Bi-Layer Lithography Using Nanoimprinting

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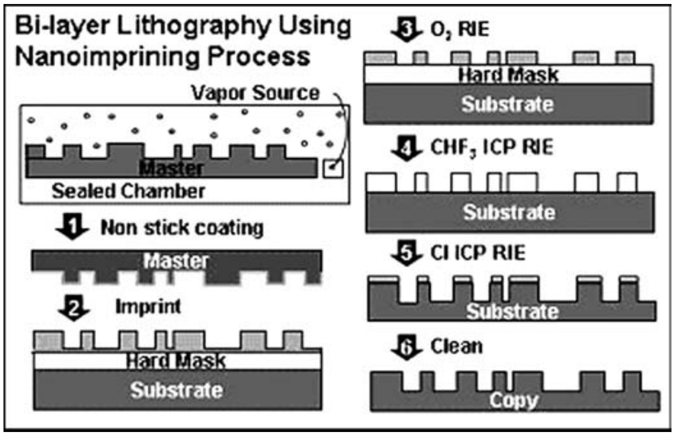
Abstract:

Nanoimprinting is a way to replicate nanoscale features of 10 nm or less in size from one surface into another. To reproduce nanoscale features, traditional techniques such as electron-beam lithography can cost thousands of dollars per wafer and can be time consuming. With nanoimprinting, only a master, using traditional fabrication techniques, needs to be made and it can be stamped repeatedly into polymer-coated substrates. These patterns can then be transferred to the substrates by reactive ion etching techniques.

In this work, the bi-layer process of imprinting into a polymer and transferring the pattern into the substrate by chlorine-based reactive ion etching is developed and described.

Introduction:

Nanoimprinting is a low cost, fast, and relatively easy method of replicating nano- and micro-scale features. With a single master, many negative molds of the stamp can be reproduced over large surfaces. This technique has many applications in industry and research, such as nano optical coating, greater memory capacity, nanofluidic channels and high-resolution OLED pixels. These applications require a deep pattern transfer into a substrate from the imprinted polymer. Chlorine-based reactive ion etching (RIE) is often used to etch nano-scale feature dimensions deeply into silicon and many compound semiconductor materials, such as GaAs and GaN. Since chlorine-based RIE often attacks polymers at similar or higher rates than the substrates, an intermediate hard mask, such as SiO_2, is desired to provide a better etch mask for the substrate. Therefore, a bi-layer process was developed that would effectively transfer a shallow pattern deeply into a substrate.



This paper will look at and address the three main areas of the process: imprint polymers, pattern transfer to the hard mask, and silicon etch into the substrate.

Experimental Procedure:

A master stamp was made by electron-beam lithography and dry etched into a Si substrate. In our case, only a small amount of the overall stamp area was patterned, featuring a repetitive square field of channels and holes ranging in size from 80-1000 nm in width, and 100 nm in depth. The master was chemically cleaned and O_2 plasma was used to remove any particle matter left on the surface. After cleaning, perfluroctlytrichlorosilane, a self-assembled monolayer of fluorocarbon monomers, was vapor coated in a clean dry environment to give the master a non-stick surface (Figure 1, step 1).

The master was then used to imprint a prepared bi-layer sample, consisting of a polymer and a hard mask layer on top of a Si substrate. The hard mask material, an SiO_2 that was deposited by Plasma Enhance Chemical Vapor Deposition (PECVD), was 200 nm thick. The imprint polymer, a thermal-plastic resist, NX-1010 by Nanonex Corp., was spin-coated to 200 nm in thickness and baked to drive out solvents. The sample was then imprinted by heating up the polymer and uniformly pressing the treated master into the mold for a set time. This caused the viscous polymer film to compress and deform as the polymer flowed into the master mold (Figure 1, step 2). After imprinting, the pattern was then transferred into the hard mask. Prior to the pattern transfer, the thin residual layer was removed by O_2 RIE (Figure 1, step 3). It was removed to allow for a window in the polymer film for the fluorine-based etch to penetrate into the hard mask.

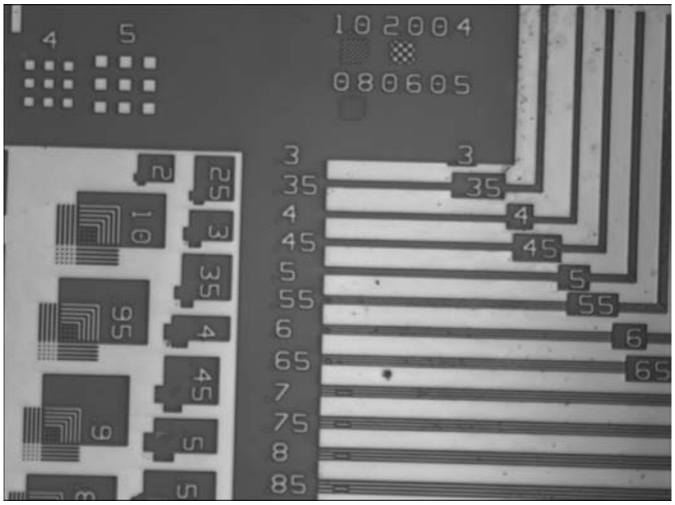


Figure 2: Optical image of full polymer flow.

Next, a CHF_3 inductively coupled plasma (ICP) RIE transferred the pattern through the hard mask (Figure 1, step 4). Finally, a Cl_2 ICP RIE etch was used to etch deeply into the substrate (Figure 1, step 5). Cl_2 was used instead of CHF_3 because of its isotropic etch properties. Any leftover SiO_2 on the surface was then removed through a wet chemical process (Figure 1, step 6).

Results and Conclusions:

Three polymers, ZEP-540A, NX-1010, and FOX-14, were tested to see which polymer had the best characteristics for imprinting. NX-1010 gave the best results because of its lower imprint conditions and smaller number of imprint defects. For NX-1010 on PECVD SiO_2 and Si substrate, the minimum imprint parameters for the polymer flow into all regions of the mold were 300 psi at 130°C for 1 minute (Figure 2 shows a copy with complete polymer flow into the master mold). Etch rates for the NX-1010 resist layer, the SiO_2 layer, and the Si substrate were determined to be 100 nm/min, 200 nm/min, and 200 nm/min for O_2 RIE, CHF_3 and Cl_2 ICP RIE, respectfully.

Using these parameters, three samples went through the complete process. Due to overetching of the NX-1010 resist in oxygen, we were left with ~ 50 nm of polymer mask. Using this very thin 50 nm polymer mask and the bi-layer process, we were able to etch over 350 nm deep lines and over 400 nm deep holes into the silicon substrate, giving net etch ratios of ~ 7:1 and 8:1 (Figure 3). This successfully demonstrated a good aspect ratio which allows for deep etches into the substrate.

Future work could include further enhancing the etch ratio, improving Cl_2 etching to reduce trenching, edge wall slope, and determining the imprint parameters for different types of master patterns.

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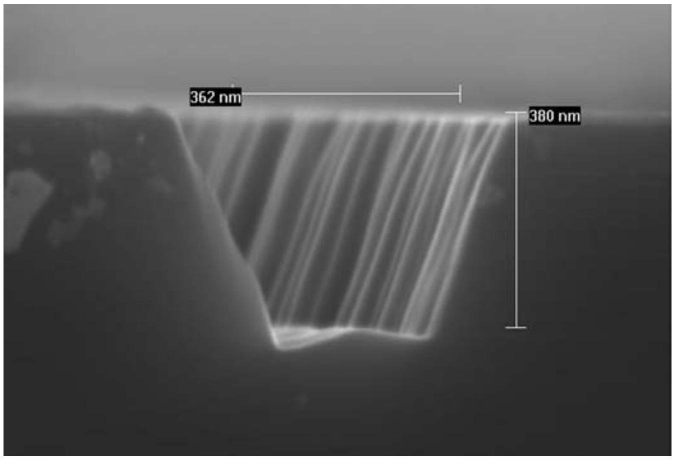

Figure 3: SEM of the ICP RIE Cl_2 etch of a line.