Gas phase synthesis and electrical field mapping of metallic nanoparticles embedded in nanocapacitor devices

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Introduction

The control of electrical properties by combining conductive and insulating materials is of prime importance in microelectronic devices. The interactions between these materials have spurred much fundamental and applied research over the years. The ongoing miniaturisation and the search for low-energy consumption devices require the exploration of new solutions for the elaboration and study of these systems.

Nanocapacitors composed of conductive electrodes separated by an insulating material remain one of the fundamental building blocks in the development of more complex systems, and their properties will determine the speed, stability and power consumption of memories. Flash memories in particular are based on tunnel effect control of the passage and storage of electrical charges in a floating electrode isolated from the system; the stored charge then modifies the conduction properties of the device. In these systems, there is a lack of knowledge on how the electromagnetic fields are precisely mediated along devices at the nanoscale level. In addition, a large work remains to be carried out on the charge trapping mechanisms which change the capacitance and performance of real devices by modifying the threshold voltage and frequency response [1]. Some traps are expected to be stable over time and others occupied dynamically as a function of the applied bias. Much discussion has been made of the nature of the traps and where they occur but the uncertainty concerning their location arises from the fact that the majority of the characterisation techniques are based on indirect measurements.

In this thesis work, we propose an original approach based on the elaboration and study of electrical properties at the nanoscale of a nanocapacitor with metallic nanoparticles (NPs) embedded in the insulator. Through a perfect control of their size and position, we aim to investigate the resulting charge distribution whilst applying bias with state-of-the-art electron microscopy methods.

Work

The PhD student will have in charge the elaboration and the study of the structural, chemical and electrical properties of the nanodevices.

From conductive substrates, a dielectric layer will be grown by radio-frequency magnetron sputtering including metallic nanoparticles synthesized in vapor phase and size-selected by a quadrupole mass filter in the same ultra-high vacuum chamber [2,3]. This original fabrication technique at CEMES laboratory allows to independently control the nanoparticles' size and density and their distance from the substrate and from the free surface. In addition, it is possible to obtain extremely pure NPs, *i.e.* free from any ligand or surfactant resulting in high chemical purity due to the absence of organic solvents. The top electrode will also be grown by sputtering deposition. The PhD student will determine the optimal conditions of elaboration by sputtering for the whole system by investigating the morphological, structural and chemical properties through advanced TEM based techniques (high-resolution, STEM-HAADF, STEM-EDX) down to the atomic scale. Particular attention will be given to understanding the processes involved in the nucleation and growth of nanoparticles in the gas phase.

In parallel, the PhD student will participate in *operando* electron holography experiments. Electron holography is a powerful TEM technique for measuring local fields in materials, from electric and magnetic [4] to crystalline strain. Indeed, the phase of the electron hologram can be directly related to the electrostatic potential encountered by the fast electron along its trajectory. Whilst it was shown early on that electric fields could be measured in semiconductor devices in such way [5], the development of *operando* experiments has however been a long one. Rare have been the studies of biased devices [6.7] due to bottlenecks to solve such as sample preparation, surface damage layers, stray fields, electron radiation and low signal-to-noise ratio. For several years, the CEMES laboratory has developed state-of-the-art expertise on these different problems and has demonstrated that an electric field can now be measured in different nanodevices using *in situ* biasing electron holography with unprecedented sensitivity [8.9]. Using this original method, the PhD student will study the resulting charge densities in the thin-layer device under electrical biasing by mapping the electric fields at the nanoscale and will conduct a modelling study to understand the influence of experimental parameters to construct a realistic model of the nano-object under observation.

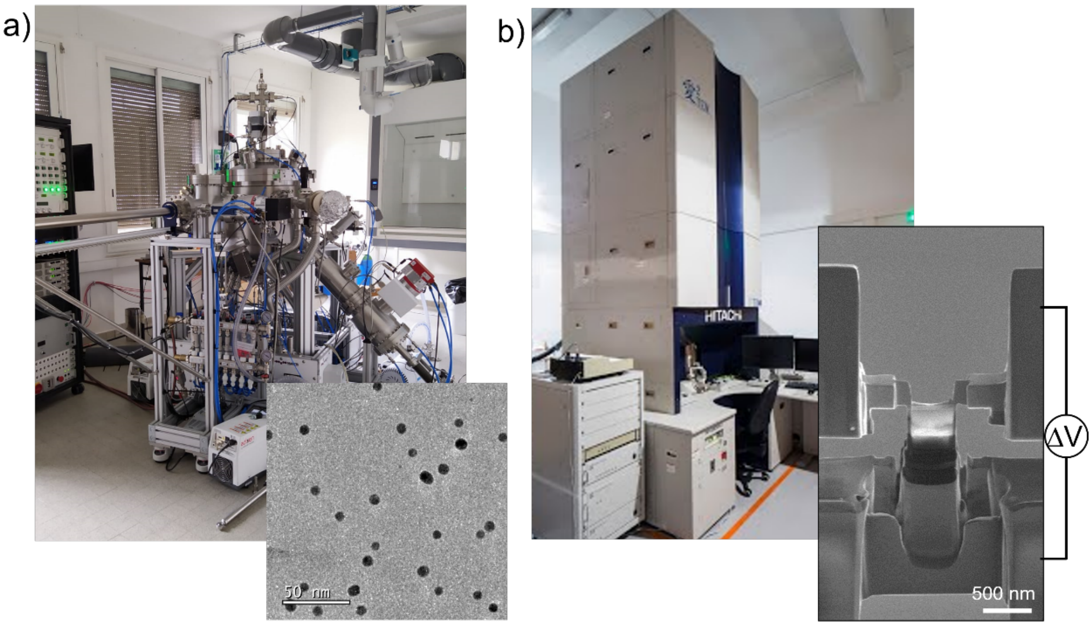

Figure. a) UHV sputtering chamber with quadrupole mass filter for nanoparticles synthetized in vapor phase. Ag nanoparticles are shown in inset. b) Dedicated transmission microscope for interferometry and *in situ* studies. In inset is presented a connected nanocapacitor for *in situ* biasing electron holography studies.

Skills:

Candidates should have a good background in condensed matter physics, physical chemistry and a genuine interest in experimental physics. Experience in the synthesis of metallic NPs by physical methods and the knowledge of programming languages (python, matlab, etc.) will be highly appreciated.

Keywords: metallic nanoparticles, magnetron-sputtering, gas-phase synthesis, transmission electron microscopy, electron holography, charge densities.

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