Fabrication of Metallic Structures via Multi-Photon Polymerization

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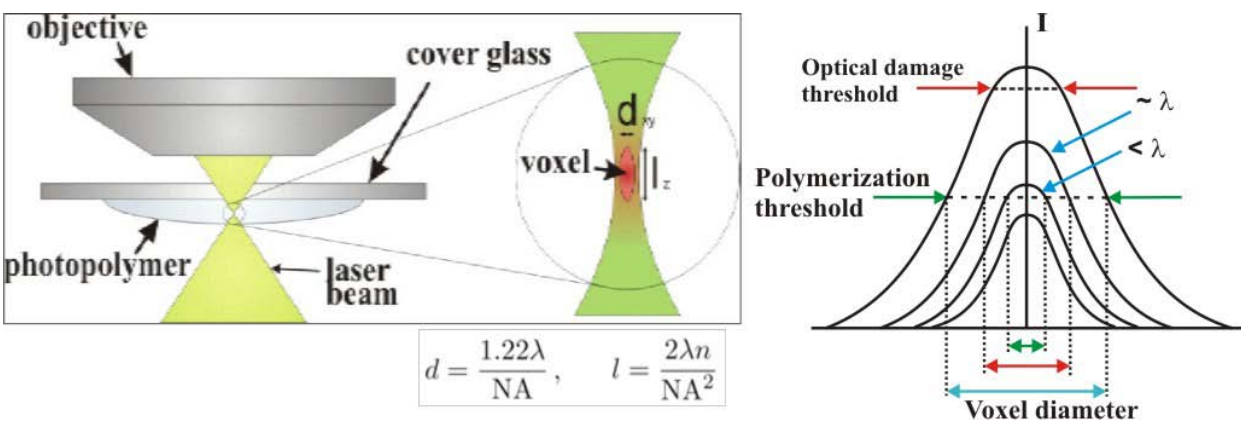
Abstract

We present our research into the modeling and fabrication of three-dimensional (3D) nanostructures by direct laser writing, using an organic-inorganic hybrid polymer that can be selectively covered with metal. This material exhibits low shrinkage when structuring, metal binding affinity and ohmic conductivity when covered with metal, allowing the fabrication of three-dimensional conducting nanostructures.

1. Introduction

Direct Laser Writing (DLW) by multi-photon polymerization offers true 3D micro/nanostructuring of photopolymers. Exposed to a tightly focused femtosecond laser beam, the photopolymer undergoes a multi-photon absorption induced polymerization. Due to non-linear nature of the process, the material is finally photomodified only within the volume where the laser intensity exceeds the threshold value, which is a volume of sub-diffractional dimensions (Fig. 1) [1]. There is no restriction in the sample translation trajectory, thus point-by-point photomodification can be induced with no geometrical restrains. DLW is a versatile tool to fabricate 3D nanostructures from various photosensitive materials for diverse applications in photonics, microoptics, nanofluidics and biomedicine [2-5]. The fabrication and metallization of nanostructures for metamaterial applications has become one of the recent research interests using DLW [6]. Here we discuss the fabrication of nanometer scale metamaterial structures using DLW and subsequent metallization. The structures fabricated are free standing split ring resonator and wire combinations, aimed to give negative refraction index response [7] in the infrared, as well as helical spiral structures which can offer polarization selective transmission of infrared light [8].



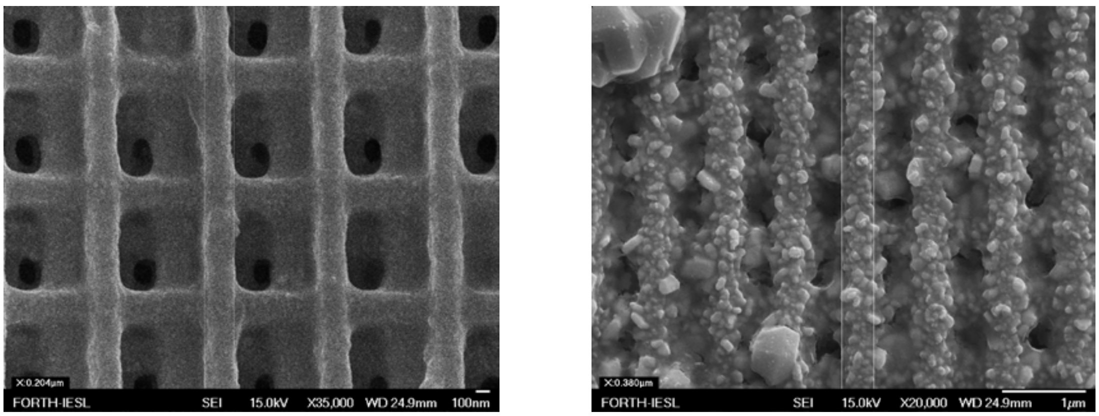
$$d = \frac{1.22\lambda}{\mathrm{NA}}, \qquad l = \frac{2\lambda n}{\mathrm{NA}^2}$$

Fig. 1: By precise adjusting introduced laser intensity I, the photomodified region – voxel – can go below diffraction limit, corresponding to applied laser light wavelength, in dimensions [9].

ISBN 978-952-67611-0-7

2. Materials

As the desired dimensions of the structure fabricated via DLW and subsequently metalized are in the few-hundred nanometer-scale, laser intensities near the threshold value are used. Material shrinkage, which is particularly important when the structures are fabricated near the polymerization threshold, is an issue that preferably should be avoided. Therefore, following the results of the shrinkage investigation of zirconium-silicon composite [2], a zirconium based sol-gel is used as a base. This allows the fabrication of high quality and resolution nanostructures that do not suffer from shrinkage distortion. Due to the incorporated metal binding groups, the material can be readily metalized with silver and other metals by simple immersion in a metal bath, without the need to modify the surface of the structures or to use other, complementary techniques [10]. An example is shown in Figure 2, where the structure has been covered with silver. As seen, by applying appropriate reduction time, the uniform silver coating without blemishes is achieved (Fig. 2b).

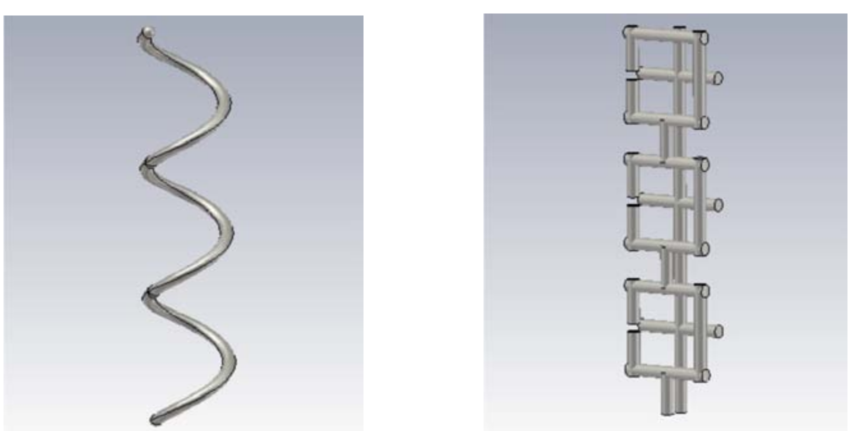


a) *b)*

Fig. 2: A) Metalized 3D photonic crystal structure, 4 hours reduction time, b) similar metal coated structure, 8 hours reduction time.

3. Structures

The attempt is made to fabricate nanostructures, which have minimum feature size ~600 nm, via DLW and coat them with metal so that they behave as metamaterials. Helical-spiral (Fig. 3a) is expected to allow only one of the two possible circular polarizations. Structures like connected split ring resonators and wires (Fig. 3b) are modeled to behave as a “left-handed” metamaterial, i.e. to show negative refractive index response, and to be used for demonstration of imaging using anisotropic “left-handed” metamaterials [11].



a) *b)*

Fig. 3: a) A helical spiral, b) rectangular split ring resonators with wires.

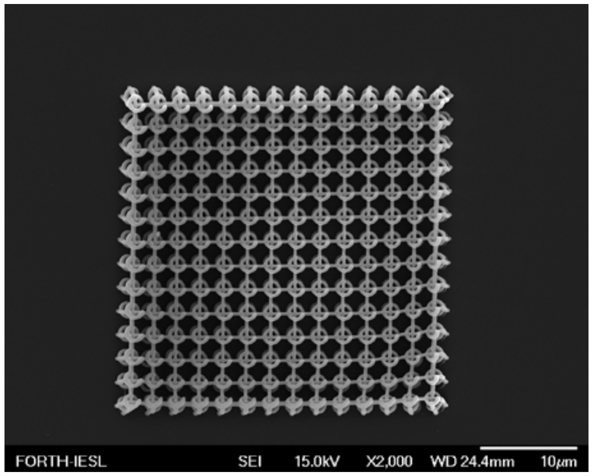


Fig. 4: Helical spiral photonic crystal of Zr-containing hybrid polymer.

4. Conclusions

DLW technique is employed as a tool to fabricate both dielectric and metallic 3D nanostructures for various applications in microoptics, photonics, biomedicine and metamaterials. Here we demonstrated the power of the method in metamaterial applications like negative refractive index and polarization selective transmission.

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