Metasurface polarization splitter: supplementary material

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This document provides supplementary information to "Metasurface polarization splitter." We provide additional details of the full-wave modeling, calculated transmission of the metasurface, device fabrication, optical characterization, and the impact of the silica overetch on the device reflectivity.

I. FULL-WAVE MODELING

The full-wave simulations were performed with the commercial finite-element frequency-domain solver HFSS (Ansys). The optical properties of silicon and quartz used in the simulations were obtained experimentally using spectroscopic ellisometry at Vanderbilt. The reflectivity of the metasurface was calculated using the Floquet mode solver in HFSS, assuming periodic boundary conditions in x and y. The backscattering cross section, calculated as the ratio of the total power scattered into the incident air medium and the incident intensity, was calculated for a four-particle unit cell at a semi-infinite air-quartz interface with absorbing boundary conditions. The electric and magnetic field plots were obtained in the z=0.230 μm plane, halfway through the cylinder height. The effective parameters ϵ and μ were calculated for the zero-order mode using S-parameter inversion,[1] where the effective layer thickness of 0.92 μm was chosen such that ϵ and μ calculated for one and two layers are equal.

II. CALCULATED TRANSMISSION

In the manuscript we showed that for light polarized along the long axis of the rectangular lattice of the metasurface ($\mathbf{E}||\mathbf{y}$), the reflectivity is less than 2% at the design wavelength of 1.55 μm. Since the metasurface consists of nearly lossless materials, the transmission for y-polarized light is greater than 98% at 1.55 μm. However, because the periodicity of the metasurface along y (1.3 μm) is larger than the design wavelength in the quartz substrate (1.07 μm), the substrate supports higher-order diffraction modes, namely $\pm$1 orders. A significant fraction of the transmitted power could be carried by these diffracted modes which would compromise the performance of the device as a beamsplitter. Figure 1 shows the calculated transmission of the zero-order (specular) and $\pm$1-order (diffracted) modes for $\mathbf{E}||\mathbf{y}$. At the design wavelength of 1.55 μm, nearly 40% of the incident light is diffracted into the $\pm$1 modes, resulting in only 60% transmission of the zero-order mode. One way to increase the transmission of the zero-order mode is to use a lower index substrate. For example, we find that the zero-order transmission can be greater than 90% when the quartz substrate is replaced by porous Si, which does not support higher-order modes due to its low refractive index of 1.1.

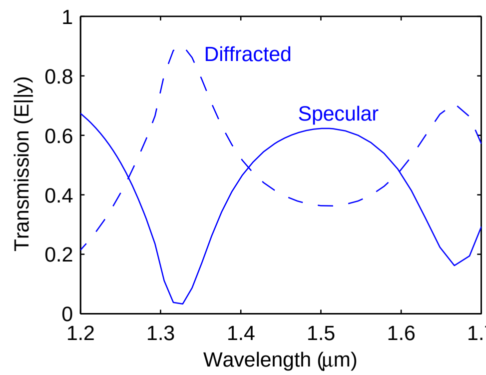

FIG. 1. Calculated zero-order (specular) and higher-order (diffracted) transmission of the metasurface polarization splitter for $\mathbf{E}||\mathbf{y}$. At the design wavelength of 1.55 μm, although nearly 99% of incident light is transmitted, 40% is diffracted into higher-order modes. One way to increase the transmission into the specular mode is to use a low index substrate.

III. DEVICE FABRICATION

Wafers were first prepared by growing a 460 nm thick polysilicon layer on quartz using low pressure chemical vapor deposition. In preparation for electron beam lithography (EBL), the wafer was spin coated with PMMA and a 10 nm thick chromium (Cr) layer was deposited using thermal evaporation to prevent charging during lithography. After the patterns were written using EBL the Cr layer was removed using a chemical etchant and the arrays were developed in MIBK:IPA 1:3. A Cr layer was deposited into the developed pattern to

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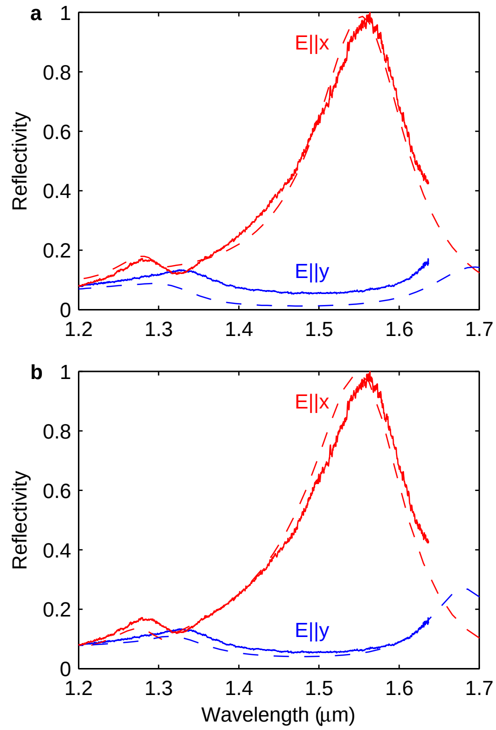

FIG. 2. Measured and simulated reflectivity for a model with an overetch depth of zero (**a**) and 45 nm (**b**).

serve as a hard mask during etching and the surrounding areas lifted-off via a PG Remover soak. Inductively coupled plasma etching was subsequently carried out with a SF6/C4F8 recipe and the Cr mask was removed using a chemical etchant.

IV. OPTICAL CHARACTERIZATION

Illumination of the samples was provided by a supercontinuum laser with a beam size of 12.6 mm^2 incident through an infrared objective with a numerical aperture of 0.4 (Mitutoyo, 20X), where the maximum angle of incidence is approximated as 11.3. The polarization of the incident light was controlled by placing an infrared polarizer before the objective and the reflectance spectrum was measured using a grating spectrometer with an InGaAs detector (Horiba, Jobin Yvon). The absolute reflectance spectrum was obtained by using a gold mirror as a reference, taking into account the absolute reflectance of gold in this spectral range.[2]

V. IMPACT OF OVERETCH

We attribute the discrepancy between the measured and modeled reflectivity for $\mathbf{E}||\mathbf{y}$ to a slight overetch of the poly-Si cylinders. This was confirmed by recalculating the reflectivity for both polarizations with an additional silica disc below the cylinders (Figure 2). As a result of the overetch, the reflectivity for $\mathbf{E}||\mathbf{y}$ increases while the reflectivity for $\mathbf{E}||\mathbf{x}$ is largely unchanged. We find that an overetch depth of 45 nm provides acceptable agreement with experiments. This value is in agreement with the value approximated from SEMs.

[1] D. R. Smith, S. Schultz, P. Marko, and C. M. Soukoulis, Phys. Rev. B **65**, 195104 (2012).
[2] E. D. Palik, *Handbook of optical constants of solids. Vol. 3* (Academic Press, 1998).