

**Experiment title:**

The temperature dependence of magnetic ordering in buried iron-oxide nanolayers

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Report:

The aim of the experiment was to study the temperature dependence of the magnetic structure of an oxide nanolayer present in a magnetically coupled Fe/native-oxide/Fe trilayer system. It was already observed that such systems exhibit a strong magnetic coupling between the metal layers which is mediated by the magnetically ordered oxide spacer layer[1,2]. Iron oxide (FeO) is normally not magnetically ordered in bulk at room temperature, and it is therefore obvious that the magnetic state in this system is modified by the reduced dimensionality and the proximity to the ferromagnetic Fe layers. Thus, performing a temperature dependent study of the magnetism of the oxide was necessary to understand the mutual influence of the metal and the oxide on their respective magnetic properties. In order to study exclusively the magnetic structure of the oxide, we used the isotope sensitive technique of nuclear resonant scattering of synchrotron radiation in combination with a selective ^{57}Fe doping of the oxide layer only.

The experiment was carried out in grazing incidence in a He-flow cryostat capable of reaching temperatures below 10 K. The sample (placed on the cold finger of the cryostat) was in the center of the poles of an electromagnet generating magnetic fields as high as 1.2 T (the field needed to saturate the magnetization in the sample [2]). First, the sample was field cooled to 10 K in a 1.2 T field. At this stage, the timespectrum shown in Fig.1a was recorded. Although it displays a complex beating pattern, careful analysis allowed to extract the hyperfine field (HF) distribution of the ^{57}Fe sites. As it is seen in Fig.1b, the main components (around 75%) display large HF values centered around 41 T, indicating the magnetic order of the oxide. The remaining 25 % percent have low hyperfine fields relating to non magnetic sites.

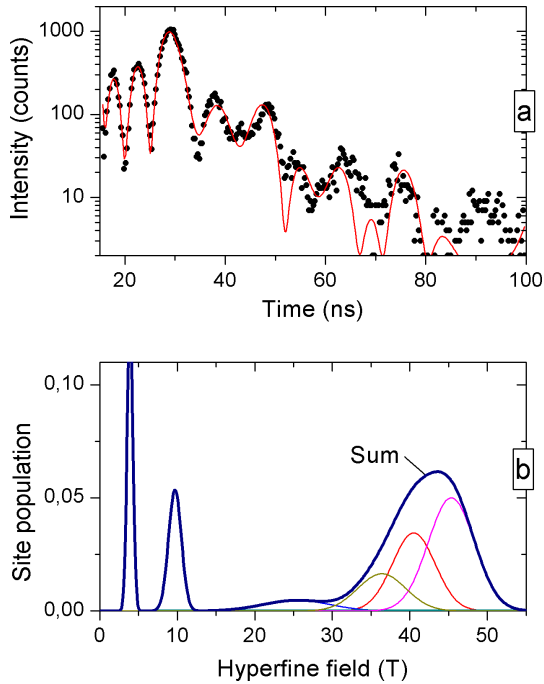


Fig. 1: (a) Nuclear timespectra of a buried native ^{57}Fe -oxide nanolayer recorded at 10 K. The red line is a fit. (b) Hyperfine field distribution extracted from the fitting procedure. The broad distribution of hyperfine fields centered at 41 T accounts for 75 % of the total site population.

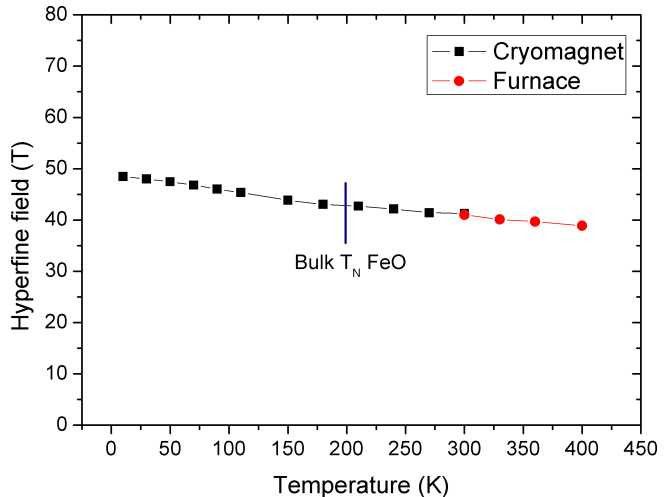


Fig. 2: Evolution of the mean value of the major hyperfine field component in the native oxide. A large hyperfine field persists much above room temperature up to 450 K.

The temperature was then slowly raised to follow the evolution of the magnetic state. Fig.2 shows the evolution of the largest HF site with temperature. It is remarkably surprising that the hyperfine field decreases linearly with increasing temperature, up to room temperature. We therefore decided to switch to a furnace system, in order to see up to which temperature the magnetic state is still stable. As it is seen, the HF field continues to decrease linearly up to 450 K. Above this temperature, atomic diffusion occurs, preventing further increase of the temperature.

These measurements are quite surprising. It is known that the oxide layer present an FeO type structure [3]. However, FeO is normally an antiferromagnet having a Néel temperature of 198 K. The fact that the HF field decreases linearly up to 450 K indicates that we are still far away from the Néel temperature T_N . This effect means that an oxide nanolayer can in fact have a much more stable magnetic state than its bulk phase. So far, the increase of the Néel temperature is attributed to the presence of ferromagnetic Fe at both interfaces, which stabilizes the magnetic structure in the oxide.

These results are fundamental for understanding the stabilization mechanism of magnetism on the nanoscale and will be the subject of a forthcoming publication.

- [1] Th. Diederich, S. Couet and R. Röhlberger, Phys. Rev. B **76**, 054401 (2007)
- [2] S. Couet, K. Schlage, Th. Diederich, R. Ruffer, K. Theis-Bröhl, K. Zhernenkov, B. Toperverg, H. Zabel and R. Röhlberger, New J. Phys. (2009), in press
- [3] S. Couet, K. Schlage, K. Saksl and R. Röhlberger, Phys. Rev. Lett. **101**, 056101 (2008)