Effects of different gases on electrical properties and reliability of Ge MOS capacitors with GeO_x/GeO_xN_y as gate dielectric

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Abstract. In this paper, germanium oxides/oxynitrides were prepared in different gases. The effects of different gas ambients on the electrical properties and reliability of Ge MOS capacitors were analyzed. The experiment results showed that the nitride incorporation could improve the performances of Ge MOS capacitors with reduced interface-states and gate leakage current.

Introduction

Different high-k dielectrics such as HfO_2 [1-2], Al_2O_3 [3] and ZrO_2 [4-5] were used as gate dielectric for Ge MOSFETs. But directly depositing high-*k* dielectrics on Ge substrate leaded to high gate leakage current [6-7]. In order to improve the quality of the interface between dielectric and Ge substrate, GeO_2 [8] and GeON [7] were used as an interlayer between the high-*k* dielectric and Ge substrate. Both were claimed to be effective interlayers for improving device qualities. In this section, Ge MOS capacitors with GeO_2 and GeON gate dielectrics were fabricated to compare these two dielectrics. GeO_2 and GeON gate dielectrics were grown by thermal oxidation in dry/wet O_2, dry/wet NO or dry/wet N_2O ambient. The electrical properties and high-field reliability of these capacitors were measured. Compared with GeO_2/Ge, GeON/Ge was found to have the better electrical properties with lower interface-state density and smaller gate leakage current.

Experiment and Results

Device fabrication

MOS capacitors with GeO_2 and GeON gate dielectrics were fabricated on (100)-oriented n-type Ge substrate with a doping concentration of 2.65×10^{16} cm^{-3}. After cleaning and drying, Ge wafers were received thermal oxidation to grow GeO_2 and GeON. GeO_2 was thermally grown at 550 ^oC in dry/wet O_2 ambient (denoted as DO2/WO2 samples respectively) for 10 min. GeON was prepared by dry/wet NO or dry/wet N_2O oxidation at 550 ^oC for 10 min (denoted as DNO/WNO and DN2O/WN2O samples respectively). Then, each sample received a 500 ml/min dry N_2 annealing for 5 min at 550 ^oC. Al was thermally evaporated and patterned as the gate electrode of the MOS capacitors with an area of 7.85×10^{-5} cm^2. Finally, forming-gas annealing was performed at 300 ^0C for 20 min.

Results and discussions

Fig.1 shows the typical 1-MHz HF C-V curves of the samples under dark condition, swept in both directions. It is obvious that the wet samples have larger capacitance, thus thinner gate dielectric grown in the wet ambient. A possible reason is that the growth of unstable GeO_x or GeON with low N content (hydrolysable in water) is suppressed in the wet ambient, resulting in thinner gate dielectric. There are obvious bumps in the depletion regime of the dry samples, indicating interface traps in their gate dielectrics. On the other hand, the wet samples have smooth C-V curves in the depletion regime, suggesting better quality for their gate dielectrics.

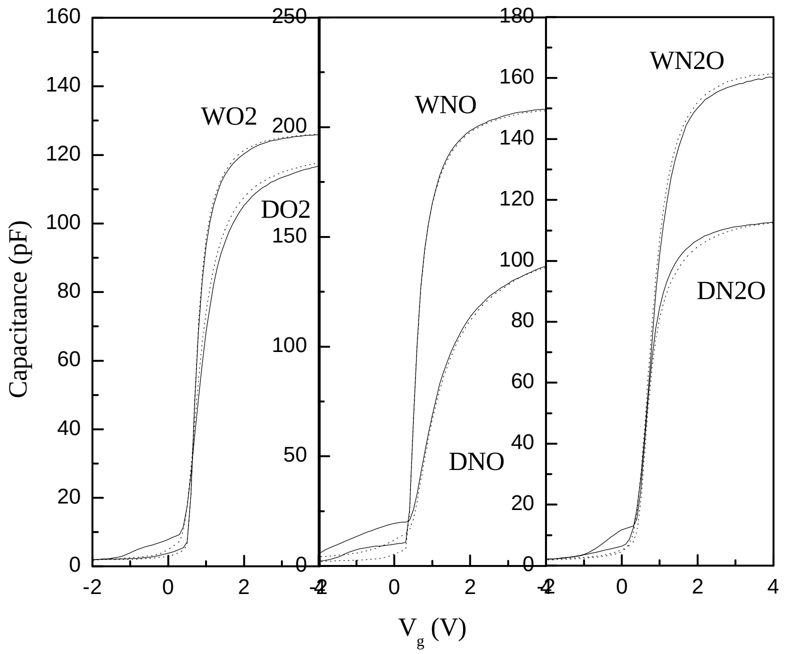
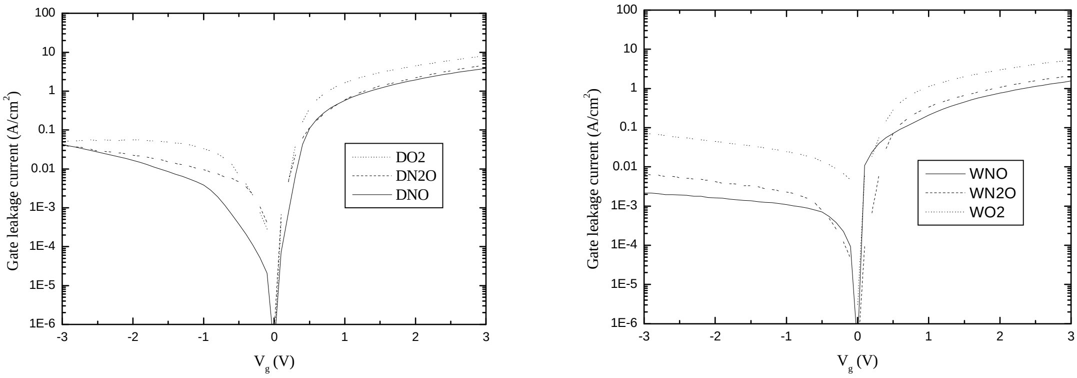


Fig.1 High-frequency C-V curves for DO2/WO2, DNO/WNO and DN2O/WN2O samples.

Table 1 Extracted parameters from high-frequency C-V curves

Sample	C_{ox} (pF)	t_{eq} (nm)	D_{it} at midgap ($cm^{-2}eV^{-1}$)	V_{fb} (V)	Q_{ox} (cm^{-2})
DO2	118.5	2.3	6.4×10^{12}	0.52	-4.25×10^{12}
WO2	126.2	2.1	2.7×10^{12}	0.53	-4.66×10^{12}
DN2O	113.1	2.4	5.3×10^{12}	0.43	-3.23×10^{12}
WN2O	161.2	1.7	3.1×10^{12}	0.52	-5.76×10^{12}
DNO	141.4	1.9	7.3×10^{12}	0.46	-4.40×10^{12}
WNO	208.7	1.3	1.3×10^{12}	0.32	-4.15×10^{12}

Table1 lists the device parameters extracted from the 1-MHz HF C-V curves. D_{it} is determined by Terman's method for comparison purpose. In table 1, the values of flatband voltage (V_{fb}) and equivalent oxide-charge density (Q_{ox}) of the WO2 sample are larger than those of the DO2 sample due to OH^--related negative charges decomposed from the wet ambient. On the other hand, the WNO sample has smaller V_{fb} and Q_{ox} than the DNO sample, mainly due to the N incorporated in the gate dielectric, resulting in positive charges and thus reduced V_{fb} and Q_{ox}. The combined effects of OH^--related negative charges and N-induced positive charges result in net negative charges, thus larger V_{fb} and Q_{ox} than those of the DN2O sample. During the wet-NO oxidation, the growth of unstable and hydrolysable GeO_x and low-N-content GeON is suppressed, resulting in the growth of high-quality GeON with high N content. Among all the dry samples, the DNO sample has the largest V_{fb} and Q_{ox}, which are attributed to the largest N-induced positive charges in its dielectric. As compared to the Ge MOS capacitors with GeO_2 dielectric, the Ge MOS capacitors with GeON dielectric have smaller D_{it}, due to N passivating the dangling bonds at the interface between gate dielectric and Ge substrate. Among all the wet samples, the WNO sample has the smallest D_{it}, due to the suppressed growth of GeO_x (compared with the WO2 sample) and suitable N incorporation (compared with the WN2O sample) which can passivate the Ge-surface dangling bonds and thus reduce D_{it}.



(a) (b)

Fig.2 Gate leakage current of DO2/WO2, DNO/WNO and DN2O/WN2O samples.

Fig. 2 depicts the gate leakage properties of the samples. The dry samples show larger gate leakage current than the wet samples, due to a larger amount of unstable GeO_x existing in the gate dielectric. Among all the samples, the WNO sample has the smallest leakage current, which should be due to suitable N incorporation, thus high quality of the gate dielectric.

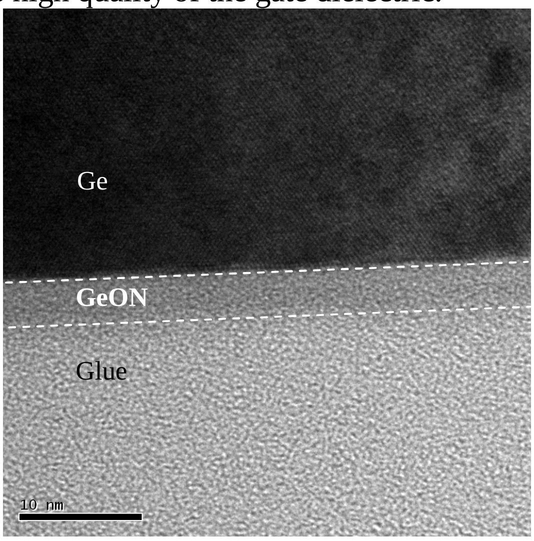


Fig. 3 TEM picture for WNO sample.

Fig. 3 shows the TEM picture of the WNO sample. It is observed that the dielectric is amorphous and has smooth interface with the Ge substrate. The thickness of the gate dielectric and the dielectric permittivity are ~ 3 nm and ~ 8.

Fig. 4 shows the flatband-voltage shift after high-field stressing at10 MV/cm. It is obvious that the dry samples have larger flatband-voltage shift than the wet samples. This is due to the existence of a larger amount of weak Ge-O or Ge-O-N bonds, which are easy to be broken during the high-field stressing, thus generating a large amount of trapped charges. Among all the wet samples, the WNO sample has the smallest change of flatband-voltage, indicating that high-quality GeON can be grown by the wet-NO oxidation.

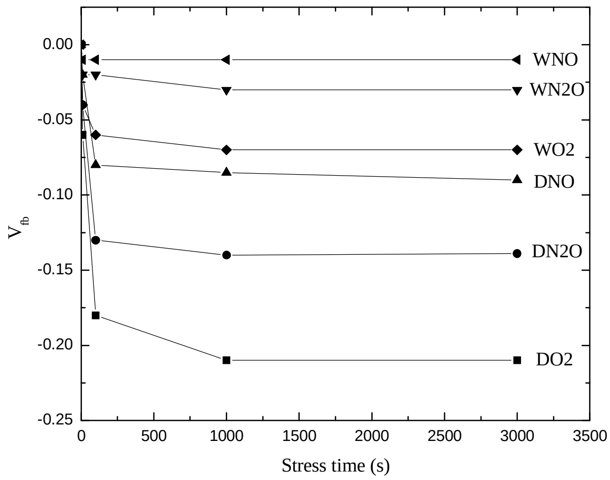


Fig.4 Change of flatband voltage under high-field stress at 10 MV/cm.

Summary

Germanium oxide grown by wet/dry O_2 and germanium oxynitride grown by wet/dry N2O and NO were used as the gate dielectric of Ge MOS capacitors to evaluate the interface quality of GeO2/Ge and GeON/Ge. Experimental results showed that the WNO sample has the lowest interface-state density, smallest flatband-voltage and smallest flatband-voltage increase after high-field stressing, indicating the high quality of the GeON/Ge interface grown by the wet-NO oxidation. In conclusion, wet-NO oxynitriditon is a promising method to prepare high-quality GeON dielectric for high-performance Ge MOSFETs.

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