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Spectroscopic, Morphological, and Electrical Characterization of PdGe Ohmic Contacts to n-GaAs

A.J. Howard, M.L. Lovejoy, K.R. Zavadil, P.A. Barnes*
D.J. Rieger, R.J. Shul and J.C. Zolper.

Sandia National Laboratories, Albuquerque, NM 87185-0603

*Auburn University, Dept. of Physics, Auburn, AL 36849-5311

ABSTRACT

Novel material systems such as ZnS_ySe_{1-y} and $Zn_xCd_{1-x}Te$ that are commonly grown at low temperatures (~300 ^oC), require unique, low temperature processing schemes. For example, ohmic contact formation with the common AuGeNi n-GaAs contact is not appropriate for this application due to its relatively high anneal temperature (~400 ^oC). For this reason, we investigated the effects of anneal temperature (150 to 400 ^oC) and time (5 to 30 min) on the contact resistivity of PdGe to n-GaAs substrates. The contact surface morphology was measured by AFM and the material composition profile was analyzed by XPS. The characteristics of the PdGe contact are compared to our standard AuGeNi n-GaAs contact.

ZnS_ySe_{1-y} and $Zn_xCd_{1-x}Te$ are just two examples of materials systems that have received significant attention recently for their visible wavelength light emitting potential that are deposited at relatively low growth temperatures (~300 ^oC). The fact that they are grown at these low temperatures makes them inherently unstable at T > 300 ^oC and incompatible with standard GaAs-based processing temperatures. Incongruent evaporation, dopant diffusion, and dopant deactivation are just a few of the problems which can be caused by device processing above the growth temperature. For example, the standard AuGeNi n-GaAs ohmic contact requires an anneal temperature of ~400 ^oC. Also, standard PECVD temperatures are ~300 ^oC. Both of these common GaAs processing steps will degrade these II-VI materials. Consequently, for devices fabricated from these materials systems to make the transition from "research curiosity" to commercial product, new low temperature device processing schemes must be developed. In our specific application, a processing sequence was required to fabricate optical modulators using II-VI $Zn_xCd_{1-x}Te$ active layers which were grown at 300 ^oC by MBE on n-GaAs substrates. In this

paper, we report the results of a study on the utility of PdGe[1],[2] as a low temperature contact to n-GaAs; the PdGe is intended for use as a backside n-type low temperature ohmic contact to GaAs for II-VI device applications. This paper focuses mainly on the morphological and spectroscopic characterization results, for electrical details, see ref.[3]. The morphology and composition profile is of interest due to observations in our laboratory of abnormally rough surfaces on the AuGeNi ohmic contact and previous reports of incomplete solid-phase mixing in annealed PdGe[1].

EXPERIMENTAL

The substrates used for this study were (100) oriented 2 inch diameter n-GaAs (~2.5 x10^{17} cm^{-3}) (Sumitomo, Inc.). Approximately 500 Å of Pd followed by 1360 Å of Ge was e-beam evaporated and patterned by liftoff in the shape of circles ranging in size from 10 to 60 microns in diameter. A low temperature (~150 ^{o}C) SiO_2 dielectric PECVD process, developed specifically for this project, was used to deposit ~2000 Å of SiO_2 as an inter-layer dielectric between the PdGe dots and the 100 micron diameter lifted-off Ti/Au probe pads. Via holes in the SiO_2 were etched using a photoresist mask in a RIE system using a CHF_3/O_2 chemistry. The contact annealing was performed in a tube furnace under flowing N_2 at temperatures ranging from 150 to 400 ^{o}C and times from 5 to 30 min.

The effects of anneal temperature and time on PdGe surface morphology were characterized by atomic force microscopy (AFM). All AFM micrographs were taken using a Digital Instruments Nanoscope III atomic force microscope operating in air in contact mode. Using the AFM system, which has a built-in software package for the analysis of RMS surface roughness, 512 X 512 resolution images were taken and the roughness analyzed.

The electrical characteristics of the PdGe contacts were measured using a HP 4145 semiconductor analyzer. The effects of anneal temperature and time on the current-voltage relationship were determined. The Cox and Strack method[4] was used to measure the contact resistivity. Several sets of samples were prepared and measured using nominally the same fabrication procedure.

X-ray photoelectron spectroscopy (XPS) was performed on as-deposited and annealed (250 ^{o}C for 30 min - the apparent optimum conditions for our application) PdGe samples. Sputtering was performed using 3 keV Ar^+ ions with a current density of 2 $\mu A/cm^2$. The ion beam raster area was much larger than the analysis area to eliminate crater sidewall effects. Quantization of surface constituents was achieved by scanning a single region that included the Pd(4p), As(3d), Ge(3d), and Ga(3d) transitions. Spectra were obtained using a 600 W Al(K) source at constant energy resolution.

RESULTS AND DISCUSSION

Processing with the standard AuGeNi contact is not suitable for our application due to its relatively high anneal temperature (~400 ^{o}C), contact-spiking, and poor surface morphology which causes interconnect metallization problems. The use of PdGe was investigated due to its reportedly excellent specific contact resistance to n^{+}-GaAs at low (~300 ^{o}C) anneal temperatures[2].

The current-voltage characteristics were measured between two large area PdGe contacts. For samples with 30 minute anneals at temperatures less than or equal to ~200 ^{o}C, non-linear I-Vs, similar to back-to-back Schottky diodes, were observed. At anneal temperatures of ~250 ^{o}C or greater up to 400 ^{o}C, highly linear I-Vs (ohmic behavior) were observed. Using the Cox and Strack method[4] on the samples with linear I-Vs, an average specific contact resistance of ~2 $\mu\Omega$-cm^2 was obtained at 250 ^{o}C. From 225 to 400 ^{o}C, the measured contact resistances were low, ranging from ~2 to 4 $\mu\Omega$-cm^2, and relatively constant. The mechanism believed to be responsible for the excellent ohmic property is doping of the GaAs surface by Ge that diffuses through the underlying Pd film. Ge diffusion through Pd is known to occur at ~200 ^{o}C which is consistent with our electrical results[2].

Based on the electrical results, the 250 ^{o}C, 30 minute anneal was chosen as our optimum low temperature PdGe condition. The surface morphology of the as-deposited and annealed PdGe contacts was characterized by AFM. These results were compared to the morphology of as-deposited AuGeNi (260 Å Ge, 540 Å Au, 150 Å Ni, 2000 Å Au) and AuGeNi annealed at 400 ^{o}C for 30 sec. The RMS roughness of the as-deposited films were comparable, RMS(PdGe) ~ 0.55 nm, RMS(AuGeNi) ~ 1.1 nm, but after annealing, the AuGeNi films became much rougher. AFM images of the two films after annealing are shown in Figure 1(A&B). As shown, the rough mound-like appearance of the annealed AuGeNi film is consistent with its larger RMS roughness (3.97 nm), whereas the PdGe annealed sample is much smoother (RMS=1.30 nm). The mound-like features in the AuGeNi sample are probably associated with underlying Ge-rich islands which lead to its contact spiking problems. Clearly, the PdGe annealed surface is much smoother which is advantageous for subsequent processing steps.

The sputter depth profile analysis of the as-deposited and 250 ^{o}C, 30 minute annealed samples are shown in Figure 2(A&B) and indicate that Ge is capable of diffusing through the ~500 Å Pd underlayer and incorporating into the GaAs matrix at deposition temperatures which are estimated to be ~80 ^{o}C. The penetration depth is estimated to be 1200 Å with a near-interfacial Ge concentration of

2 atomic percent. Thermal annealing results in inter diffusion of the layers producing a mixed Ge/Pd layer with a ~ 2:3 composition adjacent to the GaAs interface. The Ge profile in the GaAs is not significantly changed with thermal annealing. Annealing appears to produce Pd incorporation into the GaAs at larger near-interfacial concentrations (4 - 10 atomic percent) and shallower penetration depths than Ge.

CONCLUSIONS

The utility of PdGe as a backside, low-temperature ohmic contact to n-GaAs for a II-VI device application was studied. The anneal temperature/time combination of 250 ^{o}C/30 minutes was found to be optimum based on a measured minimum specific contact resistance of ~2 $\mu\Omega$-cm^2. Using AFM, the contact surface morphology and RMS roughness was measured and the RMS roughness of the PdGe contact (RMS=1.30 nm) was ~one-third of the roughness of the AuGeNi contact. The material composition profile was analyzed by XPS and the results indicate that Ge is capable of diffusing through the ~500 Å Pd underlayer and incorporating into the GaAs matrix at deposition temperatures.

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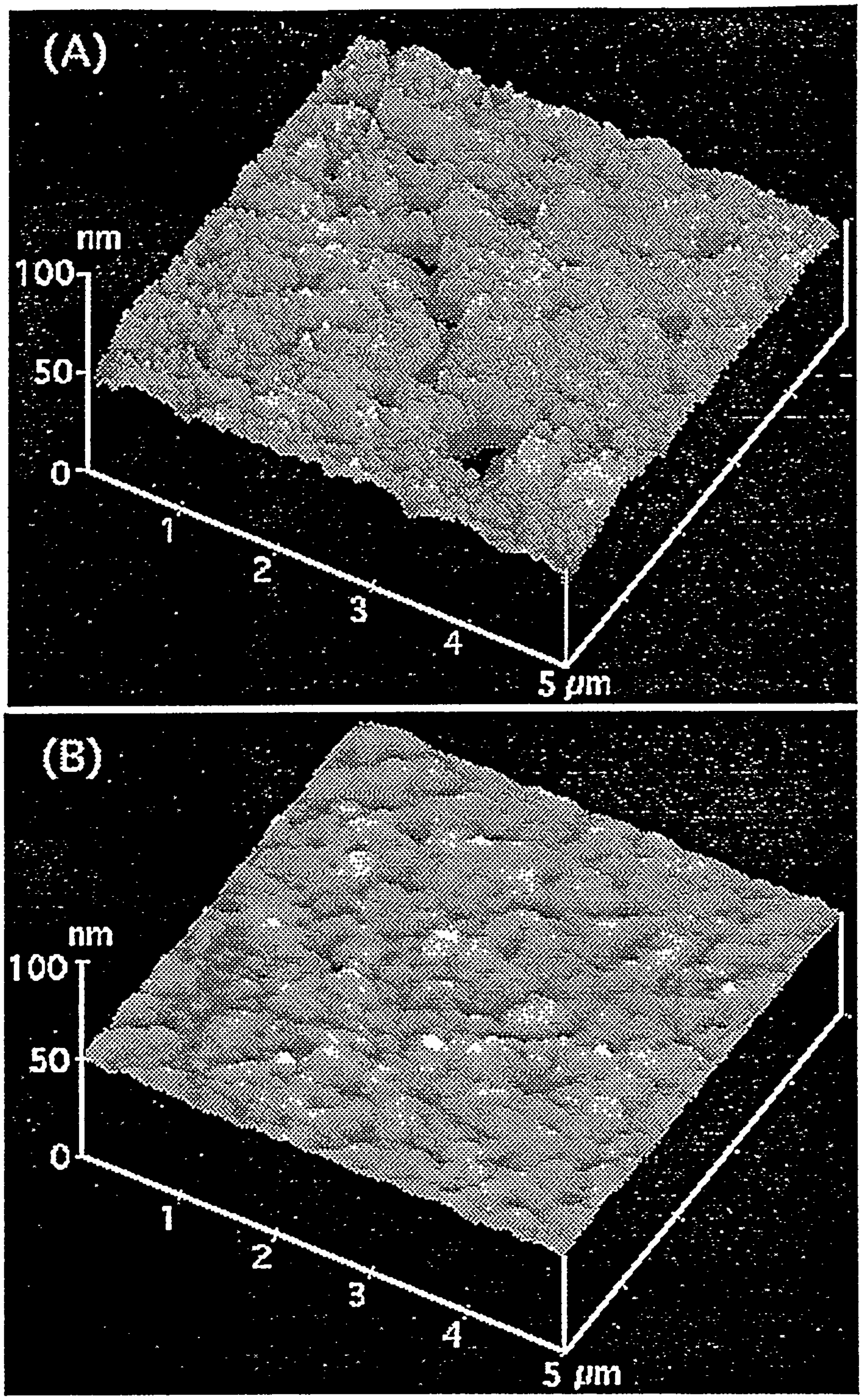

Figure 1: AFM images of annealed ohmic contacts:
(A) Standard AuGeNi, (B) New PdGe.

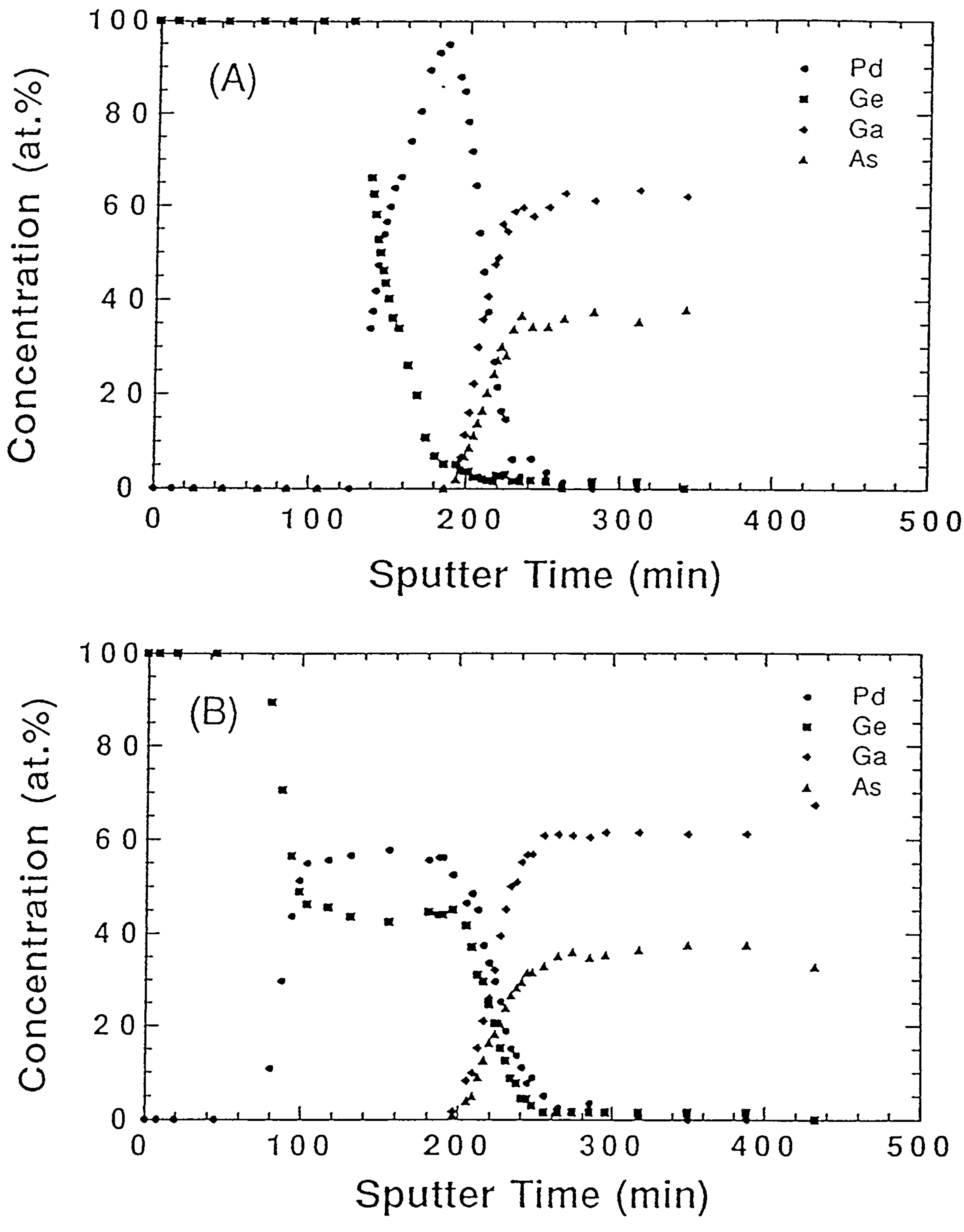

Figure 2: XPS profiles of PdGe on GaAs: (A) As Deposited, (B) Annealed at 250 ^{0}C / 30 min (Ref. [3]).