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Fabrication and analysis of AlN/GaAs(001) metal-insulator-semiconductor structure

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1 Introduction

Since GaAs metal-insulator-semiconductor (MIS) systems have once again attracted much attention for possible next generation transistor applications, atomic-layer-deposited high dielectric constant (high-k) oxide materials on GaAs, such as Al_2O_3 or HfO_2, are being investigated extensively [1]. However, the physics and chemistry of oxide/GaAs interfaces have not been fully understood yet; effects of Ga-O and As-O bonding are still controversial. Thus, it will be informative and useful to study GaAs MIS systems using non-oxide high-k insulators. AlN is an important non-oxide high-k insulator, because of a possible high breakdown field $\gtrsim 10$ MV/cm, a high dielectric constant ~ 9, which are comparable to those of Al_2O_3, and also a high thermal conductivity, ~ 10 times higher than that of Al_2O_3. Previously *in-situ* deposition of AlN by metal-organic chemical vapor deposition (MOCVD) on GaAs was studied [2]. However, deeper understanding of the AlN/GaAs(001) interface is desired, and it should be favorable to employ a more accessible method for the AlN deposition on GaAs than MOCVD, such as sputter deposition, which has been applied to the AlN deposition on InP [3]. The purpose of this work is to investigate and elucidate the AlN/GaAs(001) obtained by sputter deposition. We fabricated and analyzed the AlN/GaAs(001) MIS structures, and estimated the interface state density.

2 Experiments and Results

AlN films were obtained by RF magnetron sputtering at room temperature in N_2-mixed (3 %) Ar ambience using an AlN target. We first determined the refractive index of the AlN, using ellipsometry measurements of 22 nm thickness films on Si(001) substrates. Figure 1 shows the measured refractive indices at 630 nm wavelength, for deposition working pressures $P_w = 0.2$, 0.5, and 0.8 Pa. From the measurements, we employ $P_w = 0.5$ Pa as a standard condition giving the highest refractive index of 1.94, which is close to the literature value.

Using the standard condition, an AlN film of 1 nm thickness was deposited on a Si-doped n-GaAs(001) substrate ($n = 1.6 \times 10^{18}$ cm^{-3}), in order to investigate the AlN/GaAs(001) interface. Before the deposition, the GaAs surface oxide was removed by Semicoclean. We carried out X-ray photoelectron spectroscopy (XPS) for the AlN/GaAs(001) after the deposition, whose XPS data include the information of the interface, in comparison with the GaAs(001) before the deposition. Figure 2 and 3 show the As3d and Ga3d XPS spectra, respectively. Although we observed As-O bonding for the GaAs(001) surface, it disappears for the AlN/GaAs(001). This indicates that the As-O bonding is removed in the initial stage of the sputter deposition and almost does not exist at the interface. On the other hand, Ga-O and As-As bonding, observed both before and after the deposition, exist at the interface.

We prepared AlN films of 22 nm thickness on the n-GaAs(001) substrates using the standard condition. By X-ray diffraction measurements, we confirmed that the AlN is amorphous. Al2p XPS spectra (not shown) of the AlN films are dominated by Al-N bonding, suggesting that the AlN is almost stoichiometric. Moreover, by N1s electron energy loss spectroscopy, we obtained the AlN bandgap $E_g \sim 6.3$ eV, which is close to the literature value. The AlN films of 22 nm thickness are used for AlN/GaAs(001) MIS structures. After the backside Ohmic AuGe/Ni/Au electrode formation and the sputter deposition of the AlN insulator film, we carried out a 350 °C annealing for 30 minutes in H_2-mixed (10 %) Ar ambience. The formation of 100 μm diameter Ni/Au gate electrode on the AlN insulator completed the MIS structure, shown in the inset of Fig. 4. Figure 4 shows I-V characteristics of the fabricated AlN/GaAs(001) MIS structure, indicating good insulating properties of the AlN. Figure 5 shows measured C-V characteristics of the MIS structure for several frequencies, in which we observe a small hysteresis and a frequency dispersion for forward biases. This is attributed to the AlN/GaAs(001) interface states, probably related to the Ga-O or As-As bonding at the interface. We carried out an analysis using the equivalent circuit shown in the inset of Fig. 6, with the insulator capacitance C_0, the semiconductor capacitance C_s, the interface state capacitance C_i and the interface state conductance G_i. Since G_i satisfies [4]

$$\frac{G_i}{\omega} = \frac{q^2 D_i \ln(1+\omega^2\tau^2)}{2\omega\tau}, \qquad (1)$$

where ω is the angular frequency, D_i is the interface state density, τ is the electron trapping time, we can estimate D_i from the plot of the frequency dependence of G_i/ω shown in Fig. 6. Figure 7 gives the estimated D_i for the Fermi levels corresponding to the gate voltages; we obtain the interface state density $D_i \sim$ 3-5 $\times 10^{12}$ cm^{-2}eV^{-1}.

3 Summary

We fabricated and analyzed the AlN/GaAs(001) MIS structures obtained by AlN sputter deposition. We observed Ga-O and As-As bonding at the interface, and a frequency dispersion in C-V characteristics attributed to the interface states, probably related to the Ga-O or As-As bonding. The interface state density was estimated by the analysis of the C-V characteristics.

References

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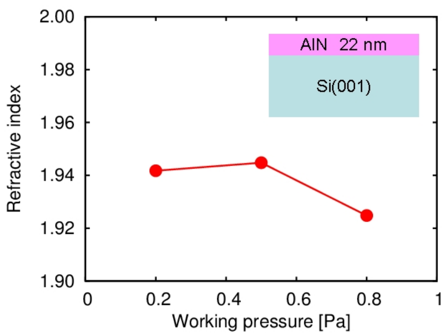

Fig. 1: Refractive indices at 630 nm wavelength for 22 nm thickness AlN films on Si(001) substrates obtained by ellipsometry measurements.

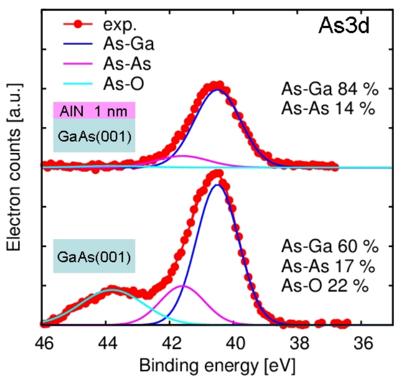

Fig. 2: As3d XPS spectra for the AlN/GaAs(001) after the sputter deposition and the GaAs(001) before the deposition.

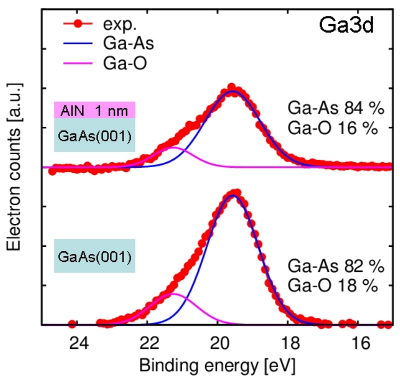

Fig. 3: Ga3d XPS spectra for the AlN/GaAs(001) after the sputter deposition and the GaAs(001) before the deposition.

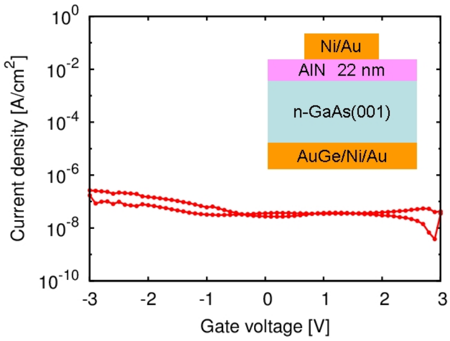

Fig. 4: *I*-*V* characteristics of the AlN/GaAs(001) MIS structure (Inset) with 100 μm diameter gate electrode.

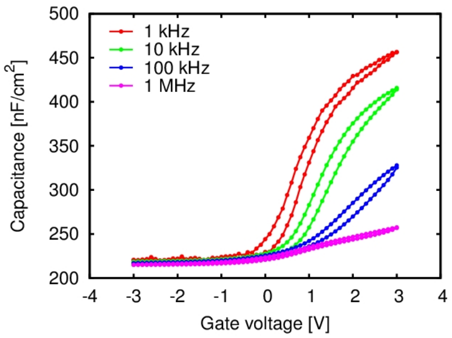

Fig. 5: *C*-*V* characteristics of the AlN/GaAs(001) MIS structure with 100 μm diameter gate electrode for several frequencies.

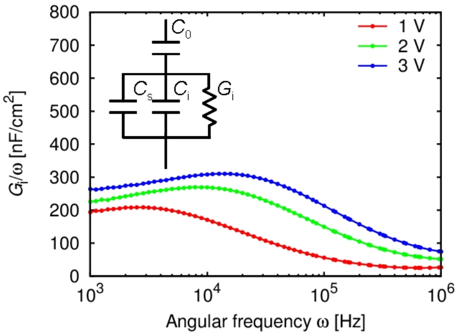

Fig. 6: Frequency dependence of G_i/ω for several gate voltages. Inset: the equivalent circuit for the analysis.

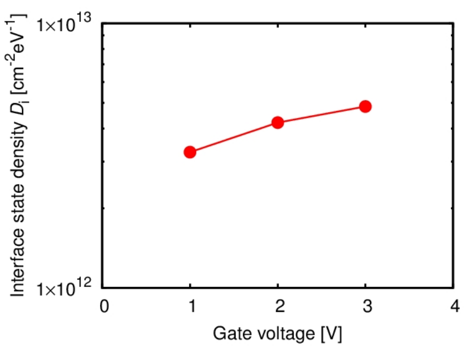

Fig. 7: Estimated interface state density D_i for the Fermi levels corresponding to the gate voltages.