Focused Neon Ion Beam Induced Sputtering of Copper: Monte Carlo Simulations

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A Monte Carlo simulation has been developed to model the physical sputtering and nanoscale sputtering evolution to emulate nanomachining using the Gas Field Ion Microscope. In this presentation, we will present experimental and simulation results of focused neon ion beam induced etching of copper. Neon beams with a beam energy of 20 keV and a constant beam diameter (Gaussian with full-width-at-half-maximum of 1 nm) were simulated to elucidate the nanostructure evolution during the physical sputtering of high aspect ratio features. The aspect ratio and sputter yield vary with the ion species and 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, we correlate the nuclear energy loss and implant concentration of the etch front to observed damage revealed by transmission electron microscopy.

The neon ion beams at 20 keV were scanned in a 15nm x 15nm area (raster scan) along x and y at three different doses to investigate the evolution of the nanostructures. Figure 1 depicts the middle slices of the three dimensional nanostructures at the doses of 1.5×10^{18} ions/cm^2, 3.0×10^{18} ions/cm^2 and 6.0×10^{18} ions/cm^2 respectively [1]. The color code in the figure represents different species during the sputtering process. Blue, red, yellow and cyan represent material, sputtered, re-deposited and sputtered but re-deposited species, respectively. The dotted line in the figure represents a summation of 15x15 (1nm full-width-at-half maxima) Gaussian beams. Figure 2 is a plot of nuclear energy loss with sputtered structure. Solid and dotted black lines in the figure represent beam profile and boundary of the sputtered structure respectively. 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 doses of 1.5×10^{18}, 3.0×10^{18}, and 6.0×10^{18} ions/cm^2 are ~31nm, ~30nm and ~30nm, respectively, and the experimental sputtered depths of the nanostructures are ~120nm, ~155nm and ~210nm, respectively.

In this presentation, we will overview the current state of the Monte Carlo simulation and will review the simulation and experimental results. We will rationalize the etch evolution based on the ion-solid interactions in the materials and will opine how the observed damage front alters the copper results and discuss strategies to accommodate this in the future. Finally, we will discuss the effect of beam tails in the sputtering process.

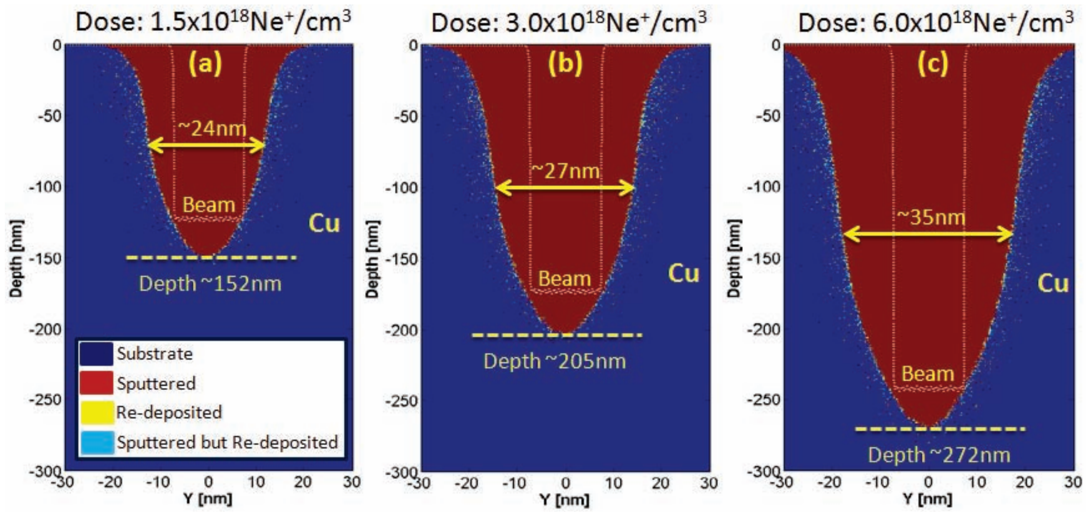

Figure 1: Sputtered nanostructures: The middle slice of three dimensional sputtered nanostructures of copper at three different doses. The color code represents different species: blue (materials), red (sputtered), yellow (re-deposited) and cyan (sputtered but re-deposited).

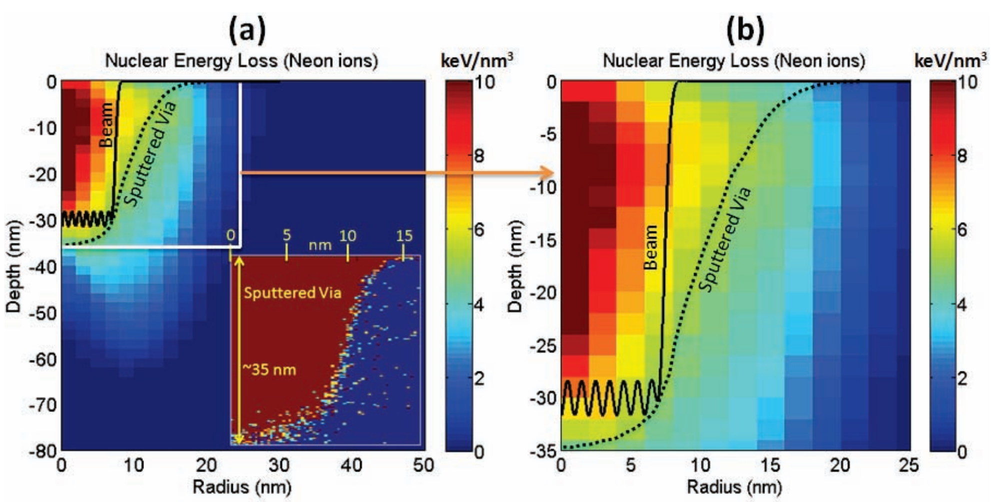

Figure 2: (a) Nuclear energy loss profile and sputtered structure of Cu (b) zoomed plot of nuclear energy loss at 20 keV for the resolution limiting effect.

References

[1] R. Timilsina, S. Tan, R. Livengood and P.D. Rack, Nanotechnology **25** 485704 (2014)

[2] S. Tan, R. Livengood, P. Hack, R. Hallstein, D. Shima, J. Notte and S. McVey, Journal of Vacuum Science & Technology B **29** 06F604 (2011)