ESRF	**Experiment title:** Manipulation of topological textures in a magnetic domain wall	**Experiment number**: MA-5884
Beamline: ID32	**Date of experiment**: from: 12.09.2023 to: 18.09.2023	**Date of report**: 20.09.2023
Shifts: 18	**Local contact(s)**: Flora Yakhou	*Received at ESRF:*

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Report:

During a previous experiment (MI-1429), we imaged the magnetic texture of a teardrop-shape sample in Permalloy by Fourier-transform holography (FTH). To our surprise, the domain wall consisted of several Bloch-wall-type segments of alternating polarities and apparent equal lengths. We wanted to figure out if this magnetic state was the true ground state of the sample, or a metastable state. For this purpose, we decided to perform magnetic imaging of the sample by Fourier-transform holography under applied field.

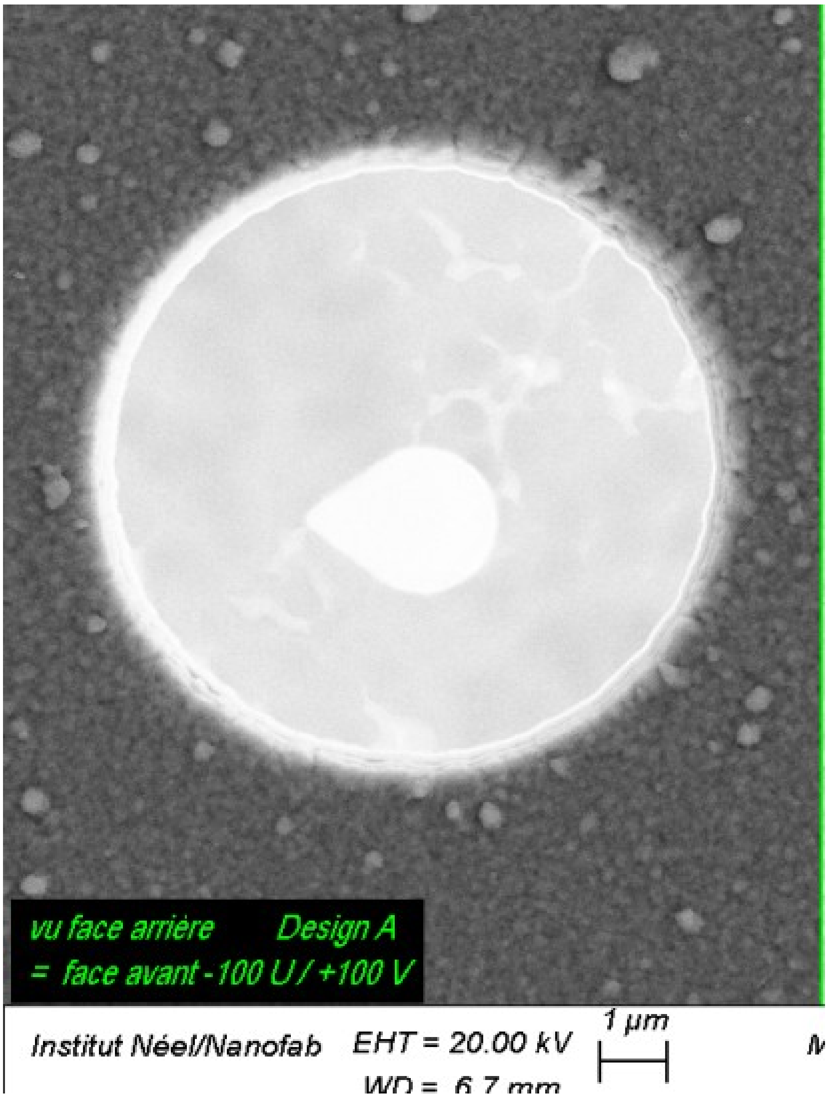

Figure 1: SEM image of the teardrop sample, seen from the back side through the aperture in the FTH mask.

The experimental set-up was the usual set-up for FTH at ID32. A big effort had been done by the beamline staff to improve the stability of the beamline and to reduce deadtimes in the acquisition chain (which was larger than the counting time). The 50-µm pinhole defining the incident beam was replaced by a 20-µm pinhole (Figure 2), in order to reduce the footprint on the sample, preventing from illuminating parasitic holes in the holographic mask. We benefited therefore from an optimised set-up, allowing to make images of excellent quality (Figure 3). In addition, we could test an acquisition procedure to record the low-q data, usually hidden by the beamstop. Most of the data were acquired with beamstop, as the low-q data did not improve massively the quality of the images for this particular sample. We tuned the X-ray energy to the L3 edge of Fe (the magnetic layer of the sample is in Permalloy). The magnetic constrast is obtained by differentiating images taken with opposite helicities of circular polarisation. The sample was kept perpendicular to the incident beam througout the experiment, such that the magnetic contrast encodes the projection of the magnetic moments perpendicular to the sample plane. Magnetic field was applied in situ with the electromagnet of the FTH chamber, providing field along the beam propagation axis.

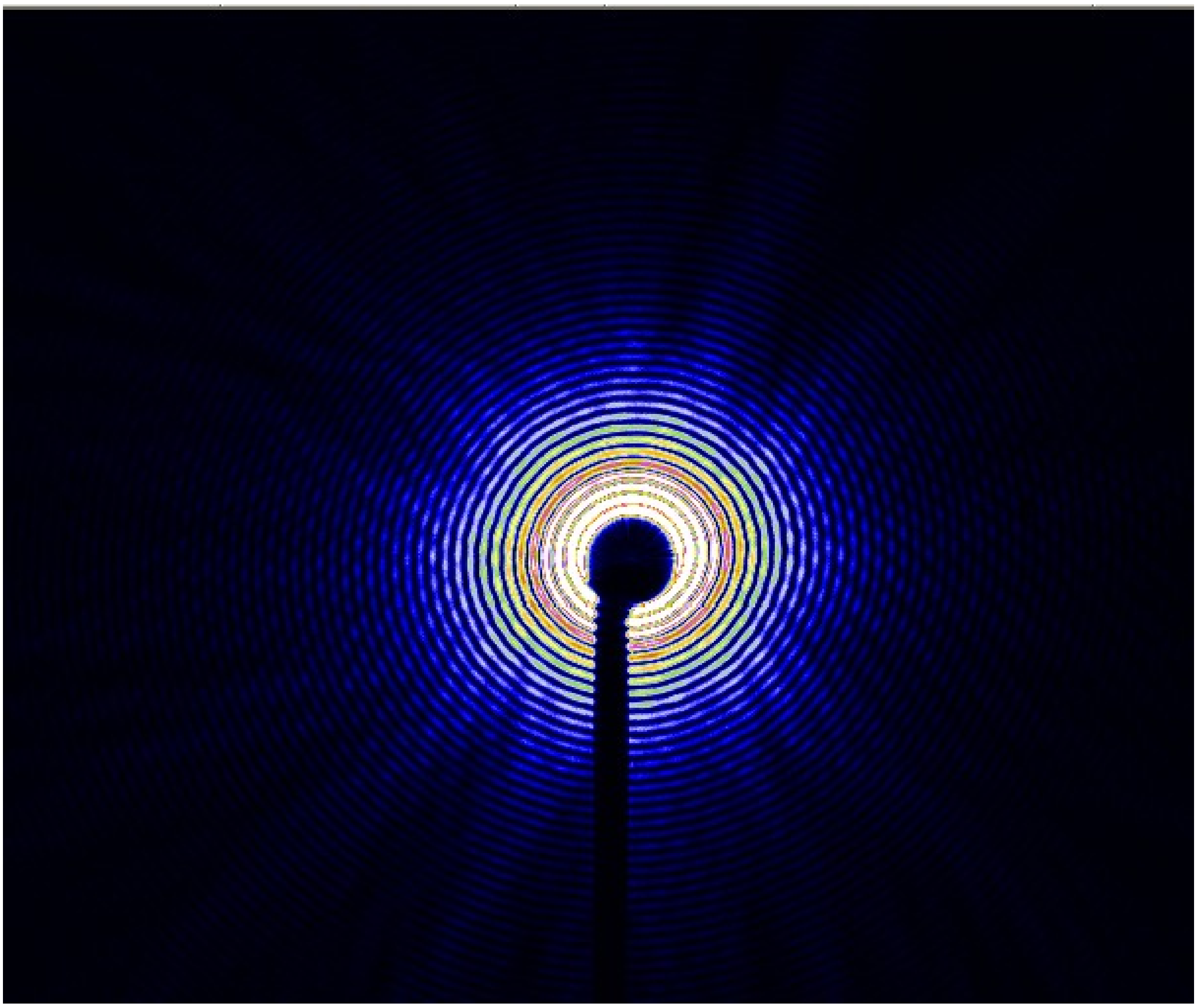

Figure 2: Image of the incident beam through the 20-µm pinhole, with beamstop and without sample.

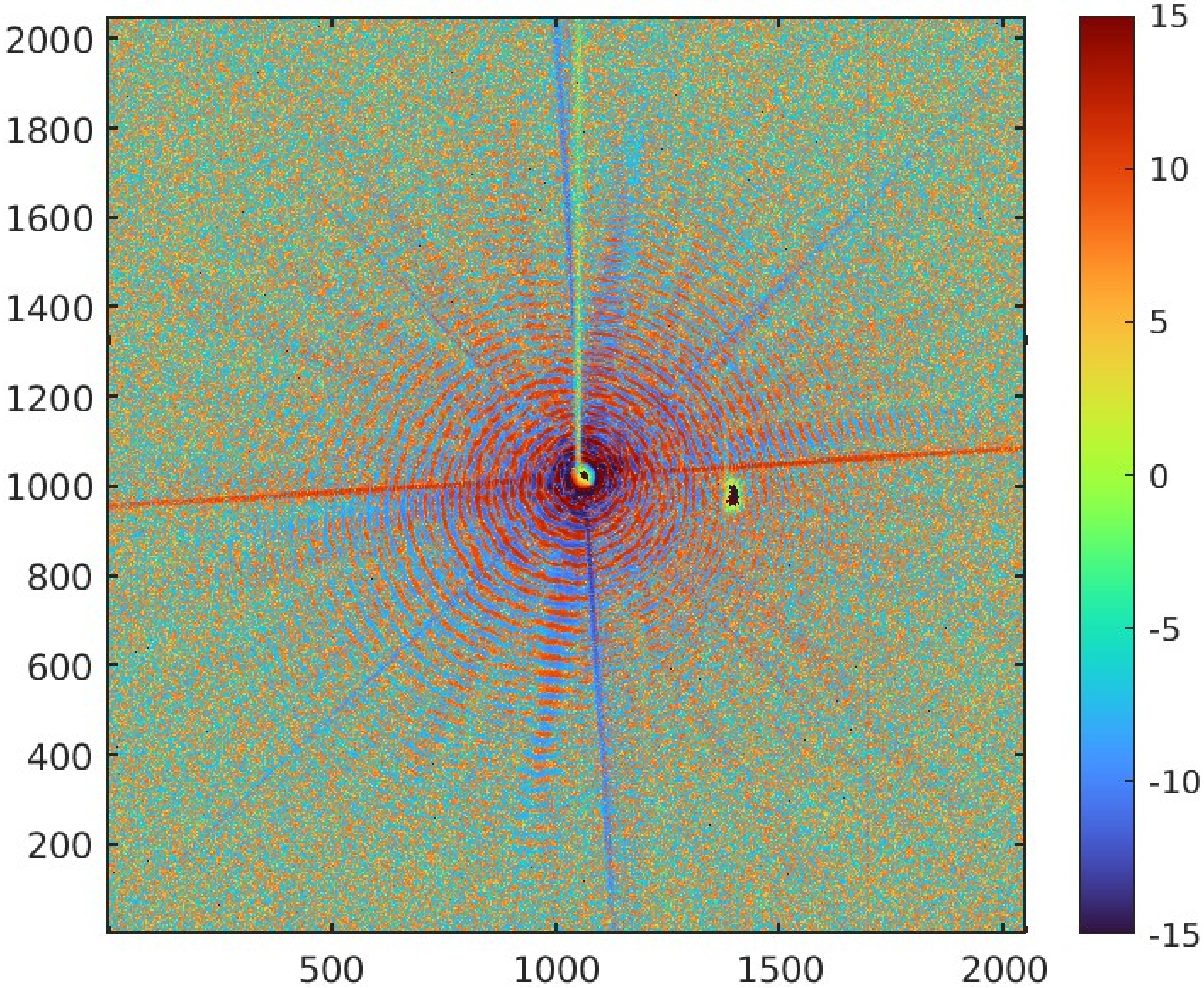

Figure 3: Typical dichroic diffraction pattern recorded during this experiment. Red and Blue colours encode contrasts of opposite sign.

The sample was found initially in the same magnetic state as we left it at the end of the previous beamtime, with 5 segments of alternating polarity (including the core) seen in the domain wall (Figure 2).

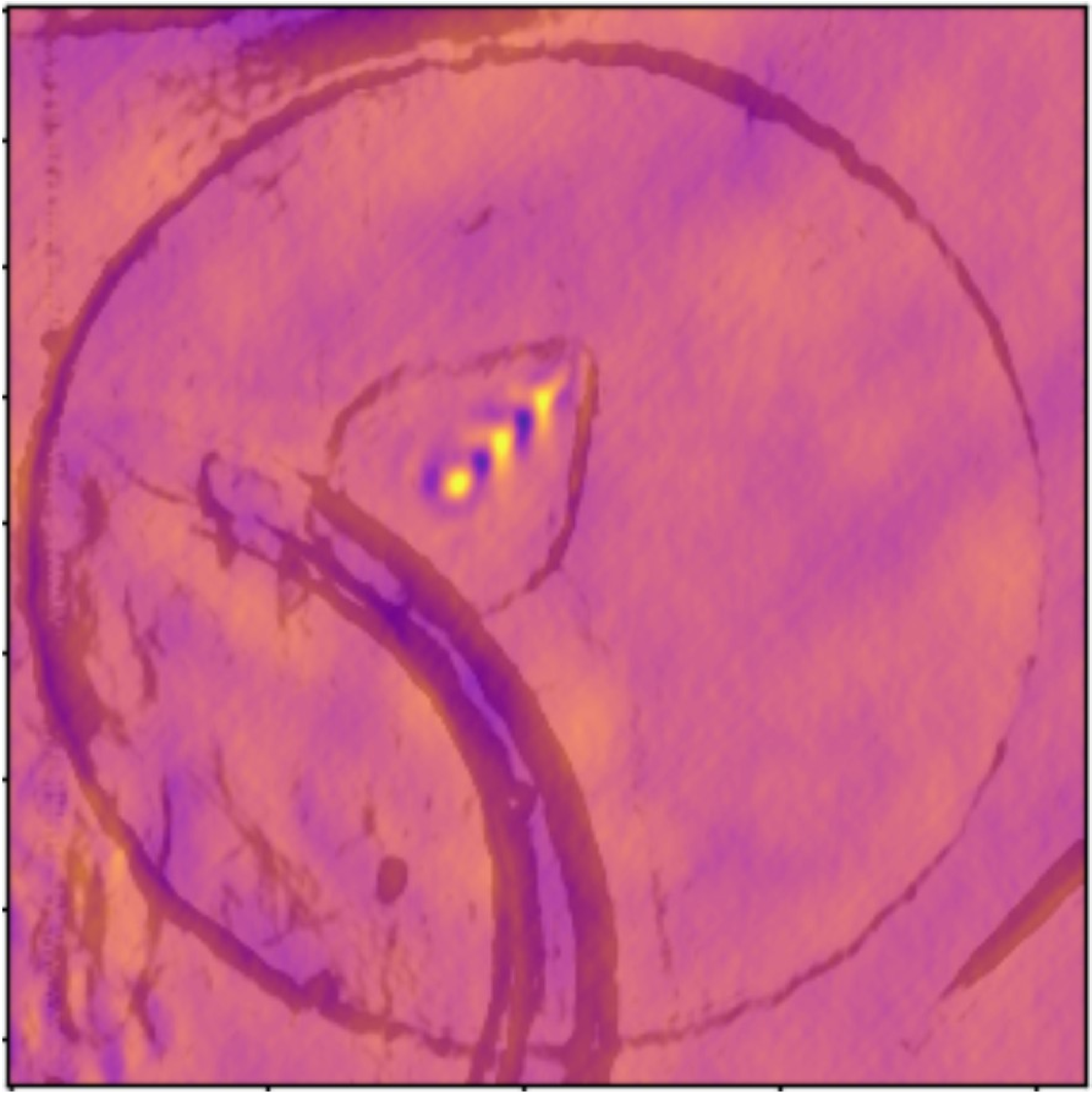

Figure 4: Image of the initial magnetic state. The structure is overlaid in grey to the magnetic contrast (in yellow/purple colour scale). The large ring shape is an artefact due to an unwanted hole in the holographic mask.

By applying several sequences of magnetic fields up to 0.45 T, we could understand in details the formation of the segments in the domain wall.

The initial state with 5 segments was found to be very reproducible upon demagnetising the sample with alternating decreasing magnetic field. Starting from the 5-segment state, when an increasing magnetic field is applied parallel (as opposed to antiparallel) to the magnetisation of the core (Figure 5), the initial segments of the domain wall are only distorted, up to ~0.22 T. Then the outer most segment of opposite magnetisation to the applied field is switched. This intermediate state persists until the field reaches ~0.25 T and the domain wall becomes monopolar. The monopolar state is stable upon releasing the applied field (Figure 6). With an opposite field of -0.28 T (but probably lower as did not record intermediate stages), the polarity of most of the domain wall, except the core, is switched and this state is stable upon releasing the field (Figure 7).

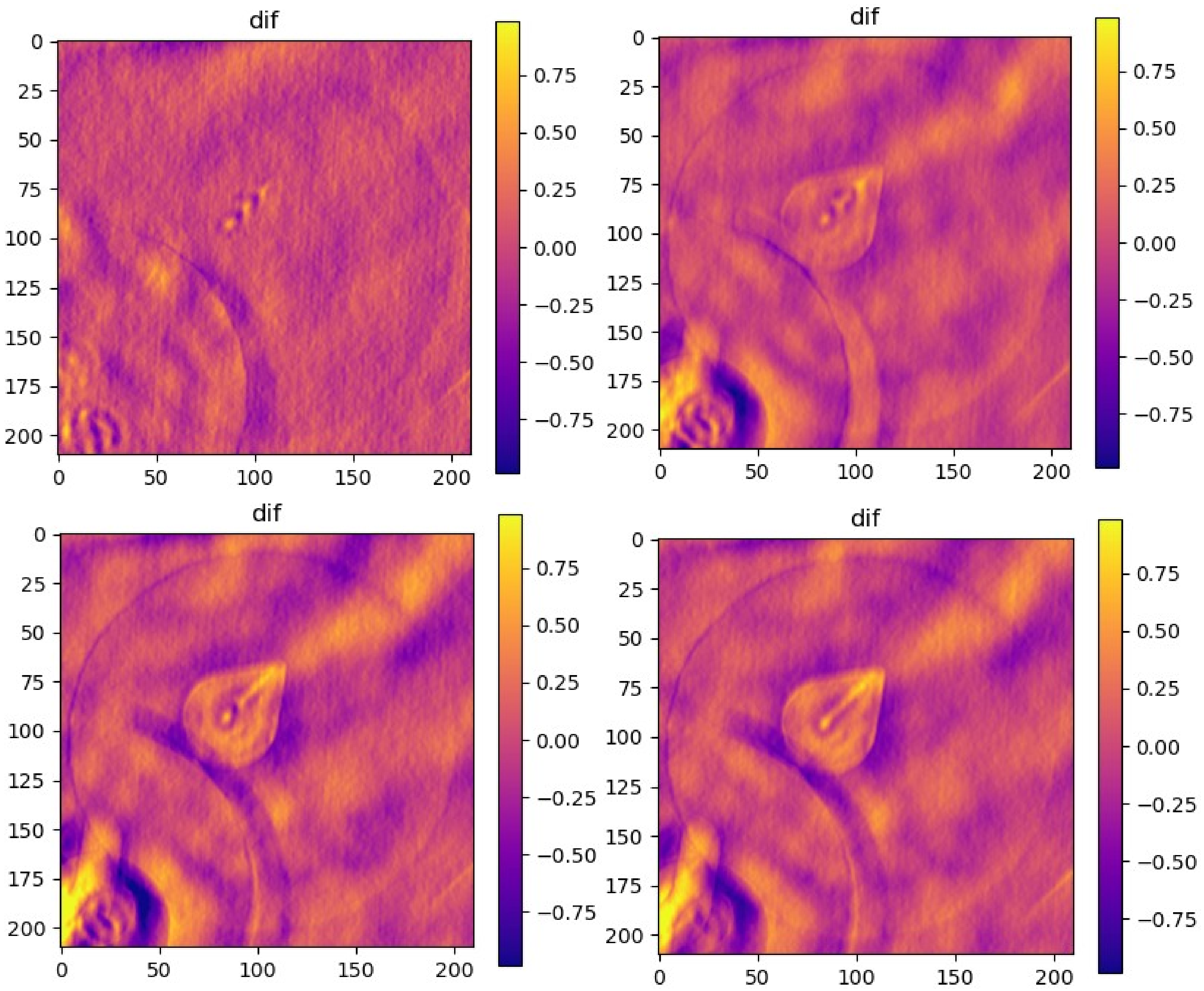

Figure 5: Successive states between the demagnetised multipolar state and the monopolar state, when the field is parallel to the magnetisation of the core (Top left: 0 T; top right: 0.22 T; Bottom left: 0.25 T; Bottom right: 0.26 T.

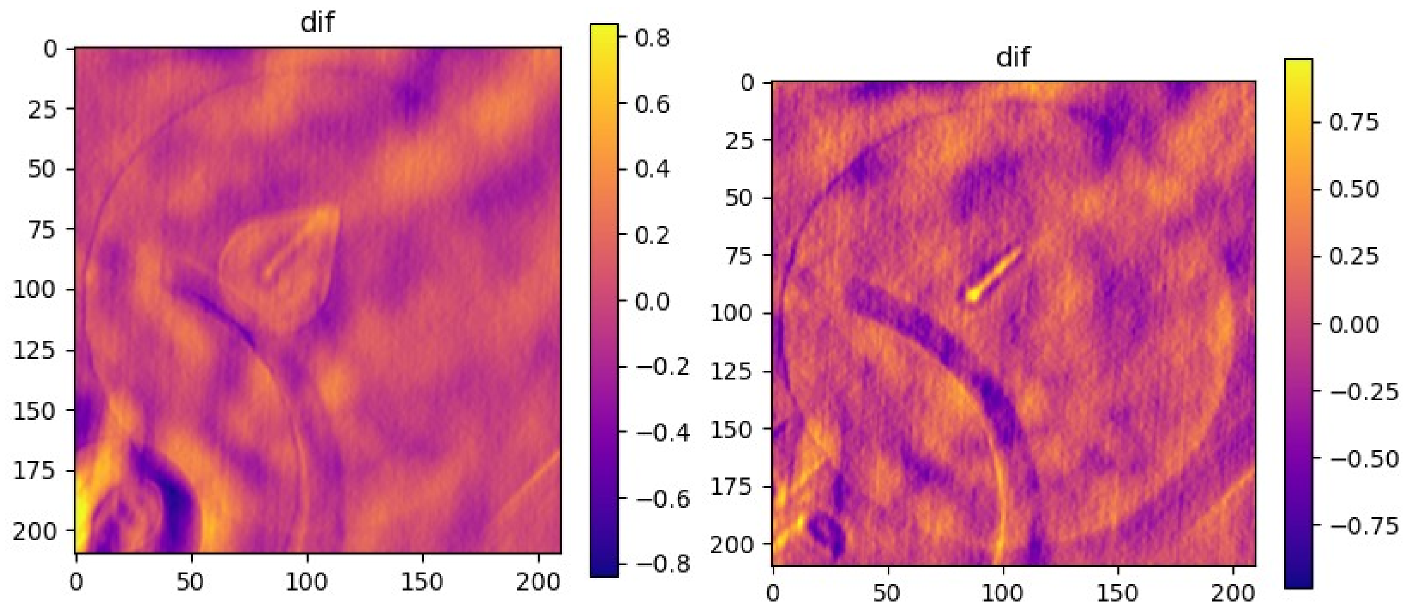

Figure 6: Monopolar domain wall under applied field (left) and after releasing the field (right). In the first case, the entire teardrop shows some contrast because the applied field pulls the magnetisation out of plane.

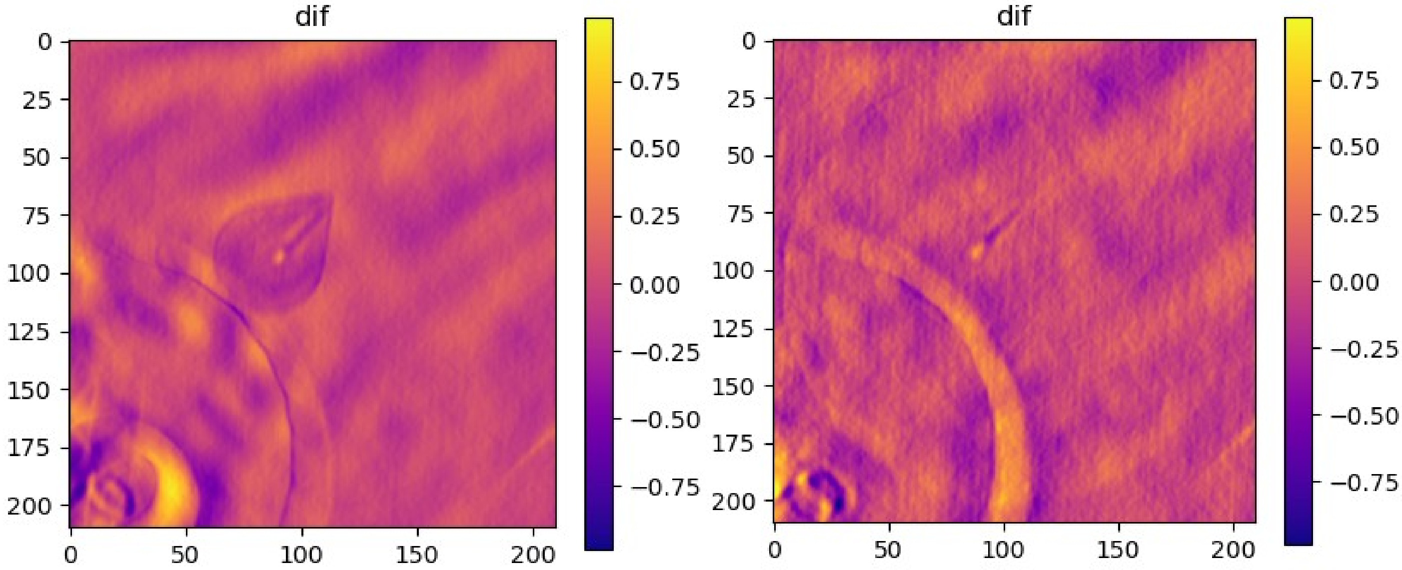

Figure 7: Intermediate state with most of the domain wall switched along the magnetic field, while the core remains opposite. Left: under applied filed; right: after releasing the applied field.

We also measured a demagnetisation loop with alternating and decreasing field, with small field steps at the transitions from 1 to 3 and from 3 to 5 segments. During our exploration with magnetic field history, we found several other states, such as 2 segments and 4 segments.

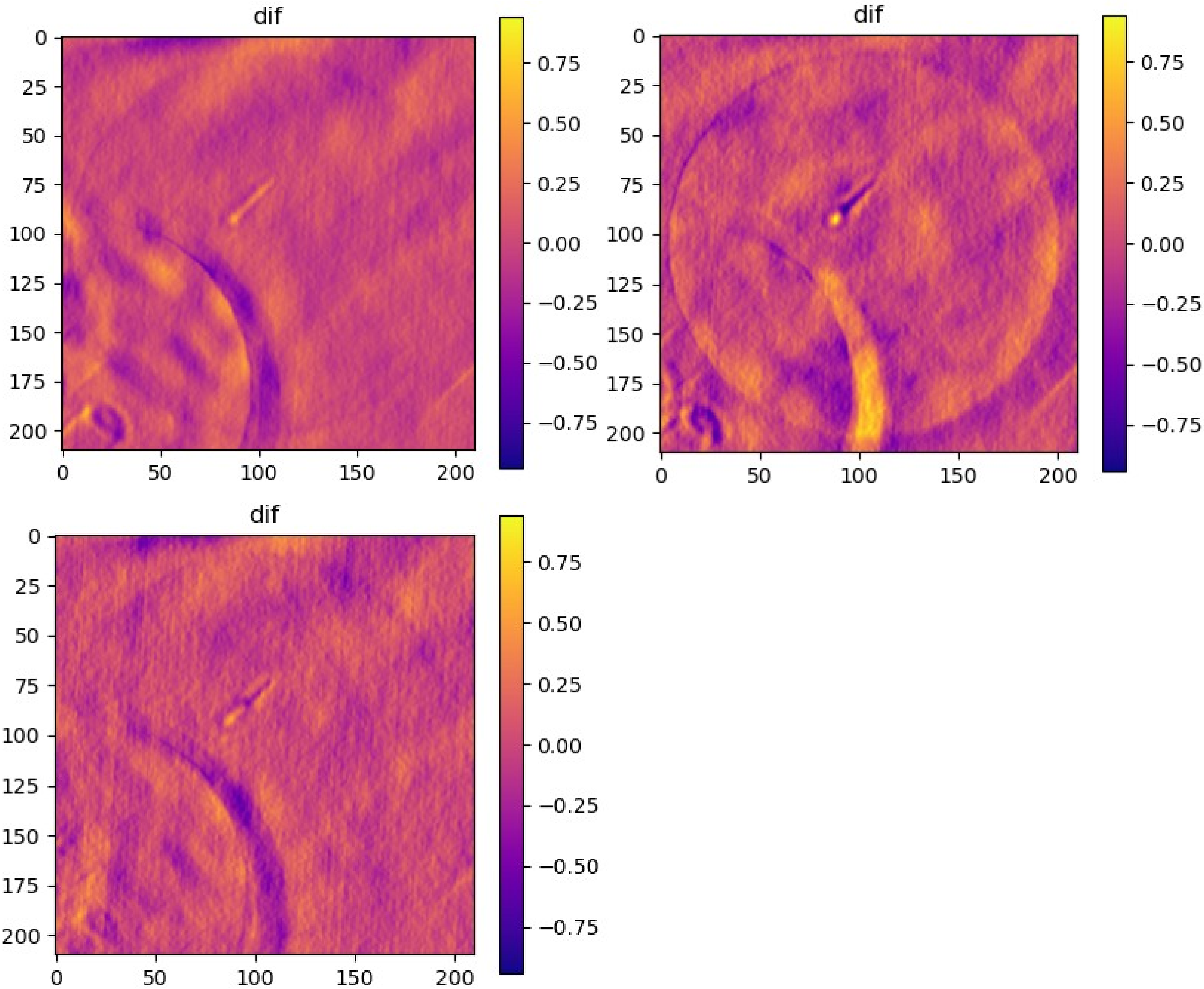

Figure 8: Sequence of demagnetisation of a monopolar domain wall. Top left: 0 T; top right: -0.03 T; Bottom left: 0.015 T.

We are know working on micromagnetic simulations to try to reproduce these experimental results. The preliminary calculations suggest that a sizable perpendicular magnetic anisotropy is necessary to stabilise the multi-segment states.