Characterization of Nanoimprinting HSQ Material

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Abstract:

Nanoimprinting is a technique for creating nanostructures based upon mechanical embossing. This process uses a mold with nanoscale surface relief structures to press into a polymer layer cast on a substrate. Under high pressures, the polymer will be shaped by the mold.

We will be looking at the rheological behavior, which determines how the polymer will deform under varying pressures and temperatures. We will look specifically at hydrogen silsesquioxane (HSQ) and find how it will behave in the imprinting process. Determining whether this polymer has a Newtonian (or viscosity independent of shear stress), or non-Newtonian flow will allow us to better understand the nanoimprinting process. Understanding how time and pressure affect the depth of an imprint will make it possible to precisely engineer devices using this method.

Introduction:

Nanoimprinting makes use of a hard mold containing nanoscale features as a pattern. That pattern is then replicated by embossing it into a polymer material found on a substrate. The process takes place under controlled temperature and pressure conditions. This mechanical process of deforming the polymer material does not have the resolution limiting factors common in the more traditional lithography approaches.

One of the more critical parts of this process is the specific polymer material. This material must have properties of interest to the project at hand, whether electrical circuits or nanofluidic channels, and more critically, the material must be amenable to the deformation process required of nanoimprinting.

Hydrogen silsesquioxane (HSQ) is one such material that has properties which make it of strong interest in the nanoimprinting field. HSQ, in contrast to many other polymers, can be imprinted at room temperature. The material also possesses a low dielectric constant. This makes it an ideal material for providing insulation within an electrical circuit. Finally, it also is hydrophilic, which means that it has a strong affinity to water, which makes it ideal for constructing nanofluidic channels. These properties make it important to study how HSQ behaves in the imprinting process and characterize it so as to make the material useful for mass production.

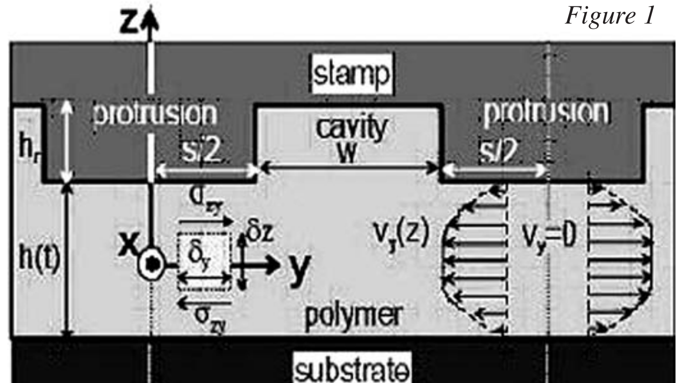
This characterization requires that we understand how HSQ will deform under stress—the science of rheology. Shear is a deformation in which both elasticity, which is reversible, and flow, which is irreversible, deformations take place. The shear rate (γ) is defined as the change in velocity of flow at which one layer of fluid passes over an adjacent layer. To simplify our model, we will treat the polymer as an ideal viscous fluid which will exhibit only deformation of flow and not those associated with that of elasticity. The stress (σ) is the force per unit area. The viscosity (η) of an ideal viscous body is defined as the stress divided by the shear rate, $\eta = \sigma/\gamma$.

Fluids that exhibit a constant viscosity are known as Newtonian fluids. The plot of the stress vs. shear rate would reveal a straight line with the slope being the viscosity. An example of a Newtonian fluid would be air or water, their viscosity remains constant regardless of the force, and thus stress, exerted. There also exist non-Newtonian fluids whose viscosity is not constant.

Theory:

Figure 1 shows how the polymer will deform under stress exerted downward. We see that the greatest

Figure 1



velocity change will take place underneath the protrusion. By modeling the polymer as an ideal fluid, we can derive equations for how the imprint depth will behave as a function of pressure and time. We find that the imprint depth will be proportional to the pressure to the -k/(k+1) power. Imprint depth is proportional to time to the -1/(k+1) power. Here k is a property of the material.

Procedure:

We used a mold with a grating pattern consisting of a large set of parallel straight-line pro-trusions. From a cross section they can be considered a square wave with an amplitude or height of 0.5 μm and a period of 700 nm. The width s of the protrusion and valley would then be 350 nm. The polymer HSQ was first spun on to a silicon substrate at 1500 rpm for 10 seconds after which the mold was immediately applied. Pressure was applied 105s after the spinning was completed. The sample was then imprinted under a variety of time and pressure combinations, and the imprint depth of the sample was measured using SEM.

Results:

We plotted the imprint depth vs. pressure for a time of 10 minutes and suggested a possible fit in the dotted line of Figure 2. The solid line represents what a Newtonian fluid would act like.

In Figure 3, imprint depth vs. time is plotted for a pressure of 850 PSI in the dotted line with the Newtonian as the solid line.

We also found that there was variation in the data depending on the day of the imprinting, so Figure 4 shows depth vs. time at 750 PSI.

Conclusion:

According to both Newtonian and non-Newtonian theory, the imprint depth vs. pressure graph (Figure 2) should resemble a Newtonian curve if k is small. However, we see a difference in the imprint depth vs. time graph (Figure 3), as our data is concave upward while the Newtonian fluid is concave downward.

Figure 4 shows that the imprint depth decreases with time, an impossibility according to both ideal Newtonian and non-Newtonian flow models. Such a deviation forces the conclusion that there were other unaccounted for variables. Several possibilities exist to account for this behavior. One such possibility is a change in the humidity which could easily affect how the HSQ deforms. Also our theory ignored elasticity. If we consider a visco-elastic model, the data would be a better fit. That would require plotting the speed at which the stress is applied.

We can conclude from Figure 3 that HSQ behaves similar to an ideal non-Newtonian fluid, however other factors are involved which will require additional research.

Acknowledgements:

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References:

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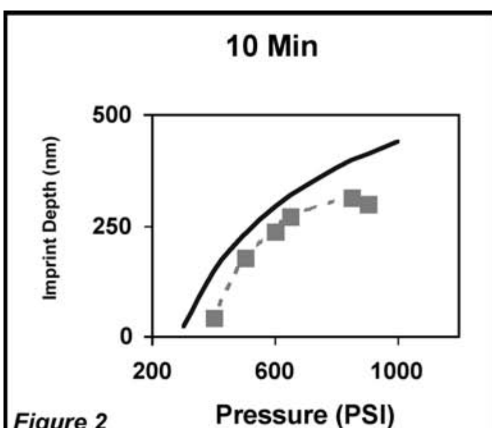

Figure 2

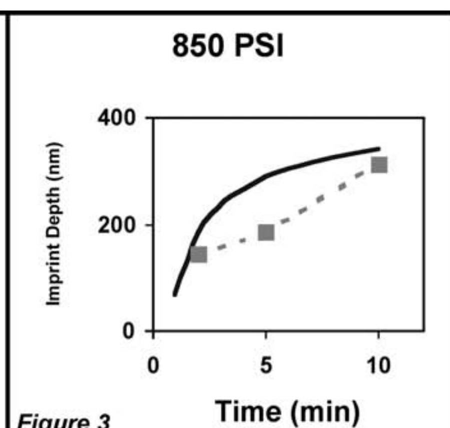

Figure 3

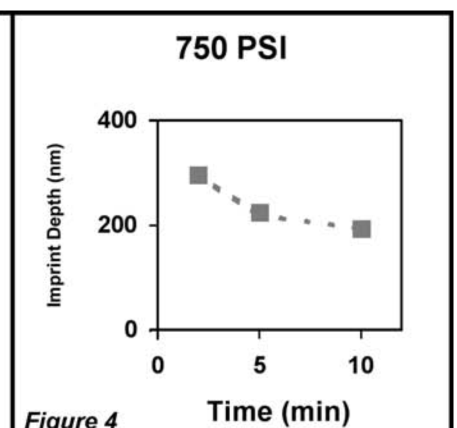

Figure 4