Study and characterization at the nanoscale of electrical and mechanical properties of silver nanoparticles dispersed in a polystyrene matrix

T. De Muijlder[1], M. Voué[2], Ph. Leclère [1,*]

[1] *University of Mons (UMONS), Research Institute for Materials Science and Engineering Laboratory for Physics of Nanomaterials and Energy (LPNE), 20 Place du Parc, B-7000 Mons (Belgium)*

[2] *University of Mons (UMONS), Research Institute for Materials Science and Engineering, Laboratory for Physics of Materials and Optics Unit (LPMO), 20 Place du Parc, B-7000 Mons (Belgium)*

*email corresponding author: philippe.leclere@umons.ac.be

Keywords: nanodielectrics; interphase; scanning probe microscopy

Nanocomposite materials composed of a polymer matrix and inorganic nanofillers, called nanodielectrics, are at the center of advances in the design of materials for electronics. In particular, they allow clear improvements in electrical properties (capacitance, electric field concentration, dielectric strength) but also in mechanical properties (tensile strength, flexibility) and this, for a wide range of temperatures. These improvements are promising for the design of energy storage devices or electrical insulation systems. More and more studies highlight the major role of the interphase forming between the matrix and the filler [1]. Due to its nanoscopic dimension, the study of interphase properties requires precise tools such as Scanning Probe Microscopy (SPM).

We have analyzed thin films (a few hundred nanometers) of Poly(styrene), a polymer with well-known properties, mixed with silver nanoparticles. Silver is known to have the highest electrical and thermal conductivities among metals as well as a very pronounced optical signature in the visible (plasmonic resonance). In our study, the nanoparticles were produced by laser photoablation (Nd-YAG in nanosecond regime) in two different organic solvent: Toluene and Tetrahydrofuran (THF). It is established that photoablation allows to produce nanoparticles with good colloidal stability. Moreover, the use of an organic solvent such as toluene leads to the formation of a carbonaceous shell surrounding the silver nanoparticles [2].

We used optical measurements at different stages of the film fabrication process: reflectometry to determine the thickness of the polymer matrix, UV-VIS spectroscopy to monitor the production of the silver particles, and finally, ellipsometry to characterize the complex refractive indices of the nanocomposite films.

In order to characterize our samples at the nano-scale, we used different modes of SPM such as the and Electrostatic Force Microscopy (EFM). We also mapped the mechanical properties (rigidity modulus, adhesion) by PeakForce Tapping (PFT) [3] (see Fig. 1) and AFM Intermodulation (ImAFM) [4] as well as the electrical properties (contact potential difference, capacitance, and its derivatives) by EFM Intermodulation (ImEFM) [5] (see Fig. 2).

In fine, we compared the different interphase models [1] with our data to explain the measured properties of our samples.

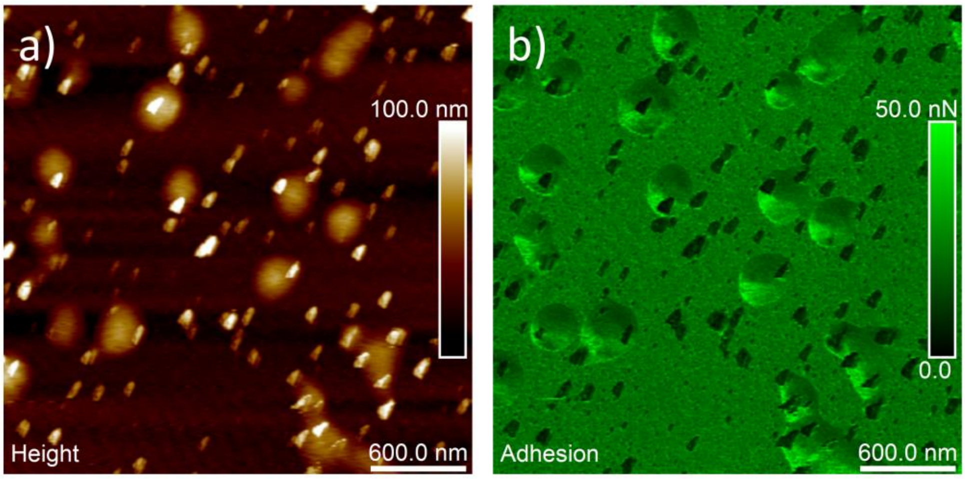

Fig. 2 – PeakForce Tapping mappings: (a) Topography, and (b) Adhesion of silver nanoparticles produced by laser ablation in THF. The nanoparticles were dropped on a Silicon substrate.

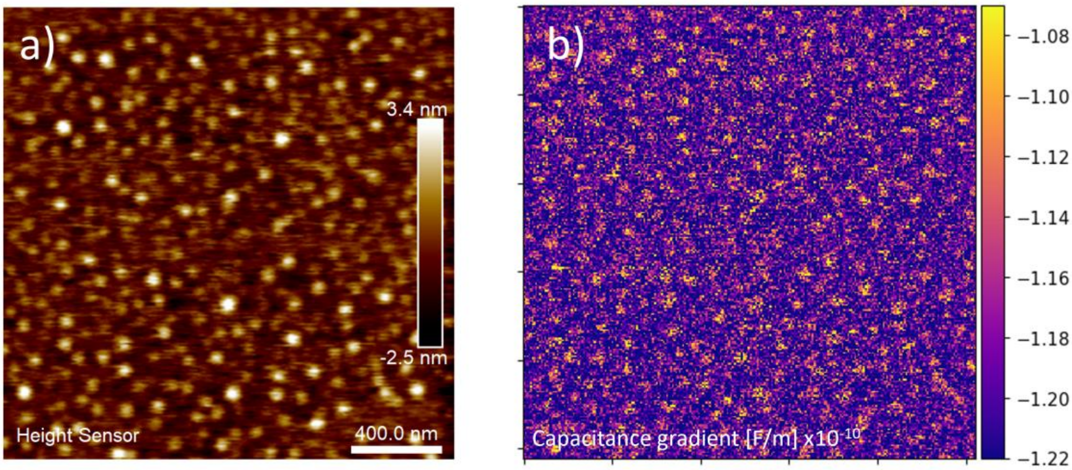

Fig. 2 – (a) Topography, and (b) Capacitance gradient of a thin film composed of Polystyrene and silver nanoparticles measured by ImEFM; Silver nanoparticles were produced by ablation in Toluene then we dissolve PS in the solution and spin-coated it on a ITO substrate.

References

[1] Seiler, J.; Kindersberger, J., Insight into the Interphase in Polymer Nanocomposites. IEEE Trans. Dielect. Electr. Insul. 2014.

[2] Amendola, V.; Polizzi, S.; Meneghetti, M., Laser Ablation Synthesis of Silver Nanoparticles Embedded in Graphitic Carbon Matrix. Sci. Adv. Mater. 2012.

[3] Bruker, Introduction to Bruker's ScanAsyst and PeakForce Tapping AFM Technology. Application Note. 2011.

[4] Platz, D.; Tholén, E. A.; Pesen, D.; Haviland, D. B., Intermodulation atomic force microscopy. Appl. Phys. Lett. 2008.

[5] Borgani, R.; Forchheimer, D.; Bergqvist, J.; Thorén, P.-A.; Inganäs, O.; Haviland, D. B., Intermodulation electrostatic force microscopy for imaging surface photo-voltage. Appl. Phys. Lett. 2014.