All-dielectric optical metasurfaces for sensing of substances with identical real parts of refractive index

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Introduction

Metasurfaces are one of the most attractive research fields in recent years, in no small measure due to their use as refractometric sensors with unparalleled sensitivity, enabling sensing not only of monatomic or monomolecular layers, but even single atoms or molecules. This sensitivity is rooted in their ability to localize electromagnetic fields in volumes orders of magnitude below the diffraction limit. This is achieved by special geometry and refractive index contrast of metasurface nanocomposites. A plethora of both conductive (metals, semimetals, alloys, TCO, 2D materials like graphene and MXenes...) and dielectric (oxides, semiconductors) materials can be used, all of them bringing different functionalities which further enhance the freedom of design when tailoring metasurfaces. However, the fundamental sensing mechanism is practically identical across all platforms and is based on the spectral shift of scattering parameters (transmission or reflection) due to the difference of the values of the real parts of refractive index between the analyte and the environment.

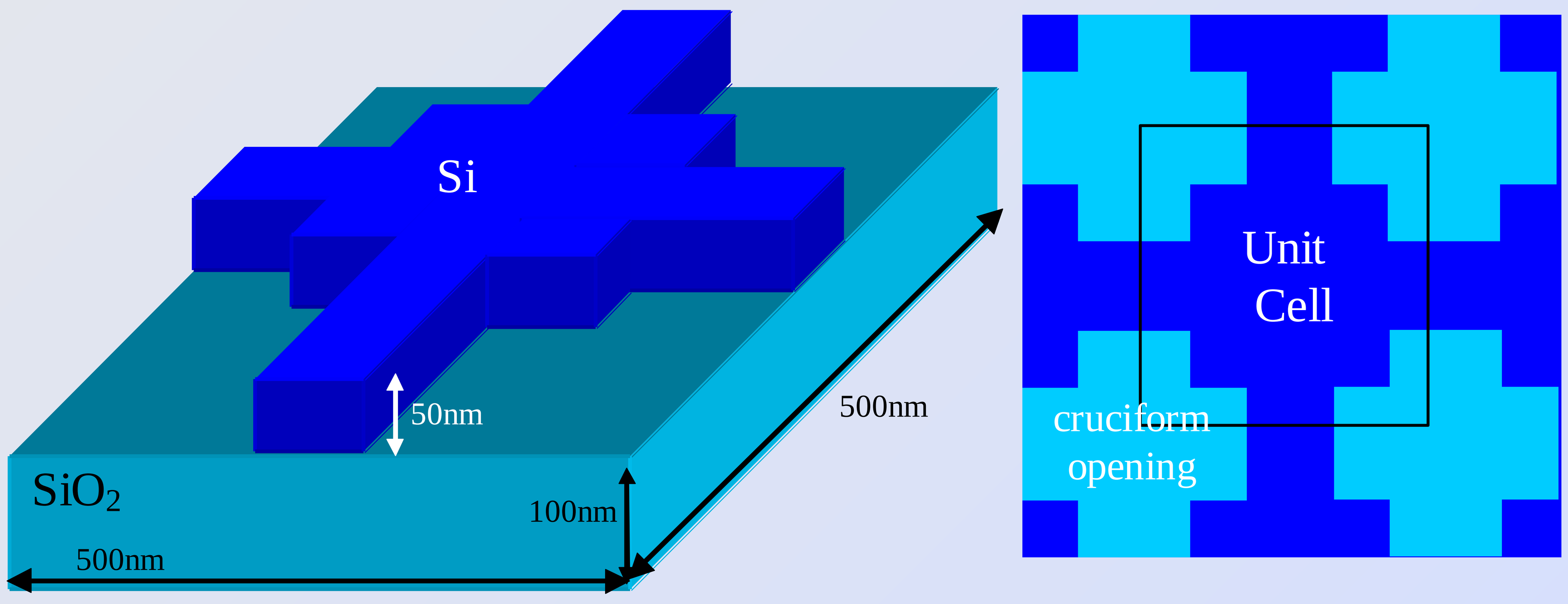

Fig. 1 Unit cell of an all-dielectric Si on SiO_2 metasurface.

Numerical analysis

We propose a metasurface as shown in Fig 1 formed by cruciform openings (cyan areas in the right part) in a thin silicon layer on a SiO_2 substrate. The structure is suspended in the air. For our FEM simulation (Comsol Multiphysics) we used realistic measured values for Si and SiO_2 refractive index taken from literature. Illumination is incident perpendicularly on the metasurface and the periodicity of the structure is simulated via Floquet-Bloch periodic boundary conditions. We gradually increase the imaginary part of the refractive index in the cruciform openings, starting with the lossless case, while maintaining the real part of refractive index equal to unity (air).

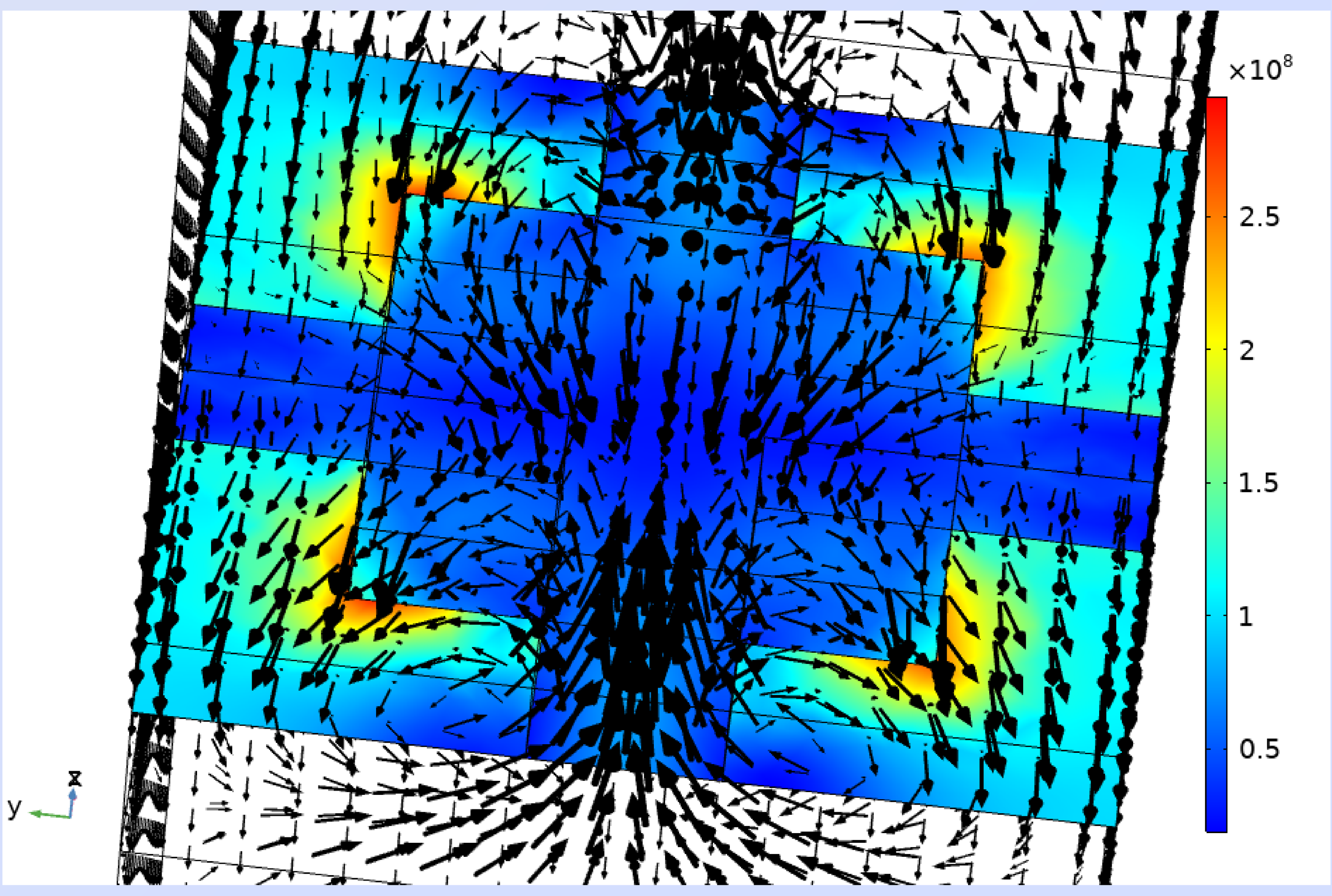

Fig. 2 Electric field distribution and circular power flow at a wavelength of 630 nm.

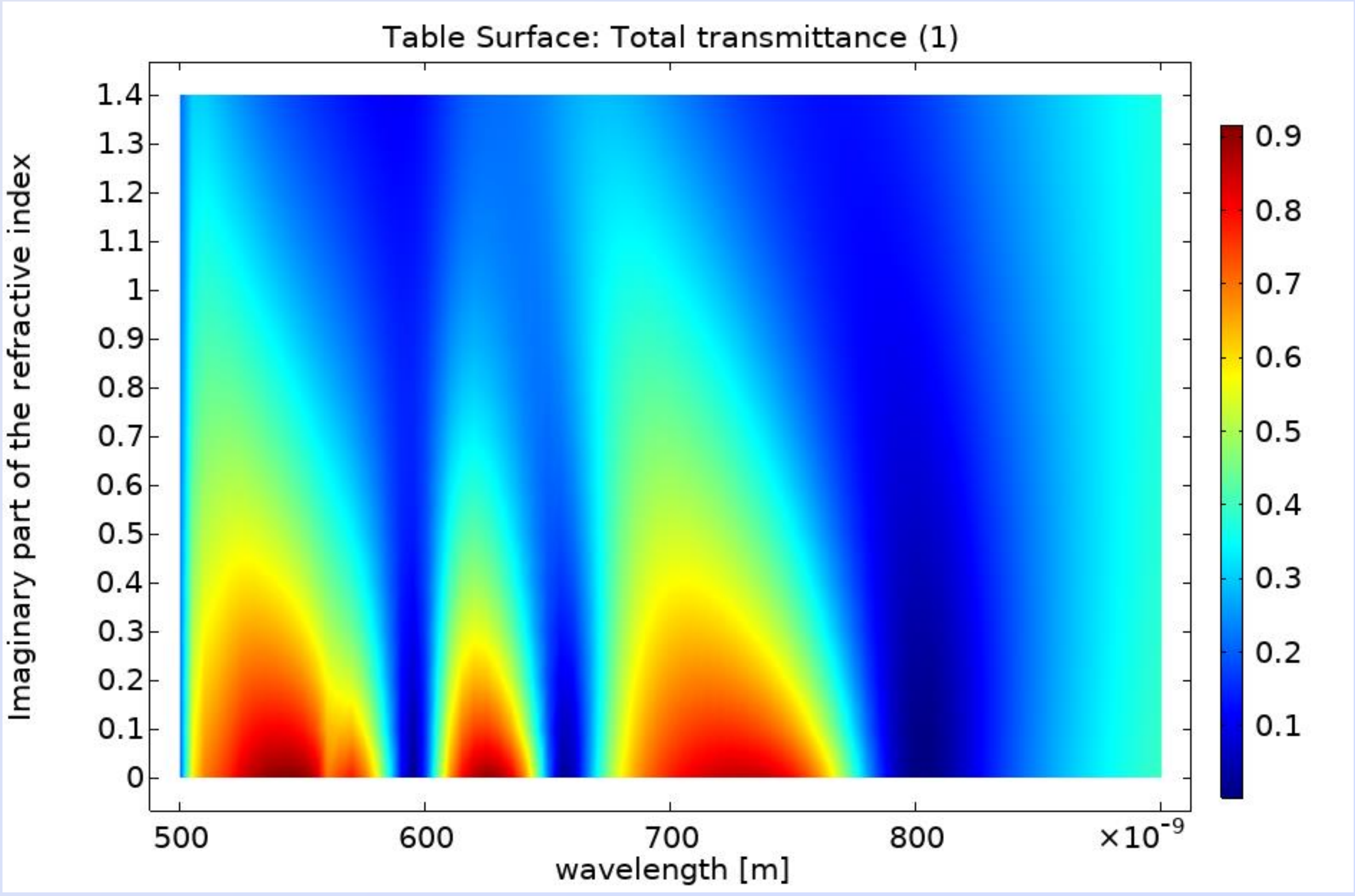

Fig. 3 Transmission dispersion depending on the material losses (imaginary part of refractive index) in the cruciform openings.

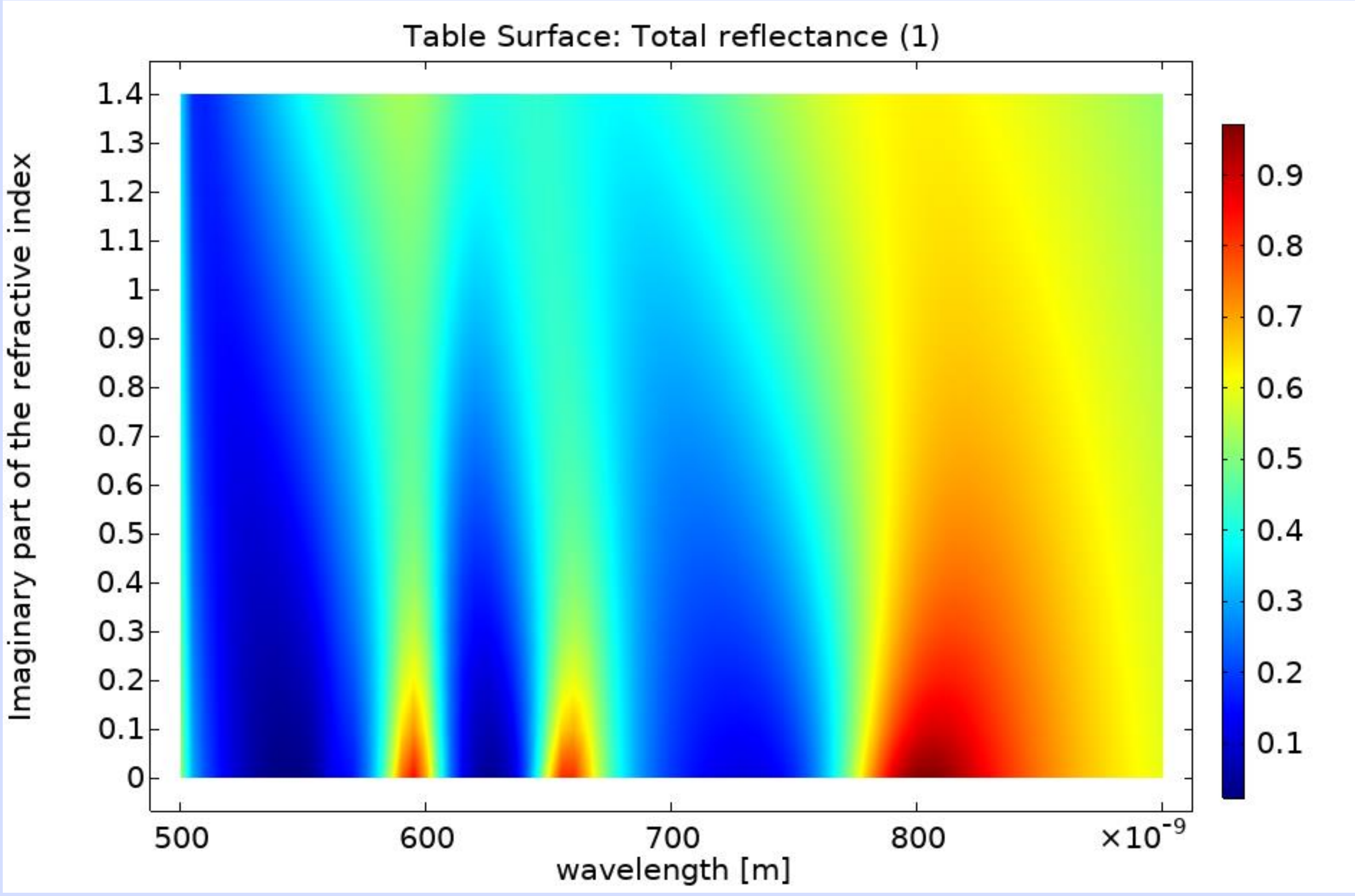

Fig. 4 Reflection dispersion depending on the material losses (imaginary part of refractive index) in the cruciform openings.

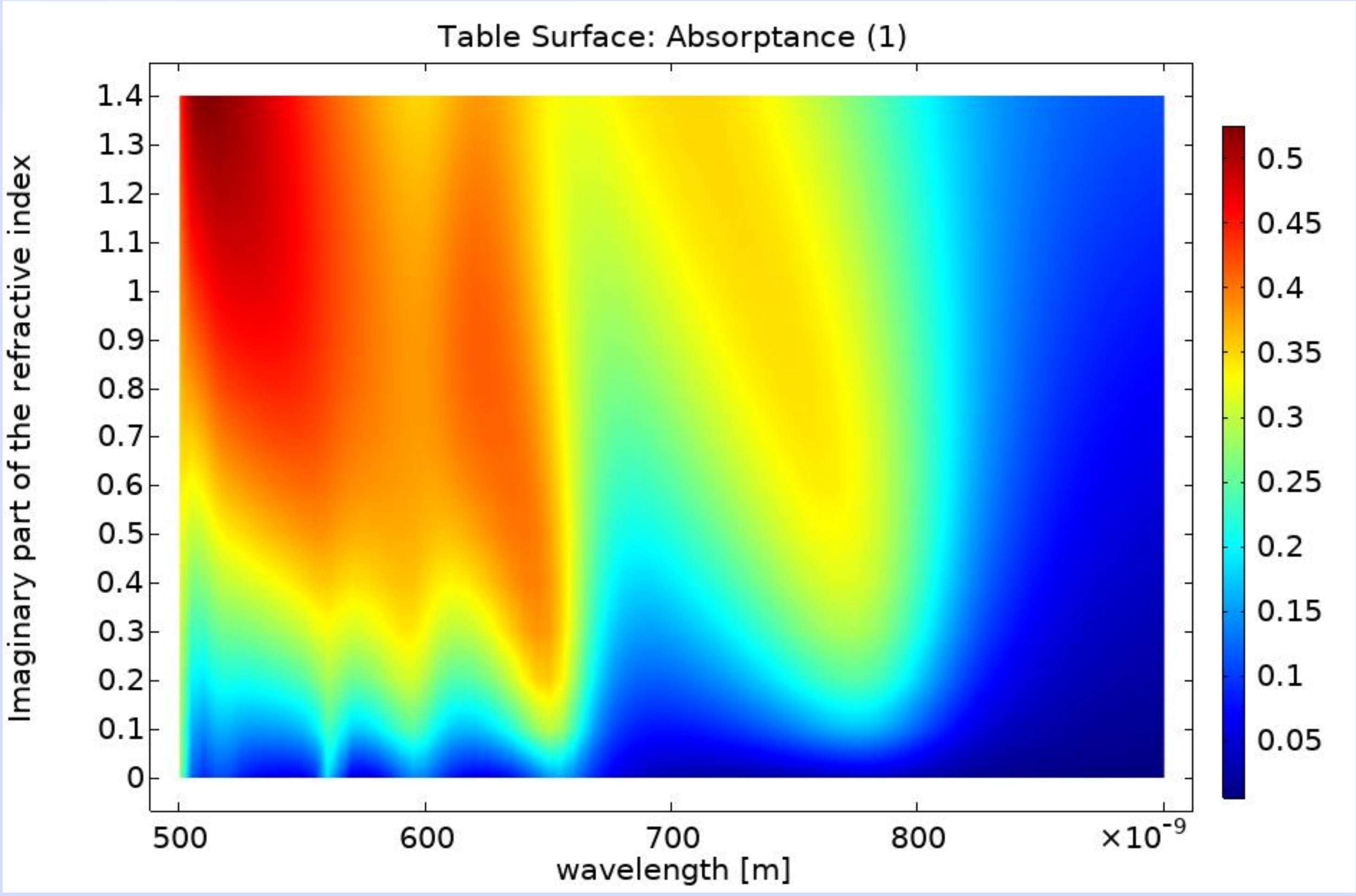

Fig.5 Absorption dispersion depending on the material losses (imaginary part of refractive index) in the cruciform openings.

Conclusion

We propose an alternative and counterintuitive approach to refractometric sensing utilizing all-dielectric metasurfaces. Instead of utilizing spectral shift we utilize quantitative changes in scattering parameters due to exceptional capabilities of optical metasurfaces in transforming optical space to sense analytes with identical real parts of refractive index but different imaginary parts (losses). The circular power flow that increases the optical path, the field localization and intrinsically low losses of the structure in the visible range all cause that adding even the smallest volumes of analyte with slightly increased optical absorption in comparison to the metasurface significantly reduces transmission through the structure, despite the exceptionally low structure thickness. The electric field distribution and its circular power flow, both at a wavelength of 630 nm, are shown in Fig. 2. Transmission, reflection and absorption dispersions depending on the material losses (imaginary part of the refractive index) in the cruciform openings are shown in Fig.3-5.

Acknowledgement

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