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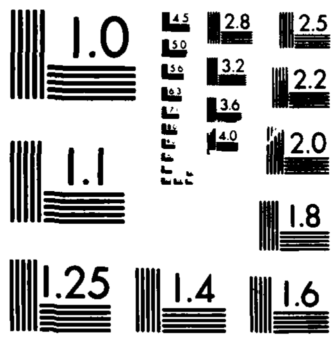

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AD-A183 039

HIGH-EFFICIENCY SILICON SOLAR CELL

(Selected Portions)

by

Shi Jiqun

FOREIGN TECHNOLOGY DIVISION

87

HUMAN TRANSLATION

FTD-ID(RS)T-1056-86 22 July 1987

MICROFICHE NR: FTD-87-C-000543

HIGH-EFFICIENCY SILICON SOLAR CELL (Selected Portions)

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English pages: 5

Source: Huazhong Gongxueyuan Xuebao, Nr. 4, 1984, pp. 67-69; 72

Country of origin: China
Translated by: Randy Dorsey
Requester: FTD/TQTD
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HIGH-EFFICIENCY SILICON SOLAR CELL

Shi Jiqun

Submitted 24 Dec 1983

ABSTRACT

This paper discusses in theoretical and technical terms the development of high-efficiency silicon solar cells and analyzes measures for increasing the circuit current density of silicon solar cells. The energy conservation efficiency of the silicon solar cells introduced in this paper is as high as 18.7%.

1. SUMMARY

The energy conservation efficiency of a silicon solar cell can be expressed by the formula:

$$\eta = \frac{V_{oc} J_{sc} FF}{P_{in}}, \tag{1}$$

where P_{in} is the surface power density of the incident sunlight, under standard ground measurement conditions (AM 1.5, 28^{o}C), its value is 100mW/cm^2; V_{OC} is the output circuit voltage of the cell; J_{sc} is the output short circuit current density of the cell; and FF is the fill factor.

The most important parameter for a cell is improving its efficiency. Since the early 70's, lots of reasearch has been done to increase short circuit current density[1] - [3]. These technological processes have already increased short circuit current density to the point where there is not much more room for improvement. Our research work on high-efficiency silicon solar cells first of all began with raising circuit voltage as well as assisting with certain measures to improve short circuit current density and fill factor. The cells which were developed had their total surface area efficiency measured at 18.7% (AM 1.5, 100 mW/cm^2, 28^oC) in evaluation tests at the Solar Research Institute in Colorado. This is the highest value obtained by a silicon cell measured at this institute. It is a relatively large improvement compared to the efficiency of silicon cells measured by similar methods previously published (see Table 1).

The structure of this type of silicon solar cell is as in Fig. 1. As a result of using such measures as surface passivation technology, circuit voltage has been increased. As a result of high circuit voltage and low series resistance extremely high fill factors have been achieved. As a result of employing designs such as double layer, anti-reflective film and decreasing electrode shading area, short circuit current density has been increased. The above three achievements combine together to create conditions for development of the high-efficiency silicon solar cell.

TABLE 1. High-efficiency silicon solar cell (100 mW/cm^2, 28^oC)

Year	Manufacturer	J_{sc} (mA/cm^3)	V_{oc} (mV)	FF	η(%)
1977	U.S. RCA Company	37.1	600	0.775	17.3
1978	Sandia	34.0	622	0.796	16.8
1981	U.N.S.W. (Austria)	31.1	635	0.801	15.8
1982	K. U. Leuven	35.1	623	0.780	17.1
1983	This paper	35.5	641	0.822	18.7

Next, we will discuss each of the measures which were taken for these three areas and some of the results.

II. MEASURES FOR INCREASING CIRCUIT VOLTAGE

Assume that under conditions of no surface compounds, the ideal circuit voltage will be:

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_L}{I_o} + 1\right). \quad (2)$$

From this we can see that under standard test conditions, the value of V_{OC} depends only on the value of reverse saturation current I_O, which is determined by semiconductor internal characteristics. In order to increase V_{OC} and to hope for lower value of I_O also requires that a substrate of low resistivity be used.

Actually, for high-efficiency silicon solar cells, the problem of studying surface compounds (regardless if on the top surface or on the back) must be emphasized. In the presence of surface compounds, just as for reverse saturation current I_O, this term increases the preceding surface compound current term, which causes V_{OC} to drop. Here, the important thing is to increase circuit voltage by reducing surface compounds.

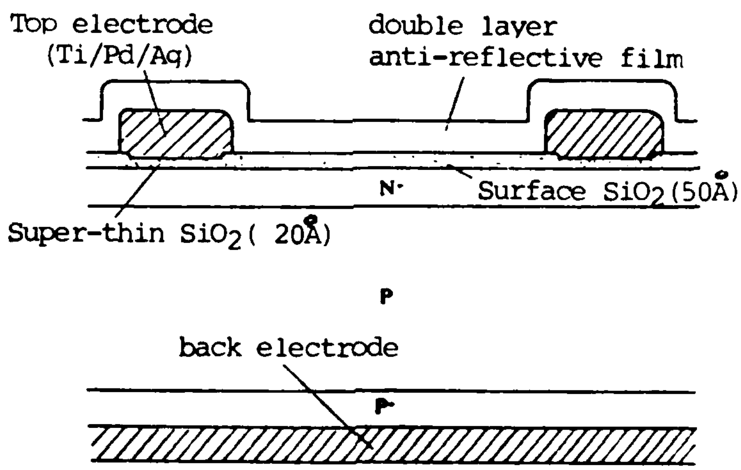

Fig. 1. Cross-sectional diagram of high-efficiency silicon solar cell
Its main feature: Employing thin oxide layer passivation top surface, electroplated metal electrode and double-layer anti-reflective film

1. Surface Passivation

The blue light waveband response and the circuit voltage of high-efficiency silicon solar cells are determined by the quality of surface passivation[4]. For improving surface passivation quality a unique scheme is employed. Passivation is carried out by thermally growing silicon dioxide film over the entire surface. However, the thickness of the silicon dioxide on the area with no electrode must be 50~100Å and the thickness of the super-thin silicon dioxide under the electrode must be approximately 20Å. The thickness of the former can be explained by the passivation of the pn junction boundary, the thickness is sufficient, but between the substrate and the electrode employing titanium-palladium-silver an electrical insulating layer is provided (palladium and silver are not low power factor metals). The latter forms a thickness of approximately 20Å, causing a "pass-through" effect to be produced, and thereby achieving effective electrical contact between the metal surface electrode and the semiconductor. However, a super-thin silicon dioxide layer is inserted between the two, avoiding metal-semiconductor contact which can bring about a high surface compound rate[5], thus lowering the surface compound rate.

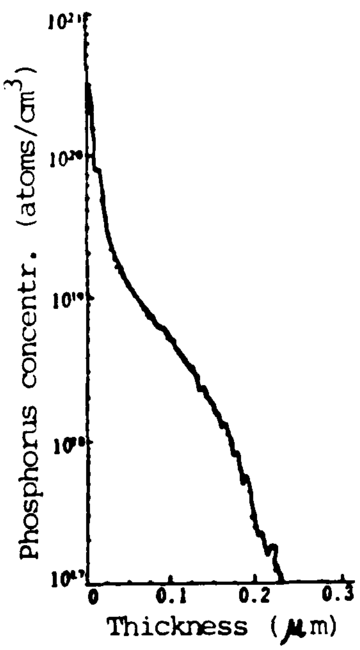

Fig. 2. Impurity distribution diagram of phosphorus concentration near the surface of high-efficiency cells

The above method was used to carry out surface passivation, which can cause surface compounds to affect the saturation current density of the cell, which operates below 5 X 10^{-14} A/cm^2. If sufficiently good volume characteristics are acheived then a cell with a circuit voltage of more than 700 mV will probably be achieved.

2. Shallow Diffusion

In order to achieve high circuit voltage, we optimized diffusion conditions [6]. Shallow diffusion impurity distribution of the curves was measured (see Fig. 2). Diffusion employed trichloro oxygen phosphorus liquid state source. Diffusion film resistance was in the range of 300 - 500 $\Omega/\square$. There are two reasons why this kind of shallow diffusion can increase circuit voltage. First, as can be seen from Fig. 2, mixed surface concentration is very near solid state solubility of phosphorus in silicon at diffusion temperatures.

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V. CONCLUSION

By carrying out the above mentioned measures, a silicon solar cell efficiency of 18.7% was achieved. Even though these cells have fairly high performance, in certain ways they can still be optimized and improved even further. For example, when titanium is used as the base metal of electrodes, improvements in problems of surface passivation, improvements in surface electrode design, improvements in cell optical properties and improvements in substrate properties, may, in fact, along with design and engineering improvements, make possible a silicon solar cell efficiency of up to 20%.

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