Elementary Negative Responses in Subwavelength Optical Structures

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We use a spatial harmonic analysis (SHA) and the finite element method (FEM) to calculate the negative electric and magnetic responses of pairs of metallic strips. Recall that optical negative index materials (ONIMs) are defined as artificial materials (or metamaterials), which demonstrate a negative real part of their effective refractive index within the optical range. A possible approach to designing such materials is a periodic array of elementary coupled metal-dielectric resonators. We have already published results that show experimental validation of a negative refractive index in a periodic structure of coupled nanorods (see for example, V.M. Shalaev *et al*, Opt. Lett. **30**, 3356 (2005)). In this paper, a closer look is taken at the fact that the negative index in a periodic ONIM structure is a combination of the negative electric and the negative magnetic responses of an elementary resonator (elementary responses) and additional positive or negative responses due to the arrangement of elementary resonators in a periodic array (collective responses).

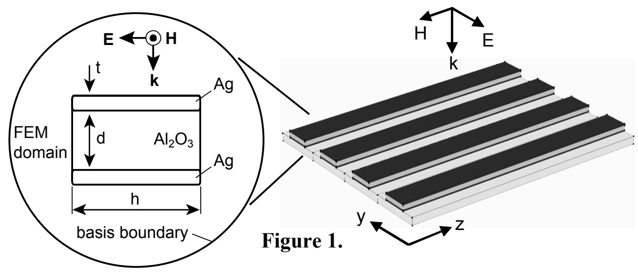

Figure 1.

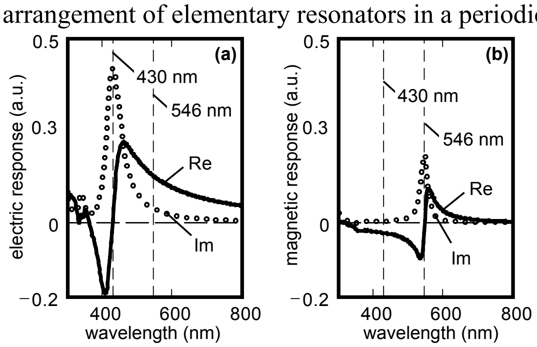

Figure 2.

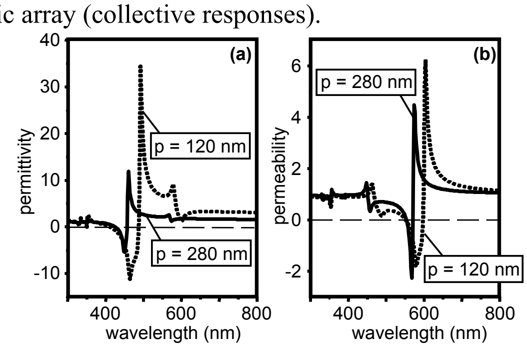

Figure 3.

To obtain the harmonic coefficients of elementary electric and magnetic responses, the SHA is applied to the field data obtained at the basis boundary. First, a truncated exact non-local boundary condition is used at the external boundary of the FEM domain to ensure the accuracy of results. The basis boundary for SHA is collocated with the external boundary of FEM, which encapsulates a given elementary resonator, as shown in Figure 1. (As an example, we choose pairs of infinitely long silver strips as the elementary resonators, $h = 70\,\mathrm{nm}$, $t = 16\,\mathrm{nm}$, and $d = 40\,\mathrm{nm}$).

A simulated example illustrating the elementary electric and magnetic responses of one pair of strips is shown in Figures 2-a and Figure 2-b respectively. Figure 3 depicts the real part of permittivity (Figure 3-a) and the real part of permeability (Figure 3-b) for the periodic structure. The period p is chosen to be 280 nm (solid lines) or 120 nm (dashed lines). It is found that $\mathrm{Re}(\varepsilon)$ of the long period array (Figure 3-a) shows a resonance at short wavelengths similar to the first odd harmonic coefficient for an elementary resonator response (Figure 2-a), however, an additional weak resonance occurs at longer wavelengths in case of the array. The deviations between the elementary resonator and the array increase for smaller periods and additional resonances appear (Figure 3-a). Similar behavior is observed for the collective magnetic response ($\mathrm{Re}(\mu)$ in Figure 3-b) in comparison to the first even harmonic coefficient shown in Figure 2-b.