ESRF	**Experiment title:** Thickness and temperature dependence of the phonon density of state of a thin superconducting ^{119}Sn film	**Experiment number:** HS 3975
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Names and affiliations of applicants (* indicates experimentalists):
S. Couet*, IKS, Celestijnlaan 200D, 3001 Leuven, Belgium
N. Planckaert, IKS, Celestijnlaan 200D, 3001 Leuven, Belgium
A. Vantomme, IKS, Celestijnlaan 200D, 3001 Leuven, Belgium
K. Temst*, IKS, Celestijnlaan 200D, 3001 Leuven, Belgium
M.J. Van Bael, VSM, Celestijnlaan 200D, 3001 Leuven, Belgium

Report:

The aim of this experiment was to resolve the phonon density of state (PDOS) of ^{119}Sn thin films above and below their superconducting transition temperature T_C. For that purpose, we employ the technique of nuclear inelastic scattering (NIS) at the 23.8 keV resonance of ^{119}Sn which allows to obtain the phonon density of state with sub-meV resolution.
In fact, we opted for the use of the superconducting alloy Nb_3Sn instead of pure Sn. Nb_3Sn has a bulk T_C of 18 K which is much easier to reach compared to the T_C of 3.7 K of ^{119}Sn. Taking into account the relatively complex geometry of the experiment, where the detector has to be placed only a few mm away from the sample at a temperature of 3 K, a higher T_C allowed to use a simpler He-flow cryostat, where the detector can be placed outside vacuum. In the end, it turns out to be very difficult to reach temperatures below 4 K, and this initiative allowed to successfully perform the experiment. From the physics point of view, the experiment is very similar since the goal was to understand the role that the phonon density of state plays on the superconducting properties of thin films, regardless of the particular material that was used. The specificity of either Sn or Nb_3Sn is therefore not crucial here. In fact, Nb_3Sn is a superconductor which shows a strong electron-phonon coupling. Thus, the effect of the PDOS on the superconductivity (or vice-versa) are likely to be more pronounced in this system.
For the experiment, we grew a series of Nb_3Sn films on MgO(100) substrates by molecular beam epitaxy using co-evaporation of Nb (e-beam source) and isotopically enriched ^{119}Sn (knudsen cell). Six samples with thickness varying from 10 to 60 nm were grown, covering the bulk (>50 nm) and the reduced dimensionality case. The crystalline quality, the composition and the superconducting properties were investigated by x-ray diffraction, Rutherford backscattering and SQUID magnetometry, respectively. The T_C of the films was found to be varying from 14.5 K for the 60 nm layer to 11 K for the 10 nm layer.
The NIS experiment was performed at the ID22N beamline. A high resolution monochromator delivering an energy bandwidth of 1 meV was used. The samples were placed in a He-flow cryostat, which allowed to reach the temperature of 4.2 K.

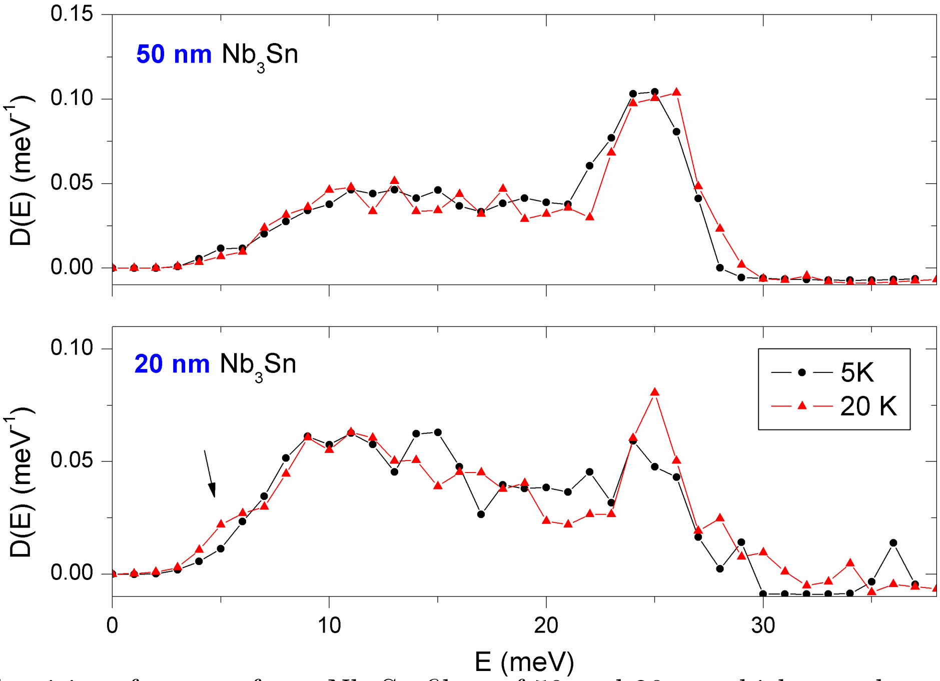

Fig. 1: Phonon densities of states of two Nb_3Sn films of 50 and 20 nm thickness above and below the superconducting transition temperature.

The samples were illuminated in grazing incidence geometry and the APD detector, which used to detect the inelastically scattered photons, was placed perpendicular to the sample surface, outside the cryostat. A compromise had to be found in order to reach the lowest temperature, still allowing to keep the detector close enough to the sample, such that the count rate decreased not too much.
The first 5 shifts of the experiment were used to set up the beamline and optimize the photon flux at the resonant energy of 23.8 keV. In order to match the sample size in grazing incidence geometry, we used a compound refractive lenses assembly, reaching a vertical beamsize of 100 μm. Once optimal parameters were found, we recorded nuclear inelastic spectra in a loop for up to 20 hours. Consequently, we had time to measure a total of four phonon densities of states. We measured two samples having a thickness of 20 and 50 nm, both above and below the superconducting transition temperature, which was determined to be 12 K and 14 K respectively. The obtained PDOS are displayed in Fig. 1.
Several features can be observed: There is a drastic change in the shape of the PDOS for the 20 nm and the 50 nm case. The 20 nm layer shows a softening of the modes and a decrease of the 25 meV peak intensity compared to the 50 nm case. This change of the PDOS is expected to lead to a modification of the electron-phonon coupling and hence, to be linked with the decreased T_C observed for the thinner film.
The second striking feature is the small difference that can be seen around 5 meV in the PDOS of the 20 nm layer recorded above and below T_C. It should be pointed out that the effect was not observed in the 50 nm film and seems therefore to be due to an extra modification of the electron-phonon coupling induced by the reduced thickness of the film. Since in a NIS experiment the low energy part of the PDOS is also the one which yields the best statistics, we can exclude statistical variations as the cause of the observed difference. This effect indicates in fact that also the phonons are influenced by the electron-phonon coupling. The reason why this effect is enhanced in thin layers (confinement effect?) is not yet clear. Further experiments on samples with different thicknesses are necessary to better understand how the layer thickness modifies the PDOS and the electron-phonon coupling. Currently, we also seek to reproduce the observed effects with ab-initio calculations.
The understanding of these effects is expected to bring significant insight into possible modification of electron-phonon coupling in superconductor thin films. We therefore expect that the results obtained in this experiment will bring the understanding of superconductivity in a confined geometry a large step forward.