Ohmic contact formation for HEMT device: how to avoid AlN formation in an Al/Ti/Si_3N_4 thin film system

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Ohmic contact formation in HEMT Power GaN device is one of the key aspects for On Resistance (Ron) improvement. The performance of the ohmic contact is influenced by the type of metal stack, the passivation layer in contact with the AlGaN/GaN heterostructure and the thermal treatment used to activate the ohmic contact. In this work we would like to present a study involving these factors, showing some peculiar reactions occurring among the different materials during thermal treatment activation.
Starting from the passivation layer, four different silicon nitride (SiN_x) layers were prepared by means of PECVD technique (Plasma Enhanced Chemical Vapor Deposition) through the modulation of some process parameters during the deposition. Fourier Transform Infrared Spectroscopy (FTIR) measurements were carried out to qualitatively determine the concentration of the Si-H and N-H bonds in the nitride films. These layers were then integrated as AlGaN passivation layers in AlGaN/GaN HEMT. Device process flow continues with the fabrication of the ohmic contacts with an Al metal layer deposited through Physical Vapor Deposition (PVD) technique. The metal stack comprises also a thin Ti barrier as bottom layer and a cap layer of Ti/TiN, while the activation is done with a thermal treatment above 500°C. The post-annealing visual inspection showed high roughness and defectivity in the ohmic contact devices prepared with the Si-rich SiN_x. Physical analysis such as TEM and EDX revealed that the nitride layer in contact with the metal stack was completely converted into AlN (Fig. 1). It has been observed that by going from Si-rich to to N-rich nitrides, the conversion of SiN_x into AlN decreases. This phenomenon can be explained as the result of two reactions:

1. During the thermal treatment activation, the Ti barrier reacts with the Si contained in SiN_x. It's reported that above a certain thermal budget the reaction between Ti and SiN_x leads to the formation of Ti silicides, or Si and TiN at interface [1]. As a result, the Ti barrier disappears, and alloys of Ti-Al-Si are formed in the Al metal.

2. Without a proper metal barrier, the reduction of SiN_x by Al can take place, forming AlN and Si (H_{298K}= -126kcal/mol)^2 [2].

   $4Si_3N_4 + Al \rightarrow 4AlN + 3\,Si$

The occurrence of this sequence of reactions is unwanted not only for morphological reasons, but also for the electrical performance of the device as described in the paper.
Indeed, nitrogen rich layers enhance the formation of Ga-N bonds, reducing Si-Ga and Si dangling bonds, thus alleviating leakage currents [3].
However, the nitride stoichiometry is not the only factor involved in the formation of AlN, also the metal layers and the following thermal budget have a significant role. We studied a solution to have an AlN free ohmic contact through the combination of a N-rich SiN_x layer and a proper modulation of the metal stack. The goal is to preserve the Ti layer, so that it is not entirely consumed by the reaction with Si; the Ti acts as a separation between Al and SiN_x, avoiding the starting of reaction 2.

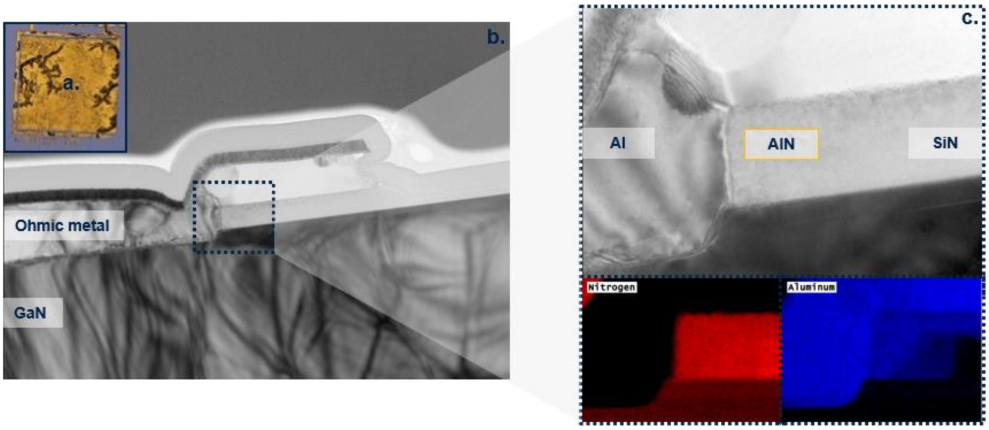

Figure 1 - Optical microscope top view of the ohmic contact after the thermal treatment showing the metal roughness (a). TEM cross section of the ohmic contact (b). Zoomed TEM image of the contact side and EDX analysis showing AlN formation at Al/Ti/ SiN_x interface (c).

References

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