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Performance of TAHOS Device as Nonvolatile TID Radiation Sensor †

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† Presented at the 3rd International Electronic Conference on Sensors and Applications, 15–30 November 2016; Available online: https://sciforum.net/conference/ecsa-3.

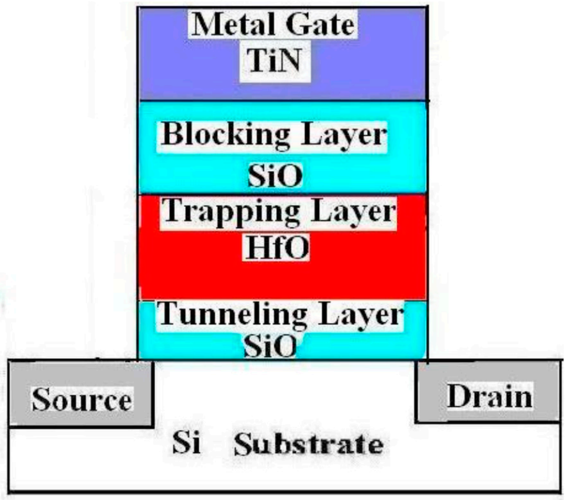
Published: 14 November 2016

Abstract: The titanium nitride–aluminum oxide–hafnium oxide–silicon oxide–silicon device using aluminum oxide as charge-blocking layer (hereafter TAHOS) could be a candidate for nonvolatile total ionization dose (TID) radiation sensor. In this paper, gamma radiation induces a significant decrease in the threshold voltage V_T of TAHOS and the radiation-induced V_T decrease on TAHOS is nearly 1.3 times of that on a standard titanium nitride–silicon oxide–hafnium oxide–silicon oxide–silicon device (hereafter TOHOS) device after 5 Mrad TID gamma irradiation. The change in V_T of TAHOS after gamma irradiation also has a strong correlation to TID up to 5 Mrad gamma irradiation. Moreover, the V_T 10yrs retention characteristic of TAHOS device can be markedly improved and is nearly 13% better than that of a standard TOHOS device after 5 Mrad gamma irradiation. Therefore, the TAHOS device in this study has demonstrated the possibility using TAHOS for high TID response and good TID data retention for non-volatile TID radiation sensing.

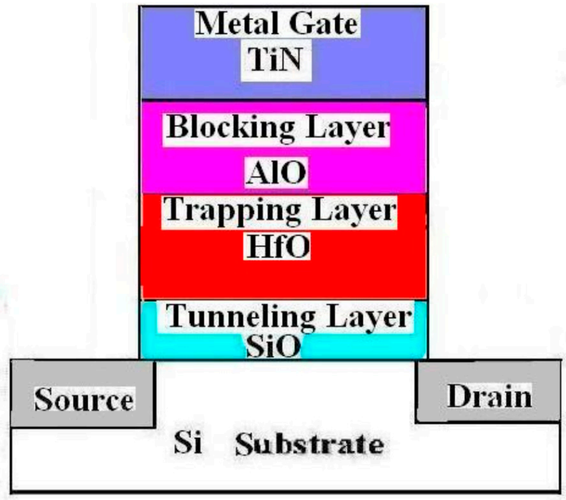
Keywords: high k; sensor; radiation; SONOS; SOHOS; MOS; TID

1. Introduction

The measurement of total ionizing dose (TID) is a major concern in various ionizing radiation applications. A titanium nitride–silicon oxide–hafnium oxide–silicon oxide–silicon (hereafter TOHOS) device has been shown to be suitable for TID nonvolatile radiation sensor applications [1–5]. The ionizing radiation induces threshold voltage V_T shift of the TOHOS device, and the V_T shift depends on the TID. However, a titanium nitride–aluminum oxide–hafnium oxide–silicon oxide–silicon device using a high k aluminum oxide (Al_2O_3) as charge-blocking layer (hereafter TAHOS) was proposed in this study. The radiation–induced charging effect and charge-retention reliability of the TAHOS device was significantly better than that of a standard TOHOS device. The comparison of radiation-induced charging effect and charge-retention reliability performance between the TAHOS and TOHOS devices after gamma irradiation were the main subjects of this study. Figure 1a,b show the cross-sectional view of a TOHOS and a TAHOS device.



(**a**)



(**b**)

Figure 1. Cross-sectional view of (**a**) an MOHOS (**b**) an MAHOS.

2. Experiments

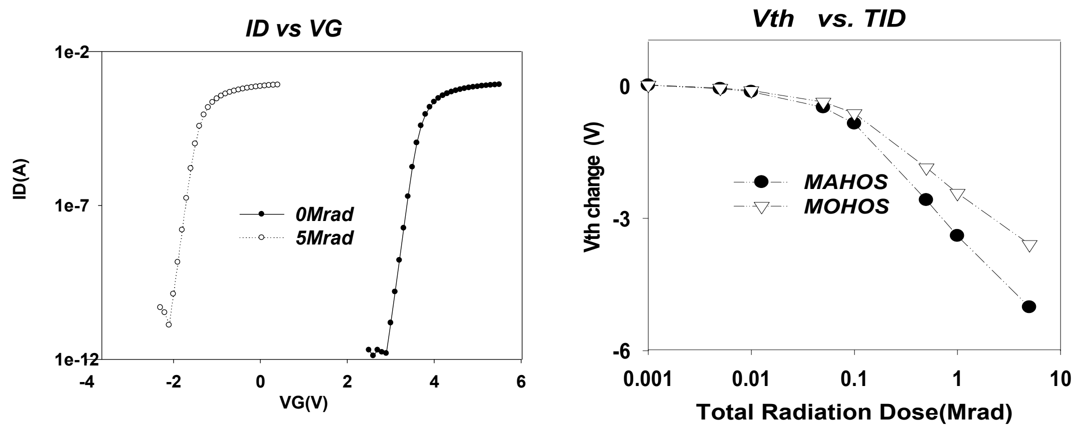
Two kinds of TOHOS type devices prepared with different blocking layers were compared: (1) TOHOS using SiO_2 as blocking layers (hereafter TOHOS) (2) TAHOS using Al_2O_3 as blocking layers (hereafter TAHOS). The blocking SiO_2 was deposited by LPCVD using tetra ethyl oxysilane (TEOS) [$Si(OC_2H_5)_4$] for TOHOS device, and the blocking Al_2O_3 was formed by MOCVD at 450~550 °C for TAHOS device. For comparison, all the devices 32 had the same thickness of tunneling oxide (30 Å–70 Å SiO_2), trapping layer (200 Å–300 Å HfO_2), blocking oxide (200 Å–300 Å Al_2O_3) and metal gate (2000 Å–4000 Å TiN). Figs. 1a and 1b show the cross-section view of a TOHOS and a TAHOS devices. For gamma TID data writing, ^{60}Co gamma radiation was impinged on all these two TOHOS type devices at a negative gate bias stress (NVS) (V_G = −2 V). For the gamma TID data read, V_T was measured at room temperature using a HP4156A parameter analyzer.

3. Results

Figure 2a shows the shifting of I_D-V_G curve for a TAHOS device with NVS (V_G = −2 V) after 5 Mrad TID gamma irradiation. The I_D-V_G curve of TAHOS shifted far to the left after 5 Mrad TID of gamma irradiation, as illustrated in Figure 3a. This indicates that gamma irradiation induces a large negative V_T shift for TAHOS. The change is due to an large increase in net positive trapped charges in the TAHOS after gamma irradiation. This negative V_T shift result is in agreement with previous studies [1–5].

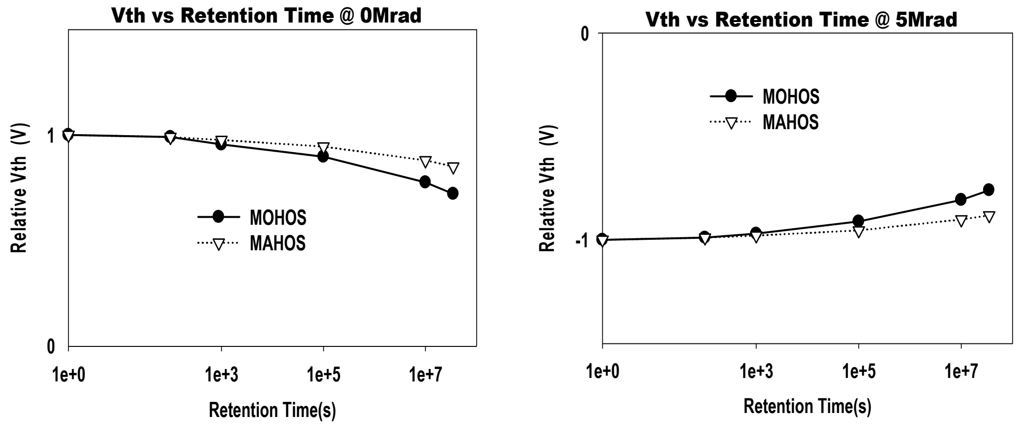
In Figure 2b, the decay of V_T for TAHOS and TOHOS devices are plotted against the TID of gamma irradiation, and can be correlated to the increase in gamma TID. These experimental results in this study are in agreement with previous studies [1–5]. It is noted that the 5Mrad radiation-induced V_T shift of TAHOS is more significant than that of TOHOS as shown in Figure 3b, which results from more radiation-induced charges in the high k Al_2O3 blocking layer than that in the traditional SiO_2 blocking layer.

Figure 3a,b show the V_T decay vs time for TAHOS and TOHOS devices under V_G = −2 V before gamma irradiation and after 5 Mrad gamma irradiation. The TAHOS device with high k Al_2O_3 blocking layer showed better charge-retention reliability characteristics both before and after gamma irradiation than the traditional TOHOS device. The result shows that high k Al_2O_3 blocking layer of TAHOS with large deeper charge traps cause to significant improvement of charge retention reliability characteristics than that of TOHOS after 5 Mrad gamma irradiation under V_G = −2 V [6].



(**a**) (**b**)

Figure 2. (**a**) I_D-V_G curve for MAHOS device after 5 Mrad TID gamma irradiation. (**b**) V_T vs TID for MAHOS and MOHOS devices after 5 Mrad TID gamma irradiation.



(**a**) (**b**)

Figure 3. Comparison for V_T change with 10 yrs retention time under V_G = −2 V for MOHOS and MAHOS devices (**a**) before irradiation (**b**) after 5 Mrad TID irradiation.

4. Conclusions

As shown in the experimental data, the radiation-induced charging effect of the TAHOS device with large radiation-induced positive-charge in the high k Al_2O_3 blocking layer is nearly 1.3 times of that of TOHOS device with traditional SiO_2 blocking layer after 5 Mrad gamma irradiation. The performance of radiation-induced 10 yrs charge retention reliability characteristic of TAHOS device with large deeper charge traps in the blocking Al_2O_3 is nearly 13% better than that of TOHOS device after 5 Mrad gamma irradiation. The results obtained in this study have demonstrated the feasibility of using TAHOS device for high TID response and good TID data retention up to 5 Mrad TID.

Acknowledgments: The authors would also like to thank National Nano Device Laboratories (NDL), National Tsing Hua University (NTHU), and Nation Chiao Tung University (NCTU) to provide the instruments for wafer fabrication and testing. This paper was funded in part by the National Science Council (NSC) sponsor.

Author Contributions: Fuh-Cheng Jong and Wen-Ching Hsieh performed the experiments and drafted the manuscript for review.

Conflicts of Interest: The authors declare no conflict of interest.

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