Understanding mechanical behavior of porous polymeric stamps during large-area metal-assisted chemical imprinting of silicon

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Current advancements in the field of nanophotonics require development of new manufacturing processes that will combine (i) sub-100 nm resolution, (ii) 3D geometrical control of the fabricated structures and (iii) high manufacturing throughput. This requirement is achieved with the advent of Metal-assisted chemical imprinting (Mac-Imprint). In this process, a catalytic stamp possessing 3D patterns is brought in contact with a semiconductor substrate by pressure-based immersion imprinting strategies. Semiconductor patterning is a result of catalyzed etching at the stamp/substrate contact interface. Particularly, a novel class of catalytic stamps made of Au-coated mesoporous polymeric membrane (i.e., porous Polyvinylidene fluoride (PVDF) and a solid polyimide film) was developed to ensure mass-transport of the reactants and etching solution storage essential for fast and accurate Mac-Imprint. The flexibility and stretchability of these porous membranes allows for the use of pressure-based actuation to bring both plannar and non-plannar substrates in conformal contact replicating the set-up of modern nanoimprinting lithography equipment. Thus, the elastic behavior of the polymeric stamp necessitates that the mechanical properties of these materials are well understood. This paper seeks to elucidate the mechanical behavior of the porous PVDF and polyimide during Mac-Imprinting both experimentally and numerically. A commercial finite element analysis software, ANSYS, was utilized to model the conformal imprinting process imitating the experimental setup during Mac-Imprinting. The FEA prediction using 2D axisymmetric model is able to capture the induced biaxial stress, strain, deflection and yield of the porous PVDF. To validate the model; (i) the maximum deflection of the center of the hemispherical bulge was measured using a contactless displacement sensor, (ii) the average induced strain at the center of the protrusion was calculated using an optical digital image correlation (DIC) technique. Without any fitting parameter, the comparison between the experimental and numerical results shows a good correlation. These findings allow for the prediction of stamp's deformation during Mac-Imprint and represent a step towards understanding changes in the stamp's morphology, which are critical for accurate pattern transfer.