High Density Memory Based on Stacked Magnetic and Josephson Junctions

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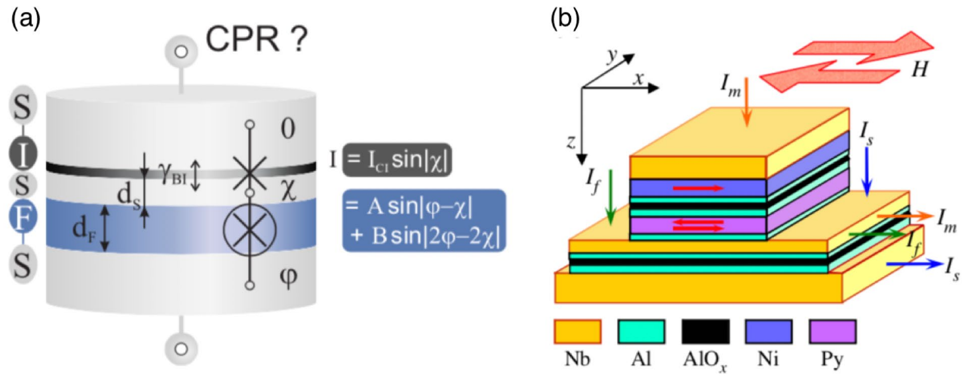
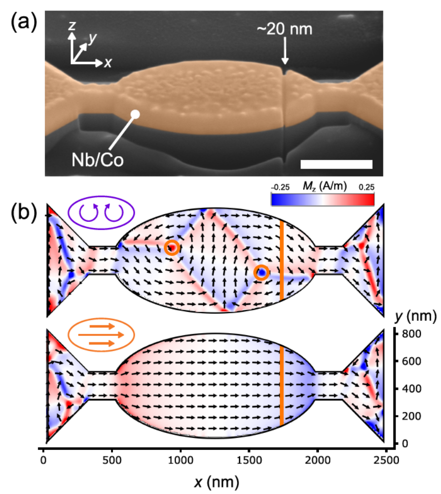
Memory cell proposals

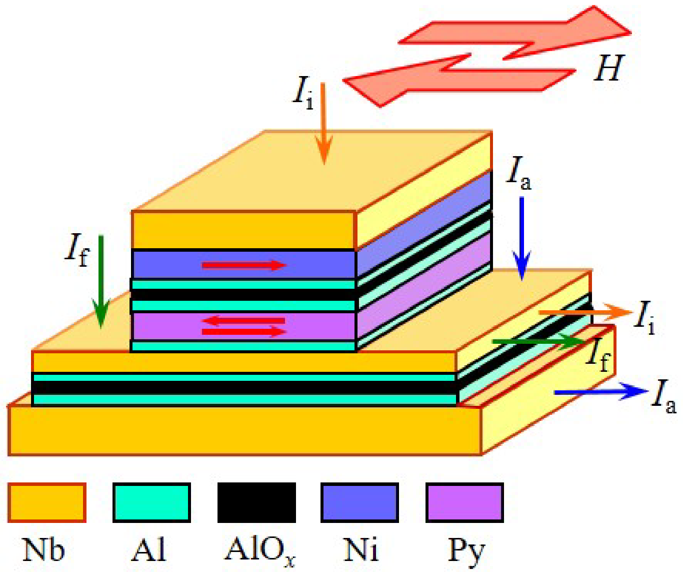


This proposal

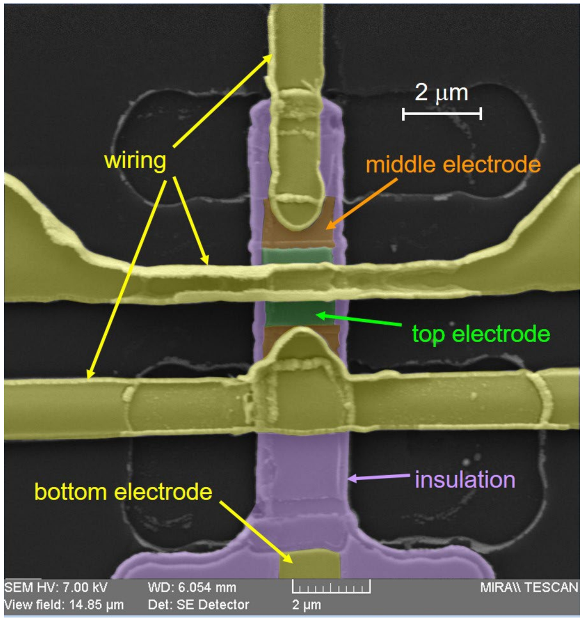


R. Fermin N. Scheinowitz, J. Aarts, and K. Lahabi,
arXiv:2206.06816v1, 14 Jun 2022

Device Structure – Multi-terminal MTJ+SIS device



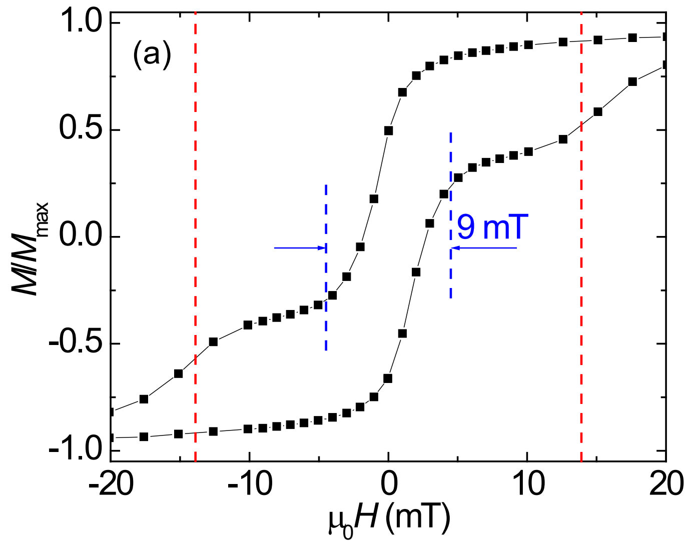
Schematic view of a four-terminal $SIS'F_1IF_2S$ device and its biasing



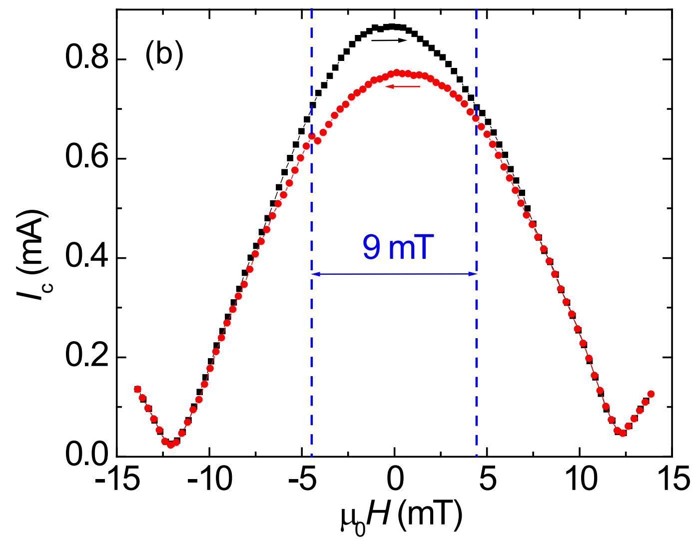
SEM micrograph of an actual $SIS'F_1IF_2S$ device

I. P. Nevirkovets, S. E. Shafraniuk, and O. A. Mukhanov, *IEEE Trans. Appl. Supercond*. **28**, 1800904 (2018).
I. P. Nevirkovets and O. A. Mukhanov, *Phys. Rev. Appl*. **10**, 034013 (2018).

Device Characteristics

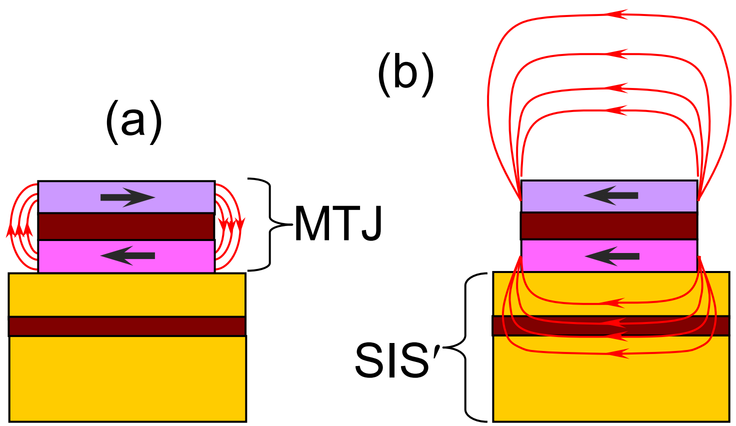


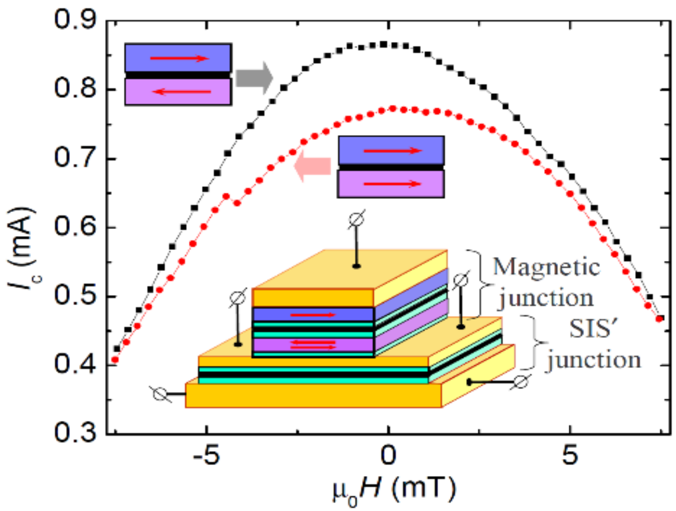
$M(H)$ dependence at 10 K for a 5 mm × 10 μm array of 2 μm × 2 μm pillars made of the same structure as the four-terminal devices. Red dashed lines denote the range of H sweeping in the panel **(b).**



$I_c(H)$ dependence for the **sensor junction** in a four-terminal SIS′F_1IF_2S device while sweeping an external in-plane magnetic field in two opposite directions in the range of ±13.9 mT after initializing the magnetic state of the device at $\mu_0 H$ +59 mT. A significant change in I_c in the range of $\mu_0 H$±4.5 mT corresponds to a most significant change in magnetic moment of Py (panel **(a)**).

Memory Cell: multi-terminal stacked MTJ+SIS



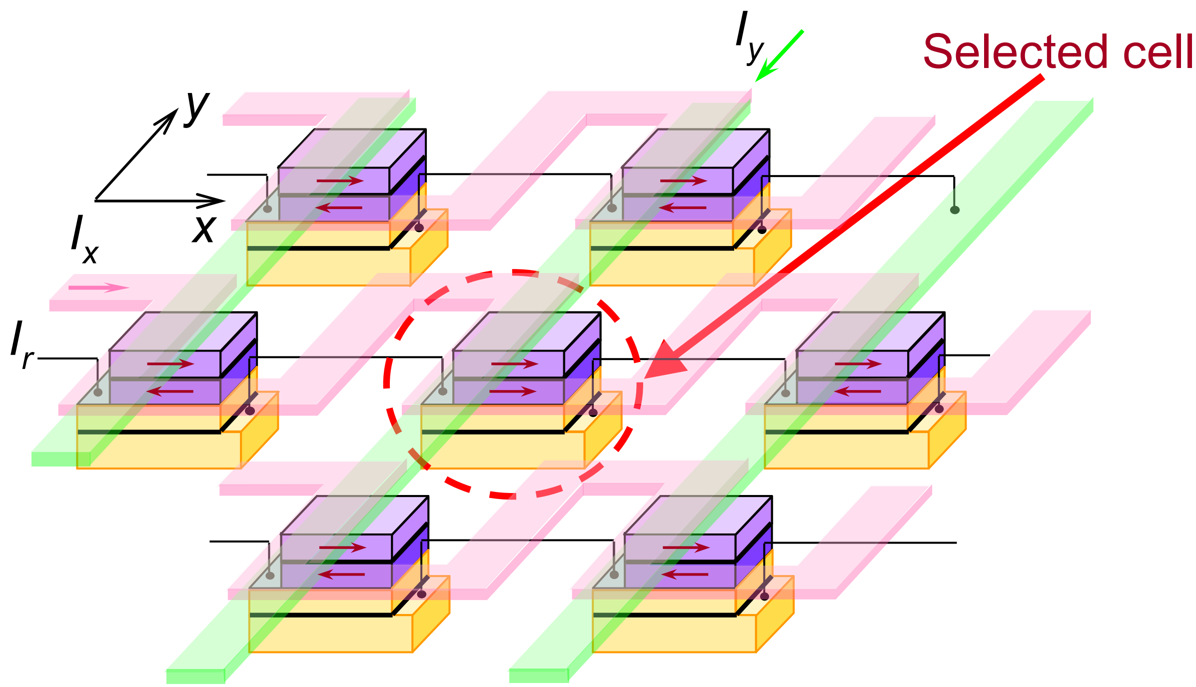


Schematic view of a **complete memory cell** consisting of vertically integrated Superconductor-Insulator-Superconductor (SIS′) and magnetic tunnel junction (MTJ). Pictures show magnetic lines of force for:

(a) anti-parallel (AP) magnetization alignment;

(b) parallel (P) magnetization alignment (causes suppression of I_c).

WRITE operation

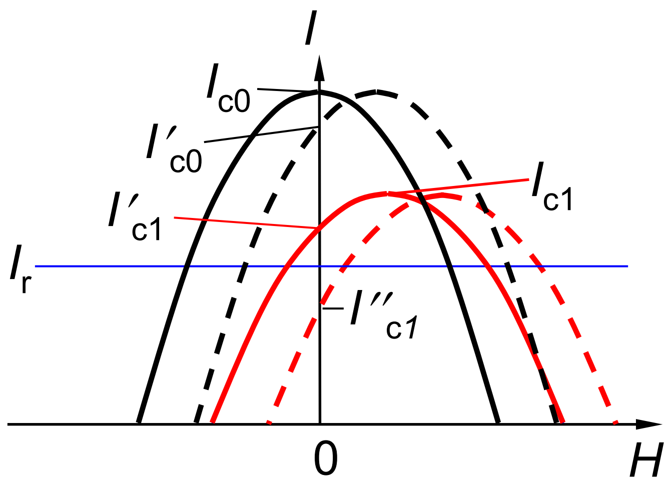


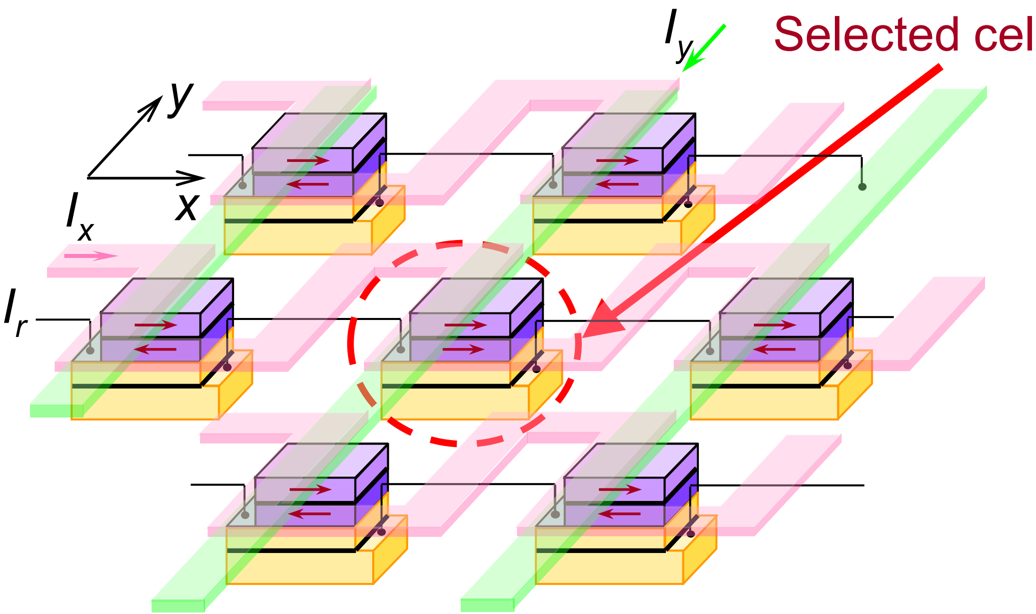
Memory array is composed of SIS′F_1IF_2S devices and independent superconducting control lines along the *x* and *y* axis. Currents $\boldsymbol{I_x}$, $\boldsymbol{I_y}$ provide cell selection and switching the magnetization direction of the "soft" magnetic layer in the F_1IF_2 junction (red arrows denote magnetization vectors).

The SIS′ junctions are connected in series in the rows. $\boldsymbol{I_r}$ is running along the *x* axis through SIS' only.

WRITE operation: Magnetization reversal of the "soft" (bottom F_1) layer is accomplished by combined action of the magnetic field induced by $\boldsymbol{I_x}$ and $\boldsymbol{I_y}$. In the selected cell, the fields from the two lines add up.

READ operation





READ operation: $\boldsymbol{I_r}$ is supplied to the desired row of SIS' JJs; simultaneously, $\boldsymbol{I'_y}$ is supplied to the respective column in order to select a cell whose state needs to be read out.

The magnitude of $\boldsymbol{I'_y}$ is such that it creates a magnetic field that shifts $I_c(H)$ along the H axis but cannot reverse the magnetization in any of the F layers in the MTJ**.**

The amplitude of the read current $\boldsymbol{I_r}$ is chosen as shown by the horizontal line. $\boldsymbol{I_r}$ is flowing through a superconducting path except the selected cell in P orientation (with suppressed I_c from I_{c0} to I_{c1}) – maximized energy efficiency (energy dissipates when reads “1” only).

Near future work

• Optimization of the device parameters towards improvement of the I_c difference for P and AP magnetization orientations. About 30% suppression has been shown (ISEC 2017)
• Further size reduction.
•Relative position of MTJ over SIS JJ should be optimized.
•Look for F materials with lower coercive fields. Perhaps alloys may help.
•Develop non-hysteretic JJs.

C3 memory teams

1. ***Northrop Grumman:*** I. M. Dayton, T. Sage, E. C. Gingrich, M. G. Loving, T. F. Ambrose, N. P. Siwak, S. Keebaugh, C. Kirby, D. L. Miller, A. Y. Herr, Q. P. Herr, and O. Naaman, Experimental demonstration of a Josephson magnetic memory cell with a programmable -junction, *IEEE Magn. Lett*. **9,** 3301905 (2018). (12 people)

2. ***Raytheon BBN:*** M.-H. Nguyen, G. J. Ribeill, M. V. Gustafsson, S. Shi, S. V. Aradhya, A. P . Wagner, L. M. Ranzani, L. Zhu, R. Baghdadi, B. Butters, E. Toomey, M. Colangelo, P. A. Truitt, A. Jafari-Salim, D. McAllister, D. Yohannes, S. R. Cheng, R. Lazarus, O. A. Mukhanov, K. K. Berggren, R. A. Buhrman, G. E . Rowlands & T. A. Ohki, Cryogenic Memory Architecture Integrating Spin Hall Effect based Magnetic Memory and Superconductive Cryotron Devices, *Sci. Rep*. **10**(1), 248 (2020). (23 people)