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Direct nanoimprinting of reflow enhanced antireflective moth-eye structures in chalcogenide glass

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Fresnel reflections occurring at the boundary between two media with different refractive indices is a major contributor to the overall losses in today's mid-infrared optical systems whose optical elements consist of a high index material such as chalcogenide glass. Solutions to this such as antireflective surface reliefs rely on a graded index matching surface design to counteract these Fresnel reflections at the interface. We recently reported on the progress towards fabricating broadband mid-infrared antireflective moth-eye nanostructures by directly transferring a surface relief onto the surface of commercially available arsenic triselenide (As_2Se_3) optical windows by thermal nanoimprinting [1]. While this proved effective, the imprints suffered from several optimization issues such as incomplete filling of the nickel (Ni) shim cavity due to suboptimal structure profiles at pattern pitches larger than 1.1µm and defects caused by the structures fracturing at the base, thus remaining imbedded in the Ni-shim cavity after separation. We now report our progress towards developing a new and improved Ni-shim fabrication process which introduces a thermal reflow post-processing step [2,3] to the deep-ultraviolet (DUV) lithography shown in step 2 in Figure 1(a).

Based on a simulation approach where the rigorous coupled-wave analysis (RCWA) method was employed, we design hexagonal arrays comprising elliptical asperities. The projected corresponding hexagonal patterns are subsequently transferred to a positive tone resist by deep ultraviolet (DUV) exposure and development steps at which point we modify the resist profile using a thermal reflow post-processing step to melt the resist structures. The elliptical shape was subsequently obtained through an inductively coupled plasma reactive ion etching process dominated by physical etching using enchants HBr and BCl_3. Finally, a Ni mold was fabricated by seed metallization with a NiV alloy of the Si pattern and subsequent Ni electroforming of a negative relief. The imprinting was performed in a custom build setup and fixture (see Figure (c)), where the chalcogenide substrate was heated to 220 °C, where after the Ni stamp was pressed into the substrate. Optical characterization was performed using a Fourier transform infrared (FTIR) spectrometer to compare transmittances of a blank window and the nanoimprinted glass window.

The etched silicon nanostructures (step 3) with and without the added reflow step are vastly different from one another as shown in Figure 2. The reflowed structures exhibit a more desirable elliptical profile and smaller gaps between neighboring structures making it much easier to transfer via a nanoimprint and should therefore alleviate some of the nanoimprinting issues that we experience. The preliminary simulation results based on the RCWA method comparing equal sized structures fabricated with and without reflow given in Figure 3 also shows us that the reflowed structures have the potential to be significantly better than its predecessor made without a reflow step.

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[1] Mikkel R. Lotz, Christian R. Petersen, Christos Markos, Ole Bang, Mogens H. Jakobsen, Rafael Taboryski, "Direct nanoimprinting of moth-eye structures in chalcogenide glass for broadband antireflection in the mid-infrared", Optica, in press.
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[3] Song, Y. M., Jang, S. J., Yu, J. S. and Lee, Y. T. (2010), "Bioinspired Parabola Subwavelength Structures for Improved Broadband Antireflection", Small, 6: 984-987, doi:10.1002/smll.201000079.

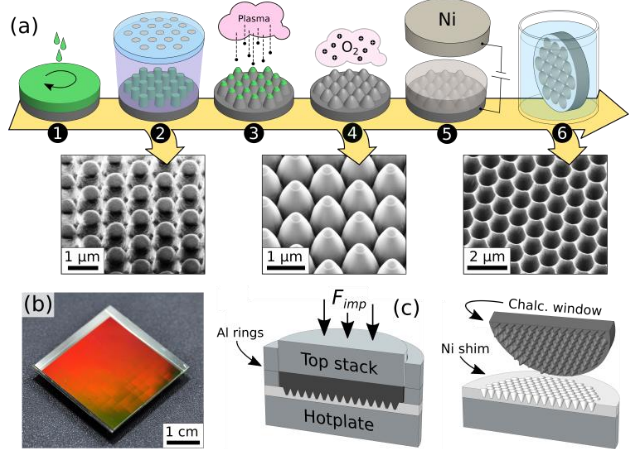

Figure 1. a) Ni shim fabrication; 1. Spin-coating resist, 2. DUV lithography. 3. ICP plasma RIE, 4. O_2 plasma etching, 5. NiV seed layer deposition and Ni- electroforming, 6. KOH wet etching and anti-stiction coating. SEM images at three different stages of fabrication; post lithography, post oxygen plasma etching, and post KOH etching. (b) A finished and diced nickel shim. (c) Sketch of the nanoimprinting. From ref. [1].

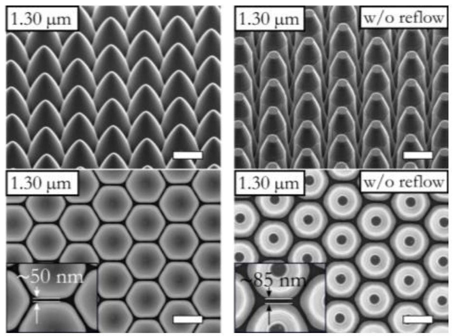

Figure 2. SEM images of two dry-etched silicon moth-eye nanostructure arrays (1.3 µm pitch) with and without adding the reflow post-processing step. The length of all scale bars is 1 µm.

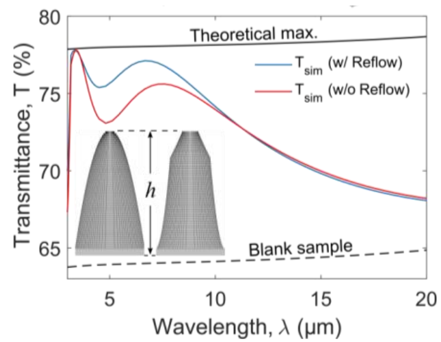

Figure 3. Preliminary RCWA simulations of the nanostructure with and without the reflow post-processing step, were they imprinted onto the surface of a chalcogenide glass (As_2Se_3) window.