Supporting Information

Probing Geometry-Induced Magnetic Defects in Cylindrical Modulated Nanowires with Optically Detected Spin Resonance in Nitrogen-Vacancy Center in Diamond

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Anodic alumina templates with modulated pores are produced by pulsed hard anodization (HA) in oxalic aqueous solution. By fine tuning the electrochemical parameters, geometrical modulations are imprinted along the nanopores' length. The aluminum disks are anodized in oxalic aqueous solution (0.3M) containing 5 vol.% ethanol at a constant temperature of 0 ^{o}C. During anodization, a constant voltage of 80 V was first applied for 400 s to produce a protective aluminum oxide layer at the surface of the disk to avoid breaking or burning effects during subsequent pulsed hard anodization (Fig.S1a-(I)). Next, the voltage was steadily increased (0.08 V/s) up to 130V and kept constant for 400s, which ensures the alignment of the nanochannels (Fig.S1(a)-(II)). Nanopores with periodical diameter modulations were produced in step (III) by applying pulses of 130V and 100V for 5 and 50 s, respectively (Fig. S1-(III)). The pulses were repeated 50 times to obtain a total length of the modulated pores of 40 microns. After an Au nanolayer was sputtered on the back side of the template, Ni magnetic nanowires (Fig. S1 (b)) were grown into the cylindrical modulated pores by electrodeposition taking the shape of already modulated AAO pores.

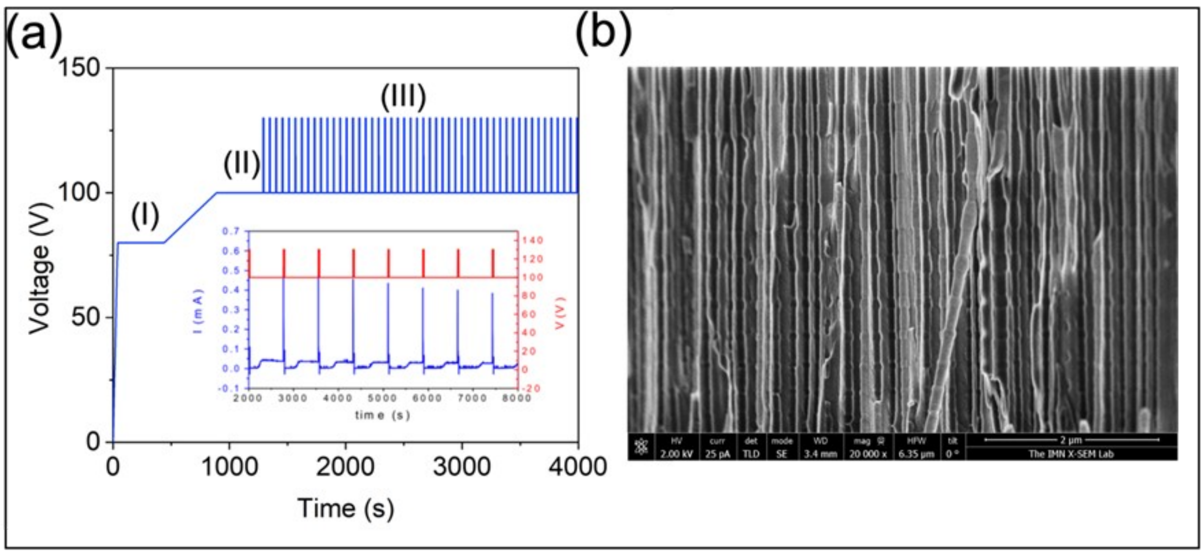

Figure S1: Anodization profile showing the voltage-time curve for (a) pulsed HA anodization (modulated wires) including MA step (A), voltage ramp (B) and HA pulses (C). The inserts show a closer look of both voltage and current during the anodization process, (b) SEM cross-section of alumina templates filled with Ni modulated nanowires.

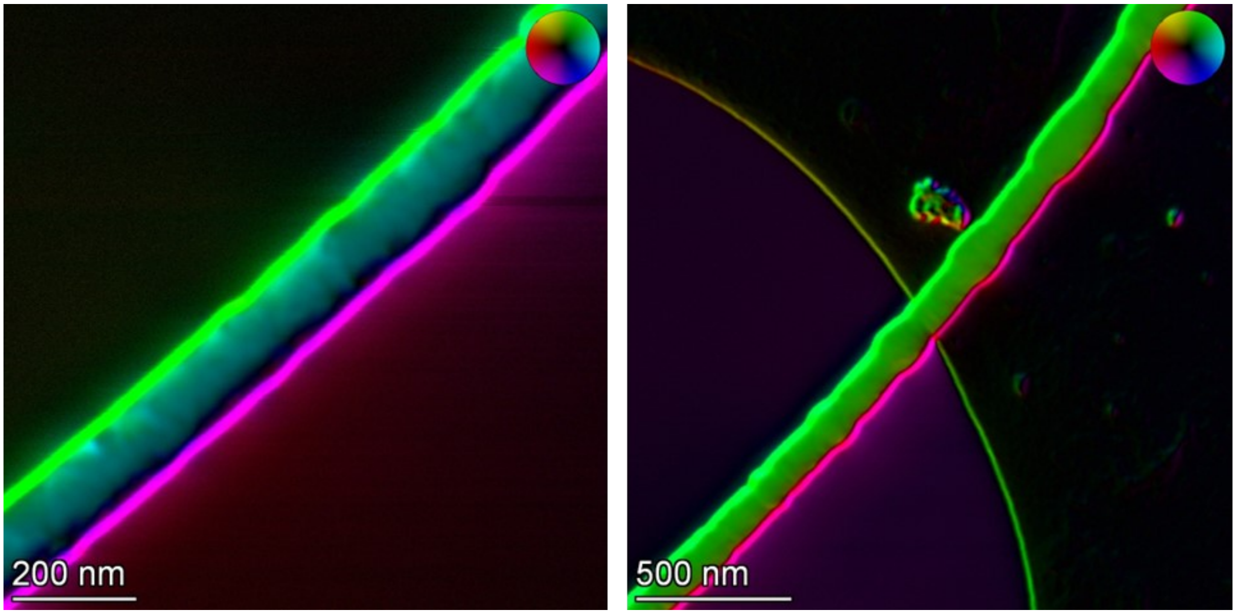

Figure S2: Differential Phase Contrast (DPC) maps of the nanowires (NWs) deposited at a holey carbon membrane. The DPC technique works in STEM mode using high camera length and aims to collect only transmitted electron beam. The beam deflection by the electromagnetic field is measured with the annular segmented detector. However, beams diffracted by the NWs also contribute to the DPC contrast formation hampering visualization of the magnetic field variations (diffraction contrast).

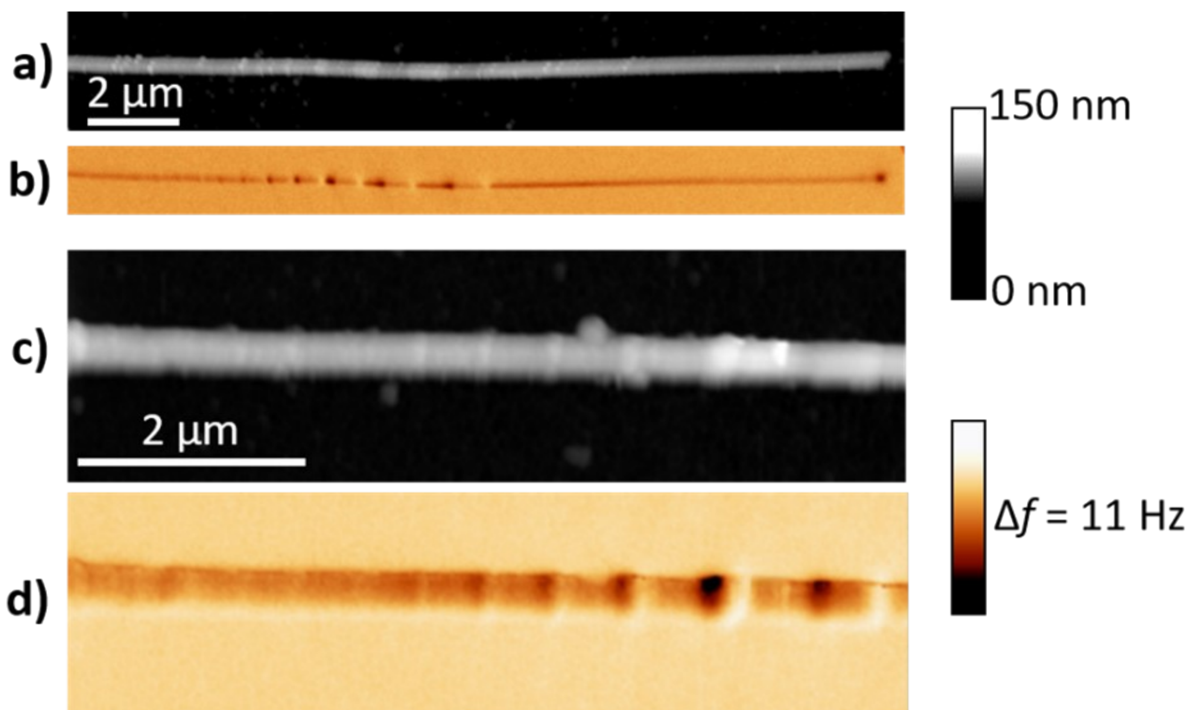

Figure S3: (a) (c) Topography and (b) (d) Magnetic Force Microscopy (MFM) images depicting two nanowires (NWs) with different lengths of their large-diameter segments. The detection of contrast corresponding to the shorter segments is not evident due to the small stray field. Note, Atomic Force Microscopy (AFM) and Magnetic Force Microscopy (MFM) images of the Ni NWs modulated in diameter were acquired using a Nanotec Scanning Probe Microscopy system controlled by the WSxM [1] software with a Nanosensors PPP-MFMR probe. The measurements were performed in amplitude mode, with the Phase-Locked-Loop feedback active. This configuration enables the recording of the magnetic signal as a frequency shift (Δf) during the second scan or lift mode. In Fig. S3, two AFM images and their corresponding MFM images are shown. In Fig. S3b, the lift distance was set around 25 nm over the NW, while is around 50nm in Fig. S3d. The modulations are discernible in both the topographic and magnetic images. In these regions, the MFM contrast is characterized by positive and negative stray field at the ends of the modulations. Nevertheless, as the modulated segments decrease in length, the strength of the stray field diminishes, until no magnetic signal is detected.[2]

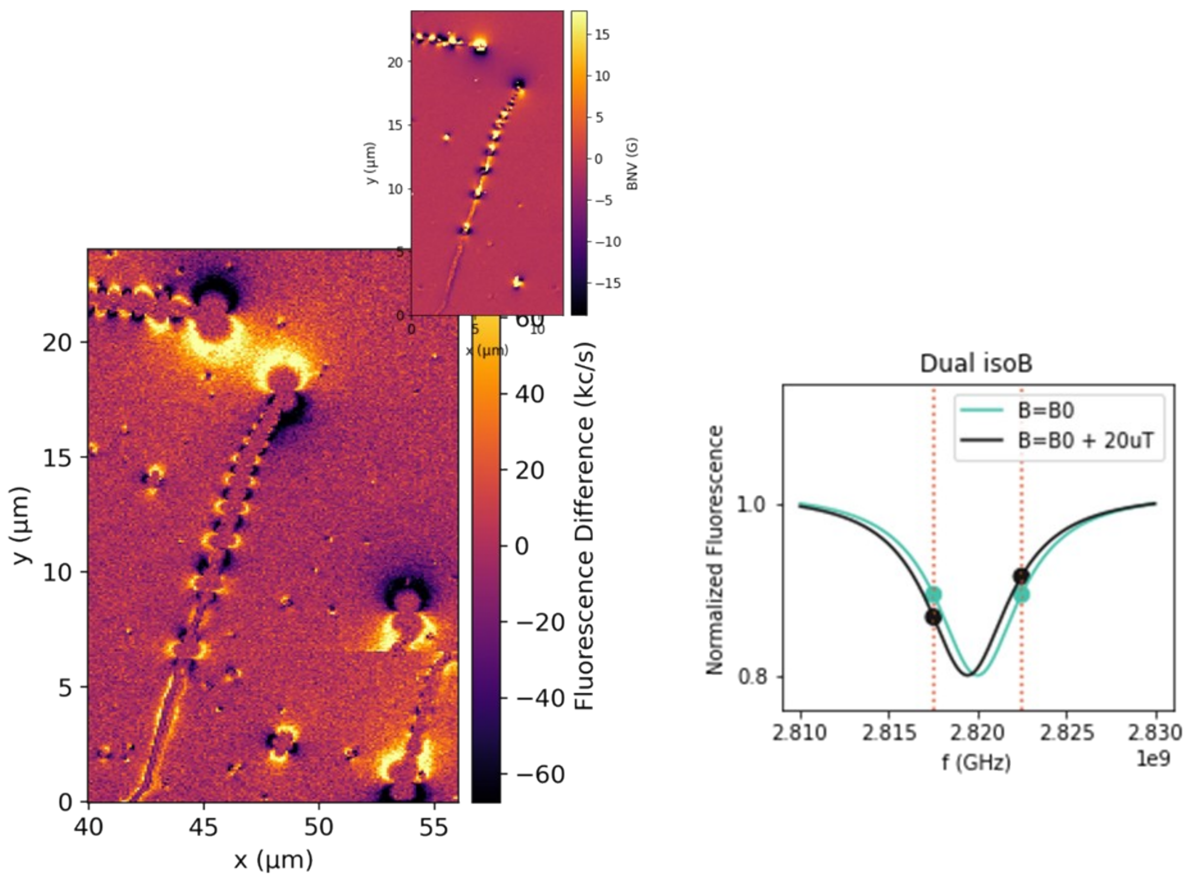

Figure S4: Dual iso-B image shown for the NW. In dual iso-B select two frequencies f1,f2, and take the Difference Fluorescence(f1) - Fluorescence(f2) as in the inset. In this way we get a purely magnetic signal and can avoid any artifacts from the topography.

References

[1] I. Horcas, R. Fernández, J. M. Gómez-Rodríguez, J. Colchero, J. Gómez-Herrero, A. M. Baro, *Review of Scientific Instruments* **2007**, *78*, DOI 10.1063/1.2432410.

[2] Kazakova, O., J. Appl. Phys. 125, 060901 (2019)