

Analysis of Deep Traps at Al₂O₃/n-GaN Interface using Photo-assisted C-V Measurement

Kazuya Yuge^{1,2}, Toshihide Nabatame², Yoshihiro Irokawa², Akihiko Ohi², Naoki Ikeda², Akira Uedono³, Liwen Sang², Yasuo Koide², and Tomoji Ohishi¹

¹ Shibaura Institute of Technology

3-7-5, Toyosu, Koto-ku, Tokyo 135-8548, Japan

Phone: +81-29-851-3354 E-mail: YUGE.Kazuya@nims.go.jp

² National Institute for Materials Science

1-1, Namiki, Tsukuba, Ibaraki 305-0044, Japan

³ University of Tsukuba

1-1-1, Tennodai, Tsukuba, Ibaraki 305-0044, Japan

Abstract

We discussed the deep traps at Al₂O₃/n-GaN interface from V_{fb} shift after photo-irradiation ($h\nu = 3.3$ eV) in depletion. The V_{fb} of all Pt/Al₂O₃/n-GaN capacitors shifted toward negative direction after photo-irradiation. The negative V_{fb} shift is dominantly due to the deep traps excited by photo and the estimated densities of the deep traps were $1.5 \sim 0.67 \times 10^{12} \text{ cm}^{-2}$ at PDA 600 ~ 900 °C.

1. Introduction

GaN-based vertical MOSFETs on free-standing GaN substrates have been widely investigated for next-generation GaN power devices [1]. To reduce the leakage current, MOS structures with Al₂O₃ and SiO₂ insulators were employed. To understand characteristics of insulator/GaN interface, the flat-band voltage (V_{fb}) shift, V_{fb} hysteresis and frequency dispersion were examined using capacitance-voltage ($C-V$) measurements. Many reports pointed out the evaluation of interface state density (D_{it}) in the energy levels close to the conduction band edge (E_C) using the conductance and the Terman methods [2, 3]. To evaluate D_{it} in the energy levels near midgap for Al₂O₃/AlGaN/GaN power device, photo-assisted $C-V$ measurement was employed [4]. However, the deep traps in the deep energy levels near the valence band edge ($E_V = 3.4$ eV) of Al₂O₃/n-GaN has not been extensively studied.

In this study, we examine V_{fb} change of Pt/Al₂O₃/n-GaN MOS capacitors using photo-assisted $C-V$ measurement and discuss the deep traps at Al₂O₃/n-GaN interface.

2. Experimental

Pt/Al₂O₃/n-GaN MOS capacitors were fabricated as follows. A 5- μm -thick Si-doped GaN epilayer ($2 \times 10^{16} \text{ cm}^{-3}$) on freestanding n⁺-GaN(0001) ($1.3 \times 10^{18} \text{ cm}^{-3}$) was used as substrate. After cleaning the surface of the substrate in the solution of a sulfuric acid peroxide mixture (H₂O₂:H₂SO₄ = 1:1) for 5 min, a 25-nm-thick Al₂O₃ film was deposited by ALD at 300 °C using a TMA precursor and H₂O gas. Post-deposition annealing (PDA) was performed at 600 - 900 °C in N₂ atmosphere. Finally, 100-nm-thick Pt gate electrodes were deposited on the Al₂O₃ film through a shadow mask and Pt(100 nm)/Ti(20 nm) ohmic contacts were deposited on the backside of n⁺-GaN substrate.

Fig. 1 shows schematic illustrations of band diagram for

Al₂O₃/n-GaN gate stack during (a) typical $C-V$ measurement in darkness and (b) photo-assisted $C-V$ measurement. A semiconductor laser ($h\nu = 3.3$ eV) was used as the light source. In Fig. 1 (a), the gate bias was swept from accumulation ($V_{fb}+3$ V) to depletion ($V_{fb}-3$ V) (Initial) and kept for 60 s in darkness to examine shallow traps in the energy levels near E_C . Next, we restarted the $C-V$ sweeping toward accumulation ($V_{fb}+3$ V) (Darkness). On the other hand, in Fig. 1 (b), after sweeping from accumulation to depletion, light was irradiated on the capacitor for 60 s to examine the deep traps which was excited by photo-irradiation in wider energy levels ($E_C \sim E_V$). After switching off the light, we restarted the $C-V$ sweeping toward accumulation in darkness ($h\nu$).

(a) $C-V$ measurement in darkness (b) Photo-assisted $C-V$ measurement

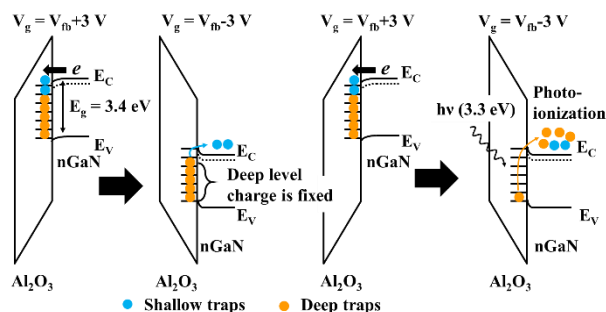


Fig. 1 Schematic illustrations of band diagram for Al₂O₃/n-GaN gate stack during (a) typical $C-V$ measurement in darkness and (b) photo-assisted $C-V$ measurement.

3. Results and Discussion

Fig. 2 shows $C-V$ characteristics of Pt/Al₂O₃/n-GaN MOS capacitors. As-grown capacitor shows a very similar $C-V$ behavior of the 600 °C capacitor. The $C-V$ curves shifted in the positive direction as PDA temperature increased from 600 to 900 °C. Fig. 3 shows $C-V$ characteristics of the 700 °C capacitor under darkness and photo-irradiation conditions. The $C-V$ curve of Darkness slightly shifted toward negative direction (-90 mV) (Fig. 3 (a)). The $C-V$ shift is dominantly due to the shallow traps of short time constant near E_C . On the other hand, a large negative $C-V$ shift (-640 mV) appeared after photo-irradiation (Fig. 3 (b)). Here, the deep traps of long time constant must be excited from the interface state in the wider energy levels by the photo-irradiation with the higher energy like the band diagram in Fig. 1 (b).

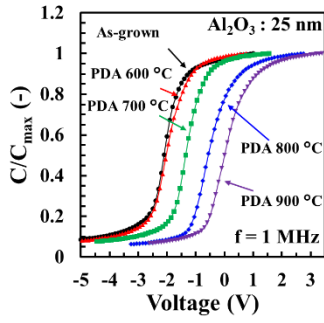


Fig. 2 C - V characteristics of Pt/ Al_2O_3 /n-GaN MOS capacitors. C - V curves shifted toward positive direction as PDA temperature increases from 600 ~ 900 °C.

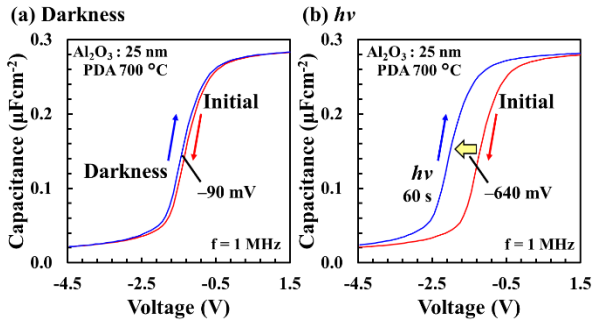


Fig. 3 C - V characteristics of the 700 °C capacitor under (a) darkness and (b) photo-irradiation conditions. A small negative shift of C - V curve of Darkness was observed because of shallow traps near E_c . A large negative shift of C - V curve of $h\nu$ occurred due to deep traps in wider energy ($E_c \sim E_v$).

Fig. 4 shows V_{fb} changes of the Initial, Darkness and $h\nu$ as a function of PDA temperature. V_{fb} of Initial ($V_{fb \text{ Initial}}$) shifted toward ideal V_{fb} as PDA temperature increases, indicating that characteristics at Al_2O_3 /n-GaN interface was significantly improved. The effect of PDA treatment on electrical properties of the Al_2O_3 /n-GaN MOS capacitors were reported [2, 5]. The difference between the V_{fb} of Darkness ($V_{fb \text{ Darkness}}$) and the $V_{fb \text{ Initial}}$ decreases from 0.1 V to 0.01 V as PDA temperature increases from 600 to over 700 °C. This suggests that the number of shallow traps near E_c becomes small because of improvement of Al_2O_3 /n-GaN interface.

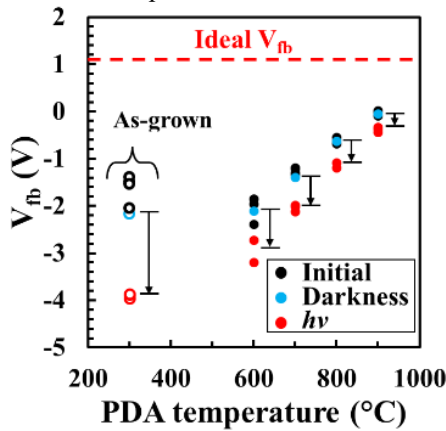


Fig. 4 V_{fb} changes of Pt/ Al_2O_3 /n-GaN MOS capacitors under several measurements (Initial, Darkness, and $h\nu$). The V_{fb} of $h\nu$ shifted significantly toward negative direction compared to those of V_{fb} of Darkness in all capacitors.

Note that V_{fb} of $h\nu$ ($V_{fb \text{ } h\nu}$) shifted significantly toward negative direction compared to those of $V_{fb \text{ Darkness}}$ in all capacitors.

Fig. 5 (a) shows the difference between the $V_{fb \text{ } h\nu}$ and $V_{fb \text{ Darkness}}$ as a function of PDA temperature. As-grown capacitor exhibited a large negative V_{fb} shift with -1.7 V. The negative V_{fb} shift decreases gradually with increasing PDA temperature. The negative V_{fb} shift is thought to be dominantly due to the deep traps in the deep energy levels near E_v because there are several interface states around E_v [6]. Here, we estimated density of deep traps according to equation (1),

$$D_{dt} = \frac{C_{ox}(V_{fb \text{ } h\nu} - V_{fb \text{ Darkness}})}{q}, \quad (1)$$

which D_{dt} is density of deep traps, C_{ox} is oxide capacitance, and q is elementary charge, respectively. As shown in **Fig. 5 (b)**, as-grown capacitor shows a large D_{dt} of $3.1 \times 10^{12} \text{ cm}^{-2}$, suggesting that the initial Al_2O_3 growth resulted in the formation of electrical defects on the surface of the n-GaN. Although the D_{dt} decreases as PDA temperature increases, a large density of $0.67 \times 10^{12} \text{ cm}^{-2}$ remains even after PDA 900 °C. We believe that the large number of deep traps in deep energy level must be related to device characteristics of mobility and threshold voltage.

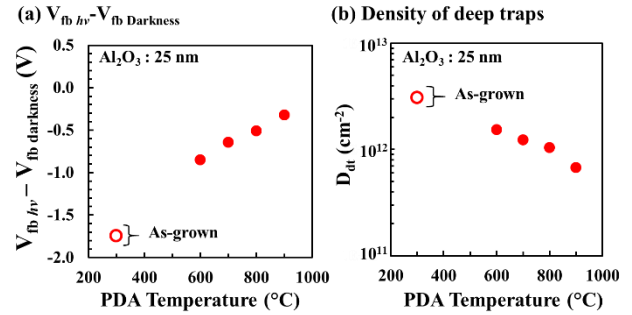


Fig. 5 (a) The difference between the $V_{fb \text{ } h\nu}$ and $V_{fb \text{ Darkness}}$ and (b) estimated density of deep traps as a function of PDA temperature. $V_{fb \text{ } h\nu} - V_{fb \text{ Darkness}}$ decreases gradually with increasing PDA temperature. The estimated the density of deep traps were $1.5 \sim 0.67 \times 10^{12} \text{ cm}^{-2}$ at PDA 600 ~ 900 °C.

3. Conclusions

We studied V_{fb} shift due to the deep traps at Al_2O_3 /n-GaN interface for Pt/ Al_2O_3 /n-GaN capacitors using photo-assisted C - V measurement. Negative V_{fb} shift was observed in all capacitors after photo-irradiation compared to those of typical C - V measurement in darkness. The negative V_{fb} shift due to the deep traps exhibited -0.32 V and the D_{dt} was estimated $0.67 \times 10^{12} \text{ cm}^{-2}$ at PDA 900 °C.

Acknowledgements

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