Non-local Spin Valve Interferometer: Experimental Observation of Superconducting Spin Current and Spin Aharonov-Bohm Effect

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An electron interferometer was designed and fabricated via a normal metal (superconductor)/insulator/ferromagnet non-local lateral spin valve with a ring-shaped normal metal/insulator spacer, and spin current interference was observed. At 4.2 K, a very high spin signal of 200 mΩ was found in a device with 2 µm injector-detector distance and magnetic field swept parallel to the plane. With a perpendicular magnetic field sweep, a Hanle effect measurement showed both spin precession and $h/e$ oscillation. Because of the non-adiabatic nature of the precessing spins at low fields as they traverse the normal metal ring, this is an experimental observation of Aharonov-Anandan’s non-adiabatic geometric phase.

In addition, our observation of identical spin resistance for normal and superconducting Aluminum is inconsistent with theoretical predictions based on the quasiparticle picture. In this designed sample, at the injector region, it is actually a superconductor/ferromagnet/superconductor lateral Josephson junction. Such a lateral Josephson junction convert spin singlet Cooper pairs from Aluminum to the long range triplet components in ferromagnet with projection of $S_z = \pm 1$. Such long range triplet components could diffuse a long distance in ferromagnet bar which is shorter than 3µm. The spin current results in superconducting Aluminum not only suggested the singlet-triplet conversion in ferromagnet, but may also suggest a new phenomenon, that is the long range triplet correlation in ferromagnet may also reversely spread out into type I superconductor and exist for a short period of time in the superconductor and finally convert to singlet correlation due to exchange interaction and spin-orbital coupling. Such an unstable triplet correlation in Aluminum could be detected in the non-local geometry. Although additional experimental work is needed to further confirm this supposition, our results might be the direct observation of superconducting spin current which was under experimental pursuit recently. The experimental results may also suggest a new research area, that is triplet-singlet conversion in type I superconductor.