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Deep level characterization of MOVPE-grown AlGaN with high Al compositions

Shinya Okuzaki[1], Katsuya Sugawara[1], Hiroyuki Taketomi[2], Hideto Miyake[2], Kazumasa Hiramatsu[2] and Tamotsu Hashizume[1]

[1]Research Center for Integrated Quantum Electronics (RCIQE) and
Graduate School of Electronics and Information Engineering, Hokkaido University, Japan
okuzaki@rciqe.hokudai.ac.jp

[2]Department of Electrical and Electronic Engineering, Mie University, Japan

1. Introduction

$Al_xGa_{1-x}N$ with a high aluminum composition is an important material for deep UV light-emitting devices and high-performance AlGaN/GaN-based transistors. However, significant reduction of light-emitting efficiency in AlGaN LEDs/LDs and drain current instability in AlGaN/GaN HEMTs have been reported. To understand these phenomena, characterization of deep levels of $Al_xGa_{1-x}N$ in both bulk and surface regions is inevitable, especially focusing on near-midgap levels that can act as non-radiative recombination centers or carrier trapping centers.

In this study, we investigate Schottky interface properties and deep levels of $Al_xGa_{1-x}N$ with a wide range of Al composition (0.25<x<0.60) by using X-ray photoelectron spectroscopy (XPS), I-V, C-V, and deep level transient spectroscopy (DLTS).

2. AlGaN samples

High-quality Si-doped $Al_xGa_{1-x}N$ layers (thickness:1μm) were grown on the (0001) AlN/Sapphire template by low-pressure MOCVD at temperatures from 1100 to 1270 °C [1]. Trimethylgallium (TMG), trimethylaluminum (TMA), and ammonia (NH_3) were used as sources. CH_3SiH_3 was also used as a source for Si doping. X-ray rocking curves for (0002) diffraction of the AlGaN layers showed small FWHM values less than 300 arcsec, indicating good crystalline quality. The Si doping into the AlGaN layers was successfully achieved by the MOVPE growth, resulting in control of electron concentration ranging from 1×10^{17} to 5×10^{18} cm^{-3}.

3. XPS analysis

First, the chemical property of the AlGaN surface was characterized by XPS. **Figure 1** shows the Al 2p and N 1s core-level spectra, where the Al 2p and Ga Auger signals were normalized by the N 1s peak intensity. As the Al composition increased, as expected, the Al 2p peak intensity increased systematically, whereas the peak height of the Ga LMM Auger emission decreased. The FWHM at each core level is constant even at higher Al compositions, as shown in Fig.1. These results indicate no significant disorder of chemical bonds in AlGaN even with high Al compositions.

4. I-V and C-V characterization of Ni/AlGaN diodes

The I-V and $1/C^2$-V characteristics of the $Al_xGa_{1-x}N$ Schottky diodes with x=0.25 and 0.37 are shown in **Fig. 2**. In the forward I-V curves, the diodes showed good linearity with relatively low ideality factors. In addition, we observed the higher Schottky barrier heights in $Al_xGa_{1-x}N$ with the higher Al compositions. Although relatively large leakage currents flowed at larger reverse voltage, the $1/C^2$-V characteristics showed good linearity for each sample. This indicates good gate control of the depletion layer in the given bias region, which is suitable for the DLTS characterization.

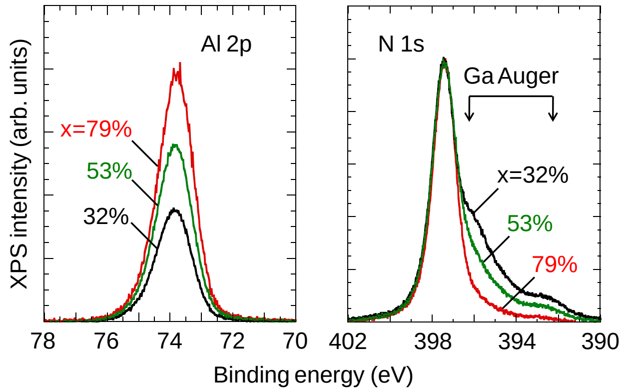

Fig. 1 Al 2p and N 1s core level spectra of AlGaN

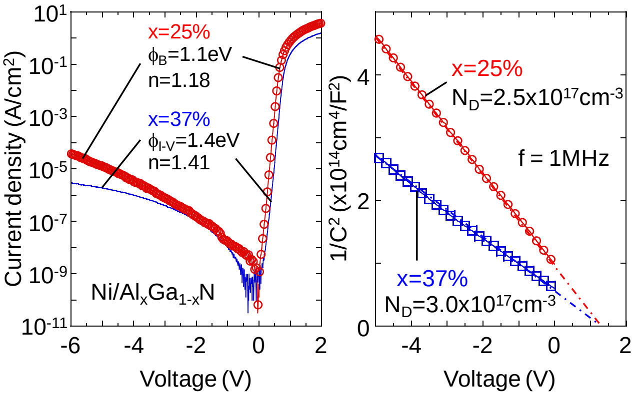

Fig. 2 I-V and $1/C^2$ characteristics of Ni Schottky diodes on AlGaN.

5. DLTS characterization

Figure 3 shows DLTS signals of Ni Schottky diodes fabricated on $Al_xGa_{1-x}N$ with x=0.25 and 0.37. To focus on the detection of deep levels with large activation energies, we set the measurement time window as long as 100 s. The dominant peaks, labeled as DL_{25} and DL_{37}, were observed at high temperature region. In particular for the sample with x=0.37, the peak appeared at around 500 K even using a very long measurement time window of 100 s. The trap densities were calculated to be 1 $x10^{16}$ and 4 $x10^{16}$ cm^{-3} for DL_{25} and DL_{37}, respectively. **Figure 4** shows the Arrhenius plots of the deep levels detected in the present samples, together with data reported for $Al_xGa_{1-x}N$ with 0.03<x<0.17 [2-5]. The activation energies of 1.0 and 1.3 eV were determined for DL_{25} and DL_{37}, respectively. Such deeper levels have not been detected in AlGaN with the lower Al composition. On the other hand, the Arrhenius plots of small DLTS peaks (A_{25} and B_{37}) are close to those reported, as shown in Fig.4.

Figure 5 shows capacitance transients at 450 K for the $Al_xGa_{1-x}N$ diodes with x=0.37 and 0.60. For the $Al_{0.37}Ga_{0.63}N$ sample, the transient is mainly caused by the electron emission from the DL_{37} level to the conduction band. On the other hand, the $Al_{0.60}Ga_{0.40}N$ sample showed an extremely slow capacitance transient.

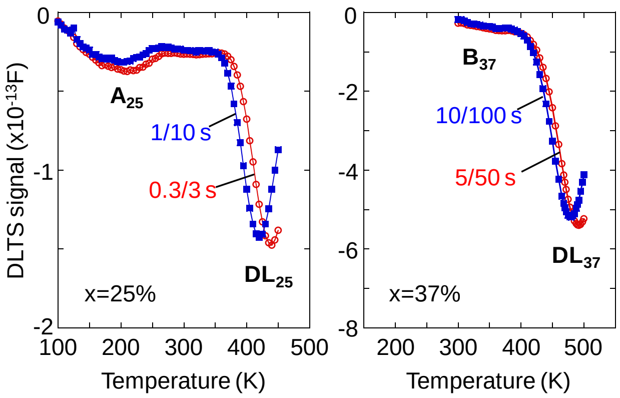

Fig. 3 DLTS signals of AlGaN with the Al compositions of 25 and 37%

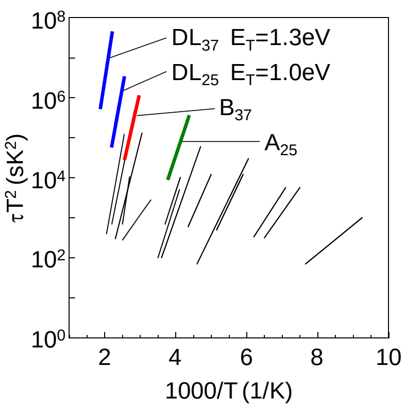

Fig. 4 the Arrhenius plots of the deep levels detected in the present samples, together with data reported for $Al_xGa_{1-x}N$ with 0.03<x<0.17 [2-5].

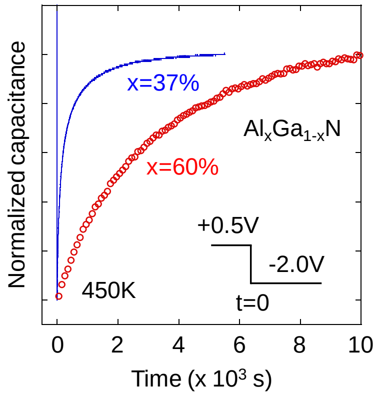

Fig. 5 Capacitance transients of AlGaN with The Al compositions of 37 and 60%

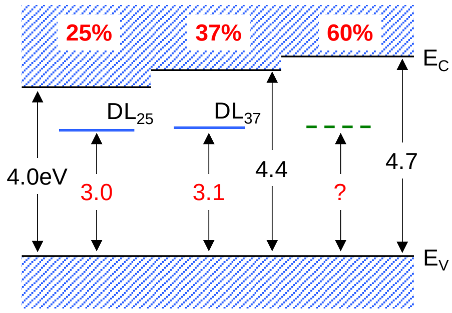

Fig. 6 Energy position of deep electron traps detected in $Al_xGa_{1-x}N$

We could not detect the DLTS peak corresponding to this transient, because of its time constant much larger than 100 s. If we assume a capture cross section of 1 x 10^{-15} cm^2, being same with DL_{25} and DL_{37}, the capacitance transient for the $Al_{0.60}Ga_{0.40}N$ sample would arise from a deep level with an activation energy lager than 1.5 eV. The energy positions of the dominant deep levels detected in the present AlGaN samples are summarized in **Fig. 6**. It is likely that the dominant levels align at the same energy with reference to the valence-band edge.

References

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