Sub-50 nm scratch-proof DLC molds for reversal nanoimprint lithography

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As a candidate for the next generation lithography technology, nanoimprint lithography (NIL) has demonstrated its strong potential to fabricate high resolution (sub-10 nm) patterns with high throughput and low cost. One of its challenges for the acceptance of the industry is related to the mold life time that significantly affects cost of ownership and manufacturing reproducibility. Nowadays, most often used Si or glass molds that are very expensive can be damaged after certain imprint cycles due to the physical contact with the embossed materials.

In our previous research work,[1] diamond-like carbon (DLC) films had been proved as an good alternative mold material for better durability and robust surface energy. Here we demonstrate the fabrication of sub-50 nm DLC molds and testing them on UV and reversal nanoimprint in SU-8. We observed a problem of mold bending in conventional nanoimprint if "female" mold (where nanostructures are concaves on the surface) is used. This problem can result in non-uniform imprinted structures, particularly non-uniform residue layer. As shown in Fig. 1a, when a "thin" female mold is used to imprint on the resist, the imprint pressure will force the mold to bend at the edges of the patterned areas, instead of pushing polymer off the wafers, which may occur if the mold is considerable thick and resist has very low viscosity. This phenomenon was studied in PMMA with two different thicknesses (~400 and 800 nm). After the conventional imprint, polymer thickness across the edges of patterned areas was measured using a profiler. The thickness variation was observed to be about 200 nm for the 780 nm PMMA sample (Fig.1b) and less than 90 nm for the 400 nm one (Fig.1c), which indicates the bending of the mold around the edges of patterns. This variation is about 25% of the total PMMA thickness.

Reversal nanoimprint can alleviate this mold-bending problem since spincoating resist on the mold will result in complete filling of the concaves on the mold and also forming a uniform residue layer (right figure in Fig. 1a). However for reversal nanoimprint, the mold must have a medium surface energy to satisfy both spincoating and mold-releasing from the resist after imprint. The DLC molds we made had a surface energy of 35-50 mJ/m^2 that is ideal for reversal nanoimprint. This surface energy is the bunk properties of DLC and therefore much more robust compared to trichlorosilane treated counterparts. The stability of the DLC surface energy was tested using hotplate to heat the sample to 180 °C up to 12 hrs. Results in Fig. 2 show that the DLC surface energy is quite stable under the relatively high temperature. This satisfies most hot embossing requirements. These DLC films on Si and quartz were used to make scratch-proof molds using electron beam lithography and inductive coupled plasma etching using similar conditions in our previous work [1]. Fig. 3 and Fig. 4a shows SEM images of the mold with structures of 200 nm and 40 nm respectively. Reversal UV nanoimprint was carried out using the DLC mold at 70 °C and 6 MPa for 10 min in 300-nm-thick SU-8 on glass substrates with 1s UV exposure (UV was induced through the glass substrates). SU-8 structures with 40 nm line and space were printed (Fig. 4b). Imprint results indicate good pattern transfer fidelity. In the paper, we will illustrate the fabrication of a sub-20 nm scratch-proof DLC mold as the Si mold at this dimensions with same etching conditions have achieved (Fig.4c). We will also evaluate the mold bending phenomenon with reversal nanoimprint using female DLC molds.

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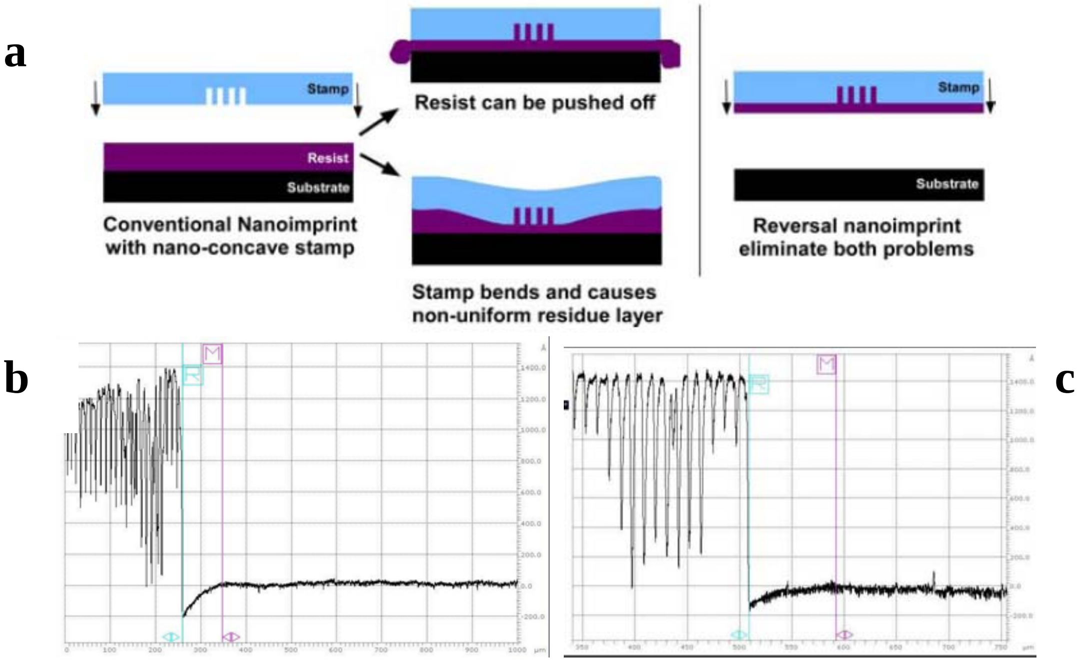

Fig 1: a) Schematics illustrates the mold bending problem for female molds on the resist using conventional nanoimprint. Reserval nanoimprint can solve this problem. b) Profiler scans of imprinted PMMA structures indicates the mold bending on 780 nm PMMA and c) 400 nm PMMA.

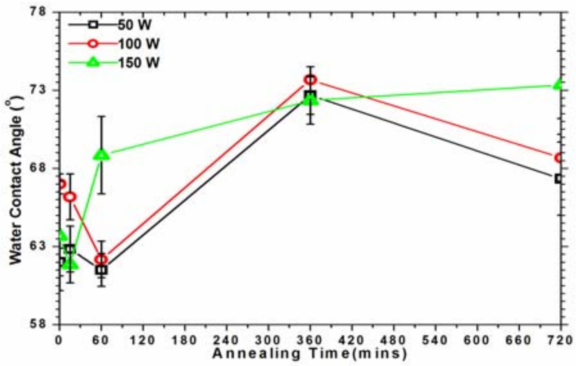

Fig 2: The effect of 180 °C annealing of DLC films on the contact angle of DI Water

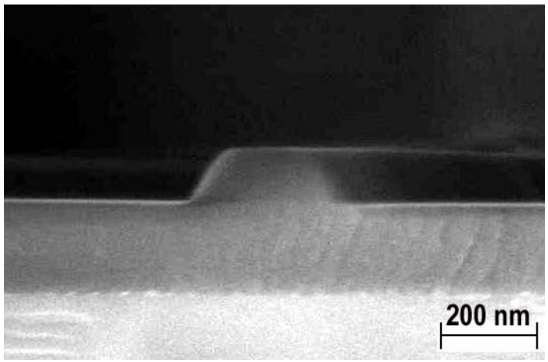

Fig 3: SEM cross-sectional image of etched DLC lines using inductive coupled plasma etching.

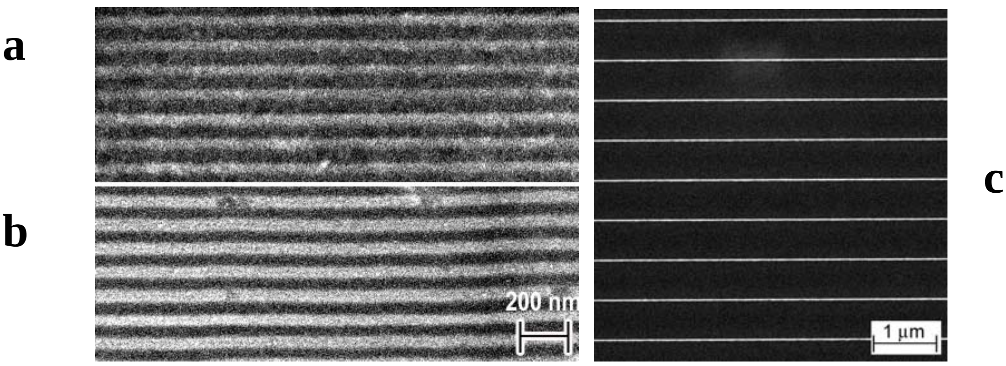

Fig 4: a) 40 nm line and space DLC mold and b) SU8 patterns via reversal nanoimprint. c) A Si mold consists of sub-20 nm wide and ~40 nm tall lines. Same process will be used to make DLC molds in the paper.