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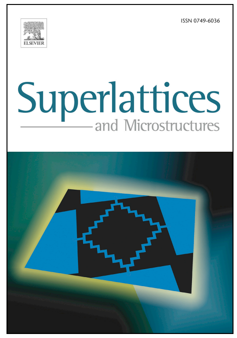

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Magnetization in pristine graphene with Zeeman splitting and variable spin-orbit coupling

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Abstract

The aim of this work is to describe the spin magnetization of graphene with Rashba spin-orbit coupling and Zeeman effect. It is shown that the magnetization depends critically on the spin-orbit coupling λ that is controlled with an external electric field. In turn, by manipulating the density of charge carriers, it is shown that spin up and down Landau levels mix introducing jumps in the spin magnetization. Two magnetic oscillations phases are described that can be tunable through the applied external fields. The maximum and minimum of the oscillations can be alternated by taking into account how the energy levels are filled when the Rashba-spin-orbit coupling is turned on. The results obtained are of importance to design superlattices with variable spin-orbit coupling with different configurations in which spin oscillations and spin filters can be developed.

1 Introduction

Graphene, a one-atom-thick allotrope, has become one of the most significant topics in solid state physics due to its two-dimensional structure as well as from its unique electronic properties ([1],[2],[3], [4], [5]). The carbon atoms form a honey-comb lattice made of two interpenetrating triangular sublattices, A and B that create specific electronic band structure at the Fermi level: electrons move with a constant velocity about $c/300$. In turn, the electronic properties are dictated by the π and π' bands that form conical valleys touching at the two independent high symmetry points at the corner of the Brillouin zone, the so called valley pseudospin [8]. In the absence of defects, electrons near these symmetry points behave as massless relativistic Dirac fermions with an effective Dirac-Weyl Hamiltonian [4] which allows to consider graphene as a solid-state toy for relativistic quantum mechanics. When the interaction between the orbital electron motion and spin degrees of freedom is taken into account, the spin-orbit coupling (SOC) induces a gap in the spectrum. SOC is the most important interaction affecting electronic spin transport in nonmagnetic materials. The use of graphene in spintronics ([9] and [10]) would require detailed knowledge of graphene's spin-orbit coupling effects, as well as discovering ways of increasing and controlling them. The SOC in graphene consists of intrinsic and extrinsic components ([11] and [12]). The intrinsic component of SOC is weak in the graphene sheet, although considerable magnitudes can be obtained in nanoscaled graphene ([13] and [14]). The extrinsic component, known as the Rashba spin-orbit coupling (RSOC) [15] can be larger than the intrinsic component [16]. The RSOC may be controlled by the application of external electric fields ([17] and [18]). On the other side, when a magnetic field is applied perpendicular to the graphene sheet, a discretization of the energy levels is obtained, the so called Landau levels [19]. These quantized energy levels still appear also for relativistic electrons, just their dependence on field and quantization

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