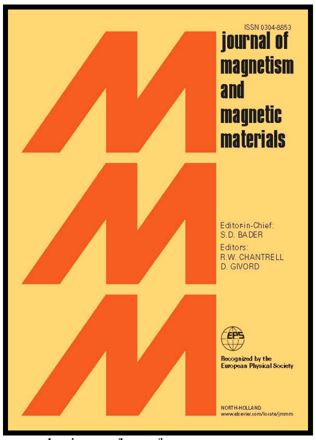

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Inhomogeneous Rashba spin-orbit coupling and intrinsic spin-Hall effect

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Abstract

The spin-Hall effect is the generation of a transverse spin-current induced by a longitudinal electric field. Among the various scattering mechanisms which can induce a finite spin-Hall effect we focus on the intrinsic contribution arising from a Rashba-type spin-orbit coupling (RSO) which for couplings linear in momentum usually vanishes. Here we show that non-homogeneity in the spin-orbit coupling arising from structure inversion asymmetry gives rise to a finite spin-Hall effect which we exemplify for a system with striped Rashba spin-orbit coupling.

Keywords: spin Hall effect, Rashba spin-orbit coupling, inhomogeneity

1. Introduction

The spin-Hall effect (SHe) has been proposed by Dyakonov and Perel [1] in 1971 and corresponds to the generation of a transverse spin current via an applied longitudinal electric field (for an overview see e.g. [2, 3]. It is at the heart of emerging magnonics [4] because it allows for the conversion of conventional electric currents into spin currents and vice versa. The physical mechanism of the SHe is closely related to the anomalous Hall effect [5] and goes back to Mott [6] who has discussed the asymmetric scattering of spin carrying particles by a central potential caused by the spin-orbit interaction. This spin-dependent interaction is nowadays known as 'skew scattering' which is one of the two 'extrinsic mechanisms' discussed in the context of the impurity induced SHe. The other is the so-called 'side jump' effect which goes back to a related work by Smit [7], again in the context of the anomalous Hall effect. Formally, the side-jump contribution arises because the spin-orbit interaction gives an additional contribution to the velocity operator which upon integration over time yields an additional 'side jump displacement' proportional to the transferred momentum. The identification of skew scattering and/or side jump in an experimental realization of the SHe is ambiguous [8]. Moreover, it has been pointed out by Sushkov [9] that the side jump effect is proportional to $1/Z^2$ where Z is the atomic mass number (cf. also Ref. [10]).

Here we are concerned with the 'intrinsic' contribution to the SHe which only relies on the spin-dependent bandstructure of the material, caused e.g. by the combination of the confining potential in a two-dimensional electron gas (2DEG) and the atomic spin-orbit coupling (SOC). In particular, Bychkov and Rashba[11] have proposed that the lack of inversion symmetry along the direction perpendicular to the gas plane leads to a momentum-dependent spin splitting usually described by the so-called Rashba Hamiltonian

$$H = \frac{p^2}{2m} + \alpha \boldsymbol{\sigma} \times \mathbf{z} \cdot \mathbf{p}, \tag{1}$$

where $\mathbf{p}$ is the momentum operator for the motion along the 2DEG plane, say the xy plane, and $\mathbf{z}$ is a unit vector perpendicular to it. $\boldsymbol{\sigma} = (\sigma^x, \sigma^y, \sigma^z)$ is a vector of the standard Pauli matrices and α a coupling constant whose strength depends both on the spin-orbit coupling of the material and of the field responsible for the parity breaking. Whereas the Hamiltonian (1) has been extensively used in the study of the 2DEG in semiconducting systems, recently it has been applied also to interface states between different metals[12] and between two insulating oxides[13]. In the latter systems higher mobilities, carrier concentration and SOC strengths have led to the expectation of observing stronger SOC-induced effects. Moreover, it has been proposed that the Rashba SOC may provide an intrinsic mechanism for phase separation [14, 15] and(or) long wave-length charge-density wave instabilities [16] in these systems. The Rashba SOC in Eq. (1) induces the formation of two

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