Magnetic Imaging Using Geometrically Constrained Nano-Domain Walls – Supplementary Information

Héctor Corte-León[1*], Luis Alfredo Rodríguez[2,3], Matteo Pancaldi[4],Christophe Gatel[2], David Cox[1,5], Etienne Snoeck[2], Vladimir Antonov[6,7], Paolo Vavassori[4,8], and Olga Kazakova[1]

[1]*National Physical Laboratory, Teddington, TW11 0LW, United Kingdom*

[2]*CEMES-CNRS 29, rue Jeanne Marvig, B.P. 94347, F-31055 Toulouse Cedex, France*

[3]*Department of Physics, Universidad del Valle, A. A. 25360 Cali, Colombia*

[4]*CIC nanoGUNE, Donostia-San Sebastian, E-20018, Spain*

[5]*Advanced Technology Institute, University of Surrey, Guildford GU2 7XH, United Kingdom*

[6]*Royal Holloway University of London, Egham, TW20 0EX, United Kingdom*

[7]*Skolkovo Institute of Science and Technology, Nobel str. 3, Moscow, 143026, Russia*

[8]*IKERBASQUE, Basque Foundation for Science, Bilbao, 48013, Spain*

**hector.corte@npl.co.uk*

1. HIGH MAGNIFICATION SEM IMAGES

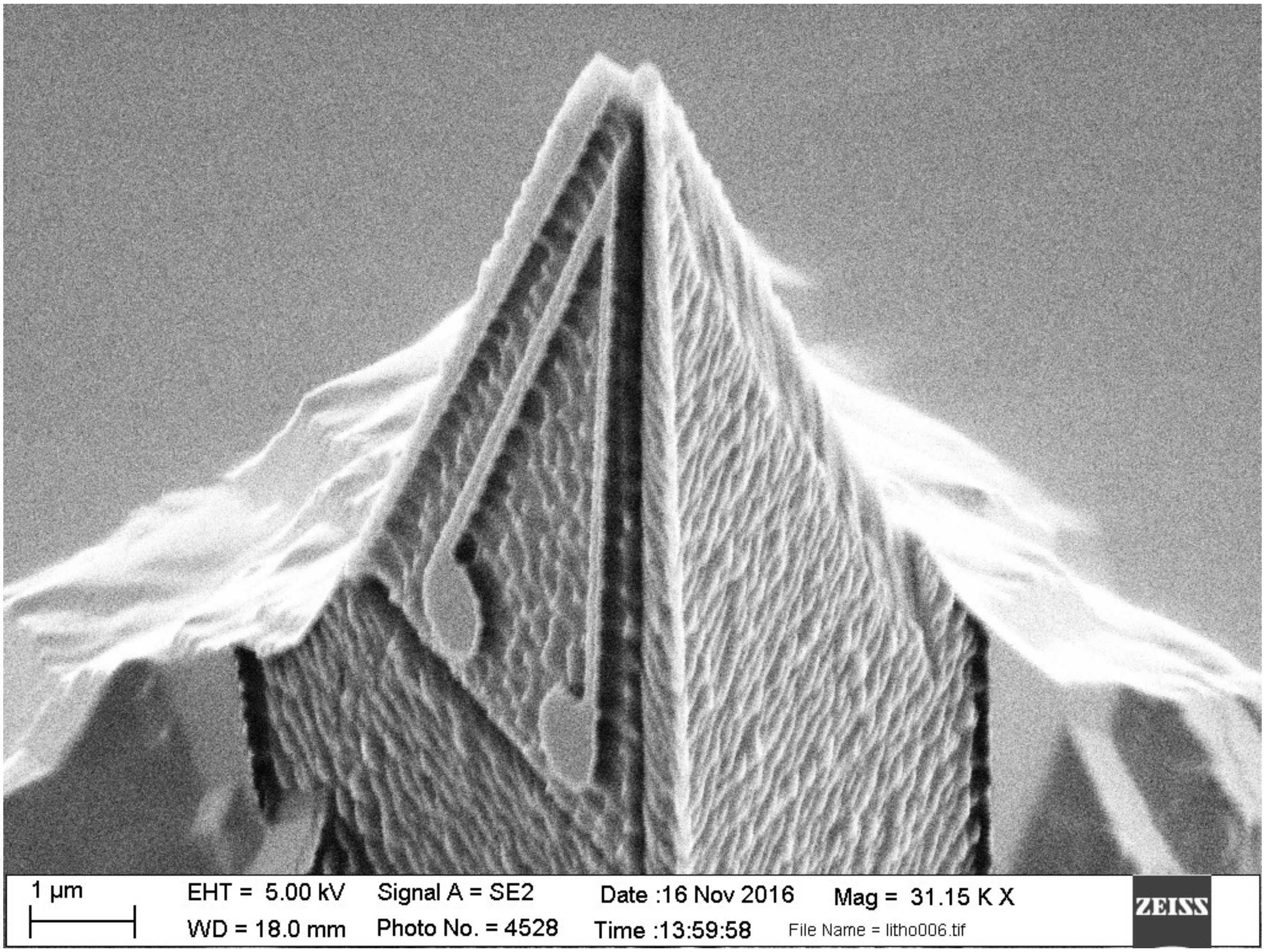

FIG. S1. SEM OF THE V-SHAPED MAGNETIC NANOSTRUCTURE ON THE PROBE APEX.

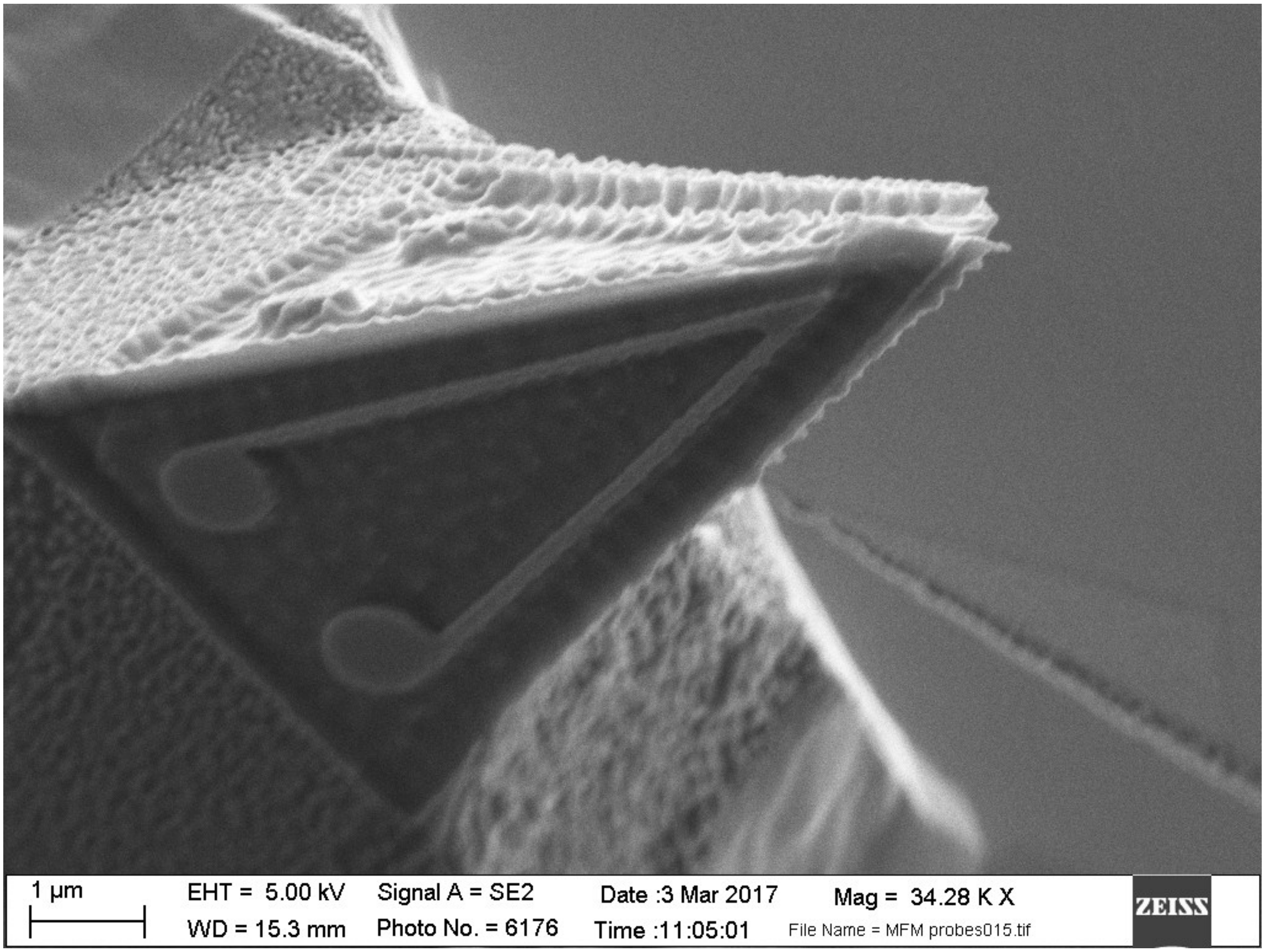

FIG. S2. SEM OF A DW-PROBE USED FOR FIB MILLING TESTING.

2. DW-PROBE SWITCHING FIELDS

In order to measure the DW-probe switching fields, several measurements were performed where the external magnetic field (out-of-plane) was ramping during the MFM imaging. Fig. S1 demonstrates how the probe structure switches from HH to curl to TT states at B = 43 and 54 mT, respectively, as the applied magnetic field gradually changed.

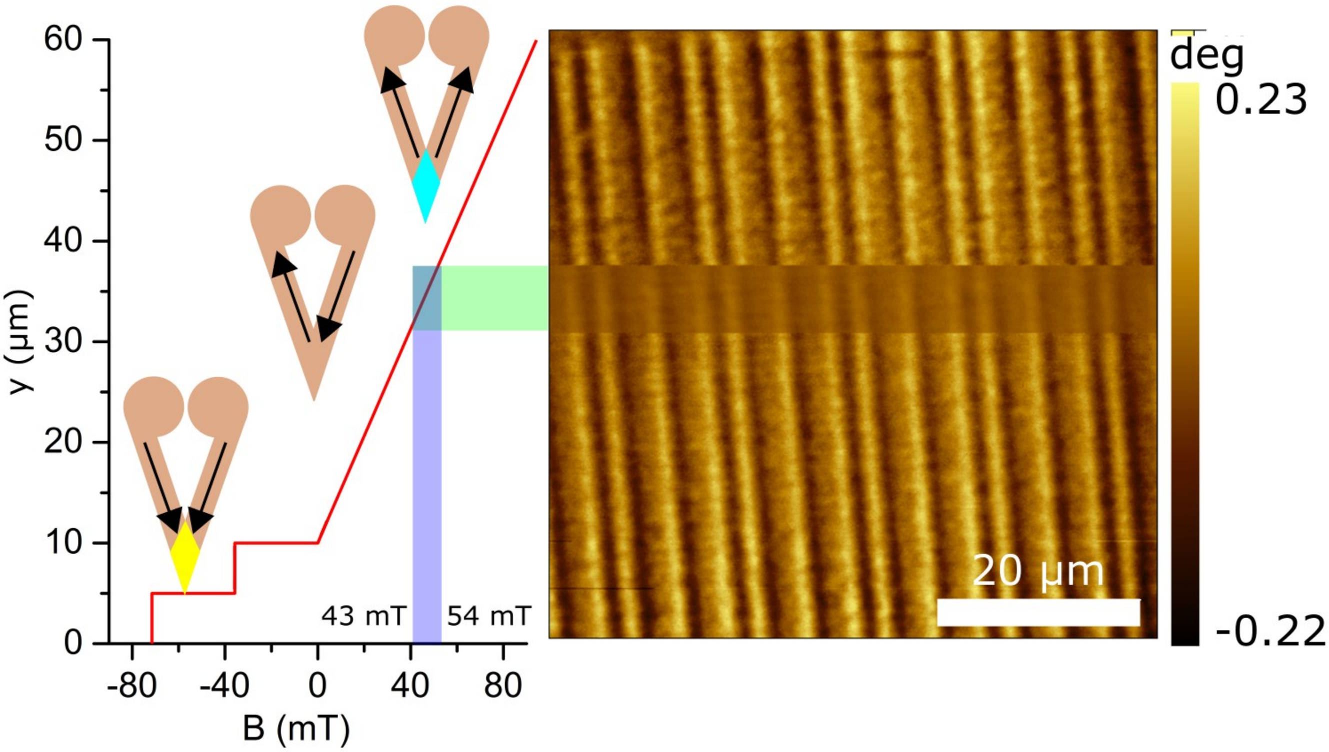

FIG. S3. MFM image of a floppy disk taken with the DW-probe, while an external out-of-plane magnetic field is being ramped from negative to positive values. Scan direction is from bottom to top.

3. MICROMAGNETIC SIMULATIONS

Micromagnetic simulation of one stable state of the Penrose pattern is shown in Fig. S2. Figure S2(a) shows the divergence of magnetisation, which is expected to provide a similar result as the phase images taken with MFM. Figure S2(b) demonstrates the corresponding magnetization state and gives information about the orientation of the different domains. Micromagnetic numerical simulations were carried out using OOMMF micromagnetic solver from NIST[45] with standard parameters for Py ($M_s = 800 \times 10^3$ A/m, $A = 13 \times 10^{-12}$ J/m, $k = 0$) and a cell size $5 \times 5 \times 5$ nm^3. The stable state was achieved by applying a field of 0.5 T along *x-axis* and then rotating it in the *x-y plane* while reducing its magnitude to zero.

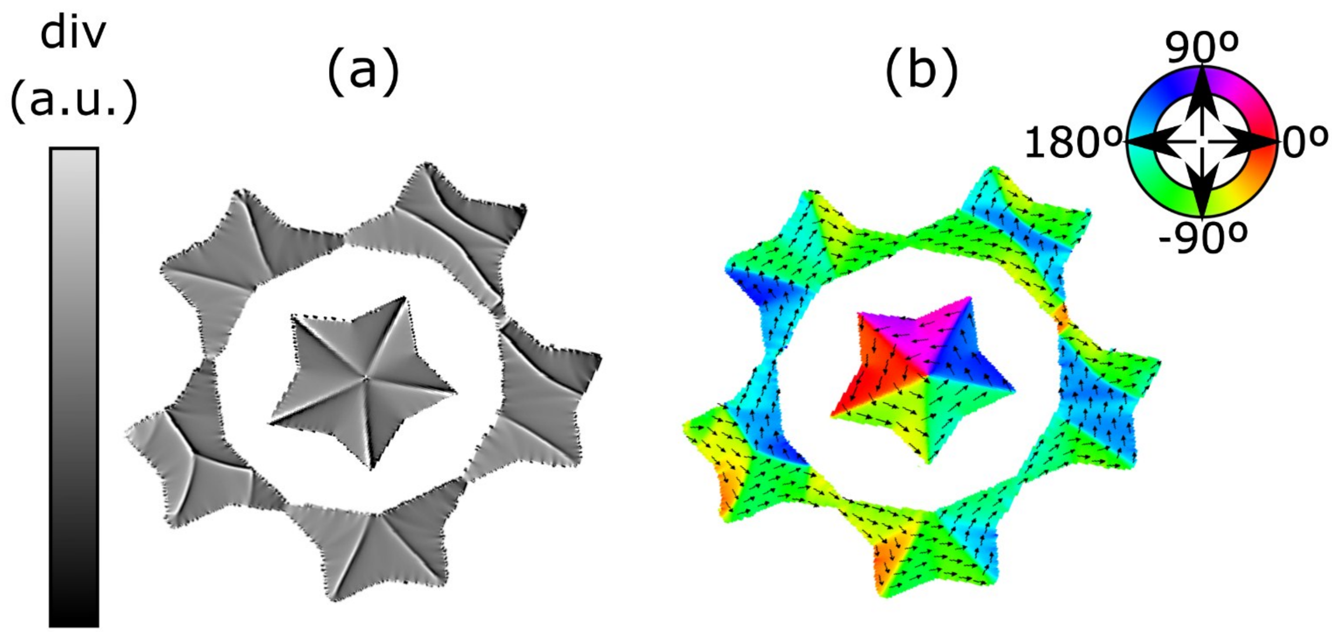

FIG. S4. OOMMF micromagnetic simulation of the Penrose pattern. (a) divergence of magnetization, (b) magnetization.

4. PROBE-SAMPLE INTERACTION

In order to demonstrate the effect of high stray fields onto the magnetization of the Penrose pattern imaged in Fig. 5, Figure S3 shows the MFM image taken using an unmodified standard moment, high coercivity, NANOSENSORS™ PPP-MFMR probe. Numbers 1-5 identify areas where the magnetization was modified while scanning. For instance, at number 1 it is clearly distinguishable a horizontal line indicating a change in magnetization. In area 2 the magnetization configuration is different than that shown in Fig. 5. Areas marked 3-5 show again a line of the scan where the magnetization changed abruptly due to the probe moving over it.

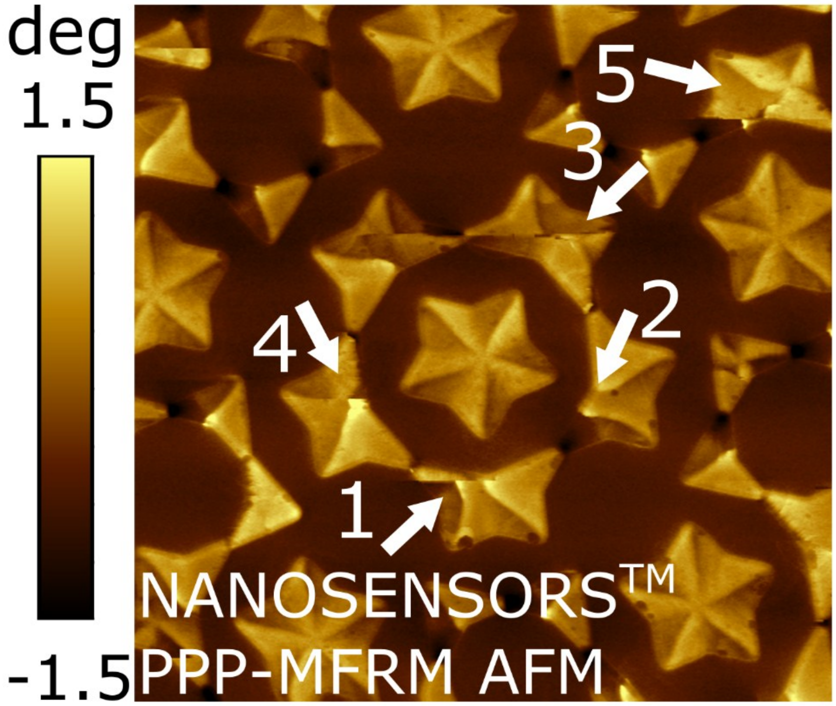

FIG. S5. MFM image taken with a standard moment unmodified NANOSENSORS™ PPP-MFMR probe. Numbers indicate areas were the interaction between probe and sample modified the magnetization of the sample.