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Impact of Post Deposition Annealing on Chemical Bonding Features and Filled Electronic Defects of AlSiO/GaN(0001) Structure

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Abstract

Chemical structure and energy distribution of defect state density in the region near the AlSiO/GaN interface before and after post deposition annealing (PDA) have been systematically investigated by using photoemission measurements. High temperature PDA in N_2 ambience was found to be effective to reduce the defect state density in AlSiO/GaN structure with suppression of GaN decomposition and subsequent Ga diffusion.

1. Introduction

Formation of the dielectric/GaN interface with high quality is of great importance in the development of GaN power devices. In general, PDA is effective to reduce the defect state density in GaN-MOS capacitors. However, decomposition of GaN and subsequent Ga diffusion occur by PDA at a high temperature, resulting in degradation of interface properties. So far, the energy band alignment at AlSiO/GaN interface and electrical properties of GaN-MOS capacitors with AlSiO gate dielectrics have been systematically investigated by changing the Si/(Al+Si) ratio as a parameter [1, 2]. From C-V characteristics, a reduction of the interfacial trap density in the energy region near the conduction band side by an incorporation of Al_2O_3 into SiO_2 has been reported. And, evaluation of the defects located near the GaN midgap and valence band side is not so easy from the conventional technique. To overcome this difficulty, we have recently developed total photoelectron yield spectroscopy (PYS) to study the energy distribution of filled state density at the GaN surface and at the dielectric/GaN interface in the range of ~3 to ~10 eV from vacuum level without gate electrode fabrication [3, 4].

In this work, this PYS technique was used to evaluate the influence of PDA on the energy distribution of electronic state density at AlSiO/GaN interface, and change in the chemical structure with PDA have been also investigated from XPS analysis under monochromatized AlKα radiation (hν = 1486.6eV).

2. Experimental Procedures

Sequential chemical surface cleaning of a 2 μm-thick homo-epitaxial GaN with a donor concentration of 5×10^{16} cm^{-3} on a GaN(0001) substrate were performed using H_2SO_4–H_2O_2 mixture, NH_4OH–H_2O_2 mixture, HCl–H_2O_2 mixture, and dilute HF solution. Then, a 3 nm-thick Al_2O_3/SiO_2 nanolaminate with Si/(Al+Si) ratio of ~22% was formed by the ALD of Al_2O_3 and SiO_2 using tri-methyl-aluminum, tris(dimethyl-amino)silane, and O_2 radical at temperature of 250 ºC. After that, PDA at 650 ºC, 850 ºC, and 1050 ºC in O_2 or N_2 ambience was performed to form the AlSiO and to densify the dielectric layer.

3. Results and Discussion

Chemical bonding features of the 3 nm-thick AlSiO/GaN structure before and after PDA were investigated from XPS core-line signals as shown in Figs. 1 and 2. In each spectrum, photoelectron intensity normalization and binding energy calibration were made by Ga $2p_{3/2}$ signals originating from the GaN substrate. For the samples after PDA in N_2 even at 1050ºC (Fig. 1(a)), Ga $2p_{3/2}$ signals in the higher binding energy side from GaN substrate originating from Ga oxide were slightly increased. In contrast, Ga $2p_{3/2}$ signals from Ga oxide component were drastically increased after PDA in O_2 (Fig. 1(b)). These increases imply the Ga oxide formation at AlSiO/GaN interface and/or Ga diffusion into AlSiO by PDA. A similar result was also confirmed from N 1s signals from GaN substrate (Fig. 1(c)). No remarkable change in the N 1s signals after PDA in N_2 at 1050 ºC was clearly observed. Al 2p and Si 2p signals originating from AlSiO dielectrics taken after the PDA in N_2 at 1050 ºC were slightly shifted toward the higher binding energy side without change in the integrated intensity of these signals. These results are likely to be responsible for the reduction of negative fixed charge in AlSiO taking into account the fact that electronegativity of Al ion (χAl = 1.61 in Pauling unit) is

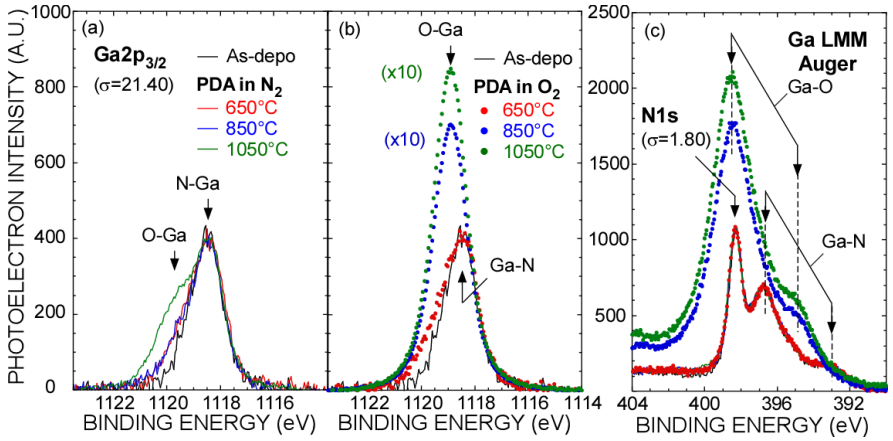

Fig. 1 (a, b) Ga $2p_{3/2}$ and (c) N 1s spectra for the 3 nm-thick AlSiO/GaN(0001) taken before and after PDA at 1050ºC in (a, c) N_2 and (b, c) O_2 ambience.

almost the same as that of Ga ion (χGa = 1.80). For the samples after PDA in O_2 at 1050 ºC, both Al 2p and Si 2p signals from AlSiO were hardly detected, which indicates formation of Ga oxide at the top surface. AFM topographic images taken for the samples after PDA in O_2 and N_2 at 1050 ºC were compared as shown in Fig. 3. Obviously, surface morphology kept flat after PDA in N_2 even at 1050 ºC. On the other hand, surface morphology was drastically changed by PDA in O_2 and significant increase in the roughness were detected owing to the Ga diffusion from the GaN substrate. These results indicates the oxidation of GaN surface through the AlSiO enhances the decomposition of GaN and subsequent Ga diffusion into AlSiO layer.

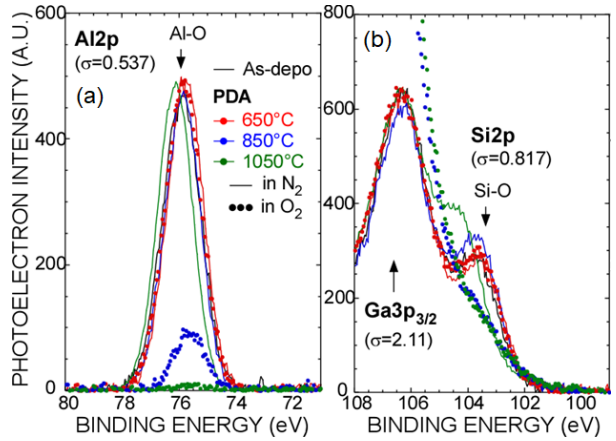

Fig. 2 (a) Al 2p and (b) Si 2p spectra taken for the samples shown in Fig. 1.

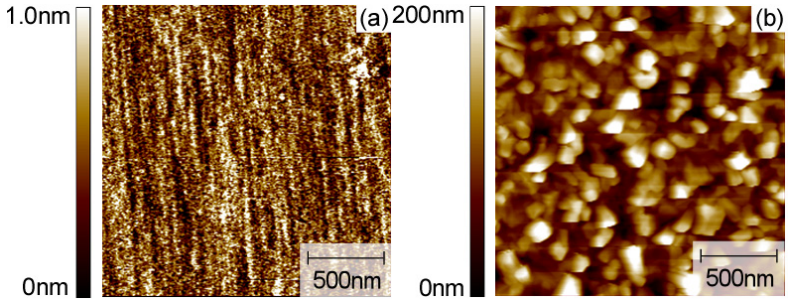

Fig. 3 AFM topographic images of 3 nm-thick AlSiO/GaN(0001) after PDA at 1050ºC in (a) N_2 and (b) O_2 ambience.

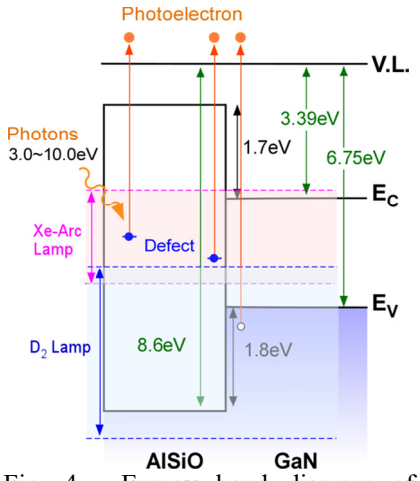

Fig. 4 Energy band diagram of AlSiO/GaN(0001) structure.

Next, to evaluate the electronic defect states in the AlSiO/GaN structure, PYS measurements for the samples before and after PDA were carried out. Based on the energy band diagram of AlSiO/GaN structure as show in Fig. 4 [1, 4], the photoelectron yield in the energy region corresponding to the GaN bandgap reflects filled defect states distributed in the AlSiO and at the AlSiO/GaN interfaces. Then, measured PYS signals were converted to the filled electronic stated density by the same procedure as described in Ref. 4. As a result shown in Fig. 5, filled defect states density was slightly decreased by PDA in O_2 at 650 ºC, and defects in the energy region near the conduction band side were markedly increased with PDA temperature up to 1050 ºC owing to the Ga diffusion into AlSiO. Notice that, filled defect states density near GaN midgap after PDA in N_2 at 1050 ºC was one order of magnitude lower than that before PDA. Taking into account the XPS results as discussed in Figs. 1 and 2, high-temperature annealing with suppression of GaN decomposition and subsequent Ga diffusion is quite effective to reduce the defects in GaN-MOS structure.

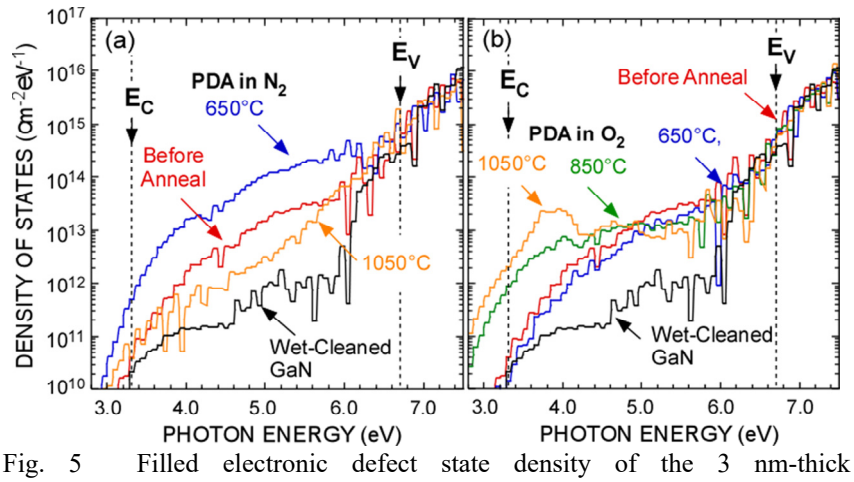

Fig. 5 Filled electronic defect state density of the 3 nm-thick AlSiO/GaN(0001) after PDA in (a) N_2 and (b) O_2 ambience converted from measured PYS spectra.

4. Summary

GaN decomposition and subsequent Ga diffusion during PDA can be suppressed in N_2 ambience as compared to in O_2 ambience. And also, PDA in N_2 at 1050°C was found to be effective to reduce the filled electronic defect density in AlSiO and at AlSiO/GaN interface.

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