Fabrication of large-area negative-index metamaterial by Electron-Beam-Lithography

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Recently the term metamaterial was introduced to define artificial media which have no natural equivalent and which derive their properties from the geometry of structured raw materials. Specifically, the interaction of light with such an artificially nanostructured compound medium is governed by the spectral response of the artificial unit cell rather than the averaged intrinsic optical properties of underlying raw materials. Thus it is possible to design and create new materials in order to achieve new optical functionalities and pave the way for future applications of nano technologies in optics. Particularly it was shown that a negative index of refraction can be achieved in a metal-dielectric compound metamaterial. Such materials are called negative-index media. They show unique physical phenomena like the reversal of Snell's law and reversed Doppler and Cherenkov effects.

The practical realization of metamaterials relies on the use of modern nano technology. Presently most demonstrated studies use planar lithography techniques to produce thin layers of metamaterials. In order to obtain a negative refractive index of these thin metamaterial films for a particular wavelength the effective electric as well as the effective magnetic responses of the film's subwavelength unit cells must be controlled [1]. This can be achieved by a periodic subwavelength structuring of double metal layers separated by a dielectric spacer. Since the lateral pattern of the layer stack is a 2D grating, this type of negative-index material is often referred to as the 'fishnet-structure' [2].

The demand for subwavelength structuring for the IR-regime can be fulfilled by today's Electron-Beam-Lithography (EBL). However the desire for large area metamaterial films of several mm² to cm² is still a demanding task which requires highly productive exposure schemes. We used a Vistec SB350OS variable shaped beam electron writer to fabricate a negative-index material based on the fishnet-structure geometry. After EBL a lift-off step of a gold-magnesia-gold layer stack was performed. For this purpose, the chemically amplified electron beam resist FEP171 was evaluated in terms of its lift-off performance. Due to the high sensitivity of the resist, EBL exposure time was negligible and a sample with several arrays of large areas (3 mm x 3 mm) has been fabricated. These arrays include variations concerning the period and the duty cycle of the 2D unit cell. In addition we performed calculations by means of rigorous diffraction theory to evaluate the dispersion of our negative-index material. The theoretical predictions were confirmed by optical transmission and reflection measurements. As a result we obtained a negative index of refraction at telecommunication wavelength ($\lambda \approx 1500$ nm), which may contribute significantly to future practical implementations of metamaterials.

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References

[1] Soukoulis et al., Science 315, 47-49 (2007).
[2] Dolling et al., Science 312, 892-894 (2006).

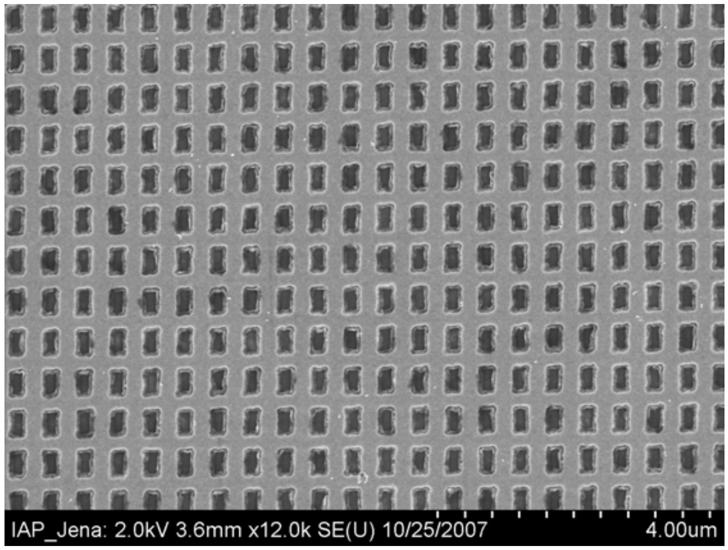

Fig 1: SEM-picture of the fabricated metamaterial (normal view).

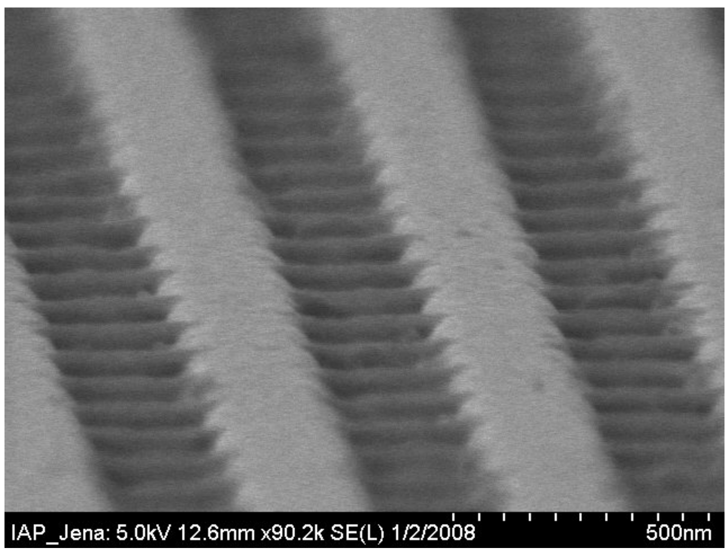

Fig 2: SEM-picture of the fabricated metamaterial (oblique view).

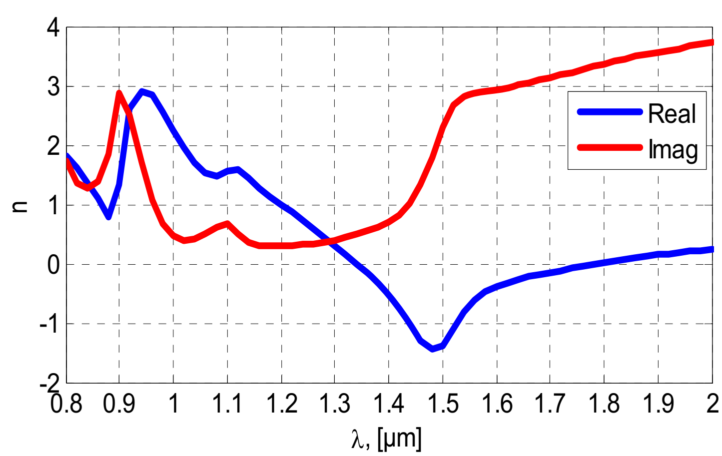

Fig 3: Effective refractive index of the fabricated metamaterial.