XPS and AES study of Au/GaN and Au/Cr/GaN Contacts

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(Received October 12 1998; accepted January 11 1999)

The Au/GaN and Au/Cr/GaN have been studied by means of interfacial reaction and band bending using XPS and AES. The interfacial reaction of Au overlayer with GaN does not occur even after annealing to 500℃, but Au results in strong clustering after annealing to 500℃. In case of using thin Cr buffer layer before Au deposition, CrN compounds, Au-Cr and Cr-Ga alloy were formed after 500℃ annealing, but there is no Au clustering. The Schottky barrier heights measured by XPS were 0.92eV, 2.15eV for Au overlayer on n-GaN and p-GaN, respectively. The Au/Cr/GaN Schottky barrier height after annealing to 500℃ is close to that of Au/GaN at room temperature.

1. Introduction

The wide-band-gap semiconductors such as GaN, AlN, InN are currently of interest [1] in the fabrication of various electronic components. In particular, GaN is useful as an optoelectronic material in light-emitting or -detecting devices, ultraviolet detectors[2-3] and high power/high temperature electronics[4-5].

In an earlier attempt to achieve ohmic contacts on GaN epilayers, Foresi et al.[6] used Al and Au contacts with 575℃ annealing. However, the specific contact resistivities of these contacts were known to be relatively poor.

We have studied interfacial reaction and barrier heights of Au/GaN and Au/Cr/GaN by X-ray Photoelectron Spectroscopy(XPS) and Auger Electron Spectroscopy(AES).

2. Experiment

GaN films were grown by metal-organic chemical-vapor deposition(MOCVD) on sapphire substrate. The carrier concentrations of these samples were 9.0×10^{17} cm^{-3} and 1.0×10^{17} cm^{-3} for n-type and p-type GaN respectively. Before mounting into deposition chamber, GaN sample was etched for a few minutes respectively by alcohol, acetone and diluted hydrofluoric acid to remove gross surface contamination. The Au(30Å) and Au(30Å)/Cr(10Å) were deposited using thermal evaporator with deposition velocity 1Å/20sec at base pressure 2.0×10^{-9} Torr under ultra high vacuum. The coverages were calibrated using a quartz thickness monitor. Samples were mounted on thin Ta sheet and heated up to 500℃ by resistive heating of Ta sheet. XPS measurements were performed by a VG-ESCALAB 210 system, using a monochromatic X-ray source(Al K_α, $h\nu$=1486.6 eV) and the hemispherical energy analyser. Band bending and interfacial reaction were monitored in situ by XPS and AES depth profiling.

3. Results and discussion

3-1 Interfacial reaction of Au and Au/Cr overlayers on GaN

Au is one of promising metals for achieving an ohmic contact with p-GaN because of its high work function(5.1eV). Fig.1 shows XPS spectra of Au overlayer(30Å) on p-GaN obtained from as introduced, pre-annealed, as Au deposited and post-annealed surfaces, respectively. The binding energy shifts of Ga3d core levels at each step are due to band bending rather than chemical reaction. This will be shown at the band bending section. There is no metallic Ga near 19eV at Fig.1(c) and Fig.1(d). This implies that the Au overlayer does not

disrupt GaN at room temperature and after annealing to 500℃. In Fig.2, the intensity of Au4f decreases clearly after post-an-

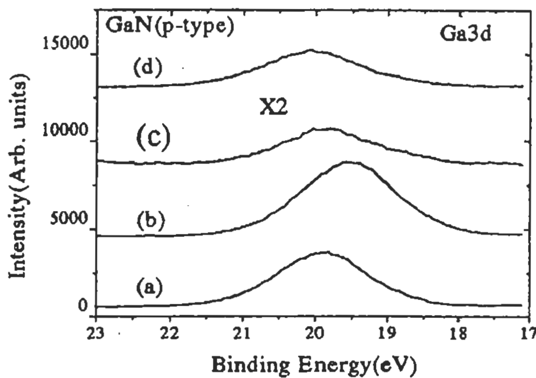

Fig1. XPS spectra of Ga3d core level on Au/p-GaN (a)As introduced, (b)Pre-annealed(500℃), (c)Au 30Å deposited, (d)Post-annealed(500℃) surfaces

nealing without peak position shift, which is attributed to the formation of Au island on GaN. It was also confirmed by Auger depth profiling as shown in Fig.3. In the case of 30Å of Au deposition, there is no crossover between Ga and N intensity not only near the interface but also in deeper

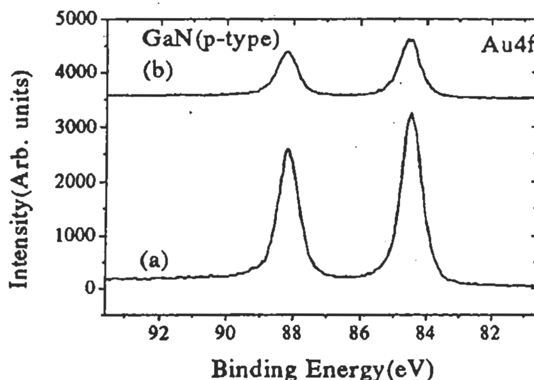

Fig2. XPS spectra of Au4f core level on Au/p-GaN (a)Au 30Å deposited, (b)Post-annealed(500℃) surfaces

layer. It means that Au does not react with GaN at the interface. In the case of 500℃ post-annealing, the Auger depth profile of Au is quite different from that of Fig.3(a) because of Au island formation. The island formation of Au after annealing to 500℃ was also confirmed by AFM image not shown here. Actually Au has been used for an ohmic contact metal in GaAs because it has not only large work function but also stable chemical properties at the interface, but the present problem is in the formation of island as increasing temperature. Therefore, we tried to solve it through using Cr as buffer layer. Fig.4 shows Ga3d core level

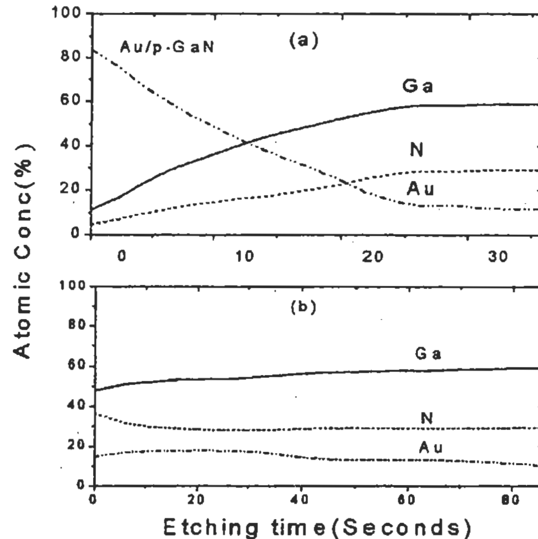

Fig3. AES depth profiling results on Au/p-GaN (a) Au 30Å deposited, (b)Post-annealed(500℃) surfaces

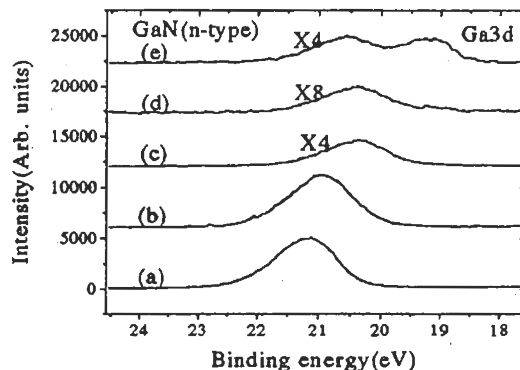

Fig4. XPS spectra of Ga3d core level on Au/Cr/p-GaN, (a)As introduced, (b)Pre-annealing(500℃), (c) Cr 10Å deposited, (d) Au 30Å deposited, (e)Post-annealed(500℃) surfaces

spectra obtained from Au/Cr/n-GaN surfaces after chemical etching, after pre-annealing(500℃), after Cr 10Å deposition, after Au 30Å deposition on Cr layer, and after 500℃ post-annealing, respectively. There is large difference at the metal core level of Au4f and Cr2p as shown in Fig.5. These spectra are more complicated than those for pure Au contact. Many phases exist at the interface dissimilar to that of single Au deposition. At the Cr2p core level spectra

((a)-(b)), there is no binding energy shift of Cr2p but the peak intensity decreased due to Au deposition. After post-annealing in Fig.5(c), there are many phases such as

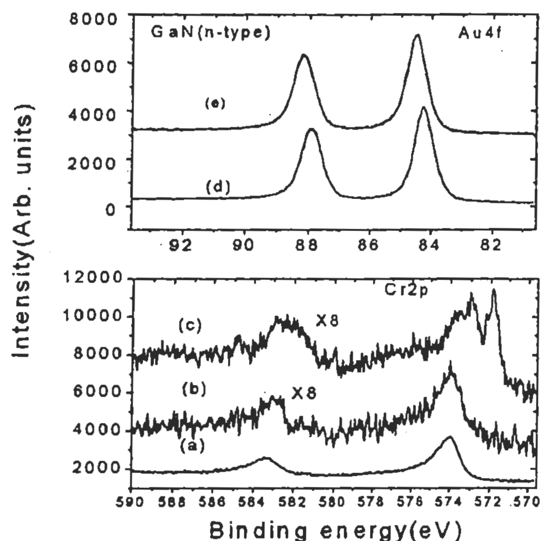

Fig5. XPS spectra of Au4f and Cr2p core level on Au/Cr/n-GaN (a)Cr 10Å deposited, (b) and (d) Au 30Å deposited, (c) and (e)Post-annealed (500℃) surfaces

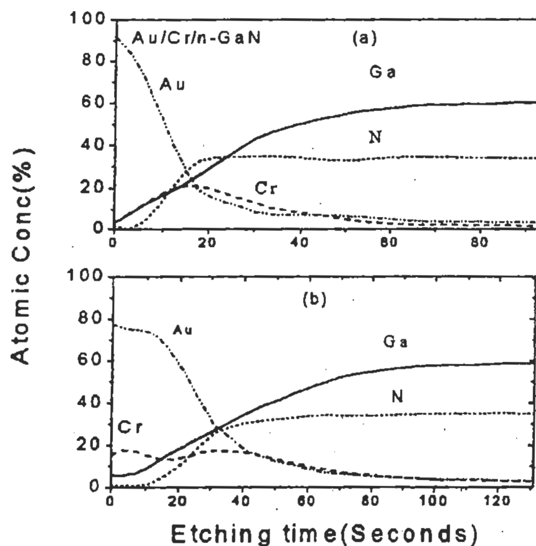

Fig6. AES depth profiling on Au/Cr/n-GaN, (a) After Au (30Å)/Cr(10Å) deposited, (b) Post-annealed(500℃) surfaces

metallic Cr, Cr-Ga alloy, Cr-Au alloy, and CrN compounds at 574, 573, 571.8 and 57 6eV respectively. In the Au4f spectra of Fig.5(d) and (e), the binding energy shifts because of formation of Cr-Au alloy after annealing, but the peak intensity does not change. From these results, we can conclude that thin Cr buffer layer is quite efficient to prevent Au from clustering. Fig.6 shows the results of AES depth profile of the Au/Cr/GaN before and after annealing. As can be seen in Fig. 5(c) and 6(b), the Cr-Ga and Cr-Au alloys are formed at the surface after post-annealing, but there is no remarkable change between as deposited and post-annealed cases in Fig.6, which is quite contrasting result to that of Au/GaN contact. From these results, we can conclude that thin Cr layer can be a useful buffer layer because of its function to prevent Au from clustering on GaN during annealing to 500℃. It was also confirmed by AFM not shown here.

3-2 Band bending

The Schottky barrier height is determined

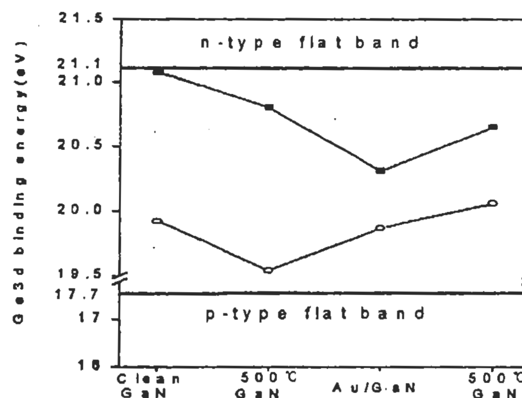

Fig7. The band bending of the Ga3d on the Au/n-Gan(—■—) and Au/p-GaN(—O—)

from the XPS data. All binding energies were measured with respect to the Fermi level. Ga3d core level was used for determining the Schottky barrier height because Ga3d is the most bulk-sensitive core level in GaN. In this study, we measured the Schottky barrier heights of Au and Au/Cr contact on n-type and p-type GaN surfaces. All GaN samples were annealed to 500℃ prior to metal deposition, which induced N vacancies would be created in the n-GaN near the interface due to N out-diffusion. This N vacancy acts as a donor [7]. In the p-GaN, H out diffusion by annealing makes Mg more active, which flattened the band of p-GaN. Fig.7 shows the changes of the Schottky barrier height in

Au contact with n-GaN and p-GaN. The Ga3d of the flat p-type band should appear at the binding energy of 17.7eV[8] and n-type at 21.1eV due to the band gap of 3.4eV. In the case of n-GaN, the Ga3d of well cleaned-sample appears at 0.03eV below n-type flat band, but the band bends by 0.5eV due to the N vacancy originating from the pre-annealing. After Au contact, The Schottky barrier heights of n-GaN and

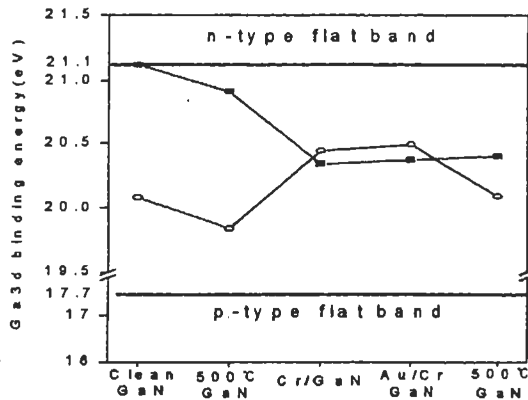

Fig8. The band bending of the Ga3d on the Au/Cr/n-Gan(—■—) and Au/Cr/ p-GaN(—O—)

p-GaN are 0.92eV and 2.15eV respectively. Considering that the ideal Schottky barrier heights of the Au contact are 1.0eV and 2.4eV, the present experimental results are in quite good agreement with those of ideal Schottky contact. But after post-annealing, bands of both n-type and p-type move to the higher binding energy side. Such changes of band are due to Au clustering at the surface. Such island formation during annealing after Au contact on GaN seems to be a big trouble for the metal contact. In the present study, therefore, the thin Cr buffer layer(10Å) was tried in order to make good Au contact without Au clustering. In Fig.8, after annealing to 500℃, the Schottky barrier height was 0.7eV and 2.53 eV for n-type and p-type, respectively. It is interesting to note that these values are close to those of Au contact on GaN at RT. We concluded that the barrier height after annealing still depend on the Au work function. Therefore, the problem of island formation for the Au contact on GaN can be partially solved by using the thin Cr buffer layer.

4. Conclusions

The Au contacts on GaN was studied by means of both the band bending and the interfacial reaction using XPS and AES depth profiling. In case of Au/GaN contact, Au does not react with GaN at the room temperature, but the island was formed after annealing to 500℃, which worsens the metal contact. The Schottky barrier height of Au/n-GaN and p-GaN were 0.92eV and 2.15eV, respectively, which are in good agreement with the ideal Schottky barrier heights. In case of Au/Cr/GaN contact, there appear three phases, CrN compound, Cr-Ga alloy, Cr-Au compound after annealing to 500℃, which does not induce island formation. The Schottky barrier height was similar to that of Cr/GaN before annealing, but after annealing, it become close to that of Au/GaN.

The present study was partially supported by ASSRC of Yonsei University, the academic research fund of Ministry of Education(BSRI-98-2433 and BSRI-98-2426), and KOSEF (981-0209-036-2).

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