

Applications of Nanofluidic Devices in Chemistry

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Abstract:

Nanofluidic channels have many uses in the chemical field, including site specific combinatorial synthesis, macro- and bio-molecular analysis, and other “lab on a chip” applications. The objective of this research is to fabricate arrays of nanochannels designed to facilitate the transport of aqueous ionic solutions by adapting a form of the nanoimprinting technique. Nanoimprinting relies on deforming the resist material under elevated pressure and, typically, temperature to replicate a mold surface.

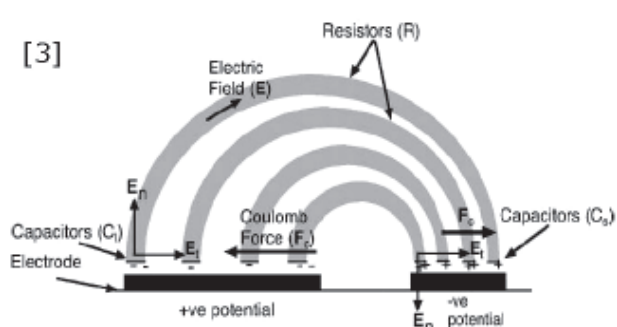
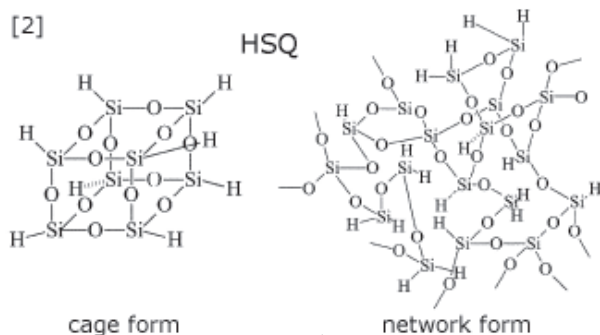
Since the contribution of capillary force is insufficient for extended channel lengths, the device is designed to employ the principle of asymmetric AC-field electroosmosis to drive fluid flow. The fabrication also incorporates the non-traditional resist of hydrogen silsesquioxane (HSQ). This material was selected due to its resulting hydrophilic surface property and unique ability to be imprinted at room temperature. This work is dedicated to developing and optimizing the processing conditions for fabricating arrays of nanochannels in HSQ capable of active pumping.

Introduction:

Scaling down of fluidic channel dimensions and the ability to construct fluidic devices in quantity can lead to new types of analyses and applications. Many of their exclusive uses stem from the high amount of surface interaction per unit volume of the mobile medium. In some cases confinement on the molecular level can be achieved. The challenge of this study lies in the fabrication and adaptation of established processes to an actively pumped device consisting of a regular array of nanofluidic channels. The resulting design and process employs two key principles: nanoimprint lithography (NIL) and asymmetric AC-field electroosmosis.

Although embossing has been around for ages, the practice of nanoimprinting is regarded as a promising technique for reproducing designs on the nanometer level. The primary motivation for NIL is the creation of smaller feature sizes on semiconductor chips. Much like traditional photolithography, it is a high throughput method of replicating structures once an initial pattern is established. Nanoimprint lithography is, however, a mechanical means of patterning. This gives it several distinct advantages: it can be accomplished without highly specialized, expensive equipment in a relatively short amount of time and it can overcome the limitations of light wavelengths to reproduce extremely small features [1]. NIL methods are applied to creating the channel structures from resist material in this project.

Though highly unconventional for this fabrication method, hydrogen silsesquioxane (HSQ) was selected as the deformed resist for properties favorable to this particular application. Hydrogen silsesquioxane is an inorganic polymer with a repeating unit of $[\text{HSiO}_3/2]$, primarily used for its low dielectric constant and, more recently, advantageous behavior as a resist for electron beam lithography. The main issue with following traditional NIL procedures with polymeric materials as the resist material is that the resulting surfaces are often hydrophobic. Structures in HSQ resemble hydrophilic silica surfaces on the molecular level. Lab observations suggest the retention of solvent in HSQ solid is responsible for its ability to be imprinted during a temporary viscous state. As it turns out, this permits replication to be achieved at room temperature, a very unusual trait for the nanoimprint technique. This material is also capable of redistributing and cross-linking from primarily the cage form to the more mechanically stable network form at elevated temperature [2].



Since the device is intended to transport aqueous solutions, it can be designed to take advantage of electro-osmosis to implement active pumping. First experimentally demonstrated by Brown, Smith, and Rennie on the micron level in the configuration applied here, asymmetric AC-field electro-osmosis induces a double layer of ionic charges to form along the electrode surfaces and relies on Coulombic forces on ions to move the bulk of water [3]. The prevention of gas formation from the electrolysis of water necessitates applying low AC potential of fairly high frequency, and electrode size asymmetry accounts for net fluid flow. Fabrication procedures were developed to make use of established processes, including electron beam lithography, for patterning interdigitated parallel electrode arrays on silica substrates.

Procedure:

Approximately 300 nm of HSQ was spin-coated on a substrate, the preparation of which will be described later in this section, using a 12% by weight solution in methyl isobutyl ketone (MIBK). This film could be verified with the following metrology tools available in the lab, used during spin characterization: DekTak 6M stylus profiler, AutoEL ellipsometer, and Nanospec 6100 optical instrument.

The sample was immediately imprinted on an in house apparatus with a uniform gas pressure of 1000 psi at 25°C for 1 minute against a surfactant coated silicon mold and later heated slightly at 80°C to expel any remaining solvent. An anisotropic CHF₃ / CF₄ reactive ion etch (RIE) may be used to remove residuals. Replication was evaluated by scanning electron microscopy on a FEI Nova Nanolab.

Sealing of the channels can be accomplished with a slight modification of the nanoimprint process. The replicated diffraction grating in HSQ acts as a mold for a low imprint depth into about 200 nm of HSQ deposited on a surfactant coated silicon wafer under a pressure of 600 psi.

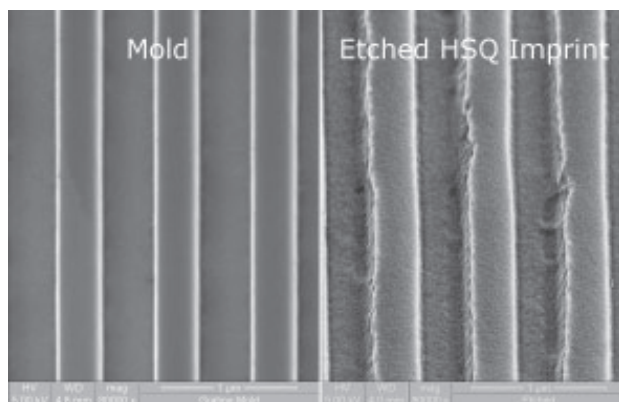


Figure 3

The initial substrate would be prepared by evaporating 50 Å Ti / 2000 Å Au over a resist on silica substrate that would have undergone electron beam lithography of the CAD electrode design shown in Figure 4 and chemically lifting off the unexposed regions.

Results and Conclusion:

The fabrication proceeded despite forgoing the substrate preparation with electrodes described in the previous section due to an extended e-beam equipment outage.

Unfortunately, the nanochannels were not tested due to time constraints and other factors, mainly involving the development of a procedure by which HSQ could be reliably imprinted, which in itself was a valuable accomplishment. However, realization of the total design would likely be relatively fault tolerant and efficient, considering the choices made.

Future Work:

Agreement among the literature studied regarding electroosmosis in microfluidics provides evidence that fluid velocity and, thus, effectiveness of such devices increases as channel dimensions decrease. The progress of work done here, therefore, has much promise in future applications.

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References:

- [1] S. Y. Chou, P. R. Krauss, W. Zhang, L. Guo, and L. Zuang: J. Vac. Sci. Technol. B 15(6), 2897 (1997).
- [2] C. Yang and W. Chen: J. Mater. Chem. 12, 1138 (2002).
- [3] A. B. D. Brown, C. G. Smith, and A. R. Rennie: Phys. Rev. E 63, 4129 (1996).

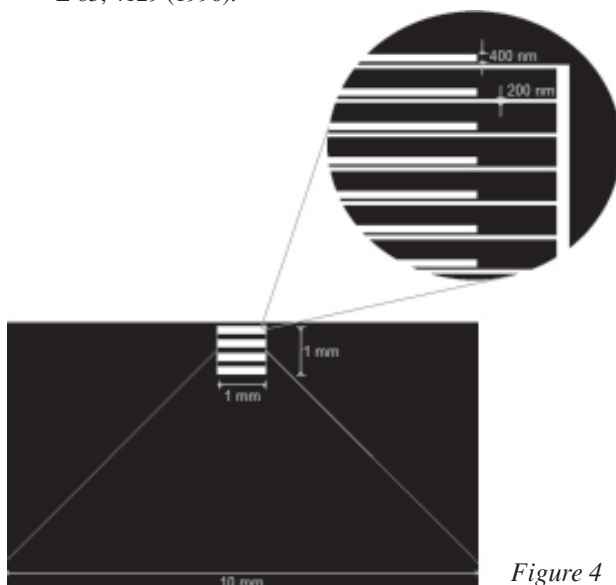


Figure 4