富山大学教育学部紀要B（理科系）No.49：41－46（平成9年）

Au-Ge Ohmic Contacts to n-GaP

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(Received March 13 , 1996)

Abstract

N-GaP/Au-Ge system has been investigated as the parameters of Ge content, sintering temperature and donor concentration. Germanium content between 0.08wt% and 1.4wt% is optimal for ohmic contacts. The optimum sintering temperature ranges from 500℃ to 530℃. The specific contact resistance between $4.0 \times 10^{-4} \Omega \cdot \mathrm{cm}^2$ and $8.5 \times 10^{-4} \Omega \cdot \mathrm{cm}^2$ was reproducibly achieved for n-GaP with donor concentration ranging from $2.1 \times 10^{17} \mathrm{cm}^{-3}$ to $10 \times 10^{17} \mathrm{cm}^{-3}$.

Key words : GaP, ohmic contact, Au-Ge, specific contact resistance

Introduction

For efficient and reliable operation of electroluminescent devices, it is essential to use ohmic contact with low resistance. Experimental results on n-GaAs/Au-Ge/Ni contact system, which consists of a Au-Ge layer deposited on n-GaAs substrate and Ni layer covering the Au-Ge layer, have been reported by several authors.(1) - (6) Especially, the Au-Ge eutectic (12wt% Ge) contact with a small amount of Ni (5wt%) presents excellent properties, such as no balling, low contact resistance and high reliability. In this contact, Au acts as a base metal and Ge as a dopant. The Ni layer improves wettability of the contact to the substrate and prevents it from balling(3) that has been frequently observed in the contact without Ni layer. The balling of the Au-Ge layer is closely related to the Ge content.

Au-Si alloy is useful as a contact material for n-type semiconductors. The evaporation temperature of Au and Si are 1397℃ and 1632℃, respectively. In the evaporation of the Au-Si alloy from a tungsten boat, Au evaporates first and then Si evaporates. Furthermore, Si is easily alloyed with the tungsten boat. On the contrary, the evaporation temperature of Ge is the same as that of Au. Fortunately, Ge does not react with the tungsten boat. Consequently, the Au-Ge alloy is appropriate in the contact fabrication process. In the present paper, the applicability of Au-Ge contact to n-GaP without Ni layer is investigated.

Experimental

N-GaP substrates with donor concentration of $2.1-10\times10^{17}\mathrm{cm}^{-3}$ were degreased and then, immersed for 30 sec in a hot (90 ℃) solution of H_2SO_4 and 31% H_2O_2 in a ratio of 3 : 1. After rinsing in deionized water, the substrates were etched for 2 min in a solution of HCl and HNO_3 in a ratio of 3 : 1 at 55℃, followed by rinsed in deionized water again. After pumping down to the pressure of 4×10^{-5} Pa, a 4000 Å of Au-Ge layer was deposited onto the GaP substrates from a tungsten boat which was placed 23 ㎝ below the substrates. Deposition was performed at the pressure of less than 1.3×10^{-4} Pa. Substrate temperature was maintained at 150℃ during the deposition.

The Au-Ge layer deposited was etched in a multidot pattern in which a Au-Ge contact had 80 μm diameter and 200 μm separation. The substrates were then sintered for 10 min in the flowing dry-argon ambient in an open-tube furnace. Sintering temperature was not constant during this procedure; it takes about 8 min to be heated up to the predetermined temperature and about 7 min to be cooled to below 100 ℃. After the sintering, metal probes were placed on pairs of adjacent contacts and I - V characteristics were inspected on an oscilloscope for linearity, symmetry with respect to the direction of applied voltage, and total resistance. The total resistance can be expressed as the sum of the spreading resistance due to the nonlinearity of the potential under the contact, the contact resistance at the contact-substarate interface layer, the residual resistance due to the GaP substrate, and the resistance of the probe system. The last resistance, which is 0.32 Ω for the present system, can be measured independently and subtracted from the total resistance. In the calculation of the contact resistance, both the spreading resistance and residual resistance were neglected. The error introduced by this treatment is less than 6.5%.

Results and Discussion

Figure 1 presents the dependence of the specific contact resistanc (the contact resistance multiplied by its area) on Ge content in Au-Ge contact.(7) It is found that the contacts with Ge content less than 0.04wt% have large specific contact resistances. Moreover, these contacts present non-ohmic characteristics. The increase of the specific contact resistance with decreasing Ge content in this region is due to the lack of Ge. In other word, the contacts could not supply enough Ge to dope heavily the GaP surface. The increase of the specific contact resistance is also found in the contacts with Ge content greater than 2wt%. It is found from microscopic observation, as shown in Fig.2, that the balling of the contacts become remarkable with increasing Ge content. As a result, the contacts does not supply enough Ge to the substrates. The balling may be caused by poor wettability of the contact with large Ge content to the GaP substrate. For this reason, the specific contact resistance increases with increasing Ge content. In the case of the present contact, the optimum content of Ge ranges from 0.08wt% to 1.4wt%. It is also interesting that the specific contact resistance within this range is almost independent of Ge content.

Figures 3 and 4 present the specific contact resistance versus sintering temperature as the parameters of Ge content and donor concentration, respectively. It is found from Fig.3 that when

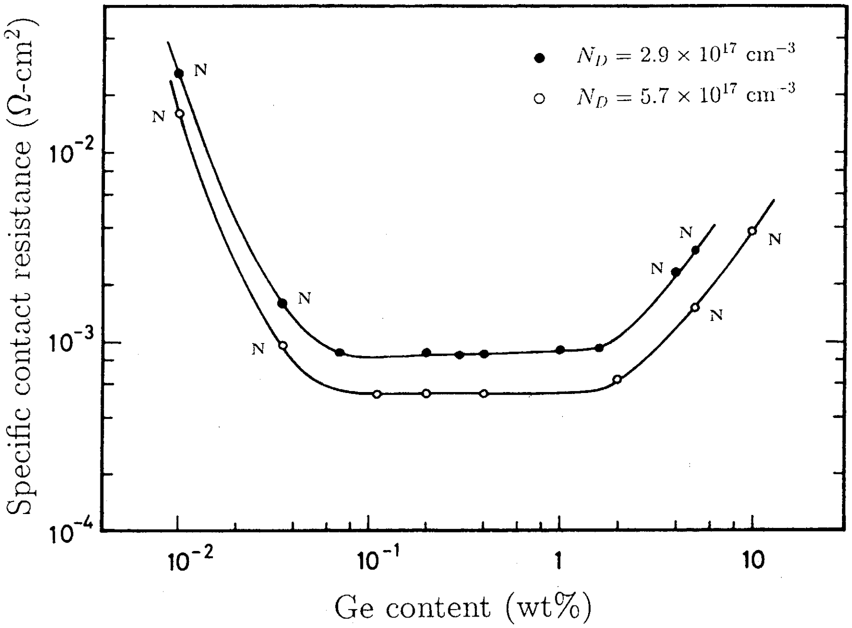
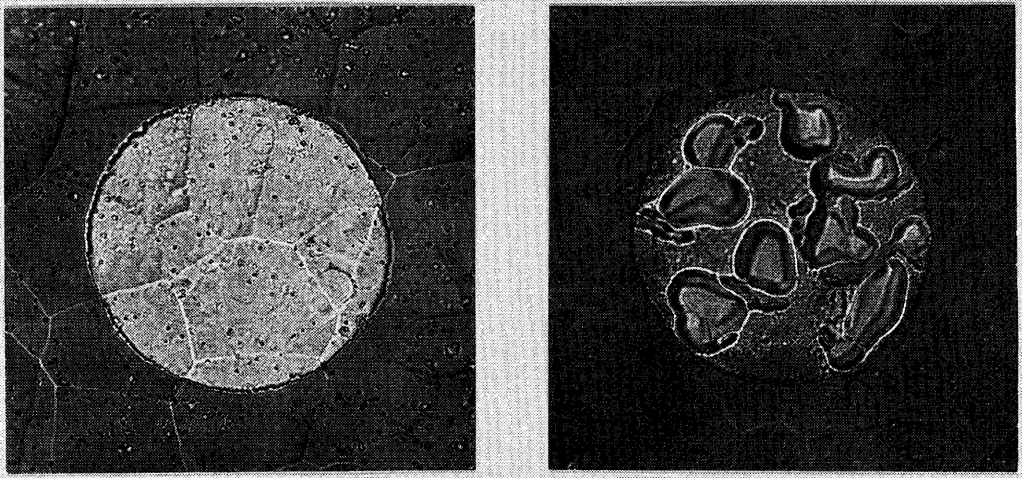


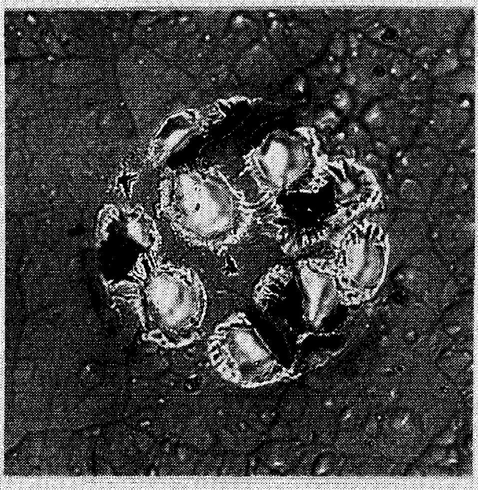
Fig. 1. The specific contact resistance versus Ge content in Au-Ge contact. Sintering was carried out at 510℃ for 10 min. N's marked near the curves stand for non-ohmic I-V characteristics.

the sintering is performed at a temperature higher than 500℃, the specific contact resistance for a fixed donor concentration is independent on Ge content. Figure 4 indicates that the specific contact resistance at a fixed Ge content decreases as the donor concentration increases. It is concluded from these results that the optimum sintering temperature ranges from 500℃ to 530℃. From the device performance point of view, however, the sintering temperature is desirable as low as possible.

The specific contact resistance is plotted as a function of the reciprocal of square-root of the donor concentration, as shown in Fig.5. In the thermionic-field emission theory,(8) the ratio kT/E_{oo} is shown to be a measure of the importance of the thermionic emission relative to the thermionic-field tunneling, where $E_{oo} = (qh/4\pi)(N_D/m^* \varepsilon_s \varepsilon_0)^{1/2}$ and q is the electronic charge, h Plank's constant, N_D the donor concentration, m^* the effective mass of the tunneling electron, ε_s the static dielectric constant of the semiconductor and ε_0 the permitivity of free space. Substituting $m^* = 0.35m_0$(9), $\varepsilon_s = 11\ \varepsilon_0$,(10) and T=300K, the ratio kT/E_{oo} has a value less than 2×10^{-5} for the substrate with the lowest donor concentration among those used in the present study. Therefore, the tunneling process may be expected as the current transport mechanism. Moreover the specific contact resistance ρ_c is given by $\rho_c \sim \exp(\Phi_B/N_D^{1/2})$, where Φ_B is the barrier height at the contact-semiconductor interface. The linear relationship, as shown in Fig.5 suggests that the carrier tunneling through the potential barrier is dominant mechanism which restricts the contact resistance.



(a) Au-2wt%Ge　　(b) Au-4.9wt%Ge



(c) Au-10wt%Ge

Fig. 2. Photomicrographs of the Au-Ge contacts with different Ge content sintered at 480℃ for 10 min.

Summary

Au-Ge was examined concerning ohmic contact to n-GaP. The specific contact resistance was measured as functions of Ge content, sintering temperature, and donor concentration. The experimental results can be summarized as follows:

(a) Ge content between 0.08wt% and 1.4wt% is optimal for ohmic contacts.

(b) The optimum sintering temperature ranges from 500 ℃ to 530 ℃.

(c) The lowest specific contact resistance of $8.5\times10^{-4}\,\Omega\cdot\mathrm{cm}^2$ was obtained for the donor concentration of $2.1\times10^{17}\mathrm{cm}^{-3}$.

(d) The mechanism of current transport is well explained by the carrier tunneling through the potential barrier.

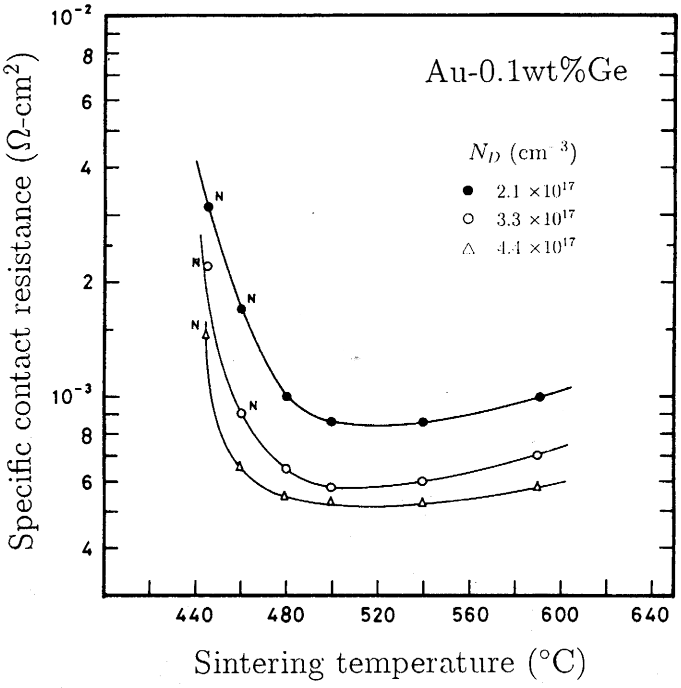


Fig. 3. The specific contact resistance versus sintering temperature as a parameter of Ge content. N's marked near the curves stand for non-ohmic I-V characteristics.

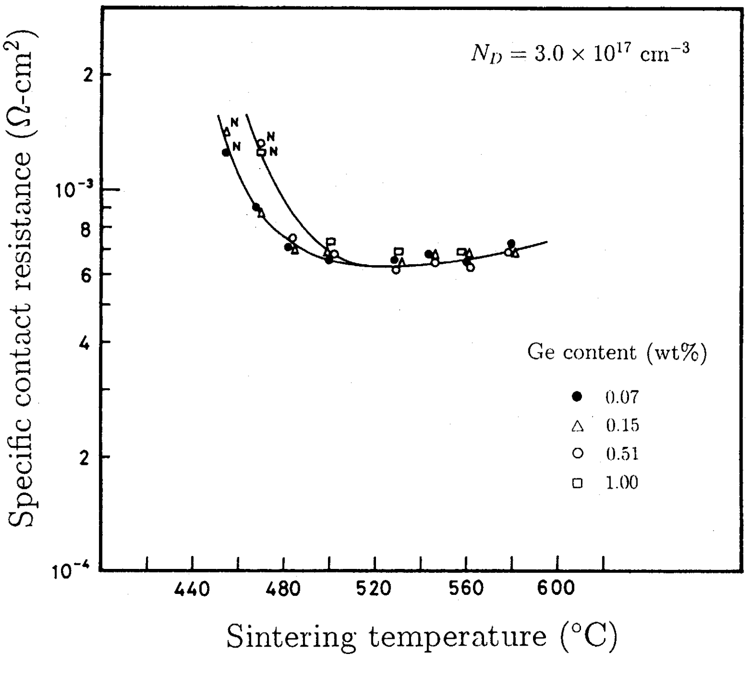


Fig. 4. The specific contact resistance versus sintering temperature as a parameter of donor concentration N$_D$. N's marked near the curves stand for non-ohmic I-V characteristics.

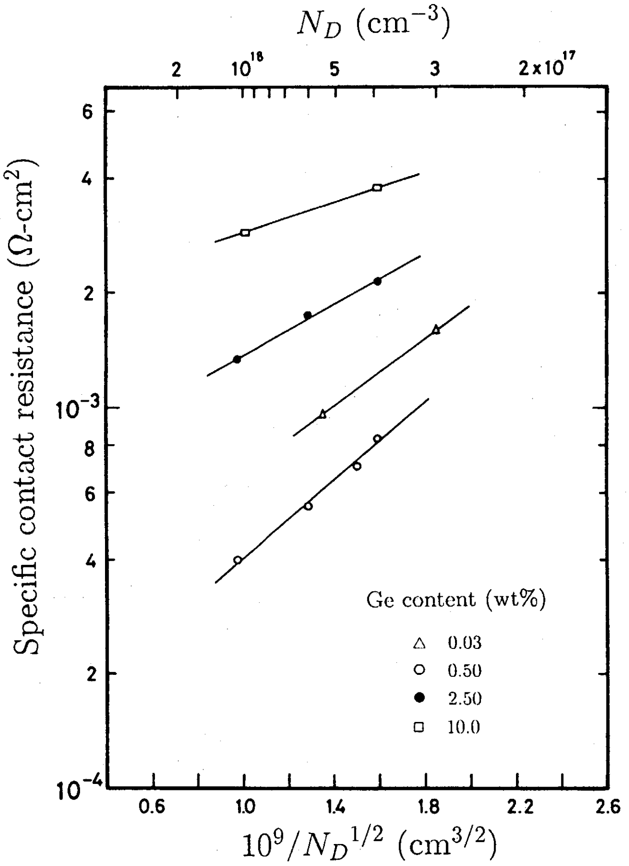


Fig. 5. The specific contact resistance versus the reciprocal of the square-root of donor concentration as a parameter of Ge content. Sintering was carried out at 510℃ for 10 min.

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