SIMS DEPTH PROFILING OF METALLIZATION CONTACT LAYERS FOR AlGaN/GaN HETEROSTRUCTURES

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1. Introduction

The heterostructures based on GaN are very important for the fabrication of high frequency microelectronic devices like high electron mobility transistors (HEMTs) and their applications in microelectronics. The counterpart for the GaN is mainly the AlGaN, which provides the formation of the two dimensional electron gas (2DEG) at the interface between these two layers due to the spontaneous and piezoelectric polarization. For the device fabricated from the heterostructure it is necessary to deposit metallic contacts. For the deposition of the metallization layers is possible to use various methods like evaporation, sputtering or different vacuum- chemical- electrolytic deposition techniques. To find the appropriate metallization system for room and high temperature application of the AlGaN/GaN heterostructures is a key issue in the process technology of the HEMTs. To achieve good ohmic contacts with low resistance the metallization scheme parameters optimization is necessary. The most used is the Ti/Al based metallization for n-type GaN and related compounds [1]. This scheme can be improved using Au on the top like Au/Ni/Al/Ti system [2], or with modifications in the semiconductor metal interface with Nb layer [3]. Based on conventional Au/Ni/Al/Ti scheme, metallic layers can be deposited by conventional evaporation methods or by pulsed laser deposition (PLD) [4]. The morphology of the metallic layers is depending on the method of preparation. Also the thickness variation and the post-deposition temperature handling operations could change the metallic contact properties.

The Schottky barrier height (SBH) commonly depends on the difference between the work function of the metal and electron affinity of the semiconductor. More simply, whether the result will be ohmic or Schottky type depends mainly on the metal work function and the wide bandgap semiconductor. While for the ohmic contact behaviour the metal stack with SBH as low as possible is needed, in the case of the Schottky contact metals with higher SBH are preferable. For the high temperature applications also the conducting metal oxides of metals like Ni, Ru and another metallic contact layers are possible to use [5], what we can demonstrate by Ni [5] and Ir contacts deposited onto AlGaN/GaN heterostructures [6].

This contribution deals with Secondary Ion Mass Spectrometry (SIMS) depth profiling for metallic structure characterization as well as the electrical and capacitance measurements for evaluation of the electric parameters of prepared metallic contacts.

2. Experimental Details

The most common ohmic metallization scheme for AlGaN/GaN is the Au (100 nm), Ni (50 nm), Al (70 nm), Ti (10 nm) stack. Using of PLD at 355 nm (3rd harmonic Nd:YAG) Au/Ni/Al/Ti and Au/Pt/Al/Ti metal stacks was prepared and subsequently annealed at various temperatures in range from 300°C to 850°C. The temperature handling is important to reach the optimal conditions. Very similar is the metallization scheme with inserted layer of Nb (20 nm) between the interface of the slightly modified metallic stack Au (50 nm), Ni (40 nm), Al (100 nm), Ti (20 nm) and the AlGaN/GaN heterostucture [3]. This stack was alloyed at 850°C for 35 s. For the high temperature applications and Schottky contact type metallization Ni [5] and Ir oxide layers are used [6]. For this purpose, 15 nm Ni or Ir was evaporated by electron beam evaporation method and subsequently were the metallic layers annealed. Thermal oxidation of Ni contact layer was performed in O_2 ambient using RTA at 500, 600, 700, and 800°C for 1 min. This leaded to creation of oxidized layers, which were our interest of investigations by the time of flight based SIMS instrument (Ion-TOF) with high energy Bi^+ primary source. For depth profiling the high energy pulsed primary ion source (25 keV) was combined with low energy sputter source at 1 keV (Cs^+).

3. Results

In the case of Au/Ni/Al/Ti ohmic metallization scheme it is necessary to compare the contact structures annealed at various temperatures (in N_2 atmosphere) with the not annealed sample. The fig. 1a reveals the SIMS depth profile for not annealed Au/Ni/Al/Ti metallization system in negative polarity secondary ions. The depth profile shows the elements deposited to the AlGaN/GaN heterostructure and almost all interfaces. For comparison the positive polarity SIMS depth profile are shown in fig. 1b.

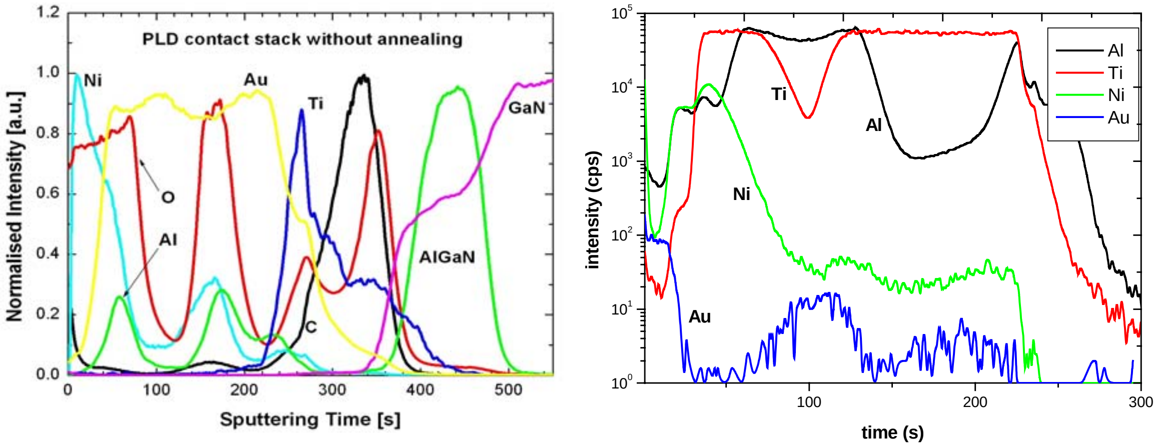

Fig.1: *SIMS depth profile for Au/Ni/Al/Ti not annealed metallization stack in a) negative polarity secondary ion and b) positive polarity secondary ion.*

This small comparison shows also the secondary ion yield differences in both polarities. The electrical properties can be characterised by the Transmission Line Method (TLM) and I-V measurements. The not annealed metal stack has Schottky contact properties. The annealed metal stacks at 750°C have linear I-V with ohmic properties and rezistivity values $R_s = 420\ \Omega$ and $R_k = 7.2\ \Omega$ mm. The R_s values are increasing to 1200 Ω and 1436 Ω at 800°C and 900 °C respectively. The lowest R_k value with 3.1 Ω mm was measured at 800°C and at 900°C the value increased to 10 Ω mm. Similarly the Au/Pt/Al/Ti showing Schottky type for not annealed and with high R_s at 650°C and lower $R_s = 236\ \Omega$ with $R_k = 132\ \Omega$ mm at 850°C.

The annealed Au/Ni/Al/Ti metallization structures in a view of SIMS depth profiling shows the differences in the annealing temperature gradients like in Au profile, Fig 2.

The modified new ohmic contact metallic system with 20 nm Nb layer added to the interface leads to improvement of both electrical parameters and surface morphology to the conventional ohmic contact system investigated by SIMS depth profiling and by Auger Electron Spectroscopy, Fig. 3 [3].

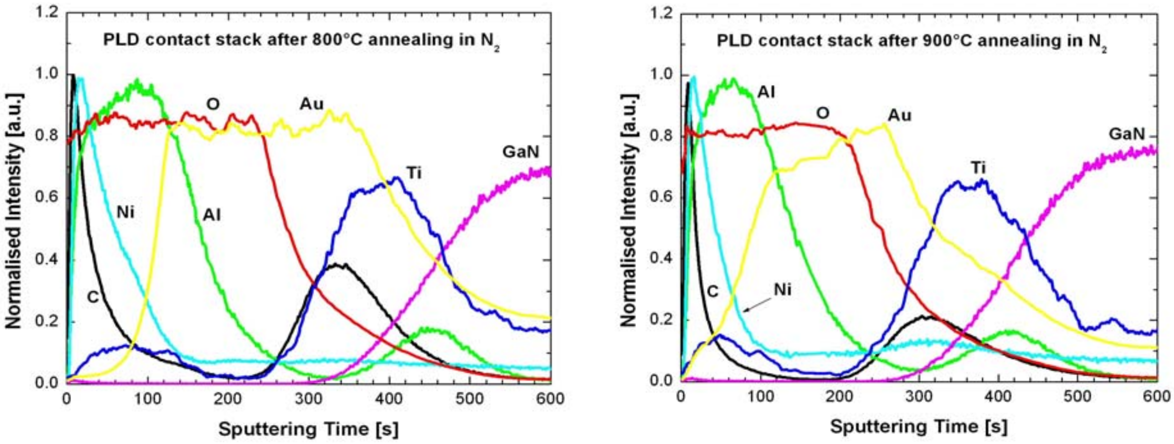

Fig.2: *SIMS depth profile a) for Au/Ni/Al/Ti metal contact system annealed at 800°C and b) after annealing at 900°C in N_2 atmosphere.*

After the contact system with Nb interlayer was annealed at optimal annealing conditions, the AES profile shows significant intermixing, fig. 3a. The Au and Ni penetrate and diffuse through the Al/Ti layers and the Ti with Nb diffused into the surface of the contact system. The SIMS depth profiling was used detect the metal nitride phases (AlN, TiN, NbN, and NiN on the interface) created on the interface after annealing responsible for the ohmic contact behavior, fig. 3b [3].

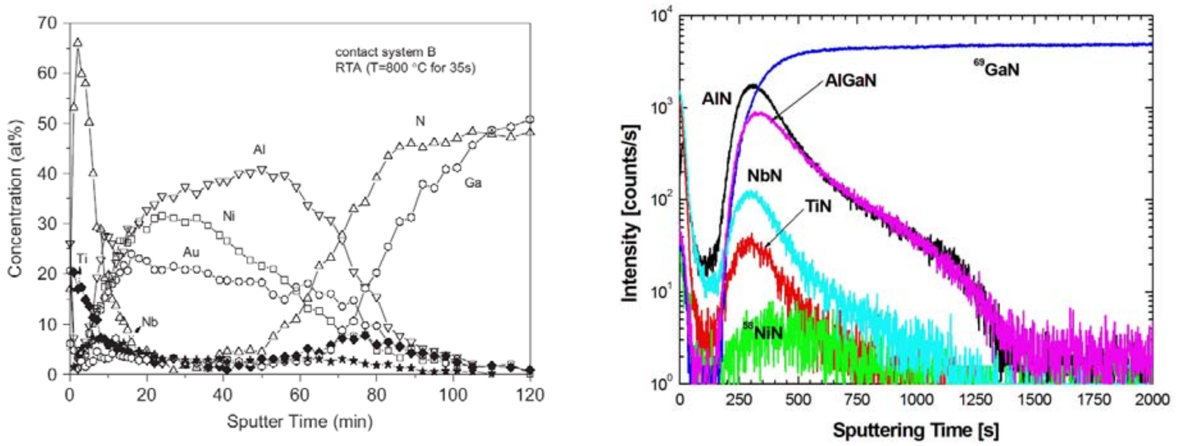

Fig.3: *a) AES depth profile of Au/Ni/Al/Ti with Nb interlayer after optimal thermal formation [3] and b) SIMS depth profile of formed metal nitride phases in the metal contact system at 850°C for 35 s.*

For the high temperature performance of metallic contacts high Schottky barrier height and excellent thermal stability are necessary. The SIMS depth profiles of such type of metallic contacts are shown in fig. 4a. The formation of NiO through the whole contact layer thickness (15 nm) is observed for oxidation after 500°C for 60 s. Ga atoms predominantly outdiffused through the Ni layer and formed GaO_x. Similarly the not annealed Ir contact SIMS depth profile shows relatively small ion yield from the metallic Ir, fig. 4b. After the oxidation process at 500°C in O_2 the SIMS depth profile shows higher yield of Ir and IrO, which are partially diffused into the AlGaN layer. The higher temperatures for annealing (800 °C) causes higher diffusion of Ir, IrO, which almost diffuse into the AlGaN layer.

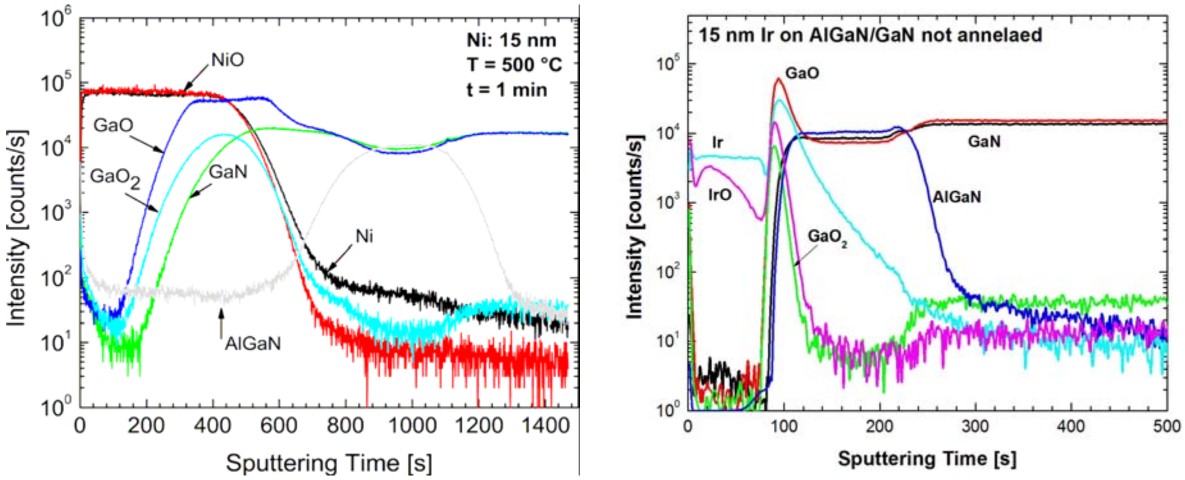

Fig.4: *a) SIMS depth profile of NiO interface formed by thermal oxidation of Ni at temperature of 500°C for 1 min. [5] b) SIMS depth profile with not annealed Ir layer.*

4. Discussion

This contribution is focused to SIMS depth profiling of different metallization stacks for AlGaN/GaN heterostructures. The Au/Ni/Al/Ti structure is after the deposition a Schottky type contact, which can be changed by with annealing at 650°C to ohmic behavior. During thermal annealing above 650°C the heat energy delivered causing diffusion of nitrogen atoms from AlGaN, which is followed by forming of nitrogen vacancies in the AlGaN. These vacancies are acts as shallow donors and on the surface of AlGaN below the contact are forming an area with high concentration of electrons. This highly doped n^{++} area causes the narrowing of the barrier at the interface and the main transport mechanism will be then the tunnelling, characteristic for the ohmic behavior. The intermetallic nitrides (TiN, AlN, NbN) are necessary for nitrogen vacancies formation. They are responsible for low ohmic contact resistance values and perfect surface morphology. The NiO contact layers have shown that they could be good candidates for thermally stable and high Schottky barrier height contacts for AlGaN/GaN HEMT devices. The annealed Ir contact shows slightly higher indiffusion into the AlGaN layers.

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