Ultracompact Optical Cavity Resonator with Fishnet Structure

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A cavity resonator is one of the most basic electromagnetic components with important applications. Reducing the size of a cavity resonator is of both theoretical and application interests. It was shown that when a slab of metamaterial with negative permittivity and negative permeability (or double negative, DNG) is paired with a conventional dielectric (double positive, DPS), a cavity resonator with size much smaller than the operating wavelength can be achieved, which is on the contrary to the common knowledge (N. Engheta, IEEE Antennas Propagat. Lett., 1, 10-13, 2002). In such a design, the metamaterial slab works as a phase compensator to the conventional dielectric slab. Such an idea has been verified experimentally in the microwave domain, but no work has been done to extend it into the optical domain.

On the other hand, the fishnet structure has gained a lot of attention for its application in optical metamaterial design. It has been demonstrated both theoretically (S. Zhang, et. al, Opt. Expres., 13, 4922-4930) and experimentally (W. Wu, et. al, Appl. Phys. A, 87, 143-150, 2007) that such a structure gives a resonating feature when illuminated by a plane incident wave and can be modeled as a slab of artificial material with simultaneously negative ε and μ. This makes it a good candidate for cavity miniaturization as described above.

In this paper we describe a numerical demonstration of sub-wavelength size optical cavity resonator by applying the fishnet concept to the DPS/DNG structure. In our design, a single layer fishnet is inserted into a Fabry-Parot cavity composed of two gold slabs of 20nm thick in free space. The composite structure then gives a transmission resonance close to $1.9\,\mu m$ at plane wave incidence, while the total length of the cavity is only $180nm$. The resonant wavelength is adjustable in the near-IR domain by varying the design of the fishnet. We specifically emphasize that, although a single layer fishnet structure may not necessarily be described as a uniform metamaterial, it indeed provides a phase shift similar to a metamaterial slab, and thus helps to reduce the size of the cavity in our design. Such a structure is of great interest in modulator and filter design and applications.