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Presented at the Materials Research Society Symposium on Epitoxy of Semiconductor Layered Structures, Boston, MA, December 1–5, 1987

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December 1987

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Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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The Influence of Current Stressing on the Structure of Ag Contacts to GaAs

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ABSTRACT

The stability of Ag Schottky contacts on GaAs after voltage and current stressing has been investigated. The barrier height and its stability against voltage and current stressing were found to depend on the diode fabrication method (metal deposition onto either air-exposed or ultra-high vacuum cleaved (UHV) substrates). The barrier height of Ag diodes formed on air exposed surfaces is 0.96 eV, and a significant decrease of 70 meV was found upon exposure to voltage and current stressing. In contrast, the barrier height of Ag diode formed on UHV cleaved samples is 0.89 eV, and no significant change was found upon exposure to stressing. The structure of the contacts was studied by transmission electron microscopy. Ag deposited on UHV cleaved substrates shows an epitaxial relationship to GaAs and atomically flat interfaces. Exposure to air before the metal deposition led to nonuniform reactions and compound formation at the interface as compared to UHV samples. After current stressing, void formation and electromigration of Ag was observed in the air-exposed contacts. Ag contacts formed on UHV-cleaved GaAs (110) were stable during current stressing.

INTRODUCTION

A detailed understanding of Schottky barrier formation at semiconductor-metal interfaces is still lacking, despite substantial experimental and theoretical study [1]. Among all single-metal/GaAs systems, the Ag/GaAs system is of special interest, as silver has the highest thermal and electrical conductivity among all metallic elements. In addition, photoemission spectroscopy studies did not find any evidence of a reaction between Ag and GaAs [2,3]. This observation is consistent with recent bulk thermodynamics predictions [4].

In this study, the changes in structure and electrical properties of Ag/GaAs diodes induced by reverse bias aging were investigated. The effects of this current and voltage stressing on the diode's electrical characteristics depend strongly on the method of semiconductor surface preparation before metal deposition. Because of the need for stable Schottky barriers, the results of this study are relevant for practical as well as fundamental reasons.

EXPERIMENTAL

The structural investigation was carried out using transmission electron microscopy (TEM) methods. Cross-section TEM samples were observed in a JEOL 200CX electron microscope

and the Atomic Resolution Microscope at the National Center for Electron Microscopy in Berkeley.

Two kinds of contacts were prepared: Ag was deposited in-situ on atomically clean n-GaAs (110) ($5x10^{16}Si/cm^3$) surfaces cleaved either directly in ultra-high-vacuum (UHV) or in air. Diodes of both types were aged by forward or reverse currents at room temperature. TEM studies were performed with both as-deposited and aged diodes. All were characterized electrically by I/V and C/V analysis.

RESULTS AND DISCUSSION

Electrical aging of UHV-cleaved Ag diodes was performed with current densities from $2{\cdot}10^{-2}A/cm^2$ (0.60 V) up to 1.4 A/cm^2 for reverse bias (–19 V). For the UHV-cleaved Ag diodes, no significant change in barrier height and ideality factor was found after electrical aging under these conditions for more than 7 hrs. By contrast, for air-exposed Ag/GaAs diodes 50 min at $4.3x10^{-5}A/cm^2$ (-14 V) was sufficient to decrease the barrier height by 20 meV. More severe conditions of $2.3x10^{-3}A/cm^2$ (-17 V) for the same 50 min period decreases the barrier height by 75 meV (Fig.1) [5].

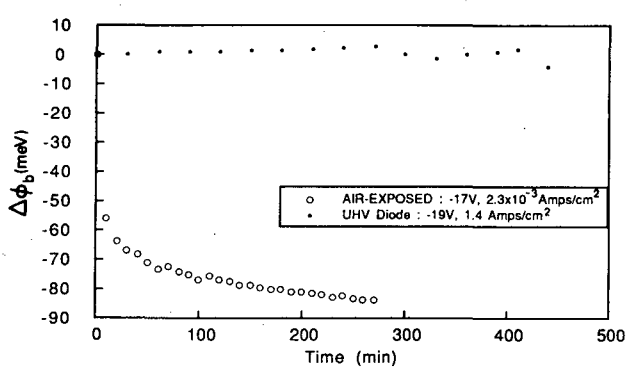

Fig.1 Typical results of electrical aging for Ag/n-type GaAs (110) diodes formed on air-exposed and UHV-cleaved GaAs (110) surfaces. The change in barrier height is plotted as a function of the of time the diodes were exposed to electrical aging.

Before electrical aging, the barrier height for air-exposed diodes (0.96 eV) was higher than that of UHV-cleaved diodes by 70 meV. The electrical aging reduced the barrier height difference between the two kinds of diodes without significantly changing the ideality factor of either kind of diode (n=1.06-1.085). Thus the electrical aging caused changes in the barrier height but did not significantly deteriorate the near-ideal Schottky characteristics of the diodes. It was also observed that the changes in barrier height were not stable: the Schottky barrier height returned almost to its initial value (before current stressing) within about five days. Light or forward current accelerated this recovery effect.

Significant differences in the structures of the two kinds of contacts were observed. The metal/substrate interface was flat in both cases (Figs.2 and 3); however, in the air-exposed samples an oxide layer ~40 Å thick was present on the GaAs surface. This oxide layer varied in thickness along the interface. The air-exposed diodes contained a higher density of twins and much smaller Ag grains in the metal layer compared to samples deposited in UHV conditions.

Current stressing of UHV-cleaved diodes did not result in any structural changes, but air-exposed contacts showed a significant change (Fig. 4). Current stressing caused a decrease in the size of the Ag grains, the formation of voids separating these grains, and poor adhesion of

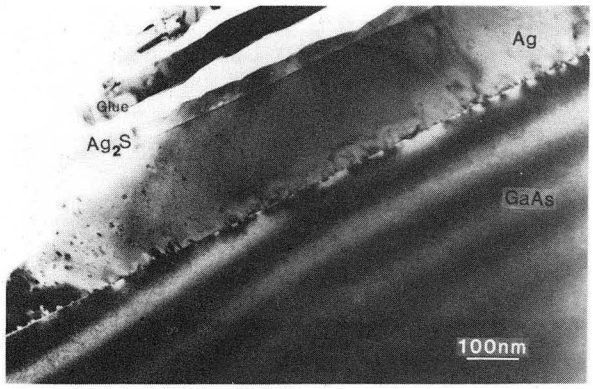

Fig. 2 TEM micrograph of the Ag/GaAs interface prepared by Ag deposition in situ on UHV-cleaved (110) GaAs. Note very large grain size and the layer of contamination (Ag_2S) for the sample that was kept in open air for a long time after electrical measurements. XBB 870-10294

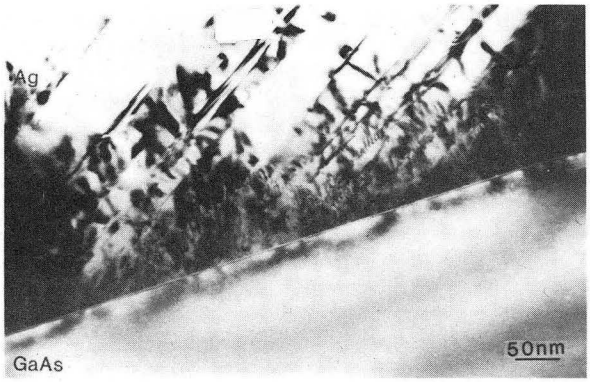

Fig.3 TEM micrographs of the Ag/GaAs interfaces prepared by Ag deposition on air-exposed cleaved (110) GaAs showing a high density of twins and an oxide layer formed on the interface. XBB 870-10295

the metal overlayer. Local electromigration of Ag resulted in Ag accumulation in parts of the contact and thinning or void formation in other parts (Figs. 4b and 5). Electromigration of Ag in the air-exposed diodes may be the result of large local current densities due to an nhomogeneous interfacial oxide layer, which acts to block current flow over part of the area of the contact.

High-resolution electron microscopy showed many areas with lattice spacings of 2.8Å, 3.1Å, and 4.2Å, larger than those characteristic of pure Ag (2.3Å). Spacings of 2.8Å and 3.1Å were observed occasionally, even in as-deposited air-exposed samples used in repeated TEM observations, but never in UHV-cleaved specimens. Similar lattice spacings of 2.8Å and 3.1Å have been reported for Ag deposited on MgO and have been identified as Ag_2O [6]. Another compound with these two lattice spacings is Ag_2S, which is often observed on the top surface of Ag layers exposed to ambient atmosphere. X-ray diffraction confirmed that the spacings were the result of the presence of Ag_2S.

The additional lattice spacings of 4.2Å, found together with 2.8Å and 3.1Å spacings in air-exposed, current-stressed samples, can be assigned to one of several Ag-As-S ternary compounds[7]. These samples also showed visible instabilities during illumination with the electron beam in the TEM. In some cases it was extremely difficult to obtain good TEM micrographs because of these structural instabilities. It cannot be decided at present whether this new compound was formed during the current stressing itself, during ion milling (which is part of the TEM sample preparation), or during electron-beam illumination. However, current-stressed samples prepared in UHV did not show this compound, although they had experienced the same sample-preparation treatment. As mentioned earlier, these diodes were also electrically stable.

The observed changes in barrier height cannot yet be ascribed unambiguously to specific structural features of the aged, air-exposed diodes, because the barrier height recovered during storage. Therefore the samples investigated by TEM experienced this recovery. However, the observed instabilities during the TEM observation and the new compound observed in those samples correlates well with the electrical instabilities found in the same samples during voltage and current stressing. Therefore it is likely that the TEM observations are related to the electrical instability in some way .

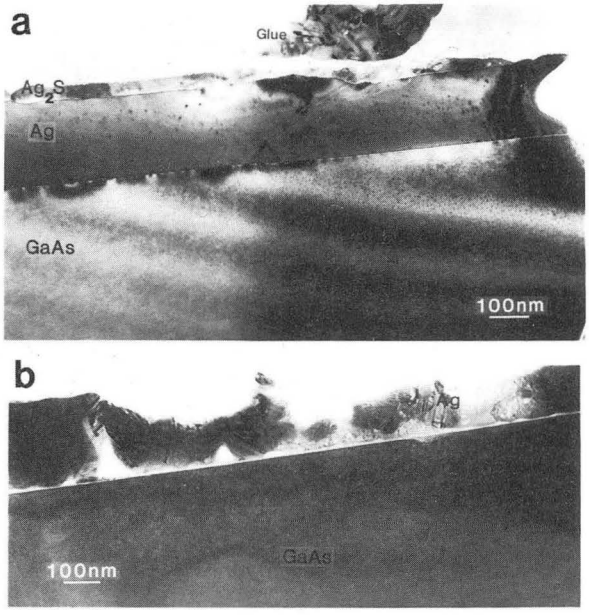

Fig. 4 TEM micrographs of Ag/GaAs interfaces after current and voltage aging:
a) Ag deposited on UHV-cleaved GaAs aged for 7 hrs, -19V, 1.4 A/cm^2;
b) Ag deposited on air-exposed GaAs aged for 50 min, -14V, 4.3x10^{-3}A/cm^2. Note smaller grain size than before aging and void formation. XBB 870-10297

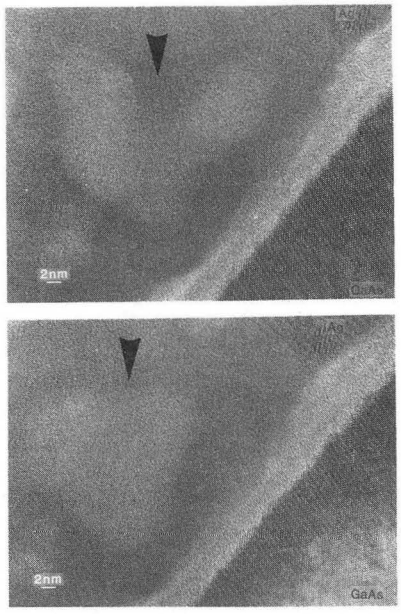

Fig. 5 A sequence of high resolution images of thin aged silver film deposited on air-exposed GaAs. Note the migration of Ag film (shown by arrow). Interval between pictures:10 sec. XBB 870-10296

CONCLUSION

The observations of void formation, enhanced electromigration combined with formation of a new compounds, can explain why Ag Schottky contacts, which are known to be generally leaky, have not been successfully applied in GaAs device technology. However, this study has shown that very stable and reliable Ag contacts can be obtained if the Ag is deposited on atomically clean surfaces such as the UHV-cleaved surfaces used for these observations.

ACKNOWLEDGEMENTS

This work was sponsored by SDIO-IST and partly supported by the Materials Sciences Division of the U.S. Department of Energy under Contract No. DE-ACO3-76SF00098. The work in Stanford was sponsored by the Air Force Office of Scientific Research under Contract AFOSR-86-0263

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