Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp26-27

Ultrathin GeO_x Interfacial Repairer Formed by Thermal Oxidation for Germanium MOS Devices

Le Han[1,2], Shengkai Wang[1], Baiqing Xue[1], Xiong Zhang[2], Wangran Wu[3], Hudong Chang[1], Wei Zhao[1], Bing Sun[1], Yi Zhao[3], Honggang Liu[1*] and Yiping Cui[2]

[1]Microwave Device and IC Department, Institute of Microelectronics, Chinese Academy of Sciences, Beijing 100029, China
Phone: +86-10-8299-5765 Fax: +86-10-6202-1601 E-mail: liuhonggang@ime.ac.cn
[2]Advanced Photonics Center, School of Electronic Science and Engineering, Southeast University, Nanjing 210096, China
[3]School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, China

Abstract

A thermal oxidation method with a thin Al_2O_3 film employed as oxygen blocking layer has been proposed to form an ultrathin GeO_x interfacial repairer for better interface quality. Also the thin Al_2O_3 layer performs well to inhibit GeO desorption from the GeO_x/Ge interface during thermal treatment. MOS capacitors and MOSFETs fabricated with the engineered Al_2O_3/GeO_x/Ge gate stacks exhibit good electrical characteristics.

1. Introduction

Utilizing high-κ gate stacks is a promising way to realize high performance Ge MOSFETs, which desires for low interface trap density (D_{it}). Many efforts such as sulfur passivation[1] and Si passivation[2] have been made to reduce D_{it} at high-κ/Ge interface. However, forming a thin GeO_x interfacial repairer (IR) between high-κ dielectrics and Ge is one of the best solutions to improve interface quality[3]. It is significant to scale down the thickness of GeO_x layer due to its low κ value. R. Zhang et al. have employed plasma post oxidation to get ultrathin GeO_x IR and maintained 1nm EOT gate stack[4]. Nevertheless, the most fundamental method to get GeO_x layer is thermal oxidation, which really needs a better thickness control. In this paper, to achieve a thin GeO_x IR, we employed a thin Al_2O_3 film as oxygen blocking layer to suppress oxygen diffusion and reaction at Ge surface. Also the thin Al_2O_3 layer performs as a diffusion barrier to inhibit surface damage causing by the GeO desorption. MOS capacitors (MOSCAPs) and MOSFETs were fabricated to study the Al_2O_3/GeO_x/Ge gate stacks.

2. Experimental

A 1.5nm-thick Al_2O_3 film was deposited on the pre-cleaned Ge wafer by atomic layer deposition (ALD) at 300℃. Thermal oxidation was carried out inside a furnace at atmospheric pressure in pure oxygen ambient at 550℃ for 60s. The second-round 3nm Al_2O_3 layer was deposited on the Al_2O_3/GeO_x/Ge samples by ALD. Post-deposition annealing (PDA) at 550℃ for 10min and low-temperature oxygen annealing (LOA) at 400℃ for 30min were performed to improve the dielectric quality and further stabilize the GeO_x/Ge interface[5,6]. For the MOSCAPs, Ti/Au (20/200nm) top electrodes and Al (300nm) back contact were deposited by metal evaporation. The Ge p-MOSFETs were fabricated on n-type Ge substrate using the same dielectric stacks fabrication flow of Ge MOSCAPs above mentioned. The main process flow of Ge p-MOSFETs with gate-first fabrication method is shown in Fig. 1.

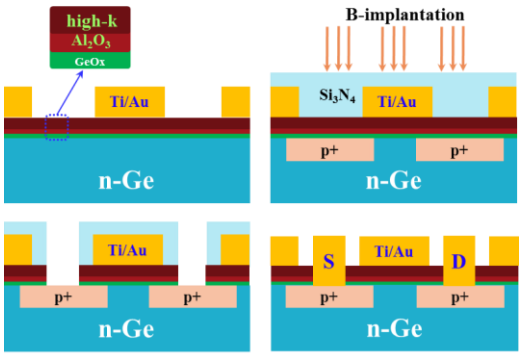

Fig. 1 Main process flow of MOSFETs with gate-first fabrication method.

3. Results and discussion

Figure 2(a) shows the reaction constant (redox reaction) for various candidate dielectric oxides on Ge surface, and figure 2(b) shows the thermal desorption spectroscopy (TDS) results of GeO desorption for (i) Al_2O_3/Ge and (ii) GeO_2/Ge. We can conclude that Al_2O_3 works as a better diffusion barrier for its better thermal stability on Ge and no GeO desorption during thermal oxidation. T. Tabata et al. also have proved that Al_2O_3 films can suppress the GeO desorption from the Al_2O_3/GeO_2/Ge stack even at high temperature[7].

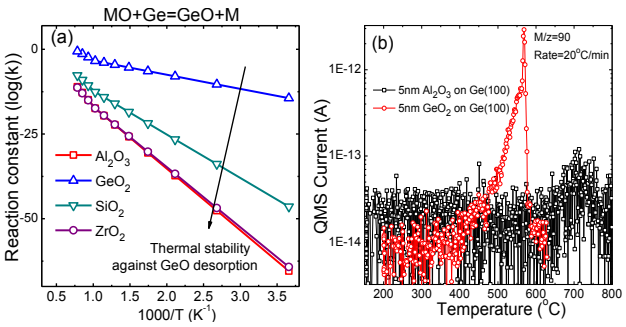

Fig. 2 (a) Reaction constant (redox reaction) for various candidate dielectric oxides on Ge. (b) TDS spectra of GeO desorption from Al_2O_3/Ge and GeO_2/Ge stacks.

Transmission electron microscope (TEM) was carried out on the MOSCAPs to determine the GeO_x thickness in the final gate stacks structure, as illustrated in Fig. 3. After the thermal oxidation at 550℃ for 60s, the GeO_x thickness is approximately 0.5nm, which demonstrates the effectiveness of an Al_2O_3 oxygen blocking layer in scaling down the GeO_x IR thickness.

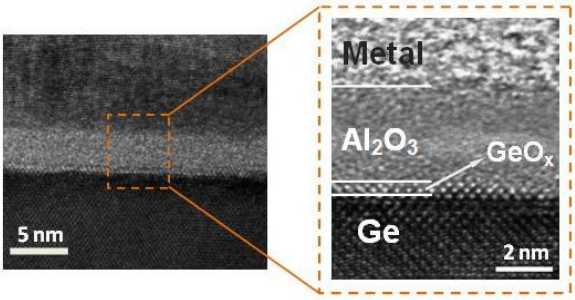

Fig. 3 TEM image of MOSCAPs with Au/Ti/Al_2O_3/GeO_x/Ge structure.

Electrical characterization of MOSCAPs was analyzed to investigate the electrical quality of the scaled GeO_x IR. Figure 4(a) shows C-V characteristics of MOSCAPs with 0.5nm GeO_x and 4.5nm Al_2O_3. The accumulation capacitance is 1.2μF/cm^2, indicating that the capacitance equivalent thickness (CET) is ~2.1nm. Well-behaved C-V curves are shown with a small frequency dispersion at flat band voltage (V_{FB}=0.1V) and the hysteresis at 1MHz is about 50mV. Also a low gate leakage is shown in Fig. 4(b), about 5×10^{-6}A·cm^{-2} at $V_G=V_{FB}+1$V.

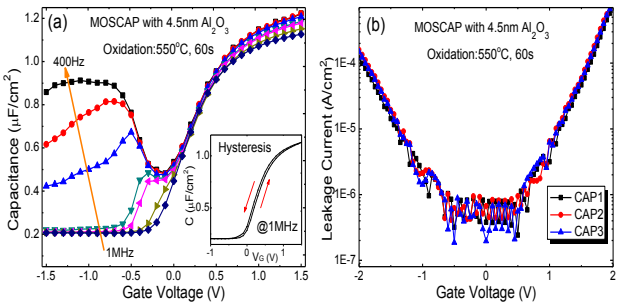

Fig. 4 C-V curves and leakage current of n-type MOSCAPs with 4.5nm Al_2O_3.

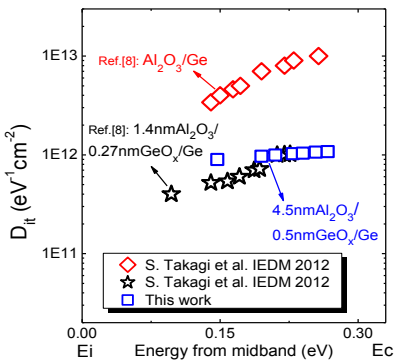

Fig. 5 D_{it} distribution of the MOSCAPs in this work, in comparison with the previously reported data by other group.

A low-temperature conductance method was taken advantage of to quantitatively observe the impact of the GeO_x interfacial repairer on D_{it} at the Al_2O_3/GeO_x/Ge interface. Figure 5 shows the D_{it} spectrum estimated by the conductance method at 160K (~1×10^{12}eV^{-1}cm^{-2} at Ei+0.25eV), in comparison with the previously reported data by other group[8].

Figures 6(a) and 6(b) show the typical output (I_D-V_D) and transfer (I_D-V_G) characteristics of Ge (100) p-MOSFETs with a channel width/length of 200um/6um. The I_{on}/I_{off} ratio at room temperature is above 1×10^4. And a subthreshold slope of 115mV/dec was achieved, indicating a small D_{it} of p-MOSFETs.

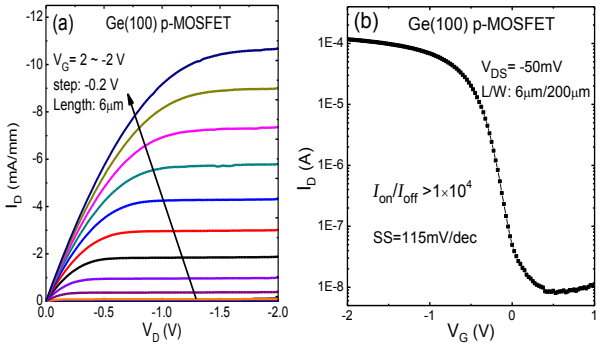

Fig. 6 (a) I_D-V_D and (b) I_D-V_G of the Ge (100) p-MOSFETs with Al_2O_3/GeO_x/Ge gate stack.

4. Conclusions

In conclusion, the thin Al_2O_3 film serves well as an oxygen blocking layer to scale down the GeO_x IR thickness and a protecting layer to suppress the GeO desorption. Thin GeO_x IR contributes to achieve high quality interface, which has nearly no impact on the EOT simultaneously. Other high-k dielectrics such as HfO_2 and La_2O_3 can take place of the second-round Al_2O_3 layer to get better properties of gate stacks. The improved thermal oxidation method needs further optimization and will provide a potentiality for Ge MOS device.

Acknowledgements

This work is supported by the National Basic Research Program of China under Grant No. 2011CBA00605 and 2011CBA00607, the National Natural Science Foundation of China under Grant No. 61204103, and the national Science &Technology Major Project of China under Grant No. 2011ZX02708-003.

References

[1] S. Sioncke *et al.*, *J. Appl. Phys.* **110** (2011) 084907.
[2] N. Taoka *et al.*, *Appl. Phys. Lett.* **92** (2011) 113511.
[3] C. H. Lee *et al.*, *Appl. Phys. Express* **2** (2009) 071404.
[4] R. Zhang *et al.*, *IEEE Trans. Electron Devices* **59** (2012) 335.
[5] H. Zhou *et al.*, *Appl. Phys. Express* **4** (2011) 104102.
[6] C. H. Lee *et al.*, *IEEE Trans. Electron Devices* **58** (2011) 1295.
[7] T. Tabata *et al.*, *International Conference on Solid State Devices and Materials* (2011) 883.
[8] S. Takagi *et al.*, *International Electron Devices Meeting* (2012) 505.