Mechanical Properties of Ag Nanoparticle Thin Films

Simone Peli[2,*], G. Benetti[1,2], E. Cavaliere[2], M. Gandolfi[2,3], C. Giannetti[2], G. Ferrini[2], C. Cancellieri[4], M. Chiodi[4], L. Gavioli[2], M. Van Bael[1], F. Banfi[2]

[1]*Katholiek Universitet, Laboratory of Solid state Physics and Magnetism, Department of Physics and Astronomy Celestijnenlaan 200D, B-3001, Leuven, Belgium.*
[2]*Interdisciplinary Laboratories for Advanced Materials Physics (I-LAMP) and Dipartimento di Matematica e Fisica, Università Cattolica del Sacro Cuore, Via Musei 41, 25121 Brescia, Italy*
[3]*Laboratory of Soft Matter and Biophysics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001, Leuven, Belgium*
[4]*Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Joining and Interface Technology, Überlandstrasse 129, 8600 Dübendorf, Switzerland*
*e-mail: pelisimone@gmail.com

Abstract: Understanding the mechanical properties of nanophase systems constituted by assembled metallic nanoparticles (NPs) will play a key role in biotechnology [1] photocatalysis, energy harvesting [2] and nano-opto-electronics applications. In this context NPs thin films made by Supersonic Cluster Beam Deposition (SCBD) are emerging as a candidate for wide-spread applications because SCBD: (a) is a high throughput technique for the synthesis of NPs thin films on virtually any substrate material; (b) allows to tune the NPs properties/composition; (c) allows synthesizing close to ideal-NPs thin films [3,4]. This work reports on the mechanical properties of Ag NP thin films deposited by SCBD on a sapphire substrate, the film thickness ranging between 15 and 50 nm. On the nanoscale, the samples morphology and composition are inspected via Atomic Force Microscopy and Photoelectron Spectroscopies. On the mesoscale the films mechanical properties are unveiled via Asynchronous Optical Sampling (ASOPS) based ultrafast optoacoustic nanometrology [5,6], see Figure 1.
The films are composed of Ag NP – average diameter in the 6 nm range –, and inter-NPs voids, the filling factor being 0.8. The films behave as high frequency acoustic cavities operating beyond the 100 GHz range, see Figure 2. The acoustic quality factors show a fundamental "quasi-dark" breathing mode whereas the second mode is an acoustically "bright mode". Rationalizing the physics in terms of an *effective* homogeneous film, the film's density and longitudinal sound velocity are found to be 80% that of polycrystalline bulk Ag, whereas the longitudinal elastic stiffness constants amount to only 50% with respect to the Ag bulk.
The mechanical properties here reported are of relevance in view of any application involving Ag NP films and promote SCBD as a cheap, high throughput production technique for optoacoustic transducers in the hypersonic frequency range.

References

[1] D. Mrinmoy, Partha, P. S. Ghosh, and V. M. Rotello, *Adv. Mater.* 2008, **20**, 4225.
[2] C. J- Liu; Burghaus, U., F. Besenbacher, Z. L. Wang, *ACS Nano* 2010, **4**, 5517.
[3] E. Cavaliere, S. De Cesari, G. Landini, E. Riccobono, L. Pallecchi, G. M. Rossolini, and Luca Gavioli, Nanomedicine: Nanotechnology, Biology and Medicine 2015, **11**, 1417.
[4] Wegner, P. Piseri, H. V. Tafreshi, P. Milani, *J. Phys. D Appl. Phys.* 2006, **39**, R439.
[5] D. Nardi, M. Travagliati, M.M Murnane, H.C Kapteyn, G. Ferrini, C. Giannetti and F. Banfi, *Sensors Journal IEEE* 2015, **15**, 514.
[6] S. Peli, E. Cavaliere, G. Benetti, M. Gandolfi, M. Chiodi, C. Cancellieri, C Giannetti, G. Ferrini, L. Gavioli, and F. Banfi, *J. Phys. Chem. C*, DOI: 10.1021/acs.jpcc.6b00160 (in press)

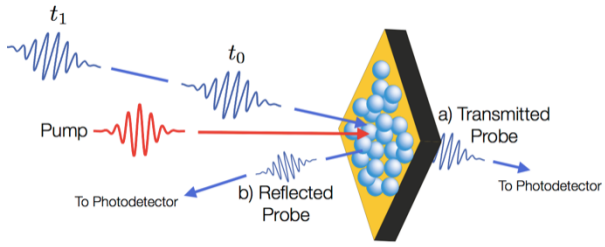

Fig. 1. Schematics of the time-resolved optoacoustic nanometrology technique[5]. The red laser beam is the pump pulse launching the breathing mode in the Ag NPs thin film. The time-delayed probe laser beams detect the film's breathing mode. The experiment is performed implementing the Asynchronous Optical Sampling technique. Figure adapted from Ref.[6].

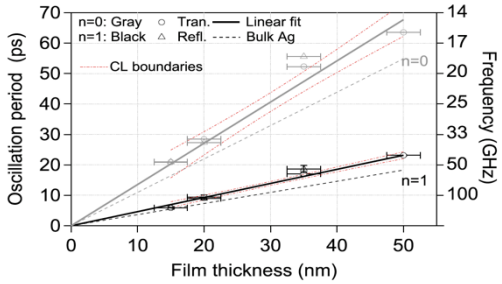

Fig. 2. Fundamental (n=0) and first (n=1) NPs film acoustic breathing mode oscillation period (left axis) and frequency (right axis) as a function of the film thickness. The full lines are a fit based on an *effective* homogenous film model based on continuum mechanics.