Properties of GaAs Surface Formed by In-situ Plasma Oxidation and its Effect on HfO_2/GaAs MOS Capacitor

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Abstract: Metal-oxide-semiconductor (MOS) gate stack on GaAs has been notorious for its poor electrical properties such as high leakage current density. We applied an in-situ plasma oxidation technique to HfO_2 metal-organic chemical vapour deposition (MOCVD) to fabricate high-k MOS capacitor on p-GaAs. Leakage current density of the HfO_2 MOS capacitor was reduced to 7.7×10^{-8} A/cm^2 with the in-situ plasma oxidation from 1.8×10^{-2} A/cm^2 at V_{FB}-1 V. The possible reason of the improvement was investigated using XPS.

Keywords: GaAs, MOS capacitor, in-situ plasma oxidation, plasma surface treatment

1. Introduction

For over 4 decades there has been a search for a suitable gate insulator for GaAs in a scientific community. Motivated from SiO_2/Si analogy and encouraged by the demonstration of low density of interface states of Ga_2O_3 on GaAs, GaAs enhancement-mode metal-oxide-semiconductor field-effect transistors (MOSFETs) demonstrated using GdGaO/Ga_2O_3 dielectric stacks [1, 2]. However, these require ultra-high vacuum (UHV) molecular-beam epitaxy (MBE) growth condition to perform a crucial UHV surface preparation [3]. The UHV MBE processing is too expensive and slow to be applied to a mass production of semiconductor fabrication [3].

In this paper, we report the effective gate stack fabrication technique which formed by a standard Si-based MOS fabrication processes with an in-situ plasma oxidation of GaAs prior to high-k deposition in TaN/HfO_2/GaAs MOS gate stack.

2. Experimental

Plasma oxidation of GaAs, HfO_2 deposition and post-deposition annealing (PDA) are carried out without breaking a vacuum in a multi-chamber metal-organic chemical vapour deposition (MOCVD) system after removing the native oxide of p-GaAs (100) in 1% dilute HF (DHF) solution.

3. Results and Discussion

Figure 1 shows that the GaAs MOS sample inserted the in-situ plasma oxidation layer reduces the leakage current of the HfO_2 gate dielectric stack comparing to the other GaAs MOS samples. In comparison, we cleaned p-GaAs substrate with $(NH_4)_2S$ after removal of native oxide using 1% DHF and before HfO_2 deposition. Our results show that MOCVD HfO_2 on GaAs without pre-deposition treatment, even in the case of sulphur passivation, have a large leakage current so that C-V characteristics cannot be measurable. However, a great improvement can be achieved by inserting an oxide layer between HfO_2 and GaAs substrate using the in-situ plasma oxidation technique. Figure 2 shows C-V characteristics of HfO_2/in-situ plasma oxide/GaAs gate structure. The X-ray photoelectron spectroscopy (XPS) results in Figure 3 show that the in-situ plasma oxide is mainly composed of gallium oxide and the gallium oxide remains after HfO_2 2 nm deposition. It can be worth noting that there is no significant change in arsenic oxide peaks of As 3d XPS spectra from samples with different pre-deposition treatment conditions. Still the mechanism of interface degradation related with (Ga, As)-oxide is not understood well. In general, arsenic oxide is well known as a main cause to arise Fermi pinning [4]. However, our results indicate that high-quality gallium oxide can alleviate the detrimental interface degradation between HfO_2 and GaAs substrate, even the case of arsenic oxide remained in the gate stack. In addition, these results show the high-quality gallium oxide can be integrated into the high-k gate dielectric stacks on GaAs using a conventional MOCVD high-k deposition technique to realize low-power and high-speed devices' mass production.

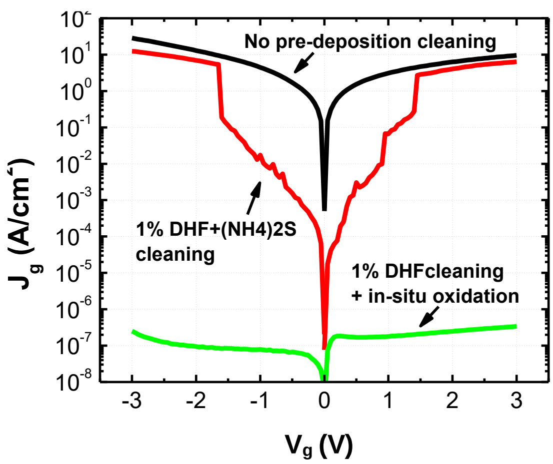

Fig. 1. Gate leakage current density curves of TaN/HfO_2/GaAs MOS capacitor with different pre-dielectric deposition processes.

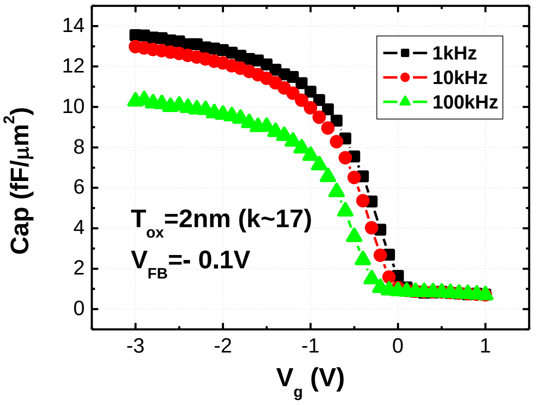

Fig. 2. C-V characteristics of GaAs MOS capacitor at various frequencies for HfO_2/in-situ oxide gate stacks on p-GaAs. The values are extracted from C-V at 1kHz.

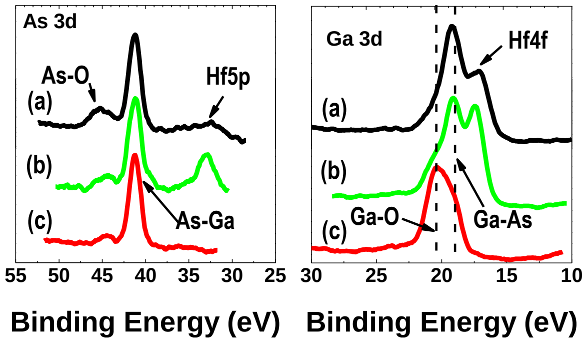

Fig. 3. XPS spectra from ~2nm thick HfO_2 films deposited (a) on GaAs without the in-situ plasma oxidation and (b) on GaAs with the in-situ plasma oxidation pre-deposition treatment, and (c) from as oxidized GaAs by the in-situ plasma oxidation.

4. Summary

In summary, a great improvement in MOCVD HfO_2 GaAs MOS capacitor characteristics by gallium oxide interfacial layer, which is grown using in-situ plasma-enhanced MOCVD process technique, is observed. The gate leakage current density reduces in a magnitude of 6 orders lower than the case without the in-situ plasma oxidation at $V_g = V_{FB}$ -1 V. From C-V characteristics, no significant degradation in the dielectric constant of the MOCVD HfO_2 (~18) is performed. In comparison to the previous decent HfO_2 MOS capacitor demonstration with the in-situ SiH_4 passivation, the in-situ plasma oxidation technique can reduce the gate leakage current density much further from ~10^{-4} A/cm^2 to ~10^{-6} A/cm^2 at V_{FB} -1 V [5]. These results might indicate that the in-situ plasma oxidation prior to high-k deposition passivates the interface between high-k layer and GaAs channel from its degradation during the fabrication processes without sacrifice of k-value in a way of compatible to the present mass production techniques.

5. References

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