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doi:10.1017/S1431927614005777
Microsc. Microanal. 20 (Suppl 3), 2014

Energy-Filtered Transmission Electron Microscope Tomography of Silicon Nanoparticles in Silicon Dioxide Deposited with High Density Plasma Chemical Vapor Deposition

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High Density Plasma Chemical Vapor Deposition (HDPCVD), a variant of Plasma-Enhanced Chemical Vapor Deposition (PECVD), has demonstrated the capability of growing SiO_2 layers with novel electronic properties. In particular, the structure of Si nanoparticles (NPs), in Si-rich HDPCVD SiO_2 layers has been correlated with the performance of metal oxide semiconductor (MOS) memory devices [1]. There remains, however, a need to understand the underlying thermodynamics and kinetics of the HDPCVD process, especially as it relates to evolution of the size, shape, and density of Si NPs in SiO_2 [2]. Such parameters as the deposition rate and the relative flow rate of reagents (e.g. SiH_4 and N_2O) [3], and their influence on Si NP configuration have been shown to play a vital role. In order to properly assess the influence of deposition parameters on the evolution of Si NPs, a detailed characterization of Si NP size and shape is essential. To that that end, Energy-Filtered Transmission Electron Microscopy (EFTEM) has been used to map the intensity of the 17 eV Si plasmon, in order to reveal the presence of Si NPs in the SiO_2 layer [4]. Furthermore, a more complete characterization of the complex structure of the Si NPs can be achieved by EFTEM tomography, which provides a 3-dimensional (3D) view of the NP-rich regions of the SiO_2 layer [5-7].

Here, EFTEM tomography has been used to provide a 3D map of the Si NPs in the SiO_2 layer within silicon on insulator (SOI) material. For this study, we use a JEM2200FS together with an “in-lens” filter and Ultrascan camera. Following extraction of cross-section containing Si NPs in SiO_2, EFTEM images are acquired in 4° increments with an 8 eV slit centered on the 17 eV Si plasmon, and then assembled using ETomo software package with tomograms generated using back-projection. Following tomogram generation, silica NPs are filtered and segmented using Avizo software (Fire 8.0). Resulting equivalent diameter distribution shows a fairly broad, flat distribution in Si NP equivalent diameter, with a mean of ~25nm [8]. A detailed examination of the Si NP morphology reveals that many of the NPs are extended parallel to the Si/SiO_2 interface. Such an extension suggests phase separation beyond that occurring during deposition, and which may be attributed to spinoidal decomposition [2]. The incidence of this mode of post-growth phase separation suggests the ability to alter Si NP morphology though the control of post-growth annealing.

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[8] Work at the Naval Research Laboratory was funded through the Office of Naval Research.

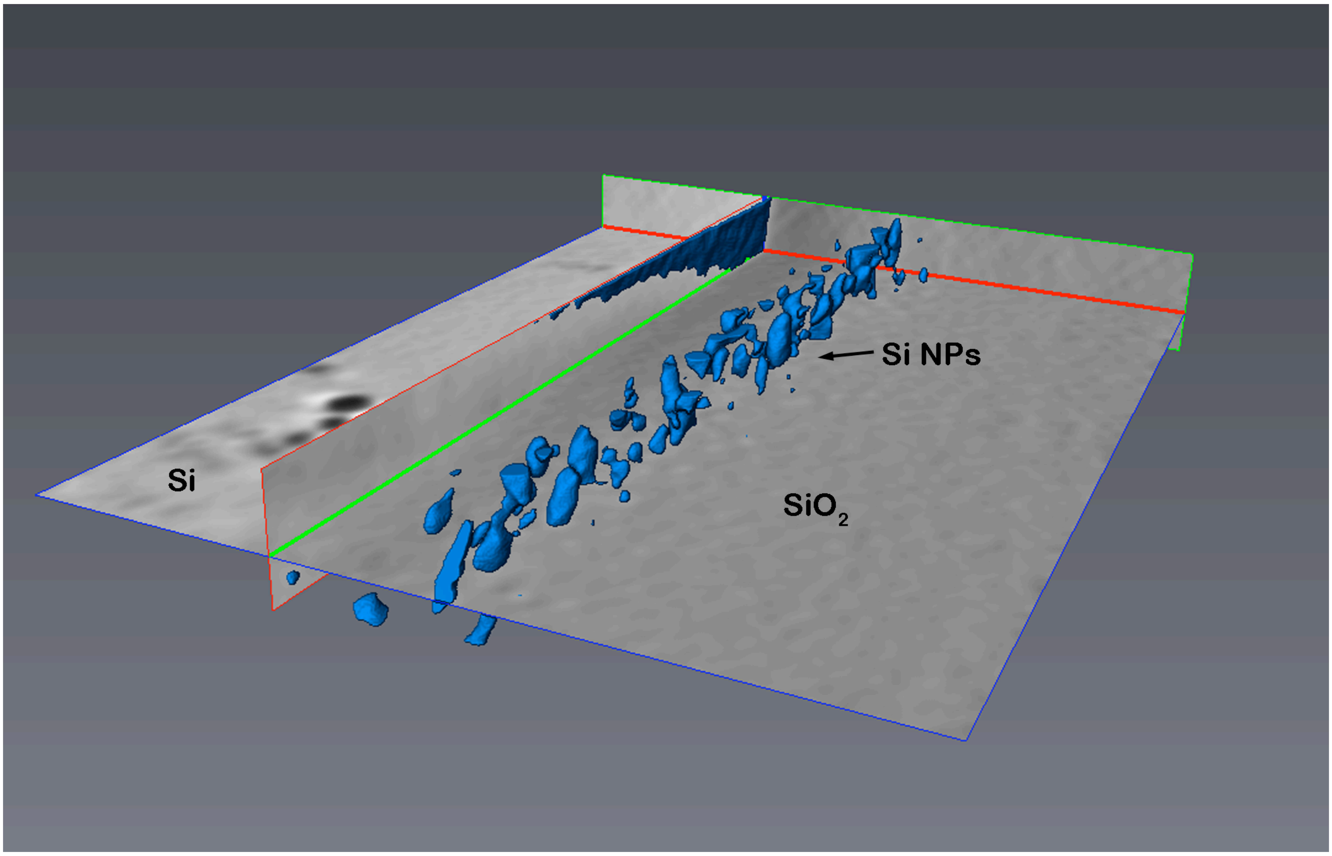

Figure 1. Segmented tomogram showing Si NPs in SiO_2. Linear slice parallel to Si NPs (with red outline) represents original SiO_2 surface. For scale, NPs are ~20nm in diameter.

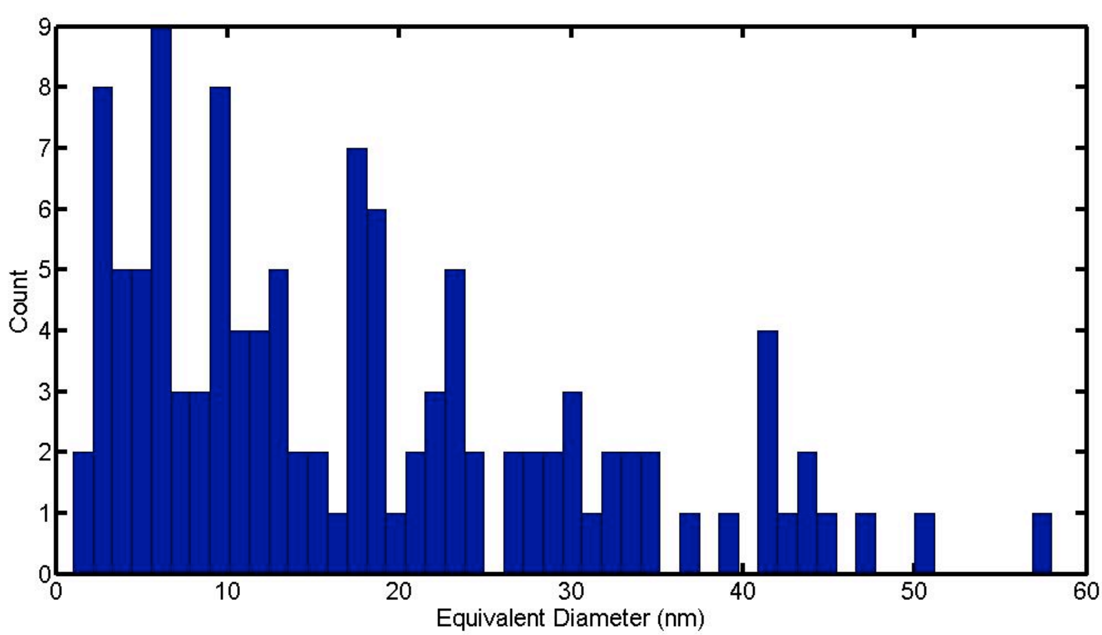

Figure 2. Histogram of equivalent diameter of segmented Si NPs in Fig. 1.

https://doi.org/10.1017/S1431927614005777 Published online by Cambridge University Press