# Fabrication of Nanoholes Smaller than 100 Nanometers

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## Abstract:

**Nanohole arrays patterned in noble metal films can function as optical biosensors, because the extraordinary optical transmission through the nanoholes changes sharply with refractive index changes near the metal surface. Smaller nanoholes have sharper resonance peaks, making a better sensor. At the same time, smaller nanoholes have lower transmission efficiency. Template-stripped silver (Ag) nanohole arrays of varying diameters were used in combination with an ultra bright white light source to look at the difference in the optical response of nanoholes with diameters below 100 nm.**

## Experimental Procedure:

To achieve the resolutions needed for the nanohole arrays, electron-beam lithography was used to pattern thermally grown silicon dioxide ($SiO_2$) on a silicon wafer. The cost and speed of using electron-beam lithography limited the arrays size to be too small for practical biosensing applications. After the electron-beam resist was patterned and developed, a reactive ion etcher was used to etch through the $SiO_2$ layer. Images of the mold were taken to measure the hole size using a scanning electron microscope (SEM) before metal deposition, as shown in Figure 1. The $SiO_2$ layer was then used as a mask for etching into the Si wafer creating a mold for nanohole arrays; 100 nm of Ag was then deposited onto the mold using an electron-beam evaporator. The use of electron-beam deposition was important because the sides of the nanoholes in the silicon mold cannot have metal deposited on them otherwise they would close up and the nanoholes would not appear.

The deposited Ag was adhered to a glass slide with epoxy. The glass slide was then peeled off the silicon mold, creating template-stripped Ag nanohole arrays with ultra-smooth metallic surface. The Ag nanohole arrays were then imaged again with a SEM, as shown in Figure 2. The diameters of the nanohole arrays were found to be 53 and 105 nm.

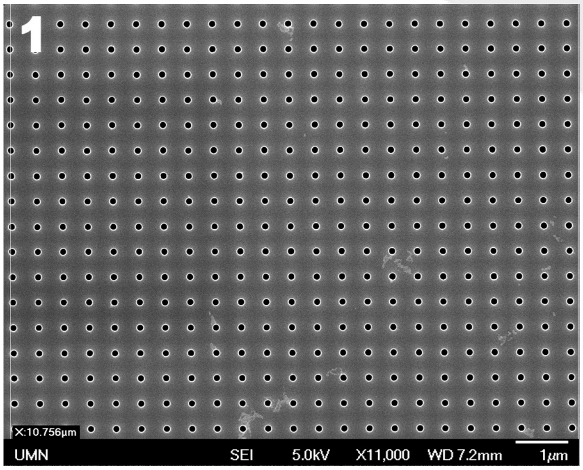
Using a broadband fiber-coupled, laser-driven light source with a 300 mm focal length imaging spectrometer, the spectrums emitted by both nanohole arrays were recorded as shown in Figure 3. The spectrums from the nanohole arrays were normalized with the spectrum of light transmitted through the glass slide. Mixtures of glycerol and water were used to measure the sensitivity of the nanohole arrays to the change to the refractive index on the exposed side of the array.

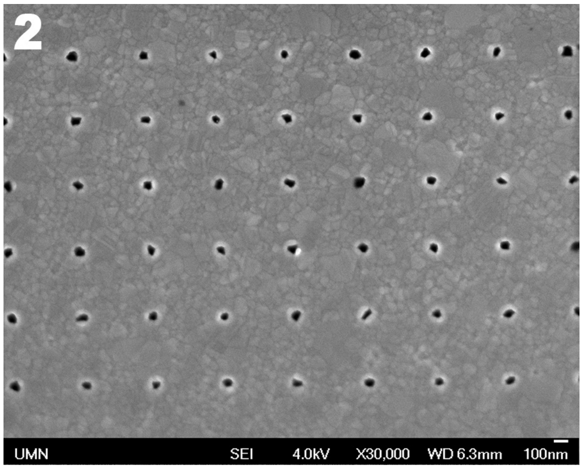
## Results and Discussion:

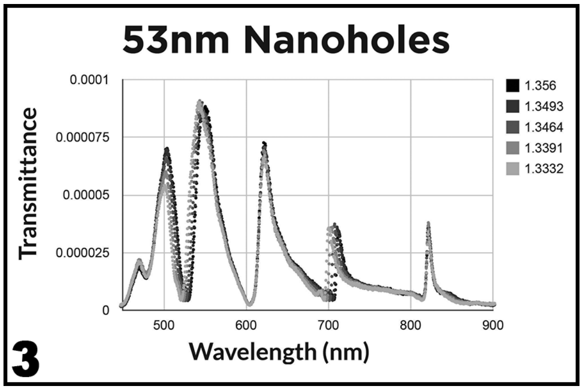
The percent of transmitted light dropped by half an order of magnitude for the 53 nm holes compared to the 105 nm holes. The spectrums then had an eighth order polynomial fitted to them. This equation was used to find the maximum value of the fourth peak and the spectral shift was plotted for each refractive index as shown in Figure 4. The sensitivity of the two arrays was 517.33 nm/RIU for the holes with a diameter of 53 nm and 505.89 nm/RIU for the holes with a diameter of 105 nm. The data in Figure 4 was expected to be linear and was with the exception of the fourth data point in both of the data sets. The cause behind this abnormality was not able to be rectified because of time constraints.

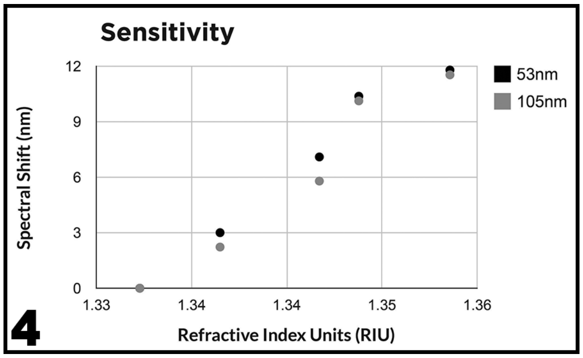
Full width at half maximums (FWHMs) were approximated to evaluate the sharpness of the fourth peaks. The FWHMs was about 10 nm for the holes with a diameter of 53 nm and about 16 nm for the holes with a diameter of 105 nm. Making nanohole arrays with a smaller hole size is an easy way to improve the sensitivity and sharpness of the resonant peaks. Making holes below 100 nm is only a useful technique if you have an ultra bright light source, such as the laser driven light source that was used in this experiment. This is because of the extremely low transmittance through these nanohole arrays.

The improved sensitivity and sharpness of holes below 100 nm can allow for biosensing experiments that need higher precision.









## Future Works:

The next step for nanohole arrays with diameters below 100 nm is to create them on a larger scale with methods such as nanoimprinting. This will allow the arrays can be used as an actual sensor. The uniformity of the nanoholes also increase by a considerable degree from the silicon molds to the template-stripped Ag nanohole arrays. Using electron beam lithography to make smaller initial holes while depositing less metal could improve these sensors as well.

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*Figure 1, top left: SEM image of bare silicon with 117 nm holes in it.*

*Figure 2, upper left: SEM images of template-stripped Ag with 53 nm holes in it created from the silicon mold with 117 nm holes.*

*Figure 3, lower left: Plot of the spectrum of light emitted from the 53 nm holes.*

*Figure 4, bottom left: Shows the change in the resonant frequency of the fourth peak against the change of the refractive index of the fluid.*