A Method for Reducing Surface Roughness During the Thermal Desorption of Silicon

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As dimensions in ultra-large scale integration metal-oxide-semiconductor technology reduce, the removal of the native oxide layer becomes an ever more important process. There currently exist several classifiable methods for native oxide removal: chemical etching, ion milling, and thermal desorption. Chemical etches can cause significant surface roughening and involve significant amounts of hazardous materials which can allow for higher concentrations of impurity contaminants on the substrates surface. Ion milling contains several drawbacks including high cost, complexity, and low throughput. The thermal desorbtion is the most commonly used method, which can be explained by examining the following reaction which occurs at approximately 800°C:

$Si + SiO_2 \Rightarrow 2SiO\uparrow$

This thermally driven chemical reaction for the evaporation of oxide species utilizes bulk Si material in a non-homogenous way such that the resulting substrate surface is characterized by either voids or central silicon columnar structures.

A new method has been developed that acts as a preventative measure to surface roughening by feeding reaction with additional silicon, such that the substrate is less damaged. This is accomplished by depositing a very thin silicon layer directly onto the native oxide surface prior to thermal treatment. The thickness of this thin layer is dependent on both the oxide thickness and its SiO_2 incorporation, and can readily be calculated by above equation. Furthermore, the structure and deposition method of the thin film is inconsequential.

Fig. 1(a) shows the typical sample surface morphology obtained from heating an untreated substrate characterized by large silicon structures as a result of reaction etching away at the substrate surface. Fig. 1(b) illustrates a sample which has been subjected to a 0.43 nm thick silicon film prior to heating. The resulting surface morphology is significantly smoother as a result of being subjected to the discussed treatment. For both samples, RHEED indicates a single crystal surface with a 2× reconstruction in the [110] direction.

Fig. 2 shows the average roughness as a function of treatment thickness. From Fig. 2, the optimum thickness, such that the surface roughness is at a minimum, is found to be 0.34 nm. Based on chemical equation, and assuming the densities of 2.3 g/cm^3 and 2.4 g/cm^3 for amorphous silicon and SiO_2, respectively, the calculated SiO_2 thickness is 0.71 nm, which is significantly less than the measured oxide thickness of 2 nm. However, native grown oxides are also comprised of SiO, which is evaporated without the consumption of bulk silicon. Conversely, after deposition of the silicon film, any reoxidation would cause an increase in the optimum thickness.

Also noteworthy, is the fact that aged non-epiready silicon wafers were utilized in this experiment, which could modify results if performed with modern epiready silicon wafers. Such modifications would manifest themselves in several changes to experimental results. For instance, the evolution of pits instead of islands could occur due to changes in the oxide desorption process, as prior mentioned. Wafer manufacturers also design natively grown oxide layers to desorb as evenly as possible, resulting in the spread and shifting of the optimum thickness value, as well as a decrease in the minimum average roughness obtainable. These manifestations when comparing results generated from non-epiready versus epiready samples have been observed when applying the proposed technique to gallium arsenide.

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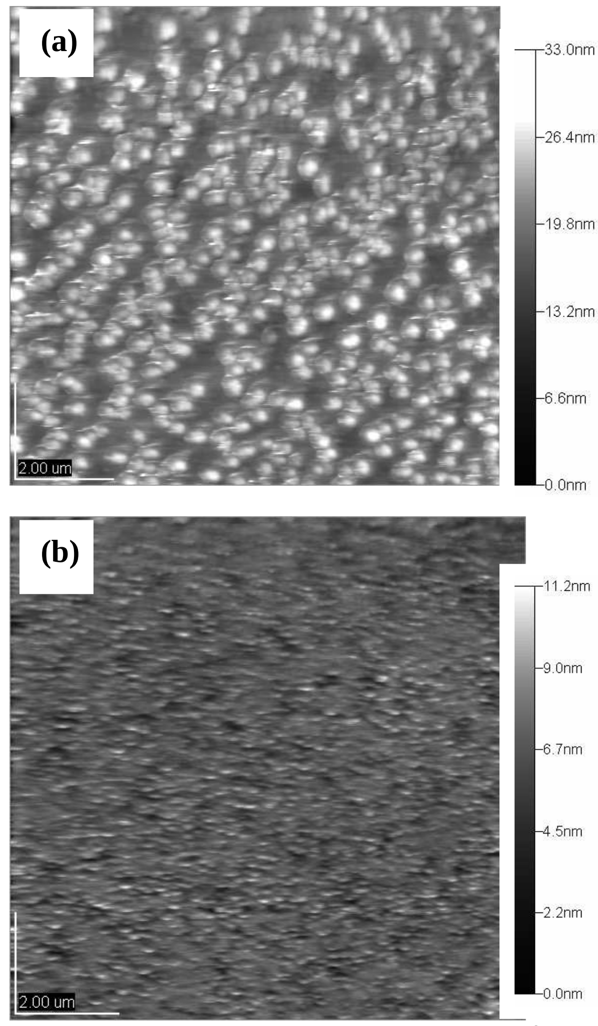

Fig. 1. Atomic Force Microscopy images of substrates subjected to (a) normal thermal desorption and (b) treatment thicknesses 0.43 nm.

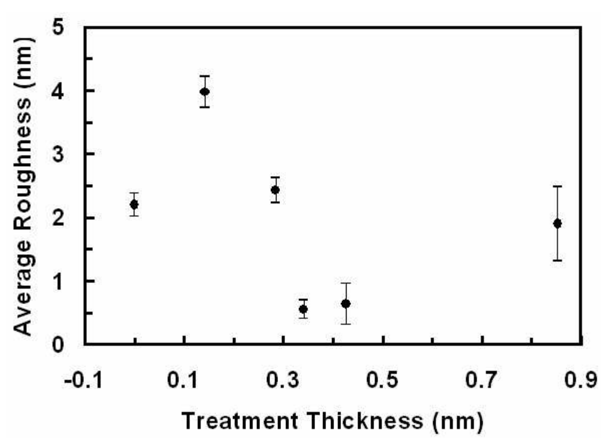

Fig. 2. Measured average roughness as a function of treatment thickness with standard deviation error bars.