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C.M. Krowne Y. Zhang (Eds.)

Physics of Negative Refraction and Negative Index Materials

Optical and Electronic Aspects and Diversified Approaches

With 228 Figures

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Preface

There are many potentially interesting phenomena that can be obtained with wave refraction in the "wrong" direction, what is commonly now referred to as negative refraction. All sorts of physically new operations and devices come to mind, such as new beam controlling components, reflectionless interfaces, flat lenses, higher quality lens or "super lenses," reversal of lenses action, new imaging components, redistribution of energy density in guided wave components, to name only a few of the possibilities. Negative index materials are generally, but not always associated with negative refracting materials, and have the added property of having the projection of the power flow or Poynting vector opposite to that of the propagation vector. This attribute enables the localized wave behavior on a subwavelength scale, not only inside lenses and in the near field outside of them, but also in principle in the far field of them, to have field reconstruction and localized enhancement, something not readily found in ordinary matter, referred to as positive index materials.

Often investigators have had to create, even when using positive index materials, interfaces based upon macroscopic or microscopic layers, or even heterostructure layers of materials, to obtain the field behavior they are seeking. For obtaining negative indices of refraction, microscopic inclusions in a host matrix material have been used anywhere from the photonic crystal regime all the way into the metamaterial regime. These regimes take one from the wavelength size on the order of the separation between inclusions to that where many inclusions are sampled by a wavelength of the electromagnetic field. Generally in photonic crystals and metamaterials, a Brillouin zone in reciprocal space exists due to the regular repetitive pattern of unit cells of inclusions, where each unit cell contains an arrangement of inclusions, in analogy to that seen in natural materials made up of atoms. Only here, the arrangements consist of artificial "atoms" constituting an artificial lattice.

The first two chapters of this book (Chaps. 1 and 2) address the use of uniform media to generate the negative refraction, and examine what happens to optical waves in crystals, electron waves in heterostructures, and guided waves in bicrystals. The first chapter also contrasts the underlying physics in various approaches adopted or proposed for achieving negative refraction and examines the effects of anisotropy, as does the second chapter for negative index materials (left-handed materials). Obtaining left-handed material behavior by utilizing a permeability tensor modification employing magnetic material inclusions is investigated in Chap. 3. Effects of spatial dispersion in the permittivity tensor can be important to understanding excitonic–electromagnetic interactions (exciton–polaritons) and their ability to generate negative indices and negative refraction. This and other polariton issues are discussed in Chap. 4.

The next group of chapters, Chaps. 5 and 6, in the book looks at negative refraction in photonic crystals. This includes studying the effects in the microwave frequency regime on such lattices constructed as flat lenses or prisms, in two dimensional arrangements of inclusions, which may be of dielectric or metallic nature, immersed in a dielectric host medium, which could be air or vacuum. Even slight perturbations or crystalline disorder effects can be studied, as is done in Chap. 7 on quasi-crystals. Analogs to photonic fields do exist in mechanical systems, and Chap. 8 examines this area for acoustic fields which in the macroscopic sense are phonon fields on the large scale.

Finally, the last group of chapters investigates split ring resonator and wire unit cells to make metamaterials for creation of negative index materials. Chapter 9 does this as well as treating some of the range between metamaterials and photonic crystals by modeling and measuring split ring resonators and metallic disks. Chapter 10 looks at the effects of the split ring resonator and wire unit cells on left-handed guided wave propagation, finding very low loss frequency bands. Designing and fabricating split ring resonator and wire unit cells for lens applications is the topic of Chap. 11. This chapter has extensive modeling studies of various configurations of the elements and arrangements of their rectangular symmetry system lattice. The last chapter in this group and of the book, Chap. 12, delves into the area of nonlinear effects, expected with enhanced field densities in specific areas of the inclusions. For example, field densities may be orders of magnitude higher in the vicinity of the gaps in the split rings, than elsewhere, and it is here that a material could be pushed into its nonlinear regime.

The chapters here all report on recent research within the last few years, and it is expected that the many interesting fundamental scientific discoveries that have occurred and the applications which have resulted from them on negative index of refraction and negative index materials, will have a profound effect on the technology of the future. The contributors to this book prepared their chapters coming from very diversified backgrounds, and as such, provide the reader with unique perspectives toward the subject matter. Although the chapters are presented in the context of negative refraction and related phenomena, the contributions should be found relevant to broad areas in fundamental physics and material science beyond the original context of the research. We expect this area to continue to yield new discoveries, applications, and insertion into devices and components as time progresses.

Washington and Golden, June 2007

Clifford M. Krowne
Yong Zhang

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