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Ag / a-Si:H (n-type) / Cr SCHOTTKY DIODES PREPARED BY AN RF MAGNETRON SPUTTER TECHNIQUE

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ABSTRACT

In this study we examined the Schottky diode characteristics of Ag / a-Si:H / a-Si:H (n-type) / Cr devices. Thin films of amorphous silicon prepared by an RF magnetron sputter technique on chromium contacted glass substrates and transparent silver electrodes (area 7.85×10^{-3} cm^2) were applied under a vacuum of 10^{-5} Torr. The current-voltage-temperature characteristics were measured in the dark and under illumination. The barrier height of silver rectifier contact was determined using Bethe's isothermal termionic emission theory and Fowler photoelectrical theory $\varnothing_{Bn} = 1.36$ eV, 1.47 eV respectively.

INTRODUCTION

One of the main problem of amorphous silicon solar cells is that of fabricating a Schottky contact which has a large barrier height and maintains the same characteristic for a long time. Accuracy in the determination of the barrier height is also important since the current mechanism of the Schottky contact can differ from one to another. These differences mainly come from the doping profile of the amorphous silicon film and from the sort of metal used for the rectifier contact. Plotting the current-voltage-temperature characteristics, at reverse biases, is the most common method for the determination of barrier height. Among the well known theories are Bethe's isothermal thermionic emission theory (Schottky 1938) and Crowell and Sze's emission theory (Crowell and Sze 1966). Here we have only dealt with Bethe's theory and Fowler's photoelectrical theory (Fowler 1931).

Recently amorphous silicon Schottky diodes have been studied by Wronsky et all (Wronsky, Carlson and Daniel 1976), Jousse and Victrowitch (Jousse and Victrovitch 1979) and Ondris and Borst (Ondris and

Borst 1979); here amorphous silicon films were prepared by decomposition of silane, RF sputtering and glow discharge methods respectively. For the studies reported here we utilized silver metal to provide the rectifier contact on amorphous silicon and some physical parameters were found from the current-voltage-temperature characteristics. Also we determined the barrier height using Fowler's photoelectrical theory.

EXPERIMENT

The glass substrates, cleaned in trichlorethylene (C_2HCl_3), with dimension 18 mm x 18 mm x 0.1 mm were coated with chromium metal under a vacuum of 10^{-5} Torr. In order to fabricate a structure of Ag / a-Si:H / a-SiH (n-type) / Cr a highly n-type doped amorphous silicon film (thickness 30 nm) and a hydrogenated intrinsic amorphous silicon film (thickness 800 nm) were deposited on the chromium metal. During the deposition processes, the pressure of the gases, substrate temperature and RF magnetron power were as follows: $P_{PH3} = 2x10^{-4}$ Torr., $p_{H2} = 5.4x10^{-4}$ Torr., $p_{total} = 5.5x10^{-3}$ Torr., $T = 550°K$, $P_{RF} = 650$ Watt, providing optimum conditions for an ideal semiconductor diode characteristic. The samples were cut into small pieces of approximately 3 mmx3 mm were placed on the fibre holder by means of araldite. A transparent silver contact with area 7.85×10^{-3} cm^2 was applied to the amorphous film Figure 1.

For the experiment, Siemens' EOPE 234 vacuum equipment, a Keitheley 610C electrometer, a Hewlett Packard 3455A digital volt-

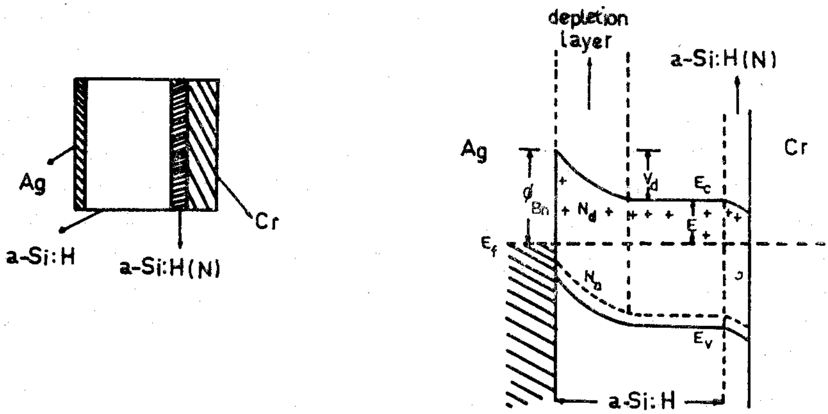

Figure 1. The structure of Ag / a-Si:H / a-Si:H (n-type) / Cr

meter, a Spex Minimate monochromator, a General Radio 1657 RLC Digibridge and the RF magnetron sputtering equipment at Kaiserslautern University, were used.

First we ensured that the chromium metal made ohmic contact to the amorphous silicon film. The samples contained in a closed metal box in a glass tube were immersed in a thermostat bath in order to measure current-voltage characteristics. Measurements were made for the temperature range 1-51°C. For the photoelectrical measurements, photon energy was between 1.70 eV and 2.48 eV.

It was observed that the Ag / a-Si:H / a-Si:H (n-type) / Cr structure had quite good photo diode properties and a good rectification ratio which increased with increasing temperature. With silver positive and chromium negative, the so-called forward bias, it was seen that current increased exponentially with increasing voltage and at reverse biases showed typical saturation values Figure 2.

For the photoelectrical measurements, we first calibrated the intensity of the light in order to supply the same intensity at each wavelength A bolometer and rheostat were connected into the power circuit of the monochromator and the photocurrent per photon was computed.

THEORY

The Bethe's theory, which our device characteristics followed, uses the approximation that the barrier height is much greater than kT and given by

$$J = A^{*}T^{2}\exp\left(-e\varnothing_{Bn}/kT\right)\left[\exp\left(eV/kT\right) - 1\right] \tag{1}$$

where A*, T, $\varnothing_{Bn}$, e, k and V are the Richardson constant, absolute, temperature, barrier height, electronic charge, Boltzmann's constant and voltage respectively. When the lowering of the height of the barrier due to image-force effects is considered, the barrier height of the rectifier contact reduces by $\triangle\varnothing$ which is given by

$$\triangle\varnothing = \left(\frac{e^{3}N_{d}}{\varepsilon^{3}\varepsilon_{0}^{3}2^{3}\pi^{2}}\right)^{1/4}(V_{d} + V)^{1/4} \tag{2}$$

where N_d, ε, ε_0, and V_d are the donor density, dielectric permittivity, dielectric permittivity of free space, diffusion potential respectively. When we substitute the barrier height in equation (1) by $\varnothing_{Bn} - \triangle\varnothing$ then we obtain current density

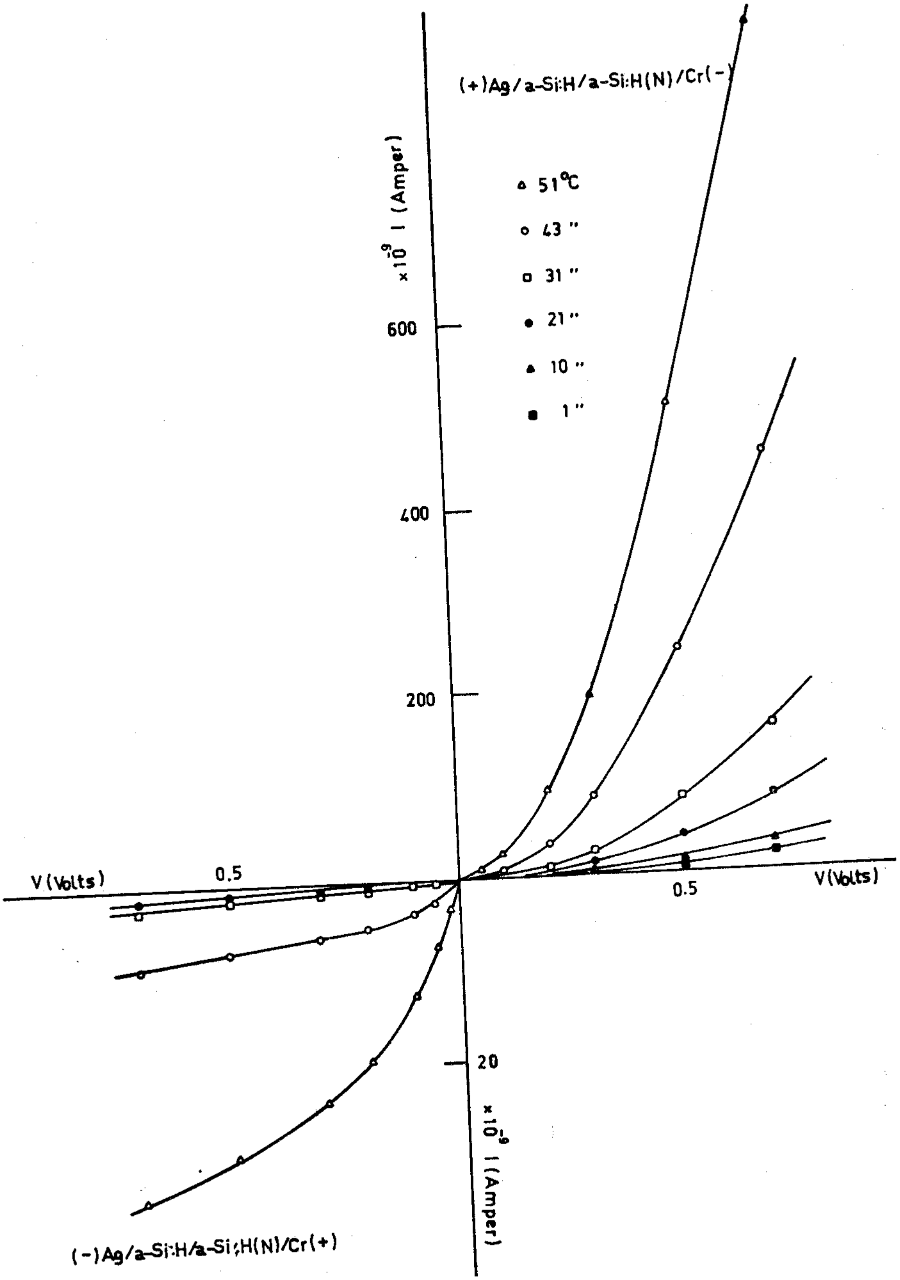

Figure 2. The current-voltage characteristics versus temperature

$$J = A^{*}T^{2}\exp(-e\varnothing_{Bn}/kT)\exp\left(\frac{e^{7}N_{d}}{k^{4}T^{4}\varepsilon^{3}\varepsilon_{0}^{3}2^{3}\pi^{2}}\right)^{1/4}(V_{d}+V)^{1/4}\left[\exp(eV/kT)-1\right] \quad (3)$$

At reverse biases which are sufficiently greater than kT, the term exp (eV / kT) is neglected. If we take the logarithm of both sides we find

$$LnJ = \left(\frac{e^{7}N_{d}}{k^{4}T^{4}\varepsilon^{3}\varepsilon_{0}^{3}2^{3}\pi^{2}}\right)(V_{d}+V)^{1/4} + Ln\left[A^{*}T^{2}\exp(-e\varnothing_{Bn}/kT\right] \quad (4)$$

The second term on the right-hand side is the intercept on the LnJ axis of the LnJ — $(V_d + V)^{1/4}$ plot. When we define the intercept as J_0 then

$$J_0 = A^{*}T^{2}\exp(-e\varnothing_{Bn}/kT) \quad (5)$$

If we divide by T^2 and take the logarithm of both sides we find

$$Ln\left(\left(\frac{J_0}{T^2}\right) = -\frac{e\varnothing_{Bn}}{k}\frac{1}{T} + Ln(A^{*}) \quad (6)$$

A reliable method for the determination of barrier height is by photoelectrical measurement. According to Fowler's photoelectrical theory the front illumination of a semi-transparent rectifier contact creates excited electrons in the metal. If the photon energy hv is greater than the forbidden band gap of the semiconductor, free electron-hole pairs are generated and photocurrent is created. For $x \geq o$, the photo-current per absorbed photon, I, as a function of photon energy hv is given by

$$I = \frac{T^{2}}{(E_{s}-hv)^{1/2}}\left[\frac{X^{2}}{2} + \frac{\pi^{2}}{6} - \left(e^{-X} - \frac{e^{-2x}}{4} + \frac{e^{-3X}}{9}\ \ldots\ldots\right)\right] \quad (7)$$

where $X = h(v-v_0)/kT$, $hv_0 = q\varnothing_{Bn}$ = barrier height, and $E_s = hv_0$ + fermi energy measured from the bottom of the metal conduction band.

Under the approximation of $E_s \gg hv$ and $h(v-v_0)/kT > 3$, equation (7) is reduced to

$$I = (hv - hv_0)^2 \quad (8)$$

When square roots of both sides of equation (8) are taken

$$\sqrt{I} = (hv - hv_0) \quad (9)$$

is obtained.

RESULTS AND DISCUSSION

The dependence of the current on the polarity of the voltage shows that rectification occurs in the Ag / a-Si: H / a-Si:H(n-type) / Cr structure. As it is expected from metal / semiconductor contact theory. At the reverse biases for which silver is positive the current increases exponentially, but it tends to saturation when silver is negative.

In the devices the thickness of amorphous silicon was 800 nm and the thickness of n-type amorphous silicon film, so the thickness was 830 nm.

It was seen that the rectification ratio increased with temperature because of the T^2 dependence of J_0. The rectification ratio also changed with voltage; this can be related to the Schottky lowering of the barrier heights due to the image-force effect. It was also observed that the structure Ag / a-Si:H / a-Si:H (n-type) / Cr has capacitance-voltage dependence and photocurrent sensivity.

When Schottky lowering was taken into consideration in Bethe's theory and the value of $V_d = 0.150$ eV was used, plotting current versus $(V_d + V)^{1/4}$ gave straight lines at different temperature, following equation (4) Figure 3. When J_0 / T^2 was plotted versus $1 / T$, the barrier height was obtained as $\varnothing_{Bn} = 1.36$ eV Figure 4.

When we calculated photocurrent values per photon and plotted them versus photon energy hv, we also obtained a straight line, following Fowler's theory. The barrier height $\varnothing_{Bn}$, from the intercept with the hv axis, was found to be 1.470 eV Figure 5.

When we compare our results with those of Ondris and Borst (1.1 eV for gold contanct) and those of Wronsky et al. (1.1 eV for platinum contact), the values determined from photoelectrical theory (1.47 eV) and from the Schottky lowering (1.36 eV) are quite close to each other. There were some differences from the results of Jousse and Victrovitch (for gold contact $\varnothing_{Bn} = 0.850$ eV). We think that these discrapancies was used in our experiments. Also the different methods in the film preparation such as glow-discharge decomposition of silane, and a different current-voltage theory such as

$$J = q\mu N_c E_s \exp(-\varnothing_{Bn} / kT) \, [\exp(qV / kT) - 1] \qquad (10)$$

are factors which influence the results.

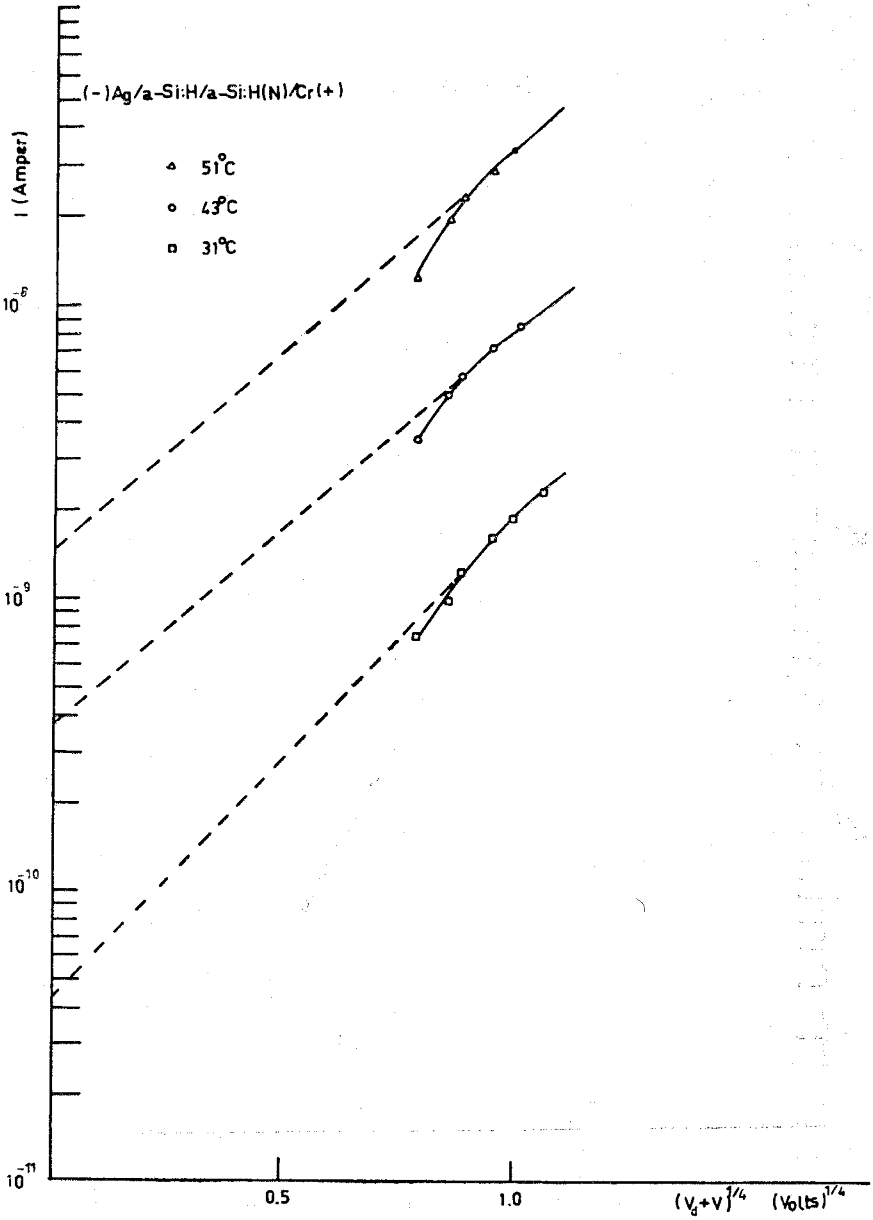

Figure 3. At Schottky lowering LnI versus $(V_d + V)^{1/4}$

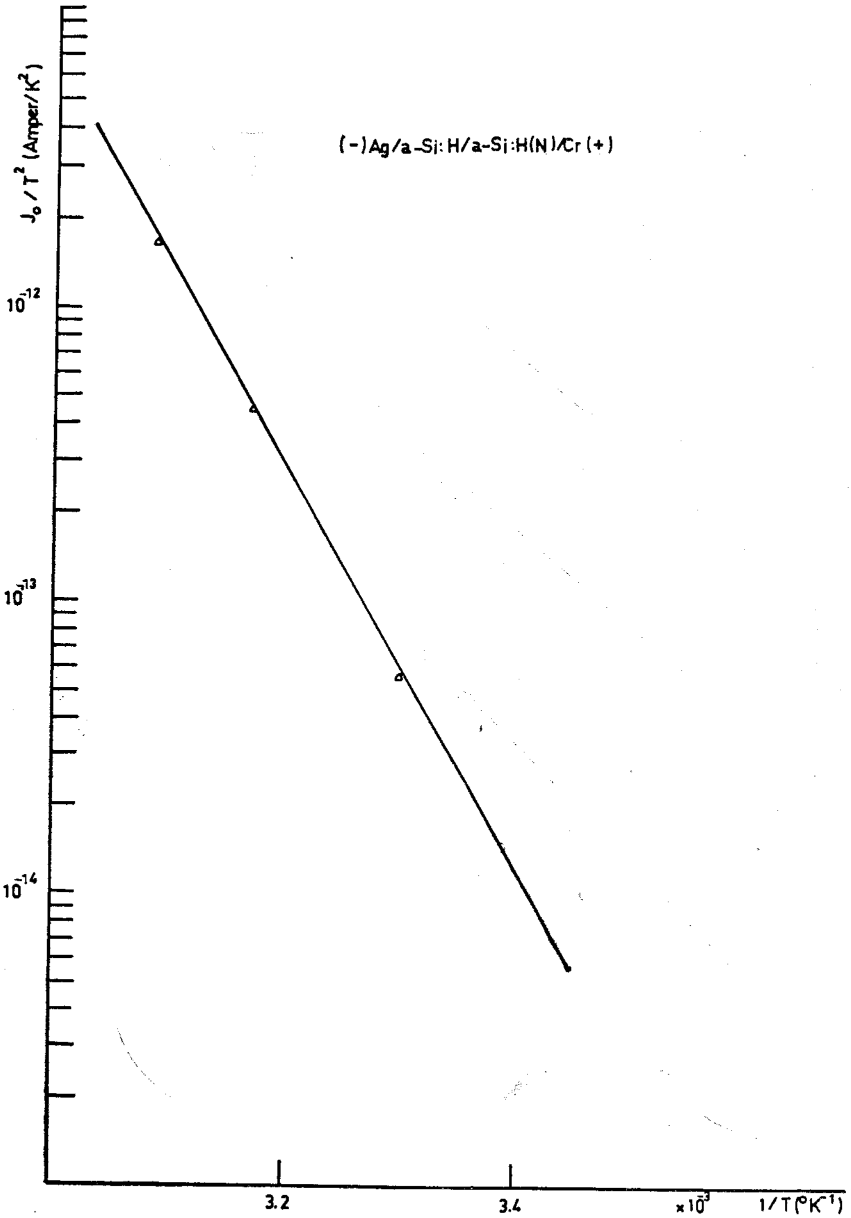

Figure 4. At Schottky lowering Ln (J_o / T^2) versus 1 / T

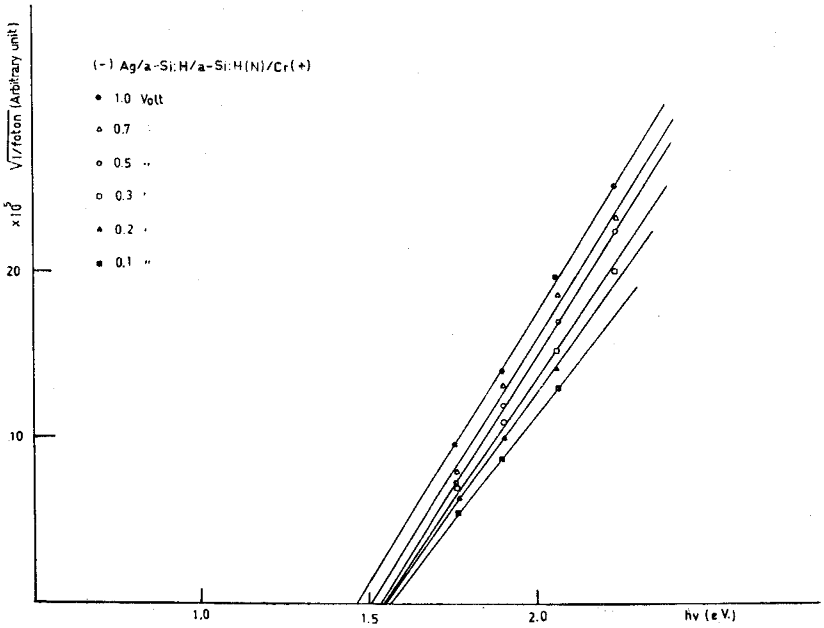

Figure 5. The square roots of photocurrent per photon versus photon energy hv.

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