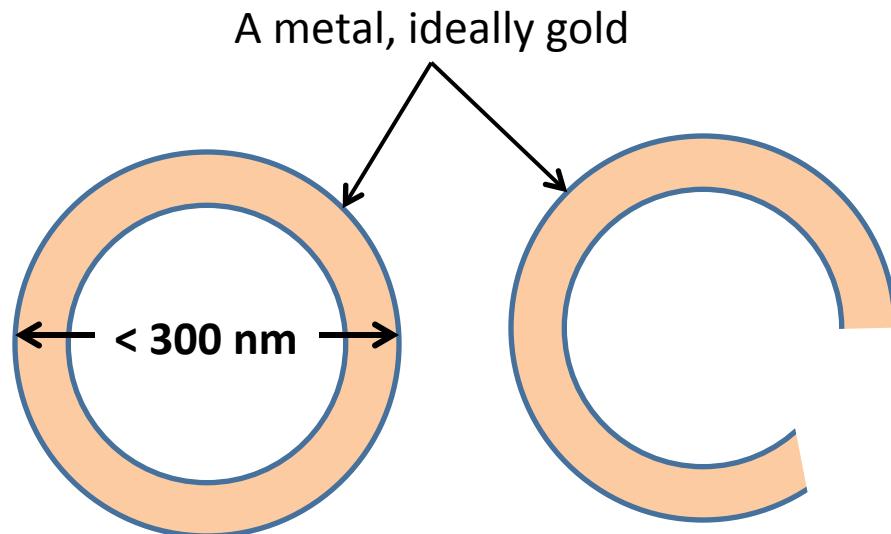
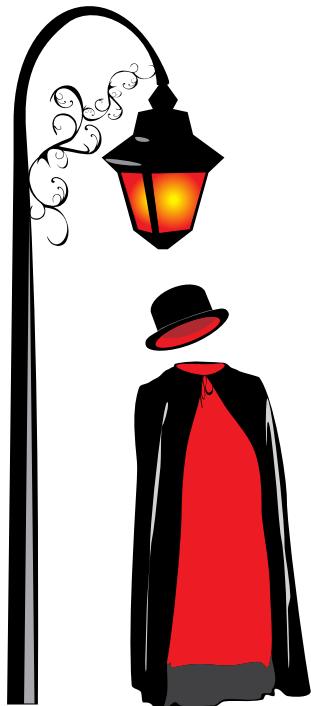


# Nanophotonics: A Case Study

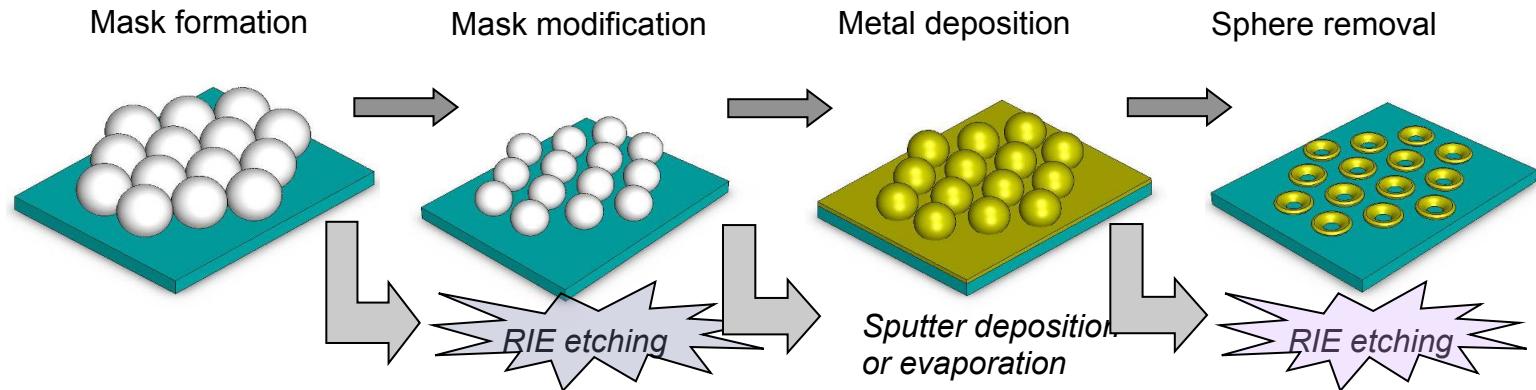
## Making Visible Metamaterials

- Soft lithography as a way to pattern structures
- Shaped soft lithography – direct metals in patterns
- Large areas of metallic crescent structures are possible

# Our Goal: Rings and C-Structures

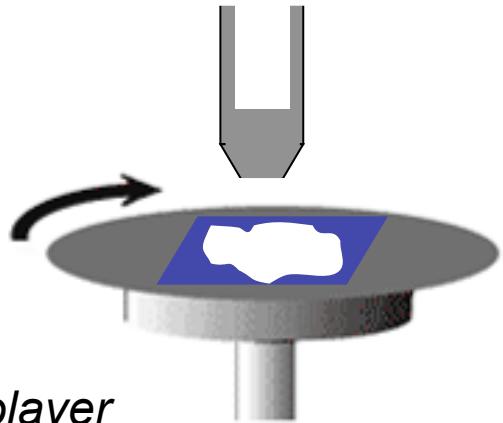


# Shaped Soft Lithography

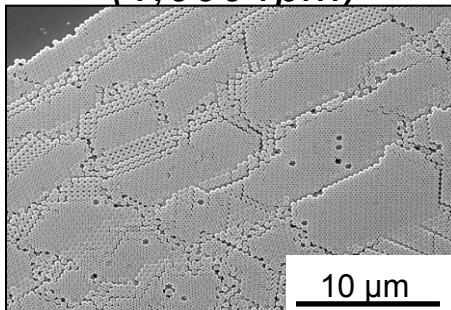


# Step 1: Forming the Mask

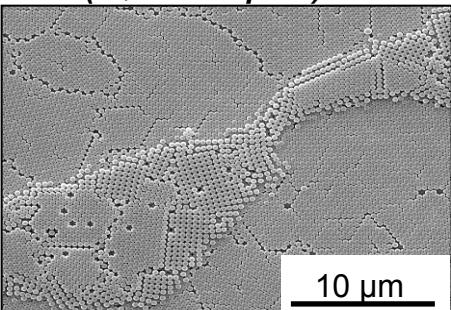
A drop of solution containing polystyrene spheres is placed on the substrate. The fluid is rotated at high speed to spread the fluid by centrifugal force and form a hexagonal closed-packed array of nanospheres. The coating thickness is adjusted by the spinning speed



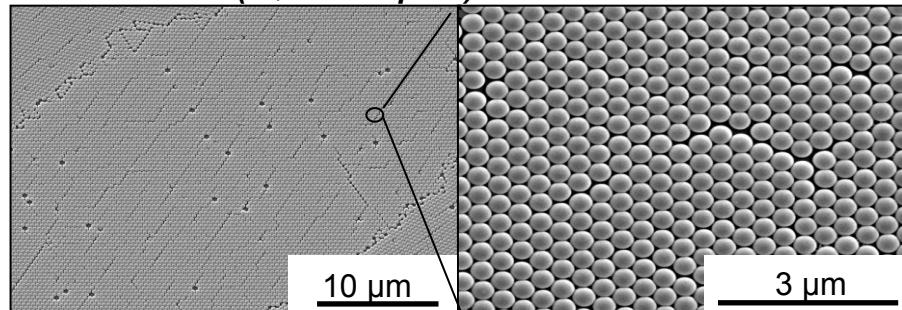
Multilayer  
(1,000 rpm)



Double layer  
(2,000 rpm)

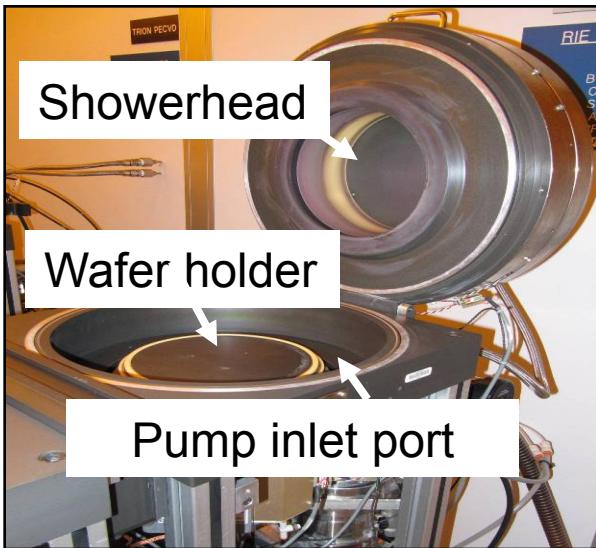


Monolayer  
(3,000 rpm)

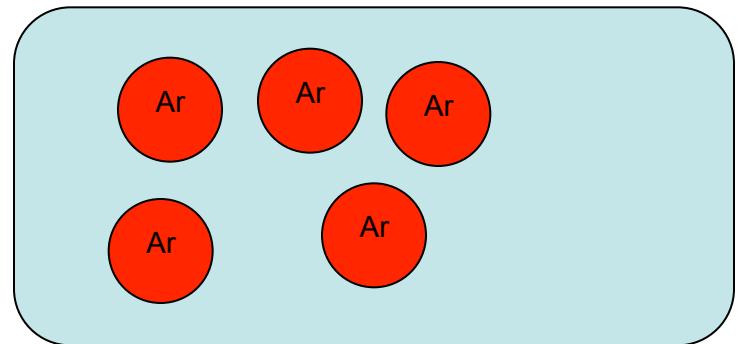


# Plasma etching shapes the spheres

*Open RIE chamber*



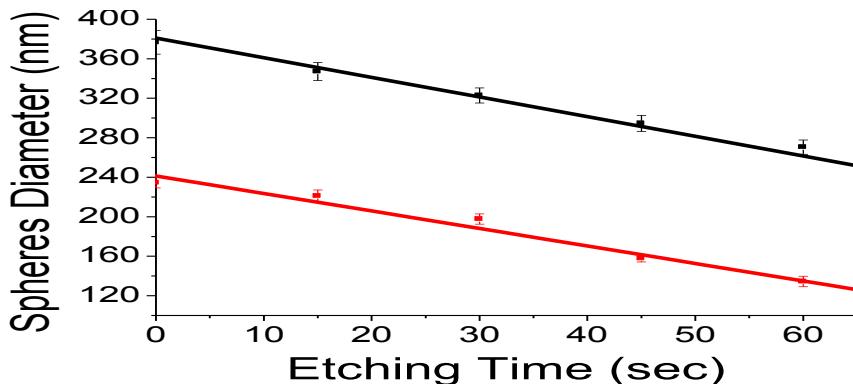
Negative Electrode



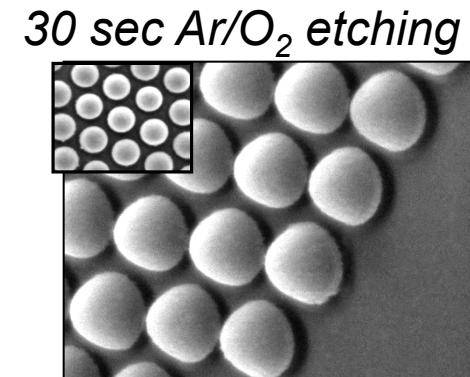
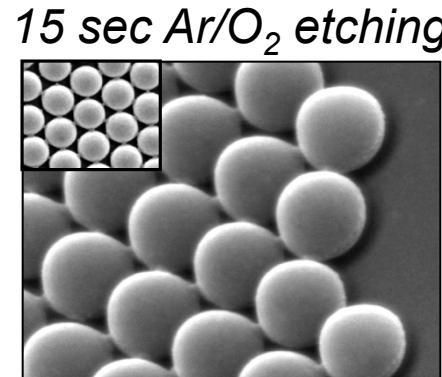
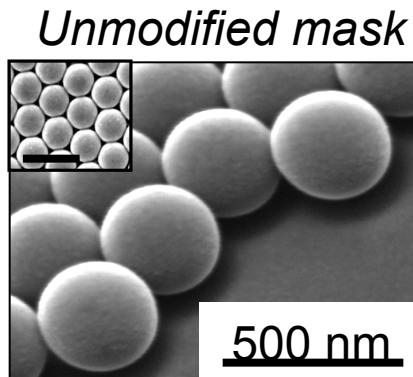
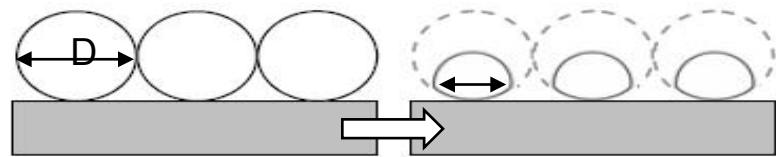
Positive Electrode

*RIE etching uses plasma to remove material deposited on wafers. Plasma is initiated in the system by applying RF (radio frequency) electromagnetic field (13.56 MHz) to the wafer holder. The oscillating electric field ionizes the gas molecules by stripping them of electrons and creating a plasma. Ions drift toward the wafer platter, where they collide with the samples to be etched.*

# Ar/O<sub>2</sub> plasma etching for mask modification



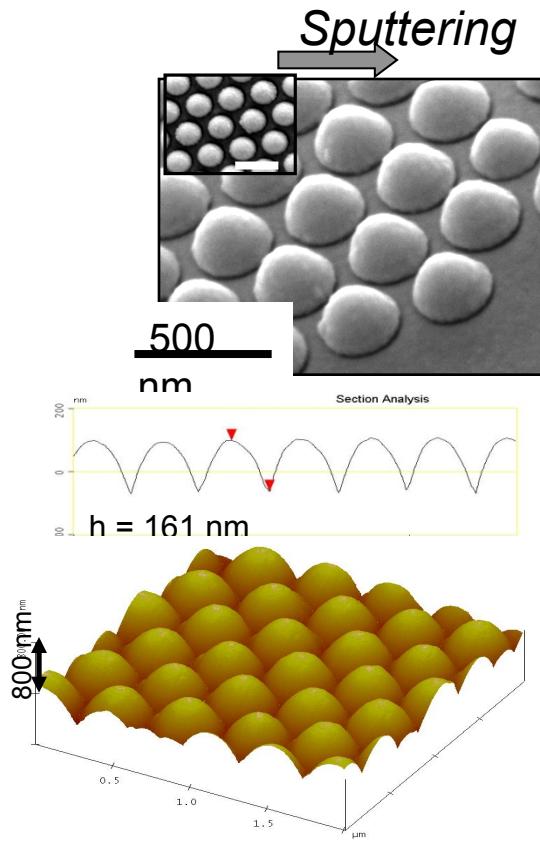
*The size of the polystyrene spheres defines the diameter of the nanorings.*



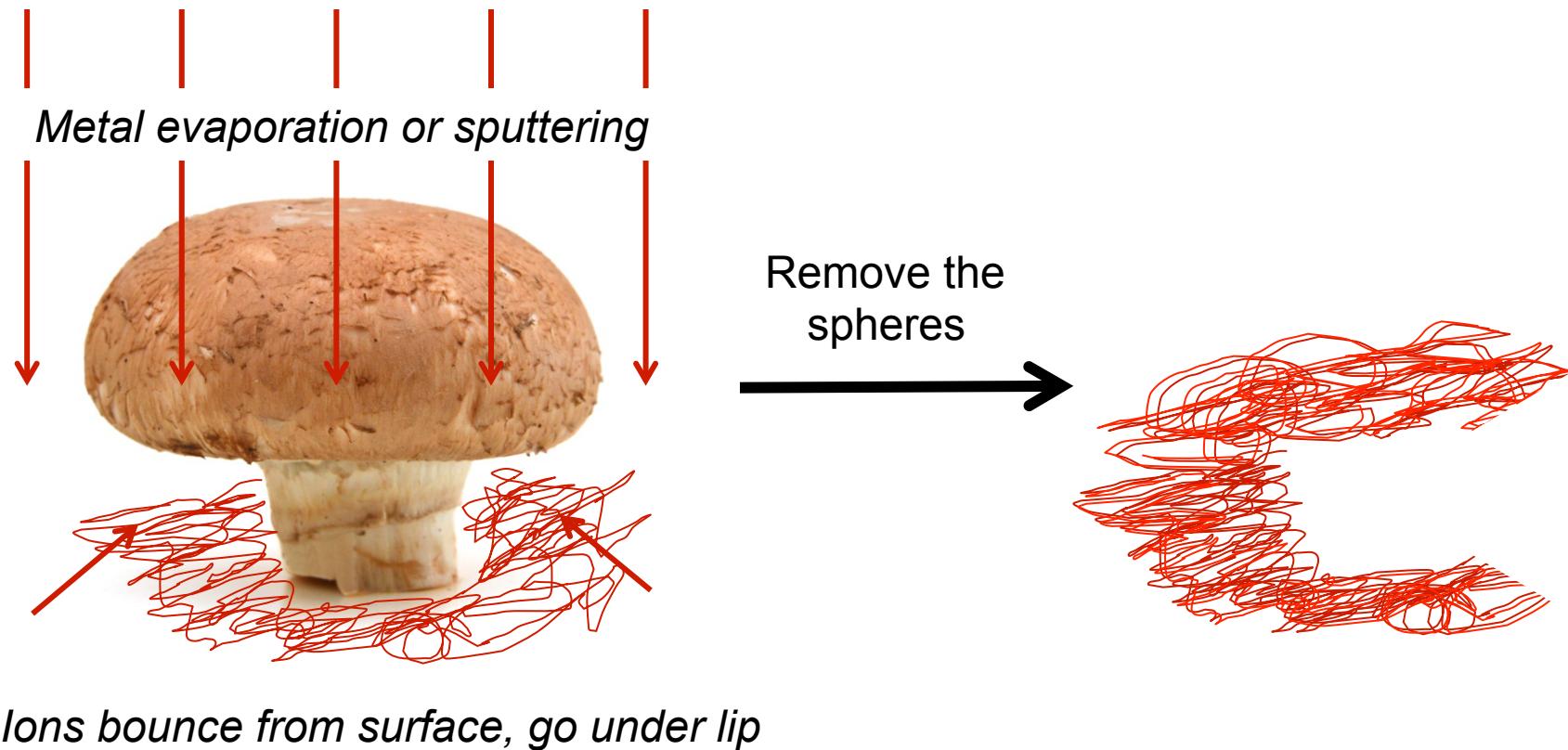
# What the etching does



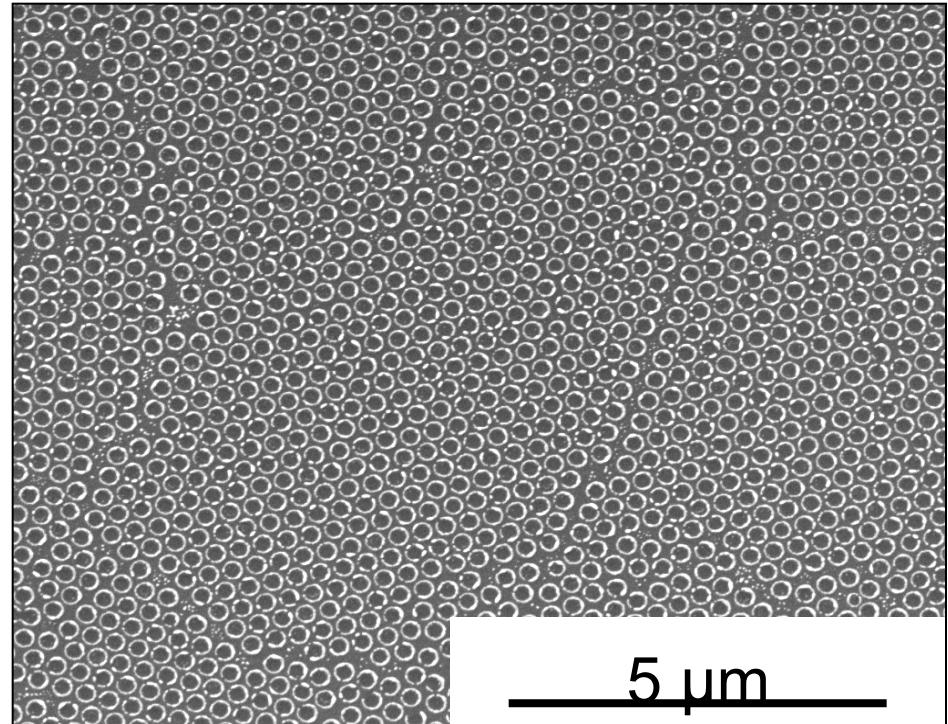
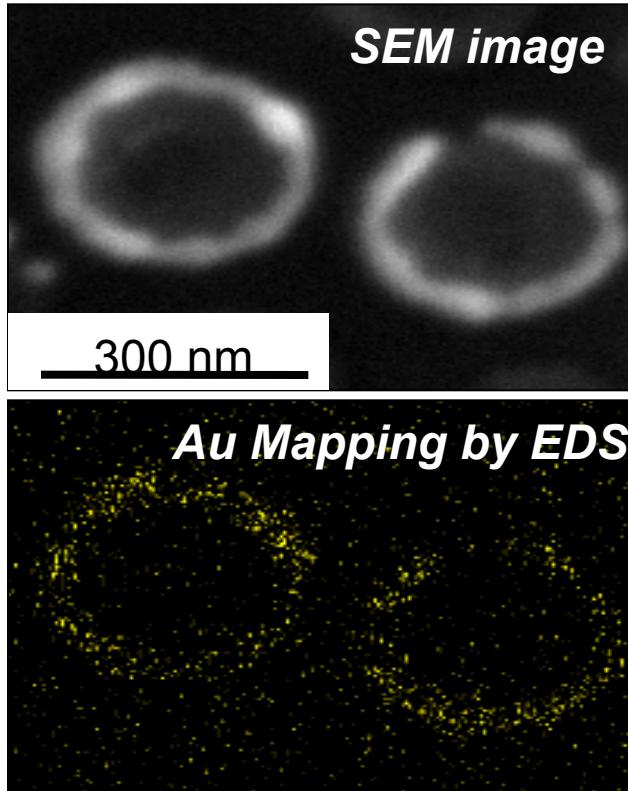
# Applying and Removing Metal to the Mask



# Laying the Metal Down

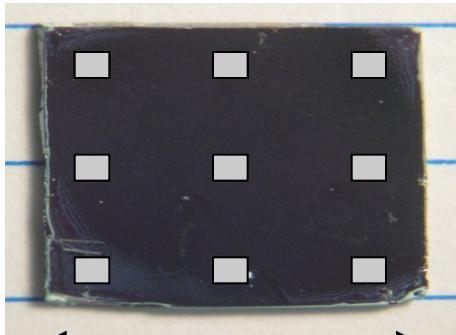


# Elemental Analysis of Nanoring Structures



# Key Challenge: Non-Uniformity

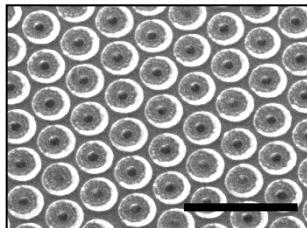
*Schematic representation of analyzed sample area*



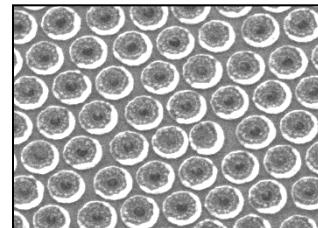
1 cm



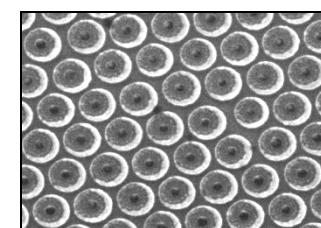
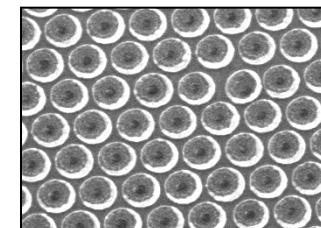
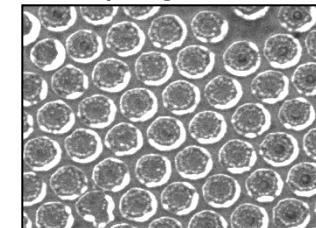
*Top left corner*



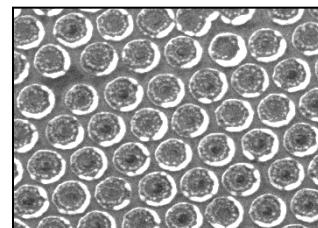
*Middle*



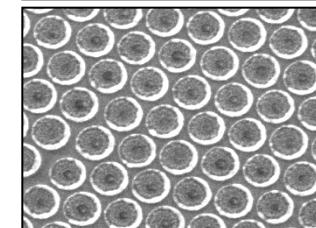
*Top right corner*



*Bottom left corner*



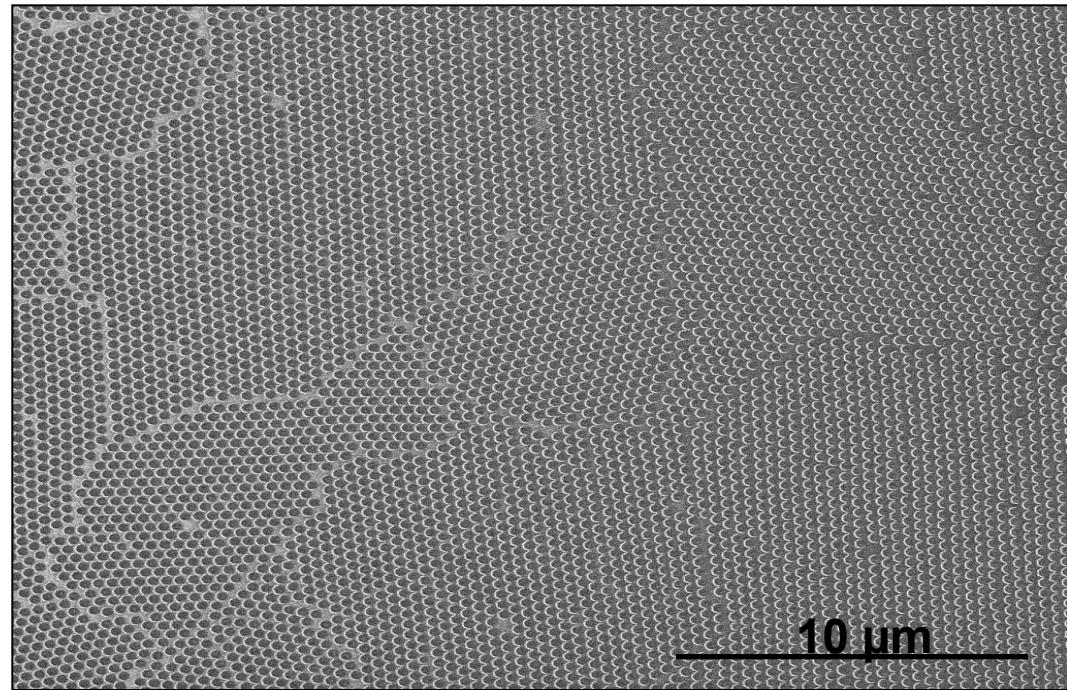
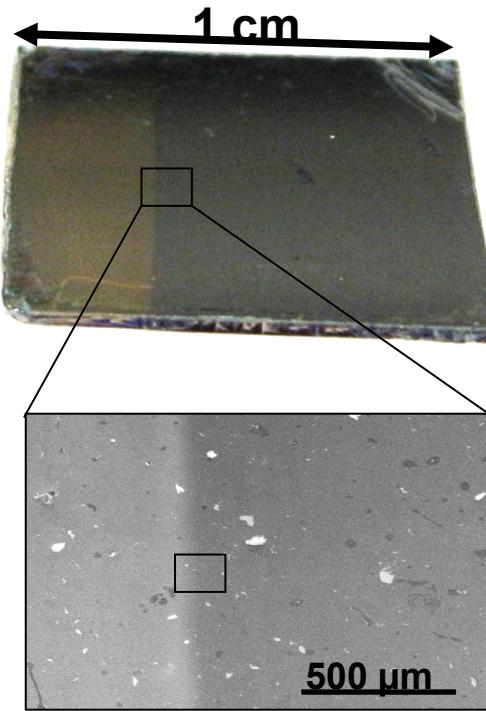
*Middle*



*Bottom right corner*

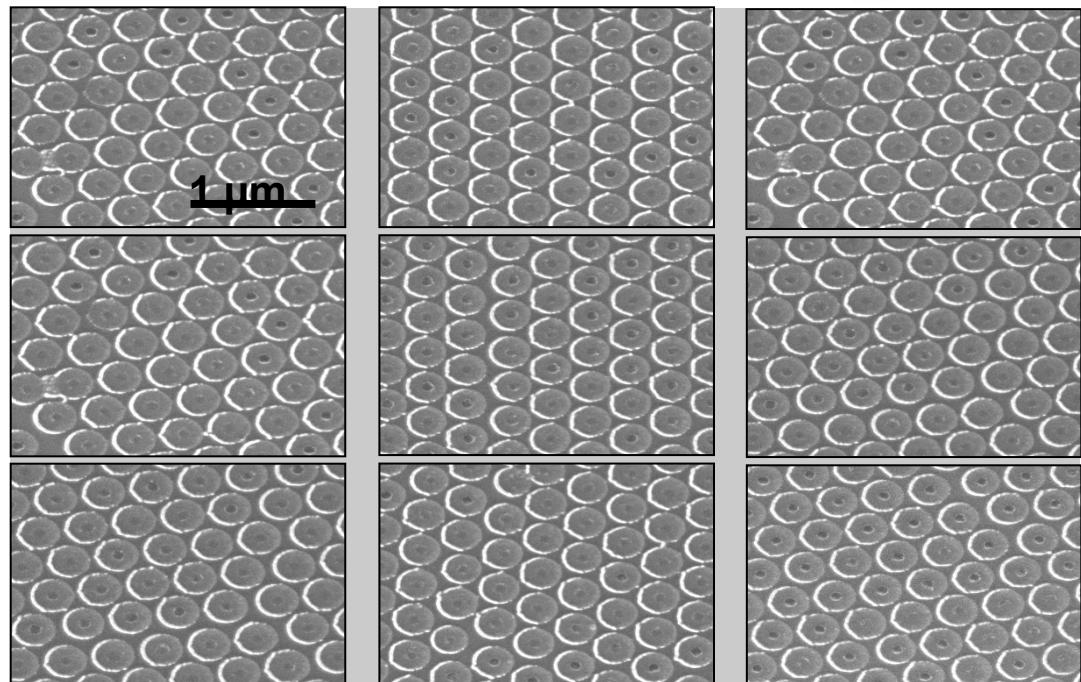
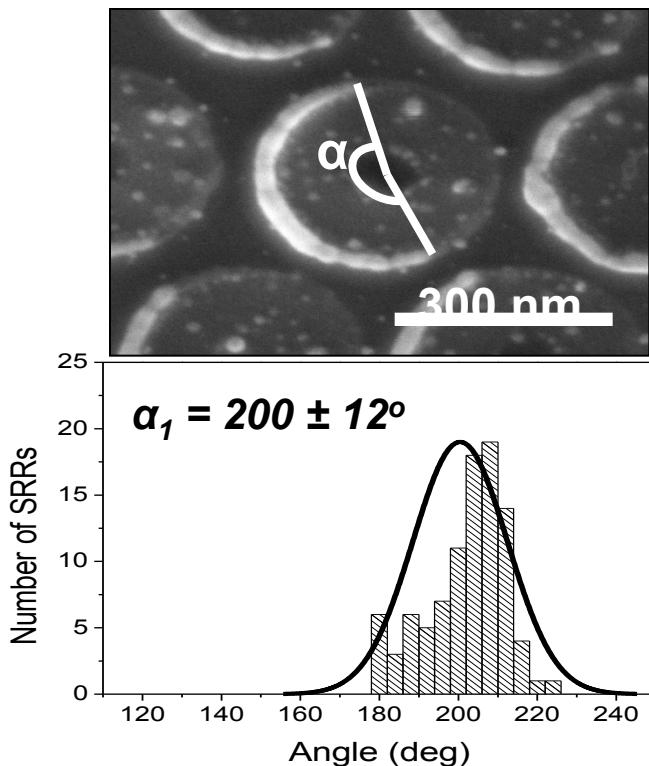
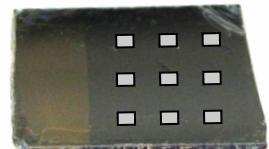


# Fixed Problem with Secondary Mask



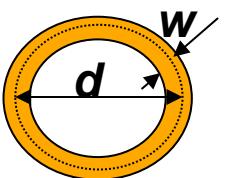
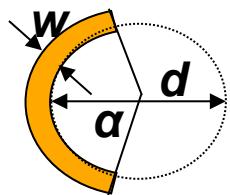
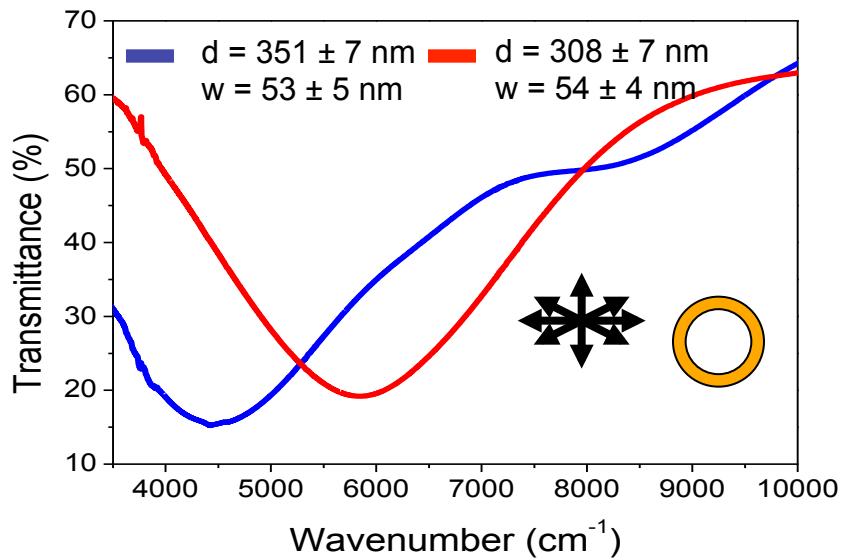
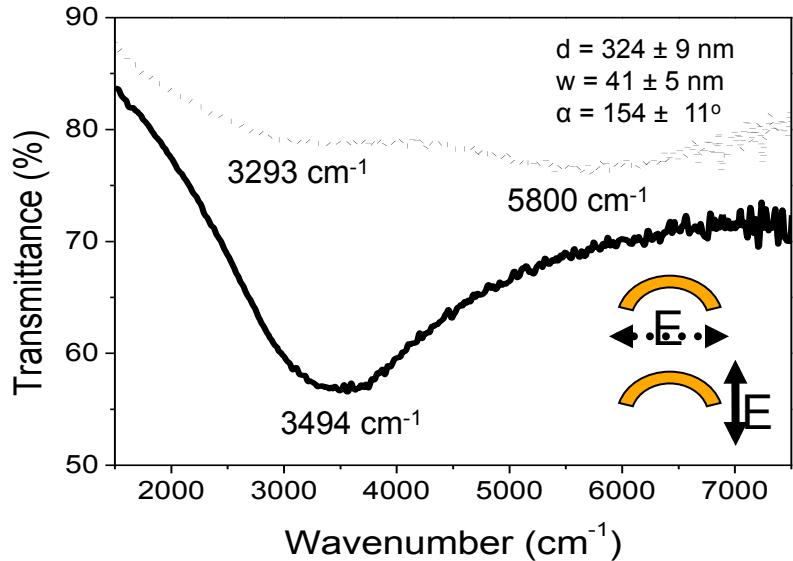
*Bombarding ions are deflected by the local electric field on the edge of secondary mask and form split ring resonators*

# Improved Uniformity: Crescents

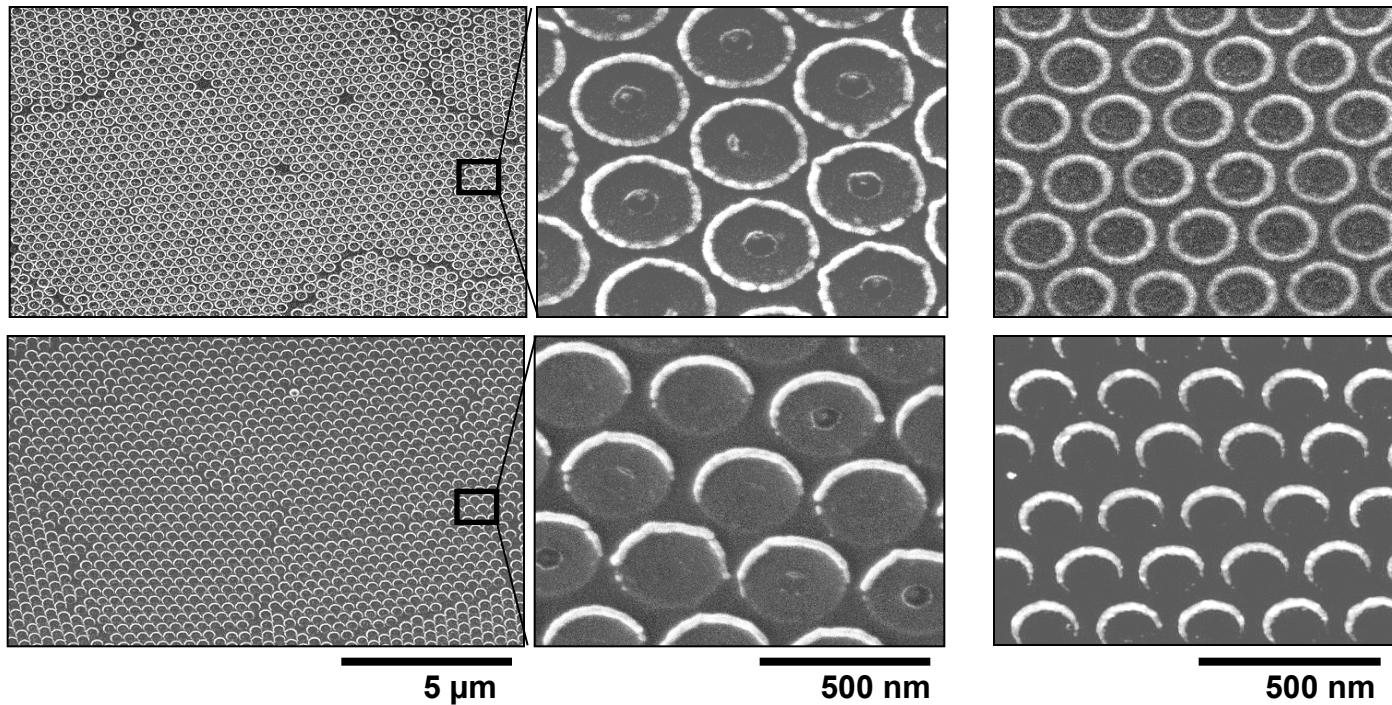


***Uniform SRRs cover the sample area of about 0.6 cm<sup>2</sup>***

# Peaks in Transmittance: Metamaterial Resonances



# Summary: Shaped Nanosphere Lithography for Infrared Metamaterials



# Shaped Soft Lithography

Week 4, Lecture 8, Nanotechnology



- Ordered arrays of spheres make good mask structures
- The spheres can be shaped into mushroom type objects so as to create a protected area for metal deposition under the lip.
- Metals laid down is directed to go straight down over the mushroom structures (rings), and etching can be directional to lead to ‘c-shapes’