# Plasmonic Nanostructures Fabricated using Helium and Gallium Ion Beam Instruments.

N.J. Zaluzec, D.J.Miller, J.M. Hiller
*Electron Microscopy Center, Materials Science Division,*
*Argonne National Laboratory, Argonne Illniois 60439 USA*

C. Huynh, L. Scipioni, M. Ananth
*Carl Zeiss NTS, LLC 1 Corporation Way, Peabody, MA, 01960 USA*
*lscipioni@zeiss.com*

Localized surface plasmons (LSP's) are electron density oscillations, which are concentrated on the exterior of nanostructured materials (NSM). Their behavior is influenced by size, aspect ratio, and composition of the NSM and can be engineered to have tailored dielectric/optical responses at the nanometer scale. Today most engineered LSP materials have been created by lithography or controlled chemical growth /dissolution, unfortunately these methods do not always allow precision control of complex shapes. In this work we report on electron microscope studies of engineered nanostructures of Gold fabricated using focused ion beam systems.

Fabrication of nanoscale plasmonic objects was accomplished using two focused ion beam instruments: a Zeiss 1540 Cross-Beam FIB and a Zeiss Orion Helium Ion Microscope. Patterns were cut into single and polycrystalline Gold freestanding thin films, which were nominally 100 and 50 nm thick respectively. Analytical characterization was carried using FEI Tecnai F20 and FEI Titan (Cs/Cc corrected) transmission electron microscopes (TEMs).

The smallest structures fabricated were achieved using the He Ion instrument, where individual through thickness holes as small as 5 nm in diameter could be created in the Au films. This allows precision milling of nanostructures to be readily accomplished as illustrated in figures 1 & 2. Using the Ga based system the smallest hole which could be created was ~ 50 nm in diameter, but more importantly the Ga beams introduced stress gradients in the thin films which severely compromised the stability and also the practical size of shapes milled in the thin film structures (figure 3,4). Practically the Ga ion beam patterns in thin Au films are more than an order of magnitude larger in size than those created using the He Ion system. In both FIB systems, no ion beam amorphization of the Au lattice was detected at the ion-milled surfaces (figure 2). In addition, for the cased of Ga ions, no Ga implantation was detected using x-ray energy dispersive spectroscopy in the TEM. Irradiation induced defects are present and clearly visible in both ion beam fabrications, however their spatial extent and size is significantly reduced in the He instrument. Additional work is in progress to measure LSP coupling between adjacent antennae as a function of their separation distance and will be reported on at the meeting.

This work was supported in part at ANL by the US DOE Office of Science, Contract DE-AC02-06CH11357.

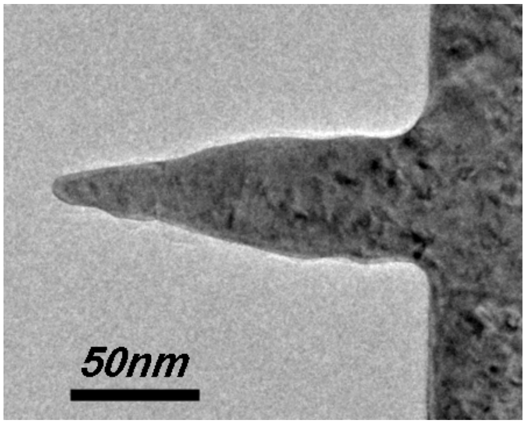


*Figure 1. Nano-antenna fabricated using He Ion Milling with a 35 kV, 1 pA beam. Note: Ion beam induced defects appear as "dark features" in this image which arise due to diffraction contrast in the lattice.*

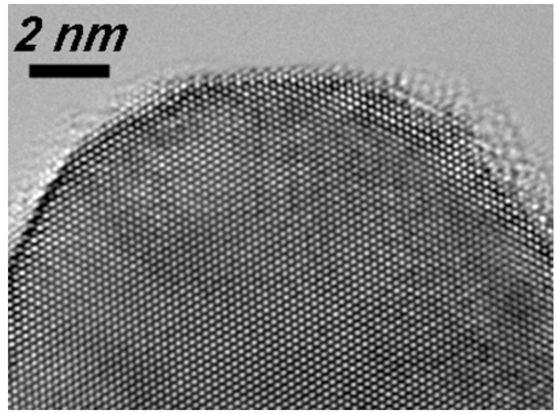


*Figure 2 High resolution TEM of the tip of a He Ion Milled nano-antenna in gold. Small amounts of hydrocarbon contamination are visible at the edge of the sample. The Au lattice is resolved to the edge of the milled tip.*

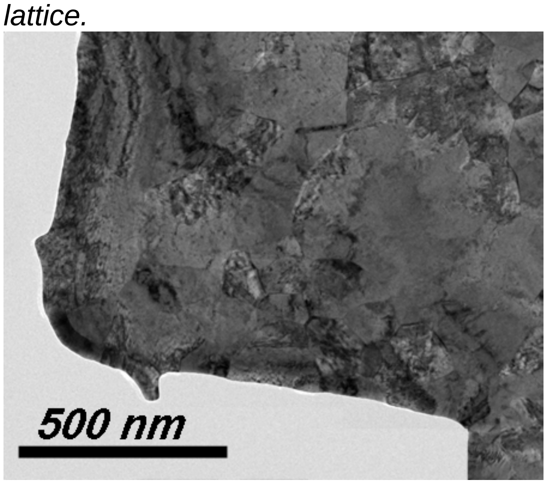


*Figure 3 Nano-antenna fabricated using Ga Ion with a 35 kV, 1 pA beam. Note: Ion beam induced defects appear as "dark features" in this image which arise due to diffraction contrast in the lattice.*

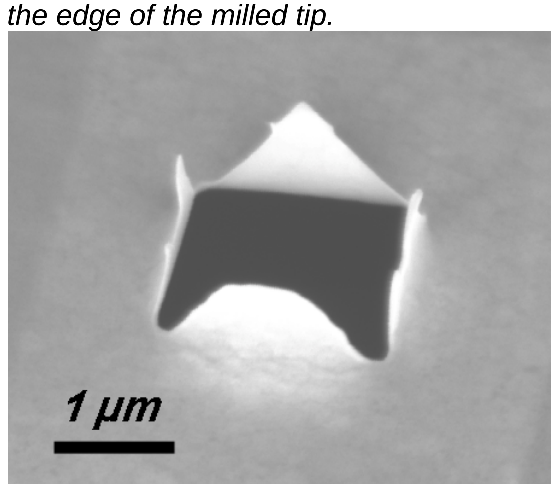


*Figure 4. Extreme example of film bending of the milled nanostructure in 50 nm Au thin film by stress relief after Ga Ion milling. The amount of bending is related to the size of the structure and thickness of the film. This did not occur in the He milled sample of the same thickness*