Silver Nanorings: Nanofabrication and Optical Properties

Julie Stern
Physics and Chemistry, Stony Brook University

NNIN REU Site: Center for Nanoscale Systems, Harvard University
NNIN REU Principal Investigator and Mentor: Prof. Ken Crozier, Division of Engineering and Applied Sciences, Harvard University
Contact: jvstern@aol.com, kcrozier@deas.harvard.edu

Introduction:

Metallic nanoparticles have become of interest for a wide variety of applications areas due to their optical properties. These properties include optical surface resonance, localization, confinement, enhancement of electric fields, and resonance wavelength tunability as a function of geometry. The main goal of this study is to elucidate the viability of silver nanorings in achieving these optical characteristics. Silver having less optical loss than gold is expected to achieve better results. An additional goal of this study is to achieve the resonant wavelength redshift from visible towards infrared wavelengths often observed with gold nanoshells and gold nanorings when geometrical parameters are tuned. The geometrical parameters under consideration consist of varying the inner ring radius as compared to the outer ring radius and fabricating nanorings with subwavelength dimensions. To obtain subwavelength spatial dimensions the nanofabrication process includes e-beam lithography at high resolution. Preliminary results from nanofabricating the silver nanorings and optical analysis are presented.

The physical phenomena we expect to obtain from the silver nanorings involve surface plasmon resonances. In metals, the charge density undergoes periodic oscillations creating dipolar and multipolar patterns of electric charges. This in turn results in electric field enhancement in subwavelength regions near the top and bottom rims outside of the rings.

It has been shown with gold nanorings [1] that the extinction peaks are in the near-infrared region with peak wavelengths affected by geometry, the ratio of the ring wall thickness to the radius of the ring. As this ratio decreased, from 0.22 to 0.16 for the gold nanorings of [1], the resonant wavelength redshifts by 400 nm.

The importance of metallic nanoparticles is evident in the applications they contribute to. One application area is ultra-sensitive single molecule detection [2]. Cancer therapy has been under development and consists of applying gold nanoshells to treat cancer [3]. Another application concept involves the idea that materials on their own rarely resonate at the near-infrared or infrared wavelengths [4] and that the ability to tune to these wavelengths by changing geometry opens new application possibilities.

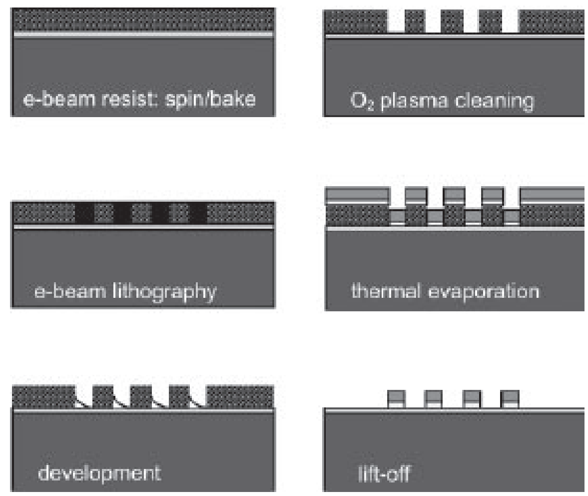

Figure 1: Nanofabrication protocol.

Materials and Methods:

Silver nanoring arrays are made using a nanofabrication protocol involving e-beam lithography and thermal evaporation of metal.

Pattern masks are designed within AutoCADLT 2005 and DesignCAD. Nanoring arrays were made to be 100 μm x 100 μm. The outer diameter of a ring was set to be 250 nm. The center to center ring distance was set to 500 nm. In the pattern mask, the ring wall thickness was set to a nominal value, and the parameters of e-beam lithography were varied to achieve different ring wall thicknesses. A smaller set of rings with the same size grid had dimensions: 120 nm outer ring diameter, and 500 nm center to center ring distance.

Figure 1 illustrates the steps of the nanofabrication process: e-beam resist, polymethylmethacrylate, is spun onto an indium tin oxide glass slide and baked, e-beam lithography is performed using the JEOL 7000 F SEM, development uses methyl isobutyl ketone, oxygen plasma cleans out the residual resist, chromium and silver are then thermally evaporated onto the slide, followed by an acetone soak and sonic vibration "lift-off" procedure.

To achieve the larger rings, the center-to-center e-beam pixel writing distance had to be reduced. Additionally, to achieve the smaller rings, a smaller e-beam dosage and smaller beam current were used.

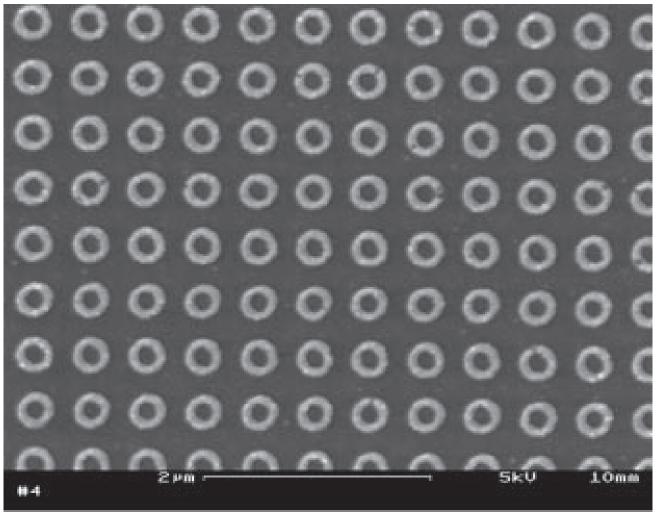

Figure 2: Silver nanorings.

Transmission data is measured from the fabricated nanoring array sample. Visible light from a xenon lamp irradiates the silver nanoring array head on. The light transmitted by the nanoring is collected into an optical fiber and into an optical spectrum analyzer. The data is normalized by incident light. A dip in transmission corresponds to a peak in absorption.

The SEM images were taken with the Leo 982 field emission scanning electron microscope.

Results and Conclusions:

The resulting silver nanoring array produced from the nanofabrication procedure and SEM imaging are shown in Figure 2. For a sample ring, the outer ring diameter was measured to be roughly 386 nm with a ring wall thickness of 80 nm. Figure 3 illustrates a tilted view of the same sample.

Smaller rings were nanofabricated (Figure 4). Only a minute amount of ring deformity and interior residual appeared. For a sample smaller-sized ring, the outer ring diameter was measured to be roughly 187 nm. The ring wall thickness was measured to be approximately 33.4 nm.

Optical characterization demonstrated resonances in the near-infrared wavelength range. In addition, the results showed that the resonances could be tuned to different wavelengths by changing the ring thickness.

Hence, the nanofabrication process worked for silver nanorings. High resolution e-beam lithography was needed to produce even smaller rings. The rings absorbed resonances within the near-infrared region of wavelengths. Geometric tunability of the optical modes was shown.

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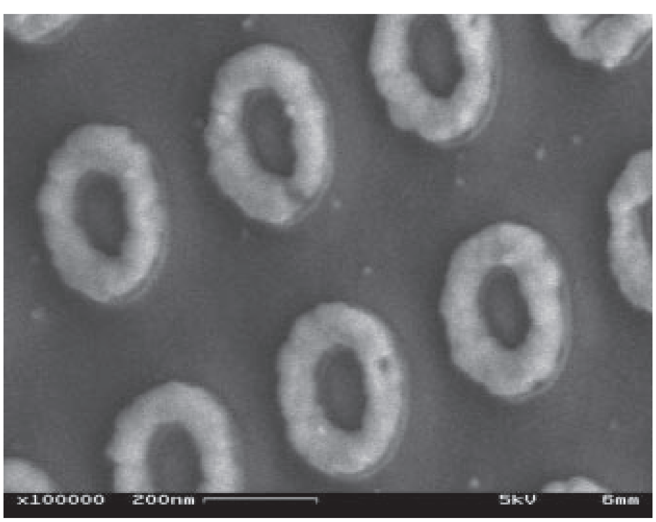

Figure 3: Tilted view of silver nanorings.

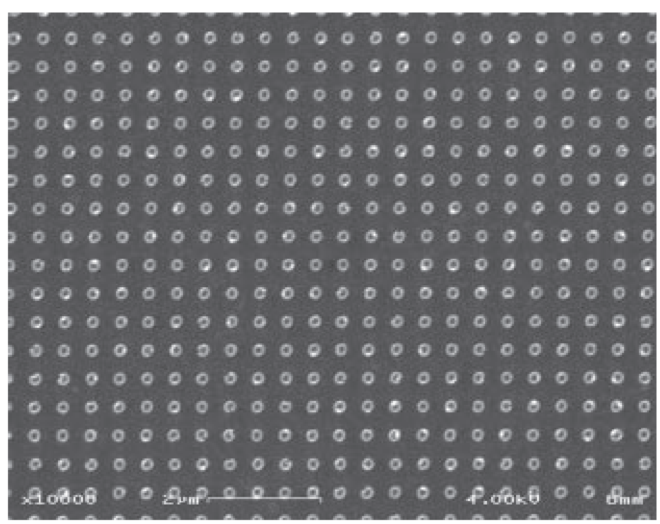

Figure 4: Smaller silver nanorings.