New Development in Electrodynamics and Preparation of Left-Handed Materials

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About 36 years ago Victor Veselago considered theoretically propagation of the electromagnetic waves in a hypothetical medium, called Left-Handed Medium (LHM) where both electric permittivity ε and magnetic permeability μ are negative in some frequency range. Since the speed of light $c^2 = c_0^2/\varepsilon\mu$ is positive, the electromagnetic waves propagate but they have unusual properties, like anomalous Doppler and Cherenkov effects, negative light pressure, and negative refraction at the interface with a regular medium. The later property is the most interesting because it provides a three-dimensional imaging. The origin of all the properties is opposite directions of energy flux and wave vector. San Diego group has recently observed the negative refraction in the artificial composite system that contains metallic loops, creating magnetic moments and metallic wires. They have claimed this composite to be a two-dimensional LHM. Note that the metallic elements increase substantially the losses in the system.

Later on the preparation of the materials with a negative refraction moved to photonic crystals (PC) containing only dielectric elements. However, the negative refraction does not mean necessarily the LHM. We show that a two-dimensional PC made from a non-magnetic dielectric is a LHM in the sense defined by Veselago if the working frequency is below a Γ-point with negative group velocity. At this frequency the PC has negative values of both the electric permittivity ε and the magnetic permeability μ. This follows from a previously proven general theorems. The negative values of ε and μ have been found by a numerical simulation. Using these values for another simulation we demonstrate the Veselago lens, a unique optical device predicted by Veselago. An approximate analytical theory is proposed to calculate the values of ε and μ from the PC band structure. It gives the negative values that are close to those obtained by the numerical simulation. The theory explains how a non-zero magnetization arises in a non-magnetic PC. Many discussions have been recently whether the Veselago lens provides focusing above the diffraction limit (perfect focusing). A non-perfect focusing has been found and discussed in this work.

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