Towards metallic microstructuring in nanocomposite glass

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Abstract: A novel, easy-to-implement, method to create fine optical structures in dielectric metal-doped nanocomposite materials is presented. We believe that our results pave a route towards creation of future optoelectronic elements based on surface-plasmon integrated circuits.

Surface plasmons (SP) are oscillation of free electrons at the metal surface. A properly structured metal surface can, in principle, take incoming light and convert it to surface plasmon and vice versa [1,2]. The linear and nonlinear optical properties of metallic nanoparticles embedded in dielectrics are strongly dominated by the SP resonances of the particles. The SP resonances, in turn, can be designed within a wide spectral range throughout the visible and NIR by choice of the metal, dielectric matrix and also manipulation of size, shape and spatial arrangement of the metal clusters to meet the ever demanding applications [3-5]. However, while a great flexibility offered by the compound materials via manipulation of their optical properties make them a very promising candidate for many applications in the field of photonics, seeking a technologically simple and economically sensible way to properly structure their optical properties still remains as a challenge and occupies many researches within the scientific community.

Here we introduce a simple, but physically very interesting, method for fine optical structuring in glass containing either spherical or elliptical silver (Ag) nanoparticles, employing an intense DC electric field and modest temperatures only. The samples were prepared from soda-lime float glass by Ag-Na ion exchange and following annealing in H_2 reduction atmosphere. In this way spherical Ag nanoparticles of 30-40nm mean diameter were formed in a thin surface layer of ~6µm. In addition to the samples with spherical Ag nanoparticles, using tensile deformation with simultaneous heating, a few samples with elongated (elliptical) Ag nanoparticles were also prepared. However, in these samples tensile deformation resulted in reduction of the thickness of the particle-containing layer to ~1µm. All of the samples were then made single-sided by removing the particle-containing layer from one side via etching in 12% HF aside. The samples were then equipped with two electrodes pressed on the surfaces, with the silver-containing layer faced the anode. The samples were heated to a temperature of 280°C, and then a DC voltage was applied step-by-step from 0.1kV to 1kV for 50min, so that the current was less than 250µA at any time. Note in passing that the employed experimental approach is essentially identical to the thermal poling of glass which has been discussed in detail elsewhere [6].

Applying this procedure resulted in complete (partial) optical transparency in the samples containing elliptical (spherical) Ag nanoparticles. We physically interpreted the phenomena in terms of the ionization of metal nanoclusters followed by the removal of ions from the clusters and their drift in the depth of the sample due to the combined action of the high electric field and temperature. We shall present the full explanation for the phenomena in a subsequent paper. Fig. 1 represent scanning electron microscopy (SEM) pictures of one of the samples before (Top) and after (Bottom) the treatment, whereas fig. 2 shows a photographic image from the same sample after the treatment. As it can be seen from fig.2 a complete optical transparency has been achieved in the area subjected to the electric field. Further studies including SEM X-ray spectral analysis of a cross section of the sample showed decrease of both Ag and Na content near the surface of the treated area and their increase in the depth of a few micron.

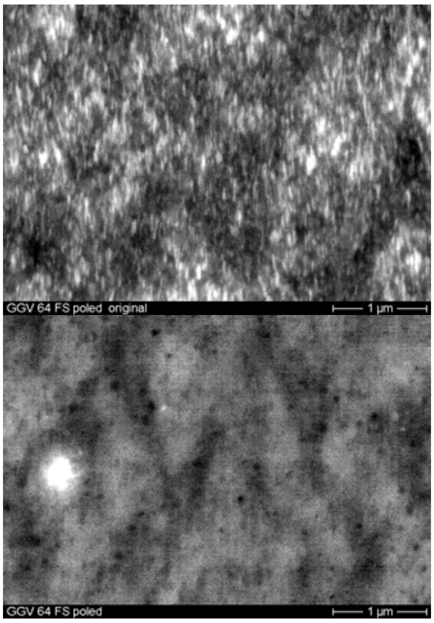

Fig. 1. SEM pictures of the sample with Ag nanoparticles before (Top) and after (Bottom) DC electric field treatment. As it can be seen, after the treatment the shiny spots (Ag nanoparticles) were disappeared.

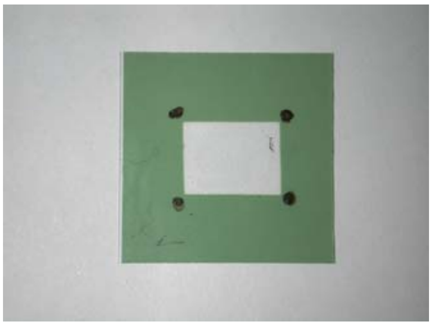

Fig. 2. Photographic image of the sample containing elliptical Ag nanoparticles after the treatment. As it can be seen the area subjectes to the electric field is totally transparent.

Employing the same procedure, however this time using sharp electrode as an anode and by heating the sample to a temperature of 300°C and applying DC voltage from 0.1kV to 0.4kV for 20min, structures as fine as <5µm in width were created (fig. 3).

In summary, we have presented a simple way towards metallic microstructuring in nanocomposite glass, by applying a combination of an intense DC electric field and moderately elevated temperature. We believe in practicality of our results to gain control over structural-and hence optical- properties of future optoelectronic elements based on metallic nanoparticles embedded in glass matrices.

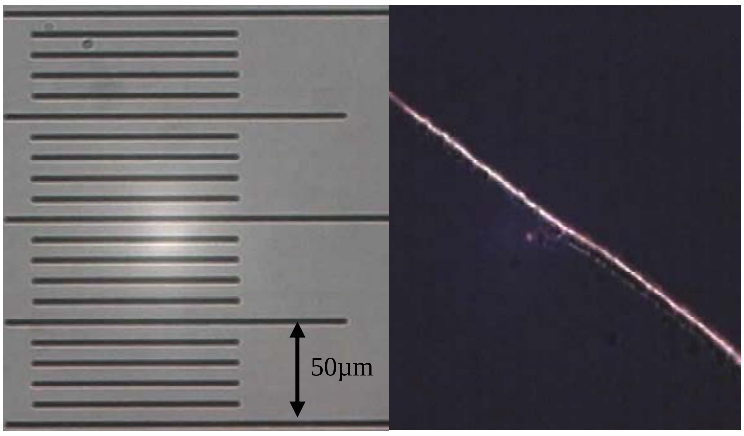

Fig. 3. An example of metallic mictostructuring in nanocomposite glass using the presented technique. This structure had <5μm width and was crated using a sharp electrode as an anode.

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