ESRF	**Experiment title:** Manipulating superconductivity in Nb film by controlling the magnetic state of implanted Fe atoms	**Experiment number:** HE 3324
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Report:

This experiment aimed at probing the magnetic state of small Fe inclusions implanted in a superconducting Nb thin film. This would allow for the correlation of the modification of the magnetic state of the imbedded Fe with the modified superconducting properties. For that purpose, we employed the technique of nuclear resonant scattering (NRS) of synchrotron radiation at the 14.41 keV nuclear resonance of ^{57}Fe. In conventional magnetometry techniques (e.g. SQUID), the magnetic signal of the imbedded nano particles is hidden due to the strong diamagnetic response of the superconductor. The NRS technique is only sensitive to the chemical and magnetic state of the ^{57}Fe nucleus, therefore allows for the characterization of the magnetic inclusions.
In fact, we opted to grow nano-islands of different sizes of the magnetic ^{57}Fe on a MgO(100) substrate and subsequently cover them with a superconducting Nb thin film of 60 nm. The growth of the Nb at room temperature on top of the nano-islands prevents the formation of any F_xNb_{1-x} alloy, which would be the case it the Fe is implanted and the system would be annealed at higher temperatures in order to form clusters. Moreover, the Nb crystalline structure would be decreased by the damage caused by the implantation process. An AFM study shows that we can tune the size of the nano-island in the range similar to the superconducting coherence length of the Nb (about 38 nm) (see Fig 1). This ensures us that the physics point of view, both systems are very similar to each other, since the goal was to probe the interaction between the materials at this length scale.
The NRS experiment was performed at the nuclear resonance beamline ID18. The resistance of the samples inside the cryomagnetic system was monitored during the NRS experiment via four probe resistance measurements. This allowed to determine the superconducting phase transition temperature very precisely.The sample were then measured around this temperature for different external magnetic fields (perpendicular to the sample surface).

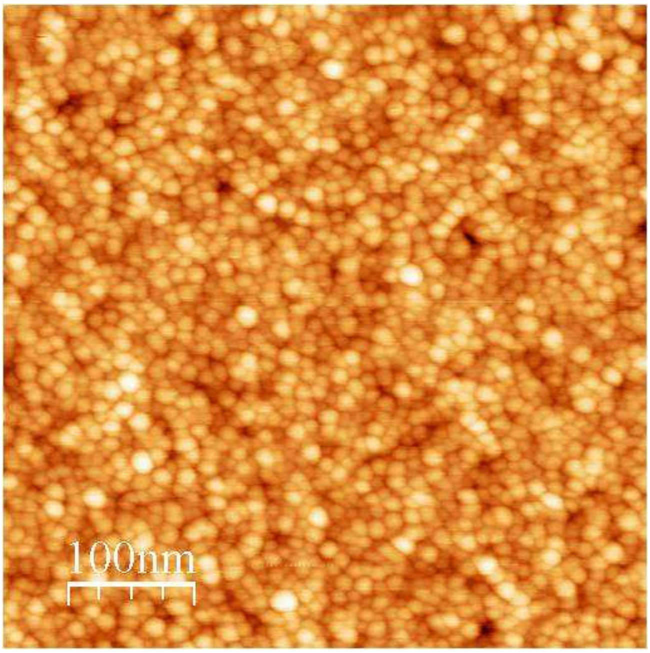

Fig. 1: AFM measurement of the Fe layer with a nominal thickness of 1 nm. This illustrates the formation of disconnected islands during growth.

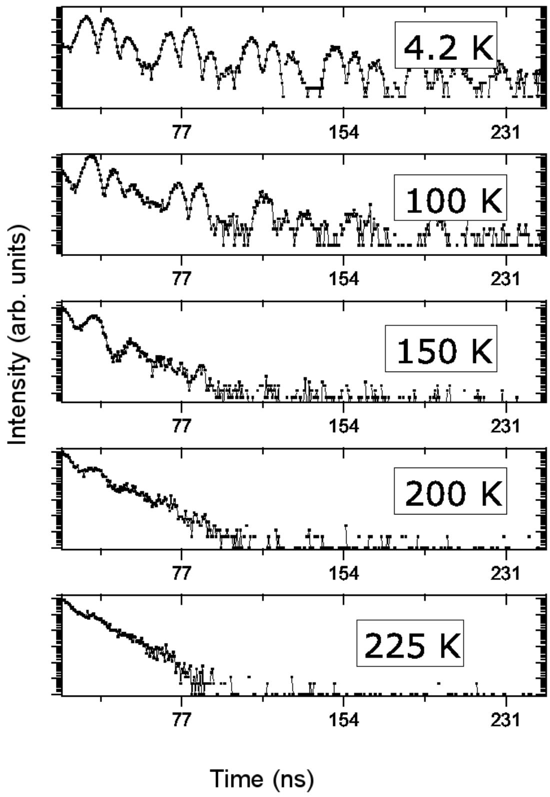

Fig. 2: Selection of time spectra at zero field at different temperatures. This series of measurements shows the dissapearance of magnetic beating at higher temperatures. This is a fingerprint of the superparamagnetic behavior of the Fe nano islands.

We mainly focused on two types of samples, with different nominal thicknesses of the Fe layer. First we measured the case of a 5 nm Fe layer, which shows ferromagnetic order at room temperature. The second type of sample which had only a 1 nm layer of Fe, represent the case were there is no ferromagnetic order at room temperature.

A selection of nuclear time spectra of the sample with a 1 nm Fe layer is shown in Fig. 2. The time structure of the NRS technique has the beneficial property that we can follow the dynamics of the magnetic spins in the MHz to GHz regime. This figure shows that the Fe nano islands are in a superparamagnetic state. At low temperatures the spins are static and are lying in plane of the Fe layer (beating pattern visible). While increasing the temperature, the spins start to fluctuate, resulting in a disappearance of the beatings in the time spectra. More detailed information can be obtained by fitting the spectra via the CONUSS program. However, still some features of the beating pattern is not yet fully understood at the early times of the spectra. A possible explanation could be the formation of an Fe oxide at the interface with the substrate.

The superparamagnetic behavior of the Fe in the small particles regime and the unique possibilty of recording this behavior via the NRS technique has some important implications in the research to superconductor(SC)/ferromagnet(FM) hybrids. The possibility exists of still decreasing the size of the islands and equalling the relevant energies of both SC and FM. This would lead to a maximal interaction between them and therefore this experiment was highly valuable in this field of research.