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Influence of Nitrogen Doping on the LaAlO Film Properties

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Introduction

A gate insulator film with a large band gap and a high dielectric constant is required for high power field effect transistors (FET) using wide band gap semiconductors, such as SiC, GaN, and diamond. The gate insulating material must have a wider band gap than SiC (4H-SiC: 3.2 eV), GaN (3.4 eV), and diamond (5.5 eV) semiconductors. Furthermore, a high dielectric constant (high-k) and low space charge are needed to obtain a high performance FET. Stable operation in severe environments and suppression of the gate leakage current are also important. LaAlO, as a compound of La_2O_3 and Al_2O_3, offers advantages such as a high dielectric constant of 25–27 and amorphous structure at a high temperature of 850 °C.[1] However, moisture absorption is a serious problem for oxide films containing La.[2]

We investigated nitrogen doping of the LaAlO film (LaAlON) as a way of improving its water resistance. This paper reports the influence of nitrogen doping on electrical and optical properties of LaAlON (N: 4%) films.

Experimental procedure

LaAlON films were deposited on p-Si (100) by physical vapor deposition. These films were annealed at 500 °C for 20 min in atmosphere. The composition ratios of LaAlON films were about La 18%, Al 22%, and O 60%.

To examine the water resistance of LaAlON films, their surface morphology was investigated with AFM after dipping in water for 1 h. In addition, these films were dipped in water for 24 h and the amount of La atoms in the water was measured by ICP-MS. The XPS spectra (O 1s core levels) of the surface of the LaAlON films were measured after dipping in water for 3 h.

The capacitance-voltage (C-V) characteristics of LaAlON films were measured by a metal-insulator-semiconductor (MIS) structure.

In addition, the band gap of LaAlON films was estimated by transmission of vacuum ultraviolet light.

Results and discussion

Figure 1 shows the AFM images of the surface of the (a) LaAlO and (b) LaAlON films after dipping in water. The surface roughness of the LaAlO film is larger than that of the LaAlON film.

Figure 2 shows the dependence of the amount of LA atoms dissolving into water on the nitrogen composition ratio. The results indicate that nitrogen doping of the films suppressed the dissolution of La atoms into water.

Figure 3 shows the XPS spectra variation for the surface of the LaAlON film. The spectra of the LaAlO film show a positive shift, indicating that the amount of La atoms around the surface is reduced; however, the positive shift of the LaAlON spectra is smaller.

These results suggest that the water resistance is improved by nitrogen doping. We think that the hydrophobic property of nitrogen suppresses the dissolving of La atoms into water.

Figure 4 shows the C-V characteristics of the LaAlO and LaAlON films. The flat-band shift of the LaAlON film can be suppressed by nitrogen doping.

Figure 5 shows the XPS spectrum (N 1s) of the LaAlON film. It is thought that the nitrogen atom in the LaAlON bonds mainly with the oxygen atom. Therefore, the flat-band voltage shifts in a negative direction occur as the negative fixed charge with the oxygen atom decreases, because the oxygen atom unites with the nitrogen atom.

Figure 6 shows the Tauc plots of LaAlON films, and figure 7 shows the band gap of LaAlON films estimated by figure 6. This indicates that the band gap is slightly decreased by nitrogen doping. Fortunately, the energy gap of the LaAlON (N: 4%) film remains above 7.0 eV. Thus, LaAlON film is thought to be suitable for wide band gap semiconductors, such as SiC and GaN.

Conclusions

We drastically improved the water resistance and suppressed positive charge shifts of the LaAlO film with nitrogen doping, while maintaining a wide band gap of more than 7.0 eV. Therefore, the LaAlON film is attractive as a gate oxide film for wide gap semiconductors.

References

1) B. E. Park, and H. Ishiwara: Appl. Phys. Lett. **82** (2003) 1197.
2) Y. Zhao, K. Kita, K. Kyuno, and A. Toriumi: Jpn. J Appl. Phys. **46** (2007) 4189.

Acknowledgments

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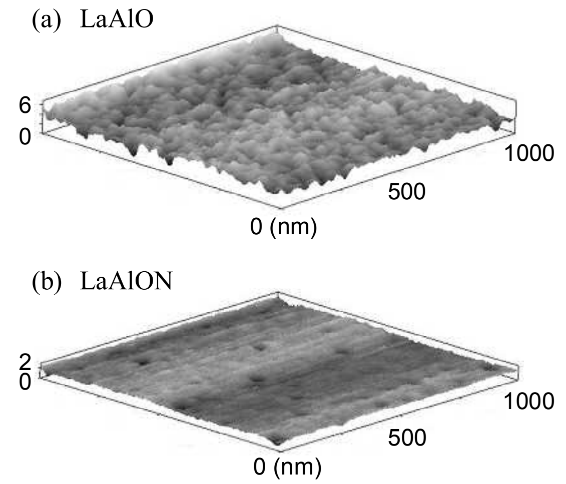

Fig. 1 AFM images of the (a) LaAlO and (b) LaAlON films.

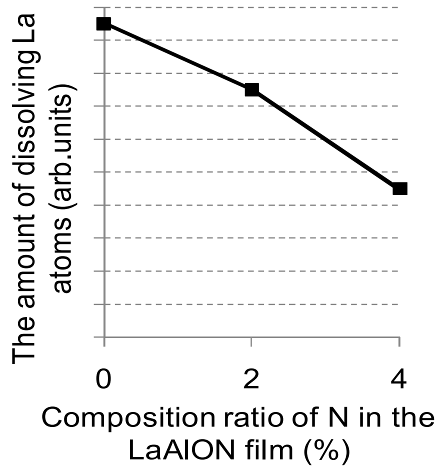

Fig. 2 Dependence of the amount of La atoms dissolving into water on the nitrogen composition ratio.

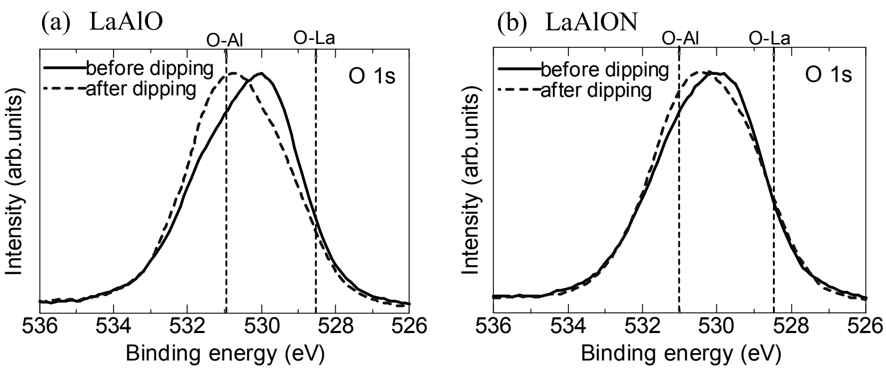

Fig. 3 XPS spectra (O 1s) of the surface of the LaAlON films (a) before and (b) after dipping.

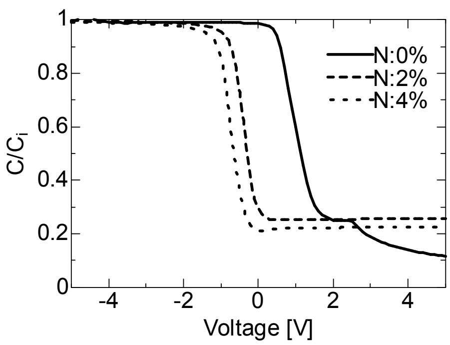

Fig. 4 C-V characteristics of the LaAlON films.

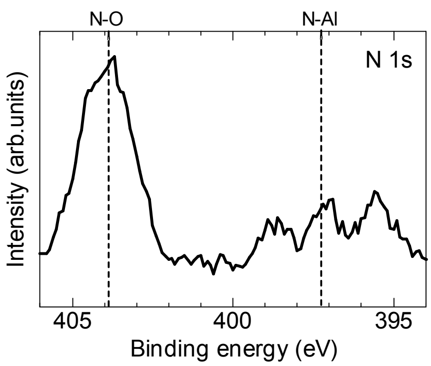

Fig. 5 XPS spectrum (N 1s) of the LaAlON film.

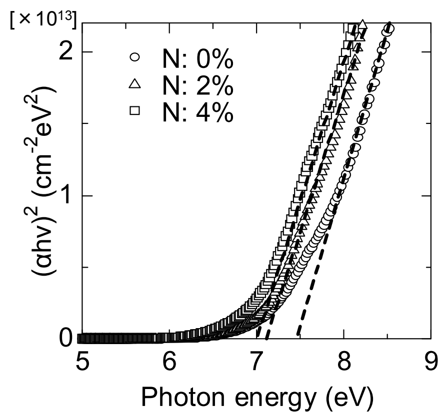

Fig. 6 Tauc plot of the LaAlON film. (N: 0–4%).

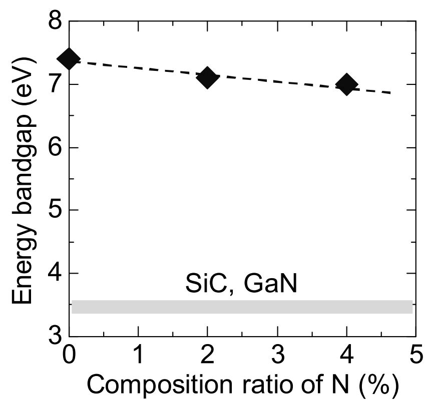

Fig. 7 The relationship between the band gap of the LaAlON film and nitrogen composition.