Memory effect of oxide/SiC:O/oxide sandwiched structures

T. C. Chang, S. T. Yan, F. M. Yang, P. T. Liu, and S. M. Sze

Citation: Applied Physics Letters 84, 2094 (2004); doi: 10.1063/1.1675924
View online: http://dx.doi.org/10.1063/1.1675924
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/84/12?ver=pdfcov
Published by the AIP Publishing

Articles you may be interested in

Charge transport in Si nanocrystal/SiO2 superlattices

Current through Si O 2 gate oxide and its low frequency fluctuations: Trapping on charged dangling bonds with negative Hubbard U
J. Appl. Phys. 97, 074104 (2005); 10.1063/1.1862768

Publisher’s Note: “Memory effect of oxide/SiC:O/oxide sandwiched structures” [Appl. Phys. Lett. 84, 2094 (2004)]
Appl. Phys. Lett. 84, 4815 (2004); 10.1063/1.1761633

Oxidation-induced traps near SiO 2 /SiGe interface
J. Appl. Phys. 86, 1542 (1999); 10.1063/1.370927

A physically based predictive model of Si/SiO 2 interface trap generation resulting from the presence of holes in the SiO 2
The memory effects of the oxide/oxygen-incorporated silicon carbide (SiC:O)/oxide sandwiched structure were investigated. The memory window is decreased with the increase of the oxygen content in the SiC:O film due to the reduction of dangling bonds. A concise model is proposed to explain the reduction of dangling bonds with increasing oxygen content. Also, a higher breakdown voltage is observed with less oxygen content in the SiC:O film, which is attributed to the high barrier height induced by electron trapping in the SiC:O film.

The memory effects of the oxide/oxygen-incorporated silicon carbide (SiC:O)/oxide sandwiched structure were investigated. The memory window is decreased with the increase of the oxygen content in the SiC:O film due to the reduction of dangling bonds. A concise model is proposed to explain the reduction of dangling bonds with increasing oxygen content. Also, a higher breakdown voltage is observed with less oxygen content in the SiC:O film, which is attributed to the high barrier height induced by electron trapping in the SiC:O film.

The memory effects of the oxide/oxygen-incorporated silicon carbide (SiC:O)/oxide sandwiched structure were investigated. The memory window is decreased with the increase of the oxygen content in the SiC:O film due to the reduction of dangling bonds. A concise model is proposed to explain the reduction of dangling bonds with increasing oxygen content. Also, a higher breakdown voltage is observed with less oxygen content in the SiC:O film, which is attributed to the high barrier height induced by electron trapping in the SiC:O film.© 2004 American Institute of Physics.

![C–V hysteresis](image_url)

**FIG. 1.** The $C-V$ hysteresis for different samples under 7 and $(-7)$ V bidirectional voltage sweeping.
film was kept at 350 °C in a low pressure of 3 mTorr with precursors of SiH$_4$ (~12 sccm), CH$_4$ (~12 sccm), and O$_2$ (~2–8 sccm) and an inductively coupled plasma (ICP) power of 900 W. This study was divided into three samples. The deposition of SiC:O with least oxygen content (~2 sccm) was defined as sample 1. From samples 1 to 3, the content of oxygen was increased with a decreased refractive index. The low pressure of 3 mTorr during deposition makes the path length an electron travels without undergoing a collision with a gas atom (or mean free path) increase, which will improve the uniformity of the thin film. The blocking oxide was deposited at 350 °C with SiH$_4$:N$_2$O=5 sccm:150 sccm and a 900 W ICP power. Finally, the Al gate was patterned and sintered to form a MOIOS structure.

To study memory effects of the oxide/SiC:O/oxide sandwiched structure, a bidirectional voltage sweeping between 7 and (~7) V was performed. Figure 1 shows the capacitance–voltage (C–V) hysteresis in this study for different samples. When the MOIOS structure is operated in positive polarity, the electrons directly tunnel from the Si substrate through the tunnel oxide, and are trapped in the forbidden gap of the SiC:O layer. When the device is negatively operated, the electrons may tunnel back to the Si substrate. The different threshold voltages can be defined as “1” or “0” for a memory device. The blocking oxide is utilized to prevent the carriers of the gate electrode from injecting into the charge-trapping layer by Fowler–Nordheim tunneling. It is clearly observed that as the content of oxygen is increased, the threshold voltage shift (memory window) is decreased from sample 1 to sample 3. The memory window of sample 1 is estimated to be about 1.1 V under 7 V operation. HDPCVD SiC:O is produced in a high-density-plasma chamber with a 900 W ICP power. The rf ICP power is used to increase the spiral motion of the charged particle. A charged particle will gain more energy the more times it moves around the spiral and a high density plasma is, hence, produced. During the deposition of the carbide layer, the simultaneous slight etching due to the bombardment of the high-density plasma is processed, which forms a densified and trap-rich layer and contributes a larger memory window than other processes to fabricate the SiC:O film. The electrical instability observed during the long time programming is the reduction of the memory window. It is inferred that there are deep trapping centers within the SiC:O film. Once the injecting electrons from the channel are trapped in the deep centers, they are not easy to erase. It is, therefore, an important issue for the operation of the nonvolatile memory devices and the improvements for the reduction of the deep trapping centers need to be taken into account.

To investigate the influence of the content of oxygen on the memory window, Fourier transform infrared spectroscopy (FTIR) was performed. In the investigation of the components of our proposed SiC:O films as a storage element, the FTIR spectrum in the following shows the main bonding types of the SiC:O films are Si–C, Si–O, Si–H, and C–H bonds. Also, the moisture absorption near 3500 cm$^{-1}$ in the FTIR spectrum is not observed even if we left the sample in the cleanroom for 24 h. Figures 2(a) and 2(b) exhibit the
bonding types of Si–C and Si–H, respectively.11 As the content of oxygen is increased, the absorbance of Si–O bond is obviously increased and that of both Si–C and Si–H bonds is decreased. We propose a model to describe the structural formula of the SiC:O film during deposition in Fig. 3. A trap-rich SiC:O film is composed of Si–O, Si–C, C–H, and Si–H bonds, and the dangling bonds, charge-trapping site, are attributed to the weak Si–H bonds which are easily broken and the C–H bonds which are not well bound as the dotted line shown in Fig. 3. As the content of oxygen is increased, Si–H bonds may be easily broken by oxygen and the oxygen atoms bind with the Si dangling bonds to form the strong Si–O bonds. Also, the increased oxygen reacts with part of the Si–C and C–H bonds to form the volatile CO compound, which makes the dangling bonds decrease. It is inferred that the memory window of the oxide/SiC:O/oxide sandwiched structure is in accordance with the amount of dangling bonds. Smaller memory window is attributed to less charge-trapping sites with more oxygen content.

Figure 4 shows the current–voltage characteristics of the oxide/SiC:O/oxide sandwiched structure. The breakdown voltage is increased with the decrease of oxygen content. The current density is shown for different samples.

In conclusion, we have demonstrated the memory effects of an oxide/SiC:O/oxide sandwiched structure for a MOIOS memory device. The memory window of the memory device is decreased with higher oxygen content of the SiC:O film due to the reduction of dangling bonds. A model is proposed to explain the impact of oxygen on the structural formula. Also, a higher breakdown voltage is observed with less oxygen content of the carbide film, which is attributed to the higher barrier height induced by more electron trapping in the SiC:O film.

This work was performed at National Nano Device Laboratory and was supported by National Nano Device Laboratory under Contract No. 92A0500001 and the National Science Council of the Republic of China under Contract Nos. NSC92-2112-M-110-020 and NSC92-2215-E-110-006.

1 The International Technology Roadmap for Semiconductors (ITRS), Tables 28a, 28b (1999).
10 S. Wolf, in Ref. 9, p. 795.