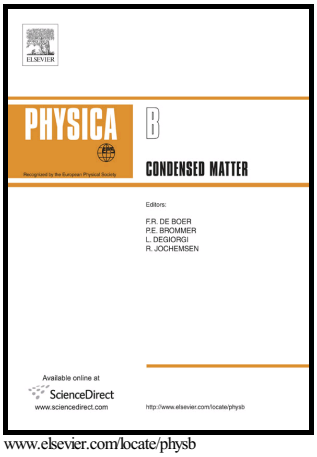
Spin current induced by a charged tip in a quantum point contact

B.S. Shchamkhalova



www.elsevier.com/locate/physb

PII: S0921-4526(16)30614-7
DOI: http://dx.doi.org/10.1016/j.physb.2016.12.028
Reference: PHYSB309769

To appear in: *Physica B: Physics of Condensed Matter*

Received date: 21 October 2016
Revised date: 9 December 2016
Accepted date: 23 December 2016

Cite this article as: B.S. Shchamkhalova, Spin current induced by a charged tip i a quantum point contact, *Physica B: Physics of Condensed Matte* http://dx.doi.org/10.1016/j.physb.2016.12.028

Spin current induced by a charged tip in a quantum point contact.

B. S. Shchamkhalova
Kotel'nikov Institute of Radio Engineering and Electronics,
Russian Academy of Sciences, Fryazino, Moscow District 141190, Russia

We show that the charged tip of the probe microscope, which is widely used in studying the electron transport in low-dimensional systems, induces a spin current. The effect is caused by the spin-orbit interaction arising due to an electric field produced by the charged tip. The tip acts as a spin-flip scatterer giving rise to the spin polarization of the net current and the occurrence of a spin density in the system.

Keywords: Quantum Point Contact; Scanning Probe Microscopy; Spin Current;

I. INTRODUCTION

Scanning gate microscopy (SGM) is a powerful technique to study electron transport in two-dimensional (2D) systems. SGM images obtained by scanning a negatively charged probe tip near the surface and measuring the conductance of the quantum point contact (QPC) as a function of the tip position are used to map out the electron flow emanating from the QPC and to get information about local potential[1–6]. Two effects of the charged tip, namely a gating effect by modifying electrostatic potential in the structure and interference effects due to backscattering of electrons passing through the constriction, are widely studied. Phase-sensitive measurements of the zero-bias anomaly in QPC conductance were carried by Brun *et.al.*[7] using scanning gate microscope to create an electron interferometer.

Spin phenomena in 2D systems, in particular spin-orbit interaction (SOI) that can be used to control electron spin by electric field, has attracted much interest recently. Basic symmetry relations for the spin dependent scattering parameters in two-terminal quantum waveguide with Rashba SOI was derived in Ref.[8,9]. In papers[10–13] electron transport in quasi-one dimensional structures with local Rashba SOI was studied. The effect of the uniform SOI on SGM of the electron flow from a QPC was investigated in[14]. The spin polarization in side-gated QPC with asymmetric confining potential was also studied[15,16].

The charge tip of scanning gate microscope is a source of a strong electric field, which creates a local SOI, and tip acts as a spin-flip scatterer. This aspect of the tip influence on the electron flow in the QPC is not considered up to now. The aim of this paper is to study the effect of the charged tip on charge and spin currents in the QPC, taking into account the spin-flip scattering caused by the local SOI. We show that the charged tip induces a spin current due to the intersubband spin-flip scattering of electrons. The electron spins are directed in the plane of 2D electron gas perpendicular to the charge current. The spin current is linear in spin-orbit coupling strength of the QPC material. The spin-density in the sample is nonuniform. The role of both potential and spin-flip intra- and intersubband electron scattering off the tip on charge and spin currents are analyzed.

II. MODEL

A model QPC is considered in the presence of the SOI of Rashba type. The charged tip is located in a point $r_0 = (x_0, y_0, z_0)$ at a distance z_0 over the two-dimensional (2D) electron gas. The Hamiltonian of the system is given by

$$H = \frac{p_x^2 + p_y^2}{2m} + U(x,y) + V(x,y,r_0) + H_{so}(x,y,r_0)\,. \tag{1}$$

Here V is a potential of the tip. The potential landscape of the QPC created by gates is approximated by the function $U(x,y)$:

$$U(x,y) = \frac{U_0}{\cosh^2(x/L)} + \frac{m\omega_y^2 y^2}{2}\,, \tag{2}$$

where x is along the QPC axis and y is the transverse coordinate. This model potential **with a saddle point at** $x = 0, y = 0$ **(see Fig. 1b)** simulates well the QPC studied in experiments and allows an exact analytical solution. The local SOI Hamiltonian due to the charged tip is given by: