Reflective Metamaterial Polarizer Enabled by Solid Immersion Lloyd's Mirror Interference Lithography

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Metamaterials with induced form birefringence arising from orderly organized subwavelength structures can effectively realize refractive indices that do not exist in nature. Applications of the metamaterials include optical elements, superlenses, antennas, absorbers, and cloaking devices.[1,2] Using lithographically-defined thin film or multi-layered metasurfaces, such form birefringence can be used for polarization and phase control in thin-film elements.

In this work we experimentally demonstrate a highly birefringent omni-directional broadband reflective metamaterial polarizer (RMP), fabricated using a solid-immersion Lloyd's mirror interference lithography (SILMIL) technique.[3] By accessing the total internal reflection (TIR)-induced evanescent fields at the interface between an immersion prism and photoresist (PR) enhanced with a dielectric resonance underlayer, the SILMIL technique is capable of creating 55 nm linewidth gratings using 405 nm exposure. For RMP fabrication, SILMIL is capable of producing large-area high aspect ratio gratings, 100 nm to 200 nm tall over cm^2 areas, with a single-step exposure, as shown in Fig. 1.

Angle-resolved reflection spectra of SILMIL fabricated subwavelength dual-silver gratings RMP exhibit excellent omnidirectionality over a broad spectral bandwidth in the optical range, as shown in Fig. 2. Behavior and mechanism of the double-layer RMP has been analyzed with rigorous coupled wave analysis (RCWA) and finite-difference time-domain (FDTD) simulations, showing coupling between excited surface plasmon polaritons (SPPs) and multiple Fabry-Pérot (FP) resonances which affect the overall performance of the RMP.

Furthermore, we propose via simulation that by switching from a dielectric resonator to a metallic resonator, the SILMIL technique can potentially fabricate dual-layer thin-film metamaterial that have the capability of phase retardation control, providing a new scheme for reflective thin-film waveplates.

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[1] **Zheludev NI and Kivshar YS.** From metamaterials to metadevices. *Nature Materials* 11, 917–924 (2012); doi: 10.1038/nmat3431

[2] **Kshetrimayum RS.** A brief intro to metamaterials. *IEEE Potentials* 23, 5 (2004); doi: 10.1109/MP.2005.1368916

[3] **Lowrey S, Bourke L, Ding B, and Blaikie RJ.** Ultrahigh NA, high aspect ratio interference lithography with resonant dielectric underlayers. *J. Vac. Sci. Technol. B* 32, 06FE01 (2014); doi: 10.1116/1.4894168

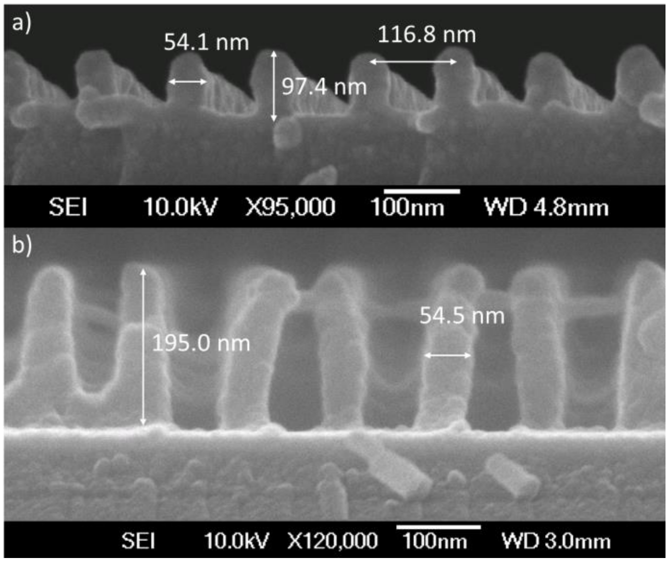

Figure 1: SILMIL-fabricated high aspect ratio gratings: These SEM images show photoresist gratings with a) ~55 nm linewidth and ~100 nm height; and b) ~55 nm linewidth and ~200 nm height where resist collapse is starting to occur. The Si substrate is coated with ~65 nm HfO_2 on 1 µm SiO_2 to act as a SILMIL reflector.

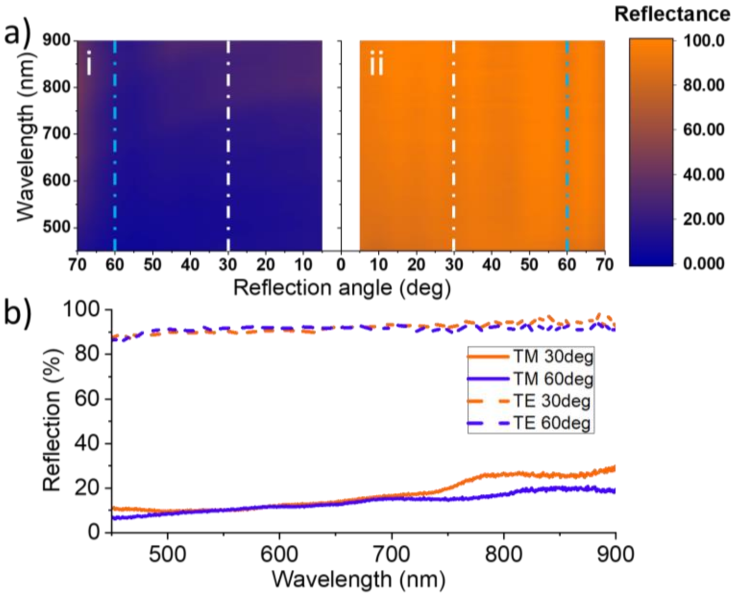

Figure 2: Reflectance of the RMP: Spectral measurements plotted as intensity in a) showing low reflection by TM incidence (i) and high reflection by TE incidence (ii). Spectral data at 30° (white-line in a) and 60° (cyan-line in a) incident angle are presented in b), showing the level of practical extinction ratio.