Negative Index Materials: New Frontiers in Optics

Costas M. Soukoulis
Ames Laboratory and Department of Physics, Iowa State University, Ames, Iowa, 50011, USA
Institute of Electronic Structure and Laser – FORTH and University of Crete, Heraklion, Crete Greece
e-mail: soukoulis@ameslab.gov

The possibility of negative refraction has brought about a reconsideration of many fundamental optical and electromagnetic phenomena. This new degree of freedom has provided a tremendous stimulus for the physics, optics and engineering communities to investigate how these new ideas can be utilized. Many interesting and potentially important effects not possible in positive refracting materials, such as near field refocusing and sub-diffraction limited imaging, have been predicted to occur when the refractive index changes sign. In this talk, I will review our own work on negative refraction in metamaterials, and describe the possible impact of them as new types of optical elements. In particular, I will present theoretical and experimental results on engineered microstructures designed to have both ε and μ negative.

Most of the negative index materials (NIMs) sample implementations to date have utilized the topology proposed by Pendry, consisting of split ring resonators (SRRs) and continuous wires. Recently different groups [1] observed indirectly negative μ at the THz region. In most of the THz experiments only one layer of SRRs were fabricated on a substrate and the transmission, *T*, was measured only for propagation perpendicular to the plane of the SRRs, exploiting the coupling of the electric field to the magnetic resonance of the SRR via asymmetry. This way it is not possible to drive the magnetic permeability negative. Also, no negative *n* with small imaginary part has been observed yet at the THz region. One reason is that is very difficult to measure with the existing topology of SRRs and continuous wires both the transmission, *T*, and reflection, *R*, along the direction parallel to the plane of the SRRs. So there is a need for alternative, improved and simplified designs that can be easily fabricated and experimentally characterized, especially in the infrared and optical regions of the spectrum. Such designs are offered by pairs of finite in length wires (short-wire-pair) and the fishnet structure, which will be discussed below.

A short-wire-pair can behave like an SRR, exhibiting a magnetic resonance followed by a negative permeability regime. Moreover, short-wire-pairs can give simultaneously a negative ε in the same frequency range, and therefore a negative *n*, without the need for additional continuous wires. Recent experiments have not shown though evidence of negative *n* at THz frequencies in the short wires-pair cases that were studied. Very recent work [1, 2] introduced new designs of short-wire-pair based metallic structures to obtain negative index of refraction in the different regimes. In addition, the fishnet structure was used and demonstrated experimentally [2] negative *n* at 1.5 microns with low losses. Finally, negative *n* at 780 nm was obtained [3] using the fishnet arrangement. The diamagnetic response and nonlinear effects of metamaterials will be also discussed.

Work supported by US-DOE, DARPA, MURI, ONR and EU (PHOREMOST, and METAMORPHOSE projects).

References

[1] C. M. Soukoulis, M. Kafesaki and E. N. Economou, *Adv. Matt.* **18**, 1941 2006); C. M. Soukoulis, *Optics & Photonics News*, June 2006, p.16.
[2] G. Dolling et. al. *Science* **312**, 892 (2006); *Opt. Lett.* **31**, 1800 (2006); *Opt. Lett.* **32**, 53 (2007).
[3] C. M. Soukoulis, S. Linden and M. Wegener, *Science* **315**, 47 (2007)