FABRICATION AND CHARACTERIZATION OF ELECTRICALLY TUNABLE MULTILAYER HYPERBOLIC METAMATERIAL

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We report on development and characterization of electrically tunable metamaterial exhibiting elliptic, epsilon-near-zero and hyperbolic dispersion regimes [1,2]. The structure under study consists out of stacks of alternating layers of silver, fused silica and indium-tin-oxide (ITO), and is covered with SiO_2 antireflective coatings. To provide high transparency of the metamaterial the thicknesses of particular subwavelength layers were chosen after initial numerical modelling. To actively tune the optical response of this metal-oxide-semiconductor heterostructure we exploit the fact that the refractive index of ITO depends locally from the strength of the applied external electric field [3]. ITO is a degenerately doped semiconductor with optical properties governed mainly by the free electrons. The amount of free electrons in ITO depends mainly on Sn doping levels and the oxygen vacancy concentration. Both factors can be changed by selection of different fabrication procedures.

Here, we discuss the details of the fabrication method and describe the encountered difficulties. In particular we concentrate on the properties of ITO layers, which strongly depend on experimental conditions. In our investigations the subsequent films were evaporated using physical vapour deposition process (PVD). Afterwards, the samples were characterised using Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy module (EDS), Atomic Force Microscopy (AFM), Hall Effect measurement system and optical microscopy. We study how the i) thermal annealing, ii) presence of oxygen, iii) ion assistance deposition and iv) substrate roughness affects the electric, optical and morphological properties of individual thin films and the entire structure. Some of these procedures have a contrary influence on the performance of the metadevice, improving one feature and decreasing the other. For example, post-annealing lead to higher transparency, but at the expense of homogeneity of the structure (see Fig. 1).

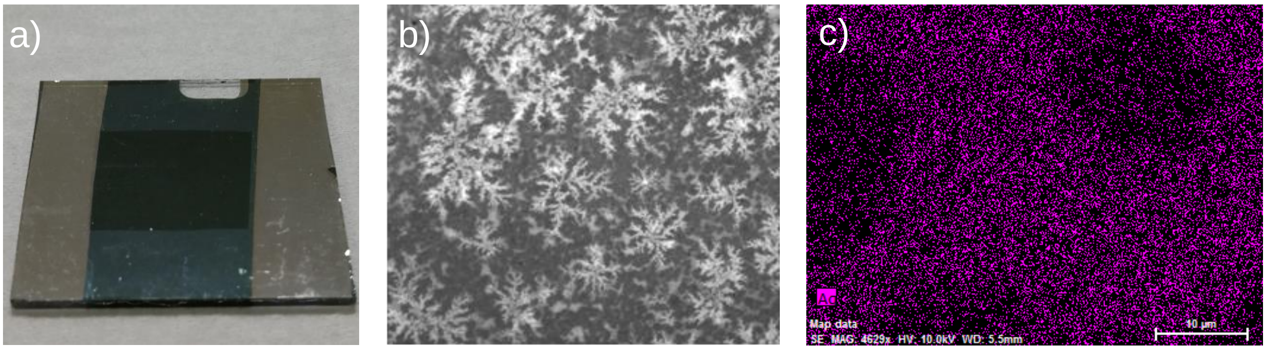

Fig. 1. (a) Photograph of the multilayer metamaterial structure. (b) Image from the optical microscopy, of the sample after post-annealing in 500 °C for 2 hours. It reveals star-like shapes. (c) Silver concentration map of the annealed sample obtained via EDS technique.

Overcoming these obstacles can possibly lead to development of electrically tuneable multilayer metamaterial, which unique optical properties like e.g.: spatial and temporal frequency filtering, hyperbolic dispersion, superresolving imaging, perfect absorption or enhanced nonlinear response can be modified across the VIS and NIR spectrum ranges simply by the applied voltage.

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