Fabrication and characterization of 3D nanocomposites made of glass doped with nanoparticles for plasmonic applications

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Abstract

In this paper metallodielectric nanocomposites, obtained by directional growth of glass fibers with incorporated silver nanospheres, silver nanowires and indium tin oxide (ITO) nanoparticles have been investigated. Description of novel fabrication process together with structural/optical characterization results will be presented.

1. Introduction

Nanocomposites of metallic/semiconducting nanoparticles embedded in dielectric matrix with resonances at optical and near infrared wavelengths have been the subject of increasing interest due to their prospective exploitation for photonic/plasmonic applications [1]. Such materials utilize the special property of structured nanometallic systems of enabling localization of light at their very small volumes, resulting in surface plasmon excitation (collective electron oscillations at the metal-dielectric interphase) and light (field) concentration at resonant frequency. This local field concentration could be used for various applications such as enhancement of (i) nonlinear properties [2], (ii) photoluminescence of rare earth ions [3], quantum dots [4] and others. In many cases efficiency of these phenomena depends strongly on sample thickness. That is why it is important to be able to fabricate volumetric plasmonic materials.
There are several methods of manufacturing metallodielectric composites based on doping dielectric glasses with metallic nanoparticles. These include: melt quenching [2], sol-gel [5], ion exchange [6], ion implantation [7], laser ablation [8] and others.
However fabrication of 3D plasmonic nanocomposites is still a big challenge of present manufacturing technologies. Such aspects as: (i) homogeneity of the obtained materials, (ii) doping with non-metallic nanoparticles (with lower losses than metallic and different resonant frequencies [9]), and (iii) doping with anisotropic particles, are at the very beginning of development.

Here, we present a novel fabrication method and an example of experimental realization of bulk isotropic material doped with silver nanospheres and ITO nanoparticles as well as of high potential for realizing anisotropic materials doped with e.g. silver nanowires. The manufacturing method is based on doping glass with plasmonic nanoparticles in directional glass solidification process. The material obtained visually demonstrates in a stunning way the phenomenon of localized surface plasmon polaritons.

2. Experimental method

Our fabrication technique (the micro-pulling down method) is based on directional solidification of the melt which flows through a capillary placed in a die at the crucible bottom with a temperature gradi-

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ent. The liquid flows through capillary laminarly and solidifies outside the crucible. This gives us the possibility of adding the nanoparticles directly into the melt so they can be incorporated into glasses and create bulk metallodielectric nanocomposites. However the matrix materials should show lower melting temperatures than the melting temperature of the added nanoparticles.

3. Results

In this work doping with silver nanopspheres, silver nanowires and indium tin oxide nanoparticles (In2O3:SnO2 90:10) in sodium borophosphate glass -$Na_5B_2P_3O_{13}$ (NBP) has been investigated. In Fig. 1a the as-grown undoped NBP glass rods obtained in ITME are shown. They are transparent and colorless. In Fig. 1b-c glass rods doped with 0,15 wt. % of silver nanospheres are shown. On the top the rod is laying on the white paper so light goes through it and reflects on white paper and comes back to us. One could see the rod in the transmitted and reflected/scattered light and it looks yellow. Below there is the same rod on black paper which means that transmitted light is absorbed and we can observe almost only reflected/scattered light. The material now looks blue.
The origin of different colors is coming from Localised Surface Plasmon Resonances (LSPRs) of silver nanoparticles.

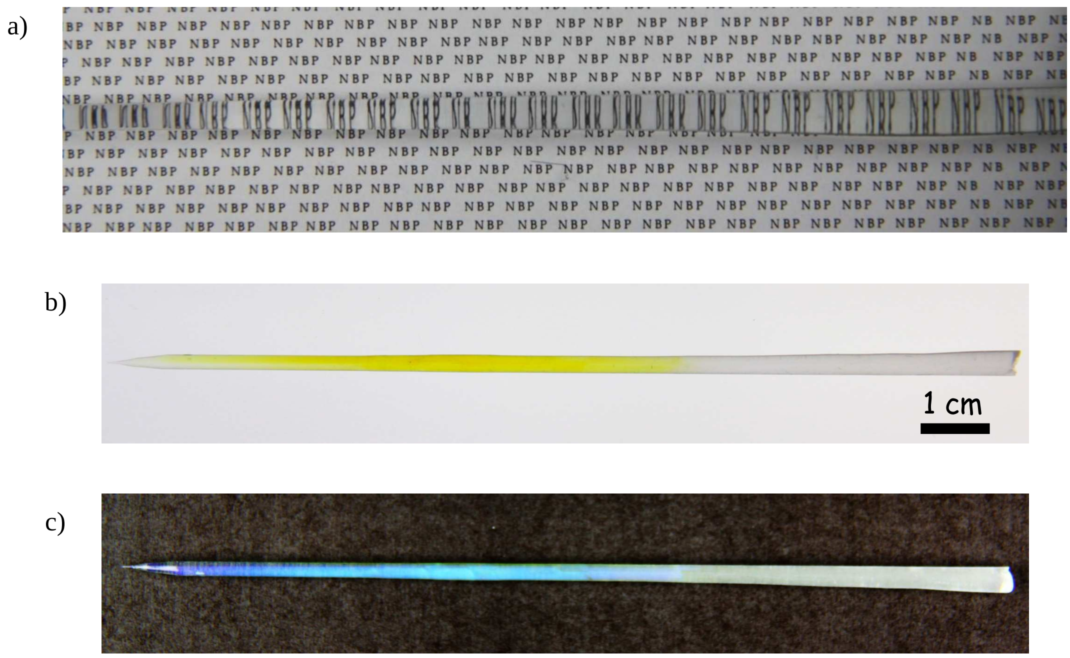

Fig. 1: NBP glass rod: a) pure, b) with 0,15 wt. % Ag (20 nm, spherical) nanoparticles observed in transmitted light, c) with 0,15 wt. % Ag nanoparticles (20 nm, spherical) observed in reflected light.

The transmission and reflection spectra of the samples were measured in dependence of their thickness and nanoparticles concentration. SEM with Energy Selective Backscattered Electron Detector detector measurements confirmed presence of silver nanoparticles in the obtained materials. UV/VIS spectroscopy investigation shows deep surface plasmon resonance from silver nanospheres at wavelength about 405 nm.

4. Conclusion

Our approach is a new method of fabricating 3D metallodielectric nanocomposites with plasmonic properties. It may enable manufacturing of isotropic bulk materials with plasmon resonances from not only metallic but also semiconducting nanoparticles as well as it may enable obtaining of anisotropic plasmonics involved materials.

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