Supporting information

Epitaxial hard magnetic $SmCo_5$ MFM tips - a new approach to advanced magnetic force microscopy imaging

Volker Neu, Silvia Vock, Tina Sturm, Ludwig Schultz†

Institute for Metallic Materials, IFW Dresden, 01069 Dresden, Germany

E-mail: v.neu@ifw-dresden.de

The hard magnetic $SmCo_5$ MFM tips are prepared by cutting a slim triangular needle from the film/substrate compound of an epitaxially grown $SmCo_5$ film on MgO(110) substrates by means of focused ion beam (FIB) in a dual beam nanomanipulation tool (FEI Helios 600i). A cuboid volume of approximate size 13 µm x 20 µm x 30 µm is cut into the small edge of the MgO substrate leaving an approximately 2 µm thick substrate/film lamella at the very edge of the film sample. Figure S1 displays this lamella in a tilted view (a) and in a top view (b) looking directly onto the cross section of the lamella. A trapezoid-shaped needle is cut from this lamella (c) and is transferred to a tipless AFM cantilever with a nanomanipulator. It is attached to the very end of the cantilever by ion-beam induced decomposition of a Pt-containing precursor gas and trimmed to its desired final triangular shape (d). A typical base length is 2 to 4 µm and the tip height is about 10 to 15 µm. It should be noted, that irrespective of the thickness of the film/substrate lamella the thickness of the magnetic triangle (about 60 nm) is defined by the thickness of the $SmCo_5$ film during film deposition.

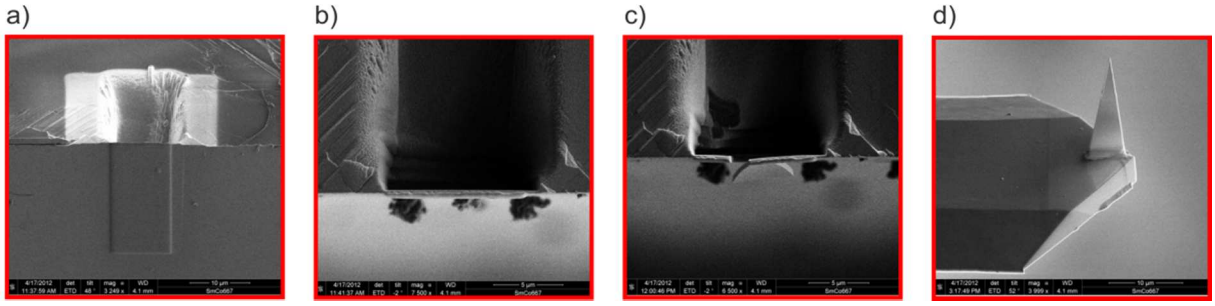

Figure S1: Series of scanning electron micrographs illustrating the different steps in probe preparation.

MFM measurements have been performed at zero field in a Dimension 3100 AFM/MFM in tapping/lift mode with an amplitude setpoint during the topography scan of 35 nm and a lift height during the MFM scan of 55 nm in case of the Co/Pt sample and a lift height of 100 nm in case of the Sm_2Co_{17} sample. In order to probe the field behavior of the tip, prior to each measurement, the tip magnetization was set in a superconducting magnet (PPMS-9T by Quantum Design). Care was taken to always measure the same position at the respective reference samples, to not only judge the average contrast strength according to the phase shift histogram, but also the polarity of the tip. Figure S2a summarizes selected measurements on the Sm_2Co_{17} bulk sample with the tip initially saturated in a positive 5 T field (corresponding to the tip magnetized “up”), and then subsequently demagnetized by applying successively larger negative fields. A contrast inversion and thus a reversal of the tip magnetization is seen at a field of -2.5 T. Figure S2b summarizes the comparable field series for measurements on the Co/Pt references sample.

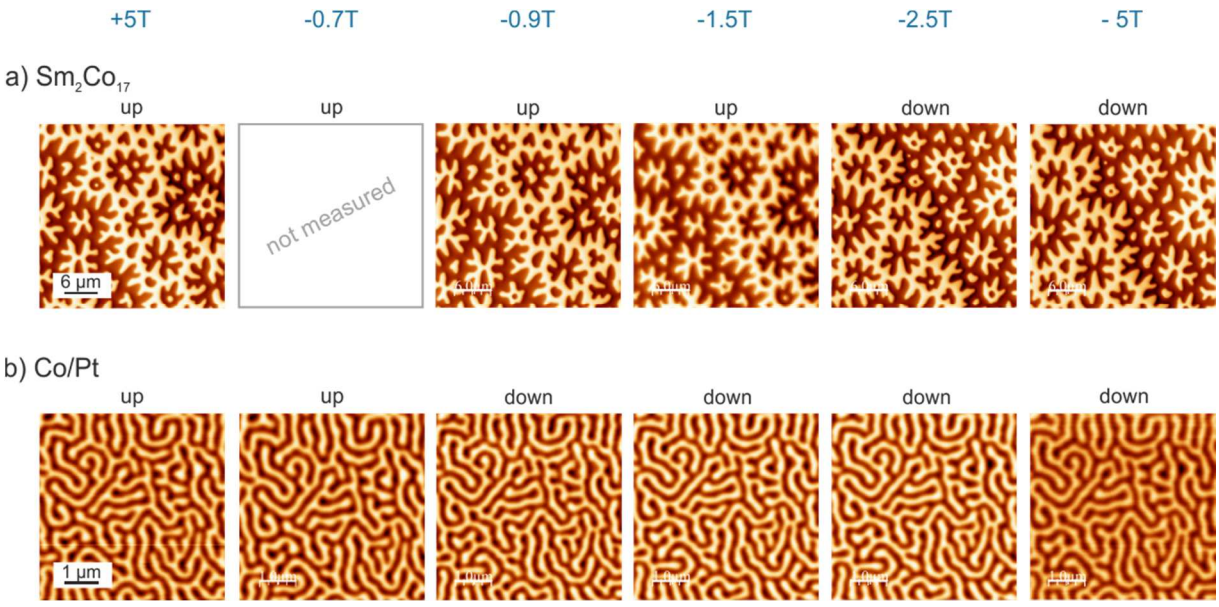

Figure S2: Series of MFM measurements performed at zero field, but with the tip being (de)magnetized at different fields prior to the MFM measurement (see label above). Measurements were conducted on a polished Sm_2Co_{17} bulk samples with large domains (a) and on a Co/Pt multilayer sample (b) with band domain of approximately 170 nm width.

Figure S3 summarizes the results of three additional $SmCo_5$ FIB tips cut from the same $SmCo_5$ film as previously presented. When imaging theSm_2Co_{17} sample (Fig. S3b) the domains with positive and negative magnetization orientation again show clear domain contrast as expected for a tip with low magnetic susceptibility. The tip in the 3rd column, however, shows additional features along the domain boundaries which is a sign for a magnetically softer behavior. The narrow domains of the Co/Pt multilayer sample (Fig. S3c) are well resolved with all three tips and no imaging artefacts are visible. The absolute MFM contrast and the polarity varies from tip to tip, as the $SmCo_5$ film is in an as-prepared state and possesses a fine scaled domain pattern. When cutting the triangular tip at a random position the net magnetization and the magnetization state at the very tip apex and therefore the MFM contrast will also vary. A more comparable quantitative signal is expected after saturating the tips in a large external field.

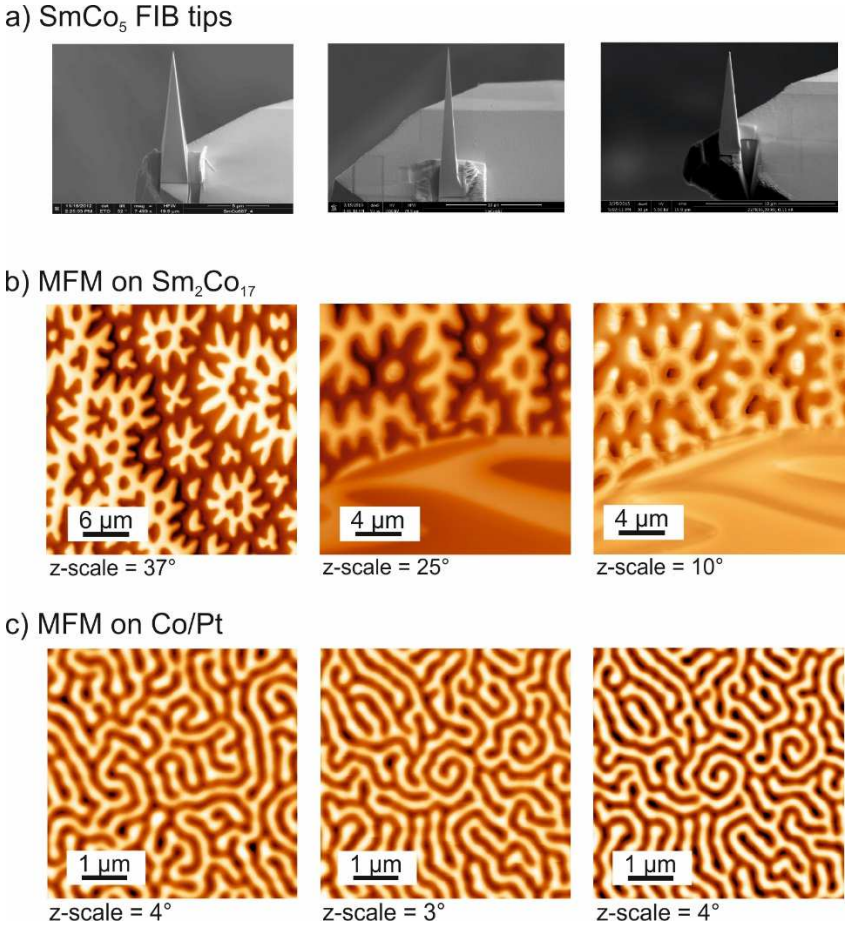

Figure S3: Scanning electron micrographs (a) and magnetic imaging performance (b, c) of three additional $SmCo_5$ FIB tips. The imaged samples are described in Figure S2. The large domains seen in (b) in the 2nd and 3rd column stem from a Sm_2Co_{17} grain with tilted c-axis orientation.