Novel technique for fine structuring in glass containing silver nanoparticles

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Direct current (dc) electric field assisted dissolution of silver nanoparticles embedded in glass is presented. Using the presented technique 125, 600 and 1800 lines of embedded metallic structures per millimeter are easily produced.

Lately composite materials containing metal nanoparticles have increasingly found various applications in different fields of science and technology [1-3]. In this context glasses containing metallic nanoparticles are of great interest because of their application in the field of photonics owing to their unique linear and nonlinear optical properties. The linear and nonlinear optical properties of such materials are determined by surface plasma oscillations of the metal clusters. The surface plasmon (SP) resonance depends strongly on shape, distribution and concentration of the nanoparticles as well as on the surrounding dielectric matrix. This offers the opportunity to manufacture very promising new nonlinear materials, nanodevices and optical elements by manipulation of the nanostructural properties of the composite medium. One of the main issues in this context is to structure the optical properties of such materials on a micro- and submicron level. While extensive research on the optical subwavelength optics such as plasmonic waveguides based on metal nanoparticles is under way [4], the micrometer scale is appropriate for many standard and advance optical elements such as: gratings, segmented filters, polarizers, etc..

Recently, we have demonstrated destruction and dissolution of silver nanoparticles embedded in glass matrix by applying a combination of an intense DC electric field (~1kV) at moderately elevated temperature (~300°C) [5,6]. The phenomenon was physically interpreted in terms of ionisation of the metal nanoclusters followed by the removal of ions from the clusters and their drift in the depth of the glass substrate. Here, due to the electric field assisted dissolution (EFAD) of the nanoparticles the treated area became optically transparent.

In this paper, using the EFAD technique embedded micron and submicron lines of metallic structures are constructed in a nanocomposite glass containing elliptical silver nanoparticles. The prototype of the samples used in our experiments is a glass containing silver nanoparticles prepared by Ag-Na ion exchange [7]. The originally spherical Ag nanoparticles, mean diameter 30-40nm, produced by this technique were then transformed into uniformly orientated ellipsoidal ones via a macroscopically thermomechanical deformation process. The thickness of the nanoparticles containing layer in the final sample was approximately 1μm. In this form the samples exhibited a strong dichroitic optical extinction, which makes these materials well suitable as polarizers [8]. Figure 1 shows the extinction spectra of one of our samples containing ellipsoidal silver nanoparticles for two different polarization.

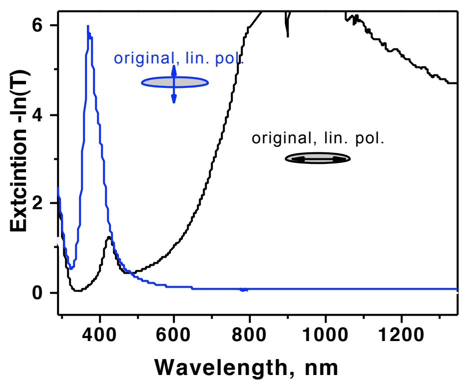

Fig. 1. Extinction spectra of the sample containing elongated Ag nanoparticles with light polarized parallel and perpendicular to the long axis of the silver clusters.

The preliminary experiment was performed by equipping the sample with two metallic electrodes pressed on the surfaces, the anode facing the layer containing nanoparticles. As an anode a structured electrode with 125lines/mm was used (fig. 2). The sample was placed in an oven and heated to a temperature of ~250°C; then a dc voltage of 600V was applied. The time of treatment was ~30min. Finally the voltage was disconnected and the temperature was reduced down to the ambient temperature. After removing the electrodes and careful examination of the sample, it was found that the exact pattern of the anode was mirrored on the sample. Fig 3 shows a segment of the sample after treatment taken in the transmission mode of a microscope spectrophotometer equipped with a CCD camera. As it can be seen from fig. 3, the whole area beneath the anode is transparent, with the exception of the metallic lines where there was no contact between the sample and anode, and thus the Ag particles has not been destroyed during the EFAD process [5]. The thickness of each line was measured to be ~4μm and the treated area was as large as 10mm × 15mm with 125lines/mm. .

Secondary experiment was then performed in order to assess the scalability of the employed technique. This time as an anode structured electrodes with 600 and 1800lines/mm were used. Other experimental parameters including the applied voltage and time of the treatment were identical to the previous experiment. This time in both cases the treated area was as large as 10mm × 25mm. Fig 4 shows a segment of the sample that was treated using the structured electrode with 600lines/mm. The picture was taken in reflection mode of the microscope spectrophotometer. The thickness of the each produced structure was measured to be ~800nm. Fig. 5 represents the scanning electron microscope (SEM) picture of the sample containing 1800 structured lines per mm. The thickness of each line was assessed from SEM to be ~300nm. In each case the structured samples were also working as gratings in both transmission and reflection at 520 and 633nm. Further analysis using scanning electron microscope (SEM) revealed that each structured line constructed from densely packed nanoparticles. This makes the study of plasmonic properties of the produced structures feasible.

In summary, we have explored the newly discovered technique of dc electric field assisted dissolution of silver nanoparticles embedded in glass matrix. This technique allowed us to produce embedded optical structures down to ~300nm in thickness in the metal-doped nanocomposite glass. Investigation of the plasmonic properties of the produce structures is currently under way.

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References

1. U. Kreibig, M. Vollmer: Optical Properties of Metal Clusters, Springer Series in Materials Science **25** (Springer Berlin 1995).
2. V. M. Shalaev: Optical Properties of Nanostructured Random Media (Springer Berlin 2001).
3. K. L. Kelly, E. Coronado, L. L. Zhao, G.C. Schatz, "The optical properties of metal nanoparticles: The influence of size, shape, and dielectric enviorment," J. Phys. Chem. B **107**, 668 (2003).
4. Maier S. A., "Local detection of electromagnetic energ transport below the diffraction limit in metal nanoparticle plasmon waveguides,"Nature Materials **2**, 229 (2003).
5. A. Podlipensky, A. Abdolvand, G. Seifert, H. Graener, O. Deparis, P. G. Kazansky, " Dissolusion of silver nanoparticles in glass through an intense dc electric field," J. Phys. Chem. B, (published online 27. Oct.. 2004).
   O. Deparis, P. G. Kazansky, A. Abdolvand, A. Podlipensky, G. Seifert, H. Graener, "Poling-assisted bleaching of metal-doped nanocomposite glass," Appl. Phys. Lett 85, 872 (2004)
6. K.-J. Berg, A. Berger, H. Hofmeister, "Small silver particles in glass-surface layers produced by sodium-silver ion-exchange- their concentration and size depth profile, " Z. Phys. D 20, 309 (1991).
7. R. Borek, K.-J. Berg, G. Berg, "Low-temperature tensile deformation of flat glass containing metal nanoparticles to generate dichroism," Glass Sci. Technol. 71, 352 (1998).

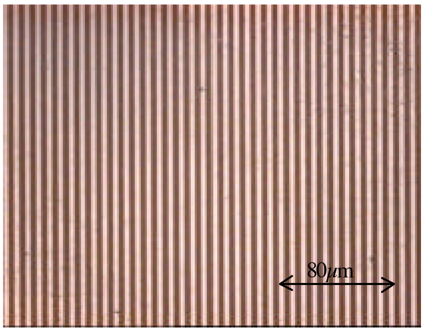

Fig. 2. A segment of the anode with 125lines/mm.

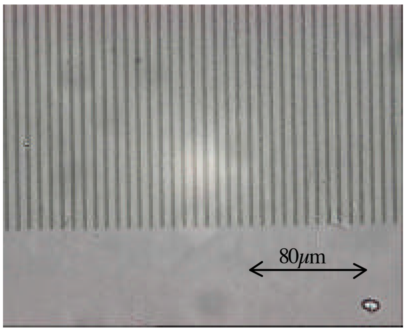

Fig. 3. Segment of the sample after treatment. The result was a area with embedded structures with 125 metallic lines/mm. Here area with the light grey colour show the transparent region after the treatment whiles the structured metallic lines are shown in dark grey.

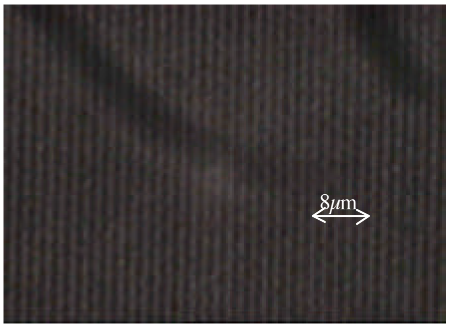

Fig. 4. Segment of the sample with 600 embedded structured lines per mm.

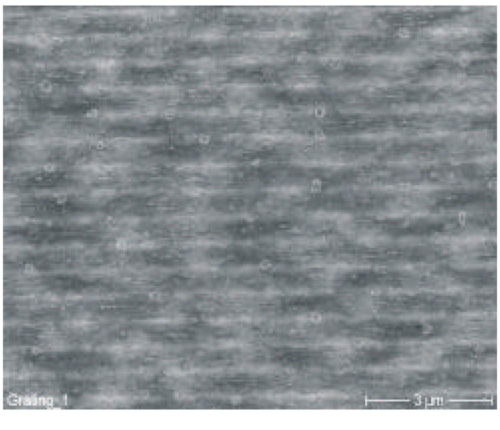

Fig. 5. SEM picture of a segment of the sample with 1800 embedded structured lines per mm. Here the structured lines are reproduced as white lines.