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Flattening of the Si-SiO_2 Interface in Ultra-Thin SIMOX Structures

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Separation by implanted oxygen (SIMOX) materials are increasing importance in semiconductor manufacturing [1]. Very thin layers enhance the performance and lower the cost of the production. However, very thin layers are difficult to be obtained uniformly across the wafer. This study provided an insight for process control to obtain the thin layers uniformly by investigating flattening mechanisms during annealing. A set of samples were investigated after they were implanted with the same oxygen dose of 4.5×10^{17} O^+/cm^2 at 65 keV using an Ibis 1000 high-current oxygen implanter, and were subsequently annealed at 1200 °C-1350 °C for different durations (0 – 4 hours). The microstructures of SIMOX materials were then investigated using transmission electron microscopy (TEM) with a Hitachi 8100 TEM at 200 keV. In addition, the Si-SiO_2 interface topographies were analyzed using atomic force microscopy (AFM). To get access to the Si-SiO_2 interface, the native oxide and the top silicon layer were removed by a diluted HF solution and 22% TMAH solution, respectively.

Fig. 1 (a-d) show TEM micrographs of the cross-sections of four samples annealed at different temperatures and through different times. The oxide precipitates in the top silicon layer can be observed in the samples annealed at 1200 °C. After holding at this temperature for 4 hours or annealing at higher temperature, the oxide precipitates incorporate into the buried oxide layer (Fig. 1 (b-d)) creating relatively smoother Si-SiO_2 interfaces [2,3]. Detail morphology of the interfaces was obtained using AFM. Fig. 2 (a-c) show AFM images of the Si-SiO_2 interfaces of those samples in Fig. 1 (b-d), respectively. It was found that the oxide surface consisted of numerous small round domains after annealing at 1200 °C for 4 hour (Fig. 2(a)). The similar domain structure was also found in the samples annealed at 1300 °C for 0 hour (Fig. 2(b)). However, after holding at 1300 °C for 4 hours, the round domains disappeared and the domains with a step-terrace structure was found on the oxide surface (Fig. 2(c)) [3].

The RMS roughness calculated from the AFM height profile at different scan size (L×L) was obtained in order to quantitatively characterize the interfaces. The RMS roughness increases with the increase of a scan length (L) and became saturated at a certain scan length, defined as a correlation length (L_c). The detail method to obtain these parameters was described elsewhere [4]. An example of the Log-Log plot between the RMS roughness and the scan length is shown in Fig. 3. The relationship of the RMS(L) and the scan length is shown in the inset of Fig. 3. This example is taken from the AFM height profile of the oxide surface in Fig. 2(b).

From the analysis, it was found that the increase of correlation length corresponds to the increase of the domain size on the oxide surface. Also, the RMS roughness of the Si-SiO_2 interface decreases while the correlation length (domain size) increases with increasing anneal temperature as shown in Fig. 4. The same trend was found for the sample sets with longer annealing durations (results not shown here).

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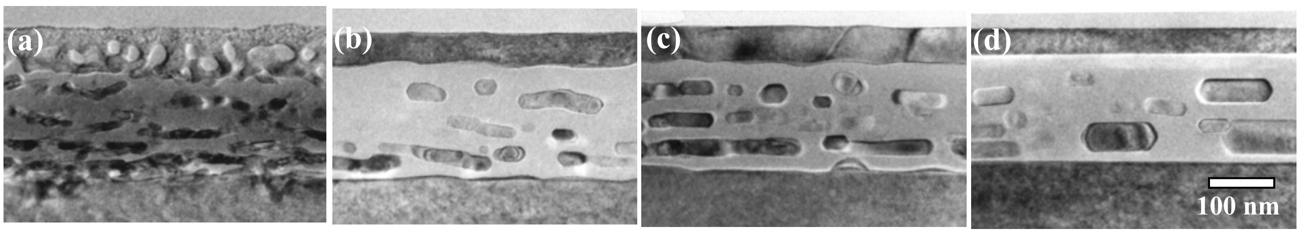

FIG. 1. TEM images of the SIMOX samples with the dose of 4.5×10^{17} O^+/cm^2 after annealing at (a) 1200 °C for 0 h, (b) 4 h, 1300 °C for (c) 0 h, and (d) 4 h.

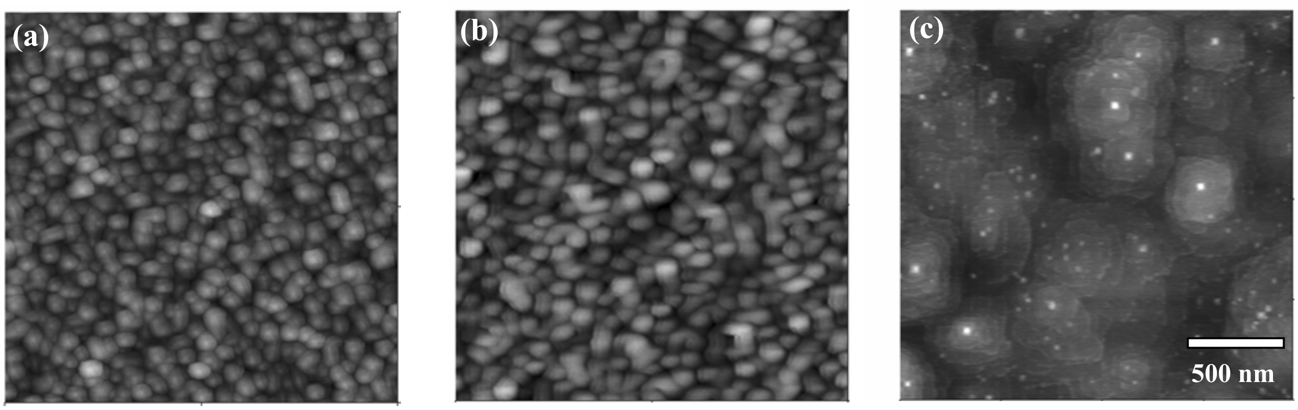

FIG. 2. AFM images of the annealed SIMOX samples at (a) 1200 °C for 4 h, 1300 °C for (b) 0 h, and (c) 4 h.

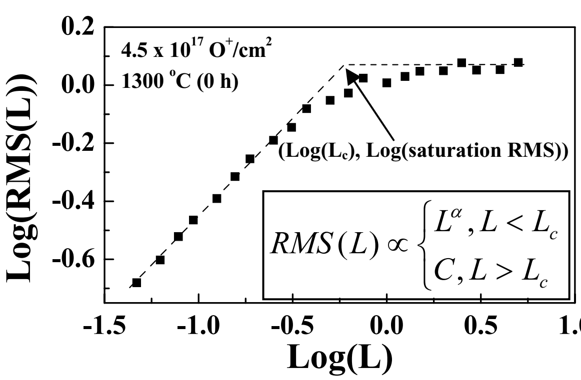

FIG. 3. An example of the relationship between log(RMS(nm)) and log(L(μm)) of the sample shown in Fig 2(b).

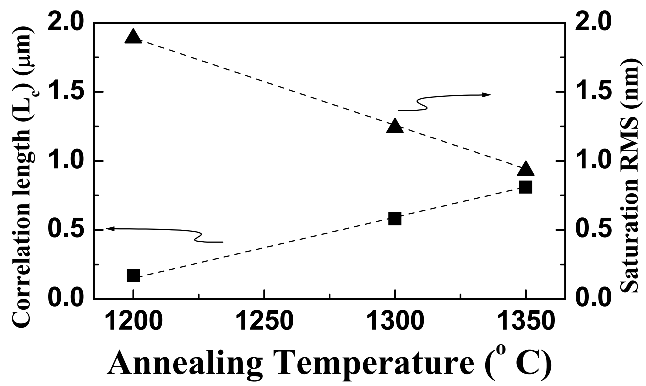

FIG. 4. A plot of the saturation RMS and correlation length as a function of annealing temperature for 4 hours.

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