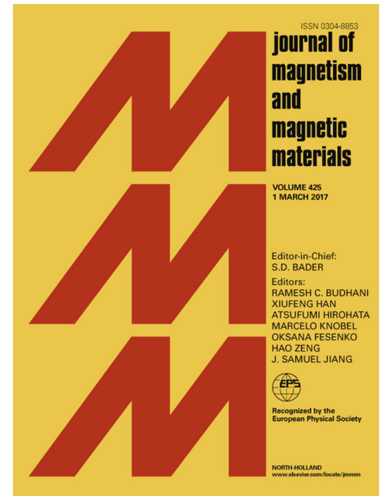

Research articles

Spin transport of electrons and holes in a metal and in a semiconductor

V. Zayets

PII: S0304-8853(17)30951-4
DOI: http://dx.doi.org/10.1016/j.jmmm.2017.08.072
Reference: MAGMA 63106

To appear in: *Journal of Magnetism and Magnetic Materials*

Received Date: 23 March 2017
Revised Date: 31 July 2017
Accepted Date: 23 August 2017

Please cite this article as: V. Zayets, Spin transport of electrons and holes in a metal and in a semiconductor, *Journal of Magnetism and Magnetic Materials* (2017), doi: http://dx.doi.org/10.1016/j.jmmm.2017.08.072

Spin transport of electrons and holes in a metal and in a semiconductor

V. Zayets[*]

Spintronic Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Umezono 1-1-1, Tsukuba, Ibaraki, Japan. e-mail:v.zayets@aist.go.jp

---

Abstract:

The features of the spin and charge transport of electrons and holes in a metal and a semiconductor were studied using the Boltzmann transport equations. It was shown that the electrons and holes carry the spin in opposite directions in an electrical current. As result, the spin polarization of an electrical current in a metal is substantially smaller than spin polarization of electron gas. It was shown that the spin properties of the electron gas are responsible for the existence of the concept of "electrons" and "holes" in a metal and a semiconductor.

Keywords: Spin transport, Spin injection, Spin detection.

Research highlights

- The spin/charge transport equations are obtained from the continuity equations.
- Spin/charge conductivities are calculated by solving the Boltzmann transport equations.
- The spin transport is substantially different in the bulk of a high-conductivity conductor, in a conductor with defects and in the vicinity of an interface.
- In an electrical current, "electrons" and "holes" carry the spin in opposite directions.
- Spin transport by an electrical current is effective in a semiconductor, but it is not effective in a metal.
- The spin properties of the electron gas are responsible for the existence of the concept of "electrons" and "holes" in a metal and in a semiconductor.

---

1. Introduction

Conventionally, the spin transport in a conductor is described by the model of spin-up/spin-down bands [1]. This model assumes that all electrons of an electron gas can be divided into two independent groups: a group of electrons with the "spin-up" spin projections and a group of electrons with the "spin-down" spin projections. It was assumed that there is no exchange of electrons between these groups or the exchange is slow. Therefore, each group of electrons has its own thermo-equilibrium and it is possible to assign different Fermi energies and chemical potentials to each group. Because of the different transport of electrons of "spin-up" and "spin-down" spin projections, an electrical current can transport the spin.

There are several unclear assumptions of this model. Firstly, the reason is unclear why there is no electron exchange between groups of electrons of "spin-up" and "spin-down" spin projections and why these groups of electrons are thermo isolated. Secondly, it is also unclear why spin-up/spin-down direction is special and why not instead the electrons of the spin-left/spin-right or any other spin projections should be thermo isolated.

Additionally, in the model of spin-up/spin-down bands the spin transport is described by the Helmholtz equitation [1], which simplifies the spin transport only to a simple diffusion of particles. Such an over-simplified description ignores several important facts. The Helmholtz equitation describes the diffusion of the spins without any accompanied diffusion of the charge. This is the case when the diffusion of the spin-polarized electrons in one direction is always exactly equal to the diffusion of spin-unpolarized electrons in the opposite direction. This condition contradicts with some experimental facts [2,3]. In the vicinity of an interface the charge is accumulated along spin diffusion [4]. The measurements of this charge accumulation are often used to estimate the magnitude of a spin current. This effect is called the spin detection [2,3]. It should be noted that the problem of the spin detection can be resolved by modifying the model of spin-up/spin-down bands. In Refs. [5-7] it was assumed that the conductivity of electrons of the spin-up and spin-down bands may be different. In this case the spin detection effect can be described.

Another over-simplified assumption of the model of Ref. [1] is the assumption that all conduction electrons have the same spin-transport properties. This is not correct. The spin-transport properties of electrons with energy higher and lower than the Fermi energy E_F are substantially different. For example, in a n-type semiconductor, where the energy of conduction electrons is higher than E_F, the direction of the spin transport is along the movement of the electrons. In contrast, in a p-type semiconductor, in which the energy of conduction electrons is lower than E_F, the spin transport is in the opposite direction along the movement of the holes. Such significant difference of the spin-transport for electrons of different energies could be understood from the different energy distributions of the spin-polarized and spin-unpolarized electrons in an equilibrium.