AMORPHOUS HYDROGENATED SILICON FILMS STUDIED BY SCHOTTKY BARRIER METHOD

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The problem of the effective ohmic junction and the question of the barrier height for thin film structures of Al/a-Si:H/n^+c-Si/Al and Al/a-Si:H/n^+c-Si/Mo are studied. Current–voltage and temperature characteristics were measured and possible mechanisms of conductivity were extracted and discussed.

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For several years authors have been making series of technological experiments with a-Si:H films on glass substrate by d.c. magnetron sputtering. The main intention of the research is to obtain large area solar cells and a matrix of thin film transistors for liquid crystal displays [1–3].

This study is a part of series of experiments in which the problem of the effective ohmic junction and the question of the barrier height in the thin film structures are investigated. Various types of sandwich structures were prepared, as shown in the Table. D.c. magnetron sputtering was used to obtain the structures and all the films. D.c. planar magnetron system was specially made to optimize the preparation conditions of the a-Si:H films as well as hydrogen partial pressure p_{H_2}, argon partial pressure p_{Ar}, substrate temperature T_s, input power P and substrate bias V_s. The a-Si:H films were obtained in the conditions earlier reported in [1, 2].

Schottky diodes were fabricated in a sandwich structure. Molybdenum or aluminum sputtered onto glass substrate, served as the back contact. An ohmic contact characterized by effective electron injection to a-Si:H, was only obtained if additional film of 0.3 μm polycrystalline silicon was sputtered in an 99% of argon and 1% of phosphin atmosphere. Then, the a-Si:H film and top Schottky electrode were deposited on the substrate. Active area of the junction was 0.005 cm^2.

Diode rectification ratios about 10^4 are observed at room temperature, as shown in Fig. 1. This ratio is ultimately limited by the series resistance of the quasi-neutral region which affects the forward current. The undoped hydrogenated silicon is highly resistive with $\varrho \approx 10^9$ Ωcm. The rectification ratio about 10^4 was
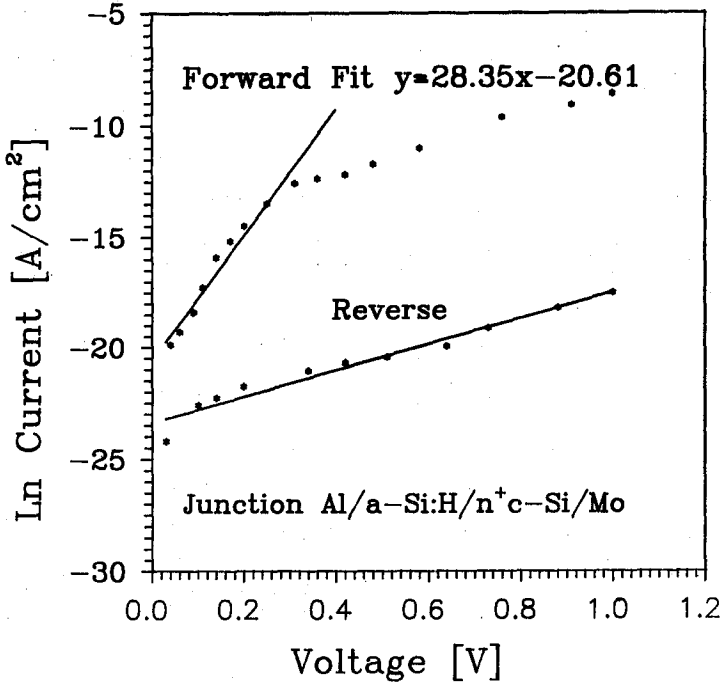
Fig. 1.   Current–voltage characteristic of Al/a-Si:H/Mo Schottky-barrier diode at room temperature.

obtained only for sandwiches depicted as 4, as shown in the Table and in Fig. 1. The current–voltage data are examined by considering the device current as a function of both the voltage across the depletion–layer region V_j and the voltage across the quasi-neutral region, or bulk, V_B. For the former

$$I = I_0 \exp(eV_j/nkT) \times [1 - \exp(-qV_j/kT)]$$

or for $V_j > 3kT/q$

$$I = I_0 \exp(eV_j/nkT)$$

where n is the diode correction function, T – the temperature, k – the Boltzmann constant, and I_0 – the saturation current. The two voltages V_j and V_B were separated as follows. First, the values of I_0 and n were determined from the linear portion of a plot of $\log I$ versus applied voltage. Then for any current, the junction voltage is found

$$V_j = nkT/e \times \ln(I/I_0)$$

and next the bulk voltage is $V_B = V_{applied} - V_j$. The currents as functions of the junction voltage and the temperature are shown in Fig. 2.
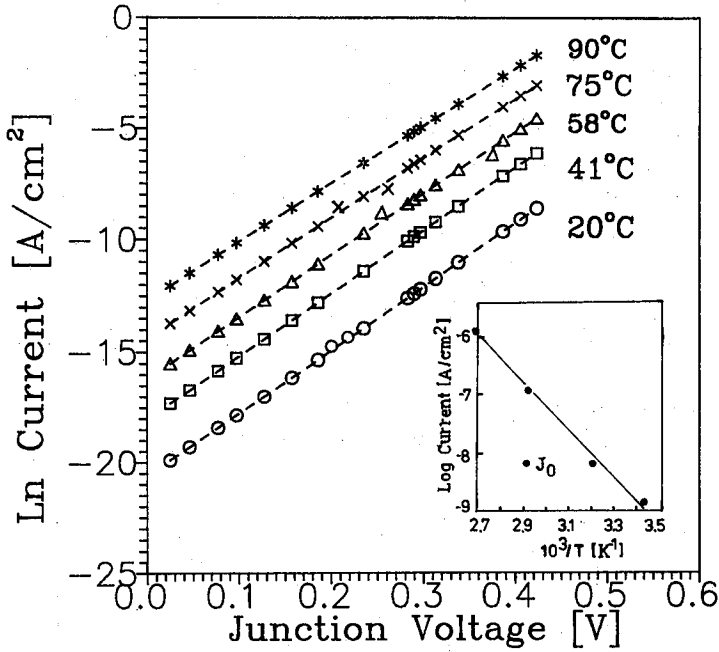
Fig. 2. Logarithm of forward current density as a function of junction voltage and temperature dependence of saturation current J_0.

Table
The structures of studied sandwiches and the results of measurements.

ohmic electrode	additional film	intrinsic material	top metal	barrier height	temper. activation energy of a-Si:H
Al $T_s=200°$C $d = 3000$ Å	—	a-Si:H $T_s=250°$C $d = 5000$ Å	Al $T_s=150°$C $d = 3000$ Å	≈ 0.67 eV	-
Al $T_s=200°$C $d = 3000$ Å	n^+ poly Si $T_s=400°$C $d = 3000$ Å	a-Si:H $T_s=250°$C $d = 5000$ Å	Al $T_s=150°$C $d = 3000$ Å	≈ 0.7 eV	≈ 0.6 eV
Al $T_s=200°$C $d = 3000$ Å	n^+ poly Si $T_s=400°$C $d = 3000$ Å	a-Si:H $T_s=250°$C $d = 5000$ Å	Al $T_s=20°$C $d = 3000$ Å	≈ 0.74 eV	≈ 0.62 eV
Mo $T_s=200°$C $d = 3000$ Å	n^+ poly Si $T_s=400°$C $d = 3000$ Å	a-Si:H $T_s=250°$C $d = 5000$ Å	Al $T_s=20°$C $d = 3000$ Å	≈ 0.79 eV	≈ 0.63 eV

Our observations of a series resistance effect are consistent with the discussion by Wronski et al. [4].

At room temperature the diode quality factor n is 1.2 and I_0 is 1.1×10^{-9} A/cm^2.

The diffusion theory of the Schottky barrier is preferred, in our case, to the thermionic theory because of the very short mean free path of current carriers in amorphous materials. According to the diffusion theory, the quantity I_0 is given by

$$I_0 = e\mu N_c E_s \exp(-e\phi_B/kT),$$

where μ is the electron mobility, E_s is the surface electric field, N_c is the effective density of extended band states and ϕ_B is the metal–semiconductor barrier height [4–6].

Using this method, we computed the values of the barrier height ϕ_B as shown in Fig. 2 and in the Table, for various types of sandwiches.
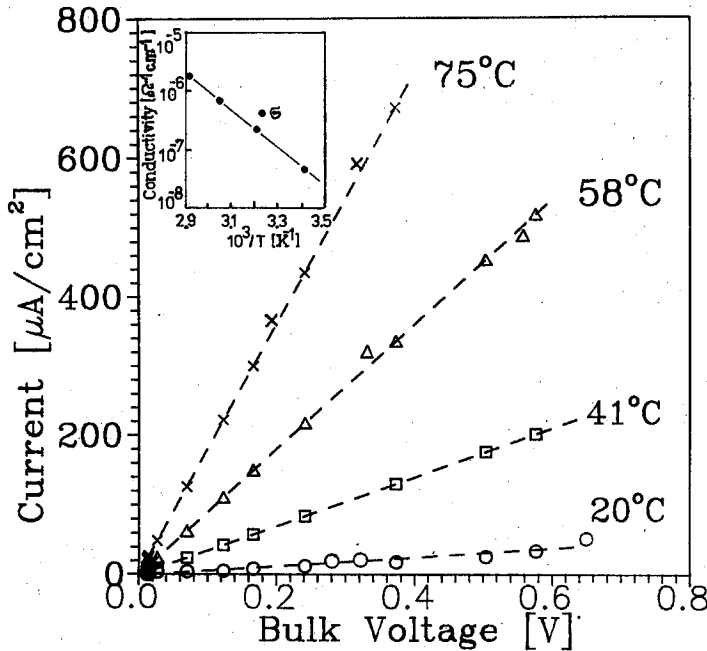

Fig. 3. Forward current density as a function of bulk voltage and temperature dependence of the bulk conductivity σ.

Figure 3 shows that the relationship between current and bulk voltage is ohmic. Slight nonlinearity for voltages greater than 0.5 V suggestive of space--charged limited current is observed.

From initial part of the fits shown in Fig. 3, one may obtain the conductivity
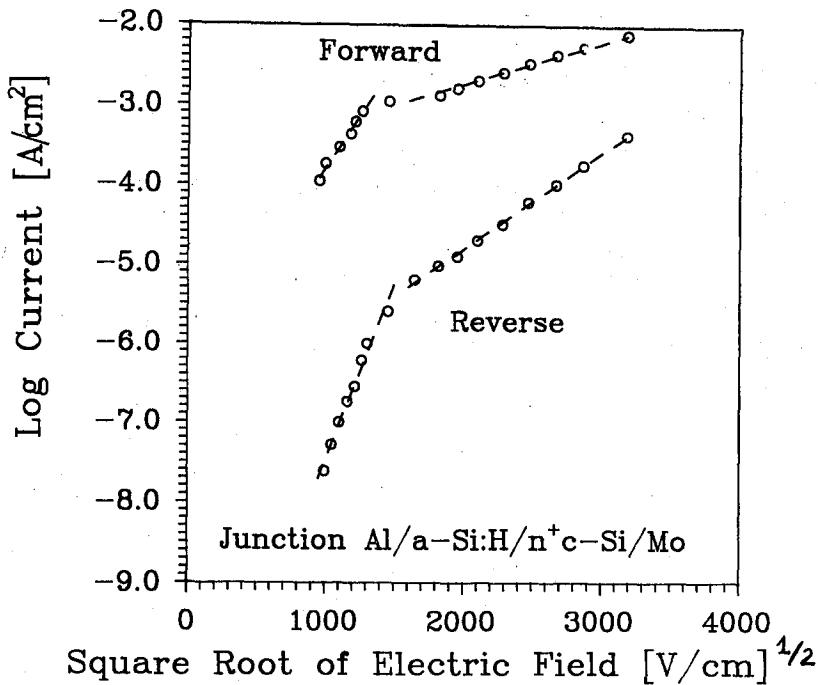
Fig. 4. Forward and reverse current density as functions of the square root of electric field for voltages greater than 1 V.

versus temperature plot. The conductivity gives a simple temperature activation, characteristic of semiconductors

$$\sigma = \sigma_0 \exp(-E_a/kT).$$

The diode reverse current does not saturate at I_0, but increases smoothly with applied voltage. The data does not fit a simple power law and does not fit simple models of reverse bias behaviour.

Figure 4 shows logarithm of forward and reverse current density as functions of the square root of electric field for voltages greater than 1 V. Two levels of fit can be seen, indicating at least two mechanisms of conductivity where the logarithm of current depends on the square root of electric field. That feature is characteristic of both forward and reverse bias indicating that the conductivity mechanism is rather bulk limited. The kind of dependence suggests that the conductivity is limited by Poole–Frenkel mechanism. Amorphous silicon is considered as having a lot of localized states in the gap and in the band tails. Two slopes, as seen in Fig. 4, could be connected with field emission from band tail traps to the conduction band and with field assisted hopping between localized states within the band.

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