

08-11 Chemical and magnetic spectromicroscopy of individual nanoparticles

N. Friedenberger, K. Ollefs, F. Kronast^a, H. A. Dürr^a, M. Farle

We aim in this project to characterize the electronic and magnetic properties of individual nanoparticles (10–50 nm) by photoelectron emission microscopy (PEEM). We use the (S)PEEM setup at the BESSY-beamline UE49-PGM-a.

We studied Fe nanoparticles with a cubic shape [1]. As a result of the colloidal preparation technique, the metallic core of the as-grown nanoparticles is surrounded by an oxidation shell and organic ligands. In order to remove the ligands, we cleaned the samples by plasma etching and protected them with a thin Al layer against re-oxidation. A gold grid was constructed by e-beam lithography on the substrate in order to mark the position of the particles and to examine exactly the same particles with SPEEM. We mounted the sample on a magnetic sample holder which allowed us to apply magnetic fields of up to 33 mT during imaging. Just before the measurement, we removed the Al capping layer by *in situ* Ar sputtering in a preparation chamber attached to the SPEEM.

Fig. 1 shows typical PEEM images that we recorded during our first XMCD study at low temperatures (110K – 130K). Panel A shows Fe nanoparticles arranged around a gold reference grid. Due to preparation conditions, we find particles in different configurations that

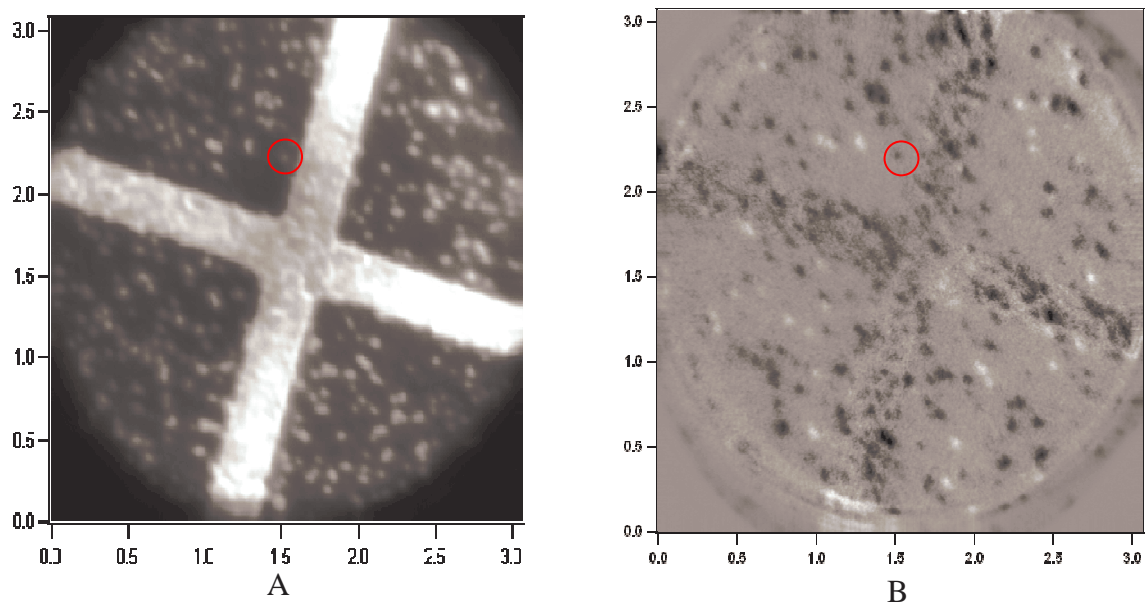


Fig. 1. The PEEM image in panel A shows the chemical contrast of the Fe nanoparticles recorded at the Fe L_3 resonance. The field of view is $3\mu\text{m}$. Panel B shows the x-ray magnetic circular dichroism recorded at the L_3 resonance at 110 Kelvin in a magnetic field of 10mT. The red circle indicates the position of a single Fe nanoparticle.

range from single particle sites to small clusters formed by a few nanoparticles. We can clearly resolve single particles as indicated by the red marker. The XMCD image in panel B visualizes the magnetic switching behaviour of these particles in an external magnetic field. After field cooling, we reduced the magnetic field to zero and applied it along the opposite direction. Bright contrast means that the magnetization of the particles still points into the field cooling direction. Dark contrast in the image indicates that the magnetization of the particles switch into the direction of the external magnetic field.

^a BESSY GmbH, Berlin, Germany

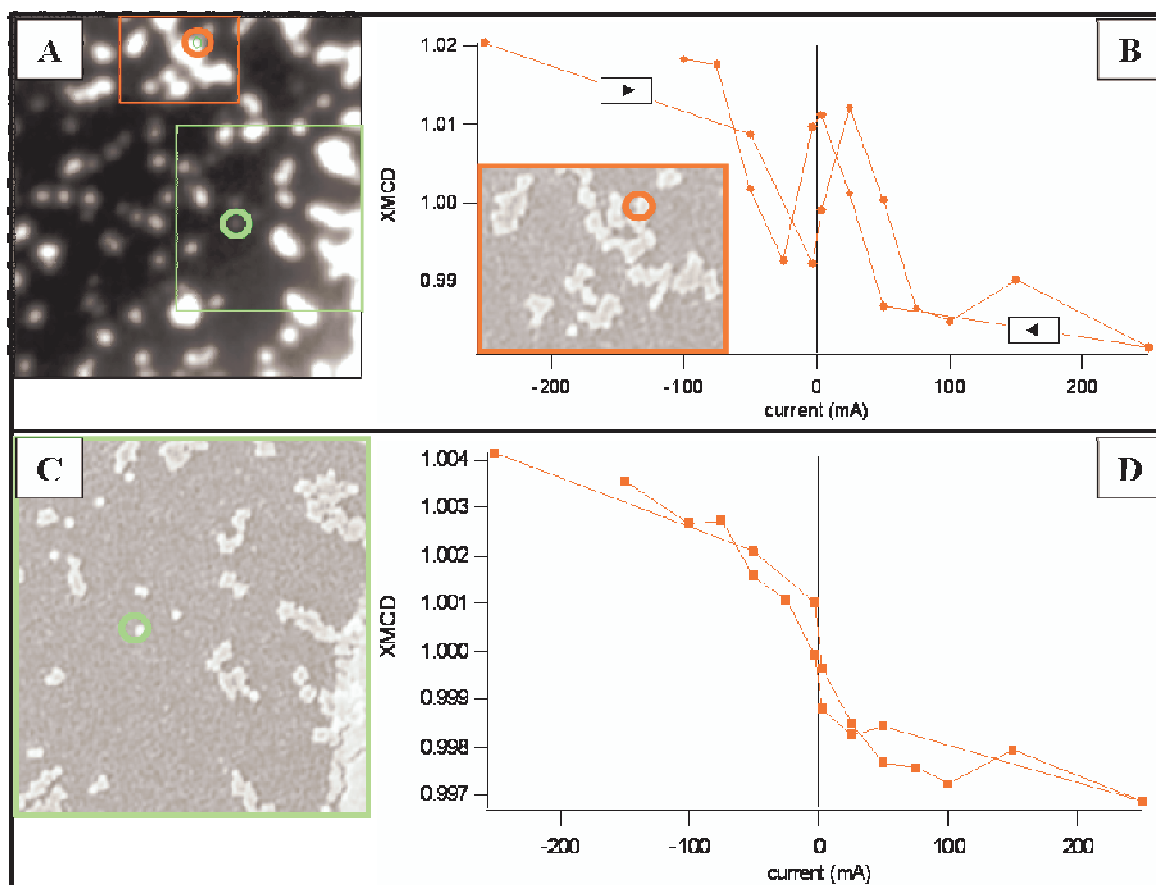


Fig. 2. Panel A shows the PEEM image corresponding to the field of view in FIG. 2. In B the hysteresis loop for dipolar-coupled nanoparticles is shown, a SEM image of the configuration is shown as inset. The hysteresis loop of a single nanoparticle is presented in D. Panel C shows the corresponding SEM image. The hysteresis loop D (and B) were recorded at the position marked with the green circle in C (and in A, red circle in B inset). The scaling for the magnetic field of the hysteresis loops is $1\text{ mA} = 0.09\text{ mT}$.

Being able to observe the switching behaviour of single nanocubes, we continued our measurements by recording hysteresis loops of single nanocubes and cubes in different configurations (monomer, dimer, trimer). Therefore, we varied the magnetic field applied through the sample holder between -25 and $+25$ mT and locally read out the XMCD intensity signal for the configurations of interest in the images.

Long image acquisition times up to 2 hours for each data point of the hysteresis loop were required to attain an acceptable signal-to-noise ratio. The magnetic switching behavior of the nanoparticles turned out to be sensitively influenced by the configuration.

Examples of our first hysteresis measurements results are shown in FIG. 2. These first results demonstrate clearly the feasibility of our approach and the challenging options of single nanoparticle magnetic measurements. In the next step, we plan to extend the investigations to different sample configurations and measure the magnetic response as a function of temperature to analyze the influence of the dipolar coupling on the “blocking” behaviour of finite-size superparamagnetic particle ensembles.

Reference

1. A. Shavel, B. Rodríguez-González, M. Spasova, M. Farle, and L. M. Liz-Marzán; *Adv. Funct. Mat.* 17 3870 (2007).