High aspect ratio lift-off process and silver optimization for negative index materials in the visible

I. Bergmair, A. Rank, M. Muehlberger
Functional Surfaces and Nanostructures, PROFACTOR GmbH, Austria
B. Dastmalchi, S. Tollabimazraehno, K. Hingerl, H. Piglmayer-Brezina, T. A. Klar
Johannes Kepler University Linz, Austria
M Losurdo, G Bruno
Institute of Inorganic Methodologies and of Plasmas-CNR, Bari, Italy
C. Helgert, E. Pshenay-Severin, M. Falkner, T. Pertsch, E. B. Kley
Institute for Applied Physics, Friedrich-Schiller-Universitaet Jena, Germany
M.A. Verschuuren
Philips Research, Eindhoven, The Netherlands
U. Huebner
Institute of Photonic Technologies, Jena, Germany
N H Shen, M Kafesaki, C M Soukoulis
Institute of Electronic Structure and Laser, FORTH, University of Crete, Greece

Negative-index materials (NIMs) have been at the forefront of optical research activities in the last decade. Typically, one single NIM layer consists of two patterned metallic gratings separated by a dielectric layer such that resonances for the electric and magnetic field occur upon interaction with electromagnetic radiation [1]. Several approaches have been applied to fabricate NIM working for infrared regime [2], [3], [4] and at visible frequencies using e-beam lithography [5] or focused ion beam cutting [6] on small area. One remaining issue in the field is the establishment of a versatile and high-speed fabrication technology which can deliver large-area nanostructured patterns for visible light NIMs. In this work we demonstrate for the first time the fabrication of large area NIMs with resonance frequencies in the visible regime by Nanoimprint Lithography – a method suitable for mass production. Our contribution constitutes an important step towards envisioned devices like perfect lenses and optical cloaks [7], [8].

For the NIL based lift-off process two materials with different etch rates, namely LOR1A (Microchem) and diluted Ormocomp (microresist technology GmbH) were used as transfer layer and as UV-NIL resist, respectively (Figure 1). When etching through the Ormocomp and LOR1A the etching rate for LOR1A is much faster such that recessed sidewalls are achieved in one etching step without the need of a liquid development step as reported in previous work [9]. Afterwards the silver and SiO_2 layers are deposited successively and lift-off is performed. This method enables to fabricated five layer NIMs on an area of around 2x2 cm² with an aspect ratio up to 3:1 (Figure 2). Afterwards the NIM material is annealed and passivated using a remote plasma process in order to optimize the optical response of the silver. We will show that by improving the chemical stability of the life time of samples under ambient conditions can be significantly increased. The optical properties of two fabricated samples with different design parameters were measured by transmission and reflection spectroscopy. From the measured data we found negative effective indices for these two samples at wavelengths around 660 nm (Figure 4) and 780 nm (Figure 3). Ongoing work is devoted to thestacking of NIM layers with the method demonstrated in ref. [9] to achieve 3D NIMs in the visible regime.

The authors acknowledge funding by the European Community's 7th Framework Programme under grant agreement no 228637 NIM_NIL (www.nimnil.org). The Austrian authors acknowledge additional funding from bmvit and ERC Starting Grant 257158.

[1] V. G. Veselago, Sov. Phys. Usp. 10, 509, (1968)
[2] Zhang et al. PRL 95, 137404 (2005)
[3] Shalaev. Opt Lett 30, 3356 (2005)
[4] D. Chanda et al., Nature Nanotechnology 6, 402 (2011)
[5] Xiao Opt. Lett. 34, 3478 (2009)
[6] C. Garcia-Meca et al. Phys. Rev. Lett. 106, 067402 (2011)
[7] D Schurig et al., Science **314,** 977 (2006)
[8] Q Wu et al. J. Opt. Soc. Am. A **24**, A45 (2007)
[9] I. Bergmair et al., Nanotechnology 22, 325301 (2011).

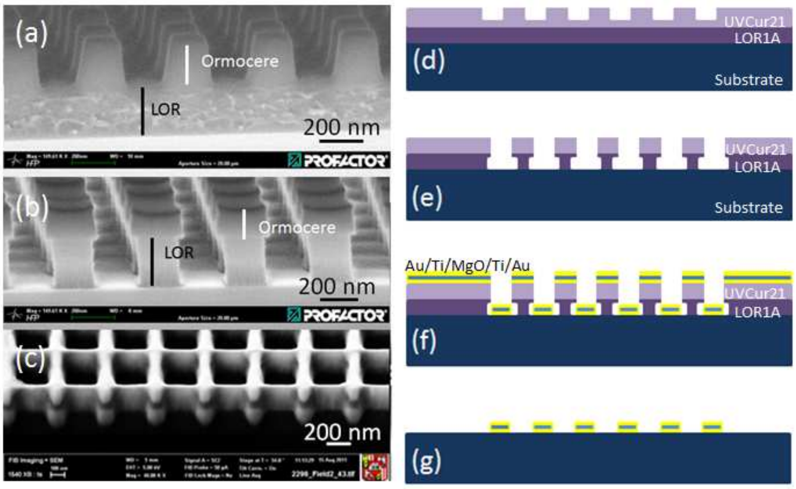

Figure 1: Cross sectional scanning electron microscope images (left) and schematic drawing of different process steps (right). (a), (d) Imprint into Ormocomp on LOR1A layer (b), (e) Imprint after etching to achieve recessed sidewalls due to different etching rates of the resists (f) Deposition of Ag, SiO_2, Ag (c), (g) Final sample after lift-off.

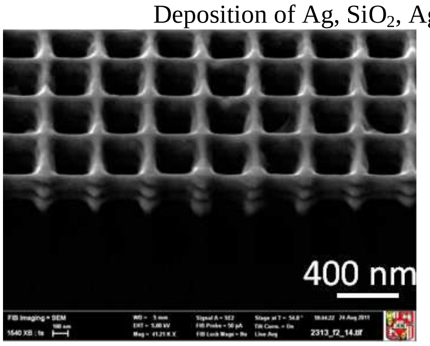

Figure 2: Cross sectional SEM image of 365 nm period NIM material showing an aspect ratio of 3:1.

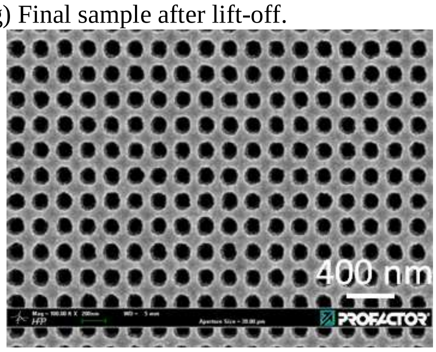

Figure 3: Scanning electron microscope image of a 200 nm period NIM material with resonance frequency at 660 nm

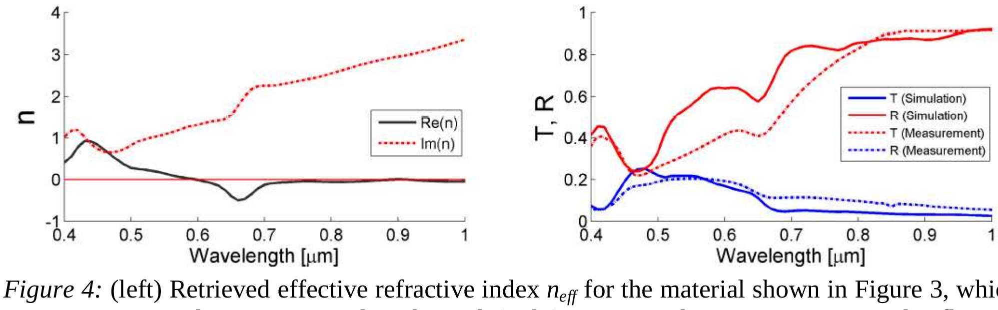

Figure 4: (left) Retrieved effective refractive index n_{eff} for the material shown in Figure 3, which is negative around 660 nm wavelengths and (right) corresponding transmission and reflection measurements compared to numerical simulations.