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Violation of Babinet principle in slab-supported complementary screens

Simone Zanotto* (1), Giorgio Biasiol(2), Giuseppe C. La Rocca(3), and Alessandro Tredicucci(1,4)
(1) Istituto Nanoscienze – CNR, and Laboratorio NEST, Scuola Normale Superiore, Piazza San Silvestro 12, 51627 Pisa, Italy. *e-mail: simone.zanotto@nano.cnr.it;
(2) Istituto Officina dei Materiali – CNR, Laboratorio TASC, Basovizza (TS), Italy.
(3) Scuola Normale Superiore and CNISM, Piazza dei Cavalieri 7, 56126 Pisa, Italy.
(4) Dipartimento di Fisica "E. Fermi", Università di Pisa, Largo B. Pontecorvo 3, 56127 Pisa, Italy.

Babinet principle states that $\psi + \psi_c = \psi^{(0)}$, where ψ, ψ_c, and $\psi^{(0)}$ are, respectively, the field scattered from a screen, the field scattered from the complementary screen, and the field in absence of any screen. Considering the vectorial nature of the electromagnetic field, Babinet principle elevates to a proper theorem, that is expressed by the relations $\mathbf{E} - c\mathbf{B}_c = \mathbf{E}^{(0)}$ and $c\mathbf{B} + \mathbf{E}_c = c\mathbf{B}^{(0)}$, where **E** and **B** are the electric and magnetic fields, and the sub/superscripts *c* and (0) have the same meaning as above [1]. Assuming that the screen does not show cross-polarization scattering, a corollary states that $T + T_c = 1$, i.e., that the transmittance of a screen plus that of the complementary screen give unity. However, the Babinet principle and its corollary require that the screen has vanishingly small thickness, that it is constituted by a perfectly conducting material, and that it is embedded in a homogeneous material. These conditions may not be met in certain technologically relevant situations. One such case occurs when the metallic patches that constitute the screen are placed on a finite-thickness dielectric membrane, like that depicted in Fig. 1a. This design, commonly employed in mid-infrared devices, allows to exploit the rich resonance spectrum provided by the guided-mode-resonance mechanism [2], and is instrumental to enable novel optomechanical light modulators [3]. We studied a series of samples that differ for the metal-to-void ratio f (Fig. 1b), where f and $-f$ constitute a Babinet-complementary pair. The spectra of Fig. 2c (dots = experiment, line = finite-element simulation) give a first insight towards the evidence of the violation of the relation $T(f) = 1\text{-}T(\text{-}f)$ that should hold if Babinet principle was at work. To provide more stringent evidence of the phenomenon, that in the experiment might have been impaired by sample imperfections (i.e., imaccurate realization of $(f, \text{-}f)$ pairs; thickness fluctuations), we studied by means of FEM a pair of exactly Babinet-complementary structures, with $t = 1.6$ µm and $f = \pm 0.25$. The transmittance spectra are reported in Fig. 1d, and show an evident violation of $T = 1\text{-}T_c$. However, if the dielectric layer is made vanishingly thin ($t \rightarrow 0$), complementary spectra are correctly recovered, as expected for complementary screens made of strongly subwavelength, almost perfectly-conducting patches. In conclusion we illustrated that Babinet principle can be violated in a situation of technological relevance in mid-infrared metsurface technology, where the presence of a dielectric in adjacency to complementary screens renders the usual symmetry relations strongly invalid.

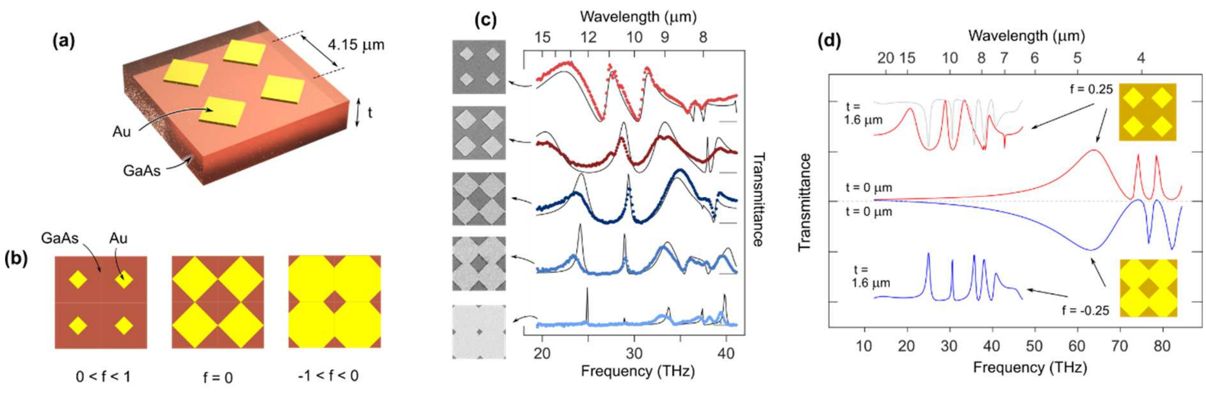

Figure 1. Schematic of the system under analysis: 3d view (a), top view (b). Transmittance spectra of different complementary screens (c). Violation of Babinet principle, in terms of $T \neq 1\text{-}T_c$, for the pair ($f = \pm 0.25$, t = 1.6 µm), as opposed to the pair ($f = \pm 0.25$, t = 0 µm) where $T = 1\text{-}T_c$ is observed (d).

References

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