Optical properties of a metasurface based on silicon nanocylinders in a hybrid anapole state

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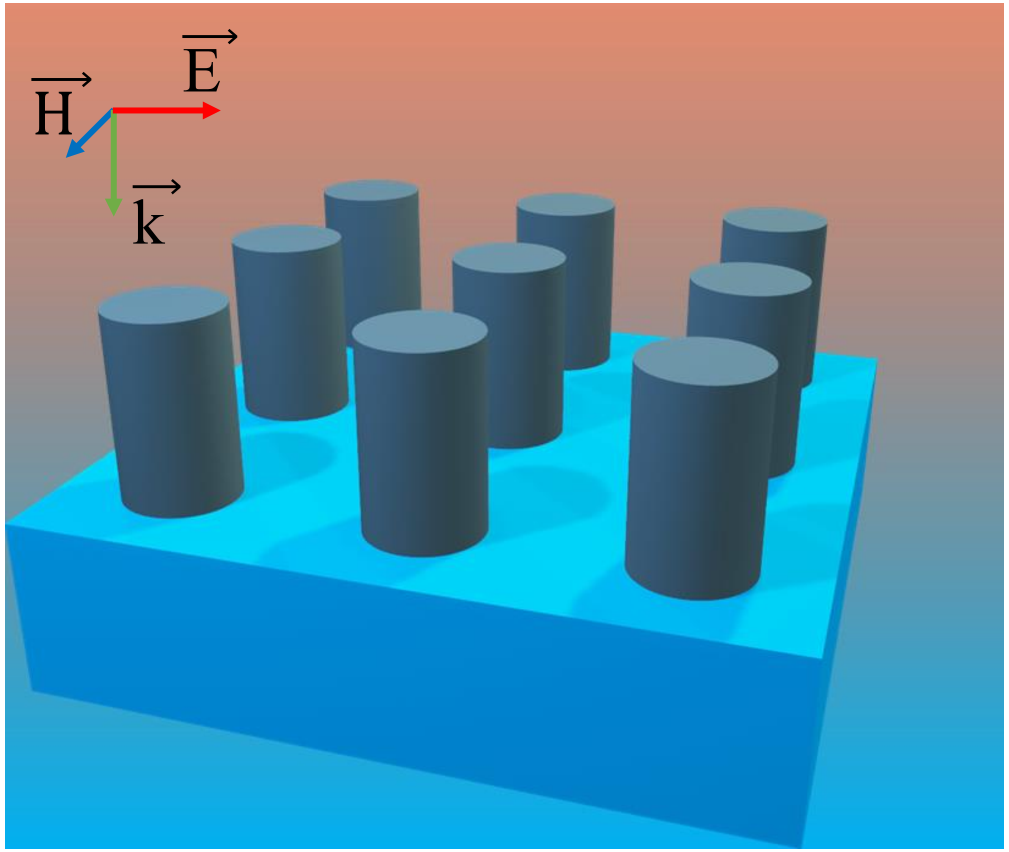

Hybrid anapoles have been recently proposed as a novel non-radiating source capable of mimicking the incident radiation from a plane wave in an almost perfect fashion, rendering a subwavelength particle virtually invisible in all angles of observation.

This is the result of the simultaneous destructive interference of scattering from all the dominant multipolar channels from the nanoresonator. Consequently, while nontrivial modes are excited inside the nanoparticle, the external field is almost identical to the incident illumination.

Here, we exploit a unique property of such states, their suppression of coupling in both the near and far fields, to realize fully transmissive metasurfaces with unprecedented compactness. In addition, the non-radiative nature of the constituents results in a remarkable robustness against fabrication-induced defects in the periodic array.

The results in this work can motivate the development of novel applications of all-dielectric nanophotonics in biosensing.

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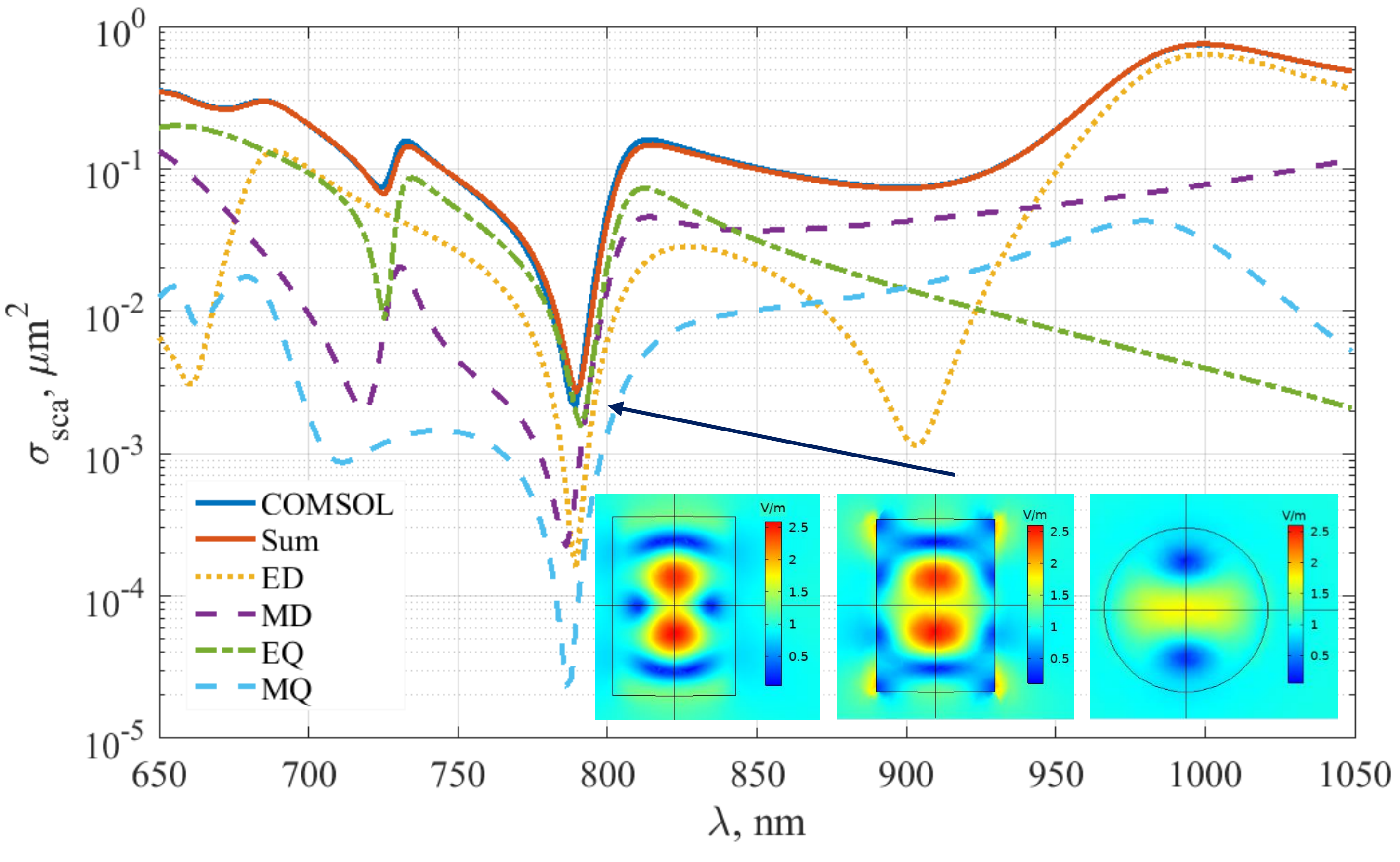
Dependence of the scattering cross section on the length of the exciting radiation for a silicon nanocylinder and fragments of the spatial electric field norm distribution in the different plane



The Cartesian multipole moments

$$\mathbf{p} = \int \mathbf{P} j_0(kr) d\mathbf{r} + \frac{k^2}{10} \int \left\{ [\mathbf{r} \cdot \mathbf{P}]\mathbf{r} - \frac{1}{3} r^2 \mathbf{P} \right\} \frac{15 j_2(kr)}{(kr)^2} d\mathbf{r},$$

$$\mathbf{m} = -\frac{i\omega}{2} \int [\mathbf{r} \times \mathbf{P}] \frac{3 j_1(kr)}{kr} d\mathbf{r},$$

$$\hat{Q} = \int \{3(\mathbf{r} \otimes \mathbf{P} + \mathbf{P} \otimes \mathbf{r}) - 2[\mathbf{r} \cdot \mathbf{P}]\hat{U}\} \times \frac{3 j_1(kr)}{kr} d\mathbf{r} + 6k^2 \int \{5\mathbf{r} \otimes \mathbf{r}[\mathbf{r} \cdot \mathbf{P}] - (\mathbf{r} \otimes \mathbf{P} + \mathbf{P} \otimes \mathbf{r}) r^2 - r^2 [\mathbf{r} \cdot \mathbf{P}]\hat{U}\} \frac{j_3(kr)}{(kr)^3} d\mathbf{r},$$

$$\hat{M} = \frac{\omega}{3i} \int \{[\mathbf{r} \times \mathbf{P}] \otimes \mathbf{r} + \mathbf{r} \otimes [\mathbf{r} \times \mathbf{P}]\} \frac{15 j_2(kr)}{(kr)^2} d\mathbf{r},$$

where p, m, Q, and M are the multipole moments in the Cartesian representation, jn denotes n-order spherical Bessel function, and k is the wave number in air.

References

[1] A. B. Evlyukhin, T. Fischer, C. Reinhardt, and B. N. Chichkov, Physical review. B 94, 205434 (2016).

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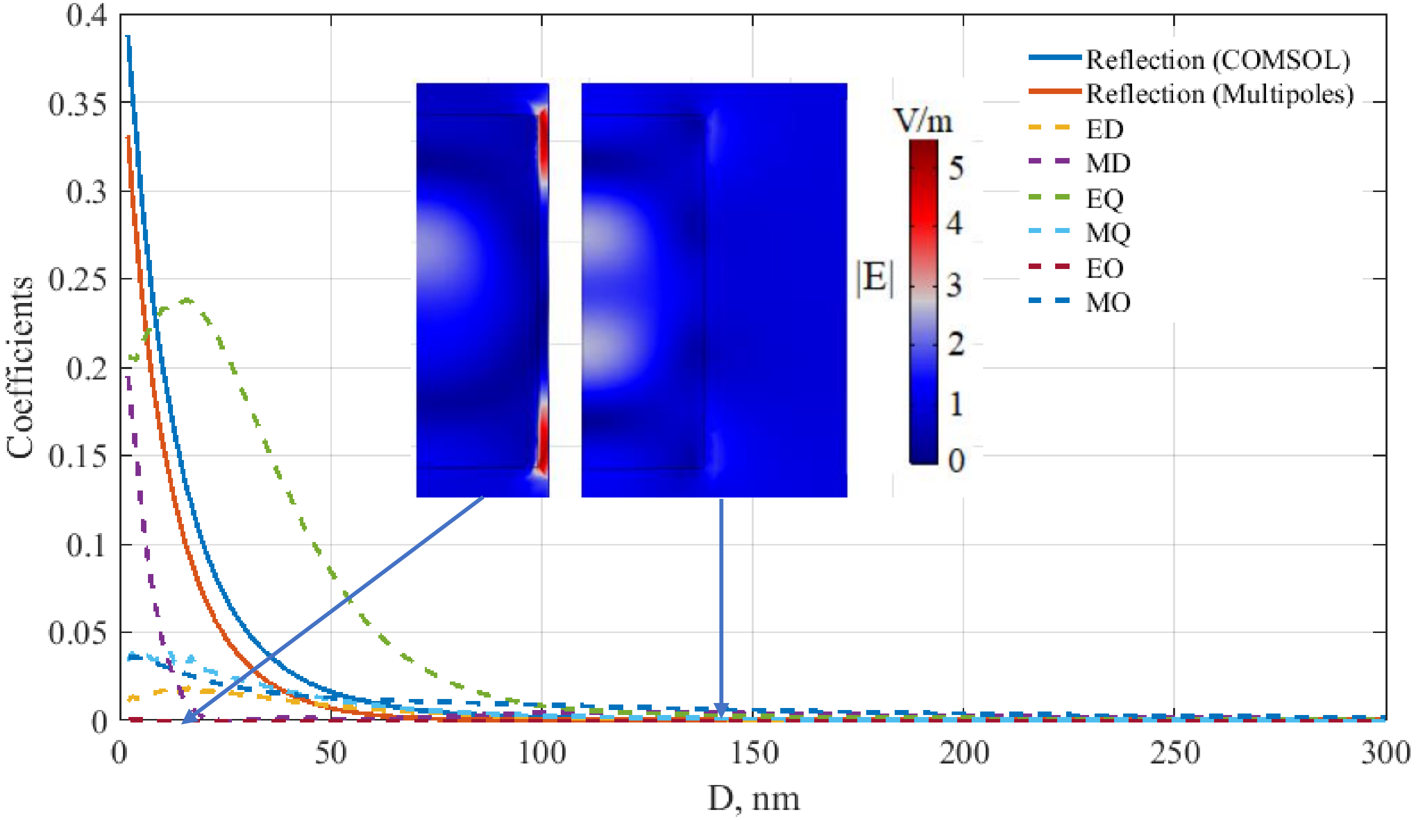
Dependence of the reflection of radiation with a wavelength of HAS metasurface consisting of silicon nanocylinders, on the distance between cylinders, fragment of the spatial electric field norm distribution in the xz-plane



Wavelength λ = 789 nm, radius R = 128 nm and height H = 369 nm
D = 20 nm and D = 144 nm

The reflection, transmission and absorption coefficients are

$$r = \frac{ik_d}{E_0 2S_L\varepsilon_0\varepsilon_d}\left(p_x - \frac{1}{v_d}m_y + \frac{ik_d}{6}Q_{xz} - \frac{ik_d}{2v_d}M_{yz} - \frac{k_d^2}{6}O_{xzz}\right),$$

$$t = 1 + \frac{ik_d}{E_0 2S_L\varepsilon_0\varepsilon_d}\left(p_x + \frac{1}{v_d}m_y - \frac{ik_d}{6}Q_{xz} - \frac{ik_d}{2v_d}M_{yz} - \frac{k_d^2}{6}O_{xzz}\right),$$

$$R = |r|^2, \quad T = |t|^2.$$

$$A = 1 - R - T$$

References

[2] Pavel D. Terekhov, Viktoriia E. Babicheva, Kseniia V. Baryshnikova, Alexander S. Shalin, Alina Karabchevsky, and Andrey B. Evlyukhin, “Multipole analysis of dielectric metasurfaces composed of nonspherical nanoparticles and lattice invisibility effect,” in Physical review, 2019.

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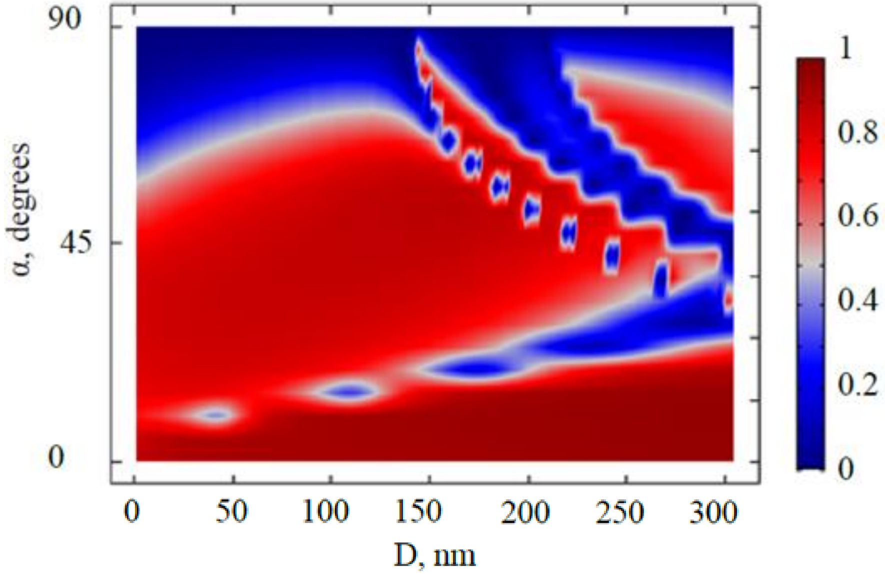
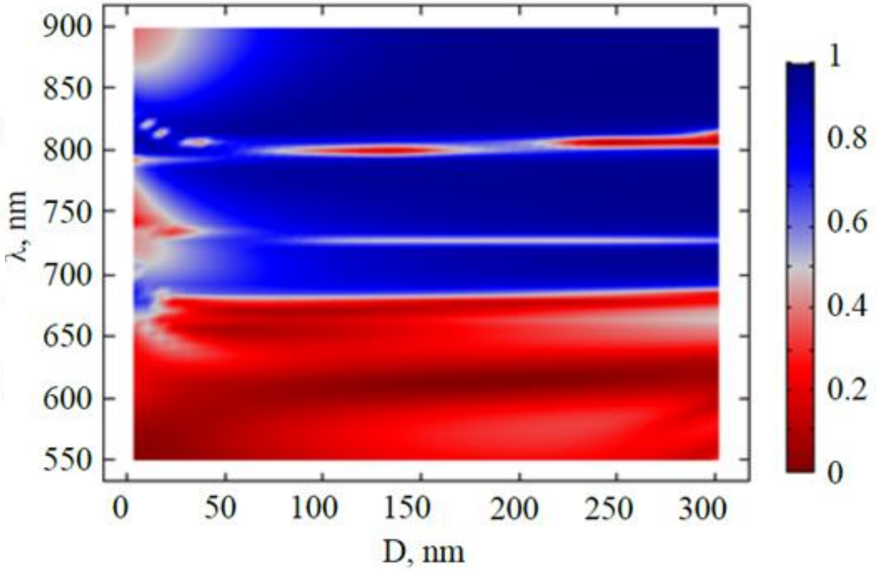
Introduction | Theory | Simulation | Setup | Results | Conclusion

Optical properties

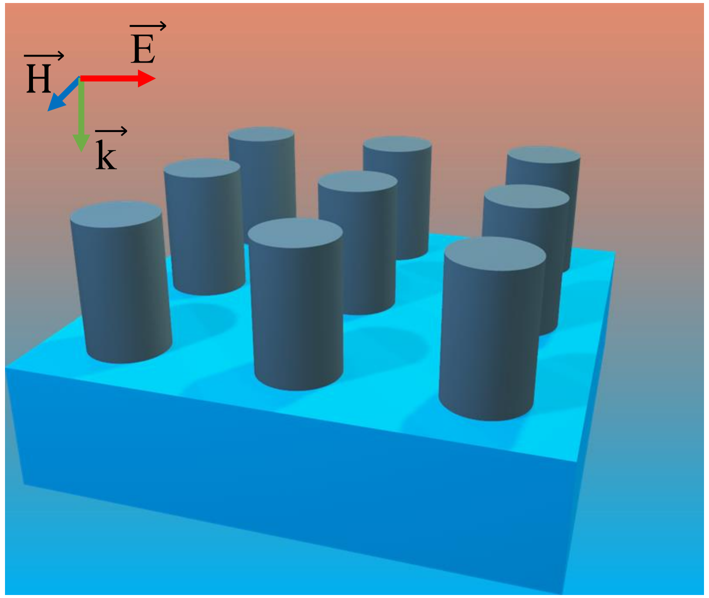


2D-dependence of the of transmission with the distance between cylinders and the angle of incidence on the metasurface consisting of silicon nanocylinders



2D-dependence of the of transmission with the distance between cylinders and the wavelength for metasurface consisting of silicon nanocylinders

Artistic representation of the considered silicon metasurface composed of nanocylinders



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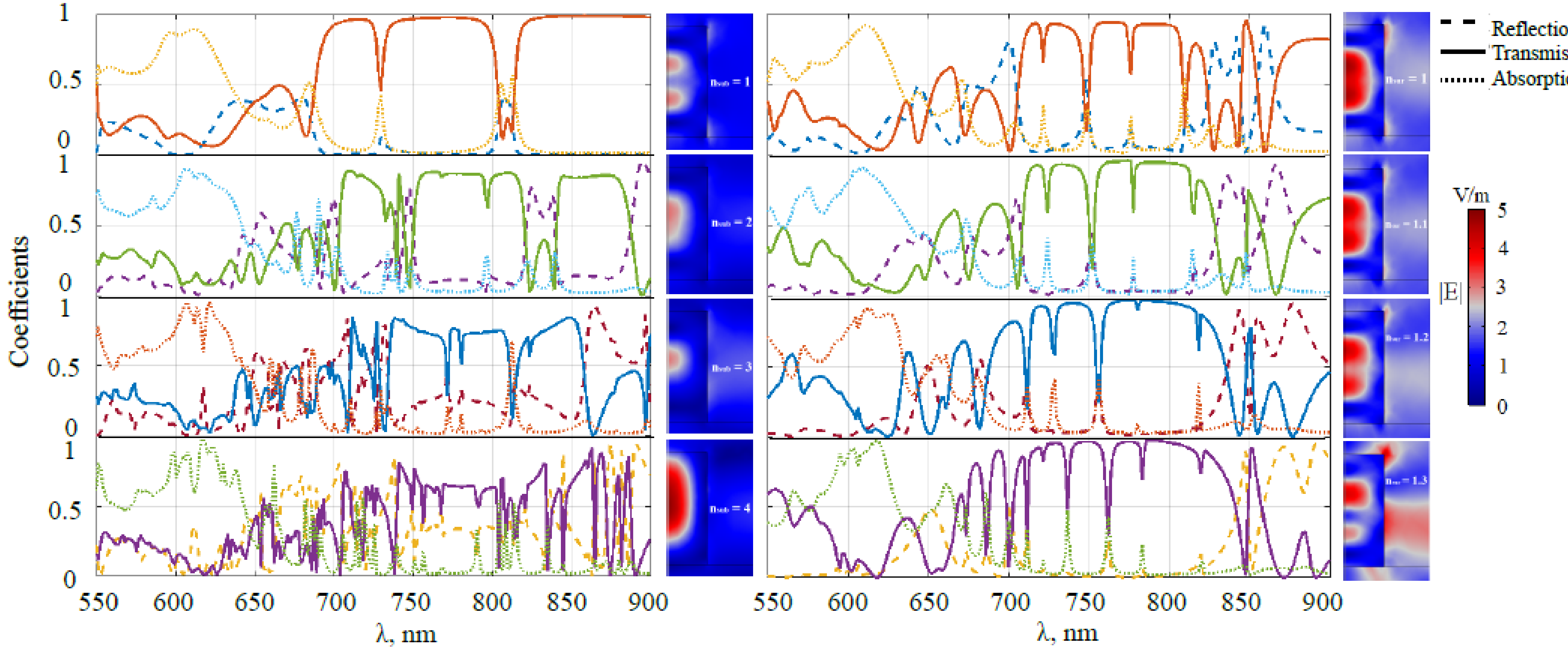
Dependence of the optical properties of metasurface consisting of silicon nanocylinders on the incident wavelength for different materials of substrate and for different surrounding medium and fragment of the spatial electric field norm distribution in the xz-plane for these cases



Distance between cylinders D = 300 nm;
Radius R = 128 nm;
Height H = 369 nm;
Substrate n_{sub} = 1.55.

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1. We investigated the unusual properties behind hybrid anapole metasurfaces and explained them in terms of the extremely weak interaction of the meta-atoms with their neighbors.

2. Contrarily to Huygens metasurfaces, the designs presented in this work display negligible near field interaction while preserving unity transmittance

3. Contrarily to other recently proposed effects inducing zero transmission, the hybrid anapole is preserved when deposited over substrates having almost zero refractive index contrast.

4. The results presented in this work will greatly facilitate the design and fabrication of future nanophotonic devices.

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