Focused Neon Ion Beam Induced Sputtering of Copper and Silicon Dioxide by Monte Carlo Simulations

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A Monte Carlo algorithm has been developed to model the physical sputtering to emulate nanomachining via the Gas Field Ion Microscope[1]. In this presentation, we will present experimental and simulation results on focused neon ion beam induced sputtering of copper and silicon dioxide. Neon beams were modeled at a beam energy of 20 keV with a 1 nm full-width-at-half-maximum (FWHM) beam diameter. The simulation elucidates the nanostructure evolution during the physical sputtering of high aspect ratio features. The aspect ratio and sputter yield vary with the ion species, beam parameters, and are related to the distribution of the nuclear energy loss. Quantitative information such as the sputtering yields, dose dependent aspect ratios, and resolution-limiting effects will be discussed. Furthermore, the nuclear energy loss and implant concentration beneath the etch front will be correlated with the damage revealed by transmission electron microscope (TEM).

A 20keV neon ion beam was simulated to pattern a 15nm x 15nm via with increasing doses. Figure 1 depicts an example of the three dimensional nanostructure formed at a dose of 3.0×10^{18} ions-cm^{-2} in silicon dioxide and copper substrates. The color code blue, red, yellow and cyan represent the bulk substrate, sputtered, re-deposited and sputtered but re-deposited species, respectively. Figure 2 shows the dependency of the sputtered and re-deposited atoms/molecules on the number of incident ions. In both copper and SiO_2, the number of sputtered atoms decrease and re-deposited atoms increase with increasing aspect ratio. The simulated results shown in Fig. 1 compare favorably with the experimental results[2]: namely the experimental full widths at half maxima (FWHM) at the dose of 3.0×10^{18} ions/cm^2 are ~37 nm and ~28 nm for silicon dioxide and copper, respectively. In addition, the experimental sputtered depths of the nanostructures are ~202 nm and ~155 nm in silicon dioxide and copper, respectively.

In this paper, the current state of the Monte Carlo simulation will be overviewed and a comparison of the simulation and experimental results will be discussed. Authors will rationalize the etch evolution and observed damage profiles based on the ion-solid interactions in the materials.

[1] S. Tan et al. J. Vac. Sci. Technol. B, Vol. 29, No. 6, 06F604 (2011)
[2] R. Timilsina and P. D. Rack, Nanotechnology, Vol. 24, No. 49, 495303 (2013)

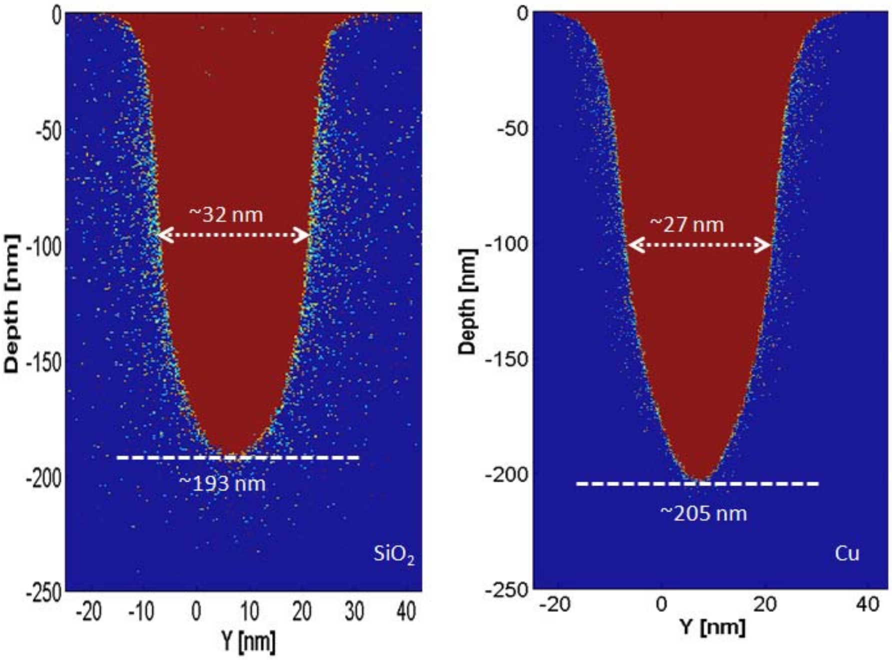

Figure 1: Sputtered nanostructures: The middle slice of three dimensional sputtered nanostructures of silicon dioxide (left) and copper (right). The color code represents different species: blue (substrates), red (sputtered), yellow (re-deposited) and cyan (sputtered but re-deposited).

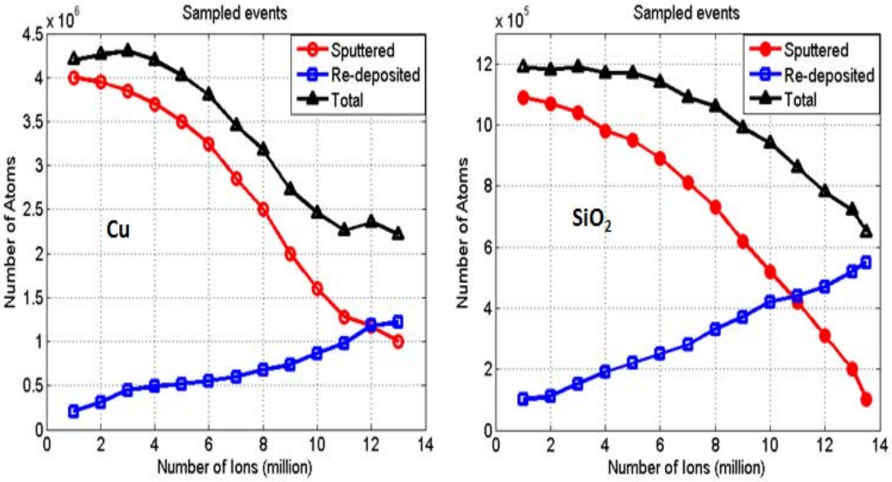

Figure 2: Incremental sputtered atom and re-deposited atom (and sum of the two) contributions during the nanoscale etching of silicon dioxide (left) and copper (right).