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OPEN-CIRCUIT VOLTAGE OF MIS SILICON SOLAR CELLS

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ABSTRACT

Open circuit voltage V_{oc} of MIS Silicon Solar cells fabricated on n-type silicon has been investigated. The effect of different parameters such as quality factor n and Schottky Barrier height $e\phi_{Bn}$ on V_{oc} are discussed. It is concluded that a high n-value is not necessary to obtain a high open circuit voltage V_{oc}.

ÖZET

Bu çalışmada, n-tipi silikon kullanılarak yapılan MIS Silikon güneş pillerinin açık devre voltajı incelendi. n kalite faktörü ve $e\phi_{Bn}$ Schottky engeli gibi çeşitli parametrelerin, açık devre voltajı üzerine etkisi araştırıldı. Neticede, açık devre voltajının yüksek olması için n-değerinin de yüksek olması şartının gerekmediği görüldü.

INTRODUCTION

The Schottky MIS solar cells based on Si and GaAs have shown that useful amounts of power can be generated on earth using incident solar energy. These devices are interesting due to the possibility for developing a low-cost, low-temperature fabrication process for terrestrial solar cells.

One of the significant possibilities for large scale cost reduction lies in getting away from cells having p-n junctions and replacing them by simply deposited metal-semiconductor junctions known as a Schottky barrier.

In practice it has been found that intimate contacts formed between metal films and crystalline semiconductors exhibit poor photovoltaic response since the thermionic emission dark current at the Schottky barrier leads to significantly higher dark currents than is normally encountered in a homojunction or heterojunction

structure. This problem, however can be solved by allowing a very thin oxide or insulating layer to be formed between the semiconductor and the metal contact /1,2/. The introduction of this layer leads to the common form of metal-Insulator-Semiconductor Schottky Barrier Solar Cell (MIS SBSC).

There are some conflicting views concerning the relation between the open circuit voltage and the n-value in these MIS devices. For example, it has been suggested that, the highest open circuit voltages are obtained for high values of n caused by an increased oxide thickness. On the other hand, high values of open-circuit voltages has been attributed to the lowered metal work function and thus an increased V_{oc} /3/. This paper is therefore particularly devoted to discuss the influence of the n-value on the open-circuit voltage.

BASIC THEORY OF MIS SCHOTTKY SILICON SOLAR CELL

Conventional Schottky theory predicts that /4/

$$V_{oc} = n\phi_{Bn} + n \frac{kT}{q} \ln \left(\frac{Jsc}{A^*T^2}\right) \qquad (1)$$

where,

n = Diode quality factor

ϕ_{Bn} = Barrier height in eV

k = Boltzman's constant

T = Temperature in K

Jsc = Short circuit current density in A/cm^2

A^* = 120 A/cm^2K^2 for electrons

This equation is valid providing that the insulator thickness is less than 25 A^o to permit the free electron tunneling. The effect of insulator is accounted for by /5/,

$$n\phi_{Bn} = Eg + \chi_s - \phi_m + (n-1)\ \phi_o \qquad (2)$$

where

Eg = energy gap.

ϕ_o = neutral level of surface states

$$\gamma = \left(1 + \frac{q\delta D_s}{\varepsilon_i \varepsilon_o}\right)^{-1} = \text{surface state factor}$$

x_s = electron affinity

δ = oxide thickness

It may then be shown that /6/

$$n \approx 1 + \frac{q\delta D_s}{\varepsilon_i \varepsilon_o} \qquad (3)$$

where

$$D_s = \text{surface state density} > \frac{\varepsilon_s \varepsilon_o}{q\, W}$$

w = width of the semiconductor space-charge layer. This equation holds for $10A^{o} < \delta < 30A^{o}$ where the surface states equilibrate with the semiconductor. A combination of Eqs. 1-3 then gives the expression,

$$V_{oc} = 4.95 - \phi_m - 0,215\ n \qquad (4)$$

using $E_s + x_s = 5,25$ eV, and $\phi_o = 0,33$ eV /7/.

This basic equation predicts that decreased n and ϕ_m are necessary to increase V_{oc} even though Eq.1 appears to suggest that a high n value is desirable. A decreased n occurs for low values of δ and D_s, but δ must exist and be large enough to influence the nucleation of the Schottky metal to lower the metal work function ϕ_m.

EXPERIMENTAL RESULTS

~200 μm thick, n-type Si, 0.1 Ω-cm in resistivity has been used. Indium was coated onto the surface as an ohmic contact and $10\text{-}30A^{o}$ thick oxide layer was then grown on the other surface at $150^{o}C$ for 72 hours. Gold contacts 100 A^{o} thick were then slowly evaporated on the oxidized surface. Final depositions included a 1000 A^{o} thick gold grid. Fig. 1. shows an example of a Schottky solar cell.

The dark I-V characteristics of three samples are plotted in order to determine the n-value and the barrier height ϕ_{Bn} (see Figs. 2-4).

The n-value for each sample is determined from the slope of the plot of ln I-V. The n-values are found to be 1.79, 2.1 and 2.23 for samples 1,2 and 3,

respectively. The barrier height ϕ_{Bn} is determined from the semilogaritmic current voltage plot by using the reverse saturation current J_o obtained from the intercept on the J axis and with the following equation.

$$J_o = A^x T^2 \exp(-\frac{e\phi_{Bn}}{kT})$$

The ϕ_{Bn} values for samples 1, 2 and 3 are calculated to be 0.8, 0.79 and 0.66 eV respectively.

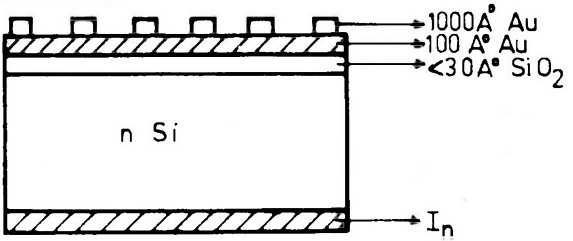


Fig. 1. n-type MIS Si solar cell structure.

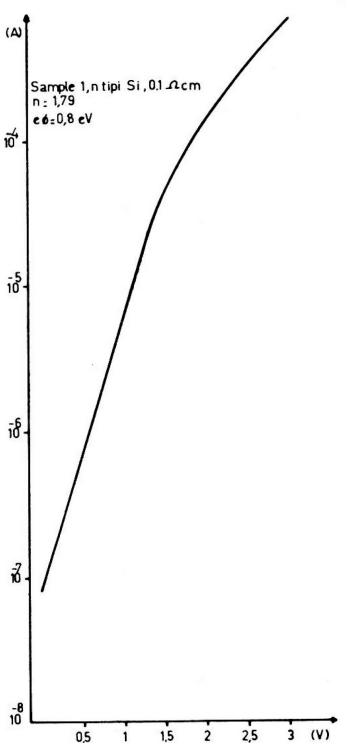


Fig. 2. ln I-V characteristic in the dark of sample 1.

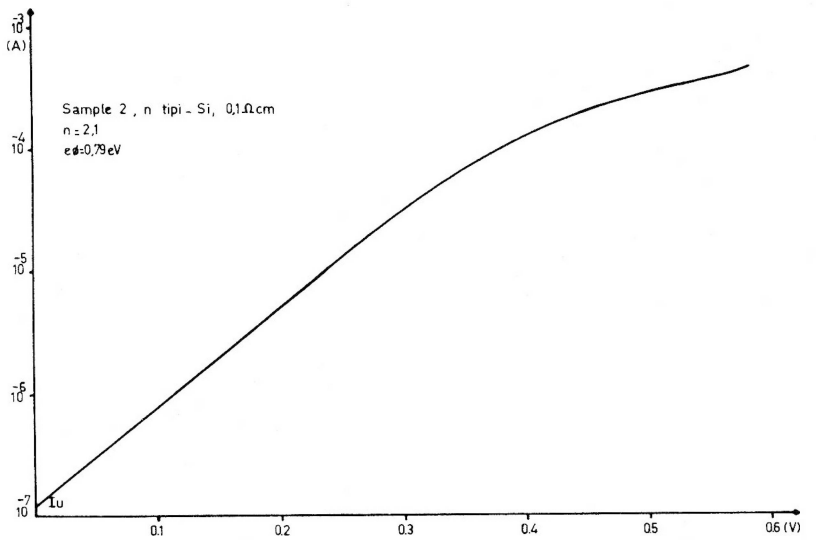


Fig. 3. ln I-V characteristic in the dark of sample 2.

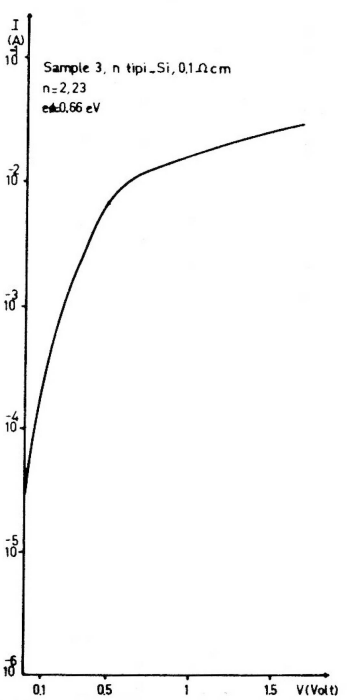


Fig. 4. In I-V characteristic in the dark of sample 3.

The values of open-circuit voltage (V_{OC}) are obtained from the photovoltaic measurements (see Figs. 5-7) and given in Table-1 together with the n and ϕ_{Bn} values. Metal work function ϕ_m for Au is then calculated using Eq.4. The photovoltaic measurements are also used with the definition of fill factor FF

$$FF = \frac{V_{pm} \quad I_{pm}}{}$$

to calculate the fill factor FF for each sample. The values of n, ϕ_{Bn}, FF, V_{OC} and calculated ϕ_m for each sample are summarized in Table-1.

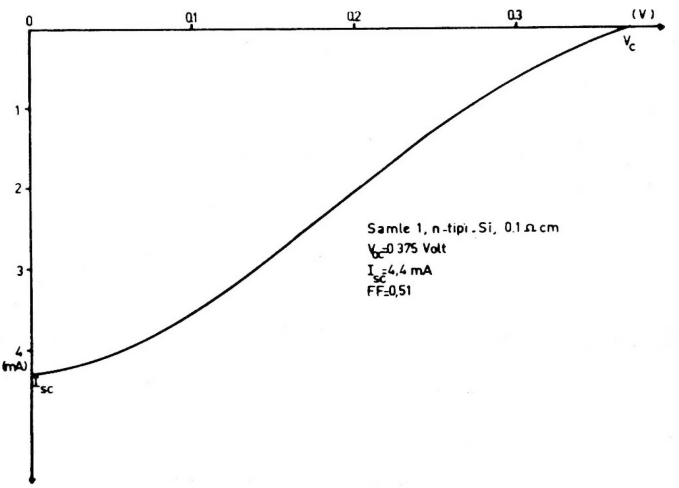


Fig. 5. I-V data for sample 1 under illumination.

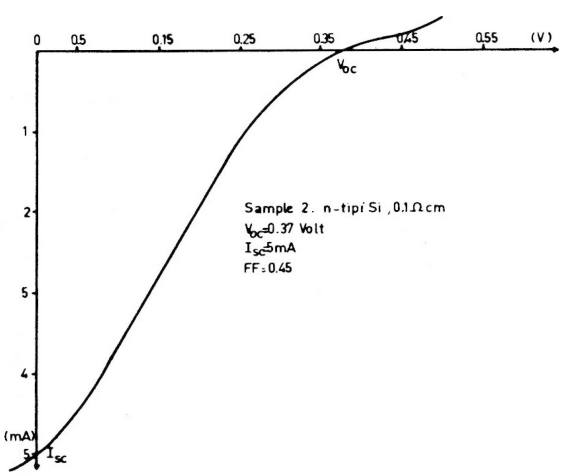


Fig. 6. I-V data for sample 2 under illumination.

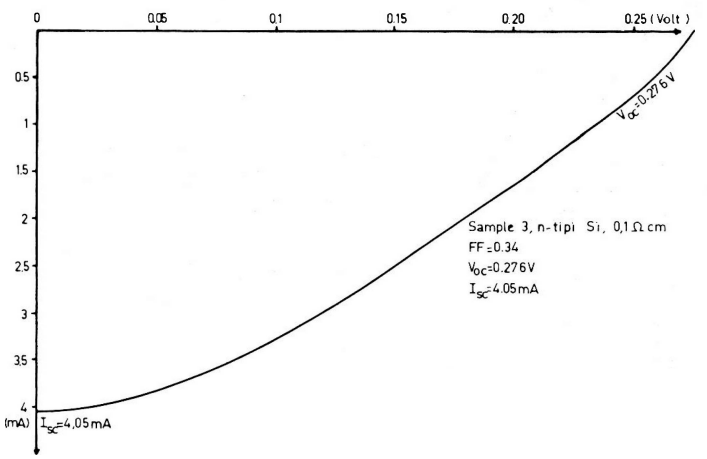


Fig. 7. I-V data for sample 3 under illumination.

TABLE-1. Open circuit voltage and work function data for MIS Schottky Solar Cells.

Sample	$e\phi_{Bn}$ (eV)	n	FF	V_{oc} (mV)	I_{sc} (mA)	ϕ_m(Au)* (eV)
1	0.8	1.79	0.51	375	4.4	3.2
2	0.79	2.10	0.45	370	5	4.12
3	0.66	2.23	0.34	276	4.05	4.2

* Calculated from Eq. 7

As it can be seen from the Table-1, the high values of V_{oc} correspond to the low values of n which is contradictory to a conclusion based on an earlier research where the highest open circuit voltages are obtained for high values of n. It is evident from our study that a high n-value is not necessary to obtain a high V_{oc}. The main factor to obtain a high V_{oc} appears to be lowered metal work function for Au in Table-1 compared to the bulk value of 4.6 eV /8/ as suggested earlier in W.A. Adenson work of Cr-p type Si schottky MIS Solar cells /3,9/. A low value of ϕ_m

for Au is caused by the slow deposition of Au on an oxide surface. This lowered ϕ_m then resulted an increased V_{oc}. It is also evident from Table-1, that, the higher values of FF correspond to the low values of n which has the same relation as the n and V_{oc} has.

DISCUSSION

The experimental data indicates that the open circuit voltage V_{oc} of a MIS solar cell may be controlled by the metal deposition rate, which is Au in our case. This suggests a change in the basic structure of the Au which causes an apparent lowered work function. A lower ϕ_m is attributed to slow deposition of Au on an oxide surface. The increased open-circuit voltage V_{oc} with decreased metal work function ϕ_m and oxide layer thickness δ is then predicted from Eqs. 3,4.

This observation is also predicted by Fonash /10/. According to Fonash, partly due to the fixed charge in the oxide layer causes an effective reduction in the metal work function ϕ_m which agreed in principal with the Eqs. 3,4.

CONCLUSION

Our experimental data have shown that the deposition rate of Au evaporation may be used to control V_{oc} in the Au-oxide-n type Si MIS solar cells. This is independent of oxide thickness in the range of between 10A° and 30A°. It has been concluded that the metal work function ϕ_m of Au is actually being decreased by slow deposition on an oxide surface to give an increased open circuit voltage V_{oc}. Our experimental data together with the other recent data /3,10/ also suggest that a high n-value is not necessary to obtain a high open circuit voltage V_{oc} which contradicts earlier conclusion.

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