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Imaging Coherent Electron Flow

R.M. Westervelt[1,2], M.A.Topinka[1], B.J.LeRoy[2], S.E.J.Shaw[2], R.Fleischmann[4], E.J.Heller[2,3], K.D.Maranowski[5] and A.C.Gossard[5]

[1]Division of Engineering and Applied Sciences, [2]Department of Physics, and
[3]Department of Chemistry and Chemical Biology
Harvard University, 9 Oxford Street, Cambridge, Massachusetts 02138, USA
Phone: 1-617-495-3296 Fax 1-617-495-9837 E-mail: westervelt@deas.harvard.edu
[4]Max-Planck-Institut für Strömungsforschung, Bunsenstraße 10, D-37073 Göttingen, Germany
[5]Materials Department, University of California, Santa Barbara, California 93106, USA

1. Introduction

Semiconductor nanostructures based on two dimensional electron gases (2DEGs) have remarkable properties. The electron mean free path and the phase coherence length can exceed the size of the device. Coherent nanostructures provide new approaches to sensing and information processing. Although much is known about electron transport in 2DEG nanostructures, the actual pattern of electron flow in a given device is unclear, and is not specified by statistical measures such as the mean free path.

2. Images of Electron Flow

Scanning a charged tip above the 2DEG inside a GaAs/AlGaAs heterostructure can image electron flow by backscattering electron waves, as illustrated in Fig. 1. A quantum point contact (QPC) is formed in the 2DEG by two closely spaced gate electrodes. As the width of the quantum point contact is increased, its electrical conductance increases in quantized steps of height $2e^2/h$, where e is the electronic charge and h is Planck's constant.

Scanned probe images of the angular dependence of the electron flow on each conductance step agree with theory [1]. A QPC sample was constructed from a GaAs/AlGaAs heterostructure containing a high mobility (1×10^6 $cm^2/Vsec$) 2DEG. Figure 2 shows measurements (outside) of electron flow through the third mode of the QPC at T = 1.7K and simulations (inside) of the electron flux. Both the experimental and theoretical images have three well-defined lobes oriented at similar angles. Fringes are observed throughout the measured flow, which are separated by half the Fermi wavelength. These fringes demonstrate the coherent nature of electron flow.

At longer distances from the quantum point contact, the smooth lobes develop unexpected dynamical channels [2]. Figure 2 shows the measured flow from a QPC at the right of the image.

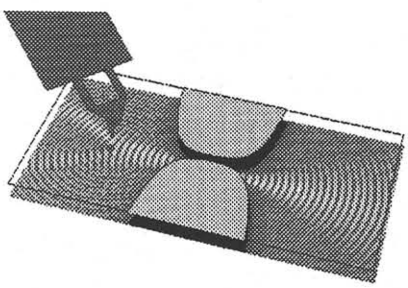

Fig. 1 Schematic diagram of the deflection of electron waves flowing from a quantum point contact with a charged SPM tip [2].

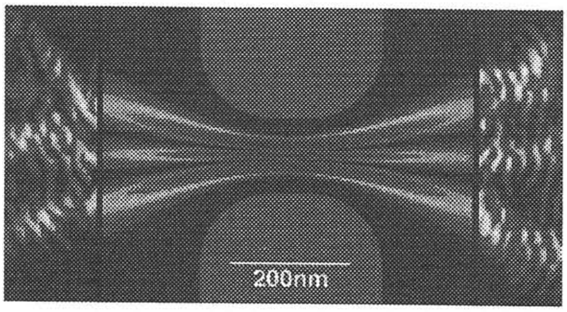

Fig. 2 SPM images of electron flow on the third conductance step, from the third mode of the QPC, with theory inside [1].

The electron flow forms persistent, narrow, branching channels rather than the smoothly spreading fans seen closer to the QPC. These branches form at distances less than the 11 μm mean free path. Fringes spaced by half the Fermi wavelength are observed throughout the image.

Theoretical simulations of flow through a quantum point contact including small angle scattering by ionized donor atoms and impurities agree well with the experimental images [2]. The channels are not due to deep valleys in the potential, but rather are caused by the cumulative effect of gentle small angle scattering.

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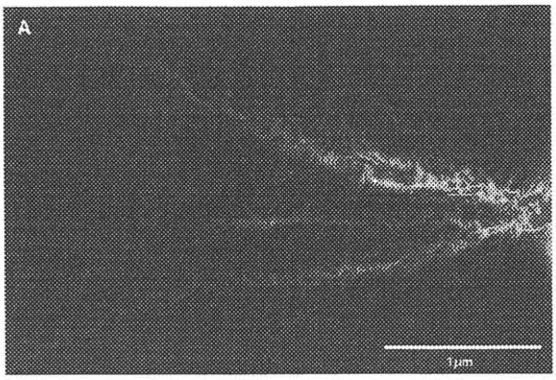

Fig. 2 SPM image of electron flow from a QPC at T = 1.7K showing channels at distances well below the mean free path [2].