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Ohmic Contact Properties of Magnesium Evaporated onto Undoped and P-doped a-Si: H

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We have investigated the current-voltage characteristics of metal/undoped *a*-Si: H/n^+ (or p^+) *c*-Si structures using Mg, Au, Pt and Al. It has been indicated that the energy band of undoped a-Si: H shows a downward bending against Mg, being analogous to n^+ *a*-Si: H/undoped *a*-Si: H contact, while the band shows an upward bending against Au, Pt and Al. Mg/undoped *a*-Si: H contact is found to allow injection of electrons into the conduction band of *a*-Si: H, providing us a good ohmic contact property. This contact does not exhibit the thermal-degradation at least up to 100°C.

§1. Introduction

Ohmic contacts with undoped hydrogenated amorphous silicon (*a*-Si: H) are technologically important for fabricating electronic devices such as thin film transistors (TFT) and thin film solar cells. For instance, if aluminum (Al) is directly deposited onto the active layer of TFT as a metal electrode, the device properties are badly affected by the non-ohmic nature of the contact.[1,2] In many cases a thin n^+ *a*-Si: H layer is sandwiched between the metal electrode and the undoped *a*-Si: H to make ohmic contacts.[1,3] However, from the viewpoint of the fabrication process, the deposition of n^+ *a*-Si: H should be considered an undesired excess step, possibly causing a cross contamination effect between n^+ and undoped *a*-Si: H layer of the device.

In this paper we report a variety of electrical properties of metal/*a*-Si: H contacts for several different metals, and indicate that magnesium (Mg) forms a good ohmic contact with P-doped as well as undoped *a*-Si: H without an intermediate n^+ *a*-Si: H layer.

§2. Experimental

Undoped *a*-Si: H films, $\sim 1\,\mu$m in thickness, were deposited on n^+ or p^+ crystalline Si (*c*-Si) heated at 250°C by the glow discharge decomposition of pure SiH_4 (100%). A flow rate of 5 sccm and a gas pressure of 50 mTorr were maintained during the deposition. The optical gap E_0 determined from the empirical relation $\sqrt{\alpha h\nu} \propto (h\nu - E_0)$, the dark conductivity at 297 K and its activation energy were 1.67 eV, $5 \times 10^{-9}\ \Omega^{-1}\,\mathrm{cm}^{-1}$ and 0.72 eV, respectively. After depositing *a*-Si: H films, four different kinds of metals, Mg, Al, gold (Au) and platinum (Pt) were subsequently evaporated onto different positions of identical *a*-Si: H films. Various electrical measurements have been performed on those metal/undoped *a*-Si: H/n^+ (or p^+) *c*-Si (*M*/*ua*/n^+c or *M*/*ua*/p^+c) structures.

P-doped *a*-Si: H films were deposited on n^+ *c*-Si heated at 300°C from PH_3/SiH_4 mixture under the gaseous impurity ratios of 3×10^{-4} and 3×10^{-3}, where a total gas flow rate of 5 sccm and a gas pressure of 50 mTorr were kept constant. Similar measurements have also been done on metal/P-doped *a*-Si: H/n^+ *c*-Si (*M*/*na*/n^+c) specimens. Fundamental properties of P-doped *a*-Si: H itself were described earlier.[4]

§3. Results and Discussion

Figure 1 shows the current-voltage (*I-V*) characteristics of the *M*/*ua*/n^+c specimens for four different kinds of metals. The essential features of the characteristics of the Au, Pt and Al specimens are almost the same, while *I-V* characteristics of the Mg specimen are quite different from the others.

I-V characteristics of the Au, Pt and Al specimens might be mainly limited by Schottky barrier junctions formed by *M* (Au, Pt, Al)/*ua* contacts because the *ua*/n^+c contact

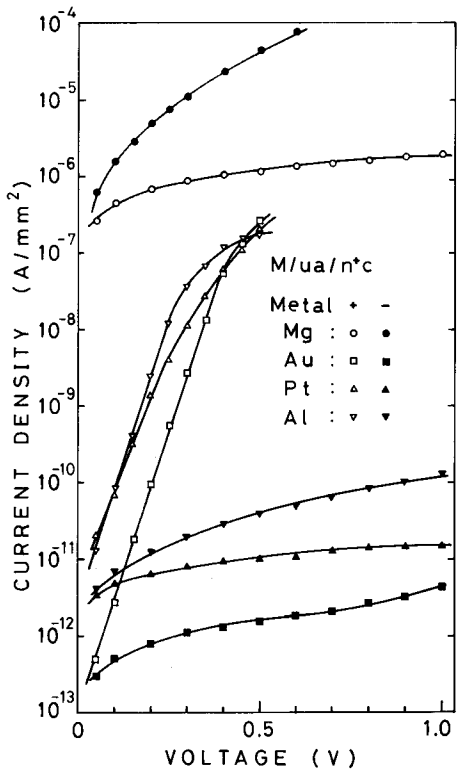

Fig. 1. *I-V* characteristics of metal/undoped *a*-Si: H/n^+ *c*-Si structures.

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is known to be ohmic.[4,5] Actually, considering the *I-V* characteristics shown in Fig. 1, it is quite reasonable to present an energy band diagram, as is sketched in Fig. 2(a), of undoped *a*-Si: H for Al, Pt and Au contacts in the three-layered structure specimens. A positive bias voltage on the metal electrodes induces forward currents flowing through the *M*(Au, Pt, Al)/*ua*/n^+c specimens.

In contrast to Al, Pt and Au, as is shown in Fig. 1, a negative bias to Mg produces the forward bias characteristics, resulting in an energy band diagram of Fig. 2(b) where *I-V* characteristics are affected by the Mg/undoped *a*-Si: H contact. It should be noted that the current levels of both forward and backward directions of the Mg contact are higher than those of the other metal contacts by several orders of magnitude, which means that Mg behaves as a good ohmic contact material for undoped *a*-Si: H.

Figure 3 shows the *I-V* characteristics of the *M*(Au, Pt, Al, Mg)/*ua*/p^+c specimens. It is considered that the currents of the *M*(Au, Pt, Al)/*ua*/p^+c specimens for a negative bias on the metal are limited by the reverse currents

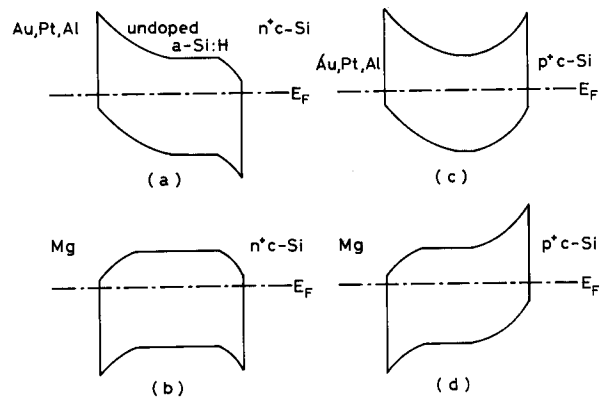

Fig. 2. Energy band diagrams of undoped *a*-Si: H.

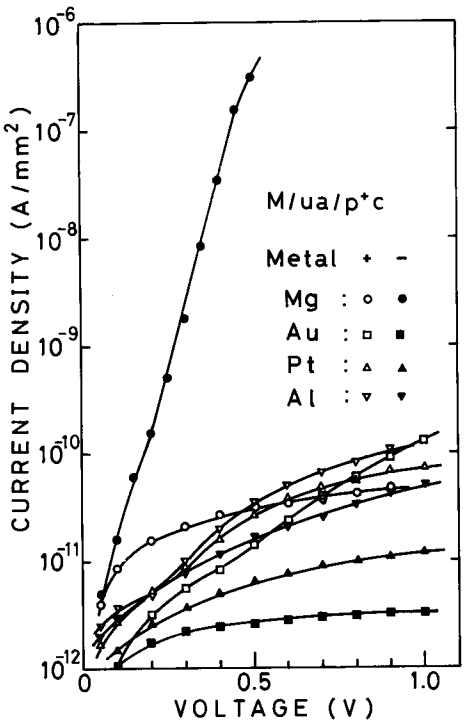

Fig. 3. *I-V* characteristics of metal/undoped *a*-Si: H/p^+ *c*-Si structures.

at the *M*/*ua* contacts, since the magnitudes are of the same order as those of the reverse currents of the corresponding *M*/*ua*/n^+c specimens shown in Fig. 1. On the other hand, the current flowing through each specimen, on applying a positive bias voltage to metal, is determined by the reverse current of the *ua*/p^+c contact, which is evident from the fact that each value coincides with every other independent of metal electrodes within a small statistical scatter. Consequently, *I-V* characteristics of the *M*(Au, Pt, Al)/*ua*/p^+c structures are considered to be those of blocking contacts with an energy band diagram shown in Fig. 2(c).

Only when a negative bias voltage is applied to an Mg electrode does the specimen show forward *I-V* characteristics probably originating from the property of the *ua*/p^+c contact, since the current level is considerably lower than that of the Mg/undoped *a*-Si: H contact under the forward bias shown in Fig. 1. An energy band diagram of Fig. 2(d) can thus be obtained for Mg/*ua*/p^+c structure.

From the above experimental results, it is clear that Mg/undoped *a*-Si: H makes good ohmic contact.

These experimental results should be discussed in terms of the difference in work functions between metal (ϕ_m) and undoped *a*-Si: H (ϕ_s). According to the conventional metal-semiconductor junction theory, the relation

$$\phi_m \leq \phi_s, \tag{1}$$

should be satisfied for making ohmic contacts when majority carriers are electron, if interface states are assumed to be absent.[6]

Work function of each metal used in the present study has been determined as 3.46, 4.20, 4.70, and 5.48 eV for Mg, Al, Au, and Pt, respectively.[7] On the other hand, the electron affinity of the undoped *a*-Si: H (χ_s) can be tentatively estimated from the photo-emission data of Yamamoto *et al.* on SiO_2/*a*-Si: H structure,[8] because the electron affinity of SiO_2, $\chi(SiO_2)$, is independently given as 0.90 eV in ref. 9. Then χ_s is calculated as

$$\chi_s = \phi + \chi(SiO_2) = 3.93 \text{ eV}, \tag{2}$$

where ϕ represents the barrier height at SiO_2/*a*-Si: H and has been estimated to be 3.03 eV by Yamamoto *et al.*[8] Since 0.72 eV is the activation energy (ΔE) of the dark conductivity of the present undoped *a*-Si: H as mentioned above, ϕ_s becomes 4.65 eV because $\phi_s = \chi_s + \Delta E$.

From the above discussion both Mg and Al satisfy the condition represented by eq. (1), while the present study indicates that only Mg forms ohmic contact with undoped *a*-Si: H. The observed non-ohmic property of Al/undoped *a*-Si: H contact might be caused by the presence of interface states, as Wronski *et al.* pointed out initially.[2] Namely, ϕ_m of Al is not low enough to make the *M*/*ua* contact ohmic.

We have also investigated *M*(Mg, Al)/*na* contacts for different doping levels of P. The results are shown in Fig. 4. As is clearly indicated, Mg forms better ohmic contacts than Al regardless of doping levels of *P* in *n a*-Si: H. It is likely that Mg is a desirable ohmic-contact material, superior to Al, even for n^+ *a*-Si: H which is usually in-

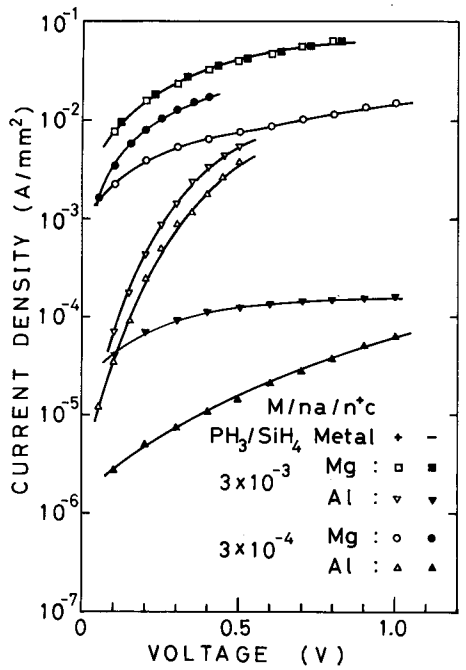

Fig. 4. *I-V* characteristics of metal/P-doped *a*-Si: H/n^+ *c*-Si structures.

troduced into *a*-Si: H devices as an intermediate layer for getting ohmic contacts.

In order to check the stability of the Mg/*a*-Si: H contact, we performed a thermal annealing experiment at 374 K for 6 hours. *I-V* characteristics of the specimen showed no change before and after the thermal annealing.

In summary, a good ohmic contact was obtained with undoped as well as P-doped *a*-Si: H films using Mg. The experimental results have clearly indicated that the Mg/*a*-Si: H contact exhibits high injection of electrons into the conduction band of *a*-Si: H. This contact is considered to be useful for making devices such as TFT and thin film solar cells from the viewpoint of the ease of fabrication. Scientifically also, the Mg/*a*-Si: H ohmic contact enables us to study *a*-Si: H/*p*-type crystalline semiconductor heterojunctions free from any uncertainties accompanying the non-ohmic problem between metal and *a*-Si: H.

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