APPLIED PHYSICS LETTERS **111**, 042107 (2017)

Direct observation of exchange-driven spin interactions in one-dimensional system

Chengyu Yan,[1,2,a)] Sanjeev Kumar,[1,2,b)] Kalarikad Thomas,[1,2,c)] Michael Pepper,[1,2]
Patrick See,[3] Ian Farrer,[4,d)] David Ritchie,[4] J. P. Griffiths,[4] and G. A. C. Jones[4]
[1]*London Centre for Nanotechnology, 17-19 Gordon Street, London WC1H 0AH, United Kingdom*
[2]*Department of Electronic and Electrical Engineering, University College London, Torrington Place, London WC1E 7JE, United Kingdom*
[3]*National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, United Kingdom*
[4]*Cavendish Laboratory, J.J. Thomson Avenue, Cambridge CB3 OHE, United Kingdom*

(Received 8 June 2017; accepted 13 July 2017; published online 27 July 2017)

We present experimental results of transverse electron focusing measurements performed on an n-type GaAs based mesoscopic device consisting of one-dimensional (1D) quantum wires as injector and detector. We show that non-adiabatic injection of 1D electrons at a conductance of $\frac{e^2}{h}$ results in a single first focusing peak, which transforms into two asymmetric sub-peaks with a gradual increase in the injector conductance up to $\frac{2e^2}{h}$, each sub-peak representing the population of spin-state arising from the spatially separated spins in the injector. Further increasing the conductance flips the spin-states in the 1D channel, thus reversing the asymmetry in the sub-peaks. On applying a source-drain bias, the spin-gap, so obtained, can be resolved, thus providing evidence of exchange interaction induced spin polarization in the 1D systems. [http://dx.doi.org/10.1063/1.4989374]

Spintronics involves engineering the spin degrees of freedom to replace charges with spins to carry information precisely to meet the future technological challenges. This has led to a volume of theoretical[1] and experimental work on spin based systems, exploiting the spin-orbit interaction and the spin-Hall effect using low dimensional semiconductors and optical systems.[2–7] Among various quantum systems, a simple yet powerful system is a one-dimensional (1D) quantum wire realised using a pair of split gates,[8] resulting in the evolution of spin degenerate 1D subbands as the confinement potential is relaxed.[9–11] One of the merits of this system is that the spin degeneracy can be easily lifted on application of an in-plane magnetic field[12] such that spin-up and spin-down electrons could be energetically separated. However, it is also predicted that the exchange can induce partial spin polarization; in other words, it creates a spin-gap in the ground state of a longer 1D system.[13,14] The origin of spin-gap in the 1D system has aroused a great interest to explain the "0.7 anomaly" in the framework of spin correlation between the 1D electrons.[13–16]

The spin polarization in a 1D quantum wire[13,14] can be measured by means of transverse electron focusing (TEF),[17–19] where the height of each focusing peak is proportional to the population of detected electrons. It has been confirmed experimentally in a GaAs hole gas[20,21] and an InSb electron gas[22] that the first focusing peak splits into two sub-peaks and each peak is associated with a spin of an electron. In this work, we provide direct evidence by means of focusing measurements using electrons in the GaAs/AlGaAs heterostructure that the spin-gap can be detected precisely up to the first excited state in agreement with observations of the "0.7" and "1.7" structures.[12,24] Furthermore, we show an effect in which spin repulsion due to the exchange interaction results in flip-flop of the spin-states. In addition, we have combined the source-drain bias spectroscopy with the focusing measurement and provide further evidence of the spin-gap in the 1D system.

The devices studied in the present work were fabricated from the high mobility two dimensional electron gas (2DEG) formed at the interface of the GaAs/$Al_{0.33}Ga_{0.67}As$ heterostructure. At 1.5 K, the measured electron density (mobility) was 1.80×10^{11} cm^{-2} (2.17×10^{6} cm^{2} V^{-1} s^{-1}); therefore, the mean free path is over 10 μm which is much larger than the electron propagation length. The experiments were performed using a cryofree dilution refrigerator with a lattice temperature of 20 mK by the standard lockin technique.

The focusing device is specially designed so that the injector and the detector can be separately controlled to avoid a possible cross-talking between them using a 90° geometry.[17,25] The linear focusing devices[17,20–22,25] used in previous work share the center gate which may introduce a lateral electric field along the confinement direction. Figure 1 shows the experimental setup along with a typical focusing spectrum obtained using the device shown in the inset. The quantum wire used for the injector and detector has a width (confinement direction) of 500 nm and a length (current flow direction) of 800 nm. It may be noted that the quasi-1D quantum wire (in the regime defined between the injector and detector quantum wires, highlighted by the red arrow in Fig. 1) has a smaller lithographic size than the injector/detector quantum wires, and thus, within the studied injector/detector gate voltage, this quasi-1D quantum wire is in the pinch-off regime and so fully reflects the focused electrons.

[a)] Electronic mail: uceeya3@ucl.ac.uk
[b)] Electronic mail: sanjeev.kumar@ucl.ac.uk
[c)] Currently at Department of Physics, Central University of Kerala, Riverside Transit Campus, Padannakkad, Kerala 671314, India.
[d)] Currently at Department of Electronic and Electrical Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD, United Kingdom.