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Interface Properties of Metal/n-GaN Schottky Contacts

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1. Introduction

GaN is the most promising material for optoelectronic devices performing in the blue-ultraviolet spectral regions as well as for high-temperature, high-power electronic devices. Development of technologies for high-quality and stable Schottky and ohmic contacts is absolutely necessary for the successful realization of these GaN-based devices. However, little is known at present about interface properties of metal/GaN system.

In this paper, interface properties of metal/GaN Schottky contact system were systematically investigated with a special focus on the correlation among electrical properties, contact formation processes and metal workfunctions.

2. Experimental

Si-doped n-type GaN layers ($5x10^{16}$-$1x10^{17}cm^{-3}$) grown on sapphire substrates by MBE were used. A series of high and low workfunction metals (Pt, Au, Ag and Sn) were deposited by two process, namely, a conventional vacuum deposition process and a novel *in-situ* electrochemical deposition process[1], and the results were compared. For vacuum deposition, surfaces were treated either in an NH_4OH solution for 15 min at 50℃ or in an $HF:HCl:H_2O$=1:5:5 solution for 1 min just before loading samples into the deposition chamber. The electrochemical process consisted of the controlled anodic etching of the GaN surface followed by *in-situ* metal deposition in the same electrolyte. HCl-based electrolytes containing metal ions were used. In the case of InP, this process resulted in formation of oxide- and stress-free Schottky interfaces with high Schottky barrier heights[1].

3. Results and Discussion

Figure 1 compares the XPS O1*s* and Ga3*d* spectra obtained from GaN surfaces before and after two kinds of surface treatments. The values of XPS integrated intensity ratios of O1*s* to N1*s* and Ga3*d* to N1*s* were summarized in **Fig.2**. Large amounts of O1*s* components existed on the surface before treatments. Significant decrease of the oxide components was observed after both of the two surface treatments. However, the detailed behavior was very different. Namely, after the NH_4OH treatment, a peak shift of Ga3*d* spectrum toward a lower energy and the reduction of the Ga3*d*/N1*s* intensity ratio took place. This can be interpreted in terms of removal of native gallium oxide layer, making the surface oxide-free and near stoichiometric (Ga3*d* / N1*s* = 0.55 corresponds to a stoichiometric surface). On the other hand, neither of these two changes took place

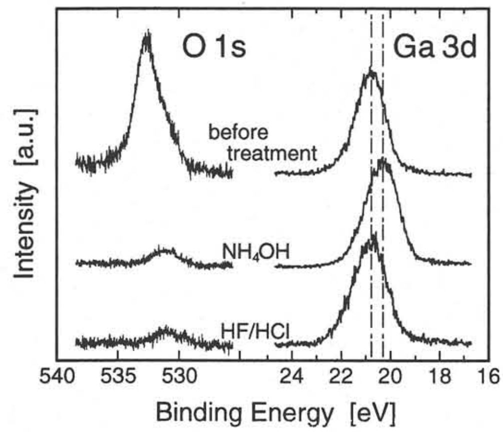

Fig.1. XPS O1*s* and Ga3*d* spectra of GaN surfaces.

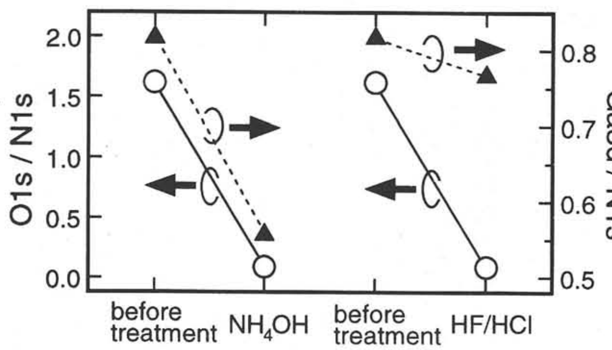

Fig.2. Integrated XPS intensity ratio of O1*s* to N1*s* and Ga3*d* to N1*s* at the GaN surfaces before and after treatments.

after the HF/HCl treatment. Furthermore, Cl-related XPS peaks appeared on the HF/HCl treated surface, indicating that a gallium chloride component was formed at the surface at simultaneously with oxide removal and gave a Ga-rich surface.

For the vacuum deposited diodes without surface treatment, poor and irreproducible I-V curves with high n-values were obtained. **Figures 3(a)** and **3(b)** show the I-V characteristics of the Schottky contacts formed by the vacuum deposition process after surface treatments. Almost all of the diodes exhibited ohmic-like characteristics after the HF/HCl treatment, as seen in **Fig.3(a)**. On the other hand, reasonably good thermionic emission characteristics with small n-values were realized on the diodes treated in the NH_4OH solution.

The XPS integrated intensity ratios of Ga3*d* to N1*s* obtained from the as-treated surfaces and the Ag/GaN and Au/GaN interfaces are summarized in **Fig.4.** For the diodes

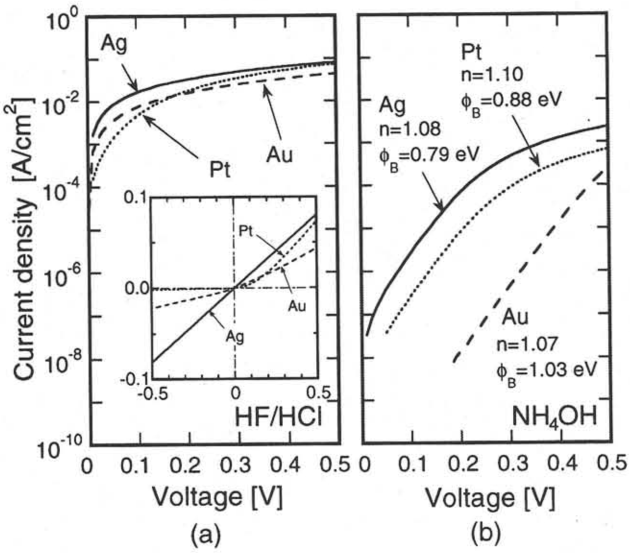

Fig.3. I-V characteristic of n-GaN Schottky diodes formed by vacuum evaporation process after (a)HF- and (b)NH_4OH-based treatments.

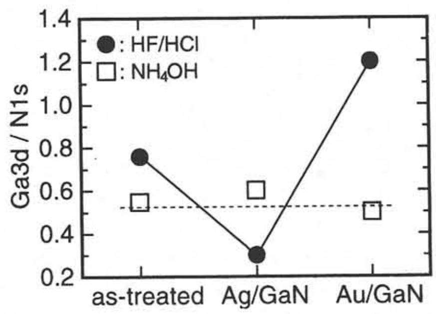

Fig.4. Change in integrated XPS intensity ratio of Ga3*d* to N1*s* before and after metal deposition.

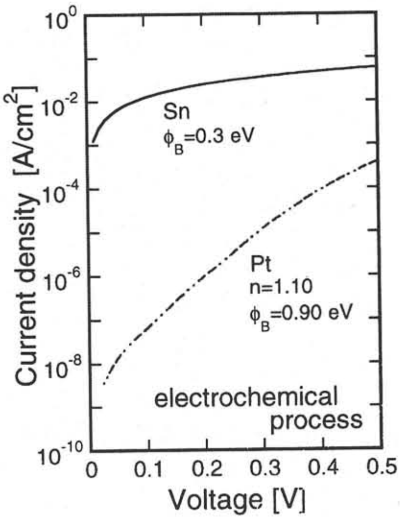

Fig.5. I-V characteristis of the electrochemically processed diodes.

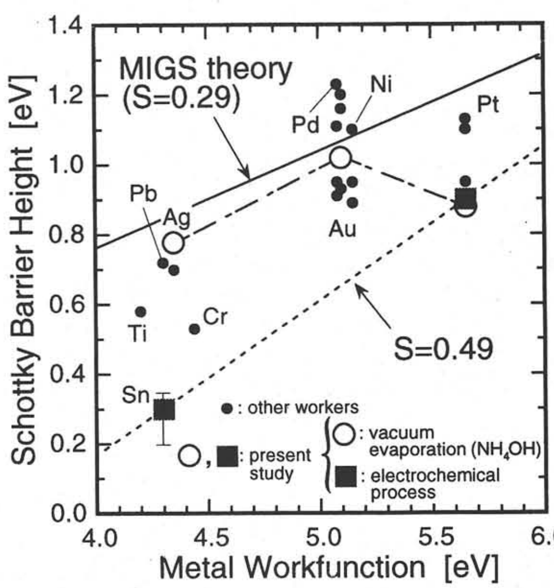

Fig.6. SBHs versus metal workfunction.

treated in the NH_4OH solution, the intensity ratio is almost the same before and after metal deposition, remaining nearly stoichiometric. On the other hand, the intensity ratio was drastically changed for HF/HCl treated diodes after metal deposition, strongly indicating that interfacial reactions took place during metal deposition, leading to formation of interfacial layers. This appears to the reason for the observed ohmic-like I-V characteristics.

The I-V characteristics of the Sn- and Pt-Schottky contacts formed by the electrochemical process are shown in **Fig.5.** An *in-situ* pulsed electrochemical etching was carried out, prior to pulsed-mode electroplating of metal. Here, strongly metal-workfunction dependent I-V behavior was observed.

Figure 6 shows the observed Schottky barrier height (SBH) values of n-GaN studied here versus the metal workfunction. Previously published data are also plotted in **Fig.6,** and all the data are compared with a theoretical line recently proposed by Kampen and Mönch[2] on the basis of the metal-induce gap state (MIGS) model. The results indicate that the electronic properties of GaN Schottky contacts depend strongly on the interface formation process and the MIGS model dose not seem to be applicable. The present electrochemical deposition process and the vacuum deposition process with NH_4OH treatment seem to be promising for formation of high-quality Schottky contacts to n-GaN. Particularly, a large slope parameter value, S, of 0.49 was obtained for the electrochemical process. An extremely low processing energy (several 100 meV at room temperature) of *in-situ* electrochemical process seems to have a capability of realizing stress- and disorder-free GaN Schottky interfaces with metal dependent SBHs similarly to the case of InP[1]. Thus, a further study may lead to formation of Schottky contacts with high SBHs as well as non alloyed ohmic contacts with vanishing SBHs by choice of proper metals and optimal electrodeposition conditions.

References

[1] H. Hasegawa, T. Sato and T. Hashizume: J. Vac. Sci. Technol. **15**, 1227(1997).

[2] T.U. Kampen and W. Mönch: Appl.Sur.Sci.**117/118**,388(1997).