Electrical properties of Pd-based ohmic contact to p-GaN with Au diffusion barrier

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In recent years, groupIII-nitrides such as GaN, InN etc, have drawn much interest as a promising material for the fabrication of efficient blue emitting devices, laser diodes, and high temperature/high power electronic devices because they have direct wide band gap (3.4eV at R.T.) and a high saturation electron velocity (3×10^7 cm/s). InN, GaN, AlN and their alloys are all wide band gap semiconductors and have wurtzitic and cubic polytypes. This makes a wide range of band gaps available for electronic and optoelectronic devices. But this wide band-gap property also makes the device application difficult from the aspect of p-type ohmic contact formation. As GaN device technology advances, more stringent demands will be made on the reproducibility, uniformity, thermal stability, and high temperature operation of the ohmic contacts to GaN-based devices. For n-GaN, Al/Ti-based ohmic contacts have been used widely as n-type ohmic contact and it showed extremely low contact resistance. On the other hand, no satisfying ohmic contacts to p-GaN have been developed because the maximum doping concentration of p-GaN was restricted under $10^{18}cm^{-3}$ and there is no metals with high work function comparable to the electron affinity of p-GaN. In order to obtain the low resistance ohmic contact to p-GaN, the use of thin layer of a reactive transition metal such as Pd or Ni may be helpful because these transition metals can easily remove the native oxide of the GaN surface. However, applying these transition metals with Au layer for ohmic contact materials, thermal stability of the contact system was degraded at relatively high temperature due to in-diffusion of Au toward the GaN interface. Ta-RuO_2 layer was reported previously to effectively suppress the oxygen in-diffusion toward the substrate and have high resistance for oxidation due to its strong network amorphous structure. So we evaluated this materials as the Au diffusion barrier in this study.

In this study, we have investigated the electrical properties of Pd-based ohmic contact to Mg-doped p-GaN grown by MOCVD with or without the Au diffusion barrier, before and after annealing at various annealing temperatures. When the Au diffusion barrier was introduced to the contact system, the electrical properties of the contact was much enhanced. In order to clarify the ohmic contact formation mechanism of Pd-based ohmic contact, materials analyses were carried out and it would be related to the electrical properties.

GaN was grown epitaxially on (0001) sapphire substrate by MOCVD and Mg-doped with the carrier concentration of about $4.4\times10^{16}cm^{-3}$ and the hole mobility was $9cm^2/Vs$. All the metal layers of Au(1000Å)/Pd(500Å)/Mg(500Å)/Pd(300Å) were deposited by an electron beam evaporator without breaking the vacuum and base pressure was below 1×10^{-6}Torr. In Au(1000Å)/Ta-RuO_2 (~1000Å)/Pd(300Å)/p-GaN contact system, Ta-RuO_2 layer, which was used for the Au diffusion barrier was prepared by using RF magnetron sputter. Prior to metallization, the samples were etched in boiling aqua regia (HNO_3:HCl=1:3) solution for 10min followed by DI water rinse to remove the possible native oxides. In order to evaluate the ohmic characteristic, I-V measurement was carried out between two front surface circular contacts and all the contacts were patterned during deposition using a stainless steel shadow mask. The interspacing of metal contacts (0.5mm diameter) was 0.5mm. Following each heat treatment, I-V characteristic was measured over a range of -4V to +4V using HP 4145B semiconductor parameter analyzer. The synchrotron x-ray scattering measurements were carried out at beamline 5C2 at Pohang Light Source (PLS) in Korea.

In order to check the ohmic behavior, I-V measurements were carried out for the two samples before and after annealing at various annealing temperatures and the results were shown in Fig. 1 and Fig.2 respectively. As shown in Fig. 1, linear I-V characteristic was obtained at the as-deposited state. After annealing at 300℃, the total resistance was increased slightly and after annealing at 600℃, linear I-V characteristic was degraded. However, the contact system with Au diffusion barrier showed the perfect ohmic characteristics and total resistance of the contact had the similar value over all range of annealing temperatures.

In order to investigate the diffusion behavior of each elements of Au(1000Å)/Pd(500Å)/Mg(500Å)/Pd(300Å)/p-GaN system and Au(1000Å)/Ta-RuO_2(~1000Å)/Pd(300Å)/SiO_2/Si system, AES depth profile was carried out before and after annealing at various annealing temperatures and the results were shown in Fig 3 and Fig4 respectively. The distinct interfaces of all metal layers were clearly shown at the as-deposited state. In the Au/Pd/Mg/Pd/p-GaN system, after annealing at 500℃ for 30s, Au began to diffuse toward the GaN interface through the metal layer and the increase of total resistance in I-V characteristic was related to Au diffusion. After annealing at 700℃, Au, Mg and Pd were intermixed each other completely. In Au/Ta-RuO_2/Pd/p-GaN system, however, as shown in Fig. 4., Au was not expected to diffuse toward the GaN interface and, even after annealing at 700℃, Au and Pd were not expected to intermixed each other.

In spite of large theoretical Schottky barrier height between Pd and p-GaN, Pd-based contact showed perfect ohmic characteristic even before annealing and it might be related to the Pd/p-GaN interface. In order to investigate Pd/p-GaN interface more precisely, we used the synchrotron X-ray radiations. Only (111) peak of Pd was observed and it indicated that Pd (111) grew epitaxially on GaN (0001). In order to examine the in-plane epitaxial quality of Pd film, phi scan of Pd (111) plane was carried out and Pd (111) plane was well aligned with respect to GaN (0001) with 6 fold symmetry and it indicated that the Pd metal layer was grown epitaxially on GaN.

According to the above results, we can conclude that good in-plane epiatxial quality play an important role in room temperature ohmic behavior. But, after annealing at relatively high temperatures, the electrical properties of the ohmic contact system where Au was introduced, without the Au diffusion barrier, was degraded due to in-diffusion of Au toward the GaN interface. From the results of the AES depth profile of the Au(1000Å)/Ta-RuO_2(~1000Å)/Pd(300Å)/SiO_2/Si system, the Ta-RuO_2 layer effectively suppressed in-diffusion of Au and this result was related to the good electrical properties of the Au(1000Å)/Ta-RuO_2 (~1000Å)/Pd(300Å)/p-GaN system at relatively high annealing temperatures.

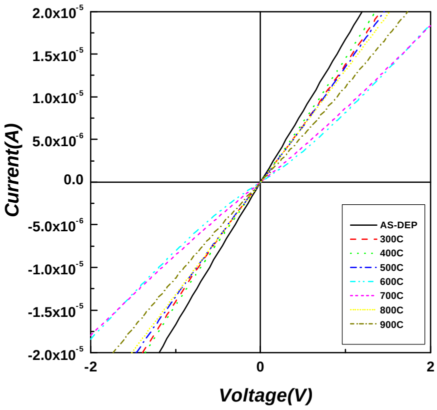

Fig. 1. I-V curve as a function of annealing temperature.

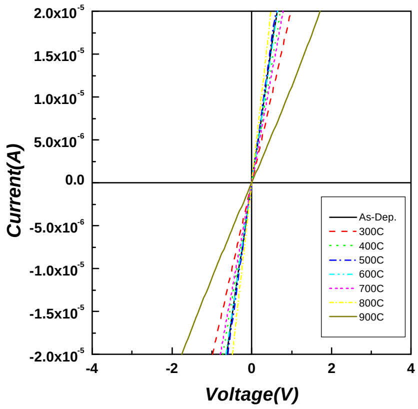

Fig. 2. . I-V curve as a function of annealing temperature

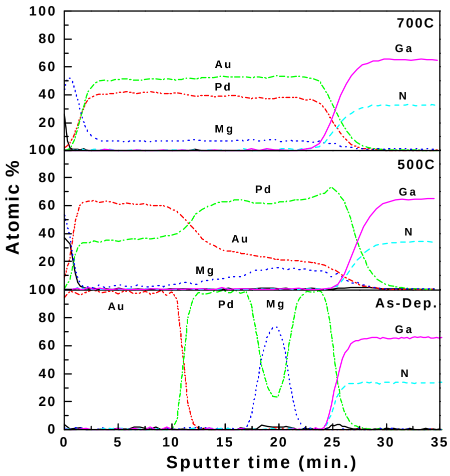

Fig3. AES depth profile of Au/Pd/Mg/Pd/p-GaN

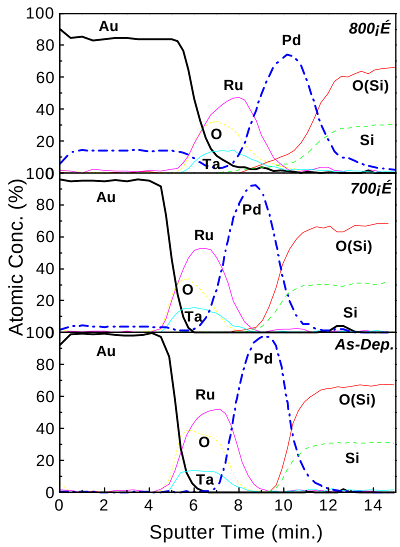

Fig4. AES depth profile of Au/Ta-RuO2/Pd/SiO2/Si