Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 296-297 **B-6-2**

Analysis of Buried-Oxide Dielectric Breakdown Mechanism in Low-Dose SIMOX Structures

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Buried-OXide (BOX) dielectric breakdown behavior in low-dose Separation by IMplanted OXygen (SIMOX) structures was analyzed in detail from the electrical evaluation results of BOX-capacitors. From the Time-Zero-Dielectric-Breakdown (TZDB) characterization, BOX breakdown was assumed to be dominated by Electrically Weak Spots (EWS) having random spacial distribution in the BOX, which show good correlation with the density of Si islands in the BOX. A model for extracting the thickness distribution of Si islands from EWS density is proposed and applied to the experimental results.

1. Introduction

Thin-Film-Silicon-On-Insulator (TFSOI) technologies, which create surface-Si layer in the range around 0.1 μm, are recently noticed as the key technology for advanced high speed or low power CMOS LSIs. Among TFSOI technologies, the low-dose Separation by IMplanted OXygen (SIMOX) [1] is one of the most promising candidates for commercial use because of its excellent layer uniformity and lower manufacturing cost than other method. While these good performances are expected, the Buried-OXide layer (BOX) of low-dose SIMOX is known to have relatively lower dielectric integrity than that of thermal oxide due to the existence of Si islands in the BOX [2, 3]. Internal-Thermal-OXidation (ITOX) process [4] was reported to improve the BOX integrity [5] and we have reported that the BOX breakdown of about 8 MV/cm, almost identical to that in thermal oxide, has been obtained in ITOX-SIMOX by reducing the Si islands in the BOX [6].

In this work, we addressed quantitatively the detailed relationship between BOX breakdown behavior and Si islands. To make the point clear, samples containing certain amount of Si islands, which shows relatively low breakdown around 5 MV/cm, were evaluated. A model to predict the size distribution of Si island in the BOX from TZDB results is also proposed.

2. Experimental

Oxygen ions were implanted at 180 keV into P-type 6" (100) Cz Si wafers with doses of 3 ~ 4 x 10^{17} cm^{-2}. The wafers were then annealed to form SOI structure and additionally oxidized to grow ITOX layer at 1350 °C in ambient of Ar and O_2 mixture. The layer thickness was evaluated by spectroscopic ellipsometry and the typical structure is consisted of about 175 nm surface-Si layer and 98 ~ 116 nm BOX layer which includes about 20 nm ITOX layer.

The Si island density was quantitatively evaluated through selective dry etching and Scanning-Electron-Microscopy (SEM) observation [3, 7] of which typical results is shown in Fig.1.

To investigate the BOX breakdown behavior, MOS capacitors using BOX as the dielectric (BOX-capacitors) having various area from 2.5 x 10^{-7} to 2.0 x 10^{-2} cm^2 were fabricated on the wafers. BOX breakdown properties were characterized by Time-Zero-Dielectric-Breakdown (TZDB) measurements in which electric field across the BOX at the current of 100 mA/cm^2 was defined as breakdown field, E_{BD}.

3. Results

Fig. 2 shows I-V characteristics of BOX-capacitors of two different area fabricated on a sample of 105 nm BOX, where both onset of high-field conduction and E_{BD} of BOX became improved with the decrease in capacitor area. In Fig. 3, BOX breakdown field histograms for capacitors of various area are shown together with those for 85 nm thermal-oxide prepared as the experimental reference. As can be seen, most of the capacitors on thermal oxide show E_{BD} value of 8.5 ~ 9.5 MV/cm, which corresponds to intrinsic E_{BD}, regardless the capacitor area. On the other hand, E_{BD} value of SIMOX BOX decreases as the capacitor area increases, showing inferior integrity compared to those of thermal oxide. However, it can be seen that about 80 % of the smallest capacitor, 2.5 x 10^{-7} cm^2, show E_{BD} value more than 8.5 MV/cm, the same as intrinsic E_{BD} of thermal-oxide.

4. Discussion

In order to understand the situation shown in Fig. 3, electrodes of BOX capacitors after breakdown measurements were observed by optical microscope. Fig. 4 shows top view of the BOX capacitor electrode after TZDB measurement and shows large single spot corresponding to the breakdown spot. For comparison, the electrode after the constant current stress of 5 μA/cm^2 for 10^4 s is shown in Fig. 5, where high density (1.3 x 10^5 cm^2) breakdown spots were observed presumably caused by consecutive occurrence of a self-healing breakdown at the Electrically Weak Spots (EWS). These results in Figs. 3, 4 and 5 indicate that the BOX property of SIMOX is intrinsically almost identical to that of thermal oxide and is deteriorated by the existence of EWS, which probably distribute uniformly in the BOX and are presumably Si islands. It is also indicated that the weakest spot dominates the TZDB breakdown.

In the situation discussed above, total EWS density can be calculated from the first term of Poisson distribution function by assuming random spacial distribution of EWS, as follows,

$$D = -\ln(1-P)/S_{Cap} \tag{1}$$

where D is total EWS density, P is yield of capacitors not showing intrinsic E_{BD} in the TZDB measurements and S_{Cap} is capacitor area. To make the substance of weak spots clear, D values calculated for each SIMOX samples with various BOX thickness are compared in Fig. 6 with Si island density observed by SEM. Reasonably good correlation between two densities was obtained in each sample, indicating the most of EWS are mainly originated from Si islands.

Then we derive the electrical field dependence of EWS density from the TZDB results. By assuming the EWS showing breakdown between arbitrary E and $E+\Delta E$ ($|\Delta E| \ll |E|$) of applied electric field randomly distribute on the electrodes, the density of the corresponding weak spots $\Delta D(E)$ can be expressed from the analogy of Eq. (1), as follows,

$$\Delta D(E) \equiv D(E+\Delta E) - D(E) = -\ln\left(\frac{1-P(E+\Delta E)}{1-P(E)}\right) \Big/ S_{Cap} \tag{2}$$

where $D(E)$ is cumulative density of weak spots showing breakdown between 0 ~ E of electric field and $P(E)$ is cumulative failure yield of capacitors at an applied E. By applying the limit of $\Delta E \rightarrow 0$ to above equation and also integrating each side of the equation, the following equation is obtained,

$$D(E) = -\ln(1-P(E))/S_{Cap} \tag{3}$$

From Eq. (3), it is easily found that the $P(E)$ value obtained from capacitors of an arbitrary area can be normalized to the yield $P^*(E)$ which is obtained from capacitors of a certain area S^*_{Cap},

$$1-P^*(E) = (1-P(E))^{S^*_{Cap}/S_{Cap}} = exp(-S^*_{Cap} D(E)) \tag{4}$$

Fig. 7 shows the weibull plot of $1-P^*(E)$, normalized for S^*_{Cap} of 10^{-2} cm^2, as a function of E obtained from capacitors of various area of SIMOX with 105 nm BOX. In this figure, each $1-P^*(E)$ curves obtained from capacitors of different area show good agreement, indicating the above analysis is appropriate for BOX breakdown. By using Eq. (4), the universal curve for $D(E)$ as a function of E is obtained which is also shown in Fig. 7.

Now we try to extract the density and size distribution of Si islands from TZDB results. For the relationship between E_{BD} and the vertical thickness of Si island, $t_{Si\,island}$, the following equation was reported [2, 8],

$$E_{BD} = E_{ox}(t_{BOX} - t_{Si\,island})/\,t_{BOX} \tag{5}$$

where E_{OX} is intrinsic breakdown field of thermal oxide and t_{BOX} is BOX thickness. By substituting the Eq. (5) into the $D(E)$ extracted from Eq. (3) or (4), $D_i(t_{Si\,island})=D(E_{BD})$ are obtained as a function of $t_{Si\,island}$, which corresponds to the density of Si islands which have vertical thickness of $0 \sim t_{Si\,island}$. Fig. 8 shows the $\Delta D_i(t_{Si\,island})$ histogram for SIMOX of 105 nm BOX derived from the results in Fig. 7. For the calculation, E_{OX} value of 8.5 MV/cm was used according to Fig. 5 and contribution of BOX-pinhole was eliminated. In Fig. 8, it is found the density of Si island increase exponentially as the vertical thickness of Si island decrease.

Effect of ITOX on the reduction of Si islands will be discussed using the proposed model.

5. Summary

BOX dielectric breakdown behavior of low-dose SIMOX structures was analyzed in detail. From the TZDB characterization of the BOX-capacitors having various area, BOX breakdown was found to be dominated by EWS, which shows good correlation with the density of Si islands in the BOX. A model for extracting the thickness distribution of Si islands from EWS density is proposed, of which appropriateness is verified by the application to the experimental results.

References [1] S. Nakashima et al., *Electron Lett.* **vol.26** (1990) p.1647. [2] L. Meda et al., *Nucl. Instr. and Meth.* **B84** (1994) p.270. [3] S. Nakashima et al., *1993 Int. SOI Conf. Proc.*, p.14. [4] S. Nakashima et al., *1994 Int. SOI Conf. Proc.*, p.71. [5] K. Kawamura et al., *1995 Int. SOI Conf. Proc.*, p.156. [6] K. Kawamura et al., *1997 Int. SOI Conf. Proc.*, p.122. [7] S. Nakashima, private communication. [8] M. Ando et al., *1997 Int. SOI Conf. Proc.*, p.12.

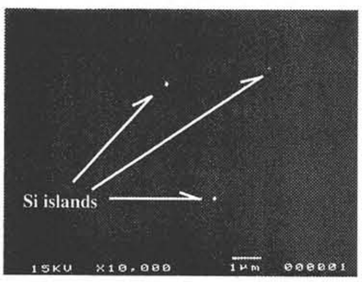

Fig. 1 SEM view of Si-island MESA structure on low-dose SIMOX wafer.
BOX Thickness : 105 nm

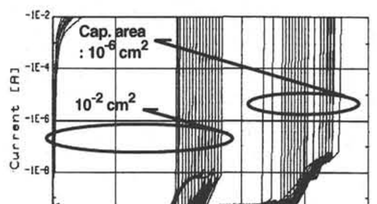

Fig. 2 Buried-oxide current-voltage characteristics of low-dose SIMOX wafer.
BOX Thickness : 105 nm

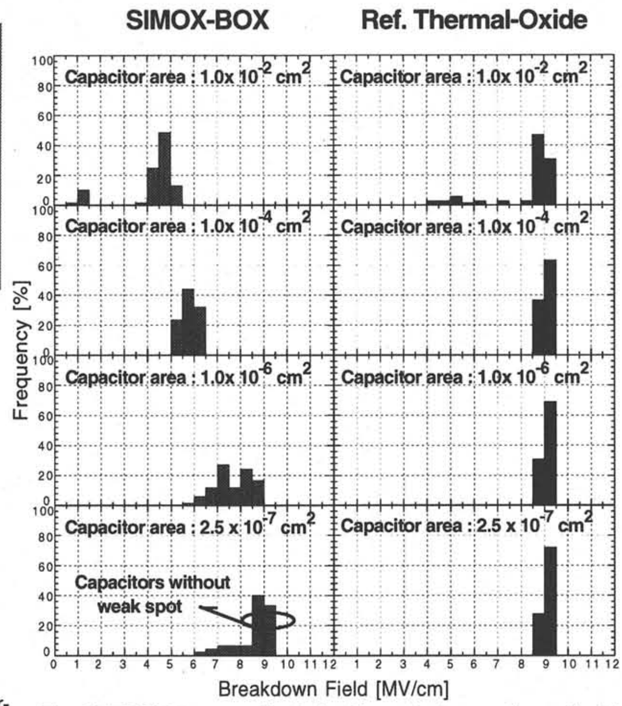

Fig. 3 TZDB histogram of buried-oxide and reference thermal oxide.
BOX Thickness : 105 nm

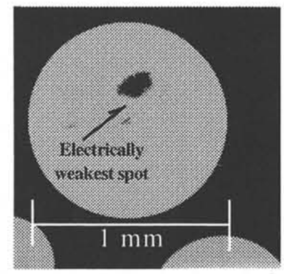

Fig. 4 Photograph of buried-oxide capacitor on low-dose SIMOXwafer after TZDB characterization.

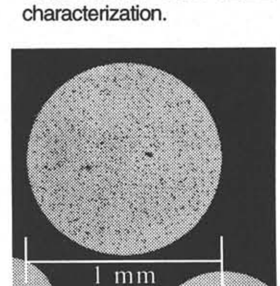

Fig. 5 Photograph of buried-oxide capacitor on low-dose SIMOX wafer after constant current stress application.

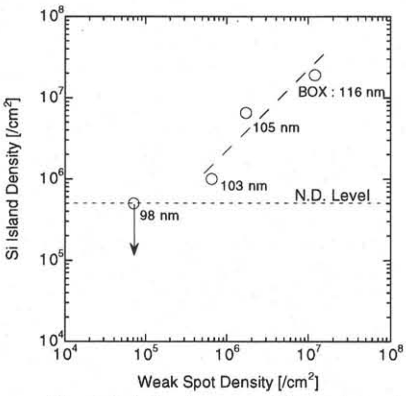

Fig. 6 Relation between Si island density and weak spot density.

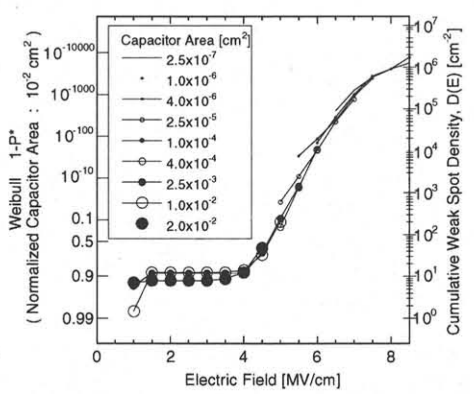

Fig. 7 Weibull Plot of normalized buried-oxide TZDB-yield obtained from capacitor with various area.
BOX Thickness : 105 nm

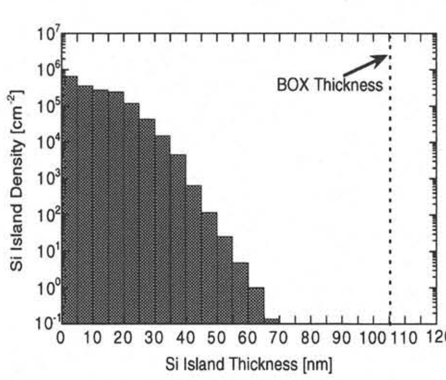

Fig. 8 Thickness distribution of Si island extracted from TZDB-yield of buried-oxide capacitor
BOX Thickness : 105 nm