Mapping the physical properties of He nanobubbles at the nanometer scale

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The physics of fluidic nanosystems raises a number of fundamental questions, which have yet to be solved. What is the behaviour of a fluid at the nanoscale? Is the macroscopic definition of pressure still relevant? How can we measure the pressure or the density of a few number of atoms? Previous studies on rare gas nanobubbles embedded in a metallic matrix have contributed to answer these questions. Namely, Walsh and co-workers have measured by EELS the mean density and pressure within an individual nanobubble [1]. In this contribution, thanks to the spectrum-image technique [2], we extend and apply the spatially resolved EELS approach to the determination, at a nanometer scale, of the physical properties of He nanobubbles (with diameter ranging from typically 5 to 20 nm) grown in a palladium based matrix.

An estimation of the He density and pressure can be obtained from the intensity of the He K-line signal at about 22 eV, subtracted from the plasmon contribution of the Pd matrix. By processing the collection of spectra in a spectrum-image, we have built maps of the He physical parameters (density, pressure and shift of the He K-line). When comparing the values measured for bubbles of various sizes, we detect a blue-shift of the energy position of the He K-line, which increases with the average He atomic density. It is probably due to the Pauli repulsion between adjacent He atoms in the fluid phase [3].

As a spectrum-image is made of spectra recorded at many pixels over a single nanobubble, we can also test and map the variations of these parameters within individual bubbles. For larger ones, the blue-shift of the He K-line increases slightly at the bubble surface, but the phenomenon is associated with a decrease of the estimated density (in contrast with a Pauli repulsion mechanism). Spectra simulations, performed in the continuum dielectric model, correlate these phenomena to the delocalisation of the He K transition due to the dielectric interaction with the Pd matrix. Such an effect, already well known for plasmon signals, is evidenced for the first time on low-energy atomic excitations measured near a surface. This effect should be accounted for when measuring the density at the interface of the nanobubble with the matrix.

References