Giant linear and nonlinear optical activity in metamaterials

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Abstract— We report million-fold enhancement of nonlinear optical activity and metamaterial polarization spectral filters for any wavelength in the context of earlier chirality-based breakthroughs in the field of metamaterials including negative index and giant optical activity of planar interfaces.

Metamaterials have had and continue to have a dramatic impact on our understanding of chiral optical effects, such as optical activity, the ability to rotate the polarization state of light. They have enhanced known chiral effects by many orders of magnitude and led to the discovery of new ones. Here, an overview will be given, stretching from the most important earlier breakthroughs to recent key discoveries.

Giant optical activity and negative refractive index. In conventional optically active materials, polarization rotation is a weak effect that only becomes significant if it can accumulate over an interaction distance that is long compared to the wavelength. In metamaterials, on the other hand, polarization rotation of 10s of degrees in layers that are thin compared to the wavelength is not unusual and has even led to a negative refractive index for circularly polarized waves [1, 2].

Optically active achiral interfaces. Conventionally, optical activity is associated with intrinsically chiral media. However, we demonstrate that optical activity can also be present if chirality is associated with the light propagation direction through an achiral structure [3]. In fact, such extrinsic chirality is present for (almost all) oblique directions of incidence onto any planar pattern lacking two-fold rotational symmetry. The associated optical activity can be huge, we demonstrate about 30 degrees polarization rotation in the near infrared for a nanostructured gold film of only 50 nm thickness. The magnitude of optical activity in such structures can be continuously controlled via the direction of incidence and its sign is reversed for opposite incident angles.

Metamaterial polarization spectral filters for any wavelength. Polarization spectral filters can give rise to a ripples-free, narrow, isolated transmission peak combined with a wide acceptance angle. However, they rely on expensive, optically active crystals with an accidental birefringence zero-crossing which limits them to selected transmission wavelengths in the optical part of the spectrum. We demonstrate that low-cost polarization spectral filters for any wavelength, from microwaves to optics, can be realized using resonant optical activity in planar metamaterials [4].

Giant nonlinear optical activity. It was predicted in 1950 by Sergey Vavilov that optical activity should depend on the intensity of light [5]. Such nonlinear optical activity has been detected 29 years later in $LiIO_3$ [6], however, until now, it has remained a tiny effect that is challenging to detect. By combining exceptionally large linear optical activity at extrinsically chiral meta-surfaces [3] with enhanced nonlinear absorption in resonant gold nanostructures [7], we achieve a 40 million times enhancement of nonlinear optical activity compared to $LiIO_3$, effectively transforming nonlinear optical activity from a curiosity of nonlinear optics to a practically useful phenomenon.

In summary, we report million-fold enhancement of nonlinear optical activity and novel metamaterial polarization spectral filters for any wavelength in the context of earlier chirality-based breakthroughs in the field of metamaterials including negative index and giant optical activity of planar interfaces.

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