Fluorinated Al₂O₃ Gate Dielectric Engineering on GaSb MOS Devices

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Abstract

In this letter, a postgate CF₄-plasma treatment is proposed and demonstrated on Mg-implanted source and drain Gallium Antimonide (GaSb) p-channel MOSFET and the effects of fluorine (F) incorporation have been studied on Al₂O₃/GaSb gate stacks. 3min CF₄-plasma treatment brings the best improvement in electrical characterization. Frequency dispersion, hysteresis and interface state density (Dₛ) are improved after F incorporation. Without post-deposition annealing (PDA), the dc output characteristics of pMOSFET had increased 200%. It is believed to be due to the reduction of the numerous oxide fixed charge in the Al₂O₃ bulk.

1. Introduction

GaSb is an attractive material for p-channel MOSFET because of its high bulk mobility for holes (~850 cm²/Vs) and the metal/GaSb interface exhibits Fermi level pinning near the valence band (Vₜ) which is suitable for obtaining low resistance ohmic contact on p-type GaSb[1]. However, the highly oxidized surface has led to main challenges in achieving low interface trap density (Dₛ). In order to reduce the Dₛ and improve the performance of GaSb MOS devices, many methods have been proposed, such as in-situ hydrogen plasma exposure [2] and Si passivation [3].

Recently, fluorine (F) incorporation into the high gate dielectric has been widely investigated on Si [4-5], Ge [6-7], and III-V semiconductors [8-9]. Chen Y T et al. demonstrated the effects of fluorine incorporation on InGaAs and InP substrate. By incorporation of fluorine, the dc output characteristics had increased 26.3% and 32.3%, respectively [8-9]. In this work, we explore an alternative postgate CF₄-plasma treatment on Mg-implanted source and drain GaSb pMOSFET. Improved electrical performance has been achieved for the fluorinated devices.

2. Experimental

GaSb MOSFETs were fabricated on n-type GaSb (100) wafers (Te doped, ~2x10¹⁸). The native oxide was removed by a cyclic rinsing between de-ionized water and diluted HCl. After that, an Al₂O₃ layer of 30nm was then deposited at a substrate temperature of 300°C as an encapsulation layer. For device fabrication, source and drain regions were selectively implanted with a Mg dose of 3x10¹⁵ cm⁻² at 45 keV through the 30-nm Al₂O₃ encapsulation layer. The source and drain activation annealing was achieved by a 30s rapid thermal anneal (RTA) at 600°C. Then, the encapsulation layer was removed by buffered oxide etch (NH₃:F:HF=7:1). After the same surface preparation (HCl), 10nm Al₂O₃ was deposited by ALD. Some samples were treated by CF₄-plasma (20W, 3min or 5min), and control samples without CF₄-plasma treatment were also fabricated as references. The flow rate of CF₄-plasma was 50 SCCM. To avoid possible carbon contamination, O₂ with a flow rate of 5 SCCM was also introduced into the plasma. After that, the source and drain ohmic contacts were made by electron beam evaporation of a combination of Ni/Pt/Au. The gate electrode was defined by electron beam evaporation of Ti/Au. MOS capacitors (MOSCAPs) were also fabricated for capacitance-voltage analysis. Figure 1 shows cross section of the device structure of post CF₄-plasma treatment.

Fig.1 Cross section of the device structure of post CF₄-plasma treatment.

3. Results and discussion

Atomic force microscopy (AFM) images of Al₂O₃ before and after CF₄ plasma treatment (20W 5min) are shown in Figure 2 (a) and (b), respectively. The surface roughness (RMS) of Al₂O₃ after CF₄-plasma treatment was 0.502 nm, compared to that of the control sample (RMS=0.627 nm), suggesting that no damage was caused by the plasma treatment.

Fig.2 Atomic force microscopy (AFM) images of Al₂O₃ (a) before and (b) after CF₄ plasma treatment.

Figure 3 shows the x-ray photoelectron spectroscopy spectra (XPS) of F1s for the Al₂O₃/GaSb gate stack without and with 5min CF₄-plasma treatment. Samples for XPS measurements were fabricated following identical ALD and
CF₄-plasma treatment procedure, except only ~3nm Al₂O₃ were deposited. The peak located at ~687 eV corresponding to the F bonds in the bulk Al₂O₃, indicating that F is incorporated into the gate stack after CF₄-plasma treatment.

![F1s XPS spectrum for samples without and with 5min CF₄-plasma treatment on Al₂O₃/GaSb gate stack.](image)

Fig.3 F1s XPS spectrum for samples without and with 5min CF₄-plasma treatment on Al₂O₃/GaSb gate stack.

To see the effect of CF₄-plasma treatment, multifrequency C-V characteristics are compared between samples with and without CF₄-plasma treatment in Figure.4. Less frequency dispersion and better gate modulation (e.g. higher \( C_{max}/C_{min} \) ratio) can be observed for samples with CF₄-plasma treatment. At room temperature, the frequency dispersions in accumulation region of samples without and with CF₄-plasma treatment for 3min and 5min are 4.9 %, 3.2 %, and 4.1 %/decade, respectively. Figure.4 (d), shows the 1MHz-hysteresis characteristics. The hysteresis reduces from ~0.5V for control sample to ~0.24V after 3min CF₄-plasma treatment. By using the high-low frequency method, we evaluated the \( D_n \) at Al₂O₃/GaSb interfaces. A midband-gap \( D_n \) value of 4.3×10¹²/cm²eV was achieved for sample with 3min CF₄-plasma treatment. This suggests that the F postgate treatment is very effective in passivating the defect states at Al₂O₃/GaSb interface.

![Multifrequency C-V characteristics of MOSCAPs for samples (a) without CF₄-plasma treatment. (b) With 3min CF₄-plasma treatment. (c) With 5min CF₄-plasma treatment and (d) 1MHz-hysteresis curves of control sample and the sample with different treat time.](image)

Fig.4 Multifrequency C-V characteristics of MOSCAPs for samples (a) without CF₄-plasma treatment. (b) With 3min CF₄-plasma treatment. (c) With 5min CF₄-plasma treatment and (d) 1MHz-hysteresis curves of control sample and the sample with different treat time.

\[ I_{d}-V_{d} \] characteristics of MOSFETs with and without CF₄-plasma treatment are shown in Figure.5. During the fabrication of the pMOSFET, PDA was not introduced after the 10nm Al₂O₃ was deposited. In this case, much oxide fixed charge exists in the Al₂O₃ bulk. The maximum drain currents under \( V_d = -1.5 \) V and \( V_g = -4 \) V for the gate dielectric without and with CF₄-plasma treatment for 3min and 5min are 1.08, 3.02 and 1.39 mA/mm, respectively. It is believed that due to the CF₄-plasma treatment, the oxide fixed charge in the Al₂O₃ bulk have dramatically decreased and the treatment of rf power of 20 W for 3min is the optimum condition.

![Is-Vd characteristics of MOSFETs without and with CF₄-plasma treatment for 3min and 5min.](image)

Fig.5 \( I_d-V_d \) characteristics of MOSFETs without and with CF₄-plasma treatment for 3min and 5min.

4. Conclusions

In summary, a postgate CF₄-plasma treatment is proposed and demonstrated on GaSb MOSCAPs and MOSFETs. The incorporation of fluorine into high-k dielectric is confirmed with XPS analysis. F incorporation can improve GaSb MOSCAPs characteristic in terms of frequency dispersion, hysteresis and interface state density. The treatment of rf power of 20 W for 3min is the optimum condition for the Al₂O₃/GaSb stack.

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References