Nodal superconducting exchange coupling

A. Di Bernardo [1], S. Komori[1], G. Livanas[2], G. Divitini[1], P. Gentile[2], M. Cuoco[2], J.W.A. Robinson[1]

[1] Department of Materials Science & Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge CB3 0FS, United Kingdom
[2]CNR-SPIN c/o Università di Salerno, I-84084 Fisciano, Salerno, Italy

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The superconducting equivalent of giant magnetoresistance involves placing a thin-film superconductor between two ferromagnetic layers. A change of magnetization-alignment in such a superconducting spin-valve from parallel (P) to antiparallel (AP) creates a positive shift in the superconducting transition temperature (ΔT_c) due to an interplay of the magnetic exchange energy and the superconducting condensate. The magnitude of ΔT_c scales inversely with the superconductor thickness (d_S) and is zero when d_S exceeds the superconducting coherence length (ξ) as predicted by de Gennes. Here we report a superconducting spin-valve effect involving a different underlying mechanism (Fig. 1) that goes beyond de Gennes in which magnetization-alignment and ΔT_c are determined by the nodal quasiparticle-excitation states on the Fermi surface of the *d*-wave superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO) grown between insulating layers of ferromagnetic $Pr_{0.8}Ca_{0.2}MnO_3$. We observe ΔT_c values that approach 2 K with ΔT_c oscillating with d_S over a length scale exceeding 100 ξ and, for particular values of d_S, we find that the superconducting state reinforces an antiparallel magnetization-alignment. These results pave the way for all-oxide superconducting memory in which superconductivity modulates the magnetic state.

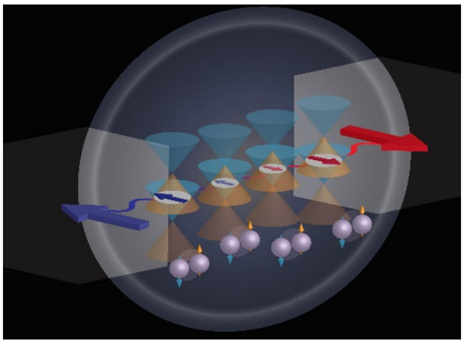

Fig. 1: Sketch illustrating the energy splitting of low-energy quasiparticle excitations in d-wave superconductor due to the exchange coupling at the superconductor/ferromagnet interfaces (YBCO/FI).

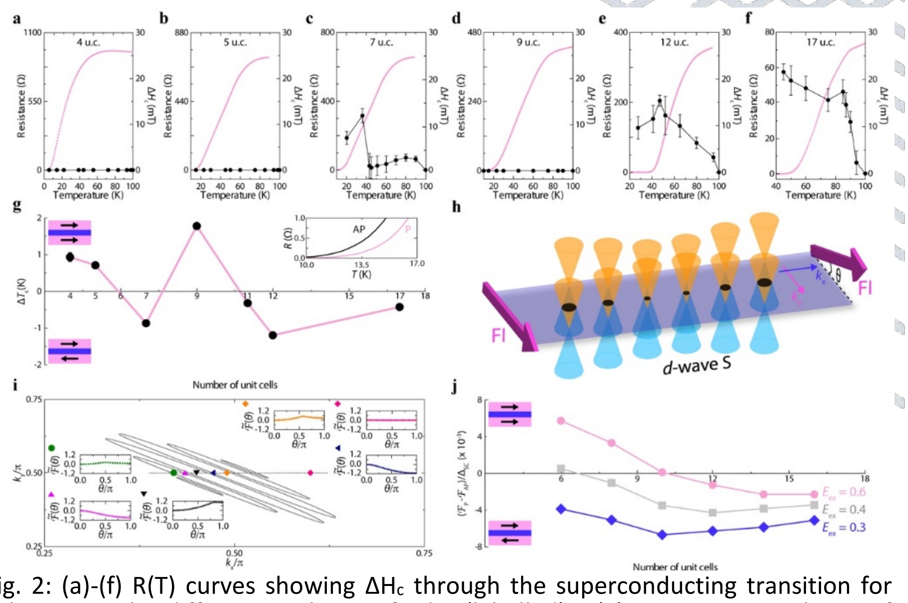

Fig. 2: (a)-(f) R(T) curves showing ΔH_c through the superconducting transition for trilayers with different values of d_S (labelled). (g) maximum values of $\Delta T_c = T_c$ (P) - T_c (AP) versus d_S with the inset showing R(T) curves in the P and AP states for d_S = 9 u.c. (h), a sketch illustrating the energy splitting of low-energy quasiparticle excitations in YBCO due to E_{ex} at the YBCO/FI interfaces. (i,) calculated Fermi surface of YBCO between two FIs with relative magnetization angle θ. Insets show free energy curves at points in k-space versus θ. (**j**) Minima in free energy for P (top) and AP (bottom) states versus d_S for different values of E_{ex} (given in units of the intra-u.c. charge hopping parameter). The sketches in g and j show the ground state (P or AP) of the trilayer.