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Electrical and Structural Properties of Ti/Au Ohmic Contacts on N-ZnO:Al

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1. Introduction
Zinc oxide (ZnO)-related wide band gap semiconductors have potential applications as materials for optoelectronic devices, such as light emitting diodes (LEDs) and laser diodes (LDs).[1] Recently, ZnO has rapidly emerged as an alternative for GaN because of a large band gap of 3.37eV, low power threshold for optical pumping at room temperature, and highly efficient UV emission which resulted from a large exciton binding energy of 60 meV at room temperature. Furthermore, ZnO has been proposed as quantum well materials in ZnO/Zn1-xMgxO superlattices which are designed for use in future semiconductor lasers covering the UV spectral range below 370 nm.[2] To commercialise the ZnO-based LEDs, it is important to grow high quality ZnO. In particular, high-quality and thermally stable ohmic contacts are crucial for the realisation of high performance optoelectronic devices.

In this work, we report on low-resistance ohmic contacts to n-ZnO:Al using Ti/Au metallisation schemes. Interfacial reactions between Ti/Au and ZnO were investigated using AES, and GXRD to study ohmic contact mechanisms.

2. Experiment
The n-ZnO:Al films studied in this work were grown on (0001) sapphire substrates using RF magnetron sputter system. The carrier concentration was 2x10^{19} cm^{-3} and Hall mobility was about 22.5 cm^{2}V^{-1}s^{-1}. Prior to lithography, the n-ZnO samples were ultrasonically degreased in trichloroethylene, acetone, methanol, and rinsed in deionised water for 5 min in each step. A standard photolithography technique was used to pattern c-TLM. The inner dot radius was 105 μm, and the spacings between the inner and the outer radii were 3, 4, 6, 12, 13, 16, and 21 μm. Prior to metal deposition, a solution of HCl:H2O (2:1) was used to remove a native oxide layer on the n-ZnO surface. The Ti (30 nm)/Au (50 nm) films were deposited on n-ZnO by electron beam evaporation (PLS 500 model). After the standard lift-off process, the samples were rapid-thermal-annealed at temperatures in the range of 300–500 °C under a nitrogen ambient. Current-Voltage (I-V) data were measured using parameter analyser (HP 4155A) and specific contact resistances were calculated by the c-TLM method. To characterise the extent of interdiffusion between the metal schemes and the ZnO, Auger electron spectroscopy (AES) and Glancing angle X-ray diffraction (GXRD) examinations were performed. Scanning electron microscope (JSM 5800) and atomic force microscopy (PSIA) were employed to characterise the surface morphology of the samples.

3. Results and Discussion
Figure 1 shows the I-V characteristics of Ti/Au contact schemes to n-ZnO. The as-deposited Ti/Au contact exhibits the linear I-V behaviour with a specific contact resistance of 2x10^{-3} Ω cm^{2}. Annealing of the contact scheme at 300 °C leads to an improved linear I-V characteristic with a specific contact resistance of 2x10^{-4} Ω cm^{2}. This improved I-V behaviour could be related to the outdiffusion of oxygen from ZnO during annealing. Further increase in the annealing temperature causes the I-V characteristics to be degraded. This is probably related to the deterioration of the interfacial contacts occurring during annealing at 500 °C.

Figure 2 shows the AES depth profiles of the sample annealed at 300 °C. It is shown that there is no obvious evidence of the outdiffusion of zinc into metal layers. Compared to the as-deposited sample (not shown), the more extensive outdiffusion of oxygen into the Ti layer occurred in the 300 °C sample. This is consistent with the fact that the enthalpy of formation for ZnO (ΔH_f = -350 kJ/mol) is much larger than that of TiO2 (ΔH_f = -944 kJ/mol).[3] Glancing angle XRD analysis was performed on the sample annealed at 300 °C to identify interfacial reaction products (Figure 3). The XRD plot shows the characteristic diffraction peaks of Au, Ti, TiO, and TiO2 phase peak, as expected from AES result. A comparison of the as-deposited and 300 °C samples shows the occurrence of additional peaks, which is indicative of the formation of a new interfacial phase. These additional phases are identified to be (110) TiO2:srilankite (26.29 °), (110) TiO2:rutile (27.67 °), (112) TiO2:srilankite (45.4 °), and (212) TiO2:rutile (79.4 °). Observation of these additional phases is consistent with the enhanced oxygen
outdiffusion with increasing annealing temperature. As shown in the AES and GXRD results, the annealing treatment leads to the extensive outdiffusion of oxygen atoms and hence leaves oxygen vacancies at the region near the n-ZnO surface. Oxygen vacancies and zinc interstitials have been suggested to act as donors. Thus, the accumulation of oxygen vacancies near the surface region would be responsible for the improvement in the electrical property of the annealed contacts. For annealing at 500 °C, the contact produced a higher resistance, compared to the 300 °C sample. This degradation could be related to either the disruption of the interface, a reduction in the contact areas due to the formation of voids (as observed by AFM), or both.

4. Summary and conclusion

We report on low-resistance Ti/Au ohmic contacts on Al-doped n-ZnO. Current-voltage curves show that both the as-deposited and 300 °C annealed contacts exhibit ohmic behaviour. The AES and XRD results showed that interfacial reaction products formed during annealing may be responsible for the improvement and degradation of the electrical properties of the Ti/Au contacts on ZnO.

References

Figure 1. The I-V characteristics of Ti/Au contacts on n-ZnO:Al as a function of annealing temperature. It is noted that the electrical properties are improved with increasing temperature.

Figure 2. The AES depth profiles of the 300 °C sample. It is clearly shown that the extensive outdiffusion of oxygen atoms into the Ti layer occurs.

Figure 3. The glancing angle XRD of the 300 °C sample, showing the characteristic diffraction peak of Ti and Au. There are additional peaks such as the rutile and srilankite TiO2 phases.