ESRF	**Experiment title:** Phonon confinement in reduced dimentionality structure studied using CE-NIS	**Experiment number**: HS 4094
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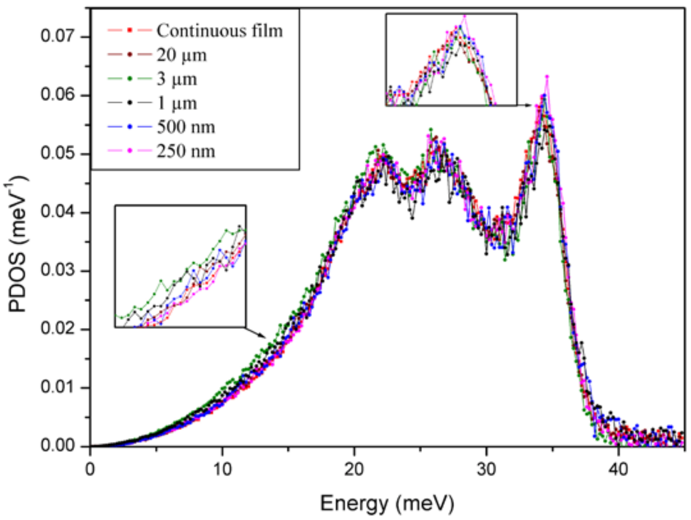
Report:

The aim of the experiment was to investigate the effect of lateral confinement on the phonon density of state (PDOS) of Fe nanostructures. Although it is quite important from the fundamental aspect as well as for applications in microelectronics, the influence of reduced dimensionality on the PDOS of a material remains unclear. Of particular interest in this field is to study the influence of reducing the structure size below the typical phonon wavelength (tens of μm) and below the phonon mean free path (< 1 μm).
For this purpose, we employed the technique of nuclear inelastic scattering (NIS), which is the best suited technique to probe the PDOS of small sample volumes with meV energy resolution. In order to overcome the technical limitations due to the small sample volume investigated, we first planned to use a double detection scheme, where both the single photon (standard NIS detection scheme) and the conversion electron (CE) channel of the nuclear de-excitation are recorded. However, the CE detection scheme could not be implemented due to the too high background generated by the prompt pulse and we thus performed conventional NIS measurements.
For this experiment, a set of samples consisting of arrays of Fe squares on Si (100) were prepared by lithography and molecular beam epitaxy. Each square has the structure Si(100)/Pt(200Å)/^{56}Fe(15Å)/^{57}Fe(200Å)/^{56}Fe(15Å)/Pt(22Å), ^{56}Fe preventing contributions from the interfaces while the high density Pt layers create a wave guiding structure, the top one also serving as capping layer. Arrays of squares with lateral dimensions of 250 nm up to 20 μm, as well as a continuous film for reference, were prepared. Their structure and composition were confirmed by SEM, AFM and x-ray diffraction analysis.
The NIS experiment was performed at the ID18 beamline. The samples were illuminated in grazing incidence geometry and the APD detector, which is used to detect the inelastically scattered photons, was placed perpendicular to the sample surface. In spite of the small sample volume probed, the intensity measured by the APD detector was satisfying. Each energy scan took approximately 30 minutes and was repeated 6 times to obtain sufficiently high statistics.



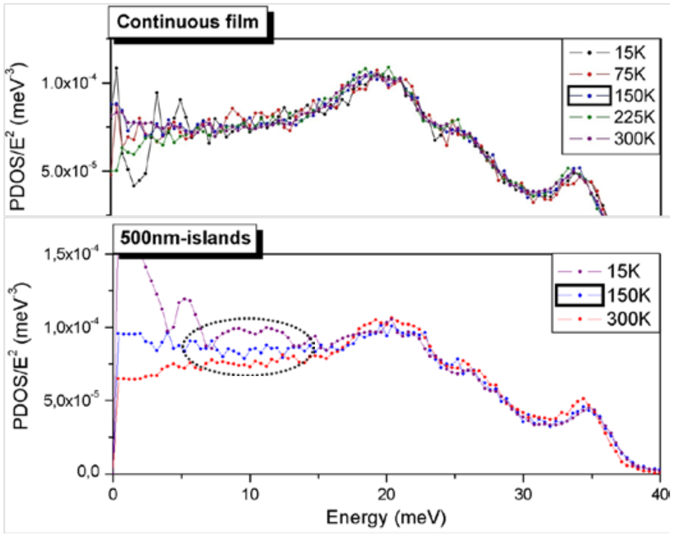


Fig. 1: Phonons densities of states of Fe squares of different lateral sizes compared with the ones of a continuous film, measured at 300K.

Fig.2: Temperature dependance of PDOS/E^2 for the 500 nm-wide-Fe squares and for the continuous reference film.

In the first part of the experiment, NIS spectra of the different samples were recorded at 300K. No major differences were observed in the NIS spectra. The phonon DOS were extracted using the DOS program of A. Chumakov and are plotted in Fig.1. At 300K, the PDOS of all samples, as well as of the continuous Fe film, look similar. Thus, there seems to be no noticeable effect of the sample lateral size reduction on the PDOS at 300K.

In the second part of the experiment, NIS spectra of sub-micron Fe squares and of the continuous Fe film were measured at several temperatures in the range from 15K to 300K. For this purpose, the samples were put in a closed cycle cryostat and cooled down to 15K. Unfortunately in the case of the sub-micron Fe squares, sample alignment was extremely difficult due to a very small patterned area (0.5x4 mm^2) and the presence of the cryostat. For this reason, only two samples showing sub-micron Fe squares could be measured. The PDOS were extracted as previously described. While no major differences were observed for the PDOS of the continuous film measured at different temperatures, the temperature seemed to affect the PDOS of the sub-micron Fe squares by modifying the number of low energy phonons modes. In order to quantify this effect, we extracted the velocity of sound for the different samples and temperatures. In the case of the continuous film, the velocity of sound was found to be $v_D \approx 3070$ *(± 60)* m/s independantly of the temperature. In the case of the 500 nm-wide Fe squares the velocity of sound was found to decrease with temperature, as seen in Fig.3:

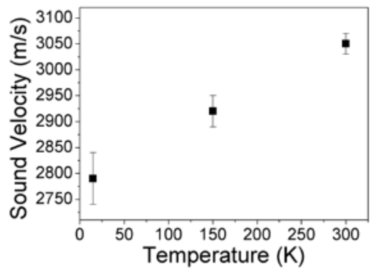


Fig. 3: Temperature dependence of the sound velocity in the 500 nm-wide Fe squares

The origin of this effect is not yet well understood. Moreover, the limited number of samples measured does not allow us to conclude.

This experiment was a first step towards the study of phonons in nanostructures using NIS. Fe squares of nanometric to micrometric lateral size were successfully probed in a very satisfying amount of time. Further studies of even smaller sized structures at low temperatures are required for a better understanding of phonons densities of states in nanostructures.