Detection and Manipulation of Abrikosov Vortices in Mesoscopic Josephson Junctions

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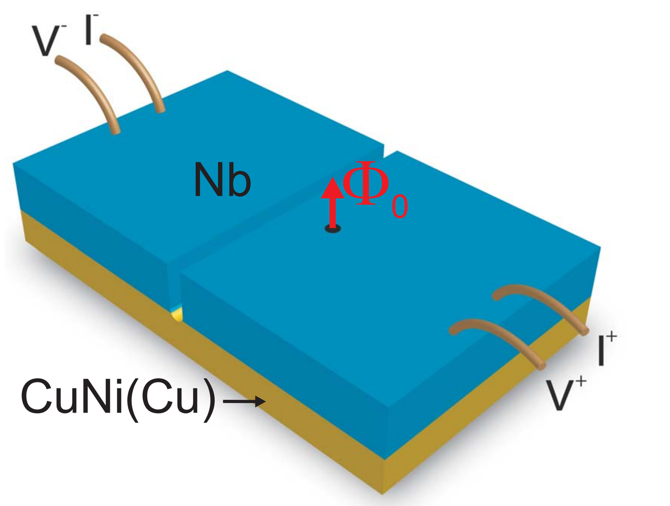
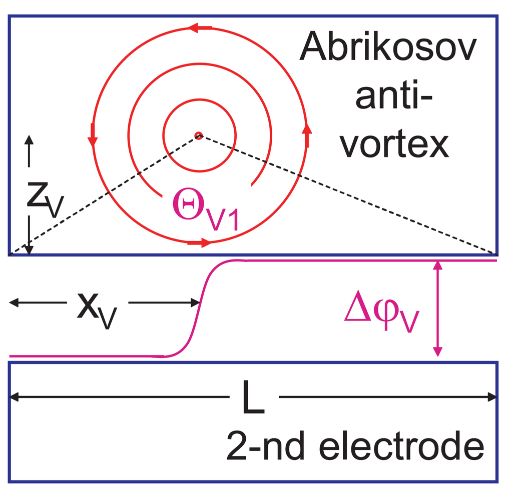
Introduction

An Abrikosov vortex in a superconductor (SC) carries a flux quantum Φ_0 localized at its center, but induces a global 2π phase rotation. This gauge field is due to the Aharonov-Bohm effect. Can this phase shift be detected by means of Cooper pair interferometry using Josephson junctions as phase-sensitive detectors? We introduce a single vortex into a SC lead with a detector junction made at the edge of the lead. We observe that the vortex induces a Josephson phase shift equal to the polar angle of the vortex within the junction length. When the vortex is close to the junction it induces a π-step in the Josephson phase difference, leading to a switchin of the junction into the $0-\pi$ state. This results in $\Phi_0/2$ quantization of the flux in the junction. The vortex may act as a tunable "phase battery".

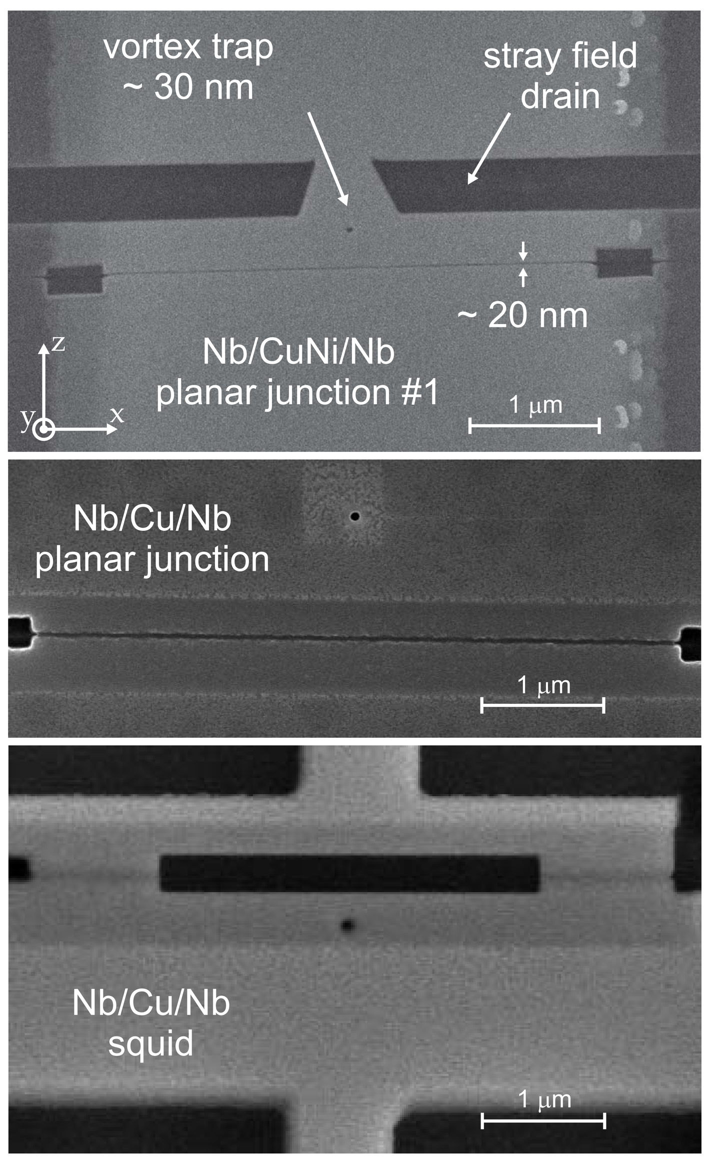
Sample fabrication

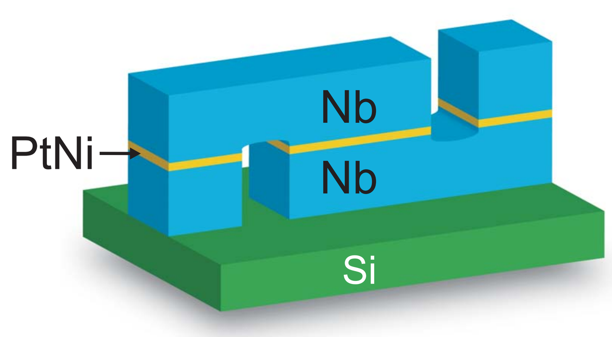
Nanoscale Nb/PtNi/Nb junctions of the overlap type made by Focused Ion Beam (FIB) sculpturing and planar Nb/CuNi(Cu)/Nb junctions of the "variable thickness" type made by cutting CuNi(Cu)/Nb double layers by FIB. The positions of vortices in the overlap-type junction are controlled by suitable sample geometry while in the planar junction we make a small hole with diameter ~ 30 nm, working as a vortex trap.

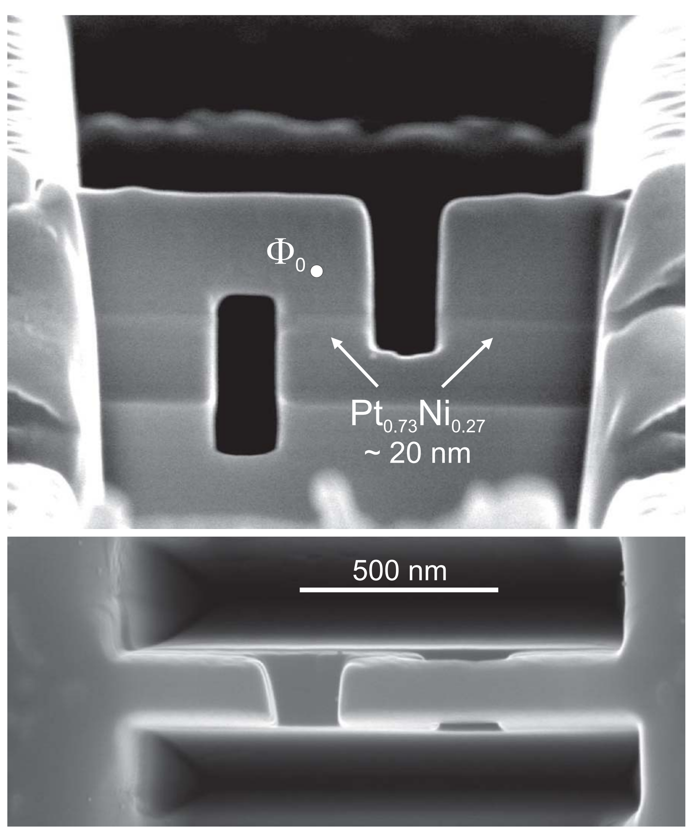




$$\Theta_v(x) = \arctan\left(\frac{x - x_v}{z_v}\right) + \text{const.}$$

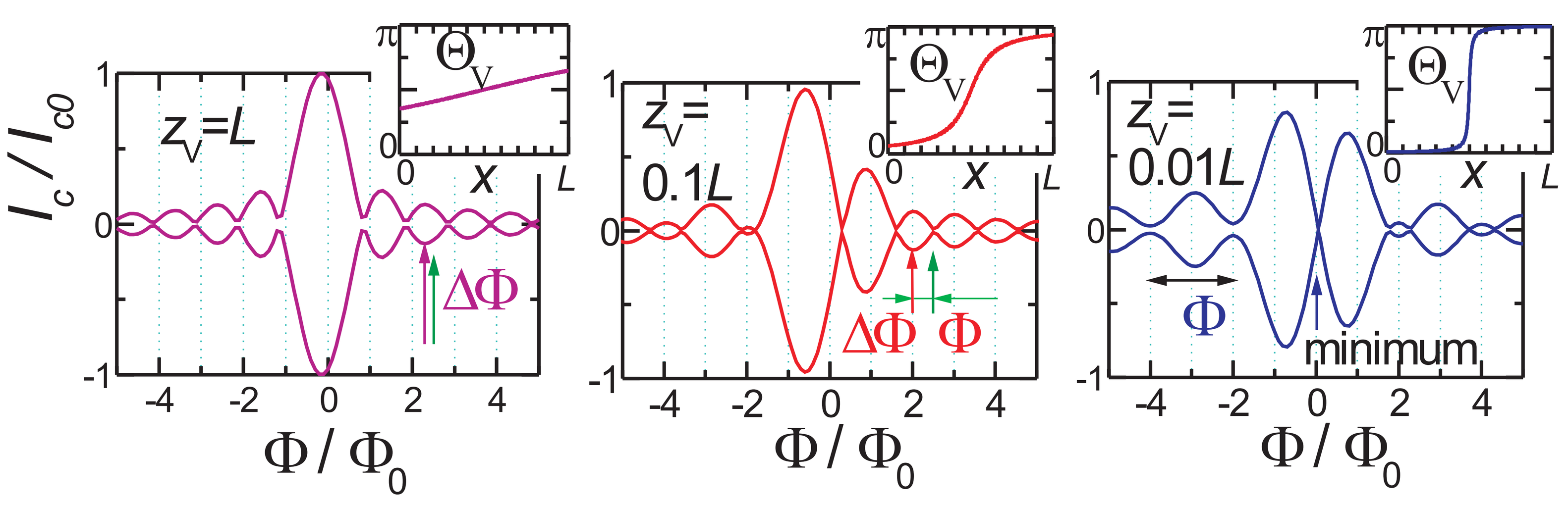




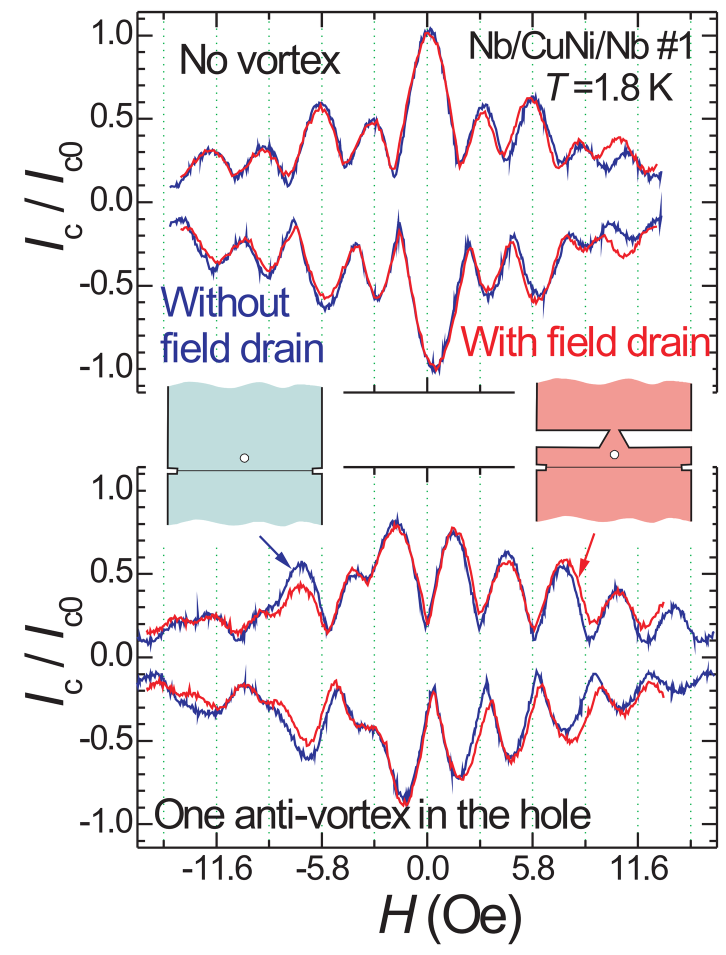


Simulation

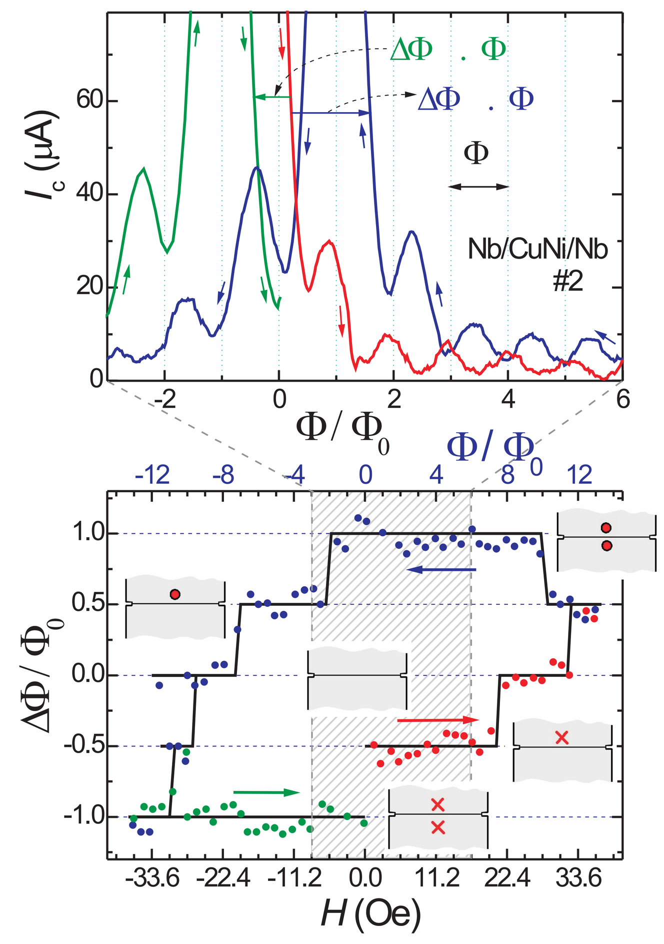
Simulated I_c vs $H_{||}$ with anti-vortex at different distances from the junction:



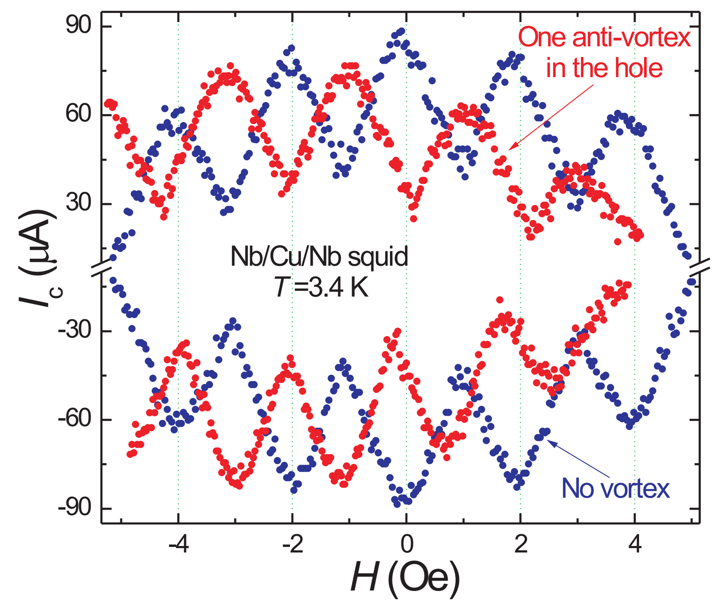
Experiment



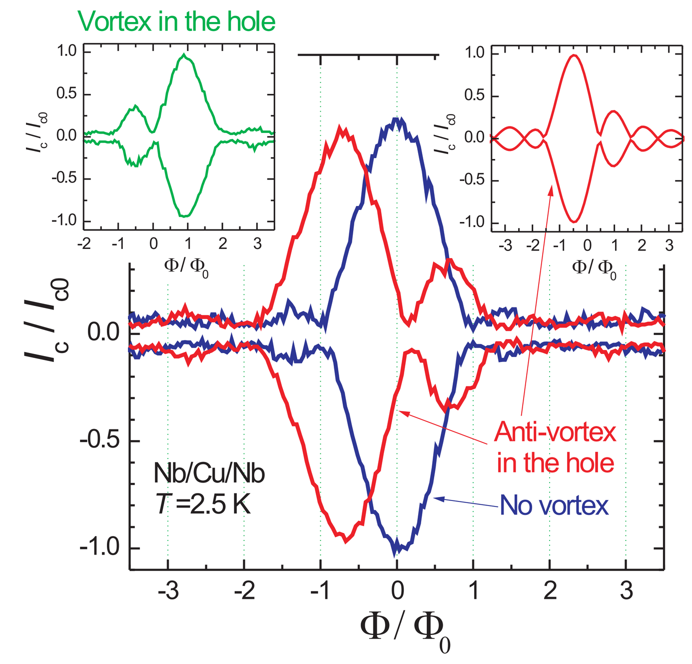
I_c vs H for a junction with the vortex hole and the stray field drain. Clear signatures of the $0-\pi$ state are seen with an anti-vortex in the hole.



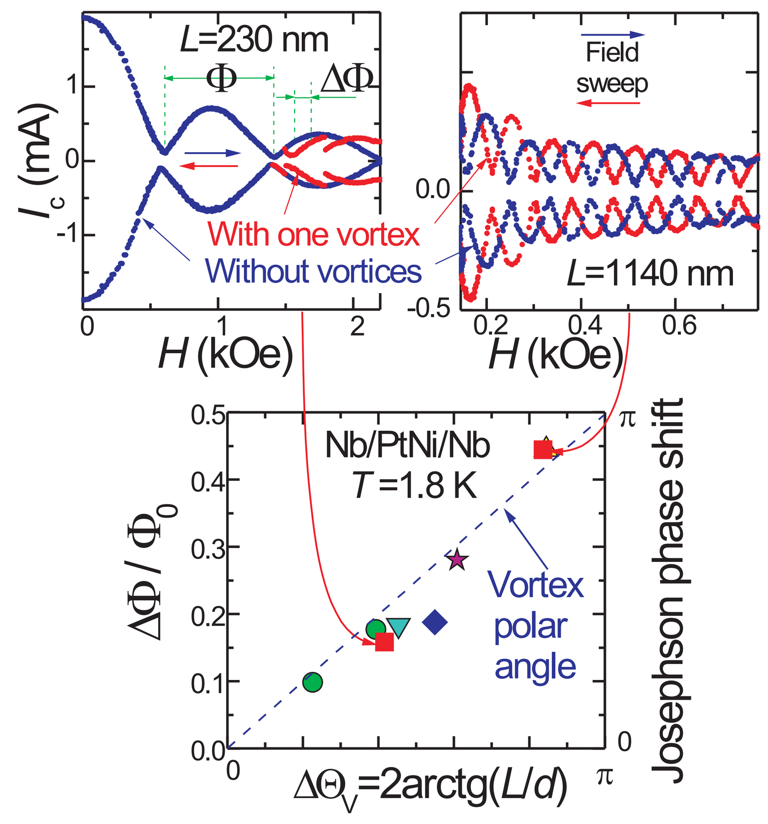
Quantized offset in $I_c(\Phi)$ patterns due to sequential entrance/exit of Abrikosov vortices. Note: the unusual $\Phi_0/2$ quantization.



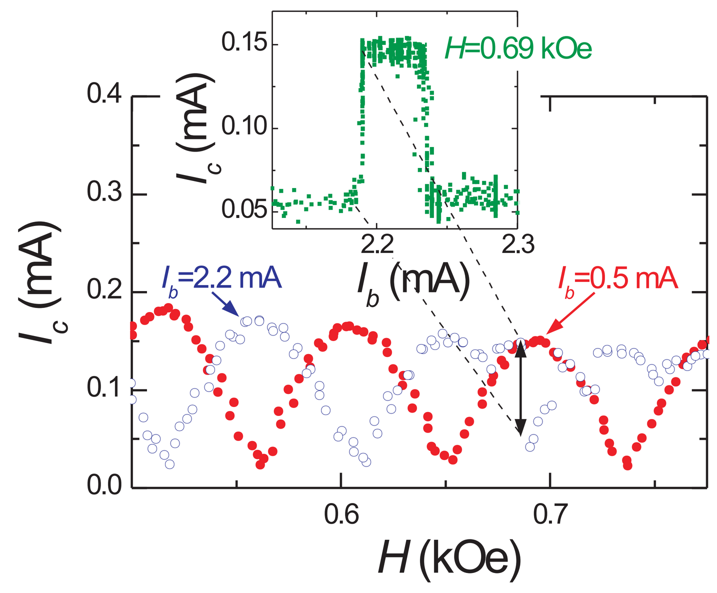
I_c vs H for Nb/Cu/Nb squid. Half flux offset appears in the presence of an anti-vortex in the hole



Measured and simulated (right inset) $I_c(\Phi)$ patterns for Nb/Cu/Nb junction with an anti-vortex in the hole. Left inset: the same junction with vortex in the hole. Left- right asymmetry appears in the presence of the anti-vortex (vortex).



Influence of the junction geometry on the flux offset in the Nb/PtNi/Nb junctions. The Josephson phase shift induced by the vortex is equal to the polar angle of the vortex.



I_c vs H for two different bias currents. At constant magnetic field, the system can be brought between two vortex states which are characte-rized by different I_c.

Conclusions

We used FIB to fabricate nano-scale Nb/PtNi/Nb overlap junction and Nb/CuNi(Cu)/Nb planar junction. An Abrikosov vortex in the electrodes induces a Josephson phase shift in the detector junction equal to the polar angle of the vortex. The vortex close to the junction induces a π-step in phase and leads to controllable switching of the junction into the $0-\pi$ state. By changing the junction bias current at constant magnetic field we toggle the system between two consecutive vortex states. Our mesoscopic SC system thus acts as a non-volatile memory cell in which the junction is used both for reading and writing information (vortex).