Low-cost and Scalable Manufacturing of Optical Metasurfaces in the Visible Using Engineered Optical Materials (Low-loss a-Si:H, PER, and Hybrid ALD Structural Resin)

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Abstract— Here, we demonstrate low-cost, scalable manufacturing of optical metasurfaces with three approaches: 1) increasing a refractive index of resin with dielectric particle embedding for single-step nanoimprinting [1–5], 2) suppressing optical losses of hydrogenated amorphous silicon (a-Si:H) to apply complementary-metal-oxide-semiconductor technologies [6], and 3) high-index atomic layer deposited (ALD) structural resin [7]. We demonstrate the effectiveness of these materials in creating optical metasurfaces operating at different wavelengths in the infrared, visible, and ultraviolet spectra. Firstly, we achieve high efficiencies of up to 90.6%, 47%, and 60% with a-Si[1], TiO_2[2–4], and ZrO_2 PER[5] at wavelengths of 940, 532, and 325 nm, respectively. Furthermore, we obtain a measured efficiency of 30% at a wavelength of 248 nm using ZrO_2 PER metasurfaces [5]. Secondly, by adjusting the deposition conditions of plasma-enhanced chemical vapor deposition, we engineer the bandgap of a-Si:H to enable low-loss operation, with minimum extinction coefficients as low as 0.082 at 450 nm [6]. Using low-loss a-Si:H, we demonstrate efficient beam-steering metasurfaces with measured efficiencies of 42%, 65%, and 75% at 450, 532, and 635 nm, respectively, marking the first Si-typed metasurfaces working at the full visible. Finally, we manufacture highly efficient metalenses using hybrid ALD structural resin with deep-ultraviolet lithography at visible wavelengths. Their measured efficiencies approach 60.9%, 77.8%, and 64.8% at 450, 532 and 635 nm, making them suitable for ultrathin virtual reality devices [7]. This approach can be extended to mass-produce metalenses for the UV region by replacing TiO_2 deposition with ZrO_2, which is transparent in the UV spectrum, has a high refractive index, and can be deposited using ALD [8]. Our approaches using PER [1–5], low-loss a-Si:H [6], and hybrid ALD structural resin [7, 9, 10] enables the low-cost, large-area manufacturing of efficient optical metasurfaces across different wavelengths, facilitating the commercialization of metasurface-based photonic devices [11–19].

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