3D Metamaterials made of Gold fabricated by Nanoimprint Lithography

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In this work we show large area fabrication of Metamaterials like Split Ring Resonators (SRRs) and Fishnet structures using Nanoimprint Lithography (NIL). Such structures are called negative index materials, when the designed structures provide resonances for the electric and magnetic field such that negative refraction occurs [1]. Such effects were shown at different groups for single layers [2],[3] and only few approaches have been done to achieve 3D negative index materials using e-beam lithography or a focused ion beam on small area e.g. [4], [5]. We fabricated first single layers of such structures and further stacked the layer on top of each other to obtain a 3D material [7].

For structuring of the single layers we used a simple two layer resist lift-off process which was done using mr-UVCur06 or mr-UVCur21 from microresist technology [6] and LORA1 underneath as transfer layer. The imprint residual layer thickness was optimized to few nanometers. The 120 nm thick LORA1 transfer-layer was removed by a reactive ion etching step using an O2 plasma. Recessed sidewalls which are favorable for a lift-off process were achieved by a controlled development of the LORA1 underneath the UV-NIL resist. For the SRRs 2 nm of Ti and 40 nm Au were deposited and for the Fishnet pattern 1 nm Ti, 30 nm Au, 40 nm MgO, 1 nm Ti, 30 nm Au. The lift-off was done by immersing the sample in acetone to get rid of the LORA1 and the UV-NIL resist. The fishnet grating has a size of 1 x 1 cm² with period of 500 nm and 600 nm (Figure 1 and Figure 2). The results for the SRR structures are patterned fields with a size of 4.5 x 4.5 mm². The periods are ranging between 10 µm (figure 3) and 1 µm and a smallest line width of 80 nm.

First approaches have been done to achieve a 3D material. A Silicon substrate with SRRs on top was brought into contact with liquid Ormostamp (from microresist technology GmbH) which was droplet dispensed or spin coated on a glass substrate. The Ormostamp was UV-cured by illumination through the glass substrate. When the silicon substrate and the glass substrate are separated again, the gold structures stick to the glass substrate and are peeled off from the Silicon substrate such that they are transferred due to the adhesion of Ormostamp to the gold. Repeating this process up to four times results in the stacked SRRs as shown in figure 4. The process was performed on our EVG®620 nanoimprinter.

Measurements and interpretation of the datas are ongoing. The fishnet showed resonance at 1.5 µm.

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[1] Veselago V G, Sov. Phys. Usp. 10 (1968) 509

[2] W. Wu et al., Appl. Phys. Lett. **90**, 063107 (2007)

[3] S. Linden et al., Physik Journal **5** (12) 29 (2006)

[4] N. Liu et al., Nature Materials, **7,** 31 (2008)

[5] J. Valentine et al., nature 07247 (2008)

[6] M. Vogler, Microel. Eng. **84**, 984 (2007)

[7] I. Bergmair, Microel. Eng., Article in Press, (2009)

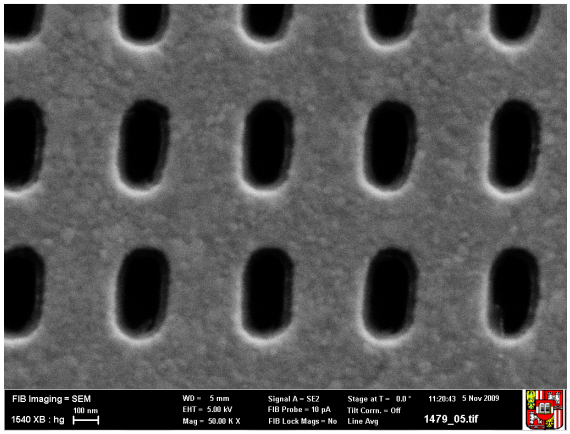

Figure 1. SEM image of Fishnet structure from top. The period in x direction is 500 nm and line width of line in x direction 220 nm. The period in y is 600 nm and line width of line in y direction 280 nm. The line width of the grating is 280 nm and 220 nm

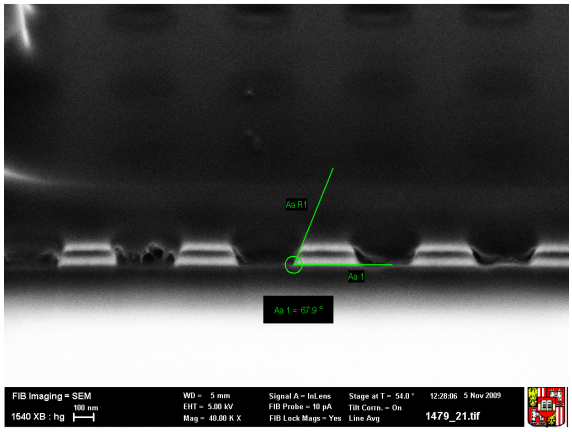

Figure 2. SEM cross sectional picture fishnet structure. The thickness of the Au layers is 30 nm and of the MgO layer in between 40 nm.

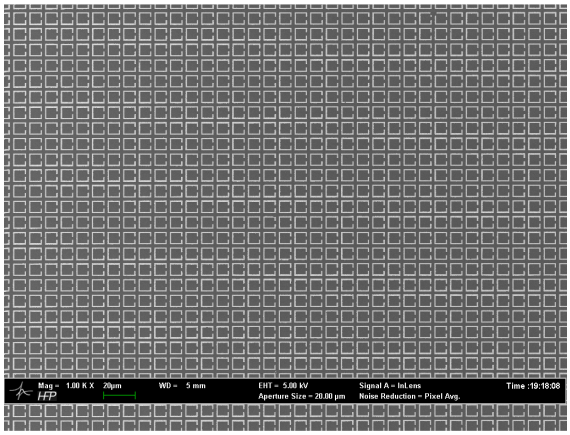

Figure 3. SEM image of Split Ring Resonators from top with a period of 10 µm and line width of 760 nm.

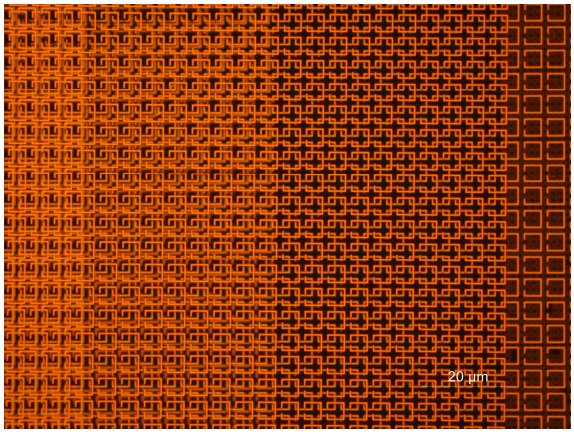

Figure 4. Optical image of four stacked layers of SRRs. They were imprinted with a shift so that from right to left, the first layer, the first and second layer, the first, second and third, and recently all four layers are visible.