A Hybrid Fabrication Approach for Near-Infrared Double-Helix Metamaterials

M. Decker¹, I. Staude¹, M. Renner², E. Waller², D. N. Neshev¹, G. von Freymann², Yu. S. Kivshar¹

1. Nonlinear Physics Centre, Research School of Physics and Engineering, The Australian National University, Canberra, ACT, Australia

2. Physics Department and Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany

3D metallic nanostructures offer unique light-manipulation functionalities for nanophotonics, including isotropic magnetic optical response, dispersion manipulation, and engineering of the complex polarization state of light. Particularly, chiral metamaterials offer remarkable opportunities to manipulate the polarization properties of circularly polarized light, leading to pronounced optical activity and circular dichroism [1-5]. As such gold-helix metamaterials have been introduced as compact and broadband circular polarizers [4,5]. However, the fabrication of 3D-chiral metamaterials optimized for operation in the near-infrared/telecom spectral range, has proven technologically demanding and to date their realization seems to be out of reach.

Here we employ our novel hybrid fabrication approach [6], combining direct laser writing with electron-beam lithography (EBL) metal nanostructure fabrication [see Fig.1(a)] to demonstrate 3D-tapered double-helix metamaterials with feature sizes well below 100 nm, which enables operation in the near-infrared (NIR) spectral range. Importantly the tapered helix design used here is expected to show improved performance and broadband operation compared to conventional (untapered) metallic helices [5].

Fig. 1 (a) Schematics of the novel hybrid fabrication approach. A glass substrate is pre-patterned via direct laser writing. Next, the electron-beam resist PMMA is spin-coated onto the pre-patterned substrate and exposed by electron-beam lithography (EBL). After PMMA development, a gold evaporation step and a standard lift-off procedure are performed. (b) Oblique and top-view (inset) SEM images of the double-helix metamaterial obtained by our fabrication approach. The lattice constant is 700 nm.

Our approach makes use of the 3D-writing capability of direct laser writing, while preserving the small feature sizes, the possibility of selective metallization, and the excellent gold quality of standard EBL-based fabrication schemes. It thereby allows for fabrication of high-quality 3D metal-dielectric nanostructures for photonic applications in the NIR spectral range. Using this approach we have fabricated and investigated a tapered helical metamaterial consisting of double-helix meta-atoms arranged in a periodic lattice with a lattice constant of 700 nm [see Fig.1 (b)]. The meta-atoms consist of two tapered helices with a pitch of 0.75 rotated by 180 degrees with respect to each other [see inset of Fig.1 (b)]. The double helices are processed on top of half-spheres with a radius of about 100 nm fabricated by direct laser writing using the photoresist IP-L from Nanoscribe. This results in a double-helix meta-atom with a diameter of approx. 200 nm, a line width of around 50 nm and a gold thickness of 20 nm. Our results open the way for new functional devices utilizing circular dichroism and optical activity in the NIR and visible spectral range.

References

- [1] E. Plum et al., "Giant optical gyrotropy due to electromagnetic coupling," *Appl. Phys. Lett.* **90**, 223113 (2002).
- [2] M. Decker et al., "Strong optical activity from twisted-cross photonic metamaterials," *Opt. Lett.* **34**, 2501 (2009).
- [3] N. Liu, H. Liu, S. Zhu, and H. Giessen, "Stereometamaterials," *Nature Photon.* **3**, 157 (2009).
- [4] J.K. Gansel et al., "Gold helix photonic metamaterial as broadband circular polarizer," *Science* **325**, 1513 (2009).
- [5] J.K. Gansel et al., "Tapered gold-helix metamaterials as improved circular polarizers," *Appl. Phys. Lett.* **100**, 101109 (2012).
- [6] I. Staude et al., "Hybrid High-Resolution Three-Dimensional Nanofabrication for Metamaterials and Nanoplasmonics" *Adv. Mater.* **early view**, DOI: 10.1002/adma.201203564 (2012).