Bull. Mater. Sci., Vol. 3, Number 2, July 1981, pp. 157-161. © Printed in India.

Investigation on Schottky diodes on amorphous hydrogenated silicon†

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MS received 30 November 1980

Abstract. Schottky barrier diodes with near-ideal characteristics have been fabricated on amorphous hydrogenated silicon prepared by decomposition of a mixture of 10% silane and 90% hydrogen. The interface properties are found to be stable up to heat treatment of 300°C. From a detailed investigation of dark and photovoltaic properties it is concluded that the density of states in the mobility gap is sufficiently small so that there is no significant carrier recombination in the space charge region.

Keywords. Amorphous semiconductors; solar cells; Schottky diodes; hydrogenated silicon.

1. Introduction

There has been a great deal of activity in amorphous hydrogenated silicon (a-Si:H) because of its potential as a material for inexpensive solar cells. a-Si:H films for solar cells are usually made by glow-discharge decomposition of silane (Carlson and Wronski 1976). We have been making in our laboratory a-Si:H films by dc discharge of a 10% silane-90% hydrogen mixture which is less hazardous and more inexpensive. Based on detailed electrical and optical measurements we have shown (Guha *et al* 1981) that the films deposited from the dilute mixture have properties comparable to the best reported results on films from 100% silane. The tools used for studying the states in the gap which essentially reflect the quality of the film were photoconductivity and field effect measurements. Another useful approach for obtaining information about the states in the gap is to investigate the ideality factor of Schottky diodes (Rhoderick 1978). A good ideality factor reflects absence of recombination within the space charge region and speaks for the quality of the material. We have prepared Pd-Schottky diodes on a-Si:H and have investigated the dark I-V and the photo-voltaic properties of the structures. To examine the stability of the structures we have also studied the evolution of the characteristics as a function of heat treatment at different temperatures. The results are briefly reported in this paper; detailed results will appear elsewhere.

† Invited paper presented at A B Biswas Memorial Symposium on the Chemistry and Physics of the Solid State, Bombay (December 8, 1980)

2. Experimental details

The a-Si:H films are deposited by dc glow-discharge decomposition of 10% silane–90% hydrogen mixture at a pressure 0·5 torr on to substrates held at 300°C. Details about the deposition conditions are described elsewhere (Guha *et al* 1981). Substrates are Corning 7059 glasses with pre-deposited NiCr-Sb or Mo-Sb contacts. Typical film thickness is 0·5 to 1 μm. Prior to evaporation of the top contact, the samples are given a brief etch in 1 HF : 1 H_2O solution and rinsed in methanol. The a-si:H film is first baked for 2 hr at 150°C in a vacuum system with a base pressure of 10^{-6} torr to get rid of surface absorbates (Guha *et al* 1980); the top Pd contact, typically 100 Å thick, is next deposited through a metal mask. Typical area of the metal contacts is $1 - 3 \cdot 10^{-3}$ cm^2. Dark I-V measurements are measured using Keithley 610 electrometer for the photovoltaic measurements, a halogen lamp was used which was calibrated for the same short circuit currents produced by AM 1 sunlight. Intensity of the light was varied by using neutral density filters. Heat treatments were carried out in a furnace up to 300°C in flowing hydrogen atmosphere.

3. Results and discussion

Figure 1 shows the I-V characteristics of a diode as a function of heat treatment. The top contact was deposited at room temperature. The current-voltage

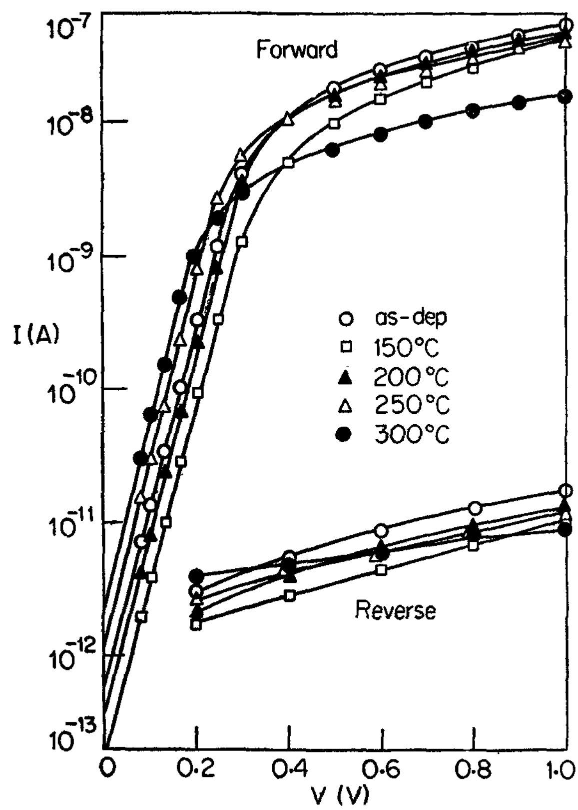

Figure 1. Evolution of dark I-V characteristics as a function of heat treatment at different temperatures.

relation is found to have the same form as in Schottky diodes on crystals *i.e.*

$$J = J_0 \left(\exp \frac{eV}{nkT} - 1\right)$$

where n is the ideality or quality factor and J_0 is the saturation current density. The as-deposited film has an ideality factor of 1·25 and saturation current density of 10^{-9} A/cm^2. The ideality factor improves to 1·13 after annealing at 200°C and again increases to 1·25 after further annealing at 250°C and 300°C. The saturation current density decreases to $3 \cdot 10^{-10}$ A/cm^2 after annealing at 150°C and then increases after annealing at successive stages to $6 \cdot 10^{-9}$ A/cm^2.

Using the diffusion model for transport across the barrier, one may write for a-Si:H (Wronski *et al* 1976)

$$J_0 = 3 \cdot 10^6 \exp\left(-\phi_B/kT\right)$$

where ϕ_B is the barrier height. We thus calculate a barrier height of 0·93 eV for the as-deposited contact and of 0·96 eV after annealing between 150° to 200°C. This agrees with published values (Wronski *et al* 1976; Wornski 1979) of barrier height of Pd on a-Si:H.

The changes in values of n and J_0 as a function of annealing can be attributed to a number of parameters. It is known (Card and Rhoderick 1971) that the presence of a thin oxide layer will increase n and decrease J_0. On annealing the metal will penetrate the oxide and thus n will decrease and J_0 will increase. If there is silicide formation due to heat treatment (Ottiavani 1979), the barrier height may change because the work function of the silicide could be different from the metal. Saturation current density may also increase due to formation of metallic spikes (Poate *et al* 1978) during annealing. It is difficult to assign uniquely which mechanism is responsible for the observed behaviour of the diodes after heat treatment. It may be speculated that annealing at 150°C causes penetration of the metal through the oxide and the formation of silicide. This will increase ϕ_B and reduce n. The increase in J_0 and n after heat treatment at higher temperature is possibly due to formation of metallic spikes.

According to the diffusion theory, the ideal diode quality factor is 1·1. Since in our case the best value of n is 1·13 which is very close to the ideal value, we can rule out effects of recombination current on the diode property and this speaks for the good quality of the material.

Under large forward bias the current becomes series resistance limited. The series resistance is found to be ohmic up to 800 mV and the resistivity agrees with the planar resistivity. After heat treatment at 300°C, the series resistance is found to increase which may be due to structural changes in the material close to the bottom contact.

Figure 1 also shows the reverse characteristic for the various heat treatment. A rectification ratio of close to 10^4 is obtained at 0·3 V even after annealing at 300°C.

The illuminated I-V characteristics of the diode at different stages of annealing is shown in figure 2. The Pd film was 20% transmitting and the diode was illuminated with simulated AMI light. An external efficiency of 2·5% is obtained after annealing

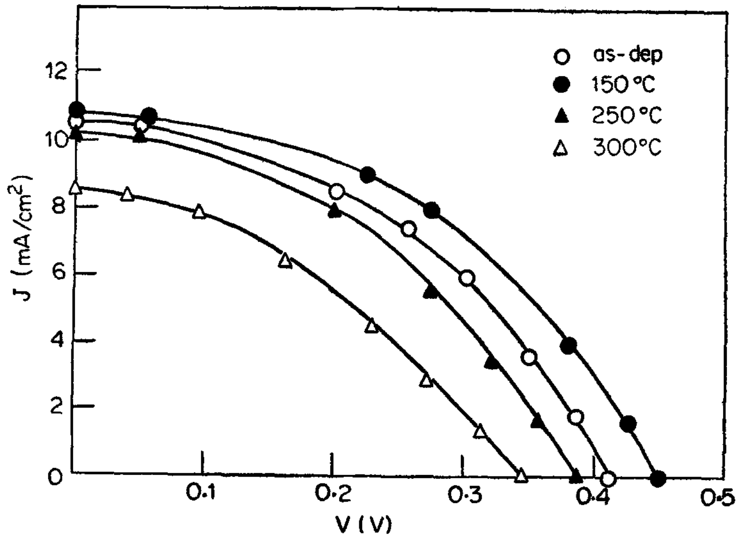

Figure 2. Evolution of lighted I-V characteristics as a function of heat treatment at different temperatures.

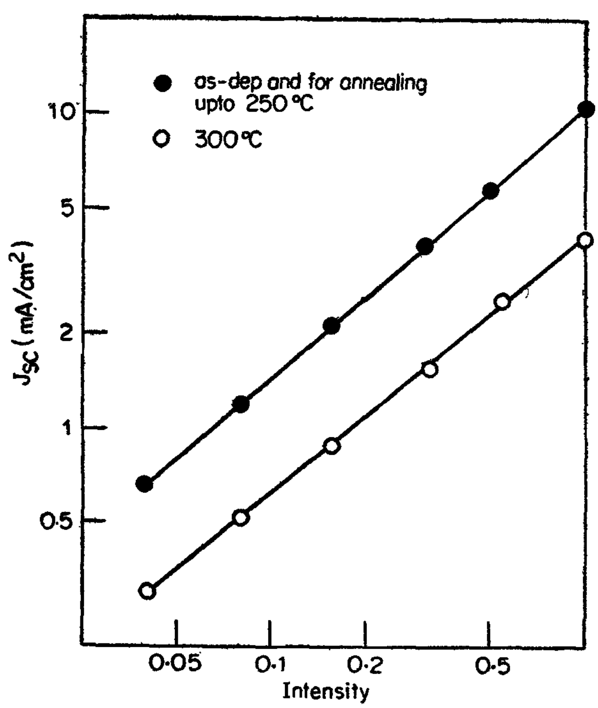

Figure 3. Dependence of short circuit current on intensity as a function of heat treatment. I=1 represents 100 mW/cm^2 of AM1 light.

at 150°C. The values of short circuit current (J_{sc}), open circuit voltage (V_{oc}) and fill factor (FF) are 10·8 mA/cm^2, 450 mV and 0·45 respectively. The effect of heat treatment on V_{oc} can be easily understood by following the effect on J_0 as shown in figure 1. A decrease in J_0 for annealing at 150°C results in an increase in V_{oc}. At higher temperature since J_0 increases, V_{oc} decreases. The decrease in short circuit current after heat treatment at 300°C is due to the increase in series resistance.

The intensity dependence of J_{sc} is shown in figure 3. J_{sc} exhibits a dependence on intensity of the form $J = AI^{\nu}$ with $\nu = 0{\cdot}9$. The magnitude of ν close to unity implies small density of recombination centres in the mobility gap (Wronski 1979). This again shows the good quality of our material.

In conclusion, we have been able to obtain near-ideal Schottky characteristic using a-Si:H prepared from a dilute mixture of silane and hydrogen. From measurements of both dark and photo-voltaic performance of the diodes we conclude that the states in the gap of the material are small. Although no optimisation in device structure is made the cells give 2·5% efficiency. Use of an M.I.S. configuration and also incorporation of an n^+ contact at the back (Carlson 1980) should improve the efficiency further. The effect of heat treatment on the Schottky barrier has been studied and the interface has been found to be stable up to 300°C.

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