Asymmetric Transmission of Light through a Planar Chiral Metamaterial

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Abstract: We report that normal incidence transmission of circularly polarized light through lossy anisotropic planar chiral meta-material is asymmetric for opposite directions. The new effect is fundamentally distinct from conventional gyrotropy of bulk chiral media and the Faraday Effect.

In this paper, we show that a previously unknown fundamental phenomenon of electromagnetism can be observed in the optical part of the spectrum. It is a polarization sensitive transmission effect, asymmetric with respect to the direction of wave propagation, and results from the interaction of an electromagnetic wave with a nano-structured *planar* chiral meta-material. The new effect partially resembles the famous non-reciprocity of the Faraday Effect in magnetized media, but crucially requires no magnetic field. Both in the Faraday Effect and in that produced by planar chirality, transmission and retardation of a circularly polarized wave are different in opposite directions.

There are also essential differences between the two phenomena. The asymmetry of the Faraday Effect applies to the transmission and retardation of the *incident* circularly polarized wave itself, whereas the planar chirality effect leads to partial conversion of the incident wave into one of opposite handedness, and it is the efficiency of latter that causes the asymmetry. The predicted effect is also radically different from conventional gyrotropy in 3D-chiral media, which is completely symmetric for waves propagating in opposite directions.

The *asymmetric* transmission phenomenon can only be observed if both *planar chirality* and *anisotropy* are present in the structure of a meta-material. It is therefore forbidden in isotropic planar chiral arrays of high symmetry such as array of 4-fold gammadions.

The new propagation phenomenon was initially discovered experimentally in the microwave part of the spectrum [1]. It was then found that it extends into the visible to near-IR parts of the spectrum using pseudo-spectral time domain (PSTD) modeling. The chiral 'fish-scale' is a continuous 2D pattern of tilted meanders periodic in both directions (see figure) existing in two enantiomeric forms interconnected by reflection across a mirror line in the plane of the structure. The composition of the modeled metamaterial included a 50 nm thick aluminium layer patterned on sub-wavelength scale (meander strip width also 50 nm) and a much thicker supporting silica substrate. The square unit cell of the double-periodic pattern of 440 x 440 nm² ensured that the nano-structured meta-material would not diffract, even in the visible spectrum.

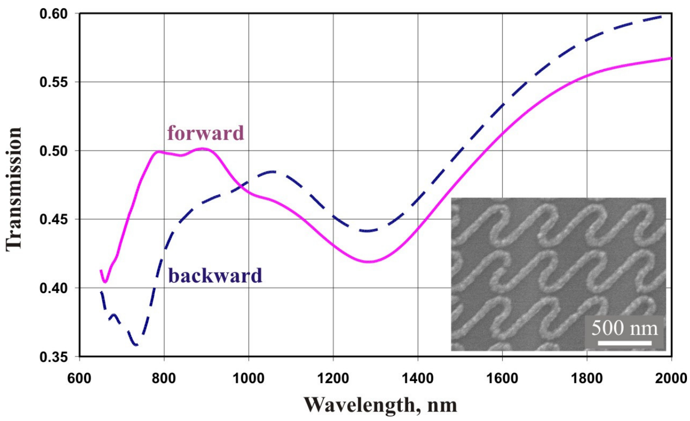

Fig.: The difference in transmission for forward (dashed line) and backward (solid) propagation (nano-wire layer considered the front) of right circularly polarized light incident on planar chiral fish-scale nanostructures is shown. The difference in transmission is the signature of the discovered asymmetry. The inset depicts an accordingly manufactured Al on SiO_2 nanostructure, seen through a scanning electron microscope.

The predicted effect, expected for a nano-structured anisotropic planar chiral meta-material in the optical part of the spectrum, results from 2D chirality and anisotropy of the metallic nano-structure and is inherently linked to dissipation in the metal. The discovery may result in the development of new spectroscopic techniques and may find numerous optoelectronic applications. For instance, when placed into a ring resonator, it will enforce generation of left and right elliptically polarized waves in opposite directions of circulation.

[1] V. A. Fedotov, P. L. Mladyonov, S. L. Prosvirnin, A. V. Rogacheva, Y. Chen, N. I. Zheludev, "Circular conversion dichroism in planar chiral metamaterials," *Phys. Rev. Lett.*, in press (2006) [arXiv: physics/0604234].