Nanoscale Magnetometry with Single Spins in Diamond at Low Temperature

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Abstract: Nanoscale magnetic stray fields of two materials are measured with an NV center scanning probe. Quantitative imaging of the Meissner effect of a superconductor allows for reliable determination of the London penetration depth. Stray fields of the 2D vdW magnet CrI_3 provide evidence for antiferromagnetic coupling in the few-layer sample.

The Nitrogen Vacancy (NV) center spin has been widely used for magnetic field sensing since it can be optically initialized and read out and offers an exceptional spatial resolution due the small extent of its wave function. A diamond scanning probe containing a shallow NV center is therefore a versatile tool to map nanoscale magnetic fields at a large temperature range [1,2].

Here, I present measurements of nanoscale magnetic fields on two different materials, using an NV center scanning probe containing a single NV center at 4K. First, the imaging of the stray magnetic field caused by the Meissner effect of a 6µm diameter thin-film disk of $YBa_2Cu_3O_{7-\delta}$ (YBCO), a type-II superconductor, demonstrates the potential of our technique in terms of resolution and robustness. The high quality of the data allows for a new way to reliably determine the London penetration depth – by direct real-space imaging of the penetration of the magnetic field into the superconductor. Using the second London equation to numerically simulate the response of the superconductor to the externally applied out-of-plane magnetic field, we can extract a penetration depth $\lambda = 249 \pm 5$nm (Fig. 1a). Moreover, we can use the measured field map to back-propagate to the current density in the superconductor, again yielding a good agreement with simulation (Fig. 1b,c). The obtained current density map reveals a deviation from the cylindrical symmetry, assumingly due to a defect in the material. [3]

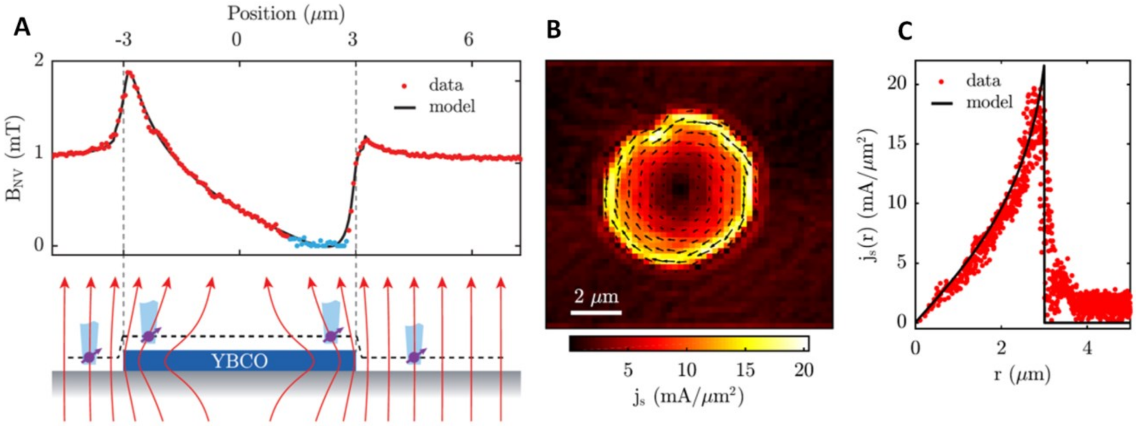

Figure 1: Magnetic stray field and current density in a 6µm YBCO disk. a) The Meissner effect is observed as a repulsion of the magnetic field above the disk, where the asymmetry of the measured field stems from the orientation of the NV center. b) 2D map of the superconductive current density inside the disk, revealing a material defect. c) Azimuthal averaging agrees with the current density expected from simulation. From [3]

Second, I present our measurements on the newly discovered 2D van-der-Waals (vdW) magnet CrI_3, which has ferromagnetic coupling of the spins within one layer. We determine the magnetization density of a monolayer to be $\approx 16\mu_B/nm^2$. We provide evidence for the postulated antiferromagnetic coupling between the neighboring layers, which leads to the even-odd effect where only stacks with an odd number of layers show magnetism (Fig. 2). Furthermore, we measured a much stronger magnetization upon an induced structural state change of the material resulting in ferromagnetic interlayer coupling. Our work yields important insight into the nature of the transition from the antiferromagnetic coupling in the few-layer regime to the ferromagnetic coupling in the bulk regime. [4]

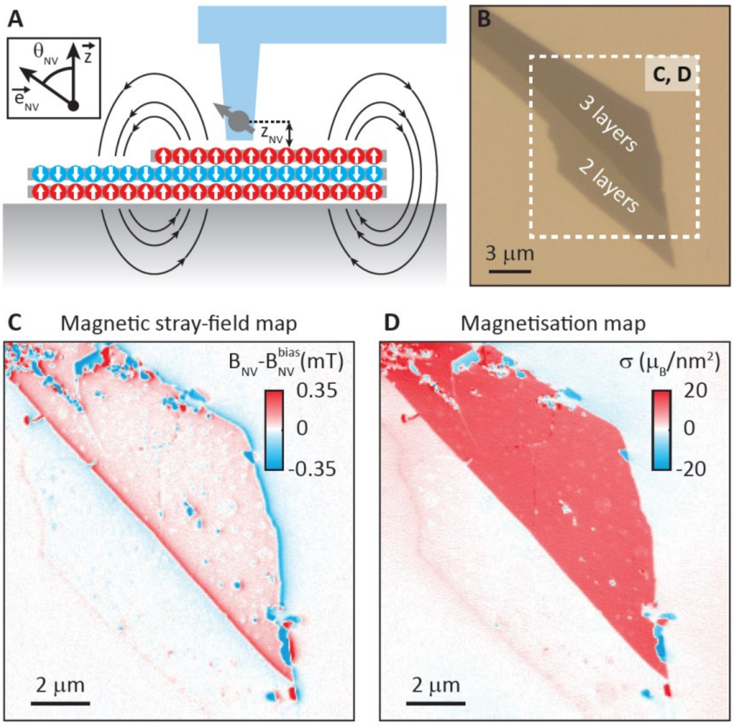

Figure 2: Magnetism in CrI_3. a) Schematic depiction of the CrI_3 layers and the resulting stray field, together with the NV scanning probe. b) Optical image of the analyzed CrI_3 flake showing areas with 2 and 3 layers. c) The magnetic field map reveals strong fields at the edges only of the 3-layer flake area, agreeing with the antiferromagnetic coupling between the layers. d) Corresponding magnetization density calculated with back-propagation of c), showing a homogenous magnetization of the 3-layer flake and a near-zero magnetization of the 2-layer flake. From [4]

References

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