Additive Full-wafer Fabrication of All-inorganic Metaoptics and AR Waveguides via Direct Nanoimprint Lithography

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Full wafer scale fabrication of high-efficiency, all-inorganic optical devices including metalenses, AR/VR waveguides, and polarization-controlled holograms is demonstrated by using additive nanoimprint lithography with nanoparticle dispersion-based inks. Approximately one-thousand 4-mm-sized metalenses are fabricated per 8-inch wafer with high optical efficiency and excellent uniformity across the wafer. The absolute and relative efficiencies of the metalenses are more than 80% and 90%, respectively, which are approximately 95% of the maximum simulated efficiencies for this specific design. The close agreement between simulated and realized efficiencies indicates that future improvements are possible, and actual efficiencies are not limited by materials or process. The use of nanoparticle dispersion inks enables the fabrication of all-inorganic high MTF AR waveguides with imprint cycle times significantly shorter than those used for polymer/nanoparticle composites. Refractive index of the metalens and waveguide structures can be increased up to 2.3 using a short post-imprint atomic layer deposition process. Combined these attributes offer superior performance and a reduced cost of manufacturing. The fabrication of polarization-sensitive, phase/amplitude-controlled holograms demonstrates that our process can replicate asymmetric nanostructures with aspect ratios of more than 10 by direct imprinting without etching. The imprinted metalenses and waveguides are free from organics due to a post-imprint calcination step and exhibit outstanding dimensional and optical stabilities, as confirmed by accelerated environmental testing. This work opens a path for true, full-scale additive manufacturing of meta-optics.