BESCHWERDEKAMMERN DES EUROPÄISCHEN PATENTAMTS | BOARDS OF APPEAL OF THE EUROPEAN PATENT OFFICE | CHAMBRES DE RECOURS DE L'OFFICE EUROPÉEN DES BREVETS

Internal distribution code:
(A) [-] Publication in OJ
(B) [-] To Chairmen and Members
(C) [-] To Chairmen
(D) [X] No distribution

Datasheet for the decision of 29 January 2015

Case Number: T 1615/11 - 3.4.03

Application Number: 06252481.4

Publication Number: 1722419

IPC: H01L27/142, H01L27/144, H01L31/06, H01L31/07, H01L31/036

Language of the proceedings: EN

Title of invention:
Surface passivated photovoltaic devices

Applicant:
GENERAL ELECTRIC COMPANY

Headword:

Relevant legal provisions:
EPC 1973 Art. 56

Keyword:
Inventive step (yes) - after amendment

Decisions cited:

Catchword:

Beschwerdekammern
Boards of Appeal
Chambres de recours

European Patent Office
D-80298 MUNICH
GERMANY
Tel. +49 (0) 89 2399-0
Fax +49 (0) 89 2399-4465

Case Number: T 1615/11 - 3.4.03

D E C I S I O N
of Technical Board of Appeal 3.4.03
of 29 January 2015

Appellant: (Applicant)	GENERAL ELECTRIC COMPANY 1 River Road Schenectady, NY 12345 (US)
Representative:	Bedford, Grant Richard GPO Europe GE International Inc. The Ark 201 Talgarth Road Hammersmith London W6 8BJ (GB)
Decision under appeal:	**Decision of the Examining Division of the European Patent Office posted on 27 January 2011 refusing European patent application No. 06252481.4 pursuant to Article 97(2) EPC.**

Composition of the Board:

Chairman	G. Eliasson
Members:	R. Bekkering
	T. Bokor

Summary of Facts and Submissions

I. The appeal is against the decision of the examining division refusing the application No. 06 252 481.

The decision was based on the state of the file, as requested by the applicant, with reference to the communication of the examining division dated 26 October 2010, in which the applicant was informed that the subject-matter of the claims did not involve an inventive step in the sense of Article 56 EPC over documents:

D1: US 2003/0145884 A

D2: US 5 589 008 A

D3: US 5 705 828 A

D5: Cid M, Stem N, "*Silicon solar cell emitters: optimization and comparison of two different technologies*", Conference Record of the 26th IEEE Photovoltaic Specialists Conference – 1997, Anaheim, Ca, Sept. 30 - Oct. 3, 1997, IEEE, NEW YORK, NY, US, pages 279 to 282

II. The appellant requested with the statement setting out the grounds of appeal of 3 June 2011 that the decision under appeal be set aside and a patent be granted on the basis of the following application documents as a main ("primary") request:

Description: Pages 1 and 4 to 25 as originally filed;

Pages 2 and 3 filed with letter of 26 October 2007;

Claims: Nos. 1 to 3 of the main ("primary") request filed with the statement setting out the grounds of appeal of 3 June 2011;

Drawings: Sheets 1/4 to 4/4 as originally filed.

Alternatively, the grant of a patent was requested based on the claims according to an auxiliary request, filed with the statement setting out the grounds of appeal of 3 June 2011.

III. Claim 1 according to the appellant's main request reads as follows:

"*A photovoltaic device (100) having a front side and a back side, comprising:*

a photovoltaic cell (102) comprising:

an emitter layer (106) comprising a crystalline semiconductor material having a doping level in a range from $1x10^{17}$ cm^{-3} *to* $1x10^{21}$ cm^{-3}*;*

a doped crystalline substrate (108) disposed adjacent the emitter layer (106), wherein the doped crystalline substrate (108) and the emitter layer (106) are oppositely doped; and wherein the doped crystalline substrate (108) comprises a single crystal or a poly crystal semiconductor material having a doping level in a range from $1x10^{14}$ cm^{-3} *to* $5x10^{16}$ cm^{-3}*;*

a back surface passivated structure (104) comprising:

an intrinsic back surface passivated layer (110) disposed adjacent the doped crystalline substrate (108), wherein the intrinsic back surface passivated layer (110) comprises an amorphous or a microcrystalline semiconductor material, and wherein the intrinsic back surface passivated layer (110) provides a surface passivation, or reduces a potential barrier for an electron (58) or a hole (48) traversing from the doped crystalline substrate (108) to a doped back surface field layer (114), or both;

the back surface field layer (114) being disposed adjacent the intrinsic back surface passivated layer (110), wherein the back surface field layer (114) and the doped crystalline substrate (108) have the same doping type;

characterized in that:

the back surface field layer (114) comprises a doped amorphous or a doped microcrystalline semiconductor material having a doping level in a range from $1x10^{17}$ cm^{-3} *to* $8x10^{20}$ cm^{-3}*;*

and further in that:

the intrinsic back surface passivated layer (114) [sic] *has a thickness in a range from 1nm to 30nm, said thickness being thin enough to facilitate tunneling of an electron (58) or a hole (48), generated in the doped crystalline substrate (108), to the back surface field layer (114) through the intrinsic back surface passivated layer with minimum hindrance at the potential barriers present at the heterojunction (112) between the intrinsic back surface passivation* [sic] *layer (110) and the doped crystalline substrate (108); and*

wherein the intrinsic back surface passivated layer (110) has a variable thickness such that the doped crystalline substrate (108) makes a point contact, or a line contact, or both with the back surface field layer (114)."

The wording of claim 1 according to the auxiliary request is not relevant for the present decision.

IV. The appellant in substance provided the following arguments concerning the main request :

In the claims of the Primary Request, independent claim 1 had been amended to recite a combination of the subject matter of previous claims 1 and 3. Whilst the Examining Division indicated that they considered the subject matter of claim 3 to lack inventive step in respect of the cited document D2, the assessment of D2 made by the Examining Division was incorrect. In particular, D2 taught the use of a roughened transparent conductive layer for providing a light trap, and not a device in which an intrinsic back surface passivated layer had a variable thickness such that a doped crystalline substrate made a point contact, or a line contact, or both, with a back surface field layer (cf column 4, lines 36-41 of D2, for example).

Thus, one objective technical problem that might be envisaged by the skilled man to exist with respect to the teaching of the cited document D2 could be how to provide for a photovoltaic device having an improved conversion efficiency. By providing a photovoltaic device as defined in claim 1 of the Primary Request, various embodiments of the invention addressed the aforementioned objective technical problem by providing a reduced amount of electron/hole pair recombination in the device by reducing the heterojunction potential barrier (cf for example, the Applicant’s description on page 19, lines 14 to 17).

None of the cited prior art documents, either alone or in any combination, disclosed or suggested the provision of the photovoltaic device as defined in claim 1 of the Primary Request with a view to overcoming the aforementioned objective technical problem. Accordingly, the claims of the Primary Request were novel and possessed an inventive step with respect to the cited documents.

Reasons for the Decision

1. The appeal is admissible.

2. Main request

2.1 Amendments

Claim 1 as amended is based on claims 1, 2, 3 and 6 to 9 as originally filed, in combination with the description as originally filed (cf page 6, lines 3 to

6; page 8, lines 30 to 32; page 9, line 31 to page 10, line 2).

Claim 2 is based on claim 5 as originally filed.

Claim 3 is based on the description as originally filed (cf page 7, lines 6 to 9).

Accordingly, the amendments comply with Article 123(2) EPC.

2.2 *Novelty*

2.2.1 *Document D2*

Document D2 discloses a photovoltaic cell (10) having a semiconductor substrate (11), a front passivation layer (12) arranged on the substrate, an emitter layer (14) having a first conductivity type (p or n), a front transparent conductive layer (15), a rear passivation layer (17) deposited on a rear surface of the substrate, a rear layer (18) producing a back surface field having a second conductivity type (n or p) opposite to the first conductivity type, as well as a reflecting element (19) comprised of a transparent conductive layer (20), an adhesion layer (21), and a reflecting layer (22) (cf column 4, line 19 to column 5, line 30; figures 1 and 2).

In particular, document D2 discloses, using the terminology of claim 1, a photovoltaic device (10) having a front side and a back side, comprising:

a photovoltaic cell comprising:

an emitter layer (14) comprising a crystalline semiconductor material;

a doped crystalline substrate (11) disposed adjacent the emitter layer (14), wherein the doped crystalline substrate (11) and the emitter layer (14) are oppositely doped; and wherein the doped crystalline substrate (11) comprises a single crystal;

a back surface passivated structure (17, 18) comprising:

an intrinsic back surface passivated layer (17) disposed adjacent the doped crystalline substrate (11), wherein the intrinsic back surface passivated layer (17) comprises an amorphous semiconductor material, and wherein the intrinsic back surface passivated layer (17) provides a surface passivation, or reduces a potential barrier for an electron or a hole traversing from the doped crystalline substrate (11) to a doped back surface field layer (18), or both;

the back surface field layer (18) being disposed adjacent the intrinsic back surface passivated layer (17), wherein the back surface field layer (18) and the doped crystalline substrate (11) have the same doping type (cf column 4, line 20 to column 5, line 20).

Accordingly, document D2 discloses a photovoltaic device according to the pre-characterising portion of claim 1, except for the doping levels of the emitter layer and the doped crystalline substrate.

Furthermore, in D2 the back surface field layer (18) comprises a doped microcrystalline semiconductor material (cf column 4, lines 54 to 57).

Moreover, in D2 the intrinsic back surface passivated layer has a thickness of 8 nm (80 Å) (cf column 3, lines 11 to 13; column 4, lines 29 to 32 and 52 to 54).

Furthermore, it is considered implicit in D2 that this thickness is thin enough to facilitate tunneling of an electron or a hole, generated in the doped crystalline substrate, to the back surface field layer through the intrinsic back surface passivated layer with minimum hindrance at the potential barriers present at the heterojunction between the intrinsic back surface passivated layer and the doped crystalline substrate.

2.2.2 Not disclosed in D2 is that:

- the emitter layer has a doping level in a range from $1x10^{17}$ cm^{-3} to $1x10^{21}$ cm^{-3};

- the doped crystalline substrate has a doping level in a range from $1x10^{14}$ cm^{-3} to $5x10^{16}$ cm^{-3};

- the back surface field layer has a doping level in a range from $1x10^{17}$ cm^{-3} to $8x10^{20}$ cm^{-3};

and that

- the intrinsic back surface passivated layer has a variable thickness such that the doped crystalline substrate makes a point contact, or a line contact, or both with the back surface field layer.

Accordingly, the subject-matter of claim 1 is new over document D2 (Article 54(1) EPC 1973).

2.2.3 Document D3

Document D3 discloses a photovoltaic cell with an p-type amorphous silicon emitter layer 2, an n-type single crystalline substrate 3, an intrinsic amorphous silicon layer 4 and an n-type amorphous silicon back surface field layer 5 (cf column 5, line 61 to column 7, line 61; figures 3A, 3B).

Not disclosed in D3 are the same distinguishing features listed above for document D2, as well as some of the materials (amorphous or single-crystalline) of the respective layers.

Accordingly, the subject-matter of claim 1 is also new over document D3 (Article 54(1) EPC 1973).

2.2.4 The subject-matter of claim 1 is also new over the remaining available, more remote prior art.

In particular, document D1 discloses a photovoltaic cell with an emitter layer 22, a base layer 24 and a back surface field (BSF) layer 25 (cf figure 1; paragraph [0017]). The BSF layer 25 passivates the base layer 24 and typically has the same doping type as the base layer 24, often has a higher doping concentration than the base layer 24, and it is desirable for the BSF layer 25 to have a higher bandgap than the base layer 24, to suppress minority-carrier photogeneration and injection in the BSF layer 25, and to reduce recombination in the BSF layer 25 (cf paragraph [0026]).

A thin, often intrinsic layer (not shown) may be placed between the emitter layer 22 and base layer 24. This thin layer at the p-n junction can serve to suppress shunting at the p-n junction, and can reduce the interface state density at the p-n junction in order to suppress minority-carrier recombination in the space-charge region (cf paragraph [0025]).

There is no mention in D1 of an intrinsic back surface passivated layer as claimed.

Also document D5 discloses a solar cell with a back surface field layer. The solar cell has a n^+pp^+ structure with the n+ layer forming the emitter layer having a doping level not lower than $5x10^{18}$ cm^{-3} (cf page 279, chapter "Introduction" and page 281, chapter "Optimization").

In document D5, however, there is no mention either of an intrinsic back surface passivated layer as claimed.

2.3 *Inventive step*

2.3.1 Document D2 is considered to form the closest prior art.

The first three distinguishing features of claim 1 over D2 listed above provide practical doping levels for the respective layers.

The fourth distinguishing feature of claim 1 over D2 listed above provides for an improved conversion efficiency.

2.3.2 According to the appellant, the claimed device addresses the problem of improving the conversion efficiency by providing a reduced amount of electron/ hole pair recombination in the device by reducing the heterojunction potential barrier (cf application as filed, page 19, lines 14 to 17.

Indeed, on the one hand, as described in the application, the provision of the intrinsic back surface passivated (i-BSP) layer between the substrate and the back surface field layer improves the conversion efficiency of the photovoltaic device by passivating unsatisfied bonds or any other surface defects present on the surface of the crystalline substrate (cf description, page 5, lines 15 to 18). As indicated, the crystalline substrate may have surface defects such as unsatisfied bonds, which may prevent collection of charge carriers at the respective electrodes. In other words, the defect states in the energy band of the lightly doped crystalline substrate resulting from bulk impurities, crystalline imperfections, and surface defects such as dangling bonds may lead to trapping and recombination of the charge carriers, thereby decreasing the charge collection efficiency of the device (cf page 4, line 29 to page 5, line 3).

On the other hand, the provision of such an intrinsic back surface passivated layer between the substrate and the back surface field layer, may form a heterojunction providing a potential barrier for charge carriers generated in the substrate as a result of incident light, traversing from the substrate towards the BSF layer to be collected at the electrode, and thus impose limitations for the charge carrier collection. The i-BSP layer may, however, be made thin enough to facilitate tunneling of the charge carriers through the i-BSP layer with minimal hindrance at the potential barriers present at the heterojunction (cf page 5, line 24 to page 6, line 10).

According to the application, in case of point and/or line contacts of the substrate with the back surface field layer, "*Advantageously, the point and/or line contact areas 116 do not suffer from any heterojunction induced potential barriers, due to a heterojunction formed directly between the highly n+-doped BSF layer 114 and the lightly doped crystalline substrate 108. Also, in these embodiments, the photovoltaic device 100 suffers relatively less Staebler-Wronski effect due to the smaller thickness of the i-BSP layer 110 and highly n+-doped BSF layer 114. However, the point and/or line contact areas 116 may suffer from low current characteristics and high recombination rates as described above with reference to FIG. 6* [sic]" (cf page 19, lines 14 to 22). Indeed, as noted in the application "*Hence, there exists a tradeoff between passivating the surface of the lightly doped crystalline substrate 22 and reducing or eliminating the potential barrier for the charge carriers at the back surface*" (cf page 16, lines 23 to 26).

2.3.3 As the first three distinguishing features over D2 listed are unrelated to the fourth, an assessment on the basis of partial problems is considered appropriate.

The first partial objective problem to be solved relating to the above first three distinguishing features may be formulated as to provide practical doping levels for the emitter layer, the substrate and the back surface field layer.

The second partial objective problem to be solved relating to the above fourth distinguishing feature may be formulated as to improve the conversion efficiency of the photovoltaic device.

2.3.4 Regarding the above first problem to be solved of providing practical doping levels for the emitter layer, the substrate and the back surface field layer, it is noted that it would indeed appear, as argued in the decision under appeal, that the person skilled in the art would arrive at the claimed doping levels for the respective layers without the exercise of inventive skills.

However, regarding the above second problem to be solved, there is no suggestion in document D2 or in any other of the available prior art documents to provide the intrinsic back surface passivated layer with a variable thickness such that the doped crystalline substrate makes a point contact, or a line contact, or both with the back surface field layer.

As discussed above, this provides, as explained in the application, a balance between passivating the surface of the substrate so as to reduce recombination and reducing or eliminating the potential barrier for the charge carriers to be collected at the back electrode, thereby improving the conversion efficiency of the device.

As shown in figure 6 of the application, such point and/or line contacts may for instance arise with a thin i-BSP layer 110 formed on substrate 108 having a rough back surface (cf description, page 19, lines 10 to 14).

Document D2 also discloses an embodiment wherein the substrate has a rough (textured) rear surface (cf column 5, lines 21 to 31; figure 2). In this embodiment, however, the rear passivation layer is similar to that described with reference to figure 1 and is of uniform thickness. In fact, the surface roughness of the substrate is passed on via this layer to the outer most surface of the completed cell, which is textured. A layer with a variable thickness such that the doped crystalline substrate makes a point contact, or a line contact, or both with the back surface field layer is neither disclosed nor suggested.

Accordingly, having regard to the available state of the art, the subject-matter of claim 1 is not obvious to a person skilled in the art and, thus, involves an inventive step in the sense of Article 56 EPC 1973.

Claims 2 and 3 are dependent on claim 1, providing further limitations. The subject-matter of these claims, therefore, also involves an inventive step.

3. The patent application documents also meet the remaining requirements of the EPC, so that a patent can be granted on the basis of these documents.

4. In view of the above, there is no need to consider the appellant's auxiliary request.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The case is remitted to the department of first instance with the order to grant a patent with the following application documents:

Description: Pages 1 and 4 to 25 as originally filed; Pages 2 and 3 filed with letter of 26 October 2007;

Claims: Nos. 1 to 3 of the main ("primary") request filed with the statement setting out the grounds of appeal of 3 June 2011;

Drawings: Sheets 1/4 to 4/4 as originally filed.

The Registrar: The Chairman:

S. Sánchez Chiquero G. Eliasson

Decision electronically authenticated