Microsensors with Nanostructured Surfaces Fabricated by 3D Lithography

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Abstract and Introduction:

At the present time, chemical sensors are prevalent devices that provide information about pollutants in the air and water. Microelectromechanical systems (MEMS) are one of the popular platforms for portable and low-power chemical sensors. The MEMS-based chemical sensor used in this research consists of a polymer-coated, microfabricated mass-sensitive resonant cantilever for gas-phase chemical detection of volatile organic compounds (VOCs). While a thick polymer sensing film on top of the microfabricated sensor improves sensor sensitivity, it also slows down the sensor response, as analyte needs to diffuse into the relatively thick sensing film.

Method:

The main goal of the project is to modify the surfaces of the (silicon-based) microsensors with 3D-printed nanoscale features to ultimately have sensing films that combine high sensitivity and short response time. Thereby, high-surface area, nano-structured sensing films are a way to improve response times while still providing sufficient sensor sensitivity. The 3D nanoscale features are achieved using the Nanoscribe Photonic Professional GT, a commercial 3D lithography system with sub-micrometer resolution based on 2-photon polymerization (see Figure 1 for schematic of the printing process).

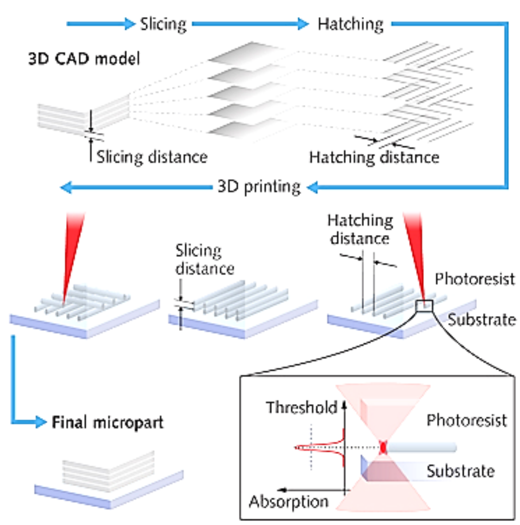
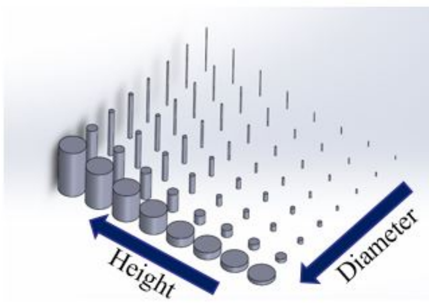


Figure 1: Printing process of the Nanoscribe Photonic Professional GT [1].

Fabrication:

The optimal process parameters were identified for an array of nano-cylindrical pillars, such as the height, diameter, laser power, scan speed, hatching and slicing pitch, as well as the photoresist developing procedure. For this process, the 63x objective was used since it provides the highest resolution. IP-Dip, a specially designed photoresist for Nanoscribe's novel Dipin Laser Lithography (DiLL), was used as immersion and photosensitive material at the same time by dipping the microscope objective into this liquid photoresist. Due to its refractive index matched to the focusing optics, IP-Dip guaranteed ideal focusing and hence highest resolution for the DiLL process.



Height (nm)	Diameter (nm)							
	100	200	300	400	800	1000	2000	5000
800								
1200								
1600								
2000								
4000								
6000								
8000								
10000								

Figure 2: (Left) CAD design of the nano-cylindrical pillars. (Right) Table to represent each pillars.

Figure 2 shows the CAD design for the array of nano-cylindrical pillars with the chosen pillar diameter and height highlighted in the adjacent table. The processing variables, scan speed and laser power, were varied around the process guideline settings recommended for the Nanoscribe system. These two variables were selected because they are the primary factors impacting dose applied to the resist. Subsequently, printed arrays were carefully analyzed by optical and electron microscopy to identify the optimal process conditions (see Figure 3).

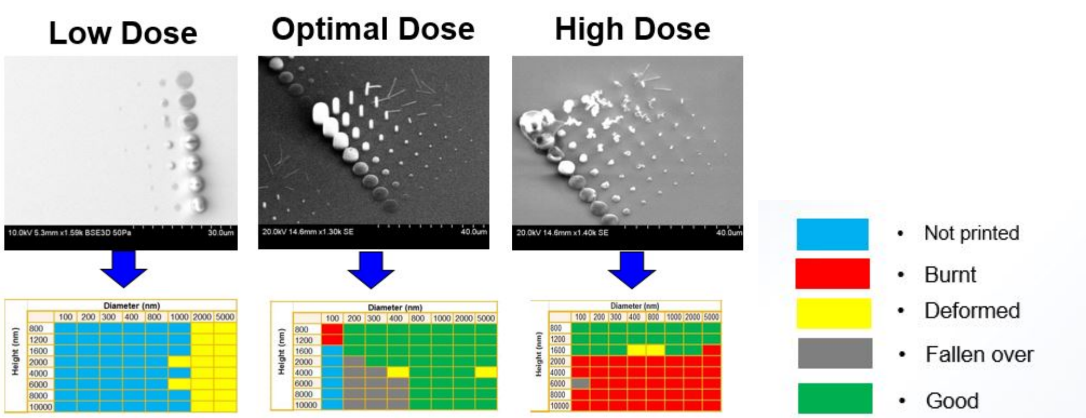


Figure 3: (Top) SEM images of different printing tests for different exposure doses. (Bottom) Color key developed to analyze printing results.

In attempt to characterize the parameters, a parameter sweep was performed to identify the optimal processing method. Figure 4 summarizes the characterization results and the optimal process parameters after printing 25 different 8 X 8 arrays of pillars.

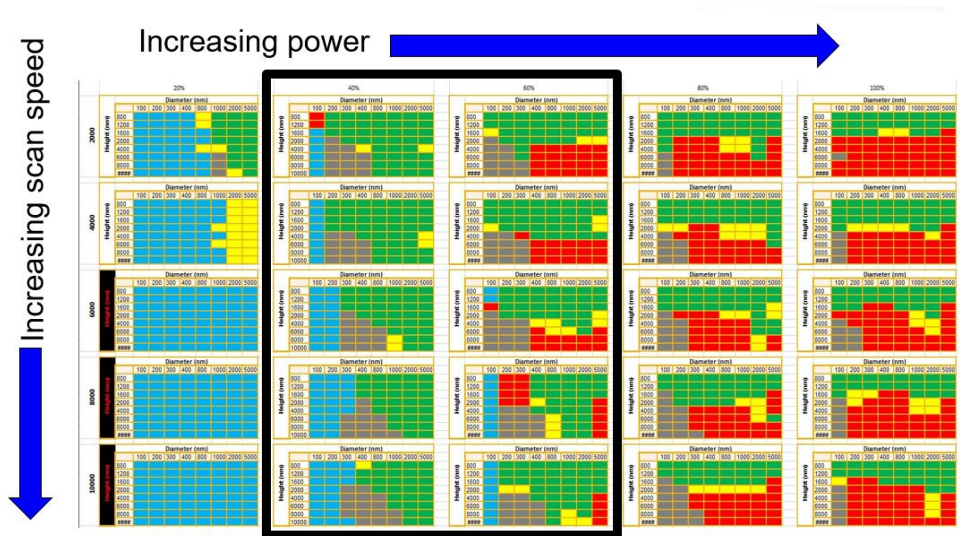


Figure 4: Characterization results for 25 printed pillar arrays with different scan speed and laser power; Colors have been assigned (Figure 3) based on their resultant structural integrity. The optimal processing conditions are highlighted by the black box.

Effect of Capillary Forces on Pillar Array:

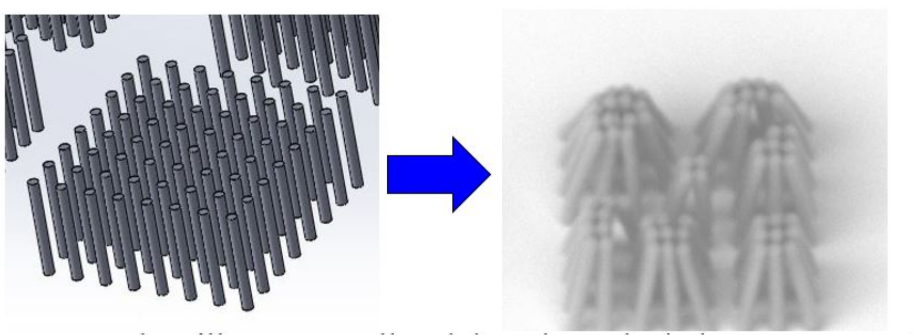


Figure 5: (Left) CAD design of 8 X 8 arrays of pillars. (Right) SEM image of collapsed pillars.

Because the pillars are small and densely packed, the structures suffer from insufficient mechanical stability against capillary forces (Figure 5, right) which mainly arise in the fabrication process during the evaporation of the developer and rinsing liquids. To resolve the problem, stiffening bars were added across the top of the pillar arrays to provide additional stabilization (Figure 6).

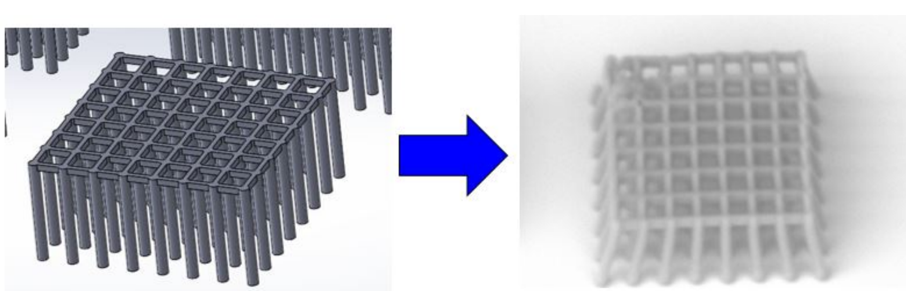


Figure 6: (Left) CAD design of 8 X 8 arrays of pillars. (Right) SEM image of pillars with support bars.

Results:

Using the best parameters identified during all of the tests made on bare silicon wafers, the 3D nano-cylindrical pillars were successfully printed directly onto already fabricated hammerhead micro-sensors (Figure 7).

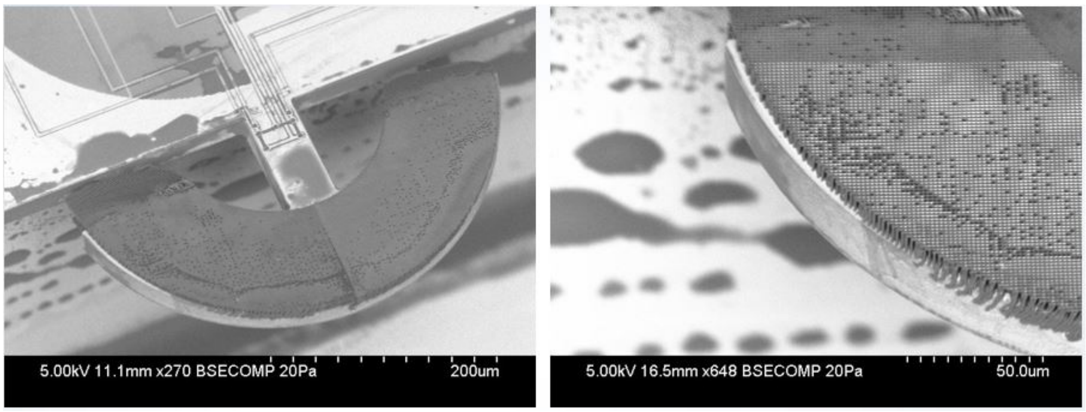


Figure 7: Nanopillar array printed on fabricated hammerhead resonator.

Conclusion and Future work:

The optimal parameters with good aspect ratio are: Height = 8000nm, Diameter = 800nm, Slicing Pitch = 1600nm, Laser Power = 40%-60% and Scan Speed = 4000-6000 µm/s. In future work, after actuating the silicon-based hammerhead resonators, the pillars will be replaced by a different material which can absorb the target gas if the current pillar resist material is unable to do so. Additionally, different structures with larger surface to volume ratio will be designed to increase the sensor sensitivity.

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References:

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