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The improvement of ohmic contact of Ti/Al/Ni/Au to AlGaN/GaN HEMT by multi-step annealing method

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ABSTRACT

A multi-step rapid thermal annealing process of Ti/Al/Ni/Au was investigated for ohmic contact of AlGaN/GaN high electron mobility transistor (HEMT). The samples were studied by Transmission Line Model (TLM), Scanning Electron Microscopy (SEM), Auger electron spectroscopy (AES) and X-ray Photoelectron Spectroscopy (XPS) measurements. By the multi-step annealing process, the specific contact resistance was decreased from $10^{-5}\ \Omega\,cm^2$ level to $4–3 \times 10^{-6}\ \Omega\,cm^2$ and the surface morphology was improved. The AES measurements showed that the limitation indiffusion of Au and outdiffusion of Al were account for the surface morphology improvement and the surface Fermi level towards the conduction-band edge resulted in a lower specific contact resistance.

1. Introduction

AlGaN/GaN high electron mobility transistors (HEMT) are excellent candidates for high power applications at microwave frequencies and high-temperature electronic devices [1,2]. One critical demand for high power application is materials with high temperature stability [3]. High quality, low-resistance ohmic contacts are a vital part of AlGaN/GaN HEMT technology [4], in addition, these ohmic contacts are required to have high thermal stability and smooth surface morphology to ensure dependable high temperature performance and to facilitate sharp edge acuity for short channel devices, respectively [5]. The development of contact metallizations for such device applications has relied, for the most part, on processes adopted for GaN epilayers, for which multilayer contacts have been utilized to obtain low-resistance ohmic performance. Among the many contact metallization schemes reported in the literature, Ti/Al-based contacts are the most widely utilized. Ti based metallization schemes reduce contact resistance by forming an intermetallic alloy with a low work function on GaN and AlGaN surfaces [6]. In this paper, a multi-step annealing scheme of Ti/Al/Ni/Au was developed, standard Transmission Line Model (TLM) and Scanning Electron Microscopy (SEM) measurements are investigated on AlGaN/GaN structures [7].

2. Device processing and experimental measurements

The AlGaN/GaN heterojunction structure is grown on a 2 in. c-face sapphire substrate by metal organic chemical vapor deposition (MOCVD). The layer structure consists of a 1 μm thick nondoped-GaN layer and 25-nm $Al_{0.3}Ga_{0.7}N$ barrier layer which is doped with silicon of approximately $2 \times 10^{18}\ cm^{-3}$. The measured room temperature Hall mobility and sheet carrier concentration are $1150\ cm^2/V\,s$ and $1.2 \times 10^{13}\ cm^{-2}$, respectively. The Ti(20 nm)/Al(90 nm)/Ni(55 nm)/Au(45 nm) (sample A), Ti(20 nm)/Al(120 nm)/Ni(55 nm)/Au(45 nm) (sample B) and Ti(20 nm)/Al(150 nm)/Ni(55 nm)/Au(45 nm) (sample C) contacts are deposited by an e-beam evaporation system. Before deposition, the surfaces of the samples were treated by the $HF:HCl:H_2O = 1:1:8$ solution to remove native oxide layer. Then the as-deposited samples are introduced into a rapidly thermal processing (RTP) system for annealing in N_2 ambient. The specific contact resistance was recorded by TLM measurements, the contacts of which are rectangular (90 × 90 μm), separated by 5, 7, 9, 11, 13, 15 and 20 μm.

3. Results and discussion

Fig. 1 shows a typical behavior of the extracted R_c values as a function of the annealing temperature for the three ohmic contact systems analyzed. As shown in Fig. 1, the contact resistance ρ_c decreases as the annealing temperature increases from 600 °C to 830 °C and the lowest value of $8.4 \times 10^{-6}\ \Omega\,cm^2$ is obtained in sample B. In order to discern the annealing temperature influence

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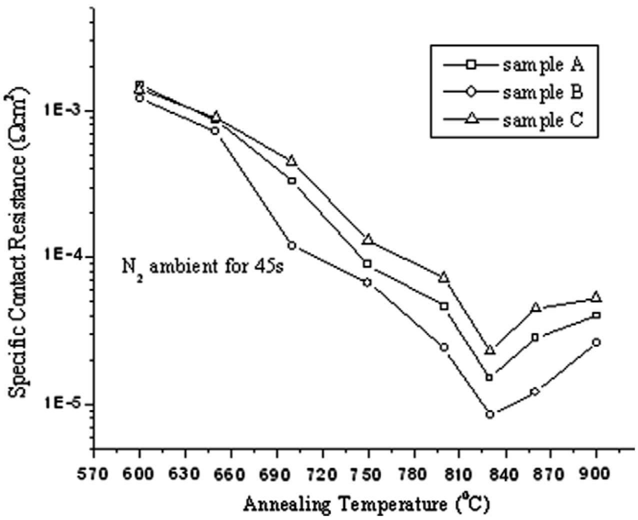

Fig. 1. Dependence of ρc of Ti/Al/Ni/Au on annealing temperature for 45 s.

on the ohmic contact resistance, Auger electron spectroscopy (AES) experiments are made of sample B. The separate layers of Ti, Al, Ni and Au on AlGaN epilayer can be clearly seen in the as-deposited profile (as shown in Fig. 2a). When the annealing temperature is low to some extent, the reaction between Ti and AlGaN epilayer results in the TiN , which has a high potential barrier between TiN and AlGaN, but the diffusion of Al atoms through the Ti layer to form the low work function Al–Ti of the intermetallic phase is limited (as shown in Fig. 2b), the ohmic contact property is poor and the specific contact resistance is high. When we compared Fig. 2c with Fig. 2b, the atom percentage of Al is up to 23 other than 15 after sputtering the ohmic contact for 50 min, it is obvious that much Al diffuses to AlGaN surface and reacts with Ti as the temperature increases from 750 °C to 830 °C, so the contact resistance decreases. When the annealing temperature increases beyond the critical value (as shown in Fig. 2d), the significant intermetallic diffusion have occurred, notably indiffusion of Au towards AlGaN interface for the atom percentage of Au is decreased from 35 to 24 after sputtering 7 min while it is equal to 20% after sputtering 30 min and outdiffusion of Al towards the contact surface for the

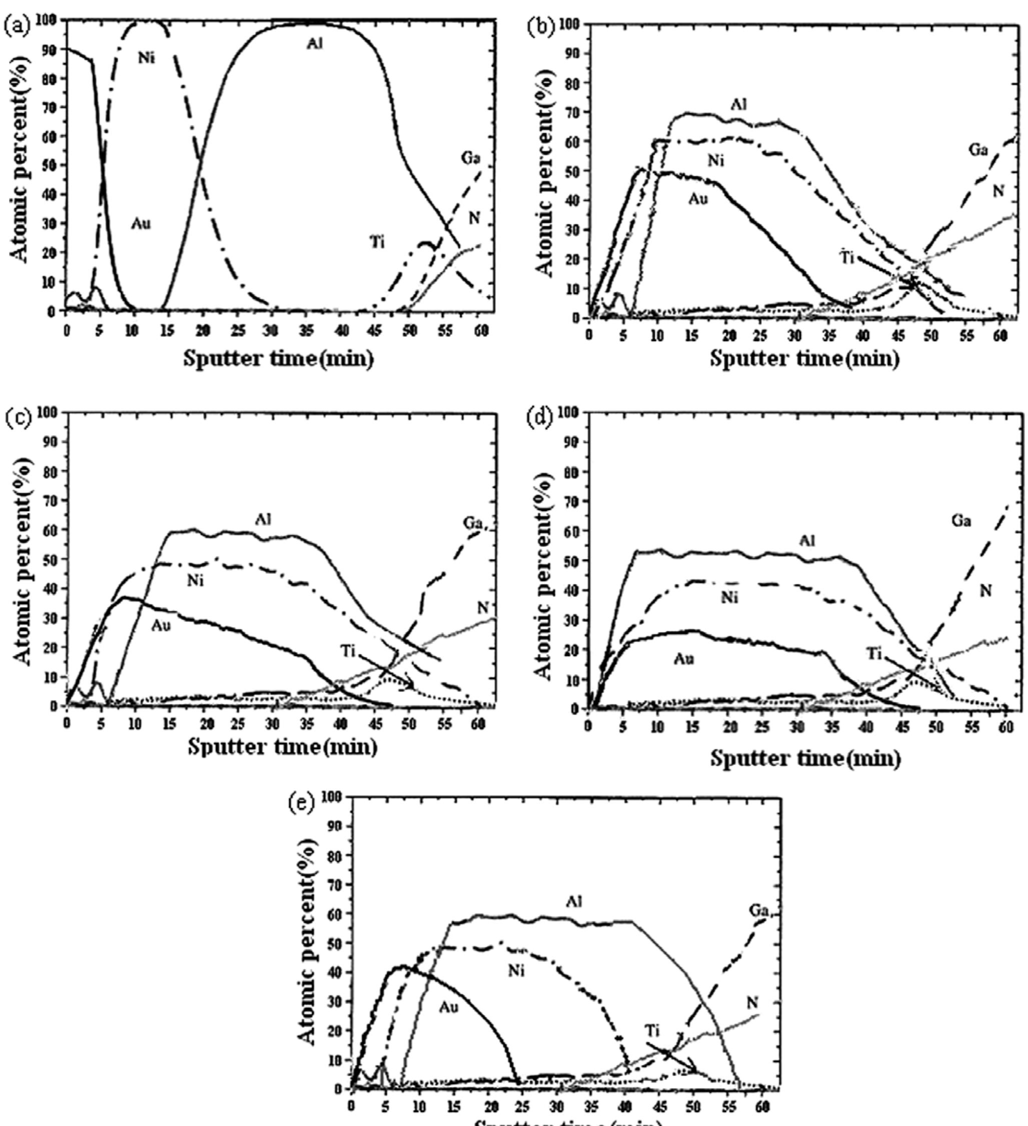

Fig. 2. AES depth profiles of Ti/Al/Ni/Au contacts on AlGaN as deposited (a), annealed at 750 °C for 45 s in N_2 (b), annealed at 830 °C for 45 s in N_2 (c), annealed at 900 °C for 45 s in N_2(d), and annealed by multi-step (e).