Physica E 59 (2014) 158–162

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Spin-dependent shot noise in diluted magnetic semiconductor /semiconductor heterostructures with a nonmagnetic barrier

Shuang Wu [a], Yong Guo [a,b,*]

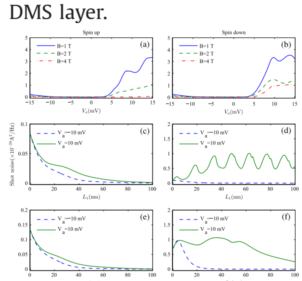
[a] Department of Physics and State Key Laboratory of Low-Dimensional Quantum Physics, Tsinghua University, Beijing 100084, China
[b] Collaborative Innovation Center of Quantum Matter, Beijing, China

HIGHLIGHTS

- The shot noise of a NMS/DMS/NMS heterostructure with a NMS barrier is calculated.
- The NMS barrier plays quite a different role from DMS layer.
- Shot noise may be used as a sensitive probe in detecting material type and its size.

GRAPHICAL ABSTRACT

The results indicate that the NMS layer makes a different contribution to shot noise compared to the DMS layer.



ARTICLE INFO

Article history:
Received 21 April 2013
Received in revised form
7 November 2013
Accepted 10 January 2014
Available online 23 January 2014

Keywords:
Spin
Shot noise
Diluted magnetic semiconductor
Heterostructure

ABSTRACT

We investigate quantum size effect on the spin-dependent shot noise in the diluted magnetic semiconductor (DMS)/semiconductor heterostructure with a nonmagnetic semiconductor (NMS) barrier in the presence of external magnetic and electric fields. The results demonstrate that the NMS barrier plays a quite different role from the DMS layer in the electron transport process. It is found that spin-down shot noise shows relatively regular oscillations as the width of DMS layer increases, while the spin-up shot noise deceases monotonically. However, as the width of NMS layer increases, the spin-down shot noise displays irregular oscillations at first and then decreases while the spin-up shot noise decreases at a quite different rate. The results indicate that the shot noise can be used as a sensitive probe in detecting material type and its size.

1. Introduction

Spin-dependent transport in semiconductors is the most important issue in the field of Spintronics because of its potential applications in information technology. Mn-doped diluted semiconductor is regarded as a promising kind of material due to its good property of owning both the character of semiconductor and stable magnetism [1]. Both theoretical and experimental investigations have achieved great progress in past decades. Theoretically, the spin splitting in diluted dual barriers structure under electric and magnetic fields along fixed direction was predicted by Sugakov and Yatskevich [2]. Later, Egues [3] showed a strong suppression of the spin-up component of the current density for increasing magnetic fields in ZnSe/$Zn_{1-x}Mn_xSe$ heterostructure. Beletskii et al. [4] studied the dependence of the current spin polarization on the external constant magnetic field, the applied voltage bias, and the distribution of Mn ions in the double-barrier resonant-tunneling diode (RTD) consisting of $Zn_{1-x}Mn_xSe$ diluted magnetic layers and demonstrated that the degree of current spin polarization in the diluted magnetic RTD can be effectively controlled by an electric field. One of us and coworkers [5] proposed a tunable spin filter based on periodic DMS/S superlattices. Experimentally, Fiederling

* Corresponding author.
E-mail address: guoy66@tsinghua.edu.cn (Y. Guo).

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http://dx.doi.org/10.1016/j.physe.2014.01.013

et al. [6] have achieved injection efficiencies of 90% spin-polarized current into a non-magnetic semiconductor device. The electron spin controlling is proved to be possible utilizing BeTe/Zn_{1-x}Se/BeTe. [7] Malajovich [8] promoted spin transporting efficiency in GaAs/ZnSe heterostructure by adding an external bias. The electric field effects have been confirmed in spin transportation of many kinds of diluted semiconductor/semiconductor structures [9–12]. In recent years, other interesting features like oscillations of longitudinal

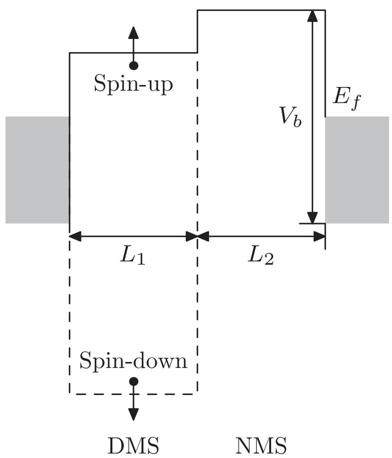

Fig. 1. Spin-dependent conduction-band edge of a band-gap-matched ZnSe/$Zn_{1-x}Mn_x$Se heterostructure with an inserted NMS barrier.

magnetoconductivity [13], asymmetric effect [14], spin states [15] and zero field spin polarization [16] have been revealed.

At low temperature, thermal fluctuations are extremely small, the current fluctuation properties are governed by the shot noise, which is a consequence of the discrete nature of electric charge. Because of its usefulness in obtaining information which is not accessible through the common conductance measurement, shot noise is a powerful tool to study quantum transport in mesoscopic systems [17]. In particular, shot noise experiments can determine the quantum correlation of electrons that are relevant for transport and reveal information on the potential profile and internal energy scales of mesoscopic systems. Here are some examples. Iannaccone and his coworkers [18] proposed an approach addressing noise properties of generic resonant-tunneling structures in the whole range of transport regimes. Marconcini and his coworkers [19] reported an analysis of shot noise suppression in a structure containing cascaded tunneling barriers. More recently, the study of spin-polarized noise has attracted growing attention [20–26]. Considering spin-related effects, shot noise is also a useful probe for detecting entanglement. Based on a beam splitter with spin–orbit interaction in one of the incoming leads, it was found that spin polarization and entanglement can be observed through shot noise measurements [27,28]. The contribution of the spin-flip scattering to the shot noise in a spin-resolved tunneling system was also considered by Brito and Egues [29]. In one of our previous work [30], spin-dependent shot noise in double-barrier DMS/S geometry has been investigated, which addresses external effects and structural asymmetry on shot noise. The relations among the shot noise in the DMS/S systems with different structural configurations and under different external magnetic and electric fields have been revealed.

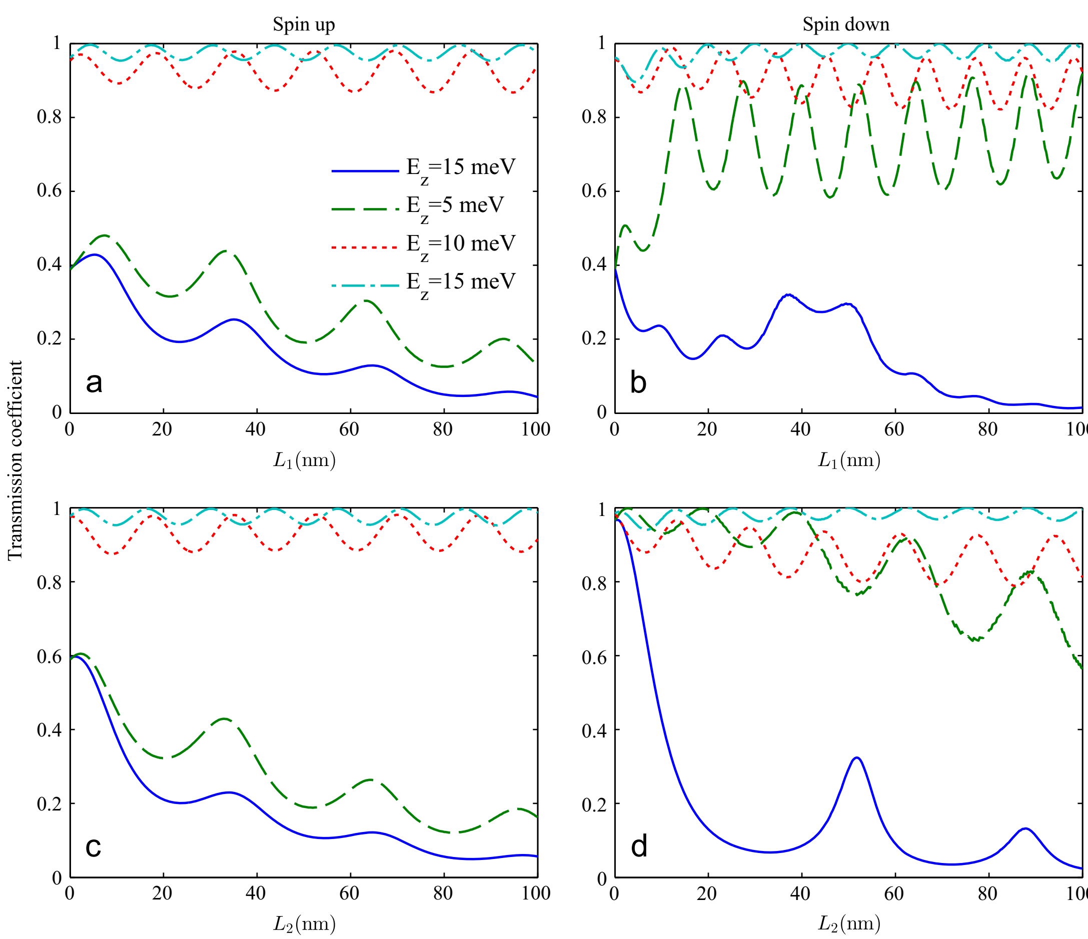

Fig. 2. The transmission coefficient as a function of the width of DMS layer L_1 (a) and (b); that of NMS layer L_2 (c) and (d). The magnetic field $B = 4$ T. The width of invariable layer is 50 nm. The solid line corresponds to reverse bias $V_a = -10$ mV. The dotted, dashed and dash-dotted lines correspond to forward bias $V_a = 10$ mV.