Bulk Inversion Asymmetry Spin-splitting in L-valley GaSb Quantum Wells

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Abstract. Very large spin-orbit, or zero-field, spin splittings are predicted for thin GaSb/AlSb symmetric quantum wells (QWs) with the absolute conduction minimum deriving from the L point of the bulk Brillouin zone. The electronic structure calculations performed with an improved tight-binding model and reproduced by a 4x4 kp effective Hamiltonian, including valley mixing and k-linear spin splittings derived from the GaSb bulk, are briefly described and specific results for [100] QWs with large splittings and valley mixing are shown which provide direct insight into L-valley III-V nanostructures.

INTRODUCTION

A promising route to spintronics is based on non-magnetic semiconductor nanostructures and spin-dependent properties originating from the spin-orbit interaction [1]. Zero-field, or spin-orbit splittings play the crucial role in phenomena like the precession of the electron spin in an applied electric field, spin resonance spectroscopy, antilocalization, and oscillatory magneto-transport [2].

Most studies however have been focused on states near the center of the Brillouin zone. Close to the Γ_{6c} conduction band minimum, the spin splitting induced by bulk inversion asymmetry is of third order in the Cartesian components of the wave vector k [3]. In heterostructures, additional k-linear contributions may originate from mesoscopic inversion asymmetry [4] and from microscopic interface asymmetry [5].

At the L point on the other hand, the spin splitting is forbidden along the [111] direction of the valley axis, while k-linear splittings are expected, on the basis of double-group symmetry considerations, for wave vectors transverse to [111]. The effective bulk Hamiltonian of the conduction band near the L minimum can in fact be written as

$$H = \frac{\hbar\ k_l^2}{2m_l} + \frac{\hbar^2 k_t^2}{2m_t} + \alpha(\vec{k} \times \vec{\sigma}) \cdot \hat{n} \qquad (1)$$

where k_l and k_t are the longitudinal and transverse wave vectors with respect to the L-valley, m_l and m_t the band masses along these directions, σ the vector of the Pauli matrices, n // [111] and α a material dependent parameter for the k-linear term. Note that this term is of the Rashba form but refer to a bulk inversion asymmetry contribution as the Dresselhaus one.

In [100] GaSb/AlSb quantum wells with GaSb layers with less than 15 monolayers (~4.5 nm), the lowest confined conduction subbands derive from the GaSb L-valleys, which have $m_t = 0.087$, $m_l = 1.3$ and $\alpha = 0.84$ eVA. The four-fold L-valley degeneracy of the bulk is broken whenever the valley axes are orientated differently with respect to the growth direction. On top, the broken translation symmetry along the growth direction also leads to valley mixing. For [111] QWs, for example, the longitudinal valley (along [111]) is split from the other three; while for [100] QWs there is a strong valley mixing within each of the two pairs of coupled valleys.

We have performed tight-binding (TB) calculations within an $sp^3d^5s^*$ nearest neighbor model

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including the spin-orbit coupling [6]. It is a 40-band model which adequately reproduces the measured band edge effective masses, interband transition energies and the cubic Dresselhaus spin-orbit splitting around Γ. The existence of large spin splittings in L-valley GaSb nanostructures is demonstrated.

RESULTS

Figure 1 shows, for example, the obtained spin-orbit split lowest L-subbands in [100] GaSb QWs with 9 and 10 monolayers. Energies are measured from the GaSb bulk L_{6c} band edge and wave-vectors from the 2D L-point. The dashed lines give the kp modeling which includes the anisotropy due to the misalignment between the growth and valley axis, treats the spin-orbit k-linear term in first-order perturbation theory and includes the valley mixing with two phenomenological parameters chosen to best fit the TB results. The details of this minimal effective Hamiltonian compatible with the QW symmetry will be published elsewhere with further results.

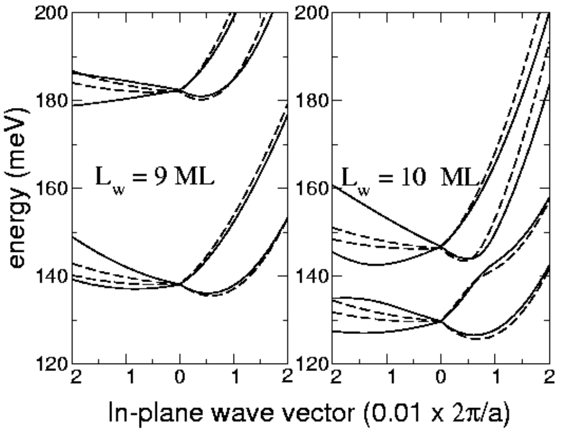

FIGURE 1. In-plane dispersion of the lowest L-conduction subbands, for $(GaSb)_9$ / $(AlSb)_{20}$ (left panel) and $(GaSb)_{10}$ / $(AlSb)_{20}$ (right panel) as a function of k along the directions [1-10] (to the right) and [110] (to the left). Solid lines give the TB calculation and dashed ones the kp modeling, a is the lattice parameter.

Besides the large splittings obtained, well exceeding 10 meV, in Fig. 1, we also note that the L-valley mixing in these QW structures is large and highly sensitive on whether it is a QW with even or odd number of monolayers. The spin splittings instead do not depend much on the well width. The deviations of the kp model seen for k along [110] represent the maximum deviation, which is limited however to a narrow range of directions. For all the other directions the agreement obtained between the TB and kp calculations is very good.

CONCLUSION

In conclusion, we have demonstrated that large spin splittings can be realized in symmetric GaSb/AlSb L-valley QWs. By a careful combination with asymmetries of the confining potential or by external electric field gating, additional freedom for the control of the spin properties of the electronic bands can be achieved. The large zero-field spin splittings of L valley heterostructures point to a new direction for future work on spin electronics.

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