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Experimental Demonstration of a Persistent Current

By combining an epitaxial FePt nano-pillar with perpendicular magnetic anisotropy and a non-magnetic nano-ring, we will demonstrate an alternative method to generate a spin-polarised persistent current in a non-magnet. Even though such a spin-polarised persistent current has been proposed theoretically almost 20 years ago [1], there has been no experimental demonstration to date. This device would open up new horizon as a spin source for quantum computation.

Quantum phases of charged particles have been investigated in mesoscopic structures, and have revealed interference and oscillatory behavior induced by an external field application [2]. For instance, electrons travelling along semiconductor or normal metal rings threaded by a magnetic flux acquire a quantum dynamical phase, producing interference phenomenon such as the Aharonov-Bohm (AB) and Altshuler-Aronov-Spivak (AAS) effects. In addition, when the spin of electron rotates during its orbital motion along the ring-shaped path, the electron acquires an additional phase contribution known as the geometrical or Berry phase.

Recently, a geometrical phase has been predicted by studying electron transport under an inhomogeneous magnetic field. The geometrical phase can drive a persistent current. A pioneering experiment has been performed using spin-orbit scattering in a two-dimensional electron gas (2DEG) semiconductor, which also strongly couples spin and orbital motion and introduces a spin rotation. For metallic rings, it has been pointed out that electrons can sense the geometrical phase even when an effective exchange field is induced by ferromagnets. However, no results have been reported on the correlation between the geometrical phase and the presence of the ferromagnets. Interestingly, as opposed to a general belief that ferromagnets destroy quantum phase effects due to their complex dephasing mechanisms, an oscillatory behavior of resistance in a permalloy nanoring has been observed and an effect of ferromagnetic ordering in a GaMnAs semiconductor has been detected experimentally [3]. Such an AB oscillation in a ferromagnetic ring has been studied theoretically, suggesting that a dynamic phase can exist under the special condition when a ferromagnetic ring possesses perpendicular anisotropy. I have previously explored the effect of ferromagnets upon the electron quantum phase using a metallic nanoring, consisting of a trilayered FeNi/Cu/FeNi structure known as a current-in-plane (CIP) giant magnetoresistive (GMR) spin valve [4].

Previously we have fabricated FePt nanopillar encircled by a Au nanopillar. At 350 mK, significant hysteresis was observed in the magnetoresistance when the magnetisation of the pillar was measured as shown in Fig. 2. The stray field from the pillar will act at a slight angle to the nanoring because the two objects do not lie in exactly the same plane. This will induce a persistent current in the ring. The simple 4-terminal configuration shown in Fig. 1 then allows the persistent current to be detected. The persistent current was observed via the hysteresis in the magnetoresistance when the magnetisation of the pillar was measured.

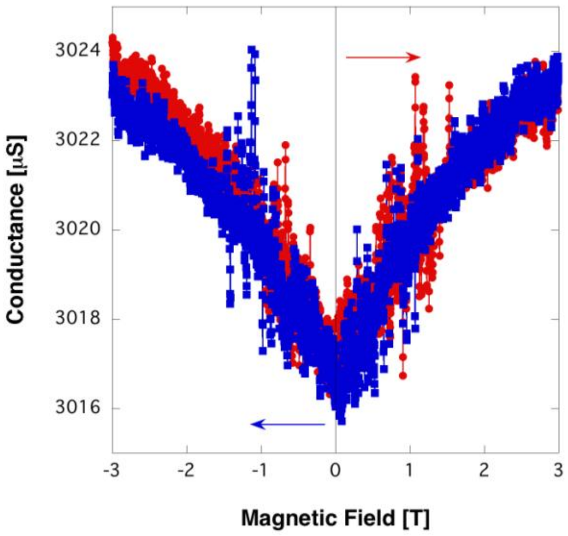

Fig. 1 Magnetoresistance of the quantum device at 350 mK.

We have further improved a new nanofabrication method has been successfully developed to produce a 260-440-nm-inner-diameter Ag nanoring and a 50-120-nm-diameter FePt nanopillar inside by using electron-beam lithography and Ar-ion milling. As shown in Fig. 1, the center nanopillar is designed to provide a non-uniform magnetic field in the nanoring at its remanent state after perpendicular saturation. Such a non-uniform field is theoretically expected to induce a persistent spin current in the nanoring [1]. The induced current is intended to be measured by four contacts fabricated near the nanoring.

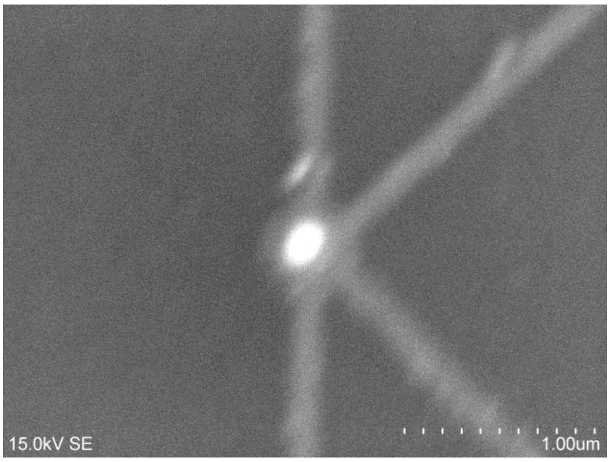

Fig. 2 SEM image of a quantum device.

We now plan to observe new quantum phenomena by measuring nanoscale spintronic devices at below 500 mK. We will first detect the observation of the AB signals to confirm the quality of the devices. Accordingly, we will focus on a persistent current induced in a non-magnetic nanoring under a non-uniform magnetic field application as predicted in Ref. [1].

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