Using Near-Field Holography to Investigate Super Hydrophobic Surfaces

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Abstract:

Near-field holography is a photolithographic process that allows the transfer of nanoscale gratings from a phase mask into photoresist. In this project, the phase grating mask was transferred with a crossed double exposure on a substrate, forming an array of dots after development. Varying the ultraviolet exposure across the substrate created a gradient of printed dot sizes. Etching the dot array created a varying diameter pillar array which could then be tested for changes in hydrophobicity. The goal of the project was to utilize the near-field holography system so that surface wetting properties could be tested easily and cheaply. It was found that as the surface area on top of the pillars was increased the hydrophobicity of deionized water decreased exponentially from 180º. The resultant nanostructured surfaces produced a contact angle range from 130º to 155º.

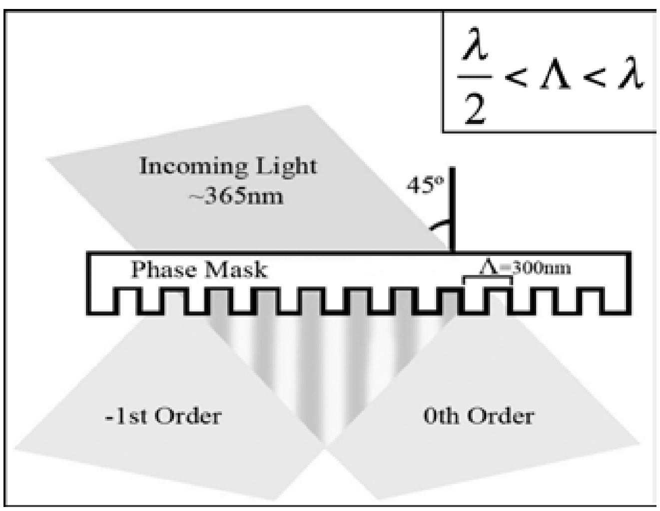

Figure 1: Schematic of NFH system.

Introduction:

The near-field holography system [1] is a tool that utilizes i-line ultraviolet light just like most photolithographic tools except for two notable differences. Instead of guiding the light into the mask at a normal, the light generated by a point source typically enters at an angle near 45º. The spatial coherence of the source makes this system less suitable for printing arbitrary features; instead it utilizes a unique phase grating mask with a period (Λ) that satisfies the condition shown in Figure 1. The incoming UV light diffracts only two orders, the -1st and 0th order, below the mask creating constructive and destructive interferences. The interference pattern, just below the mask, mimics the period of the phase mask which is then transferred into the photoactive material.

We utilized this tool by using a double exposure in which the wafer was rotated 90º to create an array of dots printed onto the substrate. Etching the substrate using the patterned photoresist films as a mask, we were able to create nanopillars ranging from 30 nm to 300 nm in height. This was important so that we could investigate the properties of nanopillars in relation to surface wetting characteristics. Improving the hydrophobicity would have applications to research in fields such as thermal cooling solutions and microfludic channel coatings [2].

Materials and Methods:

The pattern was etched into 2 inch wafers because the smaller chuck size permitted vacuum contact on the NFH system. Before depositing any of the photoactive materials onto the wafer, a 40 nm thermally grown silicon dioxide layer was implemented to act as a hard mask layer. To reduce standing waves in the vertical direction, an XHRi-16 antireflective coating (ARC) was spun onto the substrate. The ARC was thinned because the first absorbance minima occurred when light traveled 60 nm through the film. In our setup, the UV light entered the film at an angle, increasing the distance traveled. It was found that the wave traveled at a 26º angle from the normal, allowing us to decrease the thickness from 60 nm to 54 nm. The ARC was diluted to 25% creating a 53 nm film spun at 1500 rpm and baked at 175ºC.

Because the light source used was not a perfect point source, the interference patterns further below the mask became less well defined, presenting lower quality printing. This was solved by

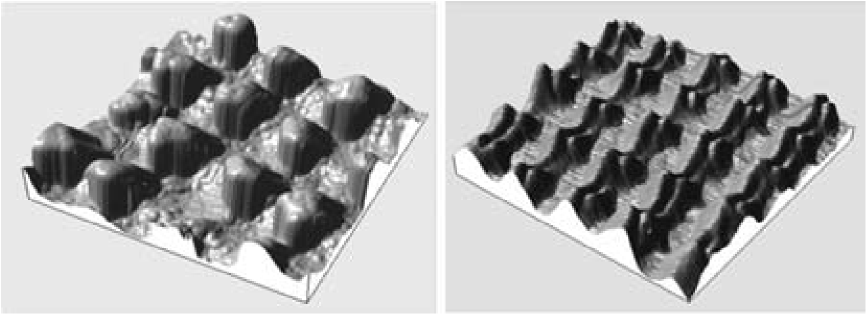

Figure 2: (L) Nanopillars created from Cl etch. (R) nanopillars created from SF_6 etch.

decreasing the thickness of the photoresist, Fujifilm OiR 620, so that the UV light interference pattern would not become incoherent before reaching the ARC layer. It was found that diluting the photoresist down to 25% could thin the film to 60 nm if spun at 6000 rpm. The optimum recipe included a softbake at 95ºC for 10-15 seconds, then exposing the wafer with a total of 29.25 ml/cm^2. After exposing the wafer, a hard bake, development in MF321 (0.21N tetramethyl ammonium hydroxide) and water rinse completed the process.

Etching was done in the Oxford 80 reactive ion etch system where, initially, an oxygen plasma was applied for 52 seconds as a clean up step. Next, a CHF_3/O_2 etch was implemented to transfer the pattern down into the oxide layer. Finally the pattern was etched into the silicon wafer using either an isotropic SF_6 etch or anisotropic chlorine etch. Creating vertical pillars was done by executing a chlorine etch and creating a pyramid type structure was done by executing an SF_6 etch (see Figure 2). The deposition of a hydrophobic monolayer, FOTS (fluoroctatrichlorosilane), onto the wafer completed the fabrication process.

Results and Conclusions:

The hydrophobicity was tested by placing a 2 μL drop of deionized water on the surface and using the VCA Optima tool to measure the contact angle with the surface. On a clean silicon control wafer, the hydrophobicity improved from a 38º contact angle to a 109º contact angle with the addition of FOTS. The observed results for the etched surfaces ranged between a 130º contact angle for the higher percentage surface area structures up to a 155º contact angle for the 20% surface area (see Figure 3). It was observed that as the percentage of surface area in contact with the liquid drop increased linearly, the surface contact angle would decrease exponentially over the range of surface areas from 20% to 100%.

We therefore conclude that NFH is an effective method to achieve nanostructured surfaces capable of producing superhydrophobicity.

Acknowledgements:

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References:

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[2] Tom N. Krupenkin, J. Ashley Taylor, Tobias M. Schneider, and Shu Yang, "From Rolling Ball to Complete Wetting: The Dynamic Tuning of Liquids on Nanostructured Surfaces," Langmuir 2004, 20, 3824-3827.

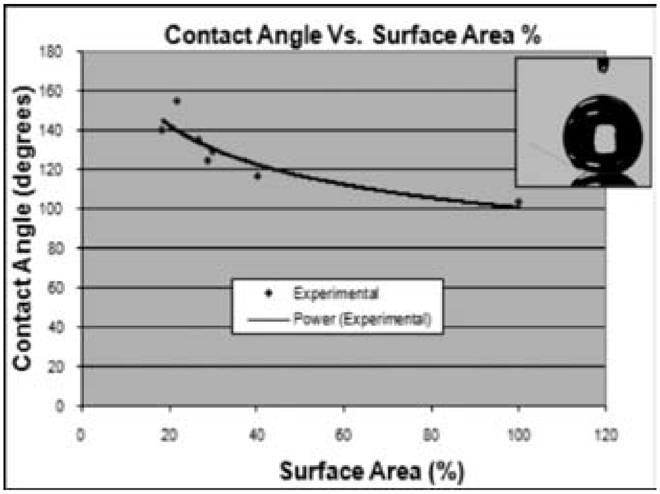

Figure: Dependence of contact angle on surface area of pillar structures for 2 µl water droplet. Inset shows droplet on 20% surface area pillars.