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Methods and Mechanisms for Ohmic Contacts on AlGaN/GaN HEMTs

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1. Introduction

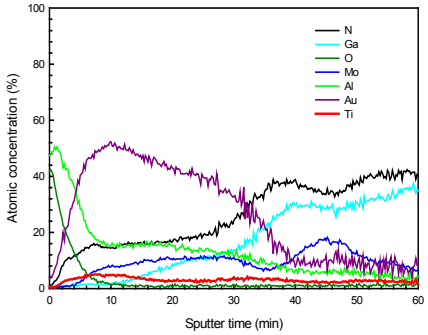
High electron mobility transistors (HEMTs) based on AlGaN/GaN heterostructures have been demonstrated to operate at high frequencies and high temperatures, which make them suitable for applications in microwave and millimeter-wave power amplifiers. Significant amount of research activities in the areas of growth and processing of AlGaN/GaN epitaxial layers have been carried out in the past decade and half. Noteworthy progress has been made in the design and fabrication of AlGaN/GaN device structures but some outstanding issues still remain to be addressed. Among these issues is the development of excellent ohmic contacts.[1)] There are some critical criteria that must be met for ohmic contacts on AlGaN/GaN and these include:[2)] (a) contact resistance less than 10^{-5} Ω-cm^2,[3)] (b) surface smoothness and excellent edge acuity to ensure good contact pattern definition and to avoid shorts, (c) oxidation and corrosion resistance during processing and after device fabrication to ensure long-term reliability, and (d) contact thermal stability to enable high temperature applications of the devices.[4)]

2. Design principles

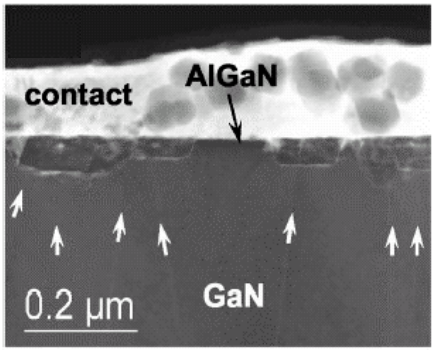
Of the vast number of studies in which single and multilayer schemes have been used to address these issues in the formation of ohmic contacts on AlGaN/GaN HEMTs, Ti/Al-based[5)] contacts have been identified as the standard in terms of their wide acceptance. Ti is used because it participates in interfacial nitride formation reactions yielding TiN, a semi-metallic compound with a work function of 3.74 eV,[6)] which renders the metal/AlGaN interface N-deficient, and consequently, n-type.[7,8)] Ti also plays the role of an oxide-getter from the surface of the epilayer. Hence, when it is coupled with metals with high conductivity, such as Al, it can enable direct ohmic contact formation. However, the propensity of both Ti and Al to easily oxidize at optimal annealing conditions poses major reliability challenges. This problem is circumvented by the deposition of a metal/Au bilayer cap where Mo is a one of the metals commonly used. The characteristic feature of the Mo layer is its high melting-points (2300 °C) and its low solid-phase Au solubility, which makes it a good candidate for barrier-layer against the outdiffusion of Ti and Al and the indiffusion of Au. The Au overcoat is believed to have the effect of minimizing or preventing the oxidation of the underlying metallic layers, and also improving the conductivity of the contacts.

3. Characterization of Ti/Al/Mo/Au

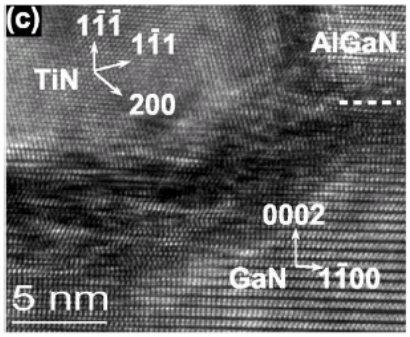
Contact resistance and specific contact resistivity of less than 0.3 Ω-mm and 10^{-6} Ω-cm^2 can be obtained reproducibly on epilayers grown on various types of substrates such as Sapphire, SiC and Si.



(a)



(b)



(c)

Fig. 1 (a) AES depth profile, (b) STEM, and (c) HRTEM images of Au/Mo/Al/Ti/AlGaN/GaN

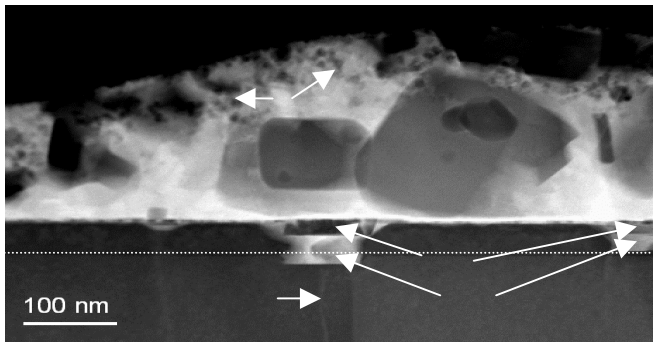
In addition, smooth surface morphology and excellent edge acuity have been demonstrated. Recent reports have also indicated that Ti/Al/Mo/Au is better suited to be optimized as a generic ohmic contact for the fabrication of AlGaN/GaN HEMTs with performance that is not dependent on the growth conditions of the heterostructure materials.[9] As shown in Fig. 1(a) and (b), microstructural analyses of annealed samples have revealed a high degree of complexity in the intermetallic and interfacial reactions suggesting that a combination of these reactions is responsible for achieving excellent ohmic performance from these metallizations.

The mechanism of ohmic contact formation in Ti/Al/Mo/Au is assisted by the formation of reaction islands, composed of TiN, penetrating across the AlGaN barrier layer and through the AlGaN/GaN heterointerface, which in turn allows for a direct contact of the metal with the 2DEG, enabling a low barrier Schottky mechanism [Fig. 1(c)].[10,11] Depth profiles and cross-sectional analyses have also indicated that $AlAu_x$ alloy formation take place in Ti/Al/Mo/Au. While these point to the possibility of the metal barrier-layer playing an active role, more than just a mere diffusion barrier, such an approach presents the possibility of inducing intermetallic reactions of Al and Au with other elements, such as Si, to explore low-temperature eutectic alloy formation.

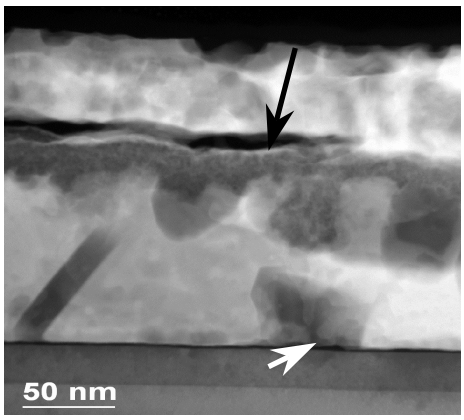
4. Si incorporation in Ti/Al/Mo/Au

Electrical characteristics of Si-containing schemes, as well as the nature of interfacial reactions, have shown strong dependence on the contents and placement of the inserted layers. Si incorporation was found to induce a significant reduction in the contact resistance and to enabole a wide processing temperature window. The microstructural characterization of Si-containing schemes indicated that the ohmic contact formation mechanisms vary considerably depending on the distribution and total thickness of the inserted Si layers.

Cases of suppression of TiN formation,[Fig. 2(a)][12] which is presumed to be a standard ohmic contact formation mechanism in Ti-containing schemes, AlN interfacial layer formation, Al-Au-Si solid solution formation, and/or Mo silicide and Ti silicide formation have been observed.[13] While direct contact of nonuniform TiN protrusion to the two-dimensional electron gas (2DEG) was responsible for the ohmic contact formation of Ti/Al/Mo/Au, a uniform and thin AlN formation [Fig. 2(b)] was responsible for contact formation of the schemes that contained optimized amount of Si. An intermediate case has been identified with the penetration of Al-Au-Si solid solutions to depths beyond the AlGaN/GaN heterointerface in the same fashion as the TiN protrusions. These complex conditions will be analyzed in the presentation.



(a)



(b)

Fig. 2 STEM images of Si-containing Ti/Al/Mo/Au samples with (a) unoptimized and (b) optimal amount of Si.

5. References

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