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High Temperature and Low Frequency Noise of AlGaN/GaN/AlGaN Double Heterostructure MOS-HFETs with Photo-Chemical Vapor Deposition SiO_2 Layer

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1. Introduction

Recently, many researches were focused on the fabrication of GaN-based metal-insulator-semiconductor HFETs by using Si_3N_4, Ga_2O_3, Gd_2O_3, and PECVD-SiO_2 as the insulating material [1-7]. In this study, photo-chemical vapor deposition (photo-CVD) system was used to grow SiO_2 layers. We used a deuterium (D_2) lamp as the excitation source. D_2 lamp emits strong ultra violet and vacuum ultra violet, which can effectively decompose SiH_4 and O_2, since O_2 could absorb photons in the wavelength region from 133 nm to 175 nm and SiH_4 could absorb photons in the wavelength region below 147 nm. Thus, energy can be directly transferred from D_2 lamp to the excited Si and O atoms. It has been reported that the quality of oxide layers grown by such a photo-CVD system is close to that grown by thermal oxidation and the electrical properties of photo-CVD SiO_2 are acceptable for device applications [8-11]. In this paper, the AlGaN/GaN/AlGaN double heterostructure MOS-HFETs with photo-CVD SiO_2 layers will be fabricated. And the electrical and low frequency noise characteristics of the fabricated MOS-HFETs will be studied and reported.

2. Experiments

The designed AlGaN/GaN/AlGaN double heterostructures were grown by metalorganic chemical vapor deposition (MOCVD, EMCORE D-180) on sapphire substrates, which consist of a 30 nm-thick GaN buffer layer, a 2 μm-thick unintentionally doped GaN layer, a 300 nm-thick unintentionally doped $Al_{0.22}Ga_{0.78}N$ spacer layer, a 10 nm-thick GaN, and a 25 nm-thick unintentionally doped $Al_{0.22}Ga_{0.78}N$ cap layer. The room temperature Hall mobility (μ_n) and the sheet carrier concentration (n_s) for the designed HFET structure were about 1310cm^2/V-s and 1.34×10^{13}cm^{-2}, respectively. Devices isolation was then implemented with an aid of inductively coupled plasma (ICP) etching system. Ti/Al (10nm/180nm) was subsequently deposited by the thermal evaporator as the electrodes for both source and drain ohmic contacts, followed by a 670^{o}C furnace annealing process in N_2 ambient for 6 minutes. Finally, a 32 nm-thick photo-CVD gate oxide and Ni/Au (40nm/80nm) gate metal defined by standard photolithography were deposited [8-11]. The carrier profiles of both structures were measured using a capacitance-voltage profiling technique. The current-voltage characteristics of these fabricated MOS-HFETs were then measured by an *HP 4156B Semiconductor Parameter Analyzer*. During low frequency noise measurements, the bias conductions were supplied and controlled by a *BTA Noise Pro System*. The noise power spectra were then analyzed by a *HP35670A Dynamic Signal Analyzer* and a *BTA 9812 Noise Analyzer*.

3. Results and Discussions

We had successfully deposited high quality SiO_2 onto AlGaN by photo-CVD, with D_2 lamp as the excitation source. The details on the chemical and physical natures of our photo-SiO_2 layers were characterized by series of analytical techniques (XPS, AFM, FTIR, and AES) and the results were already published elsewhere [8-11]. As shown in figure 1, using the standard high frequency capacitor method, the photo-CVD SiO_2/AlGaN interface state density, D_{it}, was estimated to be only 1.1×10^{11} cm^{-2}eV^{-1} at room temperature, and still 3.5×10^{12} cm^{-2}eV^{-1} even at 175^{o}C. Based on the carrier concentration versus depth data obtained from the C–V measurement as shown in figure 2, we suspect the higher carrier concentration is attributable to stronger confinement of AlGaN/GaN/AlGaN double heterostructure. Figure 3 depicts the I_{ds}-V_{ds} characteristics with gate voltage (V_{gs}) varied from -8V to 2V in an incremental step of 2V for MOS-HFETs measured at room temperature and 300^{o}C. The design parameters associated with the channel width, gate length, and source-drain distance is 75 μm, 1 μm and 5 μm, respectively. It was found that $I_{d,max}$ at room temperature and 300^{o}C were about 755 mA/mm and 323 mA/mm, respectively. The observed degradation of maximum saturation drain current was believed to be induced by thermal effect. However, no kink effect was noticed for MOS-HFETs at high temperature even when V_{ds} is as high as 20V. These results indicate that our high quality photo-CVD SiO_2 layer enables the MOS-HFETs to be comfortably operated at elevated temperatures. Figure 4 presents the curves of transconductance (g_m) and I_{ds} with respect to V_{gs}. It was found that for AlGaN/GaN/AlGaN MOS-HFETs maximum g_m is about 95 mS/mm, gate voltage swing (GVS) at room temperature could reach 8V, and GVS at 300 ^{o}C only decreased slightly to 7.5V. All these electrical characteristics of AlGaN/GaN/AlGaN MOS-HFETs were better than those of conventional devices. In this case, a large GVS within a wide temperature range suggests that our AlGaN/GaN/AlGaN MOS-HFETs could well provide a good linearity response; one of very important criteria for practical amplifier applications. Furthermore, figure 5 shows the low frequency noise power spectrum. From low frequency noise power spectrum, it was found that noise power density of AlGaN/GaN/AlGaN double heterostructure was lower and presented pure 1/f noise with fewer traps than those of conventional structure. Such a result suggests that AlGaN/GaN/AlGaN double heterostructure with a lower frequency noise are more suitable for microwave and/or communication applications.

4. Summary

High quality SiO_2 films were successfully deposited onto AlGaN by photo-chemical vapor deposition (photo-CVD) system. The interface state density, Dit, of photo-CVD SiO_2/AlGaN was estimated to be only 1.1×10^{11} $cm^{-2}eV^{-1}$ at room temperature, and still 3.5×10^{12} $cm^{-2}eV^{-1}$ even at 175^{o}C. The carrier concentration of AlGaN/GaN/AlGaN double heterostrunncture was higher and stronger confinement than that of conventional structure. With a 1μm gate length, it was found that the maximum saturated I_{ds}, maximum g_m and GVS of the fabricated MOS-HFETs were 755mA/mm, 95mS/mm and 8V, respectively. Even at 300^{o}C, the maximum saturated I_{ds} and maximum g_m of the fabricated MOS-HFETs were still kept at 323mA/mm and 41mS/mm, respectively. Furthermore, from low frequency noise power spectrum, it was found that noise power density of AlGaN/GaN/AlGaN double heterostructure was lower and presented pure 1/f noise with fewer traps than those of conventional structure.

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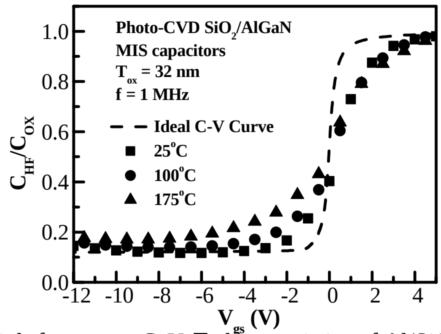

Fig. 1 High-frequency *C–V–T* characteristics of Al/SiO_2/AlGaN MIS capacitors measured at different temperatures

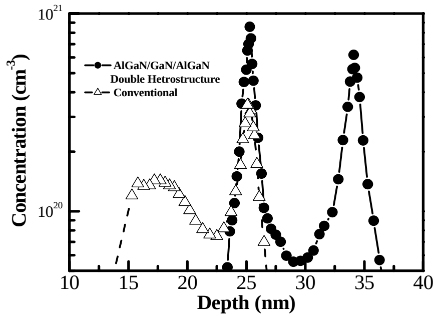

Fig. 2 Carrier concentration versus depth for both structures

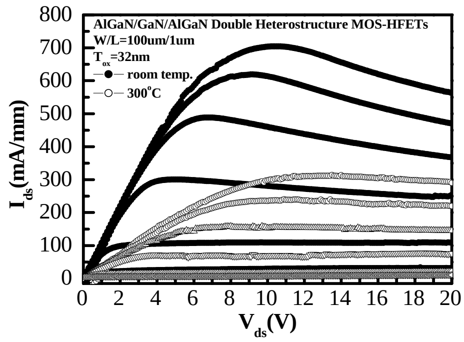

Fig. 3 I_{ds}-V_{ds} characteristics for AlGaN/GaN/AlGaN MOS-HFETs

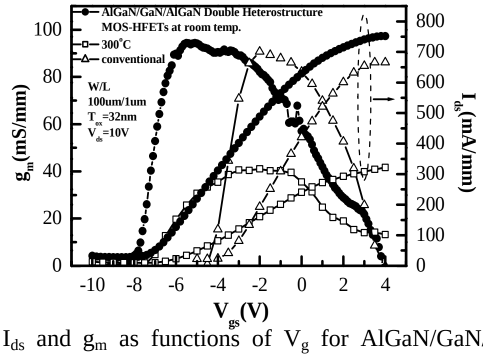

Fig. 4 I_{ds} and g_m as functions of V_g for AlGaN/GaN/AlGaN MOS-HFETs at room temperature and 300^{o}C, respectively

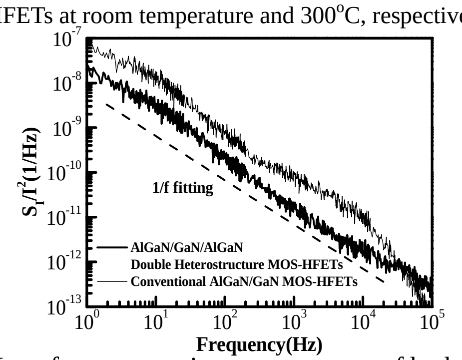

Fig. 5 Low frequency noise power spectra of both devices