Engineered Metallic Structures and Nanofabrication Techniques for Plasmonic Biosensors

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Abstract:

Optical energy can be harnessed on the nanoscale by exploiting plasmonic resonances in metallic nanostructures. These resonances are the result of the unique optical properties of metals and their abundance of conduction electrons. Utilizing these properties, it is possible to engineer metallic nano-devices that operate with large electric field intensities confined in and around the structure. Due to these large fields, optical, chemical and spectroscopic properties can be probed with high sensitivity. This project covers the various fabrication methods unique to the precise fabrication of metallic nano-structures as well as some applications as nano-optical sensors.

Introduction:

Plasmons are collective oscillations in the electron cloud density of a conductor, usually metal. At the surface of a material, they are called surface plasmons. These oscillations can be induced by electromagnetic radiation at specific frequencies. If certain conditions are met, a photon can couple with a plasmon forming a surface plasmon polariton (SPP). This is a propagating electromagnetic wave on the surface of the metal at the interface of a dielectric and the conductor. The SPP is transverse-magnetic, meaning that an evanescent electric field extends into both the metal and dielectric, normal to the interface. This electric field extends no more than a few hundred nanometers (nm) into the dielectric and is strongest near the surface. We are able to use this electric field to probe the near-field region [1]. If a plasmon is induced on a small metal particle, i.e. with size dimensions on the order of or less than the wavelength of incident light, a propagating electromagnetic wave is not formed. Instead, electrons oscillate with the changing electric field, forming areas of high electric field, or “hot-spots” [1]. This is known as localized surface plasmon resonance (LSPR). These hot-spots can be employed to trap particles and perform surface enhanced Raman spectroscopy (SERS) [2].

We can engineer structures on the nanoscale that exhibit these plasmonic properties. However, because plasmons can be excited by deformities on the surface, it is critically important that our devices have smooth surfaces to ensure optimal performance.

Fabrication Procedures:

Because smooth surfaces were so important for our devices, we platformed the entire fabrication process around the technique of template-stripping. This process required a silicon mold, which was then deposited over with metal. The metal was then epoxied to a glass slide, cured, and finally removed from the mold; this resulted in the inverse of the mold patterned in the metal, possessing ultrasmooth surfaces. Template stripping also allowed the mold to be reused, enabling high-throughput fabrication of devices [2]. We used two different methods to fabricate the molds.

For high resolution patterning, we employed electron beam lithography. After patterning a spin-coat layer of photoresist, we used etch processes to carve the mold. Depending on the etch depth needed, sometimes a hardmask layer was utilized. For lower resolution patterning, we used focused ion beam lithography. This method did not require photoresist, however it could not match the resolution capabilities of electron beam lithography. This method did enable the direct fabrication of molds.

In some cases, we determined that we did not need to template-strip our structures. In these situations, we used electron beam or photolithography to pattern a stencil mask. We then deposited metal over the mask and performed a chemical liftoff. All open areas of the stencil were filled in with metal, resulting in surfaced patterned structures.

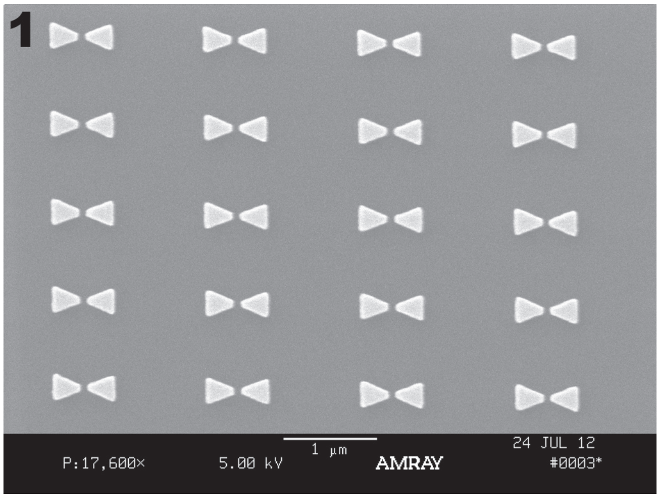
Devices:

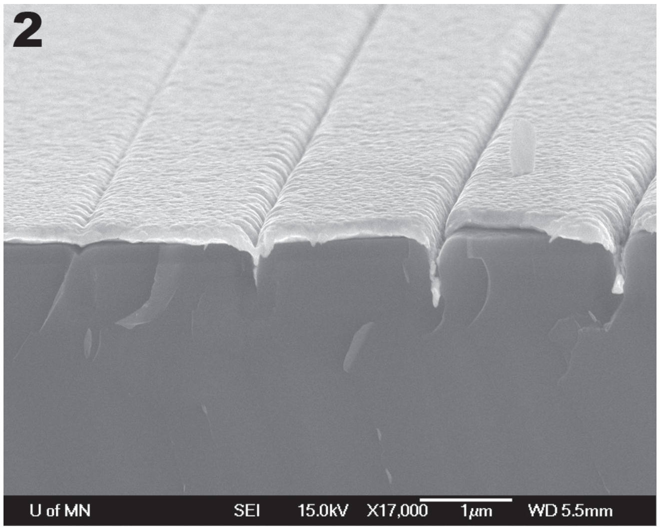
Using the methods described above, we fabricated an assortment of devices, some of which are not contained within this report. The following figures show several devices in various stages of production.

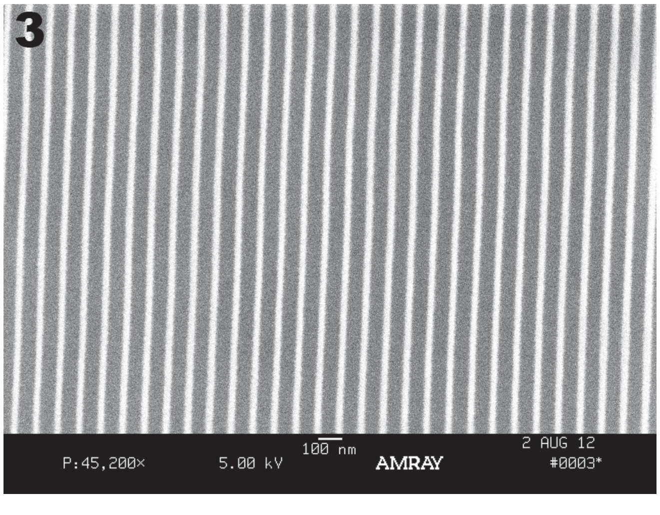
Bowtie Array (Figure 1). These bowties were fabricated by depositing gold over a stencil mask and performing liftoff. They facilitated the formation of LSPRs, with hot-spots focused in the gap at the center of the bowtie. They have been used to trap particles in this hot spot and to aid in performing SERS.

Sharptips Prior to Template Stripping (Figure 2). Using electron beam lithography, dry etching, atomic layer deposition, and thermal metal evaporation, an array of sharp-tipped lines were fabricated. When template stripped, they focused to a narrow point. These devices displayed interesting plasmonic effects and concentrated hot spots at the tips of the structures. (*Image courtesy of Timothy W. Johnson.*)

Nanochannels, HSQ on Silicon (Figure 3). Using electron beam lithography, it was possible to achieve high resolutions, as exemplified here. These were 20 nm lines of HSQ on silicon. After development, HSQ becomes chemically similar to SiO_2 and can be used as a hardmask for etching. This image was taken prior to etching.







Future Work:

The main thrust of this research was designing and building plasmonic biosensors.

As demonstrated, devices are in various stages of completion. The obvious next steps include finishing fabrication and testing the devices. Based on test results, the devices can be optimized and results published.

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References:

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