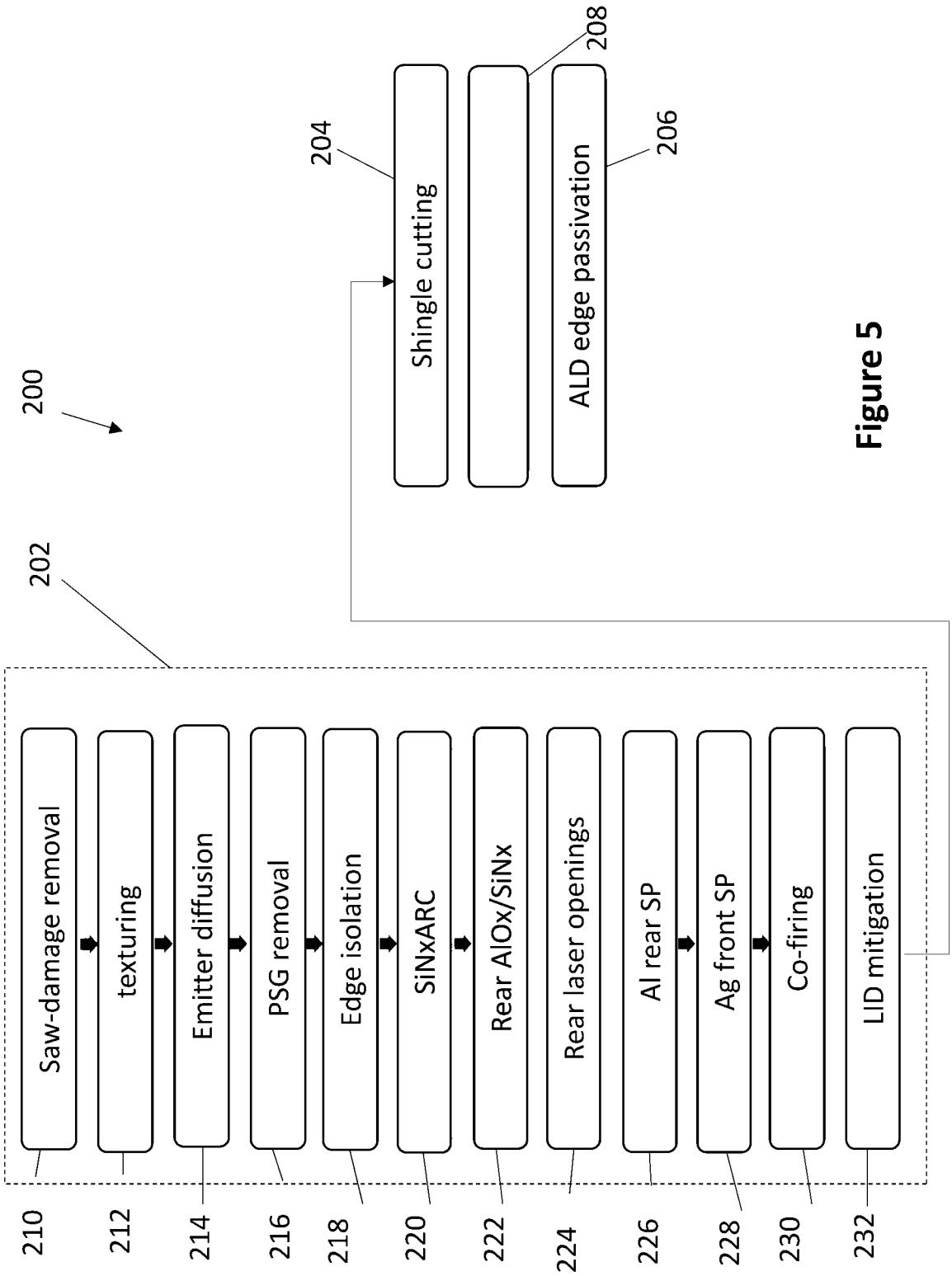


Figure 5

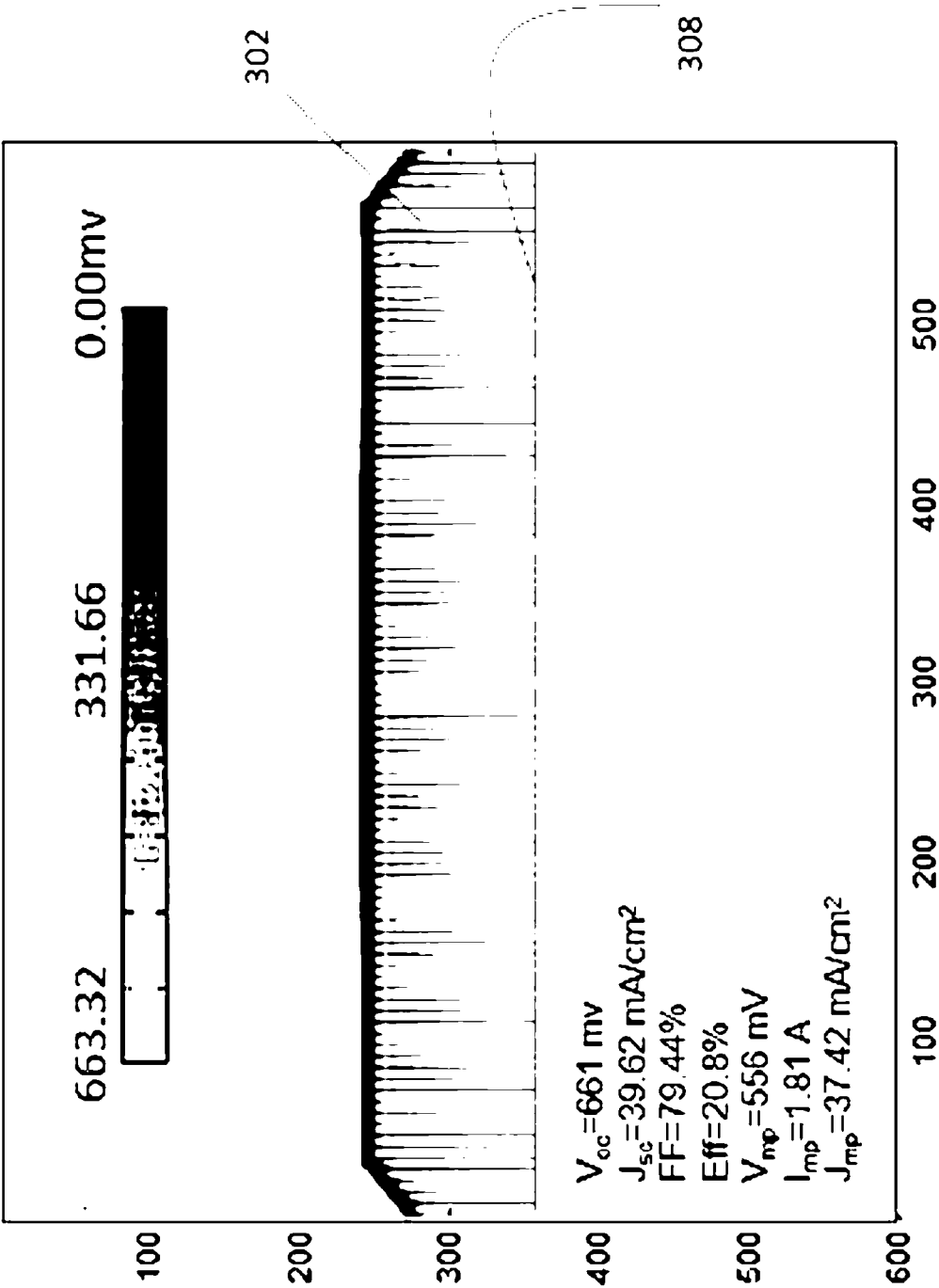


Figure 6-1

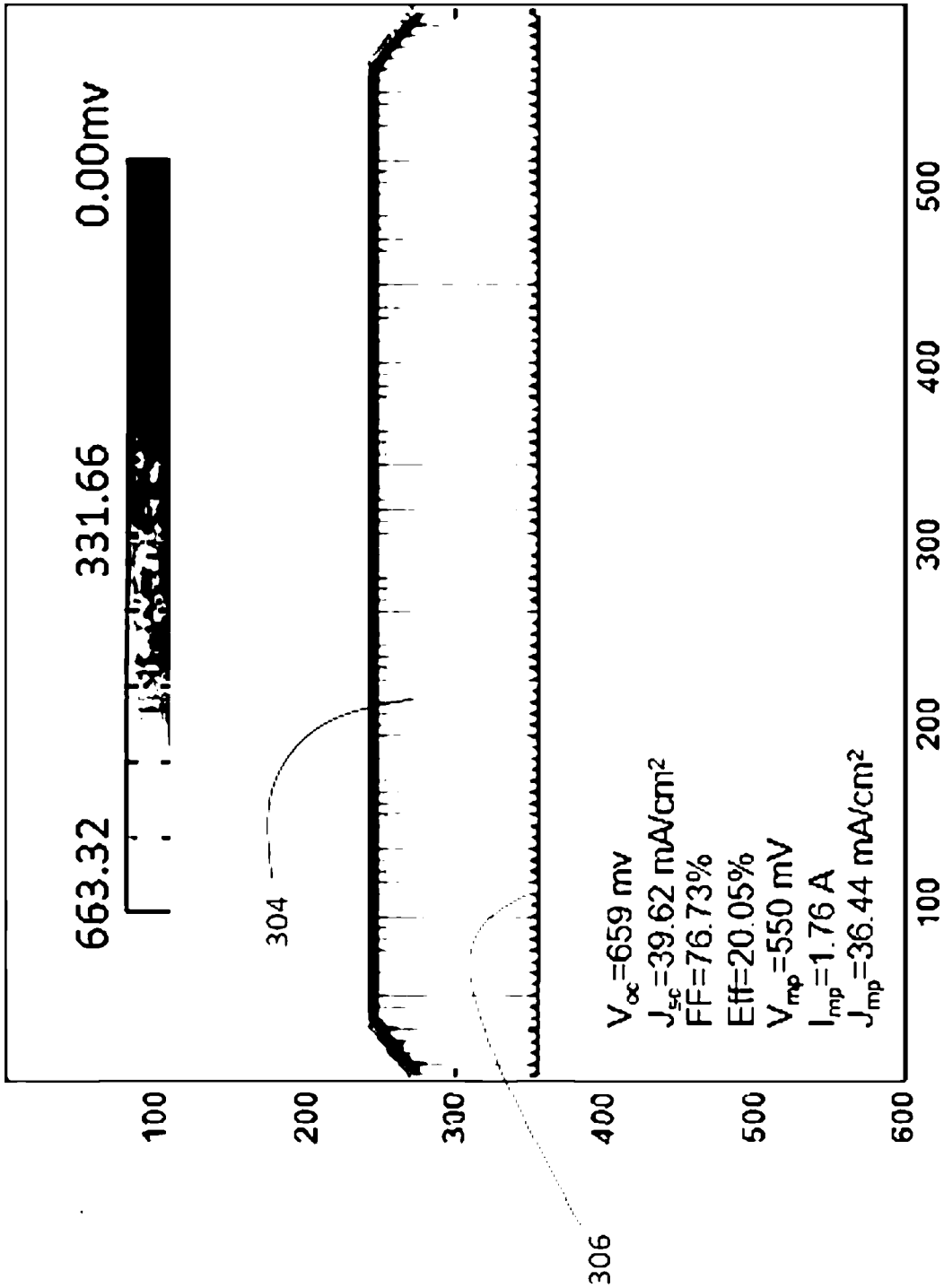


Figure 6-2

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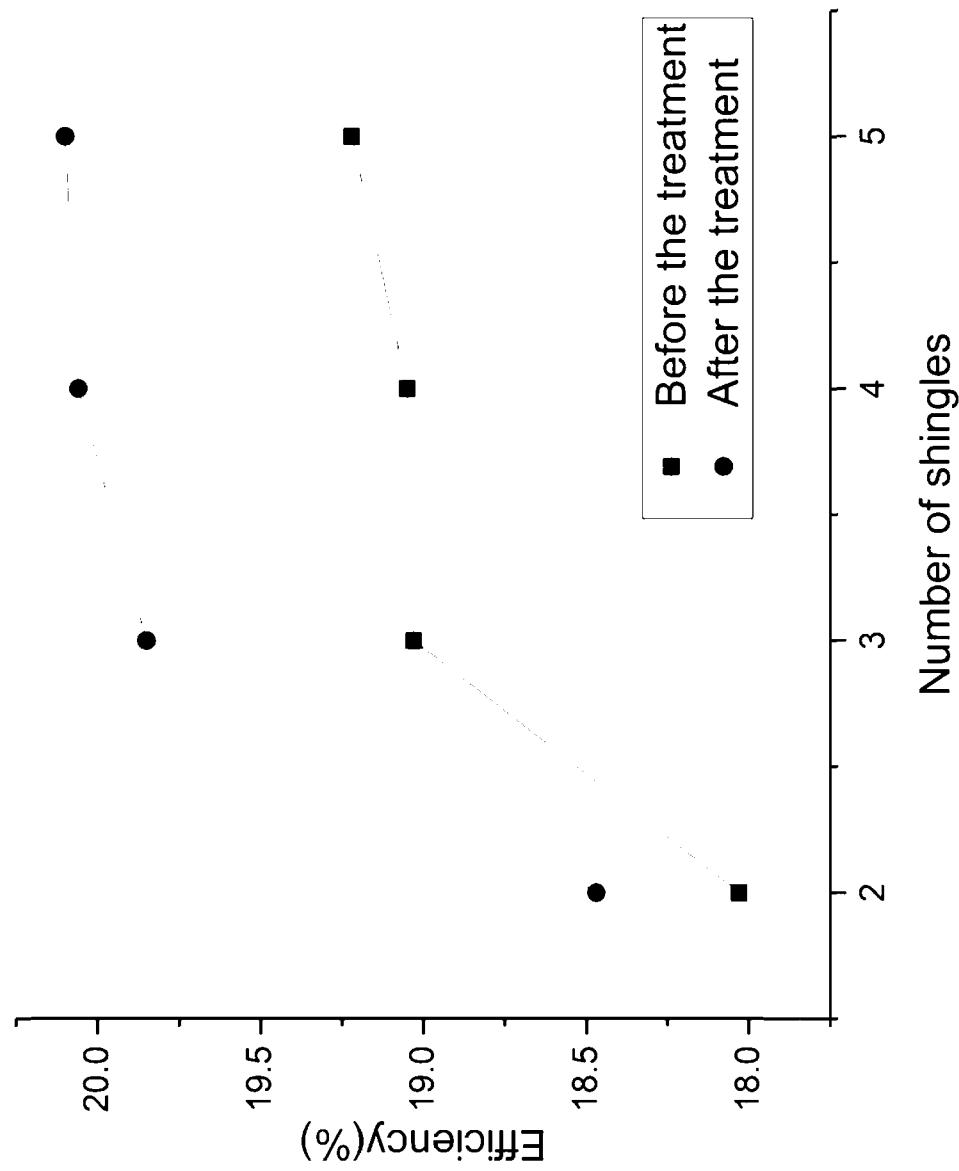


Figure 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2020/050419

A. CLASSIFICATION OF SUBJECT MATTER

H01L 21/00 (2006.01) H01L 31/048 (2014.01) H01L 31/0216 (2014.01) H01L 51/00 (2006.01) H01L 27/14 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Google Patents, E-spacenet: Applicant/Inventor's name search; IPC Marks and keywords: shingled or solar or edge or passivation and similar words. EPOQUE Internal: Database: Patenw -IPC Marks- H01L21/low, H01L31/low, H01L51/low, H01L27/14, Y02E10/50/low and keywords- solar, shingle, passivating, silicon, aluminum, metal, oxide, PERC, edge, cleave, scribe, laser and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

☒ Further documents are listed in the continuation of Box C☒ See patent family annex

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"D" document cited by the applicant in the international application	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
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"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
9 July 2020

Date of mailing of the international search report
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Name and mailing address of the ISA/AU

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INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/AU2020/050419
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/183827 A2 (COGENRA SOLAR, INC.) 03 December 2015 Entire document including abstract and drawings	1-19
X	EP 3327793 A1 (LG ELECTRONICS INC.) 30 May 2018 Entire document including abstract and drawings	1-19
A	US 2018/0130749 A1 (TAIWAN SEMICONDUCTOR MANUFACTURING CO., Ltd.) 10 May 2018 Entire document including abstract and drawings	

Form PCT/ISA/210 (fifth sheet) (July 2019)

INTERNATIONAL SEARCH REPORT Information on patent family members		International application No. PCT/AU2020/050419	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
WO 2015/183827 A2	03 December 2015	None	
EP 3327793 A1	30 May 2018	EP 3327793 A1	30 May 2018
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		US 10535609 B2	14 Jan 2020
		US 2020152576 A1	14 May 2020
End of Annex			
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001. Form PCT/ISA/210 (Family Annex)(July 2019)			