Comment on "Observation of Spin Precession in GaAs Inversion Layers Using Antilocalization"

The spin splitting of the Γ_1-like conduction band in (001) GaAs quantum wells under zero magnetic field has been recently detected by transport [1] and spectroscopic measurements [2,3]. The measured quantity is a weighted average of the spin splitting along different $\mathbf{k}$ directions in the well plane. The interpretation requires a precise knowledge of the spin splitting dependence on the in-plane wave vector $\mathbf{k} = (k_x, k_y, k_z)$. There is some controversy about the correct way to determine this dependence for a two-dimensional system. Two approaches have been used, both based on the $\mathbf{k} \cdot \mathbf{p}$ approximation for the corresponding spin splitting ΔE_c in bulk GaAs, given by Eq. (1) of Ref. [3]. The approach followed by Dresselhaus, Papavassilious, and Wheeler [1] consisted in making $k_z^2 = 0$ in the $\mathbf{k} \cdot \mathbf{p}$ approximation for the bulk. The authors make the argument that "because there is a standing wave in the confinement (z-axis) direction, there is no moving reference frame which will transform an electric field in a magnetic field" [1]. The splitting in this case is given simply by $\Delta E_c = 2\gamma k k_x k_y$, where γ is a material dependent parameter. In the second approach [2–4], the quantization in the z direction is taken into account by making $k_z^2 = \pi/d_{\text{eff}}$, where d_{eff} is the effective width of the quantum well [2–4].

In order to solve this controversy, we calculate the band structure of GaAs/AlAs superlattices along the (001) direction using the empirical tight-binding method with a sp^3s^* basis [5] including spin orbit coupling [6]. The solid symbols in Fig. 1 reproduce the spin splitting of the lowest conduction band in the (110) and (100) directions in structures with 14 (diamonds), 20 (triangles), and 30 (squares) GaAs monolayers per period (one monolayer $= a/2 = 5.64$ Å). The AlAs layers have a fixed thickness of 20 monolayers. The open squares show the calculated splitting in bulk GaAs. The linearity near $\mathbf{k} = 0$, the finite splitting in the (100) direction, and the nonmonotonicity of the curves in the (110) directions are in contradiction with the predictions of the approach of Ref. [1], indicating its inadequacy. To verify the second approach, ΔE_c was calculated (see solid lines) from Eq. (2) of Ref. [3] using $d_{\text{eff}} = d_{\text{GaAs}} + 2\delta$, where d_{GaAs} is the GaAs well thickness and $\delta = 7$ Å takes into account the wave function penetration in the AlAs barrier. The parameter $2\gamma = 17.8$ eV Å^3 was chosen so as to reproduce the spin splitting in bulk GaAs (dashed line). The spin splittings for large well widths are reasonably well reproduced, indicating the correctness of the second approach. The solution of the puzzle posed by Fig. 3 of [1] may lie in the fact that d_{eff} decreases with increasing carrier density.

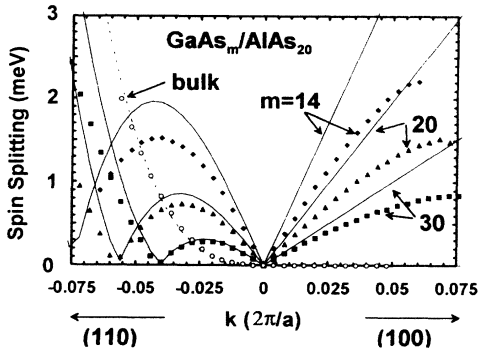

FIG. 1. Spin splitting of the lowest conduction band in bulk GaAs (open circles) and in (001) GaAs$_m$/AlAs$_n$ superlattices with $n = 20$ AlAs monolayers and different number of GaAs monolayers (m) per period. The lines are the $\mathbf{k} \cdot \mathbf{p}$ approximation of the spin splittings (see text for details).

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