New Materials and Applications of Nanoimprint Technology

Steven Froelich, Chemical Engineering, Villanova University

NNIN REU Site: Solid State Electronics Laboratory, University of Michigan, Ann Arbor

Principal Investigator: L. Jay Guo, Electrical Engineering, University of Michigan

Mentor: Philip Choi, Electrical Engineering, University of Michigan

Contact: steven.froelich@villanova.edu, guo@eecs.umich.edu

Introduction:

Nanoimprinting is a type of lithographic process that provides a simple and efficient way of patterning nanostructures. The primary motivation for accurate and efficient nanolithography is the ability to create smaller functional device structures, such as those found in nanoscale transistors. Key to the commercial success of these smaller device structures is low cost and high throughput manufacturing capabilities.

In nanoimprint lithography, a rigid mold containing nanoscale features is embossed into a polymer material that has been cast on a wafer substrate. The polymer layer thickness is such that under prescribed temperature and pressure, a thin viscous polymer fluid will form between the mold's protrusions and the substrate surface. This acts as a 'soft cushion' which protects the nanofeatures on the mold. However, as a result, the existence of a residual resist layer is present in the recessed regions of the mold. This must be removed by a separate plasma-based anisotropic etching step before pattern definition can be completed.

Nanoimprint lithography presents new challenges for further optimization of the technology. There is a demand for new materials with properties more appropriate for the particular requirements of nanoimprinting. One critical requirement is to provide mold releasing properties during the de-molding process while not compromising the adhesion of the mold to the substrate. When imprinting high density patterns, the imprinted polymer tends to adhere to the mold, creating pattern defects that are not acceptable for many applications. Therefore, a material with low surface energy is desirable. Another critical property of nanoimprint resist materials is that they must have high etching resistance to allow pattern definition to be completed.

The focus of this project is to analyze a new graft copolymer material. By investigating the spin coating rate, the plasma-based anisotropic etching characteristics, and the imprinting conditions, the material was tested for properties suitable for the imprint application. Comparing these results with other industry standard thermoplastics, this material offers some unique properties for high-throughput patterning of nanostructures.

Procedure:

A Polydimethylsiloxane (PDMS) based graft copolymer was obtained from Dow Corning. A 10% weight solution of the graft copolymer was prepared by dissolving 10 grams of the graft copolymer in 90 grams (92.88 mL) of 2-[1-methoxy]propyl acetate (PGMEA) an organic solvent. The solution was filtered using a 2 μm porous capillary filter. The solution was kept in a sealed glass container and stored in a dark cabinet. Once synthesis of the solution was completed, the spin coating pattern was characterized.

The spin pattern was determined by first applying a thin layer of solution to a silicon wafer. Then the wafer was spun at a speed between 1 and 5 thousand rpm for 30 seconds. While spinning, the solvent would quickly evaporate and a thin uniform film would form on the silicon wafer. Subsequently, the sample would then be placed on a hot plate at 80°C for 2 minutes so that any remain solvent would evaporate.

Next, the thickness of the polymer film was measured using elipsometry. The thickness of the polymer film layer was found to decrease with an increase of the speed of the spin-coating (Figure 1).

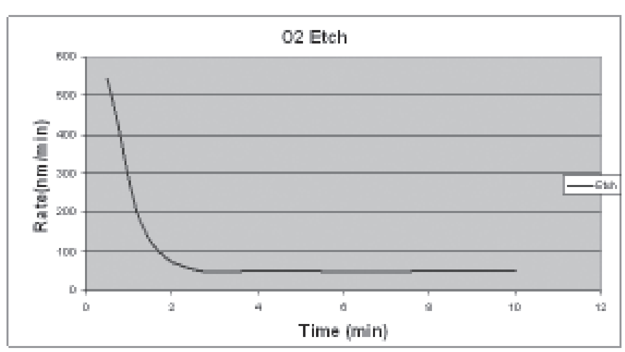

Figure 1

After the spin pattern was characterized, the graft copolymer could be tested for imprint-ability. First, the mold was treated with a perfluorosilane surfactant to form networks of covalent siloxane bonds, which make the surfactant coating layer chemically and thermally stable. This reduces the tendency of adhesion of the imprinted polymer to the mold. Then, a silicon wafer was prepared by first spin coating a thin layer of Hexamethyldisiloxane (HMDS) to increase adhesion between the polymer layer and the substrate. Next a 500 nm thick layer of the graft copolymer was prepared. After baking on a hot plate at 80°C for 2 minutes, the sample was ready to be imprinted.

The first objective was to characterize how effective the imprinting process is under different temperatures. Based on the glass transition temperature, a range between 150°C and 90°C was selected. Then samples were imprinted at 10°C intervals at 600 psi for 5 minutes, then allowed to cool below the glass transition temperature. These samples were then examined for mold separation, resolution and pattern transfer. The material imprinted optimally at 130°C (see Figure 2).

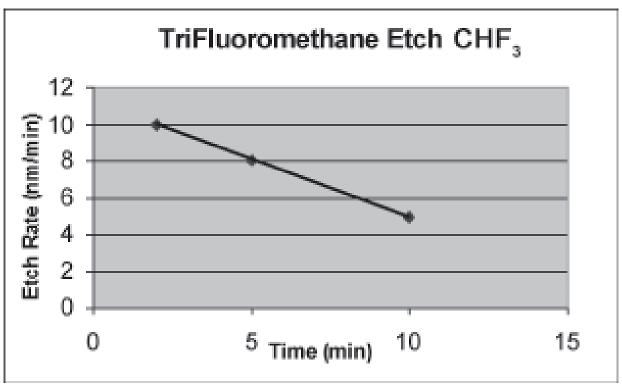

Figure 2

Finally, the plasma-based anisotropic etching character of the graft copolymer was studied. First, a sample was prepared by spin coating a selected thickness. The sample was then etched under prescribed conditions. The first objective was to separately determine the etching character of Oxygen and CHF_3 TriFluoromethane etching. The power was set to 100 Watts and the pressure was set to 200 mT. The Oxygen flow rate was set to 32 sccm and the TriFluoromethane flow rate was 25 sccm. It was found that the Oxygen etch rate stayed approximately 50 nm/min at etch times above 2 minutes (Figure 2). The TriFluoromethane etch rate was found to linearly decrease with time (see Figure 3).

Once the etching characters of both Oxygen and TriFluoromethane were found, both were used with proportional flow rates according to their etch rates. This combination optimized etching of both components while maintaining the fidelity of the pattern. However, later etches were conducted under a pressure of 20 mT in order to better preserve the pattern transfer.

Conclusions:

Imprint lithography duplicates the surface relief patterns by mechanical embossing. Based on this principle, nanoimprint techniques can achieve pattern resolutions beyond the limitations of other conventional techniques. The focus of this experiment was to analyze a new graft copolymer material. Graft copolymer materials have dual surface properties through microphase segregation that can be exploited. This graft copolymer's low imprint temperature and pressure, high resolution, high etching resistance, and low surface energy, offer some unique properties for high-throughput patterning of nanostructures.

Acknowledgments:

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References:

[1] L. J. Guo, "Topical Review: Recent progress in nanoimprint technology and its applications,"J. Phys. D: Appl. Phys, Vol. 37 (11), pp. R123-R141, 2004.

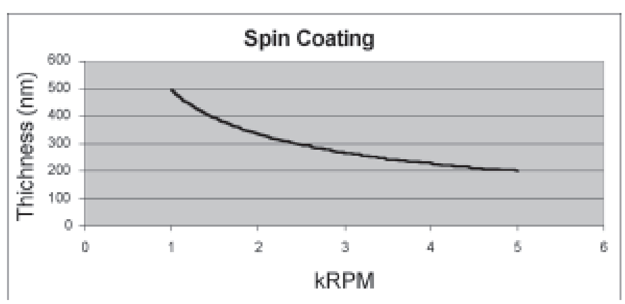

Figure 3