SCIENCE CHINA
Information Sciences

• LETTER •

June 2022, Vol. 65 169403:1–169403:2
https://doi.org/10.1007/s11432-021-3269-4

Total ionizing dose effects on aluminum oxide/ zirconium-doped hafnium oxide stack ferroelectric tunneling junctions

Xueqin YANG[1,2], Yannan XU[1,2], Jinshun BI[1,2*], Kai XI[1], Linjie FAN[1,2], Lanlong JI[1] & Gaobo XU[1]

[1] *Institute of Microelectronics, Chinese Academy of Sciences, Beijing* 100029*, China;*
[2] *University of Chinese Academy of Sciences, Beijing* 100049*, China*

Received 2 March 2021/Revised 25 April 2021/Accepted 8 May 2021/Published online 26 April 2022

Citation Yang X Q, Xu Y N, Bi J S, et al. Total ionizing dose effects on aluminum oxide/zirconium-doped hafnium oxide stack ferroelectric tunneling junctions. Sci China Inf Sci, 2022, 65(6): 169403, https://doi.org/10.1007/s11432-021-3269-4

Dear editor,

Ferroelectric random access memory (FeRAM) technologies based on hafnium oxide (HfO_2) are promising candidates for future non-volatile memory applications due to their scalability and complementary metal-oxide semiconductor (CMOS) compatibility [1]. Among them, HfO_2-based ferroelectric tunneling junction (FTJ) has been attracting greater attention for many emerging applications than Fe-cap and FeFET due to its non-destructive readout, simple structure, high density, low power consumption, and high operation speed [2]. Moreover, because of the reported rad-hard performance of HfO_2-based FeRAM in a radiation environment [3], HfO_2-based FTJ is expected to have a high potential for harsh environments, such as those in the military and aerospace. However, there is little research addressing the radiation effects on HfO_2-based FTJ. Understanding the influence of radiation on the HfO_2-based FTJs is essential before they can be applied in the field of aerospace. Up till now, the balance between the polarization value and the tunneling current strongly depending on the ferroelectric film thickness reduction has been a critical issue for HfO_2-based FTJs [4]. Recently, a new type of ferroelectric tunneling junctions based on HfO_2/dielectric bilayer structure has been reported, which can meet the above requirements [5]. The insert layer Al_2O_3 can increase the tunneling current even when the ferroelectric film is thicker than 10 nm.

Hence, this study investigates the radiation effects on a TiN/ Zr-doped-HfO_2 (HZO)/Al_2O_3/P^+-Ge FTJ structure. The electrical performances, such as hysteresis loop, capacitance, leakage current, $R_{OFF/ON}$, and endurance characteristics are studied before and after radiation. The ferroelectric properties, such as hysteresis loop and endurance are found to be extremely resistant to the total ionizing dose (TID) radiation. However, the read currents, which are related to Al_2O_3 change severely. The underlying physical mechanism is also investigated.

Results and discussion. The process of device fabrication, the corresponding physical property analysis and experiment parameter settings are described in Appendix A specifically. The P-V characteristics of the device are shown in Figure 1(a). It can be seen that there is no obvious change in the P-V hysteresis loops after radiation, and the remanent polarization is about 15.5 $\mu C/cm^2$. This indicates high radiation tolerance of HfO_2 ferroelectricity, which is consistent with previous publication [3]. Meanwhile, the endurance performance and I-V curves have negligible changes after radiation as shown in Figures 1(b) and (c), which also suggest that ferroelectric material HZO is robust to radiation. However, the C-V characteristics demonstrate some obvious changes, as shown in Figure 1(d). The capacitance decreases at a negative voltage and increases slightly at a positive voltage and the shapes of the C-V curves have some contractions with the increase of TID. The phenomenon is caused mainly by the radiation-induced positive fixed charge in the dielectric Al_2O_3 [6, 7]. A large number of electron and hole pairs were generated during the TID radiation, and the dielectric Al_2O_3 captured more holes to form net positive fixed charges as well as interface charges near the Ge side [8]. The positive fixed charge broadens the width of the depletion region of P^+–Ge and weakens the band bending in the accumulation region of P^+–Ge with the increase of TID.

Different from the traditional HfO_2-based Fe-cap, the tunneling current and $R_{OFF/ON}$ characteristics are also very critical for FTJ. The radiation effects on the tunneling current and $R_{OFF/ON}$ characteristics are discussed in Appendix A in detail.

Conclusion. In this study, the TID effects on the FTJs with HfO_2/Al_2O_3 dielectric bilayer are investigated. The P-V, C-V, I-V, endurance, and read current characteristics are analyzed before and after radiation. The I-V, P-V and endurance characteristics show very little change after the total dose of up to 1 Mrad (Si), which means the ferro-

* Corresponding author (email: bijinshun@ime.ac.cn)

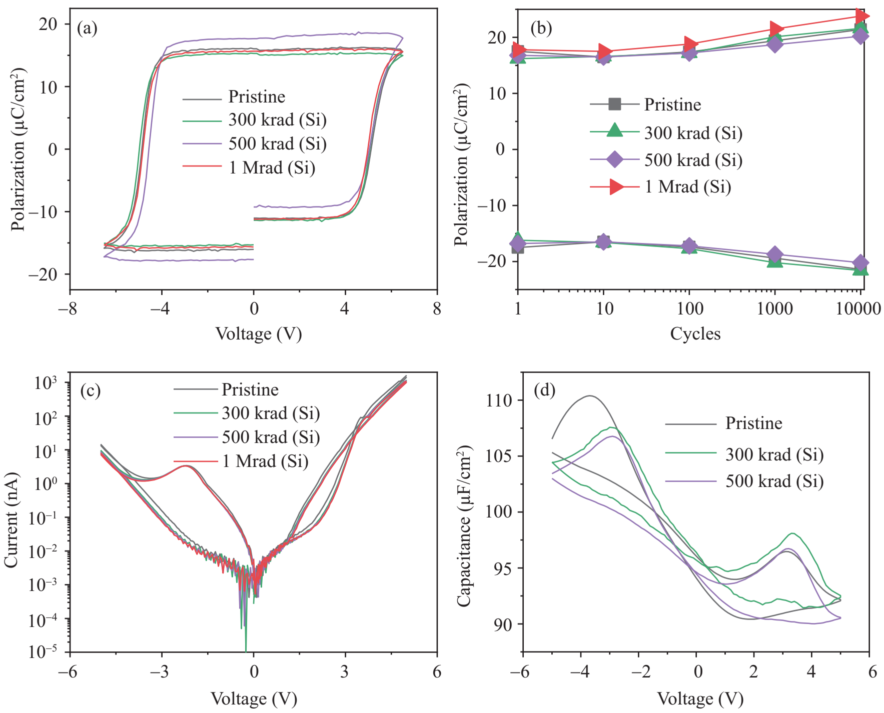

Figure 1 (Color online) (a) *P-V* hysteresis loop of FTJs, (b) endurance performance, (c) *I-V* curves, and (d) *C-V* curves with increasing total dose.

electricity is not affected by the TID. However, owing to the positive fixed charges formed in Al_2O_3 film and the interface traps accumulation during the radiation, the read current of the programed device is increasing, while the read current of the erased device is reducing after radiation. These findings are useful in understanding the radiation mechanisms of HfO_2/dielectric bilayer-based FTJs and can promote the application of FTJs in the nuclear and aerospace environments.

Acknowledgements This work was supported by National Natural Science Foundation of China (Grant Nos. 61704188, 61634008).

Supporting information Appendix A. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

References

1 Hoffmann M, Pešić M, Chatterjee K, et al. Direct observation of negative capacitance in polycrystalline ferroelectric HfO_2. Adv Funct Mater, 2016, 26: 8643–8649

2 Garcia V, Bibes M. Ferroelectric tunnel junctions for information storage and processing. Nat Commun, 2014, 5: 4289

3 Huang F, Wang Y, Liang X, et al. HfO_2-based highly stable radiation-immune ferroelectric memory. IEEE Electron Device Lett, 2017, 38: 330–333

4 Ryu H, Wu H, Rao F, et al. Ferroelectric tunneling junctions based on aluminum oxide/zirconium-doped hafnium oxide for neuromorphic computing. Sci Rep, 2019, 9: 20383

5 Shekhawat A, Walters G, Yang N, et al. Data retention and low voltage operation of $Al_2O_3/Hf_{0.5}Zr_{0.5}O_2$ based ferroelectric tunnel junctions. Nanotechnology, 2020, 31: 39LT01

6 Felix J A, Shaneyfelt M R, Fleetwood D M, et al. Radiation-induced charge trapping in thin $Al_2O_3/SiO_xN_y/Si(100)$ gate dielectric stacks. IEEE Trans Nucl Sci, 2003, 50: 1910–1918

7 Cheng Y H, Liu X, Ding M, et al. Total dose response of Al_2O_3-based MOS structure under gamma-ray irradiation. In: Proceedings of 2014 International Symposium on Electrical Insulating Materials, Niigata, 2014

8 Rafí J M, González M B, Takakura K, et al. 2 MeV electron irradiation effects on the electrical characteristics of MOS capacitors with ALD Al_2O_3 dielectrics of different thickness. Microelectron Reliab, 2013, 53: 1333–1337