$Al_2O_3/GeO_x/Ge$ MOS 界面の遅い準位密度に与える界面構造の影響

Influence of $Al_2O_3/GeO_x/Ge$ MOS interface structures on the slow trap density

○柯　夢南[1,2]，玉　旕[1,2]，竹中 充[1,2]，高木 信一[1,2]（[1]東大院工 [2]JST-CREST）
○M. Ke[1,2], X. Yu[1,2], M. Takenaka[1,2], and S. Takagi[1,2] ([1]the University of Tokyo [2]JST-CREST)
E-mail: kiramn@mosfet.t.u-tokyo.ac.jp

1. Introduction

Ge has become more and more attracting as a next generation MOSFET channel material because of the higher electron and hole mobility than Si. As one of the promising gate stacks, $Al_2O_3/GeO_x/Ge$ and $HfO_2/Al_2O_3/GeO_x/Ge$ structures realized by plasma post oxidation (PPO) have been shown to have 1 nm or thinner EOT and low D_{it} of ~10^{11} $eV^{-1}cm^{-2}$ [1,2]. However, one of the remaining critical issues is the existence of a large amount of slow traps [3-5]. We have recently reported that Y-doped Al_2O_3 can decrease the slow trap density of $Al_2O_3/GeO_x/p$-Ge gate stacks [6]. However, significant reduction in slow trap density near the conduction band edge is still strongly needed. Also, the physical origin of slow traps in $Al_2O_3/GeO_x/Ge$ MOS interfaces must be clarified to effectively eliminate them. In this study, we investigate the position of slow traps in $Al_2O_3/GeO_x/n$-Ge MOS interfaces with changing the process and structural parameters of the gate stacks.

2. Experiment

(100) Ge wafers were cleaned by de-ionized water, acetone and HF. After the pre-cleaning, 1.5-, 1.8-, 2.1-nm-thick Al_2O_3 were deposited at 300°C by ALD. Subsequently, PPO was performed by using ECR plasma of Ar and O_2 at 300 °C under 650 W with changing oxidation time and resulting GeO_x thickness. PDA was performed for 30 min at 400 °C in N_2 ambient, followed by Au gate electrode and Al back contact formation by thermal evaporation. The slow trap density (ΔN_{fix}) was estimated by the amount of the hysteresis in C-V sweep as a function of the effective oxide field (E_{ox}), defined by $(V_g-V_{FB})/EOT$ [5].

3. Results and Discussion

In $Al_2O_3/GeO_x/Ge$ interface by PPO, the amount of slow traps is studied by systematically changing the thickness of Al_2O_3 and GeO_x. Fig. 1 shows the slow trap density of 1.5-nm-thick $Al_2O_3/GeO_x/Ge$ MOS interfaces with the different GeO_x thickness of 0.67, 0.97 and 1.19 nm. The variation of ΔN_{fix} with changing the GeO_x thickness is small, suggesting a constant areal density of slow traps. Fig. 2 shows the Al_2O_3 thickness dependence of ΔN_{fix} under an almost constant GeO_x thickness. While the increase in the initial Al_2O_3 thickness slightly decreases ΔN_{fix}, the dependence seems weak. Fig. 3 summarizes the GeO_x thickness dependence of ΔN_{fix} as a parameter of the Al_2O_3 thickness. It is found that ΔN_{fix} is almost independent of the GeO_x thickness. These results means that slow traps do not simply locate only in the Al_2O_3 layers, but also exist GeO_x layers, in contrast to the previous report [5]. The weak Al_2O_3 dependence of ΔN_{fix}, seen in Fig. 2, may be a consequence of the difference in the interface reaction. Fig. 4 shows the ΔN_{fix} of $HfO_2/Al_2O_3/GeO_x/Ge$ MOS interface with changing the thickness of HfO_2 and Al_2O_3. Especially in 0.2-nm-thick Al_2O_3 interlayer case, ΔN_{fix} is also in the same level as those in the thicker Al_2O_3 samples. This result clearly indicates that Al_2O_3 is not a main reason of slow trap generation. Fig. 5 shows schematic diagrams of possible models of the location of slow traps, where any reaction with Ge substrates or any reaction between GeO_x and Al_2O_3 by the PPO process can lead to the generation of defects responsible for the observed slow traps.

4. Conclusions

We have investigated the properties of slow traps existing in the $Al_2O_3/GeO_x/Ge$ MOS interfaces by systematically changing the gate stack structures. The main slow traps can locate near the interfaces between Ge and GeO_x , or between GeO_x and Al_2O_3.

Acknowledgements

This work was partly supported by a Grant-in-Aid for Scientific Research (No. 26249038) and JST, CREST.

References

[1] R. Zhang et al., APL 98 (2011), 112902 [2] R. Zhang et al., TED (2013) 927 [3] R. Zhang et al., IEDM (2011), 642 [4] J. Franco et al., IEDM (2013) 397 [5] G. Groesenken et al., IEDM (2014) 828 [6] M. Ke et al., MEE 147 (2015), 244

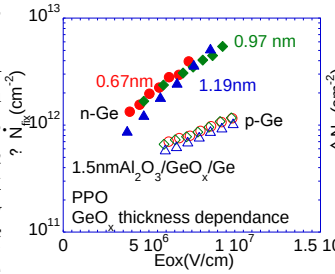

Fig.1: ΔN_{fix} of $Al_2O_3/GeO_x/Ge$ interface with different GeO_x thickness in changing E_{ox}

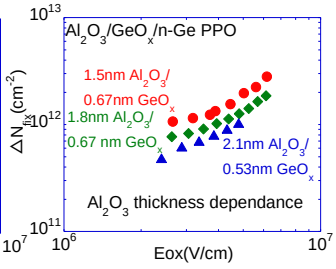

Fig.2: ΔN_{fix} of $Al_2O_3/GeO_x/Ge$ interface with different Al_2O_3 thickness

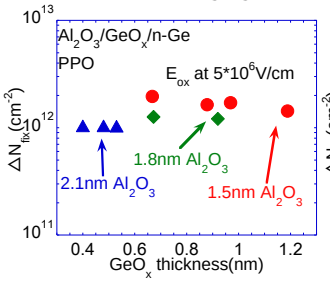

Fig.3: ΔN_{fix} of $Al_2O_3/GeO_x/Ge$ interface with different GeO_x thickness

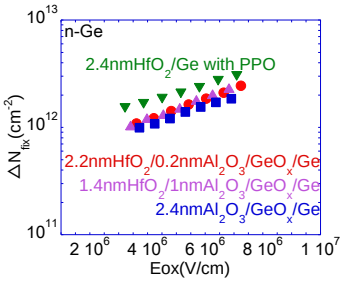

Fig.4: ΔN_{fix} of $HfO_2/Al_2O_3/GeO_x/Ge$ interface with different PPO power

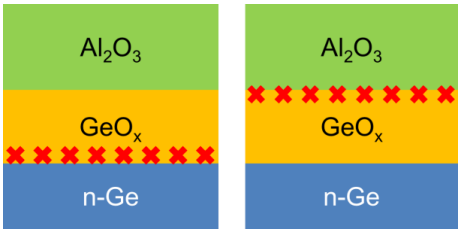

Fig.5: schematic diagram of slow traps in $Al_2O_3/GeO_x/Ge$ interface

© 2016年 応用物理学会