Novel photonic materials enabled by crystal growth techniques

D. A. Pawlak
Institute of Electronic Materials Technology (ITME), and
Centre of New Technologies University of Warsaw (CeNT), Warsaw, Poland,
Dorota.Pawlak@itme.edu.pl, Dorota.Anna.Pawlak@cent.uw.edu.pl

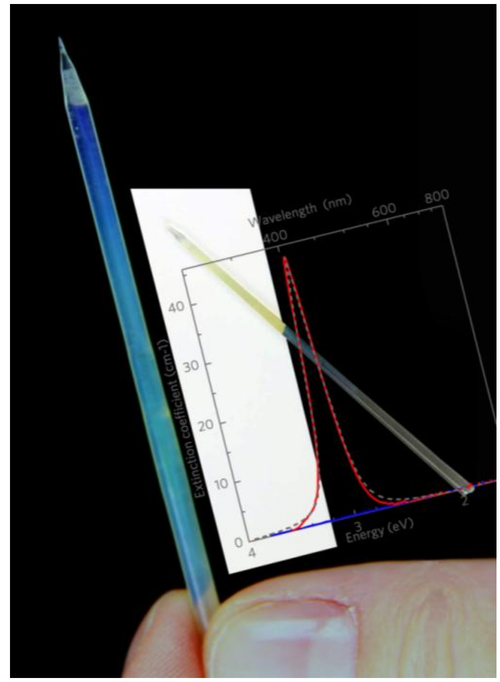

Fig. 1. Nanoplasmonic material obtained by novel NanoParticle Direct Doping method [2].

In recent years, novel research areas have been developed in the field of photonics: metamaterials and nanoplasmonics. By utilizing the ideas developed in these research areas and using specially-designed materials, unusual electromagnetic properties such as artificial magnetism, negative refractive index, cloaking and squeezing photons through subwavelength holes have been demonstrated. These novel fields need new material fabrication techniques, especially bottom-up approaches such as self-organization. Two novel bottom-up manufacturing methods will be presented: (i) method based on directionally-grown self-organized eutectic structures [1]; and (ii) NanoParticles Direct Doping method (NPDD) [2] based on directional solidification of dielectric matrices doped with various nanoparticles. In both of these methods we can easily use all available resonant phenomena to develop materials with unusual electromagnetic properties. Eutectic composites are simultaneously monolithic and multiphase materials forming self-organized micro/nanostructures, which enable: (i) the use of various component materials including oxides, semiconductors, metals, (ii) the generation of a gallery of geometrical motifs and (iii) control of the size of the structuring, often from the micro- to nanoregimes. On the other hand, the novel method of NanoParticles Direct Doping enables doping of dielectric matrices with various nanoparticles (varying chemical composition, size and shape) and with the possibility of co-doping with other chemical agents as eg. optically active rare earth ions or quantum dots. In both cases we apply one of the crystal growth methods - the micro-pulling down method - to create the material. Utilizing described above methods we demonstrated (i) volumetric eutectic-based material with localized surface plasmon resonance tunable at visible wavelengths [3, 4]; (ii) enhanced luminescence and up-conversion processes in the eutectic material exhibiting LSPR and co-doped with erbium ions; (iii) volumetric matrix-nanoparticles-based materials with plasmonic resonances at visible and IR wavelengths based on silver (Ag) [1], antimony-tin-oxide (ATO) and titanium nitride nanoparticles (TiN); (iv) matrix-nanoparticles-based composite with enhanced photoluminescence at the telecommunication frequency of 1.5 μm; (v) material with subwavelength transmission at IR frequencies [5]; (vi) material with anomalous transmission; (vii) materials with enhanced Faraday effect; and (viii) materials for phonoanodes in photoelectrochemical cells for generation of hydrogen [6, 7].

[1] D. A. Pawlak, et al. How far are we from making metamaterials by self-organization? The microstructure of highly anisotropic particles with an SRR-like geometry, **Adv. Funct. Mat. (2010) 20, 1116.**

[2] M. Gajc, et al., NanoParticle Direct Doping: Novel method for manufacturing three-dimensional bulk plasmonic nanocomposites, **Adv. Funct. Mat. (2013) 23, 3443.**

[3] K. Sadecka, et al., When Eutectics Meet Plasmonics: Nanoplasmonic, Volumetric, Self-Organized, Silver-Based Eutectic, **Adv. Opt. Mat. (2015) 3, 381.**

[4] K. Sadecka, et al., Temperature and atmosphere tunability of the nanoplasmonic resonance of a volumetric eutectic-based Bi_2O_3-Ag metamaterial, **Opt. Express (2015) 23, 19098.**

[5] V. Myroshnychenko, et al., Interacting plasmon and phonon polaritons in aligned nano- and microwires, **Opt. Express (2012) 20, 10879.**

[6] K. Wysmulek, et al. A SrTiO3-TiO2 eutectic composite as a photoanode material for photoelectrochemical hydrogen production, **Appl. Catalysis B: Environ. (2017) 206, 538.**

[7] K. Kolodziejak, et al. When eutectic composites meet photoelectrochemistry – Highly stable and efficient UV–visible hybrid photoanodes, **J. Catalysis (2017) 352, 93.**