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Editors' Suggestion

Coherent Spin Amplification Using a Beam Splitter

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We report spin amplification using a capacitive beam splitter in n-type GaAs where the spin polarization is monitored via a transverse electron focusing measurement. It is shown that partially spin-polarized current injected by the emitter can be precisely controlled, and the spin polarization associated with it can be amplified by the beam splitter, such that a considerably high spin polarization of around 50% can be obtained. Additionally, the spin remains coherent as shown by the observation of quantum interference. Our results illustrate that spin-polarization amplification can be achieved in materials without strong spin-orbit interaction.

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Introduction.—Controlled manipulation of electron spin has been a major area of research for developing future spin-based logic devices. The realization of such devices requires controllable spin transport to remain coherent over a long distance. The spin transistor fundamentally relies on the manipulation of electron spin rather than the current which drives the device. This can offer advantages in terms of accuracy and speed in comparison to the conventional transistor. First proposed by Datta and Das [1], a spin transistor utilizes the spin-precession [1–7], which can be induced by magnetic material or spin-orbit interaction (SOI) to control the transmission of a charge carrier with a particular spin orientation. However, it is difficult to extend the spin transistor scheme relying on spin-precession to materials such as n-type GaAs owing to weak SOI despite advantages such as high electron mobility and long spin relaxation time. Although one can deposit magnetic material on GaAs, there is a problem with interface scattering, and the magnetic materials may influence the spin distribution and could result in undesirable decoherence [8]. It is, thus, of broad interest to achieve a non-spin-precession approach without relying on the strong SOI.

In the present work, we demonstrate an approach to spin-polarization amplification which does not rely on the SOI. In this approach, an enhancement in controlled spin polarization in a one-dimensional (1D) channel is achieved by exploiting the transmission probability of two spin branches and quantum interference through a capacitive beam splitter erected between the emitter and collector in the magnetofocusing configuration. With this approach, we can achieve a net spin polarization of ~50% (with scope of considerable improvement).

Experiment.—The devices studied in the present work were fabricated from a high mobility two-dimensional electron gas formed at the interface of GaAs/$\mathrm{Al}_{0.33}\mathrm{Ga}_{0.67}\mathrm{As}$ heterostructure. At 1.5 K, the measured electron density (mobility) was $1.80 \times 10^{11}\ \mathrm{cm}^{-2}$ ($2.17 \times 10^{6}\ \mathrm{cm}^{2}\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$); therefore, both the mean free path and phase coherence length (calculated from the Nyquist equation [9,10]) were over 10 μm, which was much larger than the electron propagation length. The experiments were performed in a cryo-free dilution refrigerator with a lattice temperature of 20 mK using a standard lock-in technique.

Demonstrating spin amplification requires a direct measurement of spin polarization. Here we utilize a magnetofocusing scheme which is a well-established method in monitoring the spin polarization [7,11–16]. We have used both the conventional linear geometry and an orthogonal geometry which was implemented in our previous work in studying the 1D spin gap [11,12,16]. In the present Letter, an additional inclined beam splitter was patterned 45° against both the emitter and collector as shown in the inset of Fig. 1 (characteristics of the quantum point contacts (QPCs) or short quantum wire and beam splitter are presented in Supplemental Material [17] Note 1).

In the presence of a small positive transverse magnetic field $B_{\perp}$, electrons are bent from the emitter to collector leading to focusing peaks periodic in $B_{\perp}$ with a periodicity [19] $B_{\mathrm{focus}} = \sqrt{2}\hbar k_F/eL$. Here, $\hbar$ is the reduced Planck constant, k_F is the Fermi wave vector, e is the elementary charge, L is the separation between the emitter and collector along the diagonal direction, and the prefactor $\sqrt{2}$ accounts for the orthogonal device geometry. The SOI