

## Electrical Characteristics and Reliability of Pt/Ti/Pt/Au Ohmic Contacts to p-Type GaAs

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The ohmic contacts to p-type GaAs formed by GaAs/Pt/Ti/Pt/Au systems were investigated. The specific contact resistance below  $8 \times 10^{-7} \Omega \cdot \text{cm}^2$  was achieved when the interface Pt between GaAs and Ti/Pt/Au was thicker than 50 Å, which is about one-fourth of the conventional Ti/Pt/Au contact. The activation energies of the initial degradation of the Pt/Ti/Pt/Au electrodes correspond to the reaction of GaAs and Pt to form PtAs<sub>2</sub>. However, even after the initial degradation, Pt/Ti/Pt/Au with the thin Pt interface layer still shows lower contact resistivity. These systems are promising for practical p-type ohmic contacts for AlGaAs/GaAs heterojunction bipolar transistors.

**KEYWORDS:** ohmic contact, GaAs, heterojunction bipolar transistor, Pt, reliability

The AlGaAs/GaAs heterojunction bipolar transistor (HBT) has emerged as a potential candidate for high-speed devices, in the search for further applications of digital ICs,<sup>1),\*</sup> analog devices<sup>2)</sup> and microwave ICs.<sup>3)</sup> To realize the high-performance HBT, it is necessary to fabricate a thin base structure with a small-area base electrode of fine characteristics.

In the search for the base electrode in Npn HBTs, the ohmic contacts to p-type GaAs are receiving much attention. Various kinds of materials were studied, such as Ti/Pt/Au,<sup>4)</sup> Cr/Au<sup>4)</sup> for nonalloy systems, and AuZn,<sup>5)</sup> AuMn,<sup>6)</sup> AuBe<sup>7)</sup> and Zn/Pd/Au<sup>8)</sup> for alloy systems. Utilizing the large work function of the Pt, new ohmic contacts such as Pt/W/Ag,<sup>9)</sup> Pt/Zn/Au\*\* and Pt/Ti/Au<sup>10)</sup> were investigated. There are two advantages to the Pt-based ohmic systems. First, low ohmic contact resistivities were obtained without a highly doped p-layer because of the low barrier height of Pt. Second, the heat-stable compounds for GaAs and Pt give highly reliable ohmic contacts.

Especially for HBT application, the small diffusion of the ohmic constituent into the GaAs is required for the thin base formation. In this letter, the new ohmic system of Pt/Ti/Pt/Au, which fulfills this requirement, with low sheet resistance, low contact resistance and high reliability is investigated.

A 1.0 μm-thick Zn-doped ( $2.5 \times 10^{19} \text{ cm}^{-3}$ ) GaAs grown by organometallic vapor phase epitaxy (OMVPE) was used as a substrate. After etching the surface slightly, the Pt/Ti/Pt/Au ohmic metal was formed using a spacer lift-off technique. The metal was alloyed at 400°C for 60 s in N<sub>2</sub> ambient using a hot-plate-type chamber.

The contact resistance was measured by a transmission line model (TLM) method<sup>11,12)</sup> with 5 μm-wide electrodes at spacings of 5, 10, 20, 40 and 80 μm.

Figure 1 shows the interface-platinum thickness

dependence of contact resistivity. The contact resistance was reduced to below  $8 \times 10^{-7} \Omega \cdot \text{cm}^2$  when the interface-platinum was thicker than 50 Å and also reduced to about  $6 \times 10^{-7} \Omega \cdot \text{cm}^2$  when the interface platinum was thicker than 100 Å. This value is about one-fourth that of the Ti/Pt/Au ohmic.

The typical thermal degradation of contact resistance at 400°C is shown in Fig. 2. Three degradation modes, that is, the initial gradual degradation mode (mode 1), the small degradation mode (mode 2), and the rapid degradation mode (mode 3), were defined in this figure.

The depth profile of Pt(100 Å)/Ti(400 Å)/Pt(100 Å)/Au(1000 Å) systems of the as-alloyed, mode 1, and mode 3 samples were analyzed using Auger electron spectroscopy. Figures 3(a), 3(b), and 3(c) show the atomic profiles of as-alloyed (Fig. 3(a)), mode 1 (Fig. 3(b)) and mode 3 conditions (Fig. 3(c)), respectively. As shown in

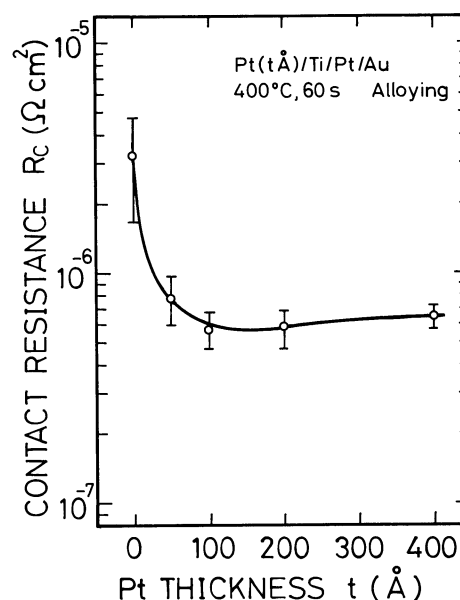


Fig. 1. Interface-platinum thickness dependence of contact resistivity. Interface Pt(0~400 Å)/Ti(400 Å)/Pt(400 Å)/Au(1000 Å) was alloyed at a temperature of 400°C and a time of 60 s.

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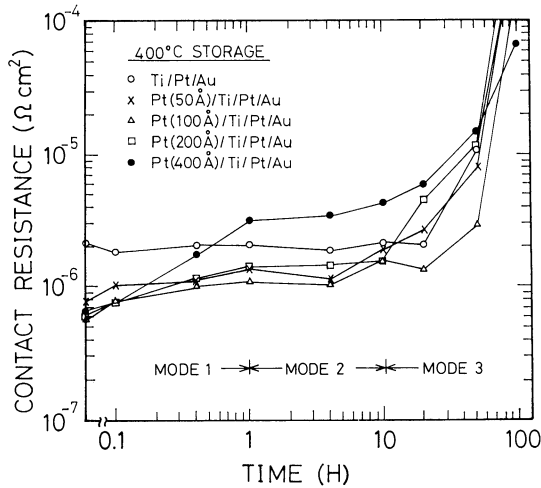


Fig. 2. Thermal degradation of the contact resistance as a function of storage time at 400°C.

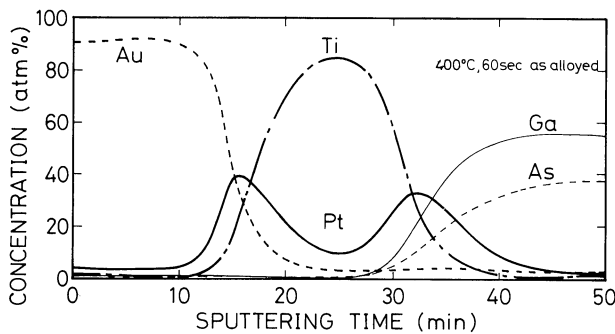


Fig. 3(a). Auger electron spectroscopy profile after alloying for Pt(100 Å)/Ti(400 Å)/Pt(100 Å)/Au(1000 Å) structure.

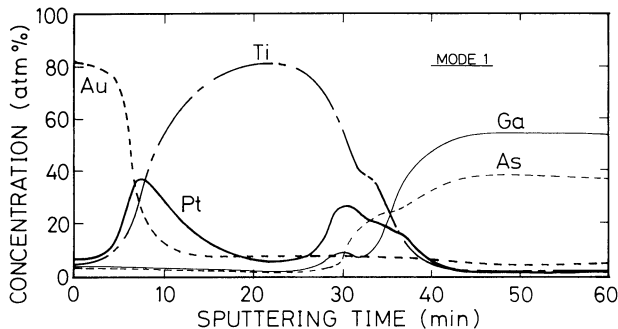


Fig. 3(b). Auger electron spectroscopy profile at mode 1 for Pt(100 Å)/Ti(400 Å)/Pt(100 Å)/Au(1000 Å) structure.

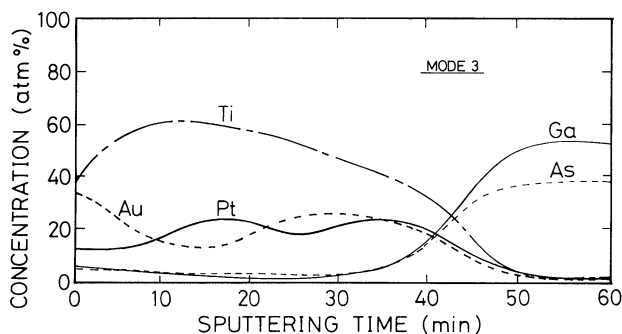


Fig. 3(c). Auger electron spectroscopy profile at mode 2 for Pt(100 Å)/Ti(400 Å)/Pt(100 Å)/Au(1000 Å) structure.

Fig. 3(a), a clear Pt/Ti/Pt/Au profile was observed with a slight interdiffusion of Pt and As. This fact suggests that the low contact resistivity of this material system depends on the low hole barrier height of Pt to GaAs even after the alloying. However, after aging at 400°C for 1 H, which is defined as mode 1, the interdiffusion of As and Pt and the pileup of Ga at the Pt/Ti interface can be seen (Fig. 3(b)). For the mode 3 degradation, the large diffusion was observed for all of the constituents, which resulted in extremely high contact resistivity, as shown in Fig. 2.

This reaction of Pt with GaAs had already been studied<sup>13)</sup> by X-ray diffraction,<sup>14)</sup> Auger electron spectroscopy,<sup>15)</sup> Rutherford backscattering<sup>14,16)</sup> and the electrical characteristics of the Schottky barrier junction.<sup>16-18)</sup> It is reported that the PtAs<sub>2</sub> compound was formed after alloying at around 400°C. In mode 1, the depth profile of the upper Ti/Pt/Au in Fig. 3(b) remains the same as in Fig. 3(a). This indicates that the mechanism of mode 1 degradation is presumably the formation of the PtAs<sub>2</sub> compound at the metal-semiconductor interface.

To evaluate the activation energies of modes 1 and 3 degradations, high-temperature storage testing was performed at various temperatures from 400°C to 480°C. The mean times to failure (MTTF),  $\mu_{20}$  and  $\mu_{400}$ , which are defined as the storage times of 20% and 400% increase on the contact resistance, were used for the evaluation. Here,  $\mu_{20}$  and  $\mu_{400}$  correspond to degradation modes 1 and 3, respectively. The Arrhenius plot of  $\mu_{20}$  and  $\mu_{400}$  for various thicknesses of Pt are shown in Fig. 4. The activation energies of the metals with interface platinum were from 1.1 to 1.5 eV. These activation energies are presumed to be due to the interaction of GaAs and Pt, that is, the formation of PtAs<sub>2</sub>, which corresponds to mode 1. Despite the hole barrier height of the Pt to GaAs,<sup>18)</sup> the contact resistance was increased because of the high resistivity of the compounds, presumably the PtAs<sub>2</sub>. The activation energy of 2.6 eV was observed for all of the Pt/Ti/Pt/Au and Ti/Pt/Au systems and was supposed to be the activation energy of interdiffusion between Ti/Pt and Pt/Au. This activation energy corresponds to mode 3 degradation. In mode 3 degradation, Au was diffused to the GaAs/metal interface and reacted with Ga. In thus appears that the contact resistance was raised by the Ga vacancy.

The long-term thermal stability of Pt/Ti/Pt/Au systems was also investigated. Table I shows the mean time to failure (MTTF)  $\mu_{50}$  of the Pt/Ti/Pt/Au metals at 150°C, which is extrapolated from the high-temperature storage. Considering practical use of the ohmic contacts, the MTTF was defined here as the storage time of 50% increase on the contact resistance. The large MTTF was observed for the thin interface Pt of under-100 Å metals. For example, Pt(100 Å)/Ti/Pt/Au systems still show lower contact resistivity compared with the as-formed Ti/Pt/Au system, even after  $5.2 \times 10^{11}$  hours storage at 150°C.

In conclusion, we have investigated the new ohmic contacts of Pt/Ti/Pt/Au for p<sup>+</sup> GaAs. The contact resistance of  $6 \times 10^7 \Omega \cdot \text{cm}^2$  was obtained with the 100 Å-thick interface Pt, which was about one fourth of the con-

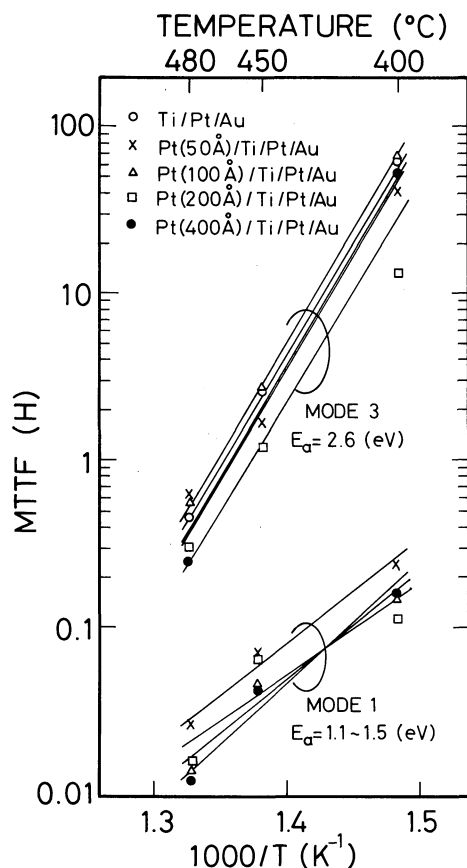


Fig. 4. Temperature dependence of the mean time to failure (MTTF)  $\mu_{20}$  and  $\mu_{400}$ . MTTF is defined as a time of 20% and 400% increase in contact resistance.

Table I. Extrapolated MTTF for various interface-platinum thickness at 150°C.

Interface-Platinum Thicknesses (Å)	$\mu_{50}$ (150°C) (hour)
0	$3.0 \times 10^{12}$
50	$1.2 \times 10^{12}$
100	$5.2 \times 10^{11}$
200	$3.0 \times 10^4$
400	$4.2 \times 10^4$

ventional Ti/Pt/Au contact.

The degradation of the Pt/Ti/Pt/Au electrodes were investigated by Auger electron spectroscopy analysis and MTTF measurements. The activation energies from 1.1 to 1.4 eV were observed for the initial degradation which corresponds to the reaction of GaAs and Pt to form PtAs<sub>2</sub>. The activation energy of 2.6 eV was observed for destructive degradation of the metals, in which the constituents of the metals and GaAs are largely diffused. Even after the initial degradation, Pt/Ti/Pt/Au with the thin Pt interface layer shows low contact resistivities, and these ohmic contacts are thought to be promising materials for base electrodes in AlGaAs/GaAs HBT.

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