Flux penetration in a ferromagnetic/superconducting bilayer

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Motivation

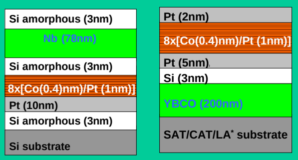
- The study of the flux penetration patterns in the presence of magnetic pinning
- The easy adjustement of the critical current density – the important parameter for applications.

Samples

Buffer (Si) layer to avoid proximmity effect

Nb grown by magnetic sputtering

YBCO grown by pulsed laser deposition (PLD)



$^{*}(SrAl_{0.5}Ta_{0.5}O_3)_{0.7}(CaAl_{0.5}Ta_{0.5}O_3)_{0.1}(LaAlO_3)_{0.2}$

Parameter \ Material	Nb	YBCO
T_c [K]	8.8	89
λ [nm]	≈ 240 At T = 7.5K	≈ 1000 At T = 80K
ξ [nm]	≈ 50	≈ 10

Estimated from dependence $H_{c2}(T)$ and $H_{c1}(T)$ using SQUID & Hall sensor measurements

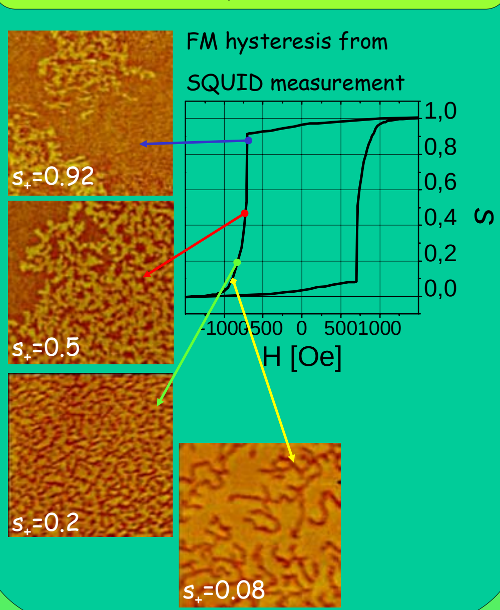
MFM measurement, T=300K

FM layer is oriented in external field and moved to MFM equipment at room temperature.

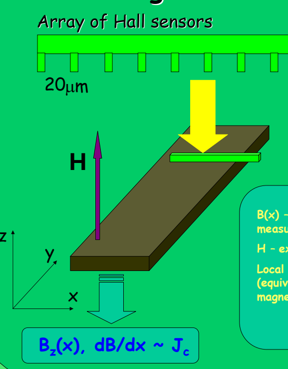
MFM picture area: 40x40 μm^2

width of domains for s_+ = 0.2: $w \sim 1$ μm (the most uniform and dense distribution of domains)

FM hysteresis from SQUID measurement



Local magnetization measurements



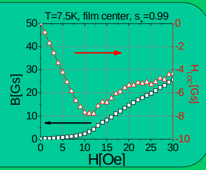
Size of sensors:5x5 μm.
2DEG in heterostructure GaAs/GaAlGaAs.
Sensitivity better than 0.1 Gs.
The width of the sample is about 200-300μm.

B(x) - magnetic field, measured by sensors

H - external field;

Local magnetic field (equivalent to magnetization):

$H_{loc} = B/\mu - H$

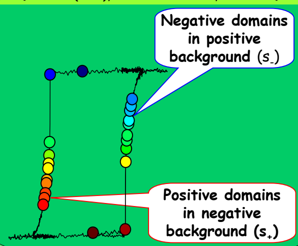


Magnetization: experimental procedure

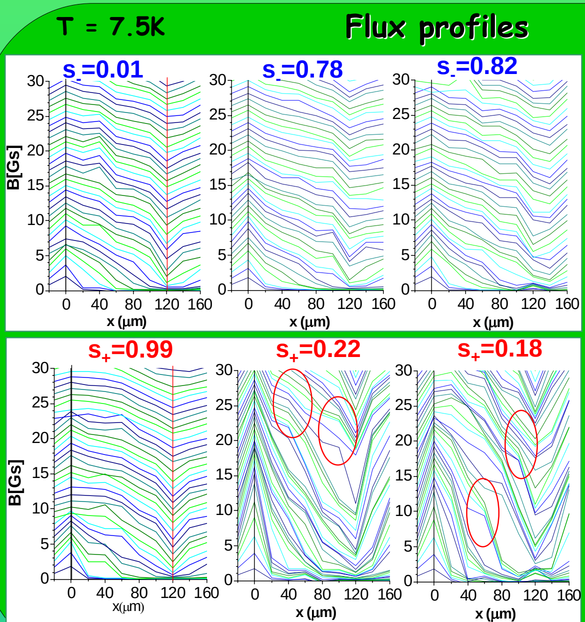
1) magnetization of Co/Pt at T=10K:
$H\uparrow \pm H_{sat}$, $H\downarrow H_{exp}$ → $s = \frac{1}{2}\left(\frac{M}{M_s}+1\right)$

2) H ↓ 0, T ↓ T*, T* = 6.5K or T* = 7.5K, T* < T_c

3) H ↑ 90 Oe (**ZFC**), 90 Oe ↓ -90 Oe, -90 Oe ↑ 0



Flux profiles

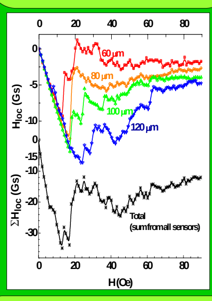


for the opposite polarity of flux and domains:

almost no effect

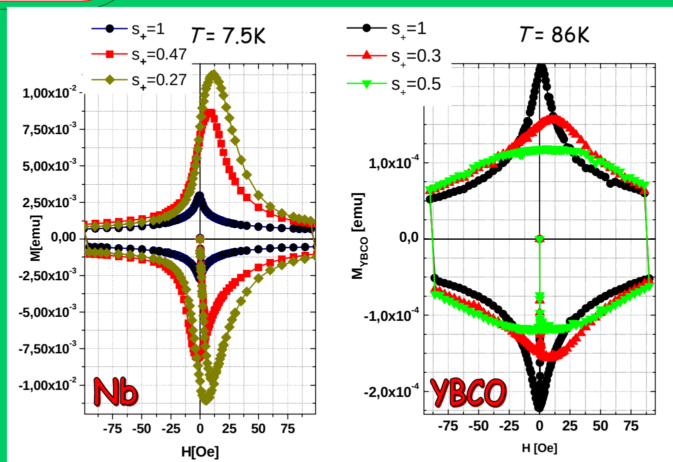
for the same polarity of flux and domains:

- terraced-like profiles
- barrier at the sample edge



Jumps of H_{LOC} noticed in histeresis are in the agreement with a behaviour predicted for the structure with disordered array of magnetic centers.

Global magnetization



For both type of samples:
- enhancement of pinning is induced by the FM domains
- magnetic pinning is the most important in the vicinity of T_c
- strong asymmetry exists with respect to the polarity of the applied field

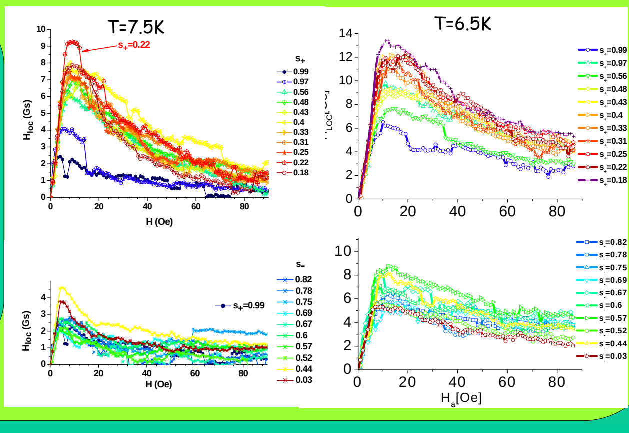
For samples with Nb (conventional superconductor)
- pinning force is much stronger for the same polarity of the applied field and domains
- maximum of magnetic pinning for $s_+ \approx 0.25$ and $s_- \approx 0.75$, not shown here)
- minimum of the enhancement is for saturated FM layer (s = 0 or s =1)
- shape of hysteresis is similar for all values of the s-parameter

For samples with YBCO (high-temperature superconductor)
- maximum of magnetic pinning is for saturated FM layer and minimum is for s_+=0.5
- histeresis loop changes shape during reoriantation of magnetic moments into FM layer

The possible origins of difference:
different size of the vortex (penetration depth) in both materials leads to differences in the vortex-domain and vortex-vortex interactions.

Edge barrier

- The **local magnetic field is enhanced at the film edge** when the magnetic domains and the entering magnetic flux point in the same direction
- "**edge barrier**": strong pinning of vortices by magnetic domains in the vicinity of the sample edge.
- The magnitude of the edge barrier is the largest for $s_+ \approx 0.22$ when the density of magnetic pinning centers is the largest.
- The magnitude of the edge barrier is the largest for H ≈10 Oe for both T = 7.5 K, and T=6.5 K
- Although H_{LOC} decreases with T the difference between maximum H_{LOC} for $s_+ \approx$ 0.2 and $s_+ \approx$ 0.99 is constant. This indicates that the magnetic barrier is temperature independent.



Conclusions

1) **Hall sensor study of the ZFC** flux penetration into FSB's reveals complex patterns:

- **the edge barrier** created by the magnetic domain pinning at the film edge;
- **terraced flux profile** inside the film.

The size and the distribution of magnetic domains determine a strenght of the pinning and the arrangement of vortices.

Our results are the first observation of the magnetic-pinning induced barrier, and the first observation of "terraced flux profile", predicted by the numerical simulations of Reinchhardt et al. and proposed by Yampolskii to explain a behavior of the flux in structure with periodic pinning arrays.

2) **Global magnetization measurements by SQUID** reveal different influence of FM multilayer on SC layer for Nb and YBCO.

The differences are most likely related to a size of vortices in both materials. Huge vortices in YBCO and small vortices in Nb may interact differently with magnetic domains. In addition, the pinning in Nb is in the single-vortex regime, whereas in YBCO this is most likely collective pinning because of much stronger vortex-vortex interactions.

Detailed mechanism is still insufficiently understood, and more experiments using local Hall-probe measurements are now under way to evaluate the behavior of the YBCO samples.