Weak (anti-)localization effect in GaAs/AlGaAs heterostructures with coexisting Rashba and Dresselhaus spin-orbit interactions

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In III-V semiconductor heterostructures, two spin-orbit interactions (SOIs) are present: one is Rashba SOI (α) which originates from broken inversion symmetry in quantum wells, the other is Dresselhaus SOI (β) due to bulk inversion asymmetry of the crystals. Determination of both α and β in the system with coexisting Rashba and Dresselhaus SOIs has been investigated by optical and transport means. While the optical method enables us to evaluate both α and β values, spin polarized electrons should be generated by laser excitation which limits the accessible materials. For a transport method [1], it has required stretchable persistent spin helix (PSH) regime which is difficult to achieve.

Here we propose the universal method for evaluating SOI parameters without requiring stretchable PSH regime. This method employs both weak anti-localization fitting based on Weigele model [1] in a Hall bar and anisotropic weak localization in a wire structure [2]. Weigele model is effective near PSH regime and enables us to determine $|\alpha\text{-}\beta|$. On the other hand, anisotropic weak localization is a fitting-free determination of α/β ratio in a wire structure. By employing two methods, we can principally determine both Rashba and Dresselhaus parameters.

In the experiment, we used GaAs/AlGaAs-based III-V semiconductor heterostructures and fabricated the Hall bar and the wire structures (wire width is 800nm). In the Hall bar structure, we observed weak anti-localization in all range of carrier density (Fig. 1(a)), then we fit the data based on Weigele model and extract $|\alpha\text{-}\beta|$. On the other hand, in the wire structure with [010] direction, we measure the amplitude of weak localization with rotating in-plane magnetic field direction (Fig. 1(b)). In this wire orientation, the effective fields induced by Rashba and Dresselhaus are perpendicular to each other, which enables us to evaluate α/β ratio by weak localization anisotropy. We observe the modulation of weak localization amplitude and from which we extract the ratio of α/β without any fitting.

[1] P. J. Weigele *et al.*, Physical Review B **101**, 035114(2020).
[2] A. Sasaki *et al.*, Nature Nanotechnology **9**, 703–709 (2014).

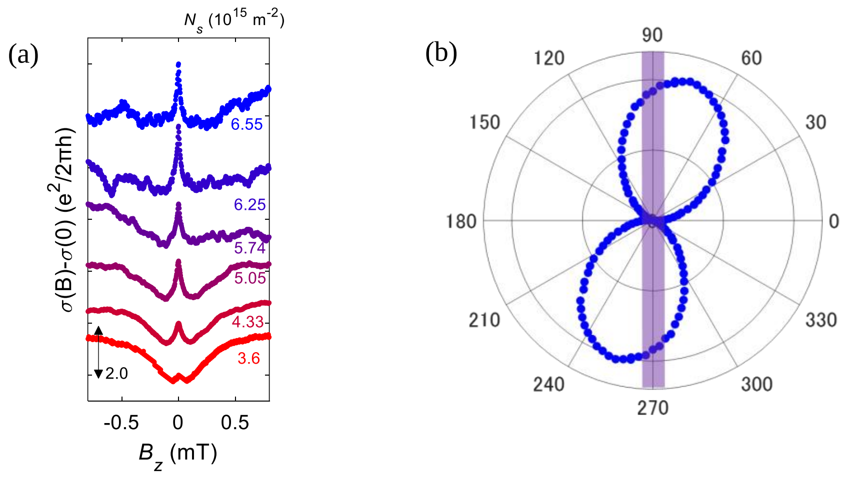

Fig.1. (a) Carrier density dependence of weak anti-localization in the Hall bar. (b) Polar plot of weak localization amplitude with different angle of in-plane magnetic field in [010] wire, B_{in}=2(T).