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Fluorinated Al_2O_3 Gate Dielectric Engineering on GaSb MOS Devices

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Abstract

In this letter, a postgate CF_4-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 Al_2O_3/GaSb gate stacks. 3min CF_4-plasma treatment brings the best improvement in electrical characterization. Frequency dispersion, hysteresis and interface state density (D_{it}) 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 Al_2O_3 bulk.

1. Introduction

GaSb is an attractive material for p-channel MOSFET because of its high bulk mobility for holes (~850 cm^2/Vs) and the metal/GaSb interface exhibits Fermi level pinning near the valence band (V_B) 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 (D_{it}). In order to reduce the D_{it} 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 CF_4-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, ~2×10^{17}). The native oxide was removed by a cyclic rinsing between de-ionized water and diluted HCl.After that, an Al_2O_3 layer of 30nm was then deposited at a substrate temperature of 300 ℃ as an encapsulation layer. For device fabrication, source and drain regions were selectively implanted with a Mg dose of 3×10^{14} cm^{-2} at 45 keV through the 30-nm Al_2O_3 encapsulation layer. The source and drain activation annealing was achieved by a 30s rapid thermal anneal (RTA) at 600 ℃.Then, the encapsulation layer was removed by buffered oxide etch (NH_4F: HF=7:1). After the same surface preparation (HCl), 10nm Al_2O_3 was deposited by ALD. Some samples were treated by CF_4-plasma (20W, 3min or 5min), and control samples without CF_4-plasma treatment were also fabricated as references. The flow rate of CF_4-plasma was 50 SCCM. To avoid possible carbon contamination, O_2 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 CF_4-plasma treatment.

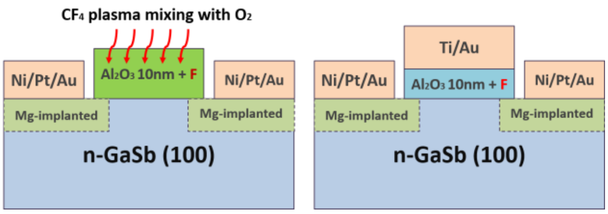

Fig.1 Cross section of the device structure of post CF_4-plasma treatment.

3. Results and discussion

Atomic force microscopy (AFM) images of Al_2O_3 before and after CF_4 plasma treatment (20W 5min) are shown in Figure.2 (a) and 2 (b), respectively. The surface roughness (RMS) of Al_2O_3 after CF_4-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.

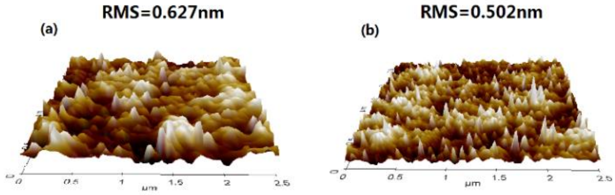

Fig.2 Atomic force microscopy (AFM) images of Al_2O_3 (a) before and (b) after CF_4 plasma treatment

Figure.3 shows the x-ray photoelectron spectroscopy spectra (XPS) of F1s for the Al_2O_3/GaSb gate stack without and with 5min CF_4-plasma treatment. Samples for XPS measurements were fabricated following identical ALD and

CF_4-plasma treatment procedure, except only ~3nm Al_2O_3 were deposited. The peak located at ~687 eV corresponding to the F bonds in the bulk Al_2O_3, indicating that F is incorporated into the gate stack after CF_4-plasma treatment.

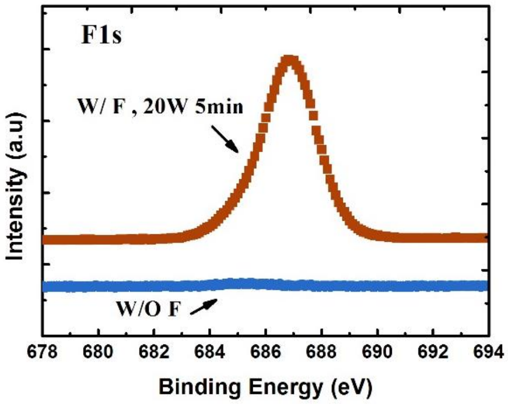

Fig.3 F1s XPS spectrum for samples without and with 5min CF_4-plasma treatment on Al_2O_3/GaSb gate stack.

To see the effect of CF_4-plasma treatment, multifrequency C-V characteristics are compared between samples with and without CF_4-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 CF_4-plasma treatment. At room temperature, the frequency dispersions in accumulation region of samples without and with CF_4-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 CF_4-plasma treatment .By using the high-low frequency method, we evaluated the D_{it} at Al_2O_3/GaSb interfaces. A midband-gap D_{it} value of $4.3\times10^{12}/cm^2eV$ was achieved for sample with 3min CF_4-plasma treatment. This suggests that the F postgate treatment is very effective in passivating the defect states at Al_2O_3/GaSb interface.

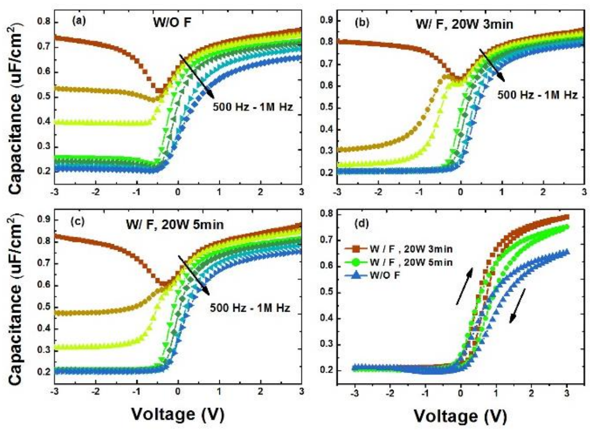

Fig.4 Multifrequency C–V characteristics of MOSCAPs for samples (a) without CF_4-plasma treatment. (b) With 3min CF_4-plasma treatment. (c) With 5min CF_4-plasma treatment and (d) 1MHZ-hysteresis curves of control sample and the sample with different treat time.

I_d-V_d characteristics of MOSFETs with and without CF_4 -plasma treatment are shown in Figure.5. During the fabrication of the pMOSFET, PDA was not introduced after the 10nm Al_2O_3 was deposited. In this case, much oxide fixed charge exists in the Al_2O_3 bulk. The maximum drain currents under V_d= -1.5 V and V_g = -4V for the gate dielectric without and with CF_4-plasma treatment for 3min and 5min are 1.08, 3.02 and 1.39 mA/mm, respectively. It is believed that due to the CF_4-plasma treatment, the oxide fixed charge in the Al_2O_3 bulk have dramatically decreased and the treatment of rf power of 20 W for 3 min is the optimum condition.

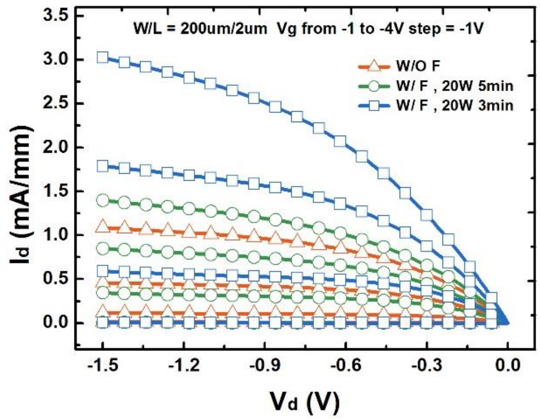

Fig.5 I_d-V_d characteristics of MOSFETs without and with CF_4-plasma treatment for 3min and 5min.

4. Conclusions

In summary, a postgate CF_4-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 3 min is the optimum condition for the Al_2O_3/GaSb stack.

Acknowledgment

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