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Focusing slabs made of negative index materials based on inhomogeneous dielectric rods

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We show the advantages of using inhomogeneous dielectric rods to design photonic crystals that behave as materials with negative refractive index. We found that the analysis of light scattering properties of inhomogeneous dielectric rods allows one to estimate the interval of frequencies where a photonic crystal exhibits negative refractive index. A triangular-lattice photonic crystal – assembled from multilayer dielectric rods designed to approximate a fish-eye profile – is shown to exhibit negative refractive index and good focusing properties at frequencies where the fish-eye dielectric rods scatter the light like a medium with negative refractive index.

1 Introduction The concept of left-handed electromagnetic media, which are also known as negative-index materials (NIMs), was introduced by Veselago [1]. Interest in these metamaterials was rejuvenated by Pendry [2] and Smith [3] who noted that the growth of evanescent fields within a NIM provides the opportunity for building a "perfect lens" that can focus electromagnetic waves to a spot size much smaller than a wavelength. Negative-index materials have recently been designed on the basis of composite wire and split ring resonator structures, backward-wave transmission lines, and photonic-band-gap crystals.

Usually, NIMs based on dielectrics are designed from homogeneous rods. In such a case, thick slabs consisting of a large number of rods are required for realizing good focusing. In the present work, we propose the design of a NIM lens from dielectric rods with a specific dielectric constant profile. This design leads to comparable or even improved focusing from much thinner slabs thus containing a much smaller number of rods.

2 Details of the approach A highly efficient and accurate multiple-scattering approach [4] is used to calculate propagation of electromagnetic waves through these structures. This procedure is much more efficient than alternative approaches such as high frequency structure simulation (HFSS) and finite difference time domain (FDTD) methods, which require much greater computer resources.

The elementary building blocks of our design are dielectric rods approximating a "fish-eye" refractive index profile [5] given by

$$n(r) = n_0/(1 + (r/r_0)^2)\,, \tag{1}$$

where r is the distance from the center of the rod and n_0, r_0 are constants. In such a material light propagates in circular (or spiral) trajectories with a radius comparable to the quantity r_0, i.e. a medium with the "fish-eye" dielectric constant profile behaves like a NIM from the point of view of light scattering. To prove that a "fish-eye" rod will exhibit properties of NIM, let us first consider the design of dielectric rods from the point of view of light scattering. We use an approach based on the effective medium concept [6] to choose appropriate parameters for the dielectric profile of the rod. This method relies on using a hypothetic background medium with variable index of refraction in