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 dis-
cussed.

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For several years authors have been making series of technological exper-
iments 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 cm².

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 $\varrho \approx 10^8 \Omega cm$. The rectification ratio about $10^4$ was

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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 $V_B = V_{\text{applied}} - V_j$. 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>
<thead>
<tr>
<th>ohmic electrode</th>
<th>additional film</th>
<th>intrinsic material</th>
<th>top metal</th>
<th>barrier height</th>
<th>temper. activation energy of a-Si:H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al $T_s=200^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$n^+$ poly Si $T_s=400^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>a-Si:H $T_s=250^\circ\text{C}$, $d=5000\ \text{Å}$</td>
<td>Al $T_s=150^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$\approx 0.67 \text{ eV}$</td>
<td>-</td>
</tr>
<tr>
<td>Al $T_s=200^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$n^+$ poly Si $T_s=400^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>a-Si:H $T_s=250^\circ\text{C}$, $d=5000\ \text{Å}$</td>
<td>Al $T_s=150^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$\approx 0.7 \text{ eV}$</td>
<td>$\approx 0.6 \text{ eV}$</td>
</tr>
<tr>
<td>Al $T_s=200^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$n^+$ poly Si $T_s=400^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>a-Si:H $T_s=250^\circ\text{C}$, $d=5000\ \text{Å}$</td>
<td>Al $T_s=20^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$\approx 0.74 \text{ eV}$</td>
<td>$\approx 0.62 \text{ eV}$</td>
</tr>
<tr>
<td>Mo $T_s=200^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$n^+$ poly Si $T_s=400^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>a-Si:H $T_s=250^\circ\text{C}$, $d=5000\ \text{Å}$</td>
<td>Al $T_s=20^\circ\text{C}$, $d=3000\ \text{Å}$</td>
<td>$\approx 0.79 \text{ eV}$</td>
<td>$\approx 0.63 \text{ eV}$</td>
</tr>
</tbody>
</table>
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 $1.1 \times 10^{-9}$ 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 $\mu$ is the electron mobility, $E_s$ is the surface electric field, $N_c$ is the effective density of extended band states and $\phi_B$ is the metal–semiconductor barrier height [4–6].

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

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

\[ \sigma = \sigma_0 \exp\left(-\frac{E_a}{kT}\right). \]

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.
References


