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Study and characterization at nanoscale of electrical and mechanical properties of silver nanoparticles dispersed in a Poly(styrene) matrix

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Context

Nanocomposite insulating polymers (i.e., **nanodielectrics**) have shown great property improvements for applications in electronics [1]:

- Tensile strength, flexibility,…
- Dielectric breakdown strength, capacitance,…

Polymers are used because of their intrinsic properties:

- Flexible
- Light
- Easy to process
- Low-cost

Adding an **inorganic filler** is known to enhance their material properties.

Studies highlighted the role of the **interphase** between the **matrix** and the **filler** [1].

Interphase ?

- The region located at the **interface** between the filler and the polymer matrix is about a few tens of nanometers large.
- Plays the main part in the **appearance of new material properties** (mechanical and electrical).

To optimize its effects on the sample, we need to avoid:

- **overlap** of the interphase ➔ **load level**
- **coalescence** of the nanofillers ➔ **good filler dispersion**.

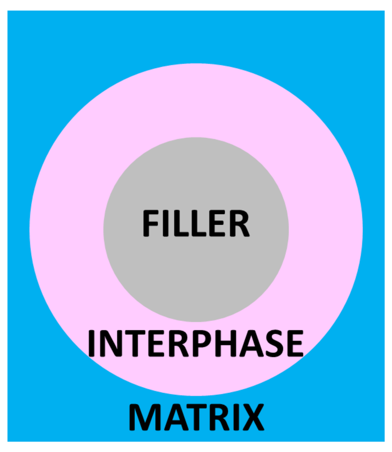

Figure 1: Different phases of a nanodielectric

Methods

Samples made of **Poly(styrene)** (**PS**) as matrix and **silver nanoparticles** (**SNPs**) as filler have been studied. **SNPs** were produced by **laser ablation** in **toluene** and **tetrahydrofuran (THF)**.

- Solutions of **SNPs** and **PS** are drop-cast on **Silicon** and **ITO substrate**: film thickness ≈ 250 nm.

We used **Scanning Probe Microscopy (SPM)** to investigate the sample properties.

- **Mechanical**: Peak Force Tapping (PFT) [2], Intermodulation AFM [3]
- **Electrical**: Intermodulation EFM [4]

We also measured the optical properties by:

- UV-Vis spectrometry
- Imaging Spectroscopic Ellipsometry

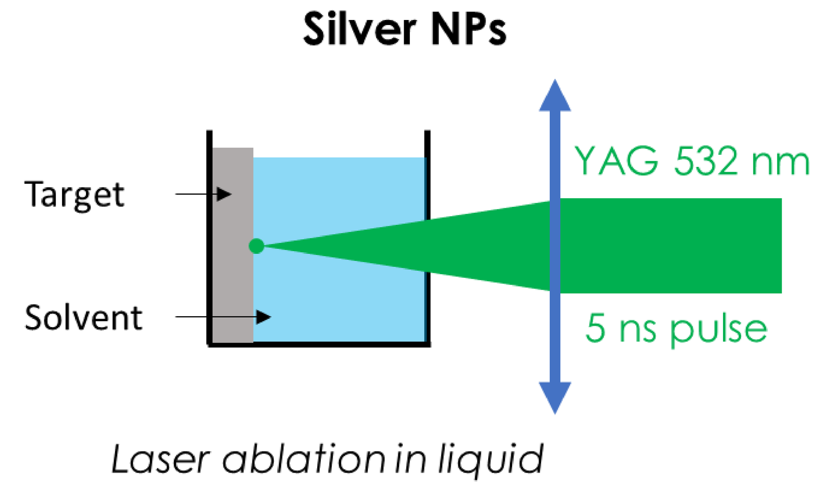

Figure 2: Simplified set-up for laser ablation of silver in toluene

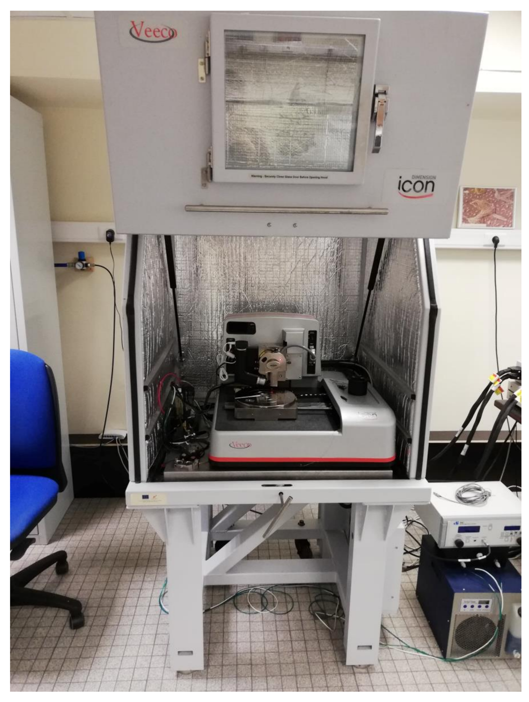

Figure 3: Bruker ICON used for the study

Results & Discussion

UV-Vis spectra allow a first distinction of the SNPs produced by ablation depending on the solvent used. Results presented in Fig. 6 show a **symmetrical** Local Surface Plasmon Resonance (**LSPR**) peak for **H_2O** solvent, an **asymmetrical** one for **THF**, and **no peak** for **toluene**. It is due to the formation of a **carbonaceous envelope** around the particles [5] that we can identify in the PFT mapping (Fig. 4). For both, there are also **"free" SNPs** (without envelope). The average SNPs diameter is about 70 nm.

Once mixed in a poly(styrene) thin film, we investigated the nanocomposite with electrical and mechanical mappings (Fig. 5). Both give detectable SNPs in the PS matrix surface: **bumps**, **local variations** of properties.

SNPs produced in **toluene** are significantly **better dispersed** than those produced in THF.

The **elastic modulus** of the PS matrix **decreases** around the SNPs produced in THF. It can be explained by the **Tanaka interphase model** (Fig. 7)[6]: a large free volume area induces a reduced modulus. This is not observed with toluene.

The presence of SNPs does **not affect the optical behavior** of the nanocomposite in the wavelength range of the ellipsometer.

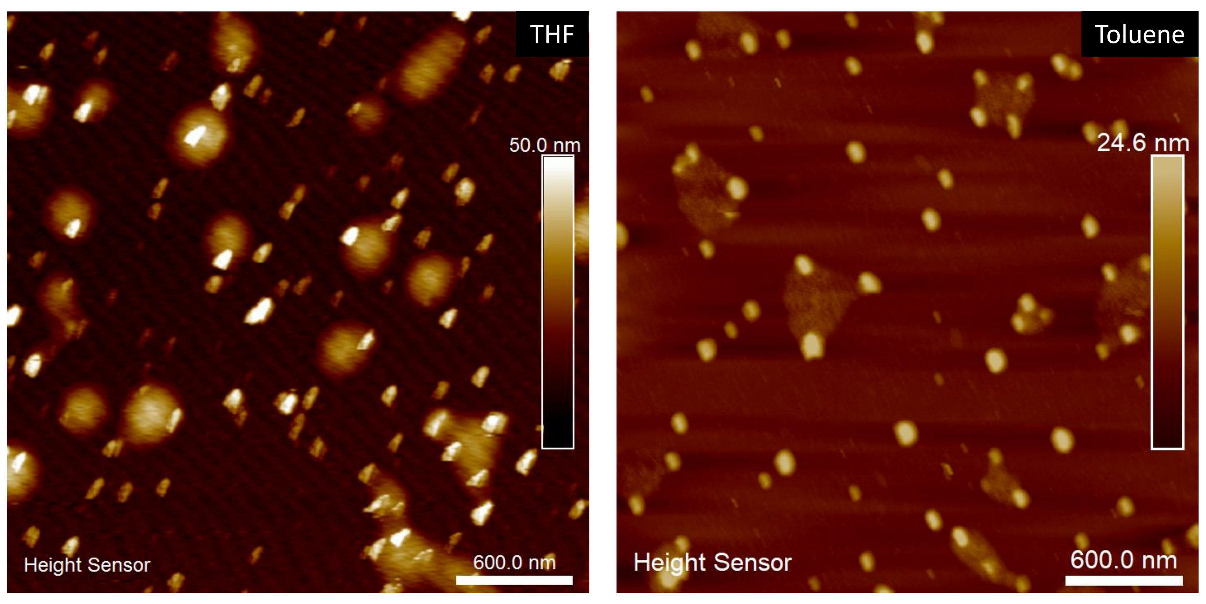

Figure 4: Topography mappings of SNPs produced by laser ablation in (left) THF and (right) toluene.

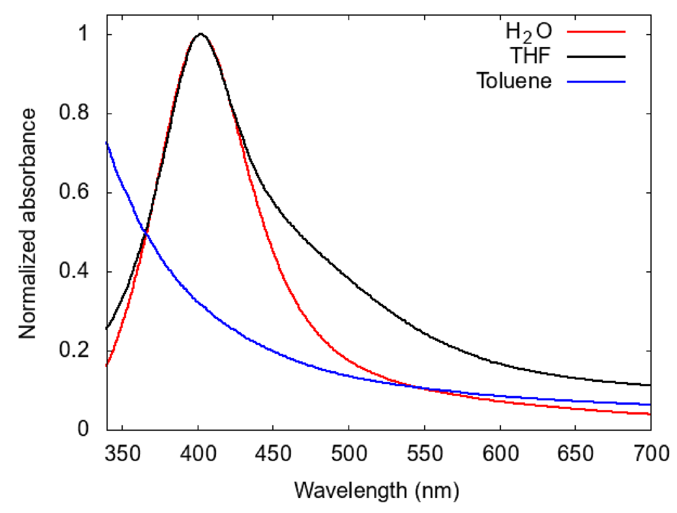

Figure 6: Ag NPs in H2O, THF and toluene UV-Vis spectra

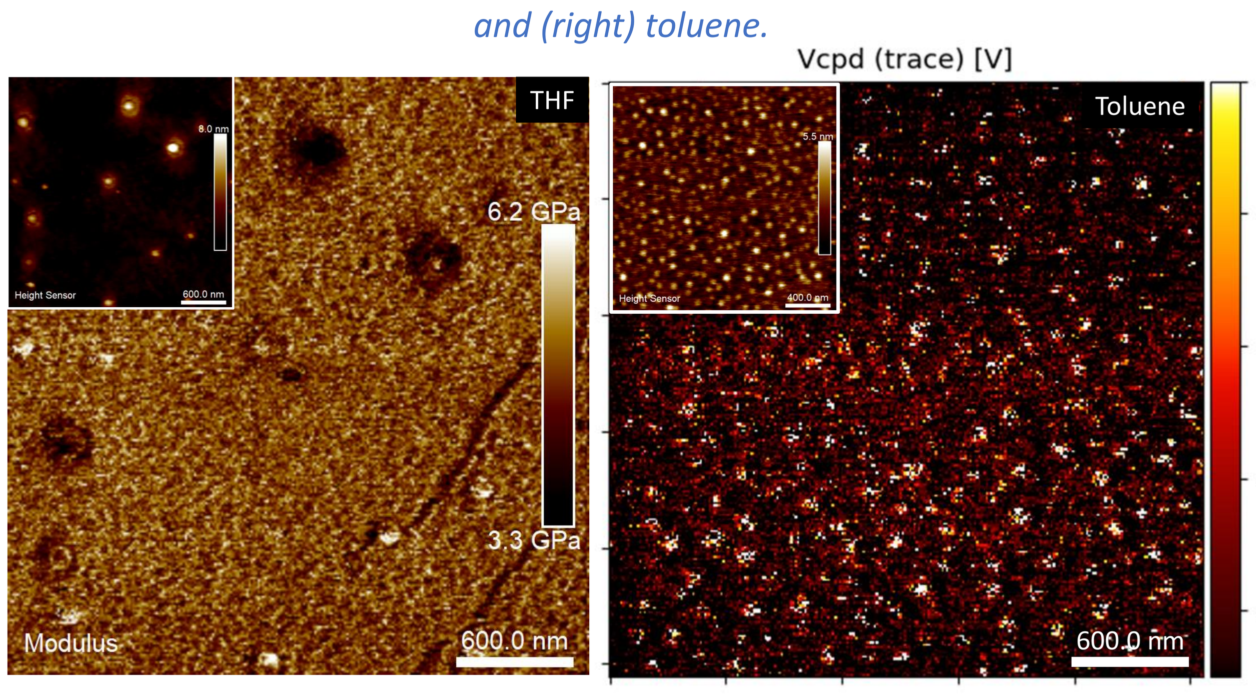

Figure 5: (left) Topography and elastic modulus mappings of PS film mixed with SNPs produced in THF, (right) topography and contact potential difference mappings of PS film mixed with SNPs produced in toluene.

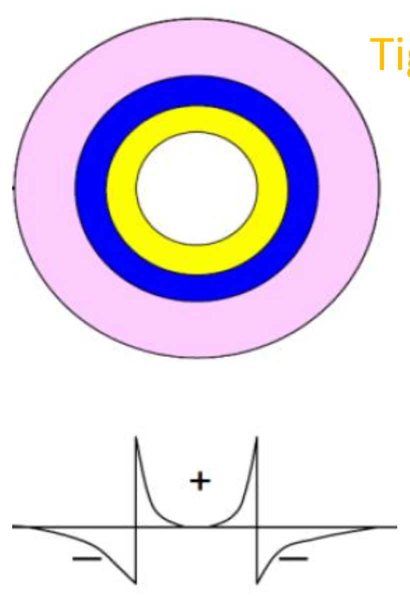

Figure 7: Interphase multi-core model [6]

Conclusions & Perspectives

Laser ablation produced SNPs show different interesting behaviors depending on the organic solvent used. SPM is a promising tool to characterize their properties at the nanoscale. For **toluene**, the **quality of the dispersion** is better than in other studies [7-8]. It is very promising for the improvement of composite material for applications in electronics. For **THF**, we could **identify the interphase** and it corresponds to **Tanaka model** prediction. We hypothesize that the **carbon layer** around SNPs plays a significant role by modifying **filler-matrix interaction** which is highlighted by the difference between the two considered solvents.

To confirm these observations, we aim to **explore** the importance of **other ablation parameters**: wavelength, fluence, number of pulses. We also aim to extend our research to **other polymer matrices**: PDMS and Epoxy Resin.

Finally, we will soon investigate our sample dielectric properties by using scanning Microwave Impedance Microscopy (sMIM) AFM mode.

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[1] J. Seiler *et al*, Insight into the interphase in polymer nanocomposites, IEEE, 2014
[2] S.B. Kaemmer, Introduction to Bruker's ScanAsyst and PeakForce Tapping AFM Technology, Application Note, 2011
[3] D. Platz *et al*, Intermodulation atomic force microscopy, Appl. Phys. Lett., 2008
[4] R. Borgani *et al*, Intermodulation electrostatic force microscopy for imaging surface photo-voltage, Appl. Phys. Lett., 2014
[5] V. Amendola *et al*, Laser Ablation Synthesis of Silver Nanoparticles Embedded in Graphitic Carbon Matrix, Science of Advanced Materials, 2012
[6] T. Tanaka, Interpretation of Several Key Phenomena Peculiar to Nano Dielectrics in terms of a Multi-core Model, IEEE, 2006
[7] V. Vodnick *et al*, Silver/polystyrene nanocomposites: Optical and thermal properties, Polymer Composites, 2012
[8] I.D. Vukoje *et al*, Characterization of silver/polystyrene nanocomposites prepared by in situ bulk radical polymerization, Materials Research Bulletin, 2014