Structural Growth and Magnetic Birth of a Self-Assembled Array of Superferromagnetic Nanoislands

K. Schlage, D. Erb, H.-C. Wille, and R. Röhlsberger

DESY, Notkestrasse 85, 22607 Hamburg, Germany

The formation of self-assembled magnetic nanostructure on ordered diblock copolymer templates constitutes a fascinating approach for cost-efficient realization of magnetic arrays of dots, antidots or nanowires. The metallic objects formed on the polymer nanodomains are characterized by an extremely small distribution in size, which can be continuously adjusted from around 200 nm down to 3 nm. The recent remarkable progress in the fabrication of diblock copolymer films allows now to arrange the polymer nanodomains into arbitrary large single crystalline lattices [1] and will support this route of templated self-assembled magnetic nanostructures.

From the scientific point of view, the bottom-up approach has a major advantage compared to nanostructures prepared via the conventional top-down approach. Here the fabrication process allows to monitor and correlate *in situ* the structural growth of the nanostructure with its magnetic state. This combined valuable information can be used as an excellent tool to study the magnetic stabilization mechanism in patterned magnetic nanostructure.

Here we study the growth and magnetic phase transition of iron islands, which are arranged in a hexagonal lattice. A heat treated sapphire substrate with a surface of oriented saw tooth pattern (see figure 1) was used as substrate for fabrication of the polymer template which allows to realize long range order in the polymer template and enables this way to introduce macroscopic easy and hard axes in the magnetic lattice.

In the sputter deposition experiment presented here we applied grazing incidence small angle x-ray scattering (GISAXS) and nuclear forward scattering of synchrotron radiation (NFS) to detect the size, shape and lateral arrangement of the iron islands and as well as their magnetic state (e.g. the orientation and strength of magnetic hyperfine fields) during formation. In addition, NFS was used to follow the magnetization dynamics which can be quantified (e.g. the amplitude and frequency) up to the GHz regime with this method.

Figure 2 shows selected data sets from this *in situ* experiment. The 2D GISAXS image and the corresponding line cut through the Yoneda peak reveals the extremely high degree of lateral ordering over the entire sample (the footprint of the x-ray beam exceeds the sample length). The

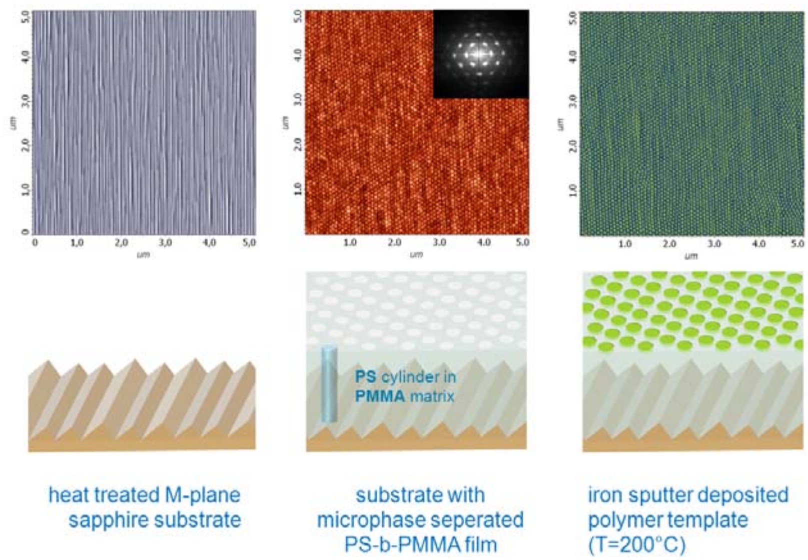

Figure 1: Schematic drawings to sketch the preparation procedure of the ordered polymer template and the formation of self-assembled iron islands. The corresponding upper images were taken with an AFM.

GISAXS data evaluation (**see detailed information about the GISAXS evaluation in the annual report of Denise Erb, "Growth of hexagonal iron nanodots on a self-assembled diblock copolymer template"**) shows a cone like shape of the iron islands which form on the polymer template at these deposition conditions (1 monolayer per minute, p_{Argon}=1.5x10^{-2} mbar, T = 200 °C). The simulation of the nuclear time spectra reveals an extremely interesting magnetic phase transition of the islands. At low deposition stage (up to 6 monolayer of nominal deposited iron) the islands with an average diameter of 52 nm, a distance of 83 nm and a height of 10 nm are characterized by isotropic superparamagnetic fluctuations with a frequency of around 50 MHz. Then a sharp transition to a collective spin precession takes place, which is accompanied by a strong reduction of the frequency by more than one order of magnitude.

This phenomenon can be attributed to a superferromagnetic behaviour of the islands, which is expected to occur only in highly ordered lattices of very similar objects with a small ratio of distance to diameter. In this case, a dipolar interparticle coupling of the superparamagnetic spins takes place which results in the observed collective behaviour. The strongly reduced frequency implies a significantly increased blocking temperature of the islands due to the lateral arrangement. The evaluation of later deposition stages is ongoing.

These results bring significantly new insight into the stabilisation mechanism of patterend magnetic nanostructure. The fabrication process and characterization technique presented here open numerous opportunities for fundamental and application-oriented research projects.

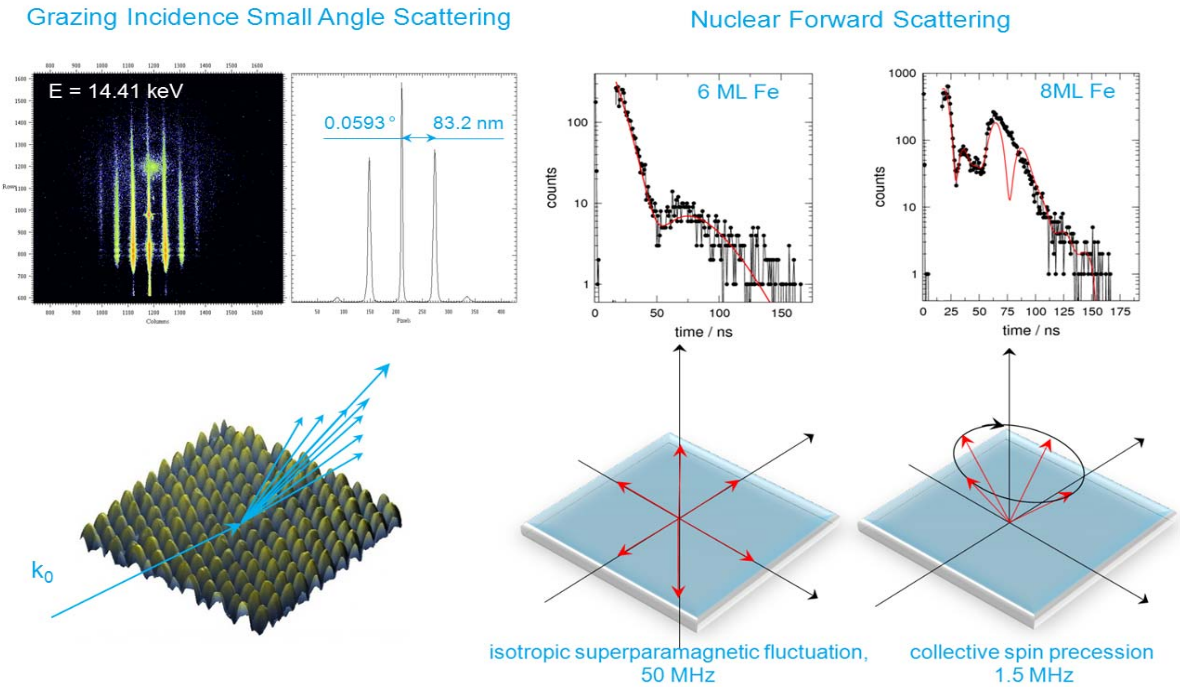

Figure 2: Selected data sets of the *in situ* sputter deposition experiment. GISAXS (see a 2D image after deposition of 3 monolayer of iron onto the template and a corresponding horizontal line cut through the Yoneda peak) was used to follow the structural growth of self-assembled iron islands (**see results from the data evaluation in the annual report of Denise Erb**) and NFS was used to detect the magnetization state of the islands during formation. The simulation of the nuclear time spectra with a dynamical model of fluctuating hyperfine fields reveals a sharp magnetic phase transition from a state of isotropic superparamagnetic fluctuations to a coupled state with a collective spin precession with a now strongly reduced frequency (see schematic drawings). This phenomenon can be attributed to a superferromagnetic behaviour in this highly ordered lattice of very similar islands, which is a result of a significant dipolar coupling between the iron islands.

References

[1] S. Park, D. H. Lee, J. Xu,B. Kim, U. Jeong, T. Xu, T. P. Russell, Science 2009, 323, 1030-1033.