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

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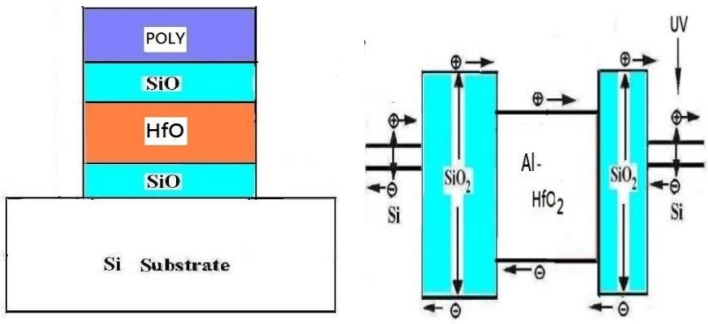
**Abstract:** The Al doped silicon–silicon oxide–hafnium oxide–silicon oxide–silicon capacitor device (hereafter Al-SOHOS) could be a candidate for blue light (hereafter BL) radiation total dose (hereafter TD) nonvolatile sensor. The BL radiation induces a significant increase in the threshold voltage $V_T$ of the Al-SOHOS capacitor, and the change in $V_T$ for Al-SOHOS capacitor also has a correlation to BL TD. The experimental results indicate that BL radiation-induced increase of $V_T$ in Al-SOHOS capacitor under 10V gate positive bias stress (hereafter PVS) is nearly 2 V after BL TD 100 mW·s/cm$^2$ irradiation. Moreover, the $V_T$ retention loss of the nonvolatile Al-SOHOS capacitor device after 10 years 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

## 1. Introduction

The measurement of blue light (hereafter BL) irradiation total dose (hereafter TD) is very important in various BL radiation applications, such as biochemical technology, medical technology. The semiconductor dosimeters offer many advantages, the dose sensing areas of semiconductor dosimeters are very small, 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 $V_T$ for SOHOS capacitor has a strong correlation to UV TD. Moreover, the reliability characteristic of $V_T$ retention for the SOHOS capacitor device is good, even after 10 years retention. The aluminate-doped silicon–silicon oxide–hafnium oxide–silicon oxide–silicon capacitor device (hereafter Al-SOHOS) was proposed in this study. The BL radiation–induced charging effect and charge-retention reliability of the Al-SOHOS capacitor devices were significant improved. Figure 1a shows the cross-section 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.




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

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

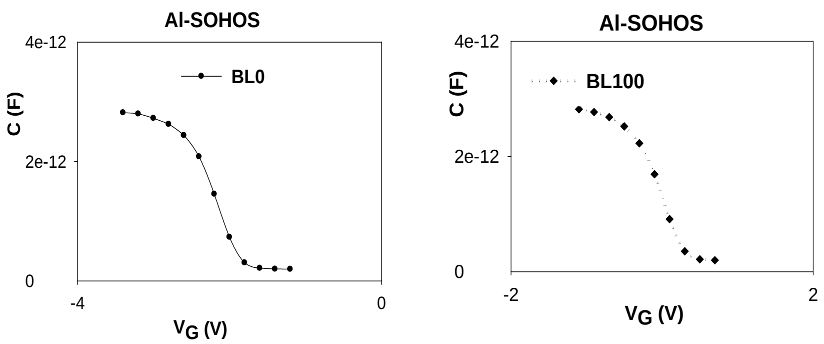
## 2. Experiments

The Al-SOHOS capacitor devices are prepared for this study. To manipulate the radiation-induced charging effects in Al-SOHOS capacitor, Al-SOHOS capacitor devices were prepared. SOHOS capacitor structures were fabricated on p-type Si <100> substrate. We used thermal $SiO_2$ for the tunneling oxide, $HfO_2$ films were deposited as the charge-trapping layers, CVD TEOS $SiO_2$ for the blocking oxide of the gate dielectric, and low-pressure chemical vapor deposition (LPCVD) poly silicon for the gate material. hafnium oxide ($HfO_2$) films were deposited as the charge-trapping layers, with Hf(tert-butoxy)$_2$(mmp)$_2$ precursor in a metal organic chemical vapor deposition (MOCVD) system at 400~550 °C. Al doped $HfO_2$ films were deposited as the charge-trapping layers, using Hf (tert-butoxy)$_2$(mmp)$_2$ and aluminum isopropoxide precursors in a metal organic chemical vapor deposition (MOCVD) system at 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 BL total dose (here after TD) up to 100 mW·s/cm$^2$ irradiation under gate PVS 10 V. This indicates that BL TD 100 mW·s/cm$^2$ irradiation induces a increase of $V_T$ (about 2 V) for the Al-SOHOS capacitor under gate PVS $V_G$ 10 V. This positive $V_T$ shift result is in agreement with previous studies [1,4]. Compare the Al-SOHOS with the F-SOHOS, the BL radiation–induced charging effect of Al-SOHOS were significant improved. [4]




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

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

**Commented [m1]:** Please use Scientific notation.

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

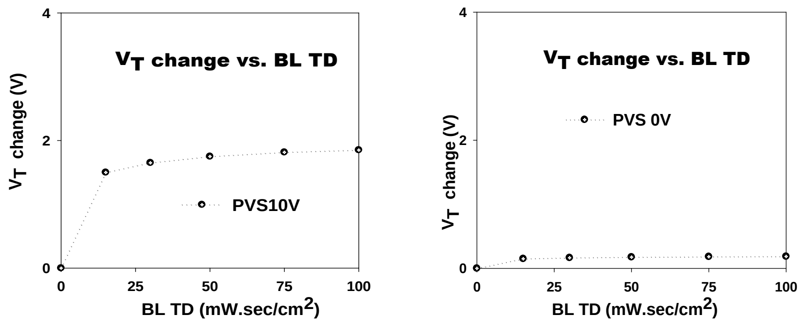
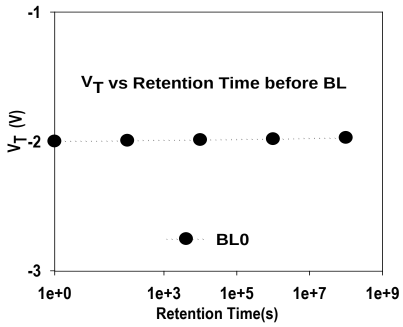


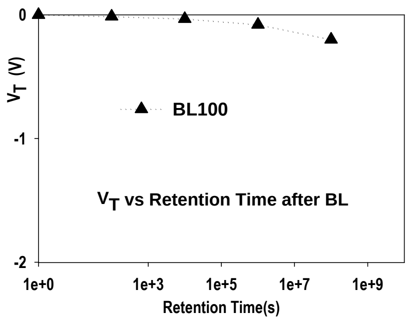

Figure 3. The dependence of the $V_T$ increase on BL TD for an Al-SOHOS (a) under PVS 10V; (b) under PVS 0 V.

### 3.2. $V_T$ Stability vs. Retention Time

The $V_T$ vs. retention time for an Al-SOHOS capacitor device before and after BL 100 mW·s/cm² irradiation under PVS 10 V are illustrated 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 naturally tunneling into the $HfO_2$ trapping layer of 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 retention is below 15%.




(**a**)




(**b**)

**Figure 4.** The $V_T$ vs. retention time for an Al-SOHOS device: (**a**) before BL irradiation; and (**b**) after BL TD 100 mW·s/cm² irradiation under gate PVS 10V.

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## 4. Conclusions

As shown in experiment data, the $V_T$ increase of the Al-SOHOS capacitor was nearly 2 V after 100 mW·s/cm² BL TD irradiation under 10 V $V_G$ PVS. Moreover, the Al-SOHOS devices showed better BL induced charge-retention reliability characteristics. The 100 mW·s/cm² BL induced charge-retention loss of the nonvolatile Al-SOHOS capacitor after 10 years retention is 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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