Abstract

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Title: Charge and spin transport and the spin accumulation in magnetic tunneling junctions.

In this work we investigated main mechanisms of the transport of carriers of electric charge and spin in the multi-layer structures with tunnel junctions, semiconductor-based resonance tunnel diodes and quantum dots. The main aim of this work is to define basic properties of the flow of electric current and the spin current in such structures. The work is a theoretical development but it also refers to the experimental results of research of the systems. The results of experiments have been published, and corresponding works can be found at the list of publications at the end of the disquisition.

This research includes an overview of the most important achievements obtained in the study devoted to spintronics. It develops some of the results relating to the resonant tunneling diodes and presents the main features of the tunneling currents and contact connectors in multi-layer tunnel structures containing potential barriers and quantum wells with quantized energy levels. The calculations were carried out analytically and numerically. We have studied the tunneling probability and various basic properties of the current which flow in the structure, where the magnetic field covers one of the outer layer. It was also examined the characteristics of current flow through the resonant level of the tunneling with the quantum well, and the influence of geometric parameters such as the thickness of the barrier to the current. Moreover, it was taken into account possible spin polarization of the current flowing through the system and the associated possibility of creation the spin accumulation layer and charge in the well. We have also study induced magnetization of the quantum well and spin splitting of the resonance level, especially the influence of the resonance energy level on the possibility of the tunneling current. In particular, it was examined the process of magnetization of the resonant level in the area of the potential well, which is not under the external magnetic field. The results confirm the possibility of manipulation of the flow in the spin resonance tunnel diodes, and thus allow to treat them as spin filters.

We have analyzed transport properties of the multilayer structures with magnetic and nonmagnetic layers specially for investigating properties of the shot noise, which is a manifestation of statistical nature of transported charge. We have taken into account the spin of the carriers and studied the Fano factor, whose values have been calculated depending on the configuration of the magnetic moments. Such analysis indicates the importance of particle granulation of spins carriers in the transmission process, and hence the properties of electronic materials with the shot noise. We have analyzed the shot noise in systems with weak and strong spin relaxation. The results were compared to the experimental data. It has been demonstrated that the relative spatial arrangement of the magnetic moments affects the scope of shot noise in doped magnetic connectors. Strong spin relaxation is found to have a significant impact on the value of the Fano factor. The analysis of experimental data shows that the Fano factor can be varied by the selection of the magnetic configuration of each layer of the system. We have investigated the influence of a possible spin asymmetry and the probability of tunneling through the various energy levels on the value of Fano factor. It pointed out the relationship between the shot noise and the spin dependent tunneling effects.

We have studied the role of shot noise in the transport processes of charge and spin carriers that flow through the multi-layered system with molecular energy levels in the central layer. That structure contained an organic compound or quantum dot. We have analyzed such case using the formalism of full counting statistics, and examined transport properties of the system with two

discrete energy levels by taking into account the existence of a strong Coulomb interaction between electrons. We have described the phenomena of shot noise and tunneling magnetoresistance in all four states double-barrier magnetic tunnel junction. Generalization of this approach is presented in previous publications by using the method of full counting statistics referring to the spin-dependent tunneling of electrons through the molecular layer located between the magnetic connectors. As the calculation method we use the solution of master equation for the probabilities in one of the possible states.

Generalization of two-level model to the case of the magnetic structure has a significant impact on the scope of the noise appearing in the system. In the case of a non-magnetic structure and equal probability of tunneling through the upper and lower energy level, we confirmed the value of the Fano factor obtained in previous publications. In addition, we discussed the probability of tunneling charges with the spin through molecular chains and relatively thick connector, when the energy levels of different molecules is not exactly the same. In this case the Fano factor has a value corresponding to the Poisson statistics.

The work also presents an overview of the results of experimental research of the spin current properties, shot noise and tunnel magnetoresistance. The results of these studies are consistent with our theoretical predictions.

In conclusion, the dissertation contains the discussion of the prospects of further work and possible directions of researches in spin electronics, with particular influence and the possible benefits arising from the future discoveries in this field.