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AMORPHOUS SILICON ON p-TYPE CRYSTALLINE SILICON HETEROJUNCTION

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Résumé. — Une jonction a été réalisée par pulvérisation cathodique en courant continu de silicium type-n sur un substrat cristallin type-p. Les contacts ohmiques ont été réalisés par évaporation d'aluminium. Il a été trouvé que la jonction obéit au modèle de Schottky dans les deux directions directe et inverse mais avec un facteur d'idéalisation « n » plus élevé, ce qui est dû à sa grande résistance interne. La relation $1/C^2-V$ indique la présence d'états localisés aussi bien en volume que sur l'interface. L'effet photovoltaïque donne un rendement de 0,25 % et un facteur de remplissage de 0,26 par suite de la grande résistance interne. L'effet photoconducteur a été également étudié.

Abstract. — A junction was grown by d.c. sputtering of n-type silicon on a p-type crystalline substrate. Ohmic contacts were deposited by evaporation of aluminum. The junction obeyed Schottky model both under forward and reverse bias conditions, but with higher idealization factor « n » due to its high internal resistance. The $1/C^2-V$ relation showed the presence of localized and interface states. The photovoltaic effect gave efficiency of 0.25 % and fill factor of 0.26 due to the high internal resistance. Photoconductive effect was also observed.

1. Introduction. — In recent years, sudden interest grew in building amorphous silicon solar cells [1, 2]. This followed the slow down in progress in the field of polysilicon solar cells [3]. There is still much to learn about the properties of amorphous silicon. The problem of dangling bonds [4] as well as the problem of localized states in the forbidden zone [5] are still under investigation.

The technique of doping [6] as well as the effect of the growth technique on the properties of the amorphous silicon film [7] are under study. Very little has been done in studying amorphous heterojunctions of the same material [8, 9] in recent years.

The objective of this work is to learn more about the properties of amorphous-crystalline silicon heterojunction, as well as the properties of amorphous silicon grown by d.c. sputtering in argon. Several measurements such as : $V-I$ characteristics, $1/C^2-V$ relation, photoresponse, were used as tools for this study. Although the junction in this form was inferior as a photovoltaic cells, the work shows the magnified effect of interface states on the device properties.

2. Experimental procedure. — 2.1 Preparation of specimen. — Substrates of (1, 1, 1) oriented mirror polished p-type silicon wafers with resistivities of 3-6 Ω-cm were used. Substrates were H.F. etched, rinsed in deionized water and dried in a blast of nitrogen before coating the back with aluminum electrodes by evaporation. Annealing at 470 °C for 30 min. in air secured good ohmic contact. The mirror polished surface was then H.F. etched, rinsed in deionized water and dried in a blast of nitrogen. The substrates were then placed in the vacuum system.

The vacuum chamber was purged several times with argon. A.C. ion bombardment was carried out for 5 min. before d.c. sputtering started. A target of 0.015 Ω-cm n-type silicon was bombarded with argon ions under 3.5 kV d.c. bias for 90 min. The pressure was maintained at 0.1 torr. There was an estimated partial pressure of oxygen of $10^{-5}$ torr in the chamber. The entire electrode distance was 5 cm. The yield on the substrate was 0.12 micron under these conditions. Dots of aluminum of 0.9 mm diameter were deposited on the surface by evaporation. Annealing for 12 min at 270 °C gave satisfactory ohmic contact on the amorphous surface, yet of high resistivity.

2.2 Measurements. — The $V-I$ characteristics under forward bias obeyed the relation :

$$\ln I = \ln A + qV/kT$$

as shown in figure 1. The factor « n » is an idealization factor that varied between 15 and 32 at low injection and one and half to twice that much at higher voltage. The presence of such high « n » is attributed to the bulk resistance in the grown amorphous thin film.

The $V-I$ characteristics under reverse bias in darkness obeyed the relation :

$$\ln I = \ln B + CV^{1/2}.$$ 

This is similar to the Schottky model reverse bias characteristics [10]. There was an obvious shift in this relation under illumination due to photo generation of carriers which, in turn, decreased the avalanche breakdown voltage as seen in figure 2.
linear with kinks at 0.5 V. In some specimens there was sudden rise in the relation as $V$ decreases. This is attributed to the formation of silicon oxide between the aluminum electrode and the amorphous silicon layer creating a MIS condition. The effect vanishes as the bias voltage exceeds the breakdown voltage of the formed silicon oxide layer. The slope of the $1/C^2-V$ relation was found to be sensitive to the testing frequency as shown in figure 3. This indeed is an indication for the presence of dense interface states that will substantially affect the measurements.

2.3 THE $1/C^2-V$ RELATION. — Both a.c. capacitance and conductance were measured under d.c. reverse bias. The $1/C^2-V$ relation was always sectionally linear with kinks at 0.5 V. In some specimens there was a sudden rise in the relation as $V$ decreases. This is attributed to the formation of silicon oxide between the aluminum electrode and the amorphous silicon layer creating a MIS condition. The effect vanishes as the bias voltage exceeds the breakdown voltage of the formed silicon oxide layer. The slope of the $1/C^2-V$ relation was found to be sensitive to the testing frequency as shown in figure 3. This indeed is an indication for the presence of dense interface states that will substantially affect the measurements.

2.4 THE SPECTRAL RESPONSE. — The normalized photoresponse was measured using a photo power meter and a set of Oriel narrow band filters in the range between 400 to 680 nm. The normalized response showed a monotonic increase with the increase in the photon energy. The relation between the square root of the normalized response versus incident photon energy showed an intersection at 1.7 eV as shown in figure 4.

2.5 THE EFFECT OF TEMPERATURE. — The $V-I$ characteristics were recorded at several temperatures ranging from 34 °C to 83 °C. The change in the value of the idealization factor $n$ was studied. The relation between $I_0/T^2$ versus $1/T$ was plotted in an attempt to measure the barrier height as shown in figure 5. The calculations showed a barrier height of the order of 0.09 eV on the average. This is too low when compared with the measurements based on the photoresponse.
2.6 The Photovoltaic Effect. — The cell efficiency was measured and found to be as low as 0.25% with a fill factor of 0.26.

3. Conclusions and discussions. — The V-I characteristics showed a high idealization factor attributed to the presence of high bulk resistance in the grown amorphous layer. These values were higher than the recently reported ones [11]. The V-I relation in the amorphous silicon [12] can be approximated to

\[ V = A(V, T) \ln I \]

where \( A(V, T) \) is a proportionality factor dependent on the temperature \( T \) and sectionally slow varying with the applied voltage \( V \). This reflects on the presence of two slopes for the relation \( \ln I \) versus \( V \) in the forward bias, where there is a small slope for the lower portion of the voltage and a higher slope for the higher portion of the voltage.

The voltage across the junction \( V_j \) is therefore

\[ V_j = V - V_a \]

where \( V_a \) is the voltage drop in the amorphous layer. Substituting in the Schottky diode equation under forward bias for the junction voltage we get

\[
\ln I = \ln I_0 + \frac{q(V - V_a)}{kT} = \ln I_0 + \frac{q(V - A(V, T) \ln I)}{kT}.
\]

Therefore

\[
\ln (1 + qA(V, T)/kT) = \ln I_0 + qV/kT.
\]

Let

\[ n = \left( 1 + qA(V, T)/kT \right). \]

Therefore

\[
\ln I = \frac{1}{n} \ln I_0 + qV/nkT.
\]

The behaviour of \( A \) with temperature was investigated by plotting \( \ln ((n(V, T) - 1)/T) \) versus \( T \) which fitted approximately a linear relation when \( n \) is of the higher value, as shown in figure 6.

In the reverse bias characteristics the drop voltage across the junction is too high compared with drop voltage in the amorphous layer, so that we can say that the applied voltage is equal to the junction voltage. The change in the reverse bias characteristics with illumination indicates the presence of high density of interface states, which helps in the photogeneration mechanism in the depletion layer. Therefore we expect more current and lower breakdown voltage.
The $1/C^2$ versus $V$ relation showed high slopes superceeding the possible values of doping in the substrate. These high values should be attributed to the presence of high density of unsaturated localized states in the amorphous silicon as well as due to the high density of dangling bonds on the interface. The density of localized states is due to the lack of hydrogen in the deposition process. The sensitivity of the slope to the measuring frequency supports the assumption that we have high density of localized states, with relatively low life time. In some cases, the $1/C^2-V$ relation had two kinks almost at the same bias voltage independent of the measuring frequency, as shown in figure 3. The extrapolation of the segments intersected with the voltage axis at 3.66, 1.7 and 0.9 V. These values can indicate the presence of more than one barrier, yet the only barrier in the visible range is 1.7 V, which agrees with the results obtained from the photoresponse measurement. Estimating the barrier height using the $\ln(I_0/T^2$) versus $1/T$ plot is too low since it is no more a simple Schottky barrier junction as mentioned above. Therefore it is not right to apply this relation for estimating the barrier height.

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