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Investigation of the Electrical Behaviors of Ge MOS capacitor on GaAs Substrate

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1. Introduction

In the past decades, the semiconductor industry community faces challenges of continue reduction of device feature sizes for silicon devices. In contrast to these Si devices, III-V materials have attracted lots of attention because of their high electron mobility, for example, InAs has an electron mobility of 20000 $cm^2V^{-1}s^{-1}$ [1]. However, III-V materials still suffer from low hole mobility, it is very critical to find a material with high hole mobility for post CMOS application. The Ge is a good choice as the p-channel material because of its high hole mobility. The Ge epitaxial film on GaAs substrate recently attracts lots of attention due to the following reasons. Ge has a much higher bulk hole mobility (μ_h =1900 cm^2/Vs) as compared to GaAs (μ_h = 400 cm^2/Vs), and the Ge/GaAs interface has a very small lattice mismatch (~0.08%). Therefor, thicker Ge films can be grown on GaAs substrates with very low threading dislocation density [2]. Hence, high-quality epitaxial Ge films can be grown on GaAs as p-channel material to fabricate a high hole mobility metal–oxide–semiconductor field-effect transistor (MOSFET). In this work, 250nm Ge epitaxial film was grown on GaAs substrate by UHVCVD. The MOS capacitors (MOSCAPs) were fabricated using atomic layer deposition (ALD) with 10 nm Al_2O_3 on Ge. The Ge surfaces were treated by HF or HF plus rapid thermal oxidation (RTO) before the deposition of oxide. The electrical properties of the MOSCAPs are investigated.

2. Experimental Procedure

For Ge deposition, epi-ready GaAs (100) wafers were used as substrates. GeH_4 is the Ge source for Ge deposition by UHVCVD system. Before loading into the load-lock, the as-received GaAs wafer did not do any pre-cleaning step. Then, the wafer was transferred into the deposition chamber after the pressure of load-lock reached 5x10^{-7}Torr. To remove the native oxide (As_2O_3 and Ga_2O_3) on the surface, GaAs wafer went through a prebake step. The prebake time without arsenic overpressure was controlled carefully to prevent the decomposition of GaAs due to the sensitive nature of GaAs substrate surface. During the step of 250nm Ge film growth, the GeH_4 flow was fixed at 10 sccm, the pressure was controlled at 20 mTorr at 600°C. For MOSCAPs fabrication, Ge film was degreased in acetone and isopropanol. Then the wafer was soaked in the HF (49%): H_2O_2=1:100 solution to remove the native oxides, and then followed by rinsing in deionized (DI) water and drying by nitrogen gun. One sample after HF treatment went through RTO for the growth of thin GeO_2 film before the deposition of Al_2O_3. The RTO was performed at 400°C for 3 minutes in oxygen atmosphere. The samples with HF and HF+RTO treatments were then loaded into ALD chamber. In ALD chamber, 10nm Al_2O_3 was deposited at 250°C. After that, post deposition annealing (PDA) was done at 450°C for 5 minutes in forming gas [3]. Finally, Pt/Au (500Å/1000Å) and Ti/Au (500Å/1000Å) were deposited for gate and ohmic metals, respectively, followed by post metal annealing at 250°C for 30 seconds in forming gas.

3. Results and Discussion

HRXRD measurement (Bede D1 XRD system) was used to check the crystal quality of the 250nm Ge film deposited at 600°C on GaAs substrate. The scanned result is shown in Fig. 1 with the GaAs substrate peak at zero, the HRXRD result is in black line and the simulated curve is in red line. The HRXRD result and the simulated curve match closely with each other. The appearance of fringes on both sides of Ge and GaAs peaks implies a parallel and very sharp interface existed in this heterojunction structure [4].

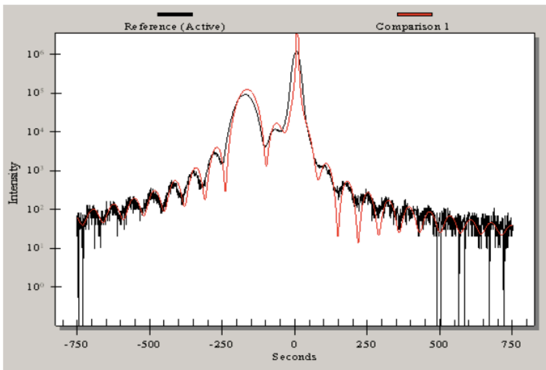
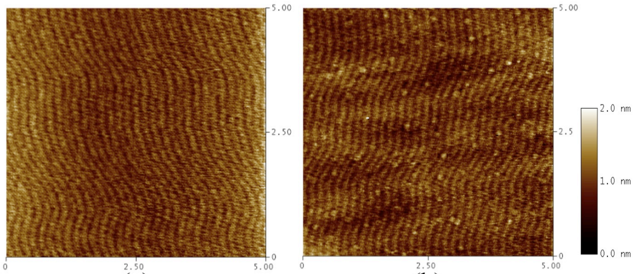


Fig. 1 XRD measurement of 250nm Ge film on GaAs substrate. The fringes on both sides imply a sharp Ge/GaAs interface.

The AFM measurement of the same sample is shown in Fig. 2. It shows the surface roughness of Ge film without and with the deposition of Al_2O_3. The root mean square roughness (RMS) and the mean surface roughness (Ra) of Ge film without Al_2O_3 were 0.189nm and 0.151nm, and the values of Ge film with Al_2O_3 deposition were 0.205 nm and

0.162nm. These indicate that the Ge film grown on GaAs substrate with Al_2O_3 deposition was very uniform and can be used for the fabrication of MOSCAP.



(a) (b)

Fig. 2 The AFM measurement of Ge epitaxial film (a) bare Ge surface and (b) after ALD Al_2O_3

Fig. 3 shows the current-voltage characteristics of MOSCAP samples. Smaller than 10^{-8} A/cm^2 in the range -5V - 3.5V gate bias were obtained. The I-V behaviors in both samples are very similar.

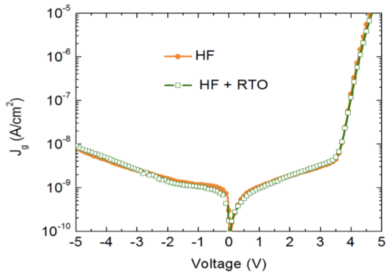
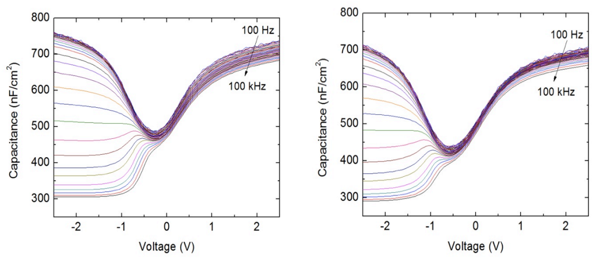


Fig. 3 The current-voltage characteristics of Al_2O_3/Ge MOSCAPs

From Fig. 4, nice C-V curves with good inversion behaviors are observed for both samples. Fig. 4b shows the improvement of HF + RTO sample such as smaller frequency dispersion in accumulation and depletion as compared to Fig. 4a (HF samples). More studies focused on RTO conditions are going on to get further devices performance improvement.



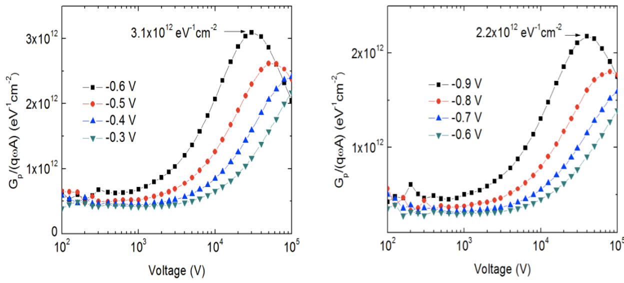
(a) HF only (b) HF + RTO

Fig. 4 The Capacitance-Voltage measurement of Ge/GaAs MOSCAP without and with RTO treatment

The interface trap densities (D_{it}) of samples were extracted using conductance method. The relationship between parallel conductance and D_{it} can be expressed as following:

$$D_{it} = 2.5(\frac{G_p}{q\omega A})\max \qquad (1)$$

where, G_p is parallel conductance, ω is measured angular frequency, and A is capacitance area.



(a) HF only (b) HF + RTO

Fig. 5 Parallel conductance $G_p/(q\omega A)$ versus measured frequency at difference gate voltage

Through Equation 1, D_{it} values estimated by conductance method (Fig. 5) are ~5.5×10^{12} and 7.75×10^{12} eV^{-1}cm^{-2} for HF (Fig. 5a) and HF+RTO treatment (Fig. 5b) samples, respectively. Notice that the estimation took into account the weak inversion layer. The true values of D_{it} might be one order lower, i.e. $5.5x10^{11}$ and $7.75x10^{11}$ eV^{-1}cm^{-2}, if the weak inversions are not taken into account.

4. Conclusions

High quality, smooth Ge epitaxial film was grown on GaAs substrate. The RMS and Ra value are very low even after the 10 nm Al_2O_3 is deposited on Ge film by ALD. Through the electronic measurement of Al_2O_3/Ge/GaAs with and without RTO treatment before Al_2O_3 deposition, the gate leakage current is low in both samples. Good inversion behaviors and low D_{it} are observed in the CV curves for both samples. The HF + RTO MOSCAP sample shows better frequency dispersion behavior and demonstrated the reduction of the D_{it} compare to that of the HF treated sample. This structure studied here is useful for the future fabrication of Ge p-channel MOSFET and for the CMOS integration with n-channel devices.

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