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TRANSPORT BEHAVIOUR IN LOW-RESISTANCE METAL/p-GaAs INTERFACES*

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The relationship between electrical properties and microstructure of pure Zn and AuZn contacts to p-GaAs has been studied. The obtained results prove that mechanism responsible for the ohmic behaviour of these contacts is associated with the lowering of the potential barrier at metal/semiconductor interface, resulting from the phase transformations in the metallization.

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We have recently reported on low-resistance ohmic contacts to GaAs with improved microstructure. It was shown that the interface of AuZn/p-GaAs contact may remain virtually intact after thermal processing necessary to form an ohmic contact [1]. Another important finding was ohmic behaviour of pure, unreacted Zn contacts to p-type GaAs [2]. High crystalline quality and uniformity of these metal/semiconductor (MS) interfaces makes it possible to analyze the mechanism of the formation of low-resistance contacts.

In the present paper emphasis is placed on electronic properties of these contacts. The Schottky barrier heights (SBH) at different stages of the formation of pure Zn and AuZn ohmic contacts were determined from I–V characteristics under forward bias for rectifying contacts, and from specific contact resistance measurements as a function of temperature [3] between 80 and 420 K in the case of ohmic contacts.

A variety of p-type GaAs (100) substrates, ranging in doping from 5×10^{16} to 8×10^{18} cm^{-3}, were used in these studies. To follow the thermally activated changes in SBH, contacts were formed on lightly doped GaAs so that the thermionic emission controls the transfer of carriers over the barrier. Substrates with higher doping concentrations were used to verify the importance of SBH modifications for the formation of low-resistance metal/p-GaAs contacts. Zn and Au were deposited by

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thermal evaporation in oil-free vacuum, on unheated substrates. The AuZn metallization with Zn concentration from 10 to 35 at.% was formed by sequential deposition of Au/Zn/Au structure. The composition of AuZn films was determined from the thickness of the elemental Au and Zn layers. X-ray diffraction was employed to identify phase transformations in the metallization. Contacts were encapsulated with SiO_2 cap to form a closed system during subsequent annealing at temperatures up to 500°C.

The heights of potential barriers, as inferred from electrical measurements, for pure Zn, and AuZn metallizations at different stages of the formation of low-resistance contacts are listed in Table. For comparison, pure Au contacts were also characterized.

TABLE

Schottky barrier heights for Zn, AuZn and Au contacts to p-GaAs ($N_A = 5 \times 10^{16}$ cm^{-3}).

Metallization	Heat treatment [°C]	SBH [eV]
AuZn	as-deposited	0.40
	200	0.38
	320–450	0.30
Zn	as-deposited	0.63
	220–320	0.35
	360	0.37
Au	as-deposited	0.50
	300	0.50

Out of three analyzed contact materials, Au metallization doped with Zn forms on p-type GaAs the lowest potential barrier. Moreover, upon annealing the height of this barrier further decreases to 0.3 eV at the temperature of the onset of the ohmic behaviour. Relatively high value of SBH at the Zn/p-GaAs interface, also diminishes under heat treatment, reaching the minimum value of 0.35 eV at the temperature when the contact becomes ohmic. In contrast, SBH of pure Au contact remains unchanged.

The results of X-ray analysis revealed that, in spite of sequential deposition of Au and Zn, in a wide range of Zn concentration, AuZn metallization consists of two phases: AuZn (50 at.% Zn) and α-AuZn (solid solution of Zn in Au). According to Elliot [4], at temperatures below 500°C, the equilibrium Au–Zn phase diagram consists of the following phases: α-AuZn, α_3-AuZn (Au_4Zn), α_2-AuZn or α_1-AuZn (low or high temperature Au_3Zn phase), Au_5Zn_3, and AuZn. Surprisingly, in AuZn thin film structures, in the composition range 10–35 at.% Zn, phase formation paths are similar. Thermally induced transformations start at around 100–200°C and proceed through the gradual decomposition of AuZn phase and formation of α_2-AuZn phase. Rising the temperature to above 300°C causes the transformation of α_2-AuZn into α_3-AuZn for Zn content smaller than 20 at.% or

α_1-AuZn, for higher Zn concentrations. Both final phases are very similar: α_3-AuZn is an orthorhombic phase with $a = 0.4026$ nm, $b = 0.4034$ nm, and $c = 0.4062$ nm, while α_1-AuZn is tetragonal, with $a = 0.4019$ nm, and $c = 0.4095$ nm.

Zn shows no evidence of reaction with GaAs during annealing up to 320°C. Our recent transmission electron microscopy (TEM) study of Zn/GaAs interfaces revealed however that at low temperatures (RT÷150°C) Zn penetrates the residual oxide at the surface of GaAs [2]. Above 320°C a tetragonal Zn_3As_2 phase with $a = 1.1778$ nm and $c = 2.3643$ nm forms.

Thermally activated changes in SBH correlate with processes at MS interfaces. AuZn phase is responsible for the formation of the lowest SBH in as-deposited contacts, since it forms at the interface as a result of interaction between the first Au layer and Zn during deposition of Au/Zn/Au metallization [3]. The onset of the ohmic behaviour of AuZn/*p*-GaAs contacts coincides with the appearance of α_3-AuZn or α_1-AuZn phase at the MS interface. For Zn/GaAs contacts, lowering of the SBH corresponds to the penetration of Zn into the native oxide layer, leading to formation of an intimate MS contact. Subsequent increase in the SBH is caused by the formation of a new phase in the interface.

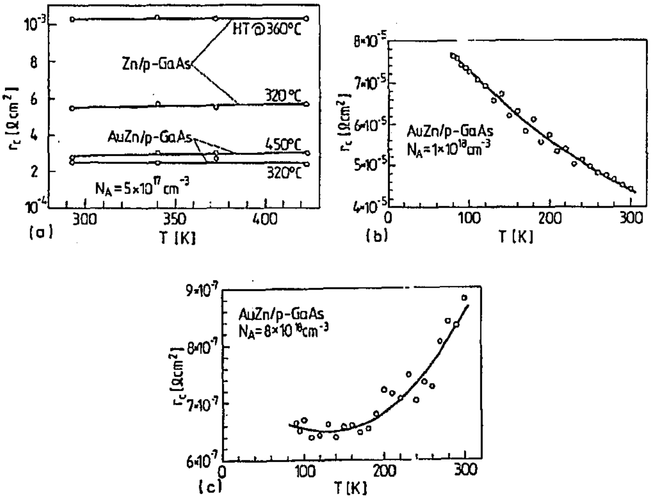

Fig. 1. Temperature dependence of specific resistance r_c of Zn/*p*-GaAs and AuZn/*p*-GaAs contacts for different doping levels of the substrate: (a) $N_A = 5 \times 10^{17}$ cm^{-3}, (b) $N_A = 1 \times 10^{18}$ cm^{-3}, (c) $N_A = 8 \times 10^{18}$ cm^{-3}.

Figure 1 shows the specific resistance of Zn/GaAs and AuZn/GaAs ohmic contacts as a function of the ambient temperature. The measurements were performed in two different temperature ranges: from RT to 150°C (Fig. 1a) or from 80 K to RT (Fig. 1b and Fig. 1c), and for various doping levels of bulk semiconductor. Note that the specific resistances of both Zn/*p*-GaAs and AuZn/*p*-GaAs contacts do not depend upon the temperature, which means that carrier transport across these contacts is controlled by tunneling.

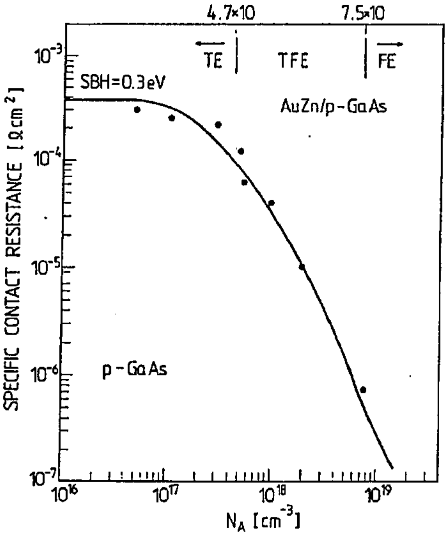

Fig. 2. The dependence of specific contact resistance AuZn/p-type GaAs contacts on doping level of p-GaAs; circles — experimental data points, solid line — theoretical prediction assuming SBH = 0.3 eV.

In Fig. 2 the data points are presented concerning specific contact resistance for AuZn/p-GaAs ohmic contacts as a function of the substrate doping level. The solid line is calculated for SBH of 0.3 eV, for ideal metal/p-GaAs contact.

In conclusion, the obtained results prove that the mechanism responsible for the formation of low-resistance Zn-based contacts to p-type GaAs is associated with the lowering of the Schottky barrier at the metal/semiconductor interface. We suggest that the ultimate properties of these contacts are determined by the presence of a single, specific phase in a direct contact with the semiconductor.

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