From Microwaves to Optics: All-Dielectric Solutions for Coordinate Transformation-Based Devices

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Invariance of Maxwell’s equations to coordinate transformations has provided a basis for the development of Transformation Optics (TO), the new powerful tool for advancing existing and creating novel electromagnetic devices with unprecedented functionalities and potential range of applications from microwaves to optics [1]. Coordinate transformations derived for compressing, expanding, bending, or twisting the wave paths enabled designs of invisibility cloaks, flat lenses, curvilinear waveguides, beam shifters, unconventional antennas etc. However, realization of the full TO potential depends on access to the media, in which prescribed by the theory spatial dispersion of material parameters, such as permittivity, permeability and/or refractive index, could be implemented. As a rule, this dispersion should be anisotropic, while material parameters should attain singular values, so that wave propagation with superluminal phase velocities could be provided. The first candidates for TO media appeared to be metamaterials (MMs), i.e. artificial material structures supporting homogenized Lorentz-type resonance responses and exhibiting the effective parameters in a wide range from negative to positive values [2]. However, conventional metamaterials composed of metallic cut wires and split-ring resonators, were found to become increasingly lossy at higher frequencies.

As an alternative to conventional MMs, this work presents all-dielectric MMs composed of identical resonators. For microwave applications, these resonators were made of ceramics [3]. Employment of nano-sized chalcogenide glass resonators provided an opportunity to develop the first invisibility cloak for the infrared range (Fig. 1a) [4]. Furthermore, in order to overcome inherent for MMs problems of homogenization and extremely narrow band of operation, all-dielectric rod arrays acting as photonic crystals (PhCs) have been proposed as the new media for TO-based devices [5]. Here the possibility to provide “superluminal response” in such PhCs and to use small topological changes of their lattices for controlling anisotropic index dispersion is demonstrated. An opportunity to employ the phenomenon of self-collimation [6] is another benefit of PhCs. Fig. 1b illustrates wave pattern observed due to self-collimation of waves moving with superluminal phase velocity along circumferences of dielectric rod arrays in the cylindrical cloak. Revealed advantages of dielectric PhCs combined with their low losses make them the most perspective media for TO applications, while mature and highly reliable technology of fabricating PhCs for optical range promises realization of optical TO devices in the near future.

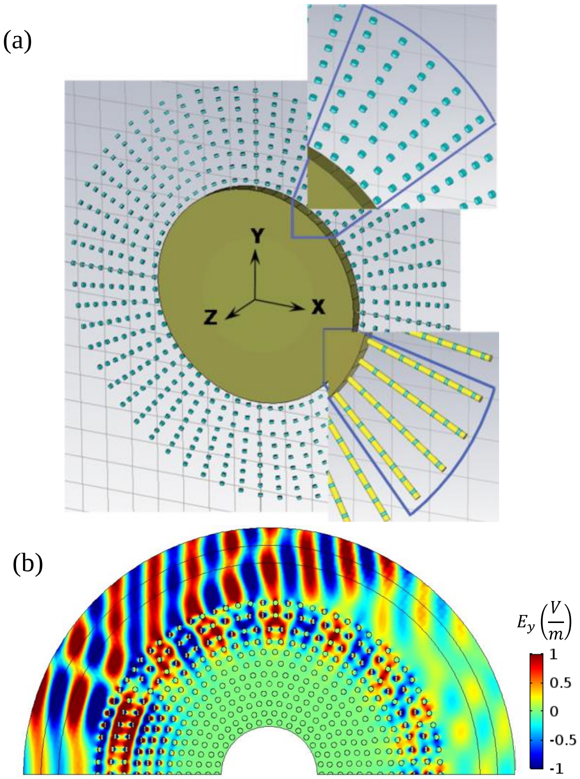

Fig. 1 (a) A glass cloak designed to hide a metal cylinder of 15 µm in diameter; upper inset highlights lattice changes; and lower inset depicts cylindrical spokes comprising glass resonators and fused silica spacers. (b) Snapshots of electric field patterns in the cross-section of a PhC-based cloak. Waves are incident from the left.

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