Template Stripping for High Throughput Fabrication of Nanohole Arrays

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Abstract and Introduction:

Surface plasmons are electromagnetic waves created at a metal-insulator interface that can confine optical energy well below the diffraction limit. Surface plasmons can be excited by periodic nanohole arrays in an optically thick metal film, which leads to the extraordinary optical transmission effect through the nanoholes [1]. The locations of the transmission peaks are dependent on the local refractive index in the nearest 100-200 nm to the interface. This makes nanohole arrays useful for biosensing as a way to monitor molecular binding kinetics in a real-time label-free manner, as molecular binding onto the metal surface results in changes in refractive index [2].

Currently, most ordered nanohole arrays are fabricated on a small scale using focused ion beam (FIB) or electron-beam lithography (EBL). However, these serial fabrication techniques are slow, expensive and lead to sample-to-sample variation. Nanosphere lithography was used to make nanoholes in a large area, but the method cannot easily create nanohole arrays with arbitrary shape, size and periodicity [3]. There is a need for a high throughput method of fabricating nanohole arrays with reproducibility so that biosensing experiments can proceed with a lower substrate cost.

Template stripping is a method of transferring nanoscale structures to metal films by depositing metal on the surface of a mold and peeling it off using an adhesive backing layer [4].

The goal of this project was to determine whether template stripping could serve as a high throughput method to manufacture nanohole arrays.

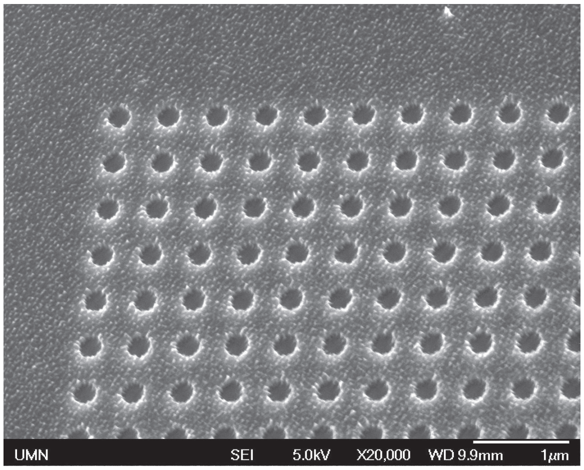

Figure 1: Nanohole pattern in a mold.

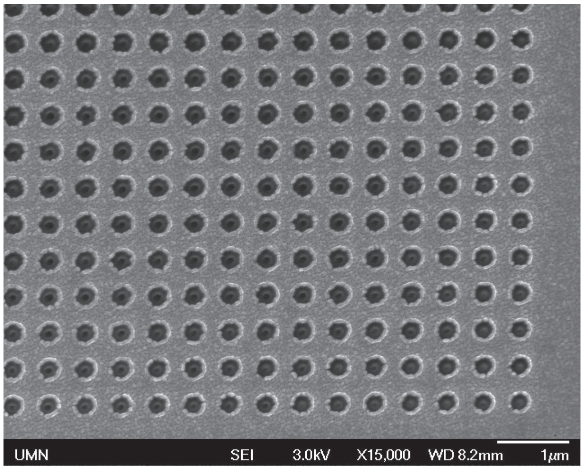

Figure 2: Nanohole array in silver film.

Mold Fabrication:

A silicon wafer with 200 nm of thermally grown silicon dioxide (SiO_2) was spin-coated with polymethylmethacrylate (PMMA) resist at 3000 rpm for 30 seconds and baked at 180°C for 90 seconds. This substrate was exposed using EBL with an accelerating voltage of 20 kV and a 10 μm aperture to produce the desired pattern of nanohole arrays.

The patterned wafer was developed in a 1:3 mixture of methyl isobutyl ketone and isopropyl alcohol for 30-60 seconds.

The mold was etched through reactive ion etching (RIE, STS etcher) to etch the thermal oxide. After cleaning in acetone and piranha (1:1 sulfuric acid:hydrogen peroxide) for 10 minutes each, the Si wafer was etched in a potassium hydroxide (KOH) solution at 30°C, which anisotropically etched the Si below the SiO_2 mask. The resulting mold has the desired nanohole array pattern in SiO_2 with under-etched pyramidal pits in Si. The pits prevented the formation of a suspended film of metal by creating discontinuous sidewalls in the mold.

Template Stripping:

After the mold had been fabricated, 100 nm of silver (Ag) was deposited on the mold using a Temescal EB evaporator. An optical epoxy was applied to a clean glass slide, and both the slide and epoxy were placed onto the Ag-coated mold. After curing the epoxy, the Ag film and slide could be easily separated from the mold. The mold could then be used again.

Spectral Measurements:

Optical transmission spectra were taken using an optical microscope and fiber optic spectrometer. The spectra were normalized with respect to a reference spectrum of incident light to produce the graphs shown. In order to examine the sensitivity of the nanoholes to changes in local refractive index, approximately 7 nm of SiO_2 was deposited using atomic layer deposition and the transmission spectra were again measured. This process occurred three times for a total SiO_2 thickness of 21 nm.

Results and Conclusions:

Figure 3 shows the optical transmission spectra of multiple nanohole arrays produced from the same mold through repeated template stripping. The spectra are consistent in shape and location of peak position. This shows that template stripping is capable of repeatedly producing samples with the same characteristics.

In Figure 4, spectra from the same nanohole array are plotted as the thickness of a thin layer of SiO_2 increases. The layer of SiO_2 increases the local refractive index near the interface, and so changes the position and intensity of the extraordinary optical transmission peaks. This result shows that the nanoholes are sensitive to refractive index changes and so can be used in refractive index sensing experiments [5].

Future Research:

Looking forward, the next steps are further work at optimizing the nanohole parameters, such as hole size and distance between holes, to produce spectra with transmission peaks at the desired wavelengths, and integration of template-stripped samples into experiments that are currently employing nanohole arrays fabricated by FIB lithography.

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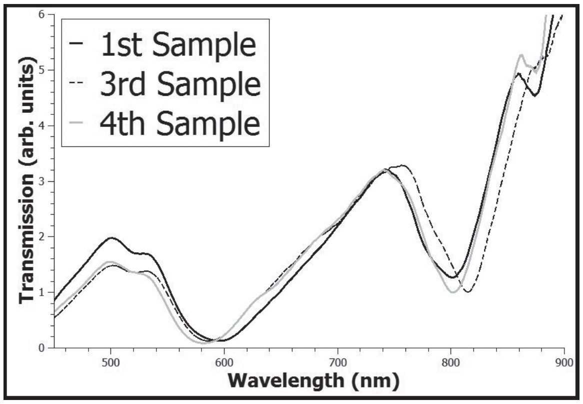

Figure 3: Transmission spectra from repeated template stripping.

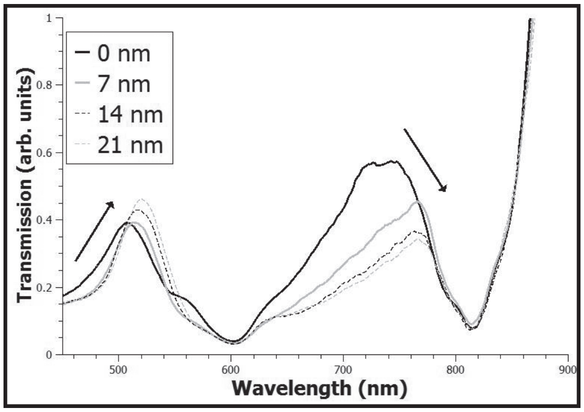

Figure 4: Transmission spectra of the same array as silicon dioxide thickness increases.