ESRF	Experiment title: **SXRMS imaging of magnetic properties in patterned structures**	**Experiment number**: HE-2221
Beamline: **ID08**	**Date of experiment**: from: 6/12/06 to: 9/12/06	**Date of report**: 8/03/07
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Report:

During our experiment HE-2221 in December 2006 we performed soft x-ray resonant magnetic scattering (SXRMS) on NiFe patterned dots, in reflection geometry, at the Ni L_3 edge using circularly polarized radiation from ID08. The response from different samples was measured in two dimensions (q_x-q_y) using a soft x-ray CCD camera mounted directly onto the UHV diffractometer. We studied the magnetization state at various stages of the switching process under applied magnetic field. We expected to obtain diffraction patterns for two types of samples at various stages of the magnetization reversal.

Using micromagnetic modelling for SXRMS we have also simulated the response of the different magnetic configurations (such as the ‘vortex’ and ‘saturated’ states), which were used to compare the ‘ideal’ theoretical predictions with the results obtained in the measurements. Assuming the magnetization profile of each dot is very similar, due to the same shape, dimensions and limited interaction between the nano-elements, the form factor of the magnetic scattering should represent the magnetic ‘shape’ of the dots. By analysing this we expect to extract the magnetization profile of the dots at various stages of the field dependence.

The inset of Fig. 2 shows a typical diffraction pattern measured on a hexagonal array of 260 nm diameter NiFe dots with a thickness of 25 nm. In order to extract the magnetic contribution we used the following procedure, according to standard practise. For each measurement at specific value of the field we also took a diffraction image of the sample in saturated state. The latter plays the role of ‘background’ and was subtracted from the diffraction maps at each point of the field. Fig. 1(a), (b) and (c) shows an example of two cases with applied field values of ~500, ~100 and 0 G (corresponding to 9, 0 and –3 V across the electromagnetic coil). Comparing the peak intensities of the diffraction patterns it was observed that the structure of the peaks varied as the applied field was reduced. This was reflected not only in the average value of the intensities, but also in the relative structure of the pattern. In particular, once the field is reduced to 0 G the diffraction pattern shows a certain structure with some peaks positive and some negative (Fig. 1(c)). It is interesting to note that the sign of the peaks appears to be antisymmetric with respect to the horizontal q_x axis (i.e. if peak 2 and 3 are negative then peak 11 and 12 are positive). Given this symmetry and the variation with the applied field, it is expected that the structure of the pattern is related to the structure of the magnetic dots. In particular, it is speculated that it most likely represents various stages of vortex displacement in the dot.

In the preliminary analysis, we used in order to simulate these results an ideal representation of the vortex, where the magnetization is circumferential around the center of the dot. The result of the magnetic structure in this case was that the irregular structure of the peaks were formed for the interval of the field where vortex formation was expected (Fig. 3(c)). Despite similar trends between the experimental and simulated results for some of the peaks we could not obtain an agreement for the whole pattern (cf. Fig. 1(c) and inset of Fig. 3(d)).

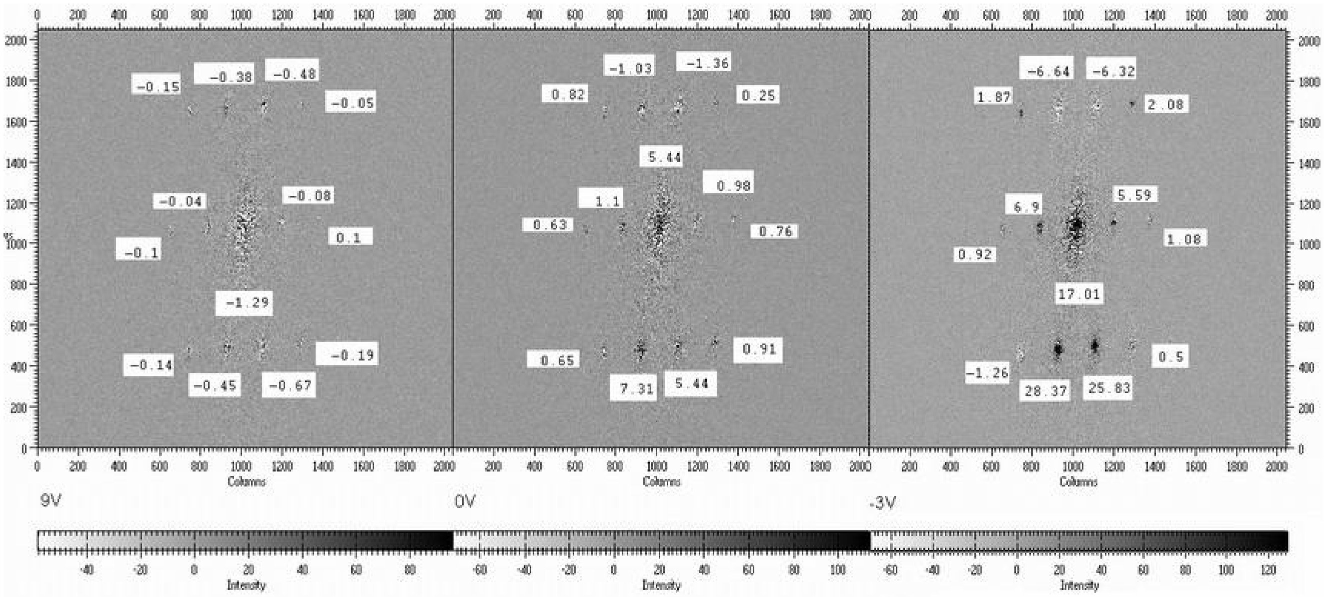

Fig. 1. Magnetic diffraction patterns at different values of the applied field (9, 0 and –3 V over the electromagnet, corresponding to approx. 500, 0 and –100 Oe) imaged using the CCD camera for a hexagonal array of 260 nm diameter NiFe dots with a separation of 390 nm. The patterns are obtained by subtracting the 'background' pattern measured at saturatation. The inserted numbers indicate the average intensities of the peaks.

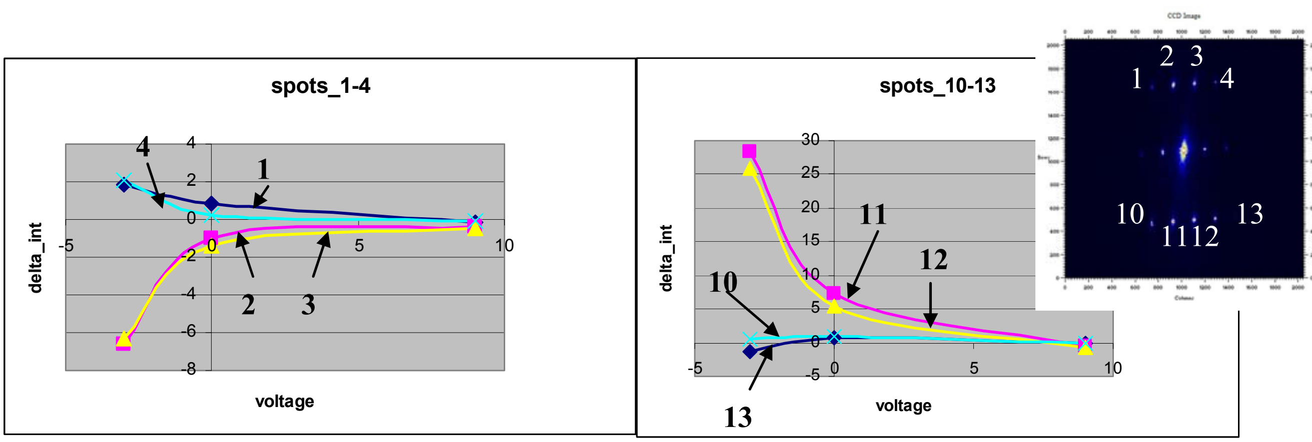

Fig. 2: The average intensities of peak 1 to 4 and peak 10 to 13 as a function of applied field (expressed in the voltage over the electromagnet). The inset shows the unaltered map of the diffraction peaks with both charge and magnetic contribution, where the numbers indicate the different peaks around the specular reflection.

The asymmetric nature of the experimental pattern (in this case comparing the intensity of the opposite peaks) suggests a more complicated structure of the magnetic dots than originally anticipated. A possible reason for this mismatch – which we would like to investigate in the next experiment – is that the applied field used in the experiment was not uniform and insufficiently large in the plane of the sample. Indeed, the configuration of the applied field used in the experiment was by and large designed for perpendicular measurements, although it was optimised (to best efforts) to provide in-plane flux, the perpendicular component of the field still remained important, so that the effect of both perpendicular and in-plane components added to create a complicated structure.

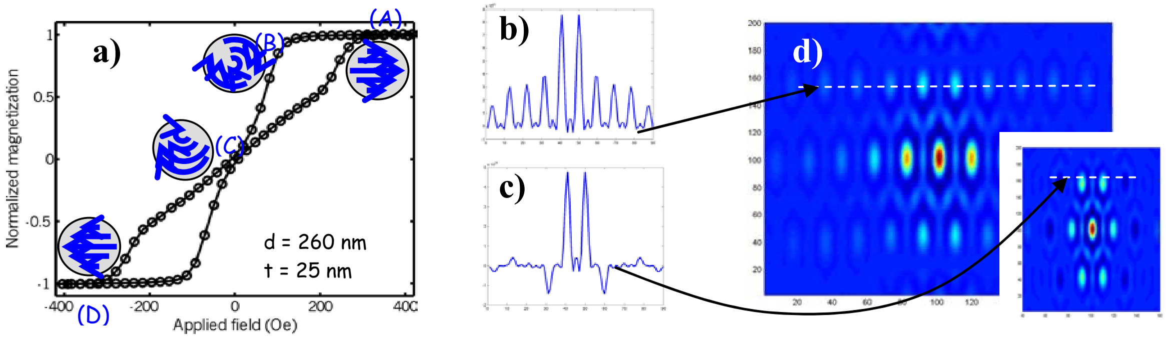

Fig. 3: a) MOKE hysteresis loop measured on a 260 nm diameter dot sample. The disks with the arrows demonstrate a schematic representation of the magnetic vortex, as it forms (B) and then propagates across the dot taking the central position (C) in the middle of the sample and finally annihilates at point (D) to become saturated again in opposite direction to the original state. d) Simulated diffraction pattern for the same sample using the same data treatment (i.e. subtracted background) in the region of the applied field corresponding to the section (A)-(B) in the hysteresis loop, and in the case of a perfect vortex (as shown in the inset). b) and c) 2D cut through the top row of the peaks (indicated by dashed line) in the corresponding cases of the two fields.