Design and Fabrication of Plasmonic Device for MIR Absorption Spectroscopy

Jacob Heppner

Applied Physics and Computer Science, Bethel University

NNIN REU Site: Minnesota Nano Center, University of Minnesota-Twin Cities, Minneapolis, MN

NNIN REU Principal Investigator: Prof. Sang-Hyun Oh, Electrical and Computer Engineering, University of Minnesota

NNIN REU Mentors: Daniel Mohr, Daniel Klemme, and Daehan Yoo; Electrical and Computer Engineering, University of Minnesota*

(2012 NNIN REU Intern at University of Colorado)*

Contact: jah73854@bethel.edu, sang@umn.edu, mohrx117@umn.edu, klemm023@umn.edu, yooxx094@umn.edu

Abstract:

Plasmonic structures, such as slits, grooves, or apertures in metal films can be used to guide optical energy beyond the conventional diffraction limit of light, allowing for optical measurements that would not be possible with standard techniques. Annular nanoapertures have been utilized for applications in plasmonic sensing and spectroscopy. We have developed a fabrication technique to utilize strongly enhanced plasmonic fields in such structures. These techniques allow small changes in the absorption or reflection spectra of the device to detect compounds within close proximity to the structures. It is expected that device sensitivity will be increased through the reduction of critical dimensions.

Introduction:

Surface plasmon polaritons (SPPs) are hybrid electromagnetic waves across a metallic interface that are commonly excited by coupling light to conduction electron plasma. The electromagnetic field from SPPs can be confined to a smaller volume with much greater intensity than is possible using conventional diffractive optics. These properties make plasmonically-active patterned metal films ideal candidates for a variety of optical sensing applications. In particular, plasmonic biosensors have been used for observing association and dissociation in binding kinetics, lowering the limit of detection of analyte in solution, and detection of known particles in solution using spectroscopy. These biosensors are metallic nanostructures that have been engineered to increase confinement of plasmons and create regions of high field enhancement.

In this work, we present the design and fabrication of annular nanogaps tuned to operate plasmonically in the mid-infrared (MIR) region of the electromagnetic spectrum. An annular nanogap is a coaxial structure where an annular gap is formed in a conducting material that is attached to the substrate. These annular nanogaps were created using a lift-off process.

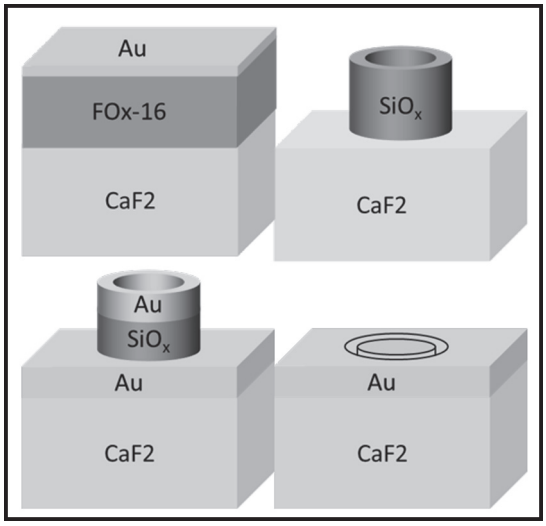


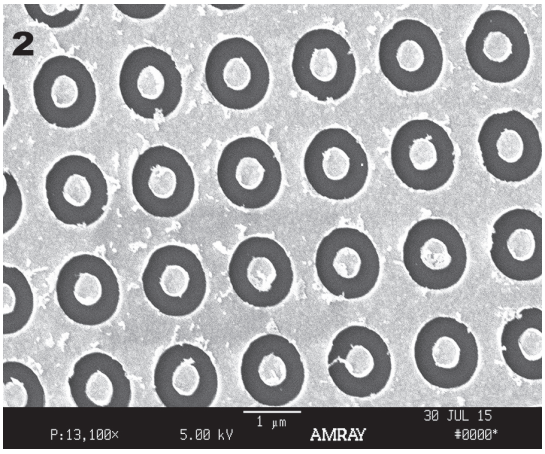
Figure 1: Process diagram for annular nanogap fabrication.

Experimental Procedure:

The first step of the process was spin coating flowable oxide-16 photoresist (FOx-16), a negative tone resist, on a calcium fluoride substrate. A 5 nm thick layer of gold was then sputtered on the insulating substrate to prevent unwanted charging during the exposure. The FOx-16 was then exposed using electron-beam (e-beam) lithography, after which the sample was developed in a 1% NaOH 4% NaCl solution. Gold, 100 nm thick, was then evaporated onto the sample by electron-beam evaporation. The sample was then sonicated in buffered oxide etch to dissolve the photoresist in the annular gaps, lifting the gold above this region. This process is shown in Figure 1. FOx-16 was chosen because it is a negative tone resist that can be spun on at large thicknesses and it would not react with the potassium iodide that we used to etch the gold discharge layer before developing.

We would like to use these annular nanogaps for MIR absorption spectroscopy to identify molecular species. These annular nanogaps will focus light into regions of high field enhancement, which will provide high sensitivity to identifying particular molecular species. One of the advantages of using an annular nanogap structure above using a thin film of gold is the ability to tune the structure to the MIR region of the electromagnetic spectrum, which is important for vibrational absorption spectroscopy of molecules. The critical dimensions on device performance are the gap width, inner radius of the annular gap, and the thickness of the metal film. The thickness was chosen to be 100 nm to balance plasmonic enhancement of the sensor and the transmission through the sensor, maximizing the signal to noise of the device. Both 300 nm and 700 nm inner radius annular gaps were fabricated, each having the same 200 nm gap width to test to different regions within the MIR.

Full fabrication of the annular nanogaps was accomplished on a silicon substrate (Figures 2 and 3). These samples were characterized using Fourier transform infrared spectroscopy, and simulations of the structures using the finite-difference time-domain technique were also performed (Figure 4).



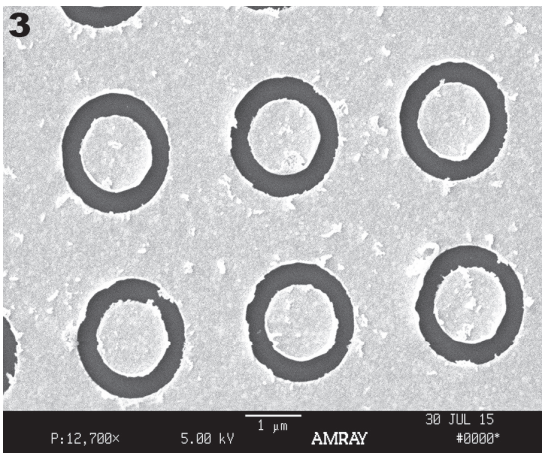


Figure 2, top: 300 nm inner radius annular nanogaps.
Figure 3, bottom: 700 nm inner radius annular nanogaps.

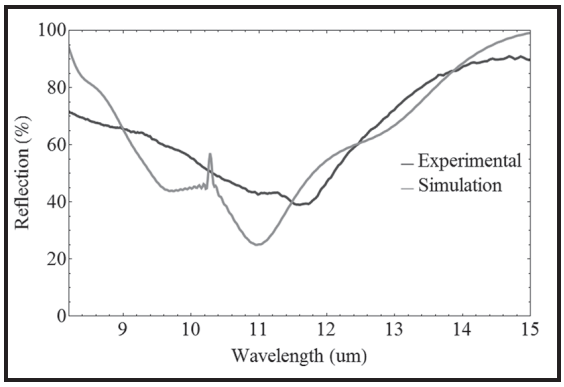


Figure 4: Reflection spectra for 700 nm inner radius sensors.

Results and Conclusions:

We saw some agreement between simulated models and the experimental data, though we did find that there were significant sources of error that contributed to lowering the agreement. One of the sources that we think played the largest part in lowering agreement is erosion of the critical features. This erosion we think came from the wet etching process that was used during the lift off process. The erosion would have occurred unevenly and would have an effect on the resonances. We also noticed that the gold that eroded away often re-deposited on the surface, which may have affected the resonances of the structure. The erosion most likely occurred from the lift-off bath etching the native oxide on the silicon substrate, undercutting the edges of the critical features. The lift-off method use will not etch calcium fluoride to the same degree, so it is unlikely that undercutting will be an issue in the future.

To conclude, annular nanogaps were fabricated for potential applications in plasmonic sensing and spectroscopy. In the future, fabrication of the annular nanogaps on calcium fluoride substrates will be completed. We will then take measurements with the sensors and compare the experimental data with simulated data to determine viability of the sensors as biosensors in real-world applications.

Acknowledgments:

I would like to acknowledge Professor Sang-Hyun Oh and his research group, specifically my mentors Daniel Mohr, Daniel Klemme, and Daehan Yoo, for their assistance in this research. I would like to thank James Marti for his assistance and oversight. I would like to thank the Minnesota Nano Center for use of their facilities. I would also like to thank the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program for giving me this opportunity to research. This research was supported by the National Science Foundation under Grant No. ECCS-0335765.