

DECLARATION OF XIN MIN LIU

I, Xin Min Liu, pursuant to 28 U.S.C. § 1746 and 37 C.F.R. § 1.68, hereby declare as follows:

1. I am a Translator for Sun IP.
2. I submit this declaration to certify the accuracy of the English translation of Li et al., *Crystalline Silicon Solar Cell with Novel Structure*, CN Patent 1949545A (Apr. 18, 2007).
3. I am qualified to perform Chinese to English translations and certify the accuracy of Chinese to English translations.
4. My statements are based on personal knowledge and my review of Li et al., *Crystalline Silicon Solar Cell with Novel Structure*, CN Patent 1949545A (Apr. 18, 2007) and its Chinese to English translation. If called as a witness about the facts contained in these statements, I could testify competently based on such personal knowledge and the investigation I have conducted.
5. Attached as **Exhibit A** is a true and accurate copy of Li et al., *Crystalline Silicon Solar Cell with Novel Structure*, CN Patent 1949545A (Apr. 18, 2007).
6. Attached as **Exhibit B** is a true and accurate copy of an English translation of Li et al., *Crystalline Silicon Solar Cell with Novel Structure*, CN Patent 1949545A (Apr. 18, 2007) (hereinafter “Li Translation”), which I reviewed based on Exhibit A and my personal knowledge of the Chinese and English languages.
7. Li Translation is, to the best of my knowledge and ability, a true and accurate translation of Li et al., *Crystalline Silicon Solar Cell with Novel Structure*, CN Patent 1949545A (Apr. 18, 2007) from Chinese to English.

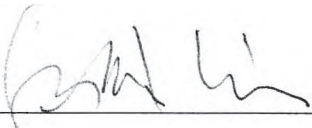
8. All statements made herein of my own knowledge are true, and all statements made on information and belief are believed to be true.

9. I have been warned and am aware that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. § 1001.

10. I understand that by submitting this declaration I may be asked to appear for a deposition asking me questions limited to the material in my declaration. With my signature below, I agree to make reasonable efforts to make myself available for such a deposition at a reasonable place and time.

* * *

I declare under the penalty of perjury that the foregoing is true and correct. Executed on July 18, 2024 in the United States.



Xin Min Liu

EXHIBIT A

[19] 中华人民共和国国家知识产权局



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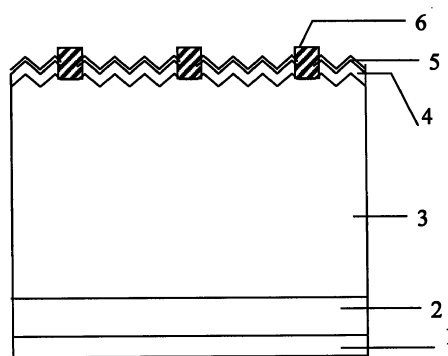
权利要求书 1 页 说明书 2 页 附图 1 页

[54] 发明名称

一种新结构的晶体硅太阳能电池

[57] 摘要

采用薄膜硅背表面发射区的晶体硅太阳能电池属于一种新结构的光伏电池。其要点是在 N 型单晶硅衬底背面沉积一层硅薄膜形成异质 PN 结，来代替常规的扩散法在电池正面制备的同质 PN 结。本发明中沉积的硅薄膜可以是非晶、微晶、或者纳米晶薄膜。本发明中的异质 PN 结可以是在 N 型单晶硅上直接沉积 P 型硅薄膜，也可以在 N 型单晶硅上先沉积一层本征硅薄膜再沉积 P 型硅薄膜。采用本发明中的电池结构，电池效率可以达到 20% 以上。



一种太阳能电池新型结构的示意图

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1. 一种异质结太阳能电池，其特征是发射区在电池的背面，同时形成异质 PN 结。
 2. 如权利要求 1 所述的太阳能电池，其结构为正电极/减反层/表面织构化的 N 型晶体硅/硅薄膜/背电极。
 3. 如权利要求 1 所述的太阳能电池，其特征是发射区在电池背面。
 4. 如权利要求 1 所述的太阳能电池，其特征是异质 PN 结。
 5. 如权利要求 3 所述的太阳能电池，其异质 PN 结的结构可以是 N 型晶体硅/P 型硅薄膜，也可以是 N 型晶体硅/本征硅薄膜/P 型硅薄膜。
 6. 如权利要求 4 所述的太阳能电池，其硅薄膜可以是非晶硅薄膜、微晶硅薄膜或者纳米晶硅薄膜。

一种新结构的晶体硅太阳能电池

一、技术领域

本发明涉及的是一种太阳能电池的新结构，属于太阳能应用领域。

二、背景技术

晶体硅太阳能电池占据着世界光伏市场 90% 以上的份额。这种电池一般采用 P 型晶体硅，通过高温扩散形成 N 型发射区，属于同质 PN 结太阳能电池。但这种电池的缺点是：高温扩散可能会使硅材料产生更多的缺陷，而且高温过程中若有污染则会极大地降低电池的效率，因此对材料和生产环境都提出了较高的要求。另外，这种电池的背表面没有有效的钝化，也没有有效的陷光结构，因而背表面的复合比较严重，还有一部分光穿透了电池活性区而未被吸收。这些都是限制常规太阳能电池效率提高的原因。

近年，日本 Sanyo 公司开发了一种非晶硅/晶体硅异质结太阳能电池（HIT 电池）。这种电池采用 N 型单晶硅片，在硅片表面沉积非晶硅薄膜。其中发射区为 P 型非晶硅薄膜，沉积在硅片的正面。电池的正面结构为：金属栅线/透明导电薄膜（TCO）/P 型非晶硅/本征非晶硅/单晶硅片。这一结构充分利用了非晶硅良好的表面钝化作用，制备的电池效率达到 20% 以上。

采用 N 型硅的优点是：N 型硅片的少数载流子寿命一般较长，比较容易获得高质量的硅片。N 型硅对杂质的耐受程度也较 P 型硅强。对太阳能电池而言，P 型硅电池在长时间光照后，会出现一定程度的效率衰减，这种衰减与材料中的硼-氧缺陷有关。采用 N 型硅后，这一问题不再存在。

采用非晶硅发射区的优点是：非晶硅有良好的表面钝化作用。而且沉积温度低（200℃）、工艺比较简单，避免了高温过程，降低了电池制造成本。

然而，HIT 电池也存在弱点。由于非晶硅发射区在正表面，非晶硅薄膜的厚度受到限制（一般在 20 μm），若厚度增加则入射光损失增加。但是，一般认为非晶薄膜要达到 50 μm 以上才能获得良好的表面钝化效果。如果非晶发射区过薄，甚至会出现发射区载流子完全耗尽的情况，使电池效率下降。另外，由于电池正面必须采用透明导电薄膜，也会带来 10% 左右的光损失（一般透明导电薄膜的透过率最高为 90%）。

针对常规同质结电池及 HIT 电池存在的问题，本发明提出了一种新的电池结构：采用薄膜硅背表面发射区的晶体硅太阳能电池。这种太阳能电池采用非晶硅（也可以是微晶硅或纳米硅）异质结发射区，并且把发射区沉积在硅片的背面。与 HIT 电池相比，这种电池首先避免了正面非晶硅层和透明导电薄膜带来的光损失，仅此就可使电池效率提高 10% 以上。此外薄膜硅层厚度不受限制，可以提供更好的表面钝化。电池背表面的薄膜硅/金属结构还可以提供良好的陷光作用。

这种新结构的电池由于将 PN 结放在了电池背面，对少数载流子寿命的要求较高，因此必须使用高质量的晶体硅材料。但电池效率的提高、工艺的简化可以弥补材料成本上升带来的不利影响。

三、发明内容

本发明的目的在于克服现有电池结构的缺点，得到一种转换效率高、制作工艺简单的背表面发射区晶体硅太阳能电池。

本发明是通过以下技术方案实现的。在 N 型单晶硅背面沉积一层硅薄膜形成发射区（可以在 N

型单晶硅背面先沉积一层本征硅薄膜再沉积 P 型硅薄膜,也可以在 N 型单晶硅上直接沉积 P 型硅薄膜)。硅薄膜可以用任意沉积方法制备,硅薄膜可以是非晶硅、微晶硅或纳米晶硅薄膜。与常规同质结 P 型晶体硅太阳能电池相比,采用本结构不仅有效的避免了 P 型电池中硼-氧缺陷的影响,还有效地对背表面进行了钝化。另外,背表面的金属电极层可以将穿透电池的光重新反射回电池体内,增强电池对光的吸收率。与国外的非晶硅/晶体硅异质结太阳能电池(HIT 电池)相比,本结构的发射区在电池背面,正表面不再需要透明导电膜来收集电流,可以避免正面硅薄膜和透明导电薄膜对入射太阳光能量的吸收而造成的效率损失。采用本发明中的电池结构,电池效率可以达到 20%以上。

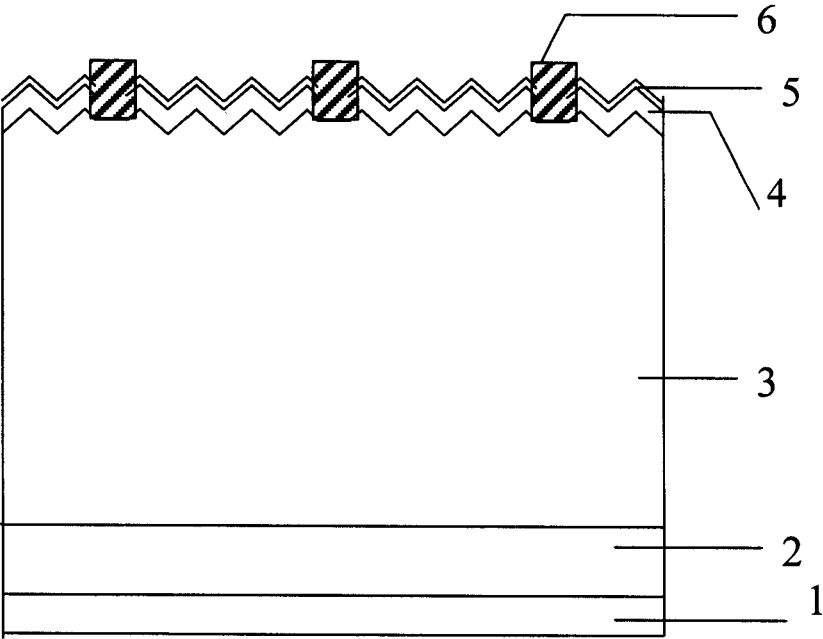
四、附图说明

附图为此种新型太阳能电池结构示意图。图中:(1)背电极;(2)沉积法制备的硅薄膜;(3)N 型晶体硅;(4)高掺杂 N^+ 层;(5)减反射层;(6)正电极。

五、具体实施方式

技术方案:采用高质量 N 型单晶硅片(3),厚度在 $300\mu m$ 以下,电阻率在 $5-500\Omega cm$ 。采用标准工业工艺清洗表面并织构化后,先在正表面扩散一层高掺杂 N^+ 层(4),薄层电阻为 $100-300\Omega/\square$ (该层的作用是利用掺杂浓度的变化钝化电池正表面,同时为正表面电极提供良好的欧姆接触)。在 N^+ 层上沉积或生长具有减反射效果的薄膜(5),例如 SiN 或 SiO_2 等,厚度在 $70-120nm$ 。在 N 型单晶硅片(3)背面沉积硅薄膜(2),例如非晶硅或微晶硅、纳米晶硅,厚度在 $20-200nm$ 。最后在减反层(5)上制备正电极(6),在硅薄膜上制备负电极(1)。

本发明采用的技术手段是在电池背面通过沉积硅薄膜实现发射区。与现在绝大部分工厂中采用的 P 型硅片扩散 N 型发射区相比, N 型硅可以有效地降低在光照下硼-氧缺陷的产生和因此导致的转换效率衰减。另外,PN 结采用低温沉积方法制备,避免了常规 $800\sim 1000^\circ C$ 的扩散过程,这样的高温过程会使硅材料产生更多的缺陷或沾污从而影响电池效率的提高。另外,在硅片背面沉积的硅薄膜,不论是非晶硅、微晶硅还是纳米晶硅均可以起到对背面的钝化作用,从而提高电池效率。在本结构的正表面或背表面至少可以有一面做绒面(texturing)处理来减少光反射并提高陷光效应,这对提高电池光电转换效率是有帮助的。绒面上可制备一层减反射膜进一步提高电池的光电转换效率。



一种太阳能电池新型结构的示意图

EXHIBIT B

[19] China National Intellectual Property Administration



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1 page of Claims 2 pages of Specification
1 page of Accompanying Drawings

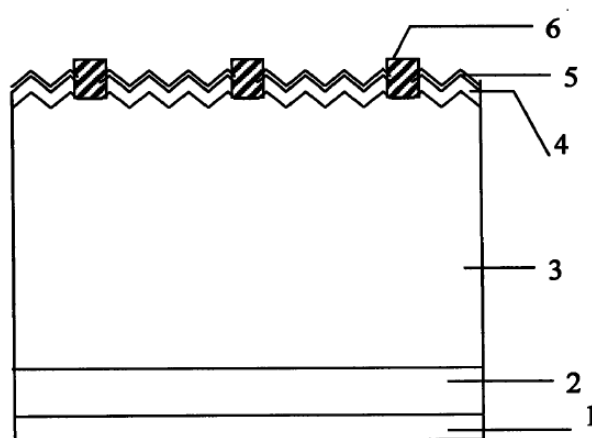
[54] Title

CRYSTALLINE SILICON SOLAR CELL WITH NOVEL STRUCTURE

[57] Abstract

A crystalline silicon solar cell adopting an emitting region on a back surface of thin film silicon belongs to a photovoltaic cell with a novel structure. The crystalline silicon solar cell is characterized in that a layer of silicon thin film is deposited on a back surface of an N-type monocrystalline silicon substrate to form a heterogeneous PN junction so as to replace a homogeneous PN junction prepared on a front surface of the cell by a conventional diffusion method. The silicon thin film deposited in the present invention can be an amorphous thin film, a microcrystalline thin film, or a nanocrystalline thin film. The heterogeneous PN junction in the present invention can be a P-type silicon thin film directly deposited on the N-type monocrystalline silicon, or can also be a P-type silicon thin film deposited on a layer of intrinsic

silicon thin film which is first deposited on the N-type monocrystalline silicon. By adopting the cell structure in the present invention, cell efficiency can reach 20% or above.



**Schematic diagram of a solar cell with a novel
structure**

1. A heterojunction solar cell, characterized in that an emitting region is on a back surface of the cell, and a heterogeneous PN junction is formed at the same time.
2. The solar cell of claim 1, characterized in that the solar cell is structurally a positive electrode/anti-reflection layer/surface textured N-type crystalline silicon/silicon thin film/back electrode.
3. The solar cell of claim 1, characterized in that the emitting region is on the back surface of the cell.
4. The solar cell of claim 1, characterized by the heterogeneous PN junction.
5. The solar cell of claim 3, characterized in that the heterogeneous PN junction can be structurally an N-type crystalline silicon/P-type silicon thin film, or can also be an N-type crystalline silicon/intrinsic silicon thin film/P-type silicon thin film.
6. The solar cell of claim 4, characterized in that the silicon thin film can be an amorphous silicon thin film, a microcrystalline silicon thin film, or a nanocrystalline silicon thin film.

Crystalline Silicon Solar Cell with Novel Structure

I. Technical Field

The present invention relates to a novel structure of a solar cell and belongs to the field of solar energy applications.

II. Background Art

Crystalline silicon solar cells account for more than 90% of photovoltaic market shares in the global world. Such cells generally adopt P-type crystalline silicon to form an N-type emitting region through high-temperature diffusion and belong to homogeneous PN junction solar cells. However, such cells have the disadvantages that the high-temperature diffusion may cause more defects in silicon materials, and when pollution is caused in a high-temperature process, cell efficiency will be greatly reduced. Thus, higher requirements are put forward for both materials and a production environment. In addition, back surfaces of such cells are free of effective passivation and an effective light trapping structure. Thus, recombination on the back surfaces is relatively serious, and a part of light penetrates an active region of the cells and is not absorbed. These disadvantages are reasons that limit improvement of the efficiency of conventional solar cells.

In recent years, an amorphous silicon/crystalline silicon heterojunction solar cell (HIT cell) has been developed by Sanyo in Japan. Such cell adopts an N-type monocrystalline silicon wafer and deposits an amorphous silicon thin film on a surface of the silicon wafer. An emitting region is a P-type amorphous silicon thin film deposited on a front surface of the silicon wafer. A front surface structure of the cell is a metal grid/transparent conductive thin film (TCO)/P-type amorphous silicon/intrinsic amorphous silicon/monocrystalline silicon wafer. The structure makes full use of a good surface passivation effect of the amorphous silicon, and the efficiency of the prepared cell reaches 20% or above.

Adoption of N-type silicon has the advantages that the N-type silicon wafer generally has a long minority carrier lifetime, and the silicon wafer with high quality is easy to obtain. The N-type silicon is also more tolerant to impurities than the P-type silicon. For solar cells, P-type silicon cells will have efficiency attenuation to a certain degree after long-term exposure to light, and the attenuation is related to boron-oxygen defects in materials. After the N-type silicon is used, the problem no longer exists.

Adoption of the amorphous silicon emitting region has the advantage that the amorphous silicon has a good surface passivation effect. Moreover, a deposition temperature is low (200°C), and a process is relatively simple, such that a high-temperature process is avoided, and the manufacturing cost of the cell is reduced.

However, the HIT cell also has weaknesses. Because the amorphous silicon emitting region is on the front surface, a thickness of the amorphous silicon thin film is limited (generally 20 μm), such that incident light loss is increased when the thickness is increased. However, it is generally believed that the amorphous thin film with the thickness of 50 μm or above can achieve a good surface passivation effect. When the amorphous emitting region is too thin, the situation of complete depletion of carriers in the emitting region may even occur, leading to reduction of the cell efficiency. In addition, because the transparent conductive thin film needs to be used on the front surface of the cell, about 10% of light loss (generally, the transmittance of the transparent conductive thin film is up to 90%) will also be caused.

In view of the problems of the conventional homojunction cells and the HIT cells, the present invention provides a novel cell structure: a crystalline silicon solar cell adopting an emitting region on a back surface of thin film silicon. The solar cell adopts an amorphous silicon (which can also be microcrystalline silicon or nano-silicon) heterojunction emitting region and deposits the emitting region on a back surface of a silicon wafer. The cell first avoids light loss caused by the amorphous silicon layer and the transparent conductive thin film on the front surface, such that the cell efficiency can be improved by 10% or above, compared to the HIT cell. In addition, the thickness of a thin film silicon layer is not limited, which can provide better surface passivation. A thin film silicon/metal structure on a back surface of the cell can also provide a good light trapping effect.

According to the cell with the novel structure, because a PN junction is placed on the back surface of the cell, requirements for the minority carrier lifetime are high, and thus, high-quality crystalline silicon materials need to be used. However, improvement of the cell efficiency and simplification of processes can make up for

adverse influence caused by increase of material costs.

III. Summary of the Invention

The purpose of the present invention is to overcome the disadvantages of existing cell structures so as to obtain a crystalline silicon solar cell having an emitting region on a back surface with high conversion efficiency and a simple manufacturing process.

The present invention is achieved by the following technical solutions. A layer of silicon thin film is deposited on a back surface of N-type monocrystalline silicon to form an emitting region (a P-type silicon thin film can be deposited on a layer of intrinsic silicon thin film which is first deposited on the back surface of the N-type monocrystalline silicon, or a P-type silicon thin film can be directly deposited on the N-type monocrystalline silicon). The silicon thin film can be prepared by any deposition method, and the silicon thin film can be an amorphous silicon thin film, a microcrystalline silicon thin film, or a nanocrystalline silicon thin film. Compared with conventional homojunction P-type crystalline silicon solar cells, the use of the structure not only effectively avoids influence of boron-oxygen defects in P-type cells, but also effectively passivates the back surface. In addition, a metal electrode layer on the back surface can re-reflect light that penetrates the cell back into the cell, thereby increasing an absorption rate of the light by the cell. Compared with foreign amorphous silicon/crystalline silicon heterojunction solar cells (HIT cells), the emitting region of the structure is on the back surface of the cell, and a front surface no longer requires a transparent conductive thin film to collect current, such that efficiency loss caused by absorption of incident solar energy by a silicon thin film and the transparent conductive thin film on the front surface can be avoided. By adopting the cell structure in the present invention, cell efficiency can reach 20% or above.

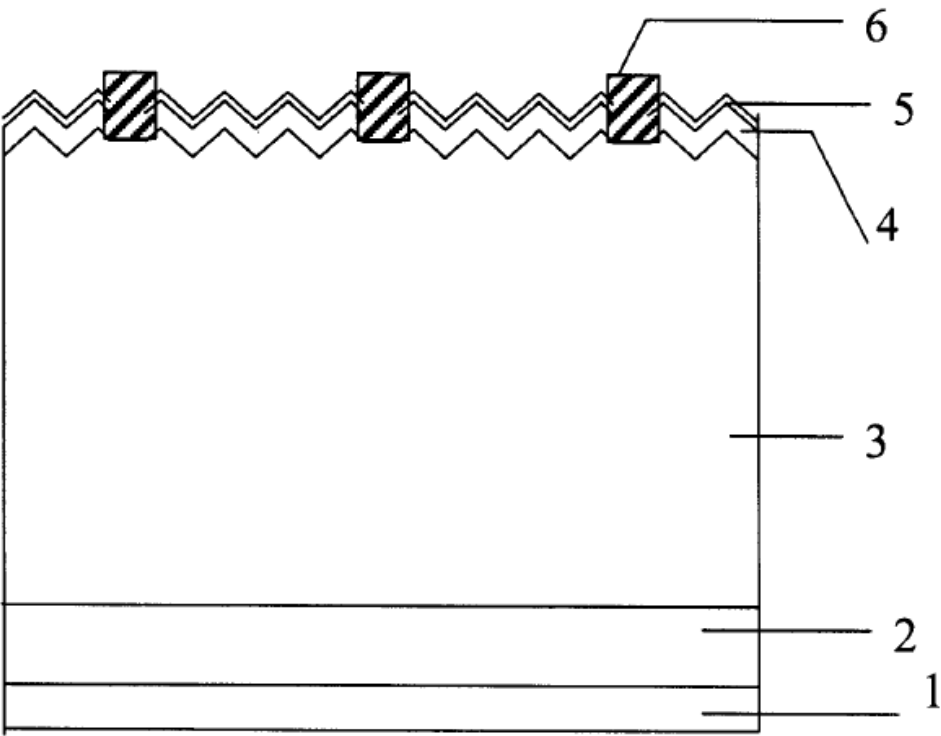
IV. Brief Description of the Drawings

The accompanying drawing is a structural schematic diagram of such a novel solar cell. In the figures: (1) back electrode; (2) silicon thin film prepared by a deposition method; (3) N-type crystalline silicon; (4) highly doped N⁺ layer; (5) anti-reflection layer; (6) positive electrode.

V. Detailed Description of Embodiments

Technical solution: A high-quality N-type monocrystalline silicon wafer (3) with a thickness of less than 300 μm and a resistivity of 5–500 Ωcm is adopted. After surfaces are cleaned and textured by a standard industrial process, a highly doped N⁺ layer (4) with a sheet resistance of 100–300 $\Omega/\square$ is first diffused on the front surface (the layer is used for passivating the front surface of a cell by using changes in doping concentration and for providing good ohmic contact to a front surface electrode). A thin film (5) having an anti-reflection effect, such as SiN or SiO₂, etc., with a thickness of 70–120 nm, is deposited or grows on the N⁺ layer. A silicon thin film (2), such as amorphous silicon, microcrystalline silicon, or nanocrystalline silicon, with a thickness of 20–200 nm, is deposited on the back surface of the N-type monocrystalline silicon wafer (3). Finally, a positive electrode (6) is prepared on the anti-reflection layer (5), and a negative electrode (1) is prepared on the silicon thin film.

A technical means adopted in the present invention is to achieve an emitting region by depositing the silicon thin film on the back surface of the cell. Compared with a P-type silicon wafer diffused N-type emitting region used in most factories at present, the N-type silicon can effectively reduce the generation of boron-oxygen defects under illumination and resulting attenuation of conversion efficiency. In addition, a PN junction is prepared by a low-temperature deposition method, which avoids a conventional diffusion process at 800–1000°C. Such high-temperature process will cause more defects or contamination in a silicon material, which will affect the improvement of cell efficiency. In addition, the silicon thin film deposited on the back surface of the silicon wafer, whether it is amorphous silicon, microcrystalline silicon, or nanocrystalline silicon, can achieve a passivation effect on the back surface, thereby improving the cell efficiency. At least one surface of the front surface or the back surface of the structure can be subjected to texturing treatment to reduce light reflection and improve a light trapping effect, which is conducive to improving the photoelectric conversion efficiency of the cell. An anti-reflection film can be prepared on the texturing surface to further improve the photoelectric conversion efficiency of the cell.



Schematic diagram of a solar cell with a novel structure