Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 418–419

Electrical and Microstructural Analyses on Pd/Ge-Based Ohmic Contact to n-InGaAs

Il-Ho Kim, Sung Ho Park, Jwayeon Kim[1], Jong-Min Lee, Tae-Woo Lee and Moon Pyung Park

Semiconductor Div., Electronics and Telecommunications Research Institute, 161 Kajong-dong, Yusong-gu, Taejon, 305-350, Korea
Phone/Fax: 82-42-860-5742/82-42-860-6183, E-mail: ihkim@cadvax.etri.re.kr
[1]Dept. of Materials Engineering, Hoseo University, San 29-1, Sechul-ri, Baebang-myun, Asan, Chungnam, 336-795, Korea
Phone/Fax: 82-418-40-5228/82-418-548-3502, E-mail: jykim@dogsuri.hoseo.ac.kr

1. Introduction

Pd/Ge-based system has been investigated as an ohmic contact mainly on n-GaAs.[1-3] It has been understood that contact resistance is lowered due to increase in doping level at the metal/n-GaAs interface by substitution of Ga vacancies with in-diffused Ge atoms, and it is believed that a similar phenomenon would occur on n-InGaAs. InGaAs has emerged as a material for high speed devices such as a heterojunction bipolar transistor(HBT) and a high electron mobility transistor(HEMT) owing to its high electron mobility and high electron saturation velocity. Thus, to realize the potential of InGaAs, reliable and low-resistance ohmic contacts on it must be developed. Shantharama *et al.*[4] have briefly discussed some non-alloyed ohmic contacts(Au/Pt/Ti, Au/SnAu, AuGe/Pd and Au/Pt/AuBe system) on heavily doped n- and p-InGaAs, and Park *et al.*[5] have reported the work on Au/Ni/AuGe, Au/Pd/AuGe, Au/Pt/Ti and Au/Pt/Ti/WSi contacts to n-InGaAs. However, there has been little information on Pd/Ge-based ohmic contact to n-InGaAs. In this study, therefore, Pd/Ge-based ohmic behaviors on n-InGaAs were investigated in conjunction with microstructural analysis.

2. Experimentals

Fig. 1 shows the schematic cross-sectional view of ohmic contact layers on n-InGaAs. Ohmic contact materials, Pd/Ge/Au/Ni/Au were deposited sequentially on n-InGaAs substrate by electron beam evaporation, and ohmic contact patterns were made by conventional lift-off technique. Ohmic alloying was carried out by rapid thermal annealing(RTA) process in N_2/H_2 forming gas atmosphere at various temperatures for 10 seconds. The standard transmission line method (TLM) was used to measure the specific contact resistance. Phase transition was analyzed by X-ray diffraction(XRD) and electron diffraction(ED), and atomic redistribution was examined by Auger electron spectroscopy(AES) depth profiling. Surface morphology and interface of ohmic contact materials/n-InGaAs were observed by scanning electron microscopy(SEM) and cross-sectional transmission electron microscopy(XTEM).

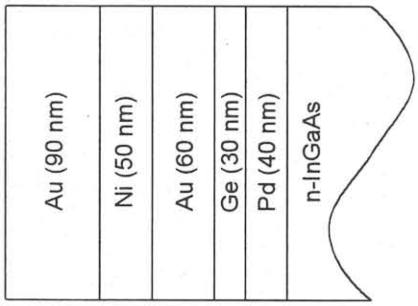

Fig. 1. Schematic cross-sectional view of Au/Ni/Au/Ge/Pd ohmic contact to n-InGaAs.

3. Results and Discussion

Fig. 2 shows the variation of specific contact resistance with RTA temperature. A relatively low value was found even without annealing and it is responsible for the low barrier height of metal/n-InGaAs contact. As the temperature increased up to 400 ℃, the specific contact resistance was reduced to low-10^{-6} Ωcm^2. However, degradation was observed above 400 ℃, and it is believed to be due to the reaction of ohmic materials with InGaAs, which consumes the n^+ layer and forms a highly resistive interface.

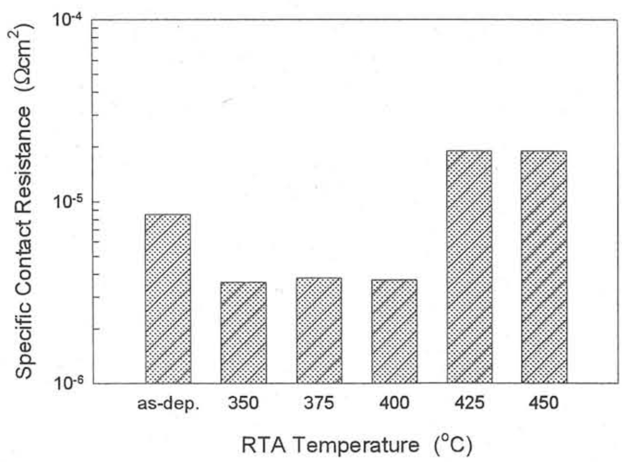

Fig. 2. Variation of specific contact resistance of Au/Ni/Au/Ge/Pd contact to n-InGaAs with RTA temperature.

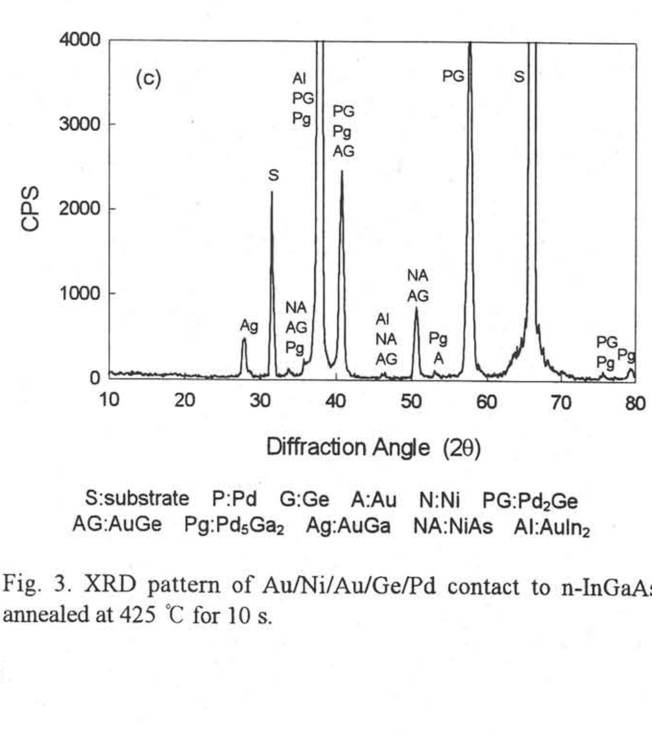

Fig. 3. XRD pattern of Au/Ni/Au/Ge/Pd contact to n-InGaAs annealed at 425 ℃ for 10 s.

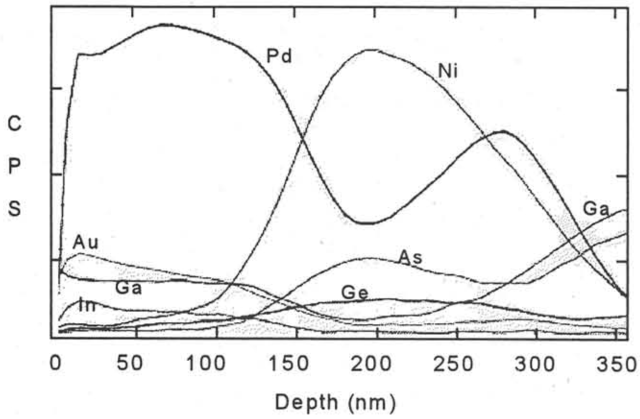

Fig. 4. AES depth profile of Au/Ni/Au/Ge/Pd contact to n-InGaAs annealed at 425 ℃ for 10 s.

No remarkable phase transition was observed below 350 ℃, but the reaction of ohmic metals and InGaAs was initiated at ~375 ℃ so that a little phase change was found. Significant phase transformation was generated at 425 ℃ and various compounds were produced as seen in Fig. 3. It is believed that formation of Pd_5Ga_2 and AuGa phases helps Ge atoms to substitute Ga vacancies and thus increase in surface doping level reduces the contact resistance. However, the specific contact resistance increased at the temperature higher than 400 ℃. It is attributed to the considerable reaction between ohmic metals and InGaAs, especially the formation of $AuIn_2$ and Pd_5Ga_2 compounds. As a result, InGaAs is changed to be nonstoichiometric, and it causes higher barrier height of metal/n-InGaAs contact to degrade the ohmic contact. This is in good agreement with the variation of specific contact resistance with RTA temperature.

Fig. 4 indicates the AES depth profiles of Au/Ni/Au/Ge/Pd contacts on n-InGaAs. No other significant diffusion was detected except a little interdiffusion of Au and Ge at 375 ℃. However, considerable intermixing was observed at 425 ℃. Out-diffusion of In would deteriorate the ohmic contact due to increase in barrier height. Out-diffusion of As is also responsible for the degraded ohmic contact at 425 ℃ because it encourages the Ge from the contact layer to occupy the As sites where it behaves as an acceptor.

The ohmic materials/n-InGaAs interface observed by XTEM was illustrated in Fig. 5 with the ED patterns of selected area. Non-spiking and planar interface was found even for the contact annealed at 425 ℃ for 10 s. After RTA, ohmic contact layers appeared to be composed of two different layers. It was confirmed by ED patterns for upper and lower layers, but further microscopic analysis was required.

Surface morphology was little changed up to 400 ℃ compared with the as-deposited contact, and it showed very smooth and gold-like shiny surface. But it was changed to rougher and silvery surface(Fig. 6) at higher RTA temperature. Moreover, as shown in Fig. 6(b), pin hole-like defects were observed in the contact annealed at 450 ℃. Surface morphology variation would affect the electrical properties and probe contact.

4. Conclusion

Au/Ni/Au/Ge/Pd ohmic contact behavior on n-InGaAs was investigated. Good ohmic contacts were obtained as the RTA temperature increased up to 400 ℃, but degradation of ohmic contact was shown above 425 ℃. This was related to phase transformation and atomic redistribution. Smooth surface and planar interface between ohmic materials/InGaAs were observed.

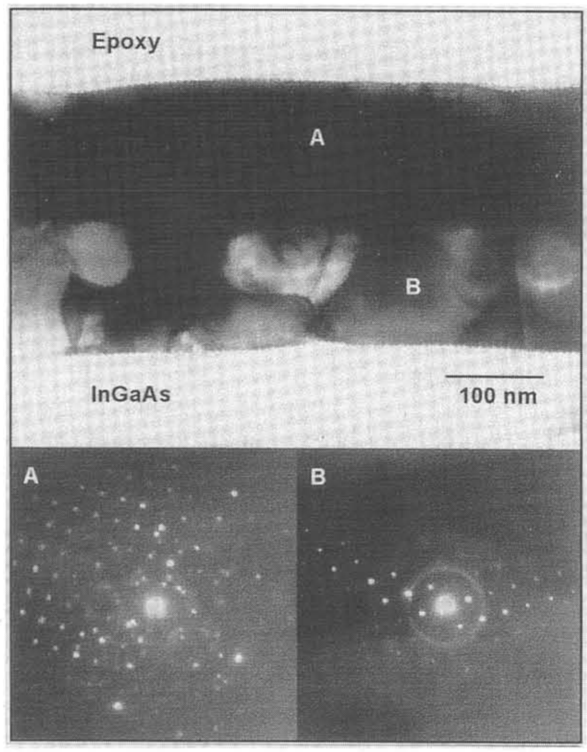

Fig. 5. Cross-sectional view and electron diffraction patterns of ohmic materials/n-InGaAs interface annealed at 425 ℃ for 10 s.

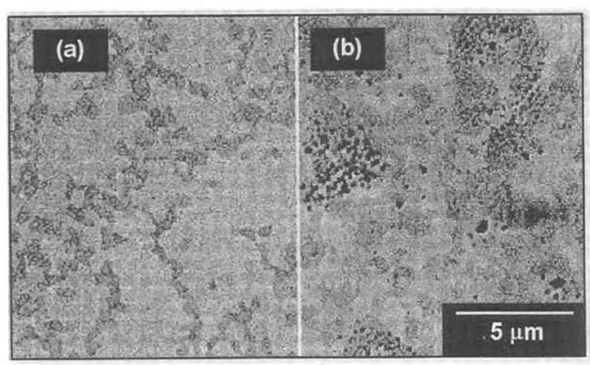

Fig. 6. Surface morphologies of Au/Ni/Au/Ge/Pd contacts to n-InGaAs annealed at (a) 425 ℃ and (b) 450 ℃ for 10 s.

Acknowledgment

The authors would like to show their appreciation to Dr. Byoung-Gue Min for his technical support with SEM.

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