Thin-Films for Metastructures, Meta-Optics, and Surface Nanofabrication

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Abstract: We analyze thin films, metastructures, and surfaces with multipolar coupling and bound states in the continuum, leading to strong and narrow resonances. We show that we can control nanostructure parameters and enable directional scattering from the metastructure. Improved quality of the thin film results in enhanced electronic and photonic functionalities.

Metastructures are based on periodic arrays and composed of unit cells with one or several elements, enabling strong mode coupling and formation of bound states in the continuum [1]. These characteristics result in narrow and high-quality-factor resonances. By engineering the surface properties and designing the arrangement and spacing of elements in a periodic lattice, one can obtain improved coupling between incident light and the collective oscillations of the nanoparticle ensemble. This collective response leads to heightened light-matter interactions, and the precise manipulation of lattice parameters permits engineering of the spectral response and directionality of light, and this capability finds applications in different fields [2].

Figure 1 shows the optical behavior of a periodic silicon array consisting of nanopillars. Tunable optical features in silicon metasurfaces are attained by precisely manipulating the nanopillar size and relative placement. The nanostructures are made on a substrate of soda lime glass, and the full-wave computations incorporate a thin Ti film necessary during the deposition. The reflectance and transmittance spectra indicate multipolar mode excitations and the manifestation of the generalized Kerker effect in the array.

Optical properties of silicon benefit from optimal material deposition rates and subsequent rapid thermal annealing (Fig. 2). Minimizing oxidation and material defects enhances silicon quality by boosting the real refractive index and reducing the imaginary part. High-temperature rapid thermal annealing aids in diminishing defects and impurities, fostering a uniform and crystalline silicon structure. Consequently, this leads to reduced light absorption, diminished optical losses, and improved light-matter interactions. These enhancements in silicon quality facilitate tuning collective modes, resulting in novel photonic functionalities and heightened sensing capabilities across optical applications.

Conclusions. We investigate directional scattering in a silicon nanopillar array by manipulating nanoantenna dimensions. Additionally, we examine the influence of deposition rate and rapid thermal annealing, leading to substantial enhancements in silicon quality. This improvement is evident in an increased real refractive index and a decreased imaginary part. The fine-tuning of collective modes presents opportunities for innovative photonic functionalities and enhanced sensing capabilities. Additionally, the collective behavior of nanoparticle arrays presents opportunities for crafting innovative photonic devices with distinctive functionalities.

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References

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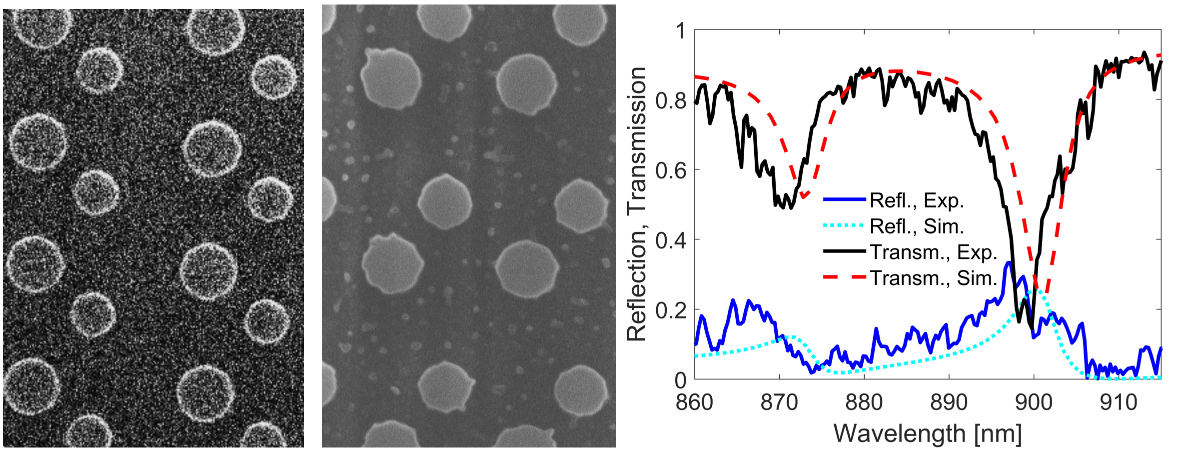

(a) (b) (c)

Fig. 1: Optical characteristics of the metasurface: reflectance and transmittance. (a) and (b) Scanning electron microscope images of the metasurfaces with two distinct nanopillars. (c) Results of the measurements vs. numerical simulations. The lattice consists of 140-nm-thick silicon pillars in the shape of nanodisks with radii of 100 and 70 nm. The elements are in a lattice with pitches of 550 and 380 nm.

(a)

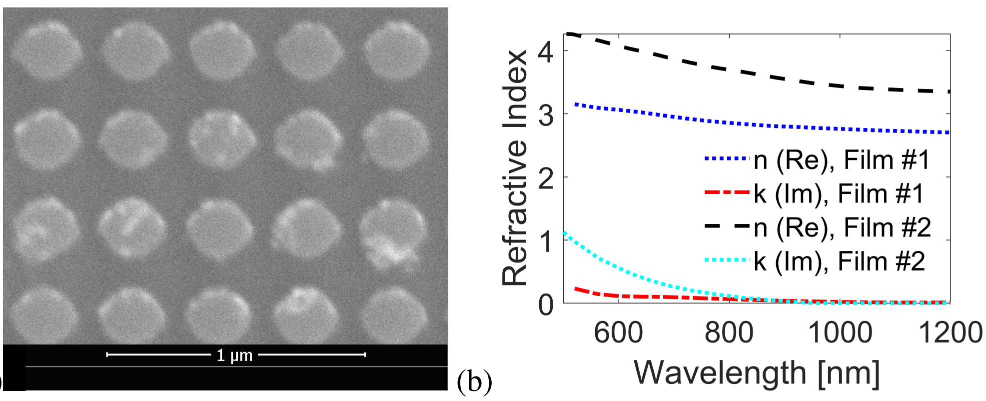

Fig. 2: (a) Scanning electron microscope image of metasurface with same-type nanopillars. (b) Refractive index of thin-film silicon deposited with electron-beam evaporator with different deposition rate. Films 1 & 2 were deposited at 5 Å/s and 15 Å/s, respectively, with the chamber pressure $4.5 \cdot 10^{-7}$ torr. We plot the real n and imaginary parts k of the refractive index. Thin Ti films were deposited on the glass substrate to decrease oxidation.