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Spin filtering in magnetic/semiconductor hybrid nanostructures

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Abstract

We study theoretically the spin-dependent electron transport in realistic magnetic-barrier nanostructures, which can be experimentally realized by depositing a magnetized ferromagnetic stripe with arbitrary magnetization direction on the surface of a semiconductor heterostructure. It is shown that highly spin-polarized current can be achieved in this kind of nanostructures. It is also shown that the spin polarity of the electron transport can be switched by adjusting the magnetized angle of the ferromagnetic stripe in the system. These interesting properties may provide an alternative scheme to spin-polarize electrons into semiconductors and may be used as a spin-filter.

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Keywords: Spintronics; Spin polarization; Spin filtering; Magnetic nanostructure

1. Introduction

The realization of spintronic devices relies on the ability to inject spin-polarized current into a semiconductor [1,2]. Extensive efforts have been made to study electron-spin polarization in a wide variety of nanostructures [3]. Previous attempts to spin inject into a semiconductor by using ferromagnetic materials have been proved to meet serious obstacles [4] and will probably be very difficult [5] to realize. Another alternative effort is to directly spin-polarize electrons in semiconductors, such as using the so-called magnetic semiconductor [6], the reflection at the interface between a semiconductor and a ferromagnet [7], as well as a spin filter [8].

Recently, the electron-spin filtering in magnetically modulated nanostructures has attracted great current interest [9–15]. Such a type of systems is the hybrid of semiconductors and magnetic materials, where a ferromagnetic material is deposited on top of a near-surface two-dimensional electron gas (2DEG) formed

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in modulation-doped semiconductor heterostructure. The magnetic materials provide a magnetic field which can influence locally the motion of the electrons in the semiconductor heterostructure. A simple, experimentally attractive proposal for spintronic devices was to exploit a single ferromagnetic stripe on top of a 2DEG [11–13]. Several groups have discussed spin effects on electronic tunneling through such a device, and many interesting results were obtained via numerical calculation. However, in these studies this device was idealized [12,13] or specialized [11]. In order to reveal the universal rule of spin-dependent transport properties in this kind of device, in this Letter we study the generic and realistic case. By numerical calculations for InAs material system, it is shown that such a device possesses the considerable electron-spin polarization in sizeable electronic energy range, especially the degree of electron-spin polarization can exceed 80% at resonance. It is also that not only the amplitude of the polarization but also its sign varies with the magnetized direction of the ferromagnetic stripe. Thus, the considered device can be employed as a spin filter, whose polarity can be switched by changing the magnetization direction of the ferromagnetic stripe.

2. Model and formulas

The system considered here is composed of a 2DEG in the (x, y) plane, provided by a quantum well and modulated by an perpendicular inhomogeneous magnetic field, which can be experimentally realized by depositing [16] a ferromagnetic stripe on top of a semiconductor heterostructure, as sketched in Fig. 1(a). Here, M, d, h and θ are the magnetization, thickness, height, and magnetized angle of the ferromagnetic stripe, respectively, while the parameter z_0 stands for the 2DEG located at a upright distance below the stripe. This magnetized ferromagnetic stripe will generate the vertical magnetic fields acting on the 2DEG as presented in Fig. 1(b). Assume that the magnetic field provided by the magnetized ferromagnetic stripe is homogeneous in the y direction and varies only along the x axis, then the magnetic profile, $\mathbf{B} = B_z(x)\hat{z}$, can be given by [17]

$$B_z(x) = B_0\left\{\left[\frac{2(x+d/2)d}{(x+d/2)^2+z_0^2} - \frac{2(x-d/2)d}{(x-d/2)^2+z_0^2}\right]\times\sin\theta + \left[\frac{z_0 d}{(x+d/2)^2+z_0^2} - \frac{z_0 d}{(x-d/2)^2+z_0^2}\right]\times\cos\theta\right\}, \quad (1)$$

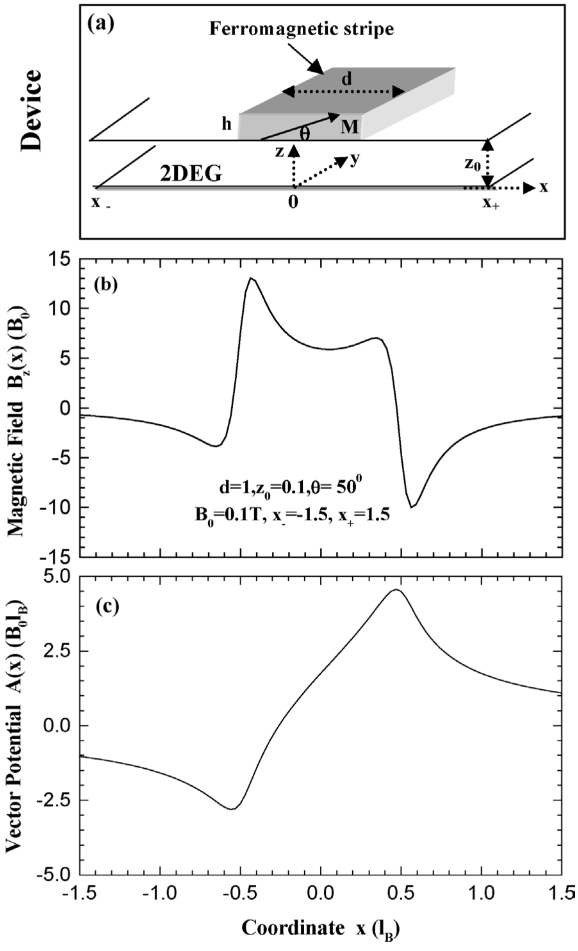

Fig. 1. (a) Schematic illustration of the spin device: a ferromagnetic stripe is deposited on top of a 2DEG, where the magnetization of the stripe is assumed to be along the arbitrary direction. (b) The magnetic field profile exploited in this work. (c) The corresponding magnetic vector potential. In this figure and the following ones, the structural parameters are chosen to be $d = 1.0$, $z_0 = 0.1$, $x_- = -1.5$, $x_+ = +1.5$, $B_0 = 0.1$ T, while the InAs system is taken as the 2DEG material.