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Impacts of crystal orientation of GaAs on the interfacial structures and electrical properties of Hf_{0.6}La_{0.4}O_x films

Abstract

One of the major challenges in realizing the GaAs channel in the metal oxide semiconductor field effect transistor is the degrading in electron transport properties at the interface between GaAs and the gate oxide. In this study, Hf_{0.6}La_{0.4}O_x gate oxide films were deposited at a low temperature (200 °C) on GaAs(111)A and GaAs(100) substrates by plasma enhanced atomic layer deposition. Microstructure analysis indicates that residuals of gallium oxide, arsenic oxide, and As element remained at the interface of Hf_{0.6}La_{0.4}O_x/GaAs(100). On contrast, a smoother interface is observed between Hf_{0.6}La_{0.4}O_x thin film and GaAs(111)A substrate. Furthermore, a reduction of interfacial layer is observed in Hf_{0.6}La_{0.4}O_x/GaAs(111)A. Electrical characterization of the metal-insulator-semiconductor Pt/Hf_{0.6}La_{0.4}O_x/n-GaAs(111)A capacitor indicated a reduction of D_{it} and leakage current compared with the capacitor fabricated on GaAs(100).

Keywords

electrical, properties, hf_{0.6}la_{0.4}ox, structures, films, gaas, orientation, crystal, impacts, interfacial

Disciplines

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Impacts of crystal orientation of GaAs on the interfacial structures and electrical properties of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ films

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One of the major challenges in realizing the GaAs channel in the metal oxide semiconductor field effect transistor is the degrading in electron transport properties at the interface between GaAs and the gate oxide. In this study, $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ gate oxide films were deposited at a low temperature (200 °C) on GaAs(111)A and GaAs(100) substrates by plasma enhanced atomic layer deposition. Microstructure analysis indicates that residuals of gallium oxide, arsenic oxide, and As element remained at the interface of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(100)$. On contrast, a smoother interface is observed between $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ thin film and GaAs(111)A substrate. Furthermore, a reduction of interfacial layer is observed in $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(111)\text{A}$. Electrical characterization of the metal-insulator-semiconductor Pt/ $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{n-GaAs}(111)\text{A}$ capacitor indicated a reduction of D_{it} and leakage current compared with the capacitor fabricated on GaAs(100). © 2014 AIP Publishing LLC. [<http://dx.doi.org/10.1063/1.4870446>]

I. INTRODUCTION

With the continuous down scaling of complementary metal oxide semiconductor (CMOS) devices, searching for new materials to provide enhanced performance and stability for CMOS is in need. GaAs channel materials attracts considerable attentions for developing metal oxide semiconductor field effect transistors (MOSFETs) because of its higher intrinsic electron mobility and lower effective mass compared to Si. However, realizing GaAs's potential in this regard has proven to be difficult, partly due to the highly reactive GaAs surface. The complex native oxides of GaAs is quite unstable, it's structure and properties can be affected when exposed to light, moisture, or even with moderate heat treatments. The native oxide of GaAs presents a surface that is neither easily characterized nor passivated. A lot of efforts have been made to improving the interface quality of conventional high-k oxide GaAs. Recently, significant improvements of MOS transistor's performance have been achieved through replacing the surface orientation of traditional GaAs(100) or $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ by the polar GaAs(111)A (Ga or In-rich) crystal face, in combination with thermal atomic layer deposition (ALD) of Al_2O_3 .^{1,2}

HfO_2 is one of the most promising high-k candidates for future CMOS devices, however, HfO_2 on GaAs showed abnormal capacitance-voltage (C-V) characteristics with no accumulation observed,³ which is attributed to the native oxides induced interface pinning between GaAs substrate and HfO_2 .⁴ Fortunately, by doping La into HfO_2 to form HfLaO_x the performance of gate dielectrics can be enhanced

considerably due to its high permittivity,⁵ relatively large conduction band (CB) offset,^{6,7} high crystallization temperature,⁸ and less Fermi-level pinning.^{9,10}

GaAs has a zinc blende structure with double fcc cubic lattice of Ga atoms and As atoms. At the $\langle 111 \rangle$ directions, atomic planes are occupied alternatively by Ga atoms and As atoms forming double layers, each atom has 3 bonds within the same double layer and one bond in the exterior of the double layer (Figure 1). The surfaces terminated by Ga atoms are called $\{111\}\text{A}$, of which we will be focusing on in this work. On the other hand, along the $\langle 100 \rangle$ directions the atomic planes are also occupied alternatively by Ga and As atoms. However, the planes are equidistant and each atom is symmetrically bonded with neighboring layers. The $\{111\}\text{A}$ facets maybe more stable assuming that the three bonds (within the same double layer) are much more difficult to break. In this paper, we will discuss the influence of the

FIG. 1. Schematic atomic displacement of GaAs in (111)A and (100) orientation.

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crystal orientation of GaAs on the interfacial structures and the electrical properties of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ gate dielectrics.

II. EXPERIMENT

N-type GaAs substrates in (100) and (111)A orientation were used in this work. It is reported a high La/(La + Hf) atomic ratio results in a better thermal stability than pure HfO_2 .¹¹ However, high La/(La + Hf) atomic ratio would lead to a low deposition rate. Thus, in this work, we choose the La percentage around 40%. The plasma enhanced ALD (PEALD) system was used to prepare $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ dielectric films. GaAs substrates were cleaned by acetone and alcohol for 10 min and then in a dilute HCl solution ($\text{HCl}:\text{H}_2\text{O} = 1:1$) for 1 min to remove organic and native oxide, respectively. $\text{Hf}[\text{N}(\text{CH}_3)(\text{C}_2\text{H}_5)_4]$ and $\text{La}[\text{N}(\text{TMS})_2]_3$ were used as metal precursors, and O_2 plasma served as oxidant. The growth temperature was set to 200 °C. The total deposition of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ film on GaAs substrate consists of 10 cycles of alternately deposited La_2O_3 - HfO_2 nanolaminates and 5 cycles of HfO_2 cap layer to avoid hydrolyzed of La-component when exposed in air. Each nanolaminate cycle consists of three sub-cycles La_2O_3 and one sub-cycle HfO_2 : 3 cycles of La_2O_3 is first deposited on GaAs surface and then followed by 1 cycle HfO_2 . As we known, due to the interfacial traps between the dielectric film and GaAs substrate which induced interface pinning near the midgap, directly deposited high-k gate dielectrics on GaAs sometimes even showed abnormal capacitance voltage (C-V) characteristics with no accumulation observed.¹² Chang *et al.*¹³ investigated the impacts of post-deposition annealing (PDA) on the GaAs MOS device; they found that post annealing lead to significant reduction of interfacial state density (D_{it}) near the midgap. Moreover, the post annealing higher than 500 °C would result in a charge transfer effect between La and Hf and improve the Hf-La-O bonding state.¹⁴ However, annealing temperature higher than 550 °C would lead to a thicker interfacial layer which deteriorates the interfacial quality.¹² Therefore, we carried out a PDA in a N_2 ambient at 500 °C for 1 min by the rapid thermal annealing (RTA) technique. Metal-insulator-semiconductor (MIS) capacitors were formed with a Pt top electrodes formed by shadow mask sputtering, and a bottom electrode formed by blanket sputtering of Pt. Post metallization annealing (PMA) in forming gas (5% H_2 /95% N_2) at 450 °C was performed to

form ohmic contact. The microstructure and chemical states were analyzed by cross-sectional high resolution transmission electron microscopy (HRTEM) and X-ray photoelectron spectroscopy (XPS). High frequency capacitance-voltage (C-V) and leakage current-voltage (J-V) measurements of the MIS capacitors were carried out using an Agilent B1500A Semiconductor Device Analyzer.

III. RESULTS AND DISCUSSION

A. Interfacial microstructures

Interfacial morphology was studied using cross-sectional TEM. It is shown in Figure 2 that the interface of the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ on GaAs(111)A is smoother than that on GaAs(100). A reduction of interfacial layer is observed on the GaAs(111)A-substrate film. The thickness of the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ film is 9.6 nm and 8.2 nm on GaAs(100) and GaAs(111)A, respectively. The reduction of the film thickness was partially due to the reduction of the interfacial layer, and the deposition rate was found to be different on the GaAs substrates with different orientations.

To further investigate the chemical structure of the interface between the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ films and the GaAs substrates, XPS measurements were performed to determine the interfacial structures. XPS was performed *ex-situ* using a monochromatic Al K α X-ray source at a power of 150 W. The binding energy was calibrated with the position of C 1s peak at 284.8 eV. According to the XPS analysis, the atomic ratio of La/(La + Hf) in $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ is 40.9% and 41.9% for the film deposited on GaAs(100) and GaAs(111) A, respectively. Arsenic oxides were commonly observed in the XPS results of the thin films deposited on GaAs(100), which was generally located at 43.20 eV, 43.98 eV, and 44.86 eV corresponding to AsO, As₂O₃, and As₂O₅, respectively.¹⁵ The As 3d spectra of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ on GaAs(111)A is shown in Figure 3(a), besides the strongest peak of As-Ga bond, there is a weak peak at 43.20 eV which is ascribed to AsO. The low coordinated oxidation state is corresponding to Arsenic surface states such as dimers and possibly dangling bonds.¹⁸ There is no As element detected in this sample. In the As 3d core level spectra of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ on GaAs(100) as shown in Figure 3(c), besides the As-Ga bond, two peaks located at 43.57 eV, and 44.47 eV related to Arsenic oxide was

FIG. 2. Cross-sectional TEM images of interface structure between $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ film and (a) GaAs(100) and (b) GaAs(111)A.

FIG. 3. XPS As 3d and Ga 2p core level spectra for $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ films on GaAs(111)A ((a) and (b)) and GaAs(100) ((c) and (d)).

detected, indicating the existence of residual As_2O_3 and As_2O_5 at $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(100)$ interface. Furthermore, the As element at 42.28 eV was also detected at the interface due to the exchange reaction between GaAs substrate and Arsenic oxide.¹⁶ For the Ga 2p spectra (Figures 3(b) and 3(d)), gallium oxide was detected in both of the samples. There are two possible causes responsible for the Ga-O bond, one is the residual Ga_2O_3 exists at the interface; the other is that the Ga_2O_3 is formed by the scattering during ALD growth and PDA process. Although there are peaks from As-O and Ga-O bonds detected in both of the samples, we observe a reduction of Ga_2O_3 and Arsenic oxides in $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(111)\text{A}$. Based on these XPS results, the ALD growth on GaAs(111)A substrate would minimum amount of interfacial Ga_2O_3 and arsenic oxides which is responsible for causing large D_{it} and Fermi level pinning.¹² Thus, GaAs(111)A would be more favorable as a substrate for high-k dielectrics.

B. Band alignment of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(111)\text{A}$

One of the most fundamental physical properties for characterizing a semiconductor interface is the band alignment. In order to determine the CB offset value, the band gap (E_g) energies of the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ films on GaAs(111)A were determined from O 1s energy loss for photoelectrons. In Figure 4(a), the onset of band to band excitation which corresponds to E_g is defined as an intercept of linear extrapolation of the leading edge to the background level. The E_g was determined to be 4.33 eV for the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ film. To study the relationship of the energy band for $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(111)\text{A}$, the valence band (VB) spectra were measured for the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ films grew on GaAs(111)A substrates, as well as the bare GaAs(111)A samples, after the Ar^+ etching of the XPS measurements. The measurement is based on the assumption that the energy difference between the core level and VB edge of

the GaAs substrate remains constant with/without the deposition of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ films.¹⁷ Figure 4(b) shows the VB spectra of GaAs(111)A substrate and the as-received $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ film on GaAs(111)A. In our work, the As 3d peak and VB edge from the GaAs(111)A substrate were chosen as the reference to determine the VB offset between the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ film and GaAs(111)A substrate. The core level positions and VB maximum of bulk materials combined with core level difference of heterojunction are used to calculate the VB offset. The VB maximum is determined by using a linear extrapolation method.¹⁷ The $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ VB offset can be obtained by eliminating the VB spectra of the GaAs substrate from the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ VB spectrum using the following formula:

$$\Delta E_v = (E_{CL}^{As3d} - E_v^{GaAs})_{GaAs} - (E_{CL}^{Hf4f} - E_v^{HLO})_{HLO} + (E_{CL}^{Hf4f} - E_{CL}^{As3d})_{HLO/GaAs}, \quad (1)$$

where E_{CL}^{As3d} and E_{CL}^{Hf4f} are the binding energy of As 3d and Hf 4f, E_v^{GaAs} and E_v^{HLO} are the VB maximum of GaAs and $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}$. Consequently, the VB offset value is 1.61 eV obtained at the top of the VB maximum at the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}$ interface. The CB offset can be evaluated by subtracting the VB offset and the E_g of GaAs substrate from the E_g of $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x$ film by the following formula:¹⁸

$$\Delta E_c^{High-k/GaAs} = \Delta E_g^{High-k} - \Delta E_v^{High-k/GaAs} - \Delta E_g^{GaAs}, \quad (2)$$

where $\Delta E_c^{High-k/GaAs}$ represents the CB offset between high-k films and GaAs, ΔE_g^{High-k} is the band gap of high-k, $\Delta E_v^{High-k/GaAs}$ is the VB offset between high-k and GaAs, and ΔE_g^{GaAs} is the band gap of GaAs which is 1.42 eV. Consequently, the $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(111)\text{A}$ CB offset ($\Delta E_c^{High-k/GaAs}$) is calculated to be 1.30 eV. The energy band diagram for $\text{Hf}_{0.6}\text{La}_{0.4}\text{O}_x/\text{GaAs}(111)\text{A}$ stack is obtained as Figure 4(c).

FIG. 4. (a) O 1s energy loss spectra for Hf_{0.6}La_{0.4}O_x/GaAs(111)A; (b) valence band spectra for Hf_{0.6}La_{0.4}O_x/GaAs(111)A stack and the bare GaAs substrate after Ar⁺ etching; and (c) energy band diagram for Hf_{0.6}La_{0.4}O_x/GaAs(111)A stack.

C. Electrical properties

The capacitance-voltage (C-V) and the leakage current density-voltage (J-V) of Pt/Hf_{0.6}La_{0.4}O_x/n-GaAs(111)A and Pt/Hf_{0.6}La_{0.4}O_x/n-GaAs(100) MIS capacitors were measured using a HP4194A impedance analyzer and an Agilent 4156C precision semiconductor parameter analyzer, respectively. As shown in Figure 5(a), the C-V measurements were performed at 10 kHz and 1 MHz. In the top inset of Figure 5(a), the inversion, depletion, and accumulation modes are clearly shown in the C-V curves, a frequency dispersion (ΔC_{ox}) in accumulation is also observed, which suggests that a high leakage current exists in both of the samples while applying high voltage. ΔC_{ox} between 10 kHz and 1 MHz is evaluated as 10.1% and 16.2% for Hf_{0.6}La_{0.4}O_x/GaAs(111)A

(10.1%) and Hf_{0.6}La_{0.4}O_x/GaAs(100), respectively. In GaAs/high-k system, the complex nature of the interface with a high density of interface states (D_{it}) can exhibit an interface state capacitance (C_{it}) that contributes significantly to the measured capacitance. The existence of C_{it} is also responsible for the frequency dispersion which is origin from a low resistivity interfacial layer adjacent to the interface.¹⁹ The reduction of frequency dispersion in Hf_{0.6}La_{0.4}O_x/GaAs(111)A indicates a suppression of the interface traps. In order to remove the effect of leakage current and interface states,^{20,21} an equivalent circuit is used to correct the capacitance as shown in the left bottom of Figure 5(a). The actual frequency independent capacitance (C_{ture}) can be calculated as follows:²²

$$C_{ture} = \frac{(\omega^2 C_m C_E - G_m^2 - \omega^2 C_m^2)(G_m^2 + \omega^2 C_m^2) C_E}{(\omega^2 C_E^2) [G_m(1 - R'_s G_m) - \omega^2 R'_s C_m^2]^2 + (\omega^2 C_m^2 + G_m^2 - \omega^2 C_m C_E)^2}, \quad (3)$$

where $R'_s = \frac{G_{ma}}{G_m^2 + \omega^2 C_m^2}$ and $C_E = \frac{-C_{ox}(G_m^2 + \omega^2 C_m^2)}{\omega^2(C_m^2 - C_{ox} C_m) + G_m^2}$, C_m and G_m are the measured capacitance and conductance, respectively. C_{ma} and G_{ma} represent the measured capacitance and conductance in strong accumulation, respectively. C_{ox} is the maximum accumulation capacitance, ω denotes angular frequency. From the actual frequency independent device capacitance curves as shown in Figure 5(a), the C_{ox} of Pt/Hf_{0.6}La_{0.4}O_x/n-GaAs(111)A capacitor is 2.5 $\mu\text{F}/\text{cm}^2$ higher than that of the Pt/Hf_{0.6}La_{0.4}O_x/n-GaAs(100) (2.3 $\mu\text{F}/\text{cm}^2$). The slope of the C-V curve of Hf_{0.6}La_{0.4}O_x/GaAs(111)A is greater than that of Hf_{0.6}La_{0.4}O_x/GaAs(100), which indicates

that the interface trap density is lower in Hf_{0.6}La_{0.4}O_x/GaAs(111). However, the C-V curve of Hf_{0.6}La_{0.4}O_x/GaAs(111)A in depletion region stretches out indicates a presence of slow interface states in GaAs band gap. The equivalent oxide thickness (EOT) for Hf_{0.6}La_{0.4}O_x film was calculated by $EOT = \epsilon_{ox} \epsilon_0 A / C_{ox}$, where ϵ_{ox} and ϵ_0 are the dielectric constants for SiO₂ and the vacuum, respectively. It turns out that the EOT value of Hf_{0.6}La_{0.4}O_x on GaAs(111)A and GaAs(100) is about 1.4 nm and 1.5 nm, the corresponding k value of as-deposited Hf_{0.6}La_{0.4}O_x film is 22.8 and 24.9, respectively. The corresponding interfacial state density (D_{it}) of the samples is extracted by the

FIG. 5. (a) Capacitance-voltage (C-V) curves of Pt/Hf_{0.6}La_{0.4}O_x/GaAs(111)A/Pt and Pt/Hf_{0.6}La_{0.4}O_x/GaAs(100)/Pt capacitors. The inset on the top is the C-V curves measured at 10 kHz and 1 MHz; and the bottom inset is the equivalent circuit model; (b) leakage current density-voltage (J-V) curves. The inset is the corresponding J-E curves at low electric field from 0.1 to 0.5 MV/cm; (c) the curve of $\ln(J/E)$ versus square root of the electric field ($E^{1/2}$) and (d) the curve of $\ln(J)$ versus square root of the electric field ($E^{1/2}$) for the as-deposited Hf_{0.6}La_{0.4}O_x films on GaAs(111)A and (100).

conductance method.²³ The D_{it} at midgap of the band gap energy is $1.62 \times 10^{12} \text{ eV}^{-1} \text{ cm}^{-2}$ and $3.25 \times 10^{12} \text{ eV}^{-1} \text{ cm}^{-2}$ for Hf_{0.6}La_{0.4}O_x/GaAs(111)A and Hf_{0.6}La_{0.4}O_x/GaAs(100), respectively. Lower D_{it} value for Hf_{0.6}La_{0.4}O_x film on GaAs(111)A indicated a better interface quality. This result is consistent with the TEM and XPS result. We have to note that the D_{it} is still as high as $\sim 10^{12}$ order of magnitude which attribute to the Ga₂O₃ in the interfacial layer.¹²

The leakage current density (J) as a function of the gate bias (V) of Hf_{0.6}La_{0.4}O_x films is shown in Figure 5(b). It is clear that the Hf_{0.6}La_{0.4}O_x film deposited on GaAs(100) has a lower leakage current density than on GaAs(111)A when the applied field is lower than 1 V. However, leakage current density in Hf_{0.6}La_{0.4}O_x/GaAs(100) is higher while the electric field is higher than 1 V. To further understand the behavior of leakage current, the current conduction mechanism of the Hf_{0.6}La_{0.4}O_x films was investigated. In dielectric films, there are several possible mechanisms responsible for the leakage current, such as Freckle-Poole (F-P) emission, Schottky emission, Fowler-Nordheim tunneling, ohmic transportation, ionic conduction, and a space charge limited current.

For F-P emission, the current density is given by²⁴

$$J_{FP} = J_0 \exp \left[\frac{q(-\varphi_{FP} + \sqrt{qE/\pi\epsilon_0\epsilon_r})}{kT} \right]. \quad (4)$$

In addition, the current density due to Schottky emission can be expressed as follows:

$$J_S = A^* T^2 \exp \left[\frac{q(-\varphi_B + \sqrt{qE/4\pi\epsilon_0\epsilon_r})}{kT} \right]. \quad (5)$$

Moreover, ohmic transportation can be expressed as

$$J_O = AE \exp(\Delta E_{ac}/kT), \quad (6)$$

where J_O represents low field current density, A^* is Richardson constant, q denotes electronic charge, ϵ_r represents dynamic dielectric constant, k is Boltzmann constant, T denotes absolute temperature, φ_{FP} is the height of trap potential well, φ_B represents contact potential barrier, A is a constant, ΔE_{ac} represents the activation energy of the electron, and E denotes applied electric field. The inset of Figure 5(b) plots J vs. E at low electric field from 0.1 to 0.5 MV/cm, a linear shape suggests that the conduction mechanism at low electric field is ohmic transportation which is due to the injection from substrate. Figures 5(c) and 5(d) show a logarithmic current density divided by the electric field as a function of the square root of the electric field [$\ln(J/E)$ vs. $E^{1/2}$] and a logarithm of the current density versus the square root of electric field [$\ln(J)$ vs. $E^{1/2}$], respectively. A linear fitting appears while the applied electric field ($E^{1/2}$) in the range of 0.5–1.3 (MV/cm)^{1/2}. For F-P emission, the slope of the straight line is 10.4 and 18.7 for Hf_{0.6}La_{0.4}O_x/GaAs(111) and Hf_{0.6}La_{0.4}O_x/GaAs(100), respectively. As to Schottky emission, the slope for Hf_{0.6}La_{0.4}O_x/GaAs(111)A and Hf_{0.6}La_{0.4}O_x/GaAs(100) is 12.6 and 21.5, respectively. The dynamic dielectric constant (ϵ_r) could be extracted from the slope of the linear region. The slope of 21.5 for Hf_{0.6}La_{0.4}O_x/GaAs(100) and 12.6 for Hf_{0.6}La_{0.4}O_x/GaAs(111)A in Schottky emission is closer to the dielectric constant which is extracted by the C-V measurement. This indicates that when the $E^{1/2}$ is in the range of 0.5–1.3 (MV/cm)^{1/2}, Schottky emissions would be the dominant leakage mechanism in Hf_{0.6}La_{0.4}O_x films on GaAs(100) and GaAs(111) due to a substrate injection.²⁵ In general, the electrons generated under positive gate bias could be from the interfaces states, traps in depletion region and back electrode of substrate. We consider that the underestimate ϵ_r value is due to the existence of low permittivity interfacial layer between Hf_{0.6}La_{0.4}O_x film and GaAs substrate.

IV. SUMMARY AND CONCLUSIONS

Hf_{0.6}La_{0.4}O_x film was successfully deposited on GaAs(111)A and GaAs(100) substrates by the PEALD method in which Hf[N(CH₃)(C₂H₅)₄]₄ and La[N(TMS)₂]₃ were employed as precursor and oxygen plasma as oxidant. Microstructure analysis shows a smooth interface and a reduction of interfacial layer between the Hf_{0.6}La_{0.4}O_x films and the GaAs(111)A substrates. XPS results indicated a reduction of

Ga₂O₃ and arsenic oxides in the interfacial layer between Hf_{0.6}La_{0.4}O_x and GaAs(111)A. Electrical properties of Pt/Hf_{0.6}La_{0.4}O_x/n-GaAs(111)A MIS capacitors show a reduction of D_{it} and leakage current comparing with the capacitor fabricated on GaAs(100).

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