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Bismuth nanowires based Josephson junctions in very high magnetic fields

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In the superconducting proximity effect, singlet pair correlations can penetrate quite far (on the micron scale) into a non superconducting (normal) conductor. This penetration, that can lead to supercurrents through normal conductors several micrometers long connected to two superconductors, results from quantum interference between all conduction channels in the sample. In a microscopic picture, the supercurrent is carried by Andreev states, combinations of time reversed electron and hole wavefunctions confined to the normal conductor. It is thus natural to consider that this interference will be destroyed not only by inelastic scattering, but also by time reversal symmetry breaking. Indeed, a magnetic field is known to suppress the supercurrent via both orbital (Aharonov Bohm phase accumulation) and spin (Zeeman dephasing) effects. Nevertheless, supercurrents have been induced through ferromagnets. The oscillatory sign and decaying intensity of the supercurrent with increasing ferromagnet thickness is an illustration of the dephasing role played by the exchange field. On the other hand, the time reversal invariant spin orbit interactions, by imposing strong correlations between spatial and spin components of the induced Andreev pairs, offer new possibilities such as coupling between singlet and triplet pairing [1, 2], arbitrary Josephson phase shifts in an exchange or a Zeeman field (φ junction behavior) [3] and the possible formation of Majorana fermions at the interface between semiconducting nanowires and superconducting electrodes [4].

In this report, we probe the superconducting proximity effect in bismuth crystalline nanowires, a system with extremely high Rashba spin orbit coupling, connected to superconducting electrodes with standard s-wave pairing and a very high critical field. The complex interference pattern we measure (Fig.1 and Fig.2), up to magnetic fields such that the Zeeman energy becomes of the order of the spin-orbit and Fermi energies, uniquely reveals the role played by both spin and orbital degrees of freedom.

References

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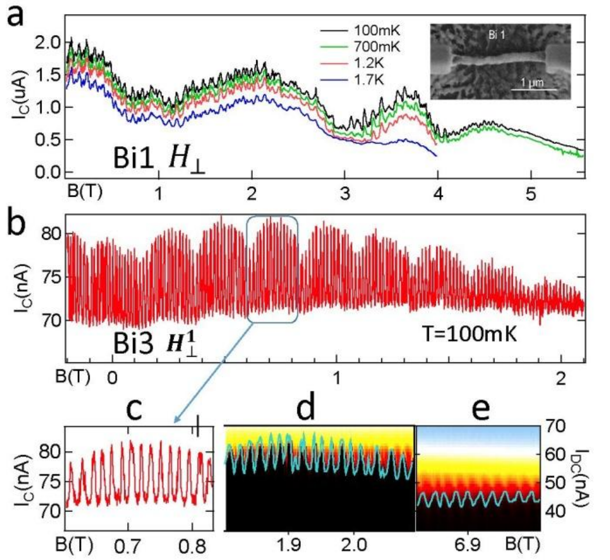

Figure 1. Field dependence of the supercurrent of Bi_1 (top curve) and Bi_3 (bottom curves), in a perpendicular magnetic field. Fast, squid-like oscillations are visible on scales of 800 and 150 G for Bi_1 and Bi_3 respectively, up to unusually high fields (up to at least 6 T for Bi_1, and to 10T for Bi_3). An additional periodic modulation with a 2300 G period is seen for Bi_3, and an irregular modulation in the Tesla range modulates the critical current of Bi_1. On Bi_3 two kind of switching measurements were done with different time scales. As expected, the measurements (b) and (c), performed on a shorter time scale, yield somewhat higher switching current values than the slow measurements (d) and (e). Inset: Scanning electron micrograph of Bi_1, connected by superconducting W wires.

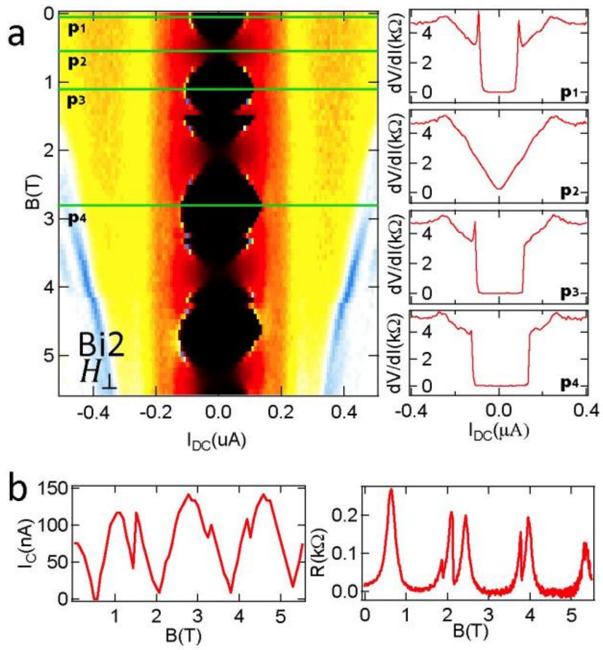

Figure 2. (a) Left panel: Color plot of the field dependence of the differential resistance of Bi_2, with some characteristic differential resistance curves (right panel). (b) and (c) Field dependence of the critical current and zero bias differential resistance extracted from the colorplot (a). Note the oscilla¬tory behaviour on the 1 Tesla field scale, and also how the maximal critical current increases with field.