Non-monotonic temperature dependence of magneto-resistance in Nb-Ni-Nb planar junctions below superconducting transition

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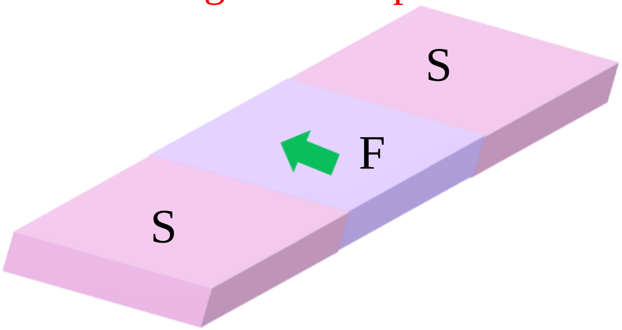
OUTLINE

- **Triplet Supercurrent Basics**
  - Motivation
  - Triplet Supercurrent
- **Experiment**
  - **Triplet Supercurrent using Planar S/F/S Josephson junctions**
    - Experimental Plan
    - Experimental Results
    - Conclusion

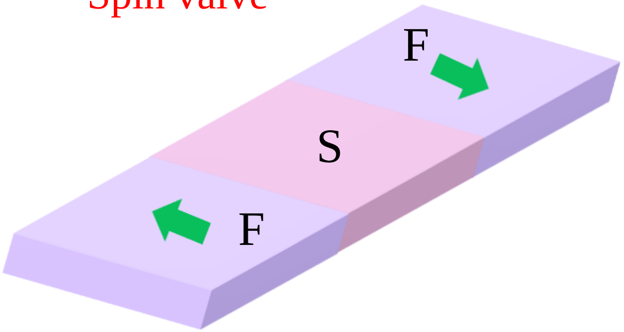
Motivation

Magnetism destroys superconductivity but some interesting effects happen at S/F interface

Magnetic Josephson Junction



Spin valve



Superconducting-Spintronics

Using superconductors as a low dissipative source

for “spin-based” devices.

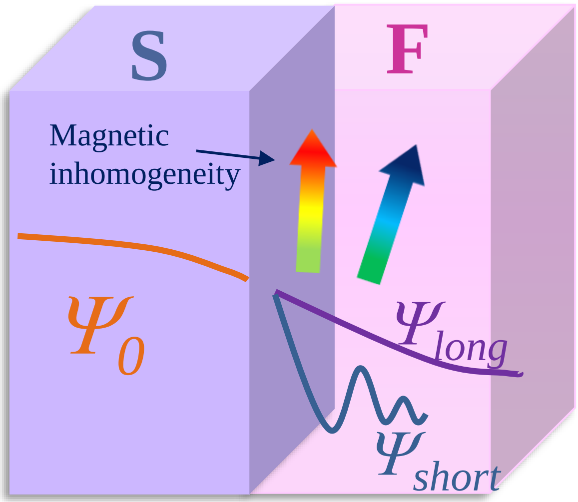
Motivation:

- To understand the interactions that arise when superconducting and magnetic order coexist.
- Finding ways to realize the effects due to triplet supercurrent in Josephson junctions.

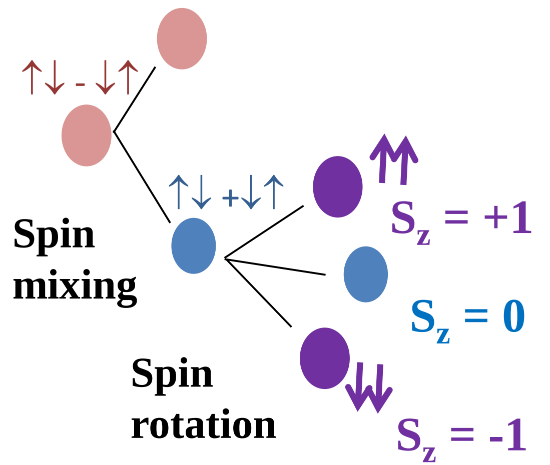
Triplet supercurrent

Key Ingredient : Magnetic inhomogeneity at S/F interface

Long range proximity effect

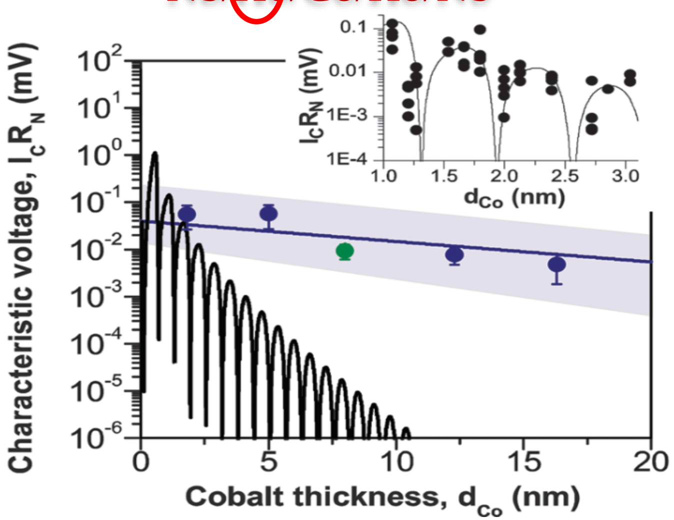


Magnetic inhomogeneity at the interface converts singlet cooper pair into triplet cooper pair



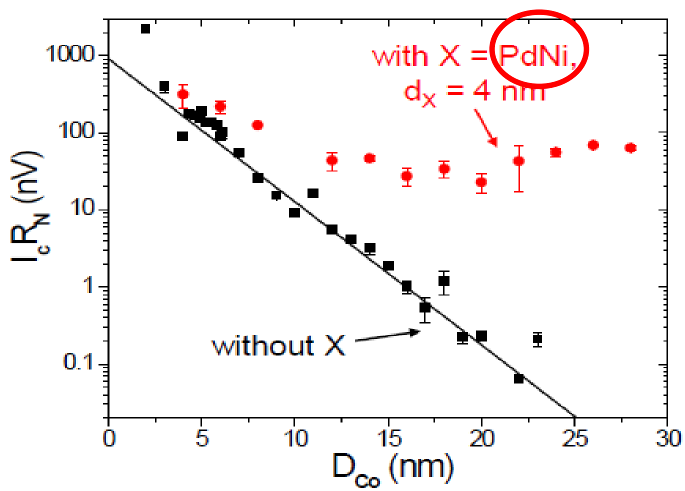
Evidences of triplet supercurrent

Nb/Ho/Co/Ho/Nb



J. W. A. Robinson, J. D. S. Witt, M. G. Blamire, Science **329 (2010) 5987 .**

Nb/Cu/X/Cu/Co/Ru/Co/Cu/X/Cu/Nb



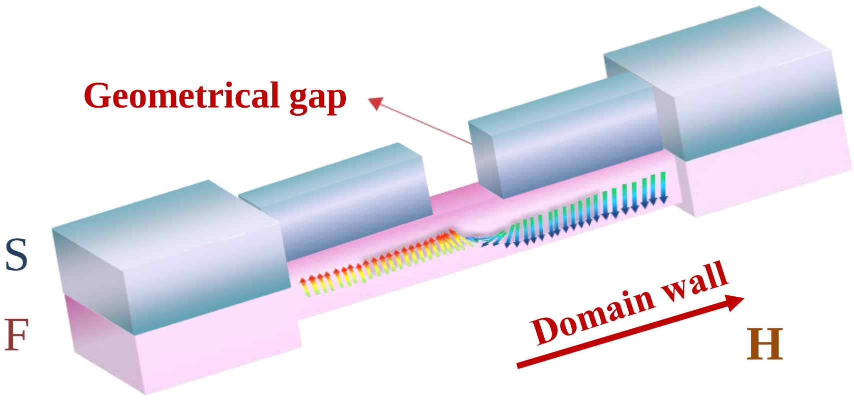
T. S. Khaire, *et al.* Phys. Rev. Lett**. 104 (2010) 137002.**

Triplet Supercurrent using planar Josephson junctions

Idea : Using the domain wall of ferromagnet as a source of magnetic inhomogeneity in SF hybrids

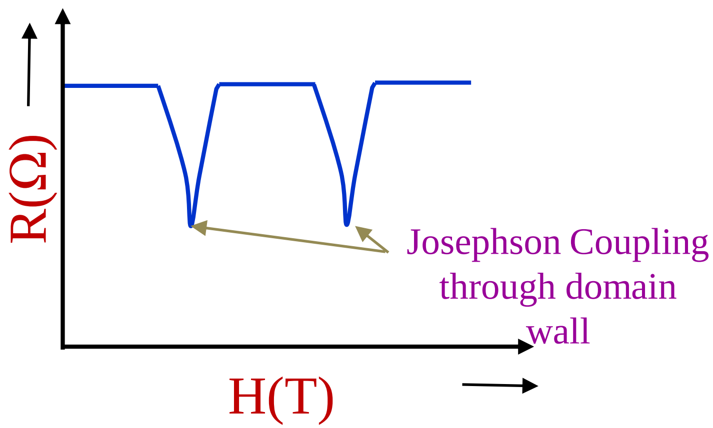
Experimental Plan:

- Domains propagate as a function of applied magnetic field.
- Motion of domains can be controlled to specific paths by making patterned films.



Sample Geometry

When domain wall lies exactly between two superconducting electrodes, a Josephson coupling will establish through triplet supercurrent.

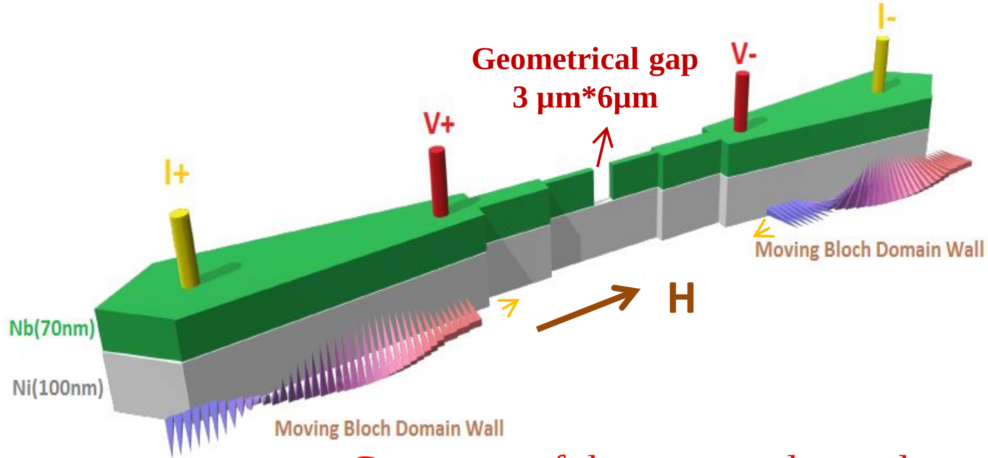


A sudden drop in resistance will be a signature of triplet supercurrent.

Resistive Switching Effects due to triplet supercurrent

Experiment

Plan: To study the resistive switching due to triplet supercurrent by making Nb/Ni/Nb planar Josephson junctions



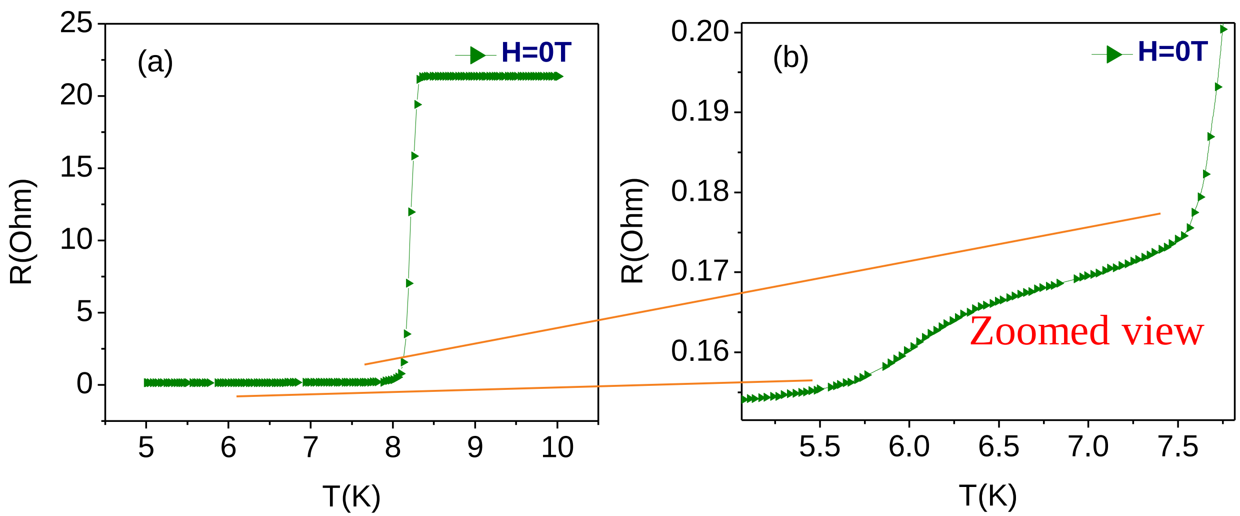
Geometry of the patterned sample

Sample details:

Nb(70nm)/Ni(100nm)/SiO_2(substrate)

Techniques Used:

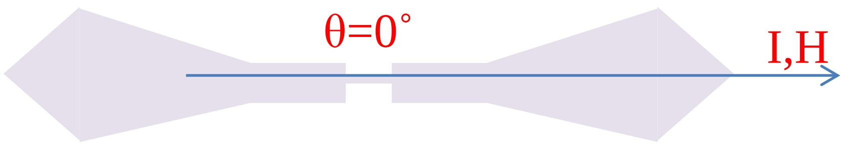
- Magnetron Sputtering
- Optical Lithography
- Reactive Ion Etching



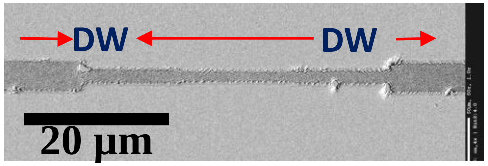
- T_c=8.3K.
- Another small superconducting transition was observed near 6.2K

Fig. a) Resitance vs Temperature curve of Nb/Ni/Nb planar Josephson junction b) Zoomed view showing an interface layer superconducting transition

Experimental Results



Schematic showing current I and field H directions



Kerr image for a patterned Ni thin film for θ=0°

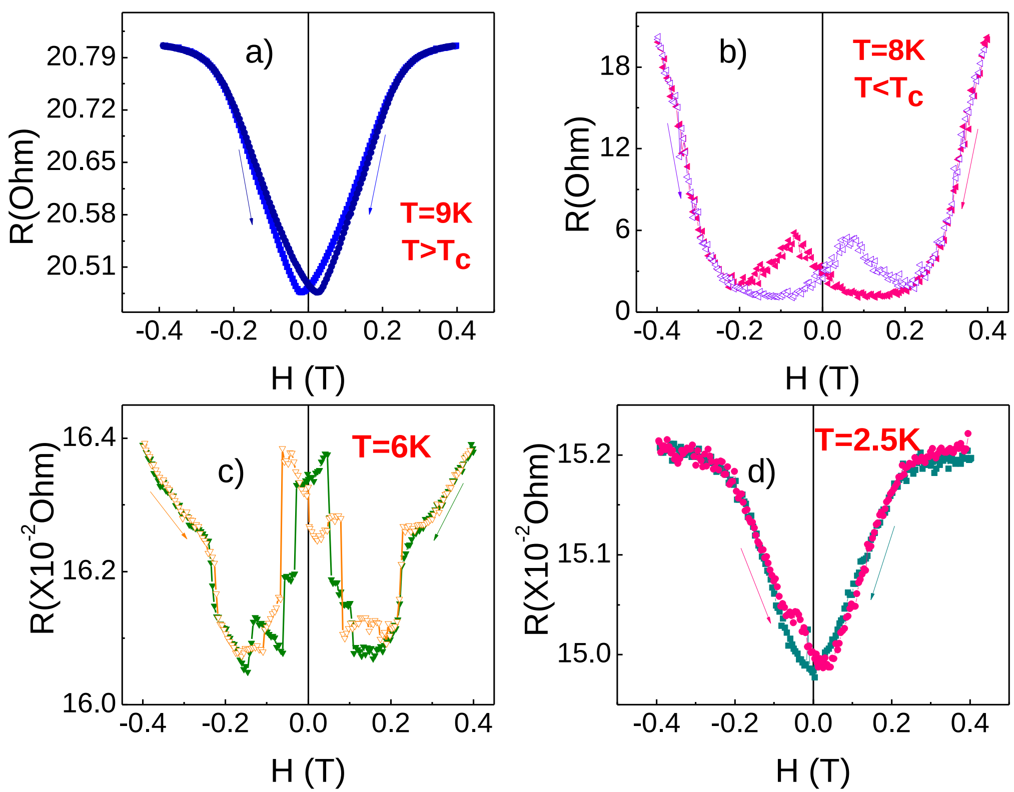


Fig: Resistance vs magnetic field for a) T=9K>T_c b) T=8K<T_c c) T=6K d) T=2.5K, where T_c = 8.3K

For T>Tc

- Anisotropic Magnetoresistance property of Nickel.

For T<Tc

T=8K

- Stray field of domain walls produce vortices.
- Vortices leads to increase in resistance.
- Maxima in resistance happens at coercive field.

T=6K

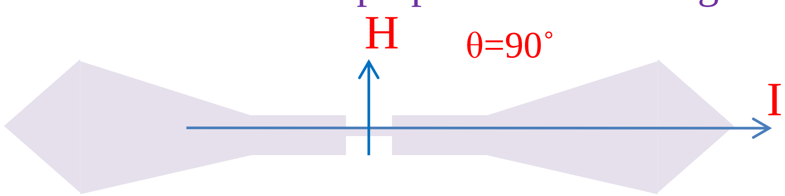
- Superconducting order parameter dominates at low temperature.
- Steps in MR appears due to vortex locking-unlocking effects.

T=2.5K

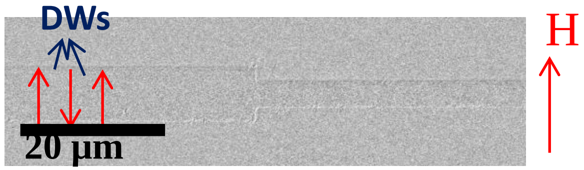
Superconductivity order parameter establish well and all the peaks and steps disappear.

Experimental Results

Current I perpendicular to magnetic field B, where I is along the long axis of stripes



Schematic showing current I and field H directions



Kerr image for a patterned Ni thin film for θ=90°

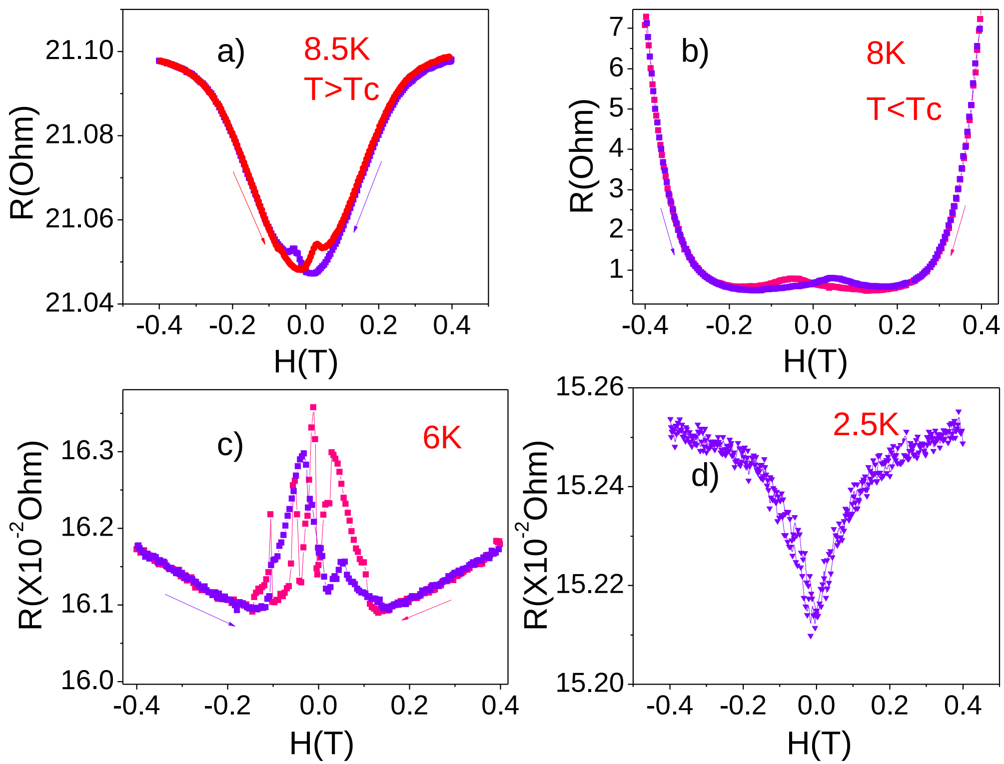


Fig: Resistance vs magnetic field for a) T=8.5K>T_c b) T=8K<T_c c) T=6K d) T=2.5K, where T_c = 8.3K

For T>Tc

- magneto-resistance peaks due to domain wall magnetoresistance.

For T<Tc

T=8K

- Stray field of domain walls produce vortices.
- Vortices leads to increase in resistance.
- Maxima in resistance happens at coercive field.

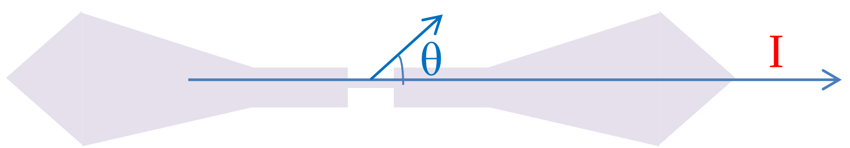
T=6K

- Steps in MR appears due to vortex locking-unlocking effects.
- Steps are smaller due to more coherent rotation of domains.

T=2.5K

Superconductivity order parameter establish well and all the peaks and steps disappear.

Experimental Results



Schematic showing current I and field H directions

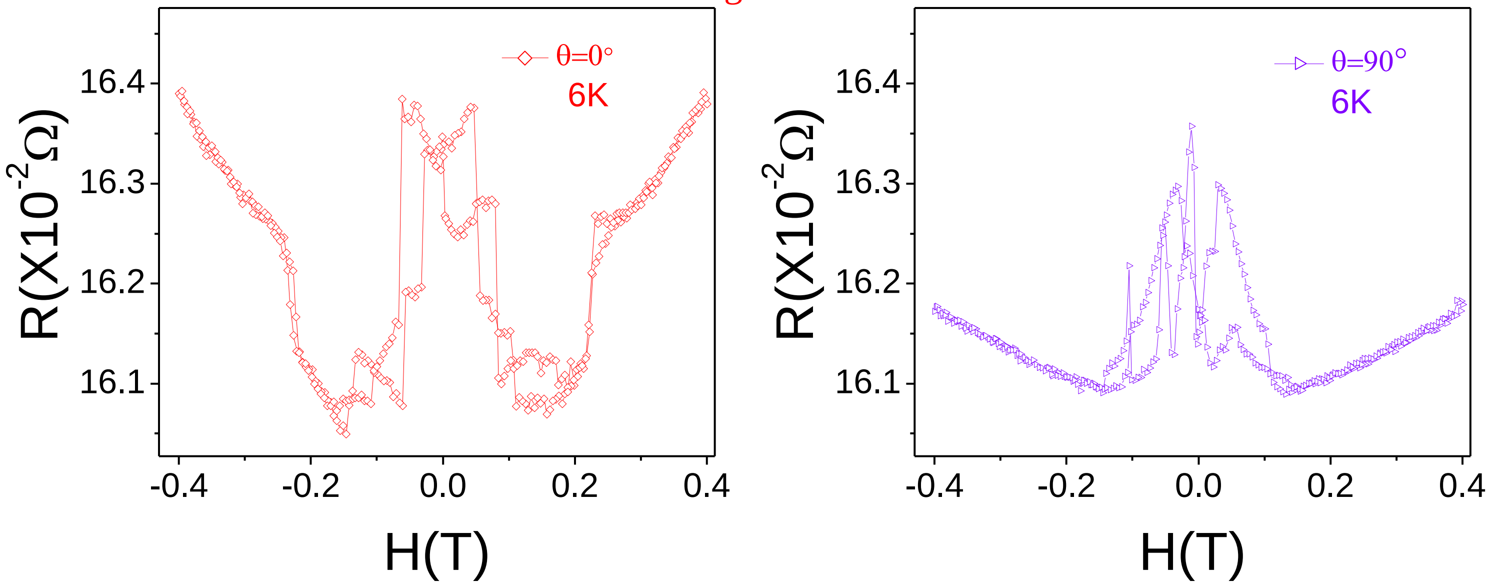


Fig: Resistance vs magnetic field for $T=6K<T_c$ for a) $\theta=0^{\circ}$ and b) $\theta=90^{\circ}$

For T=6K

- The magnetoresistance is more in the parallel case (1.91%) than the perpendicular one (1.29%).
- The steps are more sharp in the parallel case.

Signatures of Triplet Supercurrent:

- More domain wall MR in normal state for the perpendicular configuration than the parallel one while **Less MR in superconducting state for perpendicular case than the parallel one may be due to triplet supercurrent through multiple domain walls**.

Conclusion

- ✓ A higher magnetoresistance was observed in the Nb/Ni/Nb planar Josephson junctions below the superconducting transition.
- ✓ The lower magnetoresistance in perpendicular configuration than the parallel one may be due to triplet supercurrent through multiple domain walls.
- ✓ Three regimes of magnetoresistance, stray field regime, vortex locking-unlocking regime and temperature independent regime were found below the superconducting transition.

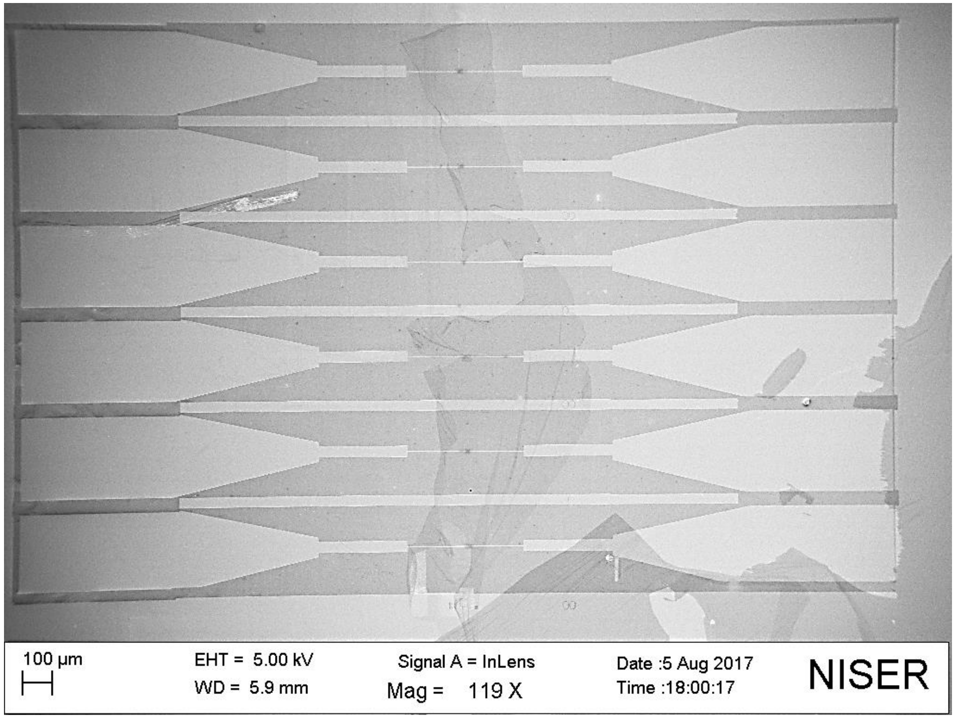
Future Perspective

- ➢ The possibility of using controllable domain wall motion to manipulate superconductivity makes it plausible to combine the advantages of superconductor and domain wall based devices with simultaneous control by temperature and field, for future spintronic as well as quantum computing applications.

Experiment

Plan: To study the resistive switching effects in Nb_Ni_Nb planar junctions with lesser dimensions, multi-gaps, different thicknesses and different patterns

a)



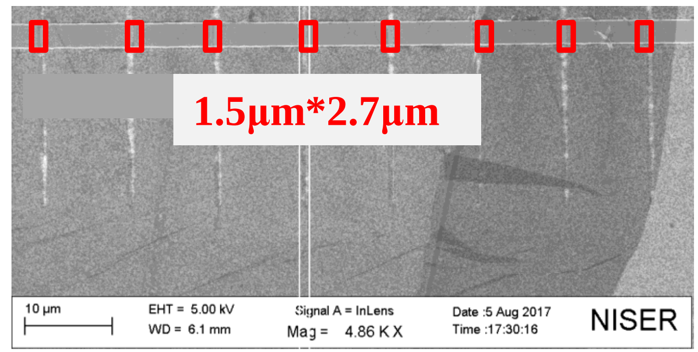
Measurement Requirements:

Field: 0.5 T

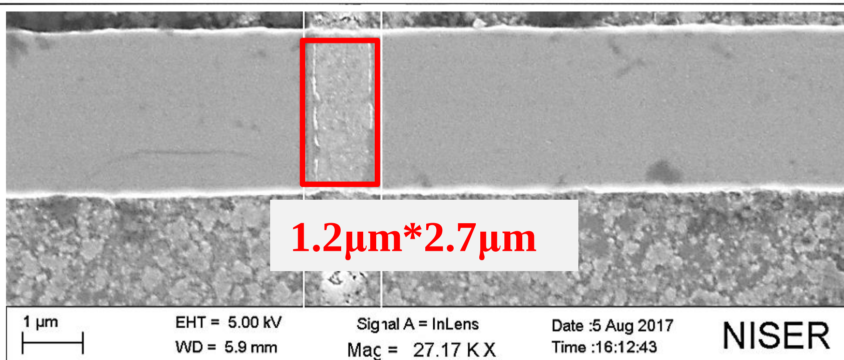
Temperature: 2K

Temperature stability: 5 mK

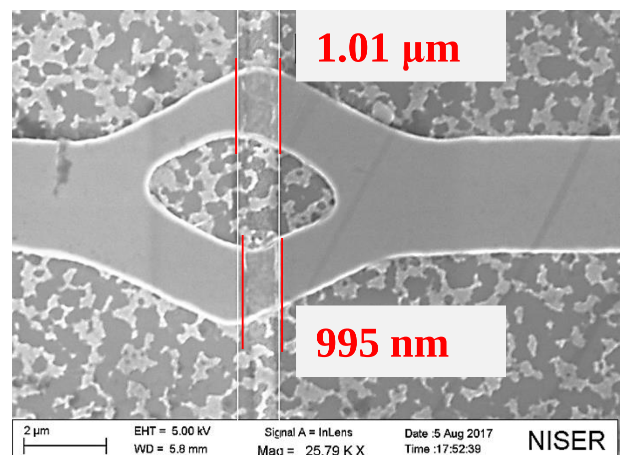
b)



c)



d)



FESEM images of the Nb_Ni_Nb planar junctions with different gap sizes, different thicknesses, multi gaps and different patterns

Acknowledgements

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Thank You!!!

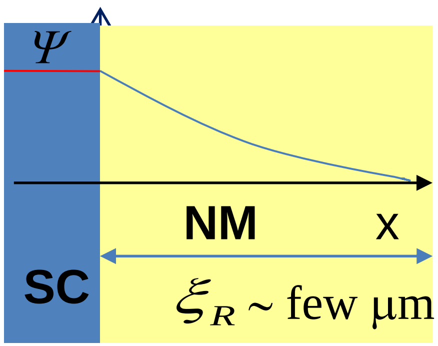
S/F interface

Exchange energy-induced oscillations of the proximity-induced order parameter

S/N Interface:

- Order parameter decay exponentially.

S/N interface



$$\Psi(x) \sim \exp\left(-\frac{x}{\xi_R}\right)$$

S/F Interface:

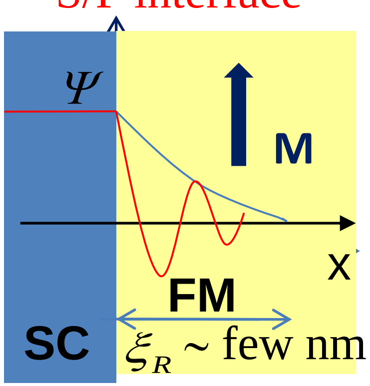
- Spin-splitting occurs at SF interface.
- Cooper pair acquires a finite momentum Δp.
- Order parameter oscillates within F-region.

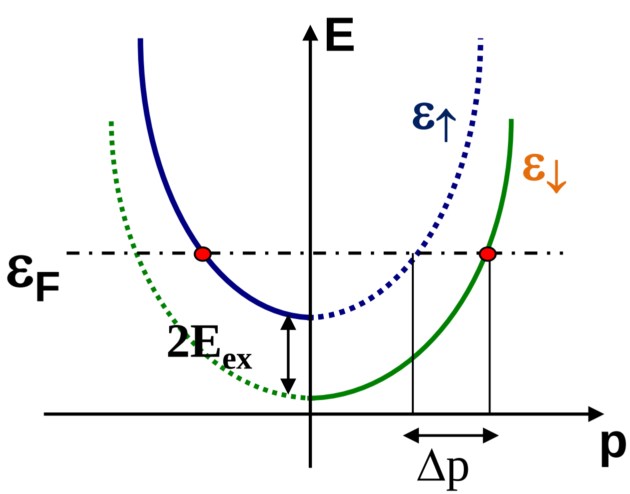
$$\Delta p = \frac{2E_{ex}}{v_F}$$

Exchange energy

Fermi velocity

S/F interface





$$\Psi(x) \sim \cos\left(\frac{x}{\xi_I}\right)\exp\left(-\frac{x}{\xi_R}\right)$$

Order parameter oscillations

Proximity decay

A. I. Buzdin, *et.al.* Rev. Mod. Phys. **77, 935 (2005).**