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Very Low EOT in Ge MOS Devices with High Oxidation State Interfacial Layer

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Abstract

An ultra-low EOT of ~0.39 nm in Ge MOS devices is achieved, and simultaneously the leakage current is decreased. The improvement can be attributed to the in-situ Ge sub-oxide desorption process in an ALD chamber at 370 ^{o}C. About 95% Ge^{4+} in $HfGeO_x$ interfacial layer are obtained by H_2O plasma process together with in-situ desorption before atomic layer deposition.

1. Introduction

Germanium has recently been regarded as a promising channel material in metal oxide semiconductor field effect transistors (MOSFETs). A Ge MOSFET with a superior GeO_x/Ge interface has been achieved with a plasma post oxidation method [1]. It is suggested that the suppression of HfO_2-GeO_x inter-mixing and the formation of high-quality stoichiometric GeO_2 in interfacial layer (IL) are crucial in obtaining superior electrical properties. A higher-k HfON and HfGeO IL for Ge MOS devices can be achieved by H_2O plasma in an atomic layer deposition (ALD) chamber [2]. A higher stoichiometric GeO_2 in IL is desirable to enhance the electrical characteristics of Ge MOS devices. In this work, Ge MOS devices with ILs grown by H_2O plasma together with different in-situ desorption processes in an ALD chamber are studied.

2. Experiment

A germanium oxide is grown on (100)-oriented n-type Ge wafers by a H_2O plasma in an ALD chamber. Then an in-situ desorption process is performed in a pressure of 0.1 torr at 370 ^{o}C for 10, 30, and 60 s. A 3 nm thick HfON dielectric is deposited at 250 ^{o}C by an ALD; the precursor and oxidizer are TEMAH and H_2O. Then, a 50 nm thick TaN is deposited by a sputtering. After lithography and etching processes, a sintering at 400 ^{o}C for 30 min is carried out.

3. Results and Discussion

Fig. 1 shows the capacitance versus applied voltage (C-V) curves for samples with various IL desorption time. The leakage current (J_g) versus equivalent oxide thickness (EOT) in Fig. 2 shows that the EOT can be scaled down to 0.39 nm and, simultaneously, the J_g is decreased by about 0.5 order with a 60 s desorption. Fig. 3 shows the EOT versus HfON thickness. The fitting line is extrapolated to around the origin, indicating an ultra-thin IL is obtained. The dielectric constant(k-value) of the ALD-formed HfON is about 29. The cumulative probability of J_g in Fig. 4 shows that the sample with 60 s desorption time demonstrates good uniformity and the lowest leakage current. The interface-trap density value shown in Fig. 5 is about $7x10^{11}$ cm^{-2}/eV for the sample with 60 s desorption time. A little frequency dispersion observed in Fig. 6 may be due to some border traps.

The X-ray photoelectron spectroscopy (XPS) Ge 3d spectra in Fig. 7 show that the binding energy (BE) values of $HfGeO_x$ are shifted to a higher energy with increasing desorption time. A very high percentage (~95%) of oxidation state in $HfGeO_x$ IL is obtained by a 60 s desorption. On the other hand, the GeO sub-oxide can be reduced by a long in-situ desorption time, thus superior electrical properties can be obtained. The Ge oxidation state extracted in Fig. 8 increases from 3.19 to 3.85 with increasing desorption time. The X-Ray Diffraction (XRD) data in Fig. 9 indicate that the formation of tetragonal HfO_2 is obtained, which can explain the high k-value.

The transmission electron microscope (TEM) images in Fig. 10 show that the IL thickness can be decreased from 0.52 to 0.24 nm with increasing desorption time. The GeO evaporation is significantly enhanced, thus, the IL thickness is reduced by the in-situ desorption. The possible mechanism is illustrated in Fig. 11. The desorption process may turn the interfacial GeO into GeO_2 and evaporate the unwanted GeO at the surface of GeO_2 film [3].

4. Conclusions

The EOT in Ge MOS device is scaled down to 0.39 nm by an in-situ IL desorption for 60 s in an ALD chamber. The excellent electrical characteristics can be attributed to the ~95% Ge^{4+} in $HfGeO_x$ obtained by the IL desorption process at 370 ^{o}C, which enhances the GeO evaporation and reduces IL thickness. The in-situ desorption is a promising approach for high-k gated Ge MOS devices.

Acknowledgements

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References

[1] R. Zhang, P. C. Huang, N. Taoka et al., *VLSI Symp. Tech. Dig.*, (2012) 161.

[2] L. J. Liu, K. S. Chang-Liao, C. H. Fu et al., *Proc. VLSI-TSA*, (2013) 1.

[3] K. Kita, S. K. Wang, M. Yoshida et al., *IEDM Tech. Dig.*, (2009) 1.

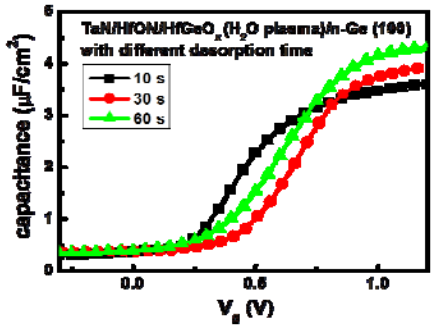

Fig. 1 The C-V curves for samples with various IL desorption time.

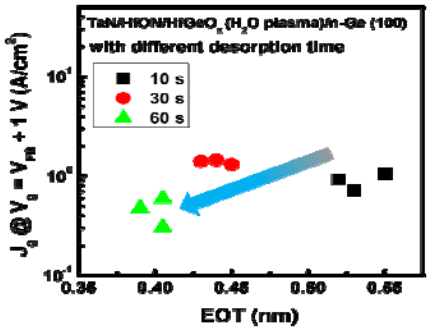

Fig. 2 The Jg versus EOT for all samples.

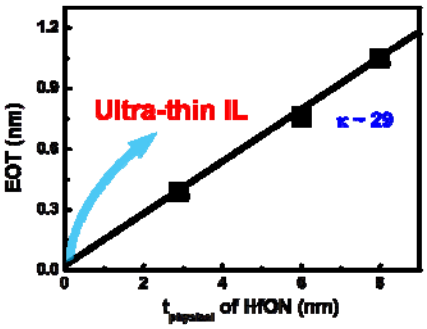

Fig. 3 The EOT versus HfON thickness for the sample with 60 s desorption.

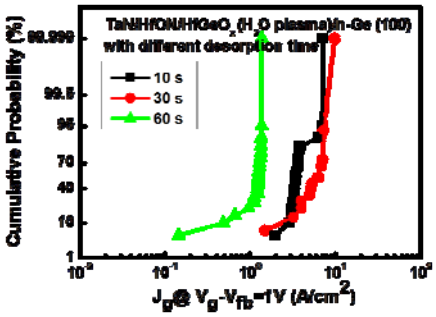

Fig. 4 The distribution of Jg for all samples.

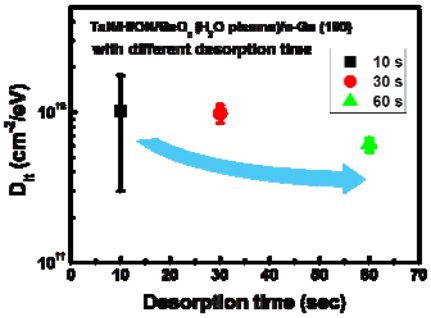

Fig. 5 The Dit for Ge MOS devices with different IL desorption time.

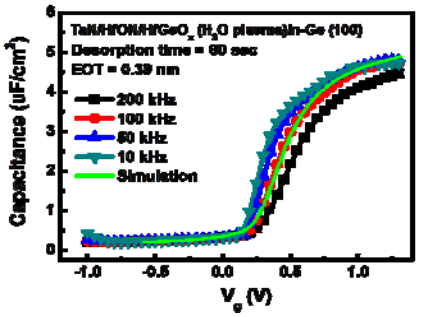

Fig. 6 The frequency dispersion for the sample with 60 s desorption.

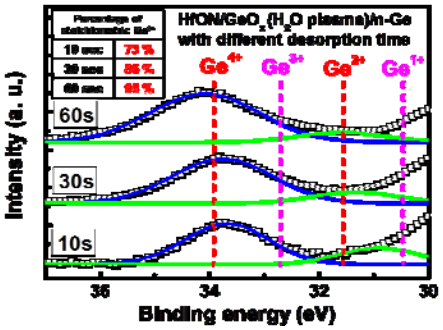

Fig. 7 XPS spectra of Ge 3d for all samples.

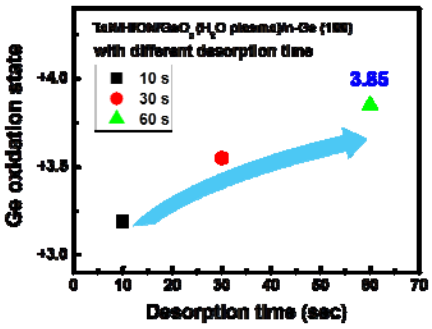

Fig. 8 The Ge oxidation state of all samples.

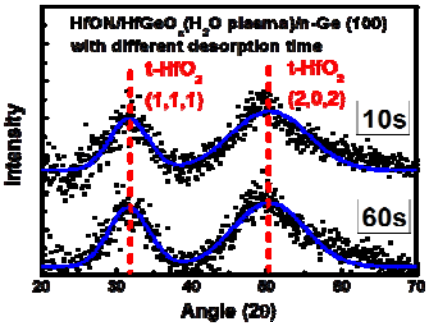

Fig. 9 The XRD spectra for all samples.

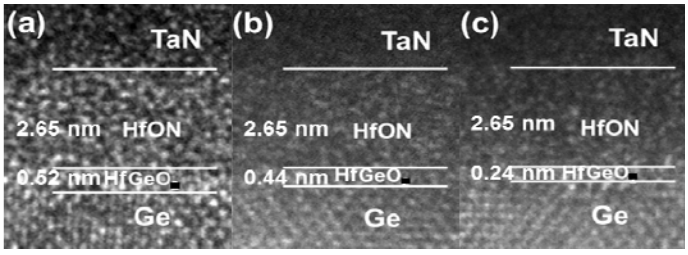

Fig. 10 TEM images of samples with the IL desorption time for (a) 10 s (b) 30 s and (c) 60 s.

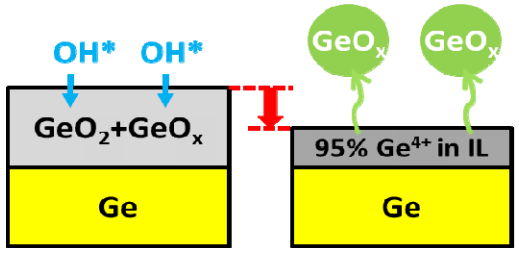

Fig. 11 Schematic mechanism of the in-situ desorption process.