Au and Ag Electrical Contacts to p-ZnSe

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The reverse bias break-down voltage and resistance of Au and Ag contacts sputter deposited on nitrogen doped p-type ZnSe, having free hole concentrations in the low to mid $10^{17}$ cm$^{-3}$ range, have been studied. Samples were heat treated over the range of 150–400°C for times of 15–45 min. The minimum break-down voltage for the Au contacts (3.0 V) was found to occur following heat treatments at 350–400°C for 30 min and for Ag contacts (2.3 V) following heat treatments at 150°C for 45 min. Secondary ion mass spectrometry and Auger electron spectroscopy were used to identify changes in the contacts induced by heat treatments. No evidence was found for the formation of new interfacial compounds, but Au diffused into the ZnSe at $T >350°C$. The data suggest that conduction through the Au/ZnSe contacts was dominated by avalanche breakdown assisted by deep acceptor levels formed by the diffusion of Au into the ZnSe. The results from the Ag contacts suggest that interfacial O forms a highly doped region in the ZnSe leading to conduction dominated by field emission currents.

Key words: Ag, Au, electrical contacts, Schottky contacts, ZnSe

INTRODUCTION

Interest in the wide-band gap II-VI compound semiconductor zinc selenide (ZnSe) has developed due to the possible applications of this material in optoelectronic devices. Having a band gap of ~2.7 eV at room temperature, ZnSe is a suitable material for fabrication of semiconductor devices which emit optical radiation in the blue region of the visible spectrum. Until recently, one of the major obstacles in the fabrication of these devices was the production of low resistivity p-type ZnSe. This problem has been overcome, however, in the case of MBE growth by nitrogen atom beam doping.$^{1-3}$ In this process, atomic nitrogen generated in a remote radio-frequency (RF) plasma discharge free-radical source is incorporated into ZnSe during crystal growth. Net acceptor concentrations in p-type ZnSe up to the high $10^{17}$ have been reported using this doping technique.$^{4,5}$

The ability to consistently produce p-type ZnSe has led to numerous authors reporting the fabrication of ZnSe based light emitting diodes$^{6,7}$ and laser diodes.$^{4,5,7}$ These devices emit light in the blue to green regions of the spectrum with wavelengths ranging from 490 to 516 nm, depending on device construction and operating temperature. While devices have been demonstrated, there are many critical issues which require improvement for good device performance. One of these issues is the establishment of a method to form ohmic contacts to p-type material.

An ohmic contact is a metal-semiconductor electrical contact which has a linear current-voltage dependance and negligible contact resistance in comparison to the bulk resistance of the semiconductor. Criteria for ohmic contact formation were established by Sze$^8$ in the early 1970s. These criteria state that for an ohmic metal-semiconductor contact with low doping concentrations, thermonic-emission must dominate conduction. This requires a low interfacial barrier height for majority carriers to prevent any im-
systems have shown good performance, vapor deposited gold (Au) has been used as a simple contact scheme to p-type ZnSe.\textsuperscript{4,5,6} Gold is selected due to its large work function, which helps to minimize the valence band barrier height at the Au/ZnSe interface. While Au has been widely used as a practical contact material, it has been consistently reported to form rectifying Schottky contacts. This is presumed to cause excessive power requirements and Joule heating, resulting in high operating voltages and degraded device lifetimes. Recent work by Qiu et al. indicates that the reverse bias break-down voltage of Au Schottky contacts is significantly reduced when deposited on low-temperature MBE grown p-ZnSe with high net acceptor concentrations ($2 \times 10^{18} \text{cm}^{-3}$).\textsuperscript{6} In these contacts, conduction across the Au/ZnSe interface is reported to result from defect assisted field emission. In other work, Akimoto et al. report pseudo-ohmic behavior from Au contacts deposited on O-doped (p-type) ZnSe.\textsuperscript{11} An interfacial oxide was intentionally formed by Akimoto et al., by exposing the ZnSe to an oxygen plasma. The oxide was reported to form a highly doped surface region through which field emission occurred. X-ray photo-emission measurements by Chen et al. have indicated that two to three monolayers of Se at the interface between Au and p-ZnSe will reduce the Au/p-ZnSe Schottky barrier height by $\sim 0.25 \text{eV}$.\textsuperscript{12} This reduction in barrier height was attributed to the high electronegativity of the Se interlayer and the physical separation of the Au and ZnSe.

Although Au/p-type ZnSe contacts are currently being used and studied, there is little information in the literature about the effects of post-deposition processing on their electrical properties. This paper reports the effects of heat treatment on Au/p-type ZnSe contacts. In addition, the electrical properties of silver (Ag) contacts to p-type ZnSe, with similar heat treatments were also studied. The contacts were examined by Auger sputter depth profiling (ADP) and secondary ion mass spectrometry (SIMS) to identify reactions induced by heat treatments which led to changes in electrical characteristics.

**EXPERIMENTAL**

P-type ZnSe was grown by MBE on semi-insulating gallium arsenide (GaAs) substrates with growth conditions selected to produce carrier concentrations in the low to mid $10^{17} \text{cm}^{-3}$ range.\textsuperscript{1} The Au and Ag contact metals were deposited using 2 in. diam U.S. Inc. DC planar magnetron sputter guns with DC potentials of 375–400 V in nitrogen or argon at a pressure of 27 mTorr. Nitrogen was used as the sputtering medium in an attempt to increase the concentration of p-type dopant at the metal/ZnSe interface by incorporation of atomic nitrogen during deposition. This attempt was unsuccessful since contacts deposited with Ar plasmas behaved exactly the same. Metal film thicknesses were between 1000 to 2000Å and were patterned with a stainless steel mask to produce circular contacts with a diameter of 1 mm. Deposition times...