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Blue Light Total Dose Nonvolatile Sensor Using Al-SOHOS Capacitor Device †

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Abstract: The Al doped silicon–silicon oxide–hafnium oxide–silicon oxide–silicon capacitor device (Al-SOHOS) could be a candidate for blue light (BL) radiation total dose (TD) nonvolatile sensor. The BL radiation induces a significant increase in the threshold voltage V_T of the Al-SOHOS capacitor, with the change in V_T of the Al-SOHOS capacitor also having a correlation to BL TD. The experimental results indicate that the BL radiation-induced increase in V_T of the Al-SOHOS capacitor under 10-V gate positive bias stress (PVS) is nearly 2 V after a BL TD of 100 mW·s/cm^2 irradiation. Moreover, the V_T retention loss of the nonvolatile Al-SOHOS capacitor device after 10 years of retention is below 15%. The BL TD data can be permanently stored and accumulated in the non-volatile Al-SOHOS capacitor device. The Al-SOHOS capacitor device in this study has demonstrated the feasibility of non-volatile BL TD radiation sensing.

Keywords: blue light; sensor; SOHOS; radiation; TD

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1. Introduction

The measurement of blue light (BL) irradiation total dose (TD) is very important in various BL radiation applications, such as biochemical technology and medical technology. The semiconductor dosimeters offer many advantages as they have very small dose-sensing areas and their dose sensitivity can be high in a small constrained space. A silicon–silicon dioxide–hafnium oxide–silicon dioxide–silicon (SOHOS) capacitor device has been shown to be suitable for nonvolatile UV irradiation TD sensor applications [1–4]. UV irradiation induces a significant increase in the threshold voltage V_T of the SOHOS capacitor device and this UV-induced increase in V_T of the SOHOS capacitor has a strong correlation to UV TD. Moreover, V_T retention of the SOHOS capacitor device has good reliability even after 10 years of retention. The aluminate-doped silicon–silicon oxide–hafnium oxide–silicon oxide–silicon capacitor device (Al-SOHOS) was proposed in this study. The BL radiation-induced charging effect and charge-retention reliability of the Al-SOHOS capacitor devices were significantly improved. Figure 1a shows the cross-sectional view of the SOHOS capacitor devices. Figure 1b shows the charge generation and trapping states of the gate dielectric in the Al-SOHOS capacitor device after BL irradiation.

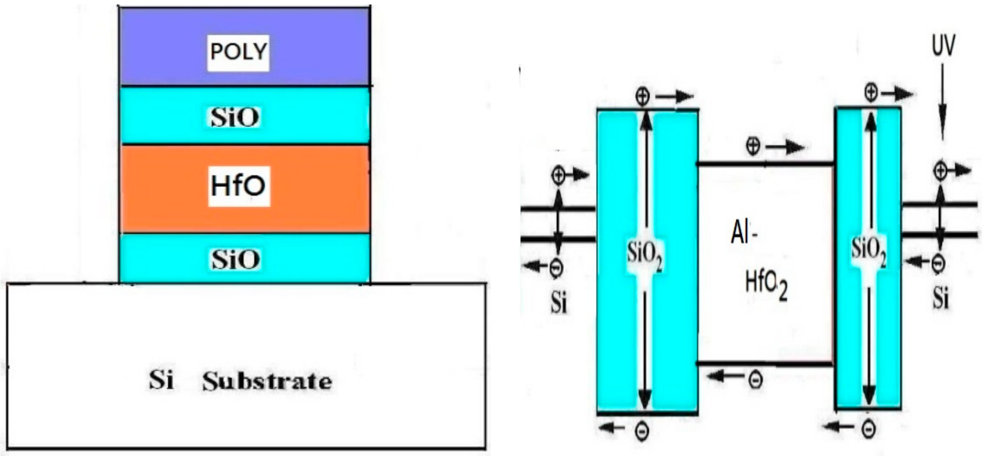


Figure 1. (**a**) Cross-sectional view of an SOHOS capacitor device; and (**b**) Charge generation and trapping in the Al-SOHOS capacitor after BL irradiation.

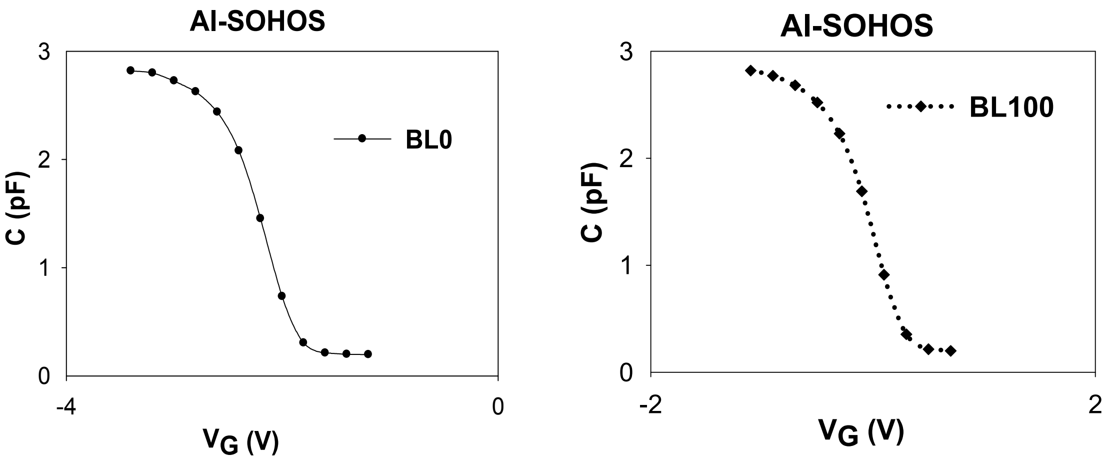
2. Experiments

The Al-SOHOS capacitor devices were prepared for this study. To manipulate the radiation-induced charging effects in the Al-SOHOS capacitor, Al-SOHOS capacitor devices were prepared. SOHOS capacitor structures were fabricated on a p-type Si <100> substrate. We used thermal SiO_2 for the tunneling oxide, CVD SiO_2 for the blocking oxide of the gate dielectric and low-pressure chemical vapor deposition (LPCVD) poly silicon for the gate material. Furthermore, hafnium oxide (HfO_2) films were deposited as the charge-trapping layers, which used a Hf(tert-butoxy)$_2$(mmp)$_2$ precursor in a metal organic chemical vapor deposition (MOCVD) system that was run at approximately 400–550 °C. Al doped HfO_2 films were deposited as the charge-trapping layers, which used Hf (tert-butoxy)$_2$(mmp)$_2$ and aluminum isopropoxide precursors in a metal organic chemical vapor deposition (MOCVD) system that was run at approximately 400–550 °C. After BL data writing, V_T was measured at room temperature using a HP4156A parameter analyzer. The experimental results of gate capacitance applied at various gate voltages (C_G-V_G) were obtained by a computer-controlled HP4284 parameter analyzer and the C_G-V_G curves were measured by sweeping V_G at room temperature.

3. Results and Discussion

3.1. Radiation-Induced V_T Shift in Al-SOHOS after BL Irradiation

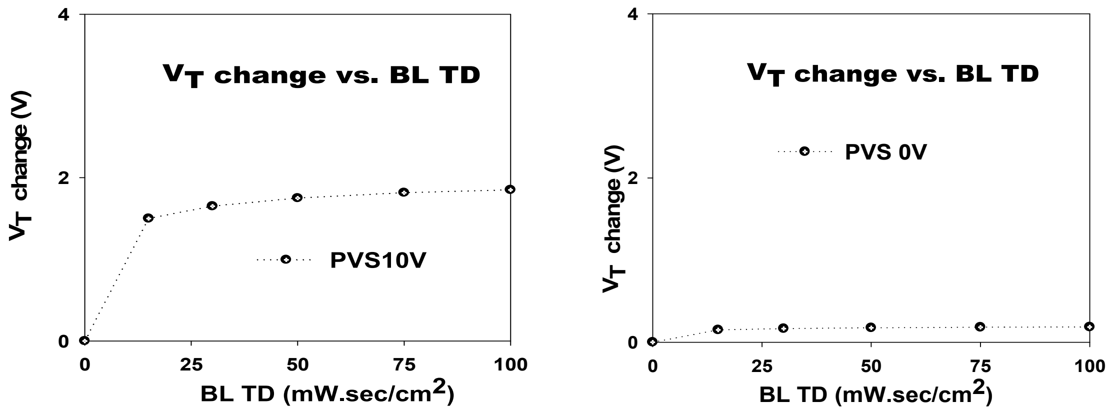
Figure 2a shows a C_G-V_G curve for a Al-SOHOS capacitor device before BL irradiation. Figure 2b shows a C_G-V_G curve for a Al-SOHOS capacitor device after 100 mW·s/cm^2 TD BL irradiation under PVS (V_G = 10 V). As illustrated in Figure 2b, the C_G-V_G curve of Al-SOHOS capacitor shifted to the right after the BL total dose (TD) was increased to 100 mW·s/cm^2 irradiation under the PVS gate with a V_G of 10 V . This indicates that a BL TD of 100 mW·s/cm^2 irradiation induces an increase in V_T (about 2 V) of the Al-SOHOS capacitor under the PVS gate with a V_G of 10 V. The finding of this positive V_T shift is in agreement with previous studies [1,4]. When comparing the Al-SOHOS with the F-SOHOS, the BL radiation-induced charging effect of Al-SOHOS were significantly improved [4].



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

Figure 2. This C_G–V_G curve for an Al-SOHOS capacitor device under a PVS with a V_G of 10 V (**a**) before BL irradiation; and (**b**) after a BL TD of 100 mW·s/cm² irradiation.

The increase in V_T was plotted against the BL TD for the Al-SOHOS capacitors under a PVS of 10 V and 0 V as shown in Figure 3a,b, respectively. The increase in V_T is shown in Figure 3a as a function of BL TD for the Al-SOHOS capacitors device under a PVS of 10 V. The increase in V_T of the Al-SOHOS can be correlated to the BL TD increase. However, there was a insignificant increase in V_T increase under a PVS of 0 V as shown in Figure 3b. These experimental results in this study are in agreement with previous studies [1].



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

Figure 3. The dependence of the increase in V_T on BL TD for an Al-SOHOS (**a**) under PVS of 10 V; and (**b**) under PVS of 0 V.

3.2. V_T Stability vs. Retention Time

V_T vs. retention time curves for an Al-SOHOS capacitor device before and after BL of 100 mW·s/cm² irradiation under a PVS of 10 V are shown in Figure 4a,b, respectively. As illustrated in Figure 4a, the increase in V_T with time for the pre-BL-irradiated Al-SOHOS capacitor device is a result of negative charges that naturally tunnels into the HfO_2 trapping layer of the Al-SOHOS device before BL irradiation. As shown in Figure 4b, the decrease in the V_T with time for the post-BL-irradiated Al-SOHOS capacitor device is a result of BL radiation-induced negative charges tunneling out from the HfO_2 trapping layer. Moreover, the V_T-retention loss of the nonvolatile Al-SOHOS capacitor device after 10 years of retention is below 15%.

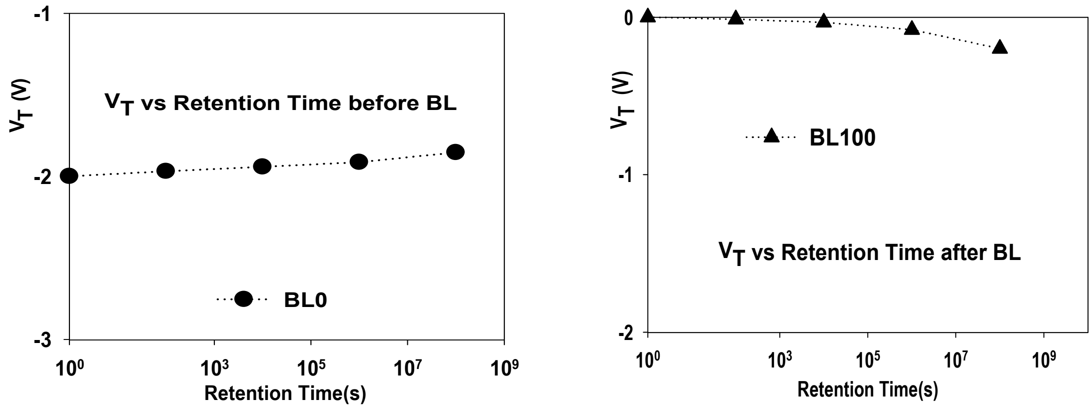


Figure 4. V_T vs. retention time for an Al-SOHOS device: (**a**) before BL irradiation; and (**b**) after BL of 100 mW·s/cm^2 irradiation under a PVS gate of 10 V.

4. Conclusions

As shown in the experimental data, the increase in V_T of the Al-SOHOS capacitor was nearly 2 V after 100 mW·s/cm^2 BL TD irradiation under a PVS gate with a V_G of 10 V. Moreover, the Al-SOHOS devices showed better BL-induced charge-retention reliability. The 100 mW·s/cm^2 BL-induced charge-retention loss of the nonvolatile Al-SOHOS capacitor after 10 years of retention was below 15%. The Al-SOHOS capacitor device in this study has demonstrated the feasibility of non-volatile BL TD radiation sensing.

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