Focus Issue on Metamaterials

INTRODUCTION

Within the past five years, metamaterials has become one of the hottest topics in several areas of science and technology, encompassing electromagnetism and photonics, materials science, and engineering. "Meta" means "beyond" in Greek–beyond conventional. What is so magical about this simple merging of "meta" and "materials" that it has attracted so much attention from researchers and has resulted in an exponentially growing number of publications in the field?

The notion of metamaterials, i.e., artificial materials with properties not available in nature, originated in the microwave community but has been quickly adopted in optics research, thanks to rapidly developing nanofabrication and subwavelength imaging techniques. Metamaterials are expected to open a new gateway to unprecedented electromagnetic properties and functionality that are unattainable from naturally occurring materials. The structural units of metamaterials can be tailored in shape and size; their composition and morphology can be artificially tuned, and inclusions can be designed and placed at desired locations to achieve new functionality.

In the broad sense as defined above, the field of metamaterials includes a large range of engineered materials with predesigned properties. However, the notion of metamaterials was originally proposed in regard to the idea of a negative refractive index, or negative-index materials (NIMs), which are also referred to as left-handed materials (LHMs). This Focus Issue of JOSA B places its attention on the theory and applications of negative-index metamaterials. Such metamaterials bring the refractive index into a new domain of exploration and thus promise to create entirely new prospects for manipulating light, with revolutionary impacts on present-day optical technologies.

In some sense, it is a luxury in science when researchers are encouraged to reconsider and possibly even revise the interpretation of very basic laws. The notion of a negative refractive index is one such case. This is because the index of refraction enters into the basic formulas for optics. Hence bringing the index into a new domain of negative values truly excites the imagination of researchers worldwide. The refractive index of a material gives the factor by which the phase velocity of light is decreased in the material compared to vacuum. NIMs have a negative refractive index, so the phase velocity is directed against the flow of energy in a NIM, which is unusual for "conventional" optics. Still, it is probably not surprising to learn that a few scientific giants considered phenomena related to NIMs quite some time ago. Their studies were perhaps so early that they could not be fully appreciated by contemporaries. Thus negative phase velocity and its consequences were discussed in papers by H. Lamb and A. Schuster in 1904, and the optical properties of NIMs were studied by two Russian physicists, L. I. Mandel'stam in 1944 and V. G. Veselago in 1967. The recent boom in NIMs was indeed inspired by Sir John Pendry, who made a number of critical contributions to the field, including his famous prediction of the NIM-based superlens with resolution beyond the diffraction limit.

I was asked to coordinate this first-ever JOSA B Focus Issue on Metamaterials and invite contributions from leading researchers in the field. The list of invited authors includes pioneers and newcomers to this intriguing and fertile area of research. Below is a brief outline of the papers included in the issue.

The area of metamaterials crosses the boundaries of traditional spectral ranges from radio waves to the optical frequencies and adopts many ideas from different areas of electromagnetics. To accommodate such a trans-spectral range of metamaterials, this JOSA B Focus Issue includes papers outside of the traditional JOSA optical range. NIMs in the gigahertz range, where the first metamaterials were fabricated, are discussed in papers by Caglayan *et al.*, and by Aydin and Ozbay, for example. Recent breakthroughs in efforts to bring NIMs to the important optical range are reflected in papers by Kildishev *et al.* (Purdue University) and S. Zhang *et al.* (University of New Mexico and Columbia University). The Purdue team demonstrated their first optical NIM by using an array of paired metal rods in a dielectric, whereas the UNM-Columbia team used the inverted system of paired dielectric holes in a metal, which is, in accordance with the Babinet principle, a physically equivalent system. Theoretical bases related to homogenization of metamaterials are discussed in an invited paper by Smith and Pendry. The spectroscopic characterization of NIMs at high frequencies is reviewed in a paper by Padilla *et al.*

Studies on the important superlensing effect are presented in several papers within this issue. Theoretical limits in the spatial resolution of a superlens are discussed in papers by Li *et al.* and by Koschny *et al.* A paper by Korobkin *et al.* studies the midinfrared superlensing effect in silicon-carbide metamaterials. Tunable superlensing in photonic crystals with mechanically controlled properties are discussed in a paper by Wu *et al.* Melville and Blaikie consider in their paper superlens applications for optical nanolithography.

Several papers in this issue describe recent developments in the theory and numerical modeling of NIMs. For example, Wangberg *et al.* propose an elegant approach for NIMs based on nonmagnetic nanocomposites. The unusual properties of superlattices involving photonic crystal slabs with a negative index of refraction are discussed by Panoiu *et al.* The eikonal equation approach and the numerical simulation of a graded refractive-index (GRIN) lens is discussed in a paper by Parazzoli *et al.* Depine *et al.* develop a vector theory for diffraction by gratings made up of NIM structures. Nonlinear optical phenomena, such as second-harmonic generation and optical solitons, are discussed in papers by Shadrivov *et al.* and Gabitov *et al.*, respectively.

A number of interesting new applications for NIMs are also discussed in this issue. Boardman and Marinov consider nonradiative NIMs and their use for developing novel detectors. Innovative ultra-thin laser cavities based on metamaterials are discussed by Ziolkowski. Iyer and Eleftheriades study NIMs based on transmission lines and their applications for superlenses. A very interesting idea of optical nanotransmission lines and their applications for novel optical circuits and sub-wavelength waveguides are discussed in a paper by Alu and Engheta.

To conclude this introduction, I would like to thank George Stegeman for suggesting this Focus Issue on Metamaterials and Allan Boardman for its editing. In addition, I am deeply grateful to all of the contributing authors for their effort and willingness to share their recent results within the framework of this JOSA B Focus Issue that promises to be a landmark collection of papers in the field of negative-index metamaterials.

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Feature Editor
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