Inverse design of general 2d-chiral lossless metasurfaces

S. Zanotto* (1), G. Mazzamuto(2), F. Riboli(2) , G. Biasiol(3) , G. C. La Rocca(4) , A. Tredicucci(1,5) , A. Pitanti(1)
(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) European Laboratory for Non-Linear Spectroscopy, via N. Carrara 1, 50019 Sesto Fiorentino (FI), Italy.
(3) Istituto Officina dei Materiali – CNR, Laboratorio TASC, Basovizza (TS), Italy.
(4) Scuola Normale Superiore and CNISM, Piazza dei Cavalieri 7, 56126 Pisa, Italy.
(5) Dipartimento di Fisica "E. Fermi", Università di Pisa, Largo B. Pontecorvo 3, 56127 Pisa, Italy.

Artificially structured electromagnetic media, that in the optical and infrared ranges are often named metasurfaces, have shown great potential about chiro-optical response, since they exhibit circular dichroism and birefringence per unit thickness far larger than in naturally occurring substances [1]. As for many passive components, metasurfaces of special interest are those without losses; due to the intrinsic Drude conductivity of metals in optical and infrared ranges the materials of choice are hence dielectrics, possibly high-index ones. In this work, we first show that wavelength-thick membranes consisting of gallium arsenide (GaAs), patterned with L-shaped holes (Fig. 1a), show strong chiral features in their spectra (Fig. 1b). Notice that the experimental spectrum (supercontinuum source based spectroscopy) is very well reproduced by the modeled one (Rigorous Coupled Wave Analysis – RCWA). The presence of transmission circular dichroism complies with the specific form of the transmission matrix (or Jones matrix, Fig. 1c). That form (i.e., the fact that $\boldsymbol{T}$ is symmetric) follows from a symmetry analysis valid for *all* non-centrosymmetric patterns [2], not only for the particular shape of the L-hole of the fabricated sample. We then addressed the inverse problem: is it possible to engineer a *specific* L-shaped hole array that matches a *numerically prescribed* form of the $\boldsymbol{T}$ matrix? We addressed the problem by a numerical search based on the interior point algorithm, relying on the MATLAB native functions and on a custom-written RCWA software (also known as Fourier Modal Method). We chose a large number (>100) of numerical instances of $\boldsymbol{T}$ matrices fulfilling the general form (Fig. 1c), and demonstrated that for each of them it is possible to find the geometrical parameters of an L-shaped hole array that satisfies the problem. A prototypical (3 cases) subset of the solution space is illustrated in Fig. 1d-f: each of the L-hole arrays (geometry depicted on the upper part) exactly has the $\boldsymbol{T}$ matrix indicated at the bottom. We also illustrated schematically the metasurface wave operation: cases (d-f) correspond, respectively, to a circular polarizer, a circular polarizer plus a phase shifter, and an elliptical polarizer. Notice that the device is overall unitary; the apparent energy loss is due to the presence of a finite reflectivity. We believe that the present study highlights the potentials of computer designed, near-infrared dielectric metasurfaces as general amplitude and polarization manipulators.

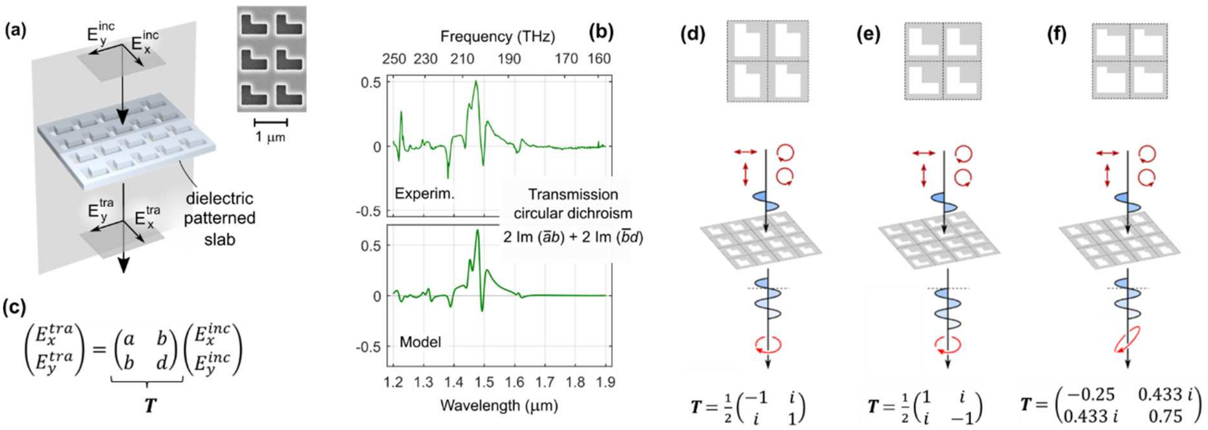

Figure 1. Concept and data illustrating the inverse design of 2d-chiral dielectric metasurfaces.

References

[1] Z. Wang, F. Cheng, T. Winsor, Y. Liu, "Optical chiral metamaterials: a review of the fundamentals, fabrication methods and applications", *Nanotechnology* **2016**, *27*, 412001.

[2] C. Menzel, C. Rockstuhl, F. Lederer, "Advanced Jones calculus for the classification of periodic metamaterials", *Phys. Rev. A* **2010**, *82*, 053811.