Antireflective structures directly imprinted on chalcogenide glasses

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Chalcogenide glasses are thermoformable materials with a relatively low glass transition temperature (between 150 to 300 degrees C) and a high refractive index that makes them attractive for optical applications. Direct nanoimprint of chalcogenide glasses could pave the way to fabricating functional nanostructures, such as Moth-Eye antireflective coating or sub-wavelength diffraction gratings. However, applying pressure and high pressure needed for the surface nanoimprint produces global deformation of the imprinted substrate. On the other hand, low pressure and temperature result in insufficient pattern transfer. To circumvent this fundamental limitation, we recently demonstrated three different new nanoimprint approaches:

The *first approach* is based on the imprint with IR radiative heating using a soft mold. Here, the mold is produced from PDMS reinforced with carbon nanotube, making it a good radiation absorber. Since chalcogenide glasses are transparent in IR, only a thin layer at the mold-glass interface is sufficiently heated above the glass transition point during the radiative imprint (Fig.1) . At the same time, the rest of the bulk remains below its glass transition point and therefore is not deformed. Using this approach, we demonstrated a full pattern transfer of micron and sub-micron-sized features on a flat surface of chalcogenide glass and on a lens [1].

The second approach is based on the soft imprinting of a solvent-plasticized glass layer formed on the glass surface [2]. Here, we established a methodology for surface plasticizing by controlling its glass transition temperature through process conditions (Fig.2). This control allowed us to imprint the surface of chalcogenide glass with features sized down to 20 nm and achieved an unprecedented combination of full pattern transfer and complete maintenance of the shape of the imprinted surface of the Chalcogenide glass substrate.

The third approach is based on an elastomeric stamp soaked in an organic solvent. During the imprint, the solvent diffuses into the imprinted substrate, plasticizes its surface, and thereby allows its imprint at the temperature below its glass transition point (Fig. 3) [3]. As two previous approaches, this one combines the full pattern transfer with the maintenance of the shape of the imprinted substrate, which is necessary for optical devices. By using this approach, we demonstrated functional antireflective microstructures directly imprinted on As_2Se_3 surface (Fig. 4). Furthermore, we showed that our approach could produce imprinted features sized down to 20 nm scale.

Overall, these three novel approaches enables facile, high-throughput, and high-quality patterning of chalcogenide glasses, pave the way for myriad future applications of these emerging optical materials.

[1] N. Ostrovsky, D. Yehuda, S. Tzadka, E. Kassis, S. Joseph, and M. Schvartzman *Adv. Opt. Mater.*,1900652 (2019)

[2] S. Tzadka, N. Ostrovsky, E. Toledo, G. Le Saux, E. Kassis, S. Joseph, and M. Schvartzman *Opt. Express*, 28 (19), 28352 (2020)

[3] **S**. Tzadka Shalit, N. Ostrovsky, H. Frankenstein Shefa, E. Kassis, S. Joseph, and M. Schvartzman *Opt. Exp*. 30 26229 (2022)

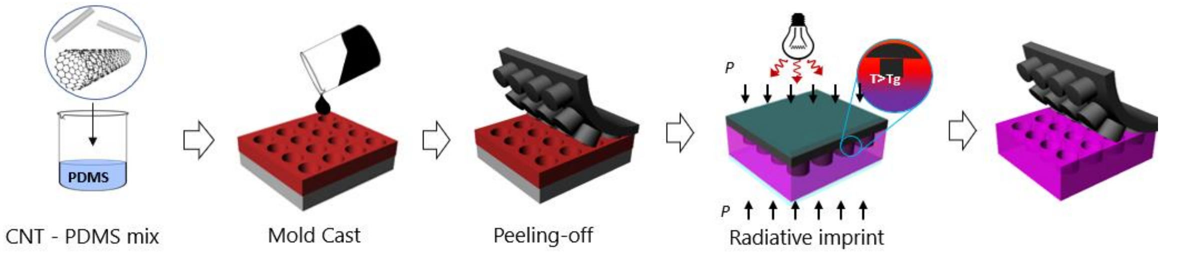

Fig. 1 : Schematic process flow of direct imprint via IR radiative heating of As_2Se_3 substrate

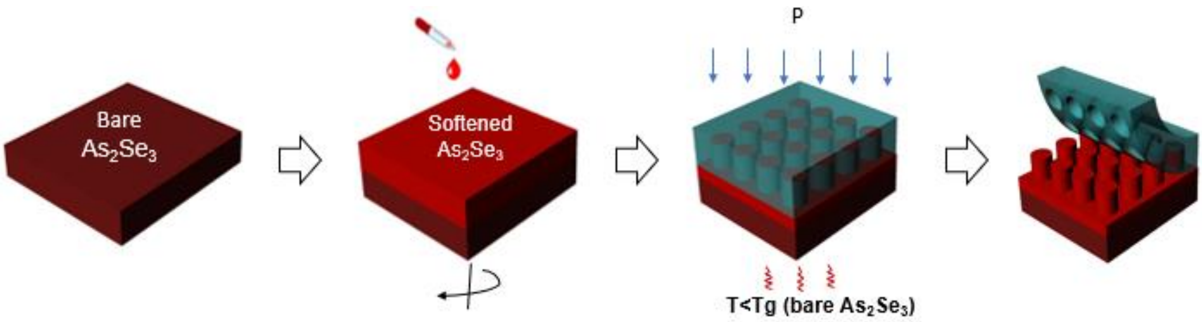

Fig. 2:) Schematic process flow of direct imprint via Surface plasticizing, of As_2Se_3 substrate

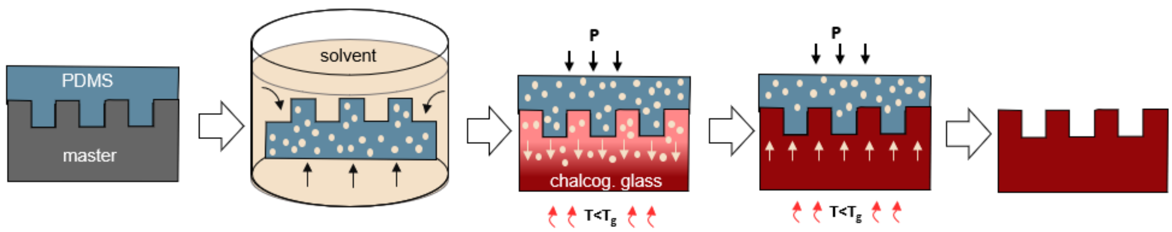

Fig. 3: Schematic process flow of direct imprint via solvent-based surface softening, of As_2Se_3 substrate

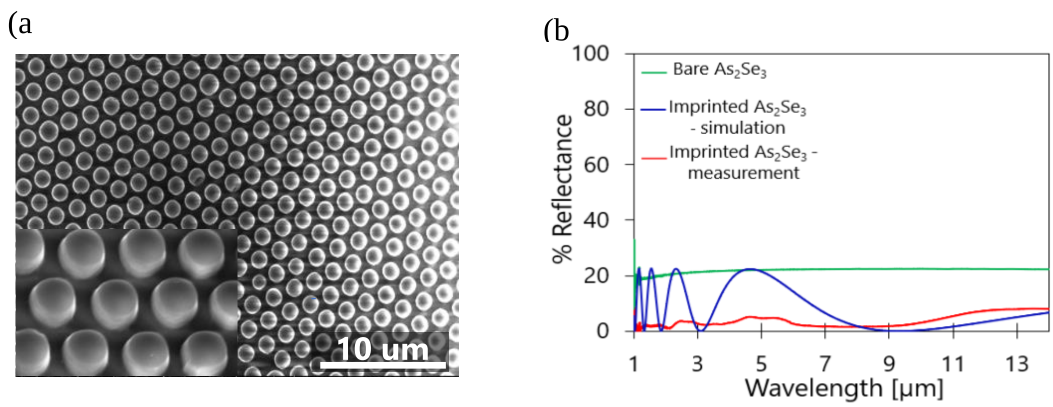

Fig 4 . (a)SEM of the imprinted antireflective structure. Inset shows high magnification tilted SEM. (b) The reflectance spectrum of surface imprinted with antireflective (red), compared to that of bare As2Se3 surface (green), and a simulated spectrum (blue