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Annealed AuGe Based Ohmic Contacts on InP with Ion Milling Prior to Metallization

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Ohmic contacts have been fabricated on *n*-type InP with an alloyed AuGe based metallurgy that involved ion milling prior to metallization. Minimum values for contact resistance and specific resistance of 0.015 Ω-mm and 3.2×10^{-8} Ω-cm^2, respectively, were found with an annealing temperature in the range, 440–480° C. Addition of Ni to the contact metallurgy improves the wetting characteristics of the AuGe and lowers the contact resistance. It is proposed that ion milling prior to metallization results in a reactive metal-semiconductor interface and low contact resistance values for samples with and without Ni.

Key words: Ohmic contacts, InP, AuGe, ion milling

1. INTRODUCTION

Field-effect transistors (FET's) fabricated with InP as the active material are desirable for high speed microwave devices and components in optoelectronic integrated circuits fabricated on InP substrates. In addition, InP/GaInAs heterojunction two dimensional electron gas devices require that source, drain, and gate metallizations are formed on InP. High speed switching requires the minimization of source and drain contact resistance to maximize the external transconductance and, hence, the maximum oscillation frequency and improve the noise behavior of the FET.[1]

Very low values for contact resistance, R_c, < 0.1 Ω-mm,[2,3] and specific contact resistance, $\rho_c \approx 2 \times 10^{-7}$ Ω-cm[2,4] have been reported using alloyed AuGe/Ni based metallurgy. When the contact is annealed, Ge is thought to diffuse into the InP, resulting in a degenerately doped region of InP immediately beneath the contact. Current is transported across the metal-semiconductor junction by tunneling. In addition, it has been shown that low resistance nonalloyed ohmic contacts can be formed by ion sputtering InP prior to metallization.[5] The present study has combined alloyed AuGe based metallurgy with ion milling prior to metallization to obtain low resistance ohmic contacts on *n*-type InP. Preliminary results are reported for contact resistance and specific contact resistance.

2. EXPERIMENTAL

The material used for this investigation was 0.8 μm thick (100)-oriented InP grown by organometallic vapor phase epitaxy on semi-insulating InP substrates. The layers were doped with tellurium ($n \approx 10^{18}$ cm^{-3}) and had values of sheet resistance of 30–70 Ω/sq. Contact resistances were determined using the transmission line model (TLM).[6] Mesa structures, 150 μm wide, were formed in the epi-layer using a concentrated HCl etch. Rectangular contact areas 200 × 100 μm^2 with spacings ranging from 10–30 μm, in 5 μm increments, were patterned, using an image reversal process for liftoff. The contact areas were aligned to completely overlap the width of the mesa structure. This configuration confines all current flow between contacts and eliminates any alternate current paths.

After patterning, the sample was dipped in HF for 2 min, then rinsed in deionized water, blown dry with nitrogen and placed on a hot plate, at 100° C, for 1 min in air. The sample was loaded into an argon ion mill where the InP was milled at 600 eV (current density = 0.1 mA/cm^2) for 20–30 sec with the InP normal to the ion beam. Subsequently, the sample was coated with a thin layer (< 50Å) of sputter deposited Au, in the ion mill, without breaking vacuum.

The sample was then transferred to an *e*-beam evaporator where metallization was completed. Two evaporation sequences were used, 1) Ge/Au/Ti/Au (450Å:800Å:500Å:3000Å) and 2) Ge/Au/Ni/Ti/Au (450Å:800Å:250Å:500Å:3000Å). The thicknesses for the initial Au and Ge deposition correspond to the AuGe eutectic, which is 88% Au and 12% Ge by weight. The base pressure prior to metallization was $<10^{-6}$ Torr and individual deposition sequences were carried out without breaking vacuum. Liftoff was completed by soaking in hot acetone. The samples were then annealed in a simple tube furnace at 440, 460 or 480° C for 90 sec under flowing nitrogen.

The 3000Å Au layer was used to reduce the resistance of the contact metal and was deposited along with the AuGe ohmic metallization to eliminate additional processing after annealing. The Ti layer was added to prevent excessive interactions between the overlayer and the InP. Although alloy formation will occur between Au and Ti, Ti has been shown to be reasonably effective at inhibiting Au-InP reactions in layered Au/Ti/InP structures.[7]

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For each metallization sequence and annealing temperature, between six and 10 TLM patterns were fabricated and tested. Resistance measurements were made using a four-probe technique where current is passed through one pair of probes and the associated voltage drop is measured with the other pair. The resistance, V/I, was found to be insensitive to probe position on the contact pads. The contact spacing was measured for all samples. Contact resistance, R_c, was determined by extrapolating the measured data to zero spacing with a least-squares linear regression analysis. It was then normalized to the contact width. Results are reported only for contacts with regression fits that had correlation coefficients of >0.995. The slope of the fitted curve is directly related to the sheet resistance of the epitaxial layer. From the TLM, the specific contact resistance, ρ_c, is calculated by the following relationship: $\rho_c = (R_c^2)$(contact width)/slope.[8] This relationship assumes the semiconductor beneath the contact has the same sheet resistance as the material between pads. The accuracy of this assumption cannot, however, be assessed in the present experiments.

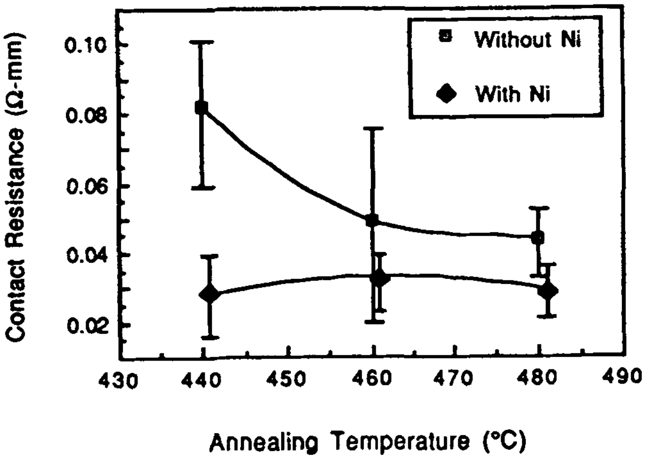


Fig. 1 — Contact resistance as a function of annealing temperature for samples with and without Ni. All samples were annealed for 90 sec.

3. RESULTS AND DISCUSSION

As expected, the contacts were found to be ohmic after metallization. Annealing produced a dramatic decrease in the contact resistance and specific resistance values. The minimum and average values are shown in Table I. Plots of contact resistance, R_c, and specific contact resistance, ρ_c, including the spread in the data are shown in Figs. 1 and 2. The lowest values of contact resistance for the samples with and without Ni compare well with other published results for low resistance ohmic contacts on InP.[2-5,8,9]

Photographs taken with a scanning electron microscope, shown in Fig. 3, revealed very different morphologies for the samples after annealing. The sample without Ni had a rough surface and revealed evidence of small scale balling beneath the top Ti/Au layers. The balls were quite uniform in size with diameters in the range of 0.5–1 μm. The sample with Ni had a much smoother surface with two visually distinct regions. Elemental analysis of the light and dark regions with EDAX did not, however, reveal compositional differences. Evidentally the addition of Ni improved the wetting characteristics of the AuGe. This corresponded to a decrease in the measured contact resistance.

The results of the present study indicate that it is possible to achieve low resistance contacts on InP using AuGe based metallurgy with and without Ni. The ion milling period (a total ion dose of ≈ 1.5×10^{16} cm^{-2}) is sufficient to remove most all of the native oxide and leave a surface that is disordered and In-rich with a uniform distribution of In clusters that are 150–600Å in diameter.[10-12] It is proposed that the formation of the In islands is the result of momentum transfer of the Ar ions causing surface segregation of metallic In rather than preferential removal of P.[10,11] This is an important consideration since Ge can be either a donor or acceptor in III-V compounds. Phosphorus depletion might cause dif-

Table I. Minimum and Average Values for Contact Resistance, R_c, and Specific Contact Resistance, ρ_c, for Different Annealing Temperatures (annealing time was 90 sec for all samples) for Metallization Sequences without and with Ni.

Samples without Ni	R_c min.	R_c avg. (Ω-mm)	ρ_c min.	ρ_c avg. (Ω-cm^2)
As Deposited	0.502	0.510	3.9×10^{-5}	4.7×10^{-5}
440° C	0.058	0.082	6.6×10^{-7}	1.5×10^{-6}
460° C	0.020	0.049	8.6×10^{-8}	6.6×10^{-7}
480° C	0.032	0.044	2.1×10^{-7}	4.0×10^{-7}
Samples with Ni				
As Deposited	0.749	0.773	8.1×10^{-5}	8.1×10^{-5}
440° C	0.015	0.028	3.2×10^{-8}	1.3×10^{-7}
460° C	0.023	0.033	1.0×10^{-7}	1.6×10^{-7}
480° C	0.021	0.037	6.9×10^{-8}	1.3×10^{-7}

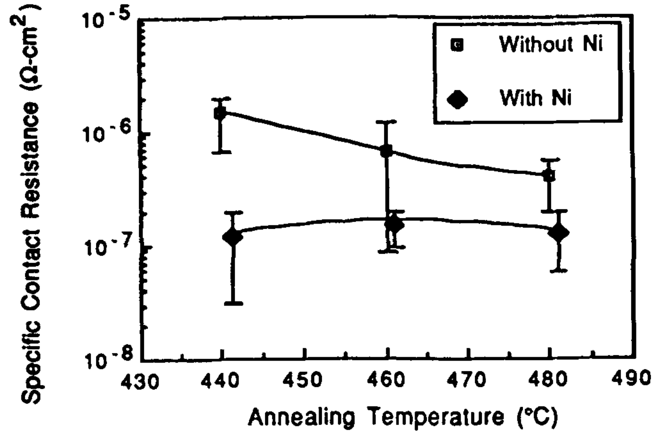
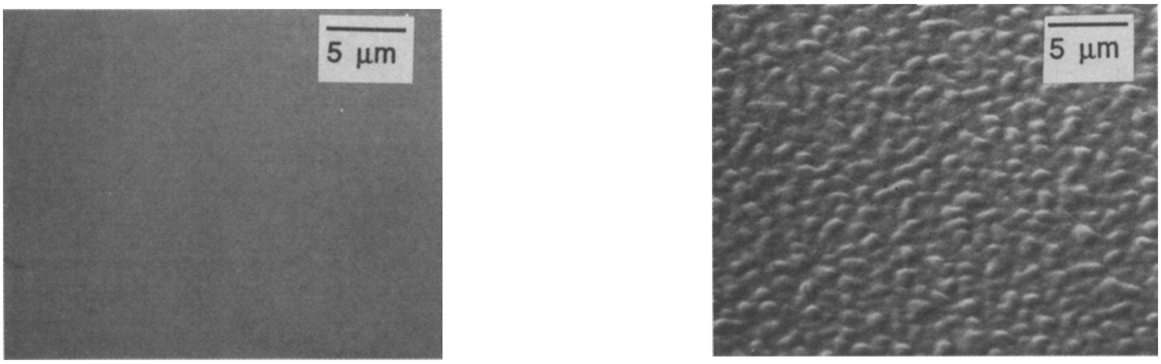


Fig. 2 — Specific contact resistance as a function of annealing temperature for samples with and without Ni. All samples were annealed for 90 sec.



As Deposited Annealed @ 460°C for 90 seconds

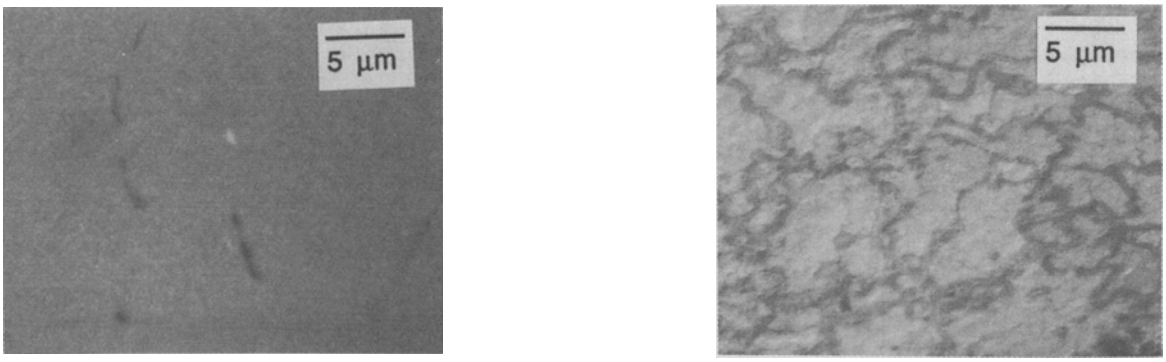


Fig. 3 — SEM micrographs showing contact morphologies before and after annealing at 460° C. The top set was prepared without Ni and the lower set with Ni. Samples were tilted at 45° in the SEM for maximum contrast.

fusing Ge to reside on P sites rather than In sites, which would reduce the net doping level in the InP. It is also important that any structural damage to the InP and the associated strain be confined near the surface. When the damage induced by the sputtering process extends too deep, the diffusion of Ge will be enhanced far away from the surface, thereby making it difficult to maintain a high donor concentration near the metal-semiconductor interface.[13]

If the subsequent sputter deposited Au atoms arrive at the InP surface with sufficient energy, it is reasonable to assume that Au-In compound formation takes place at the In clusters. Compound formation would inhibit oxidation of the surface during transport from the ion mill to the *e*-beam evaporator. The localized In-rich areas are highly reactive upon annealing, due to the low melting temperature of In. Thus, the metal-semiconductor interface, considered as a whole, will be more reactive than one with even a very thin continuous layer of native oxide. It is not known if the thickness of the sputter deposited Au is critical, but thicker layers, of approximately 100Å, yielded contacts with poor morphology and increased values of contact resistance.

In summary, low resistance alloyed ohmic contacts based on AuGe metallurgy can be formed on InP that has been ion milled prior to metallization. Adding a layer of Ni to the contact metallurgy improves the wetting characteristics of the AuGe and lowers the contact resistance. It is proposed that ion milling prior to metallization results in a reactive metal-semiconductor interface and low contact resistance values for samples with and without Ni.

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REFERENCES

1. S. M. Sze, Physics of Semiconductor Devices, (John Wiley & Sons, New York 1981) pp 343, 347.
2. J. A. Del Alamo and T. Mizutani, Solid-State Electron. *31*, 635 (1988).
3. E. Yamaguchi, T. Nishioka and Y. Ohmachi, Solid-State Electron. *24*, 263 (1981).
4. G. Bahir and J. L. Merz, J. Electron. Mater. *16*, 257 (1987).
5. W. C. Dautremont-Smith, P. A. Barnes and J. W. Stayt, J. Vac. Sci. Technol. B *2*, 620 (1984).
6. H. H. Berger, Solid-State Electron. *15*, 145 (1972).
7. J. M. Vandenberg and H. Temkin, J. Appl. Phys. *55*, 3676 (1984).
8. H. Morkoc, T. J. Drummond and C. M. Stanchak, IEEE Trans. Electron Dev. *ED-28*, 1 (1981).
9. K. P. Pande, E. Martin, D. Gutierrez and O. Aina, Solid-State Electron. *30*, 253 (1987).
10. D. K. Skinner, J. Electron. Mater. *9*, 67 (1980).
11. R. F. C. Farrow, Thin Solid Films *80*, 197 (1981).
12. M. G. Dowsett, R. M. King and E. H. C. Parker, Appl. Phys. Lett. *31*, 529 (1977).
13. M. N. Yoder, Solid-State Electron. *23*, 117 (1980).