The effect of magnetic field on edge states in InN/GaN quantum wells

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It has been recently demonstrated that, under specific conditions, the band structure of InN/GaN quantum wells (QW) may be inverted, resulting in the transition to the so-called topological insulator (TI) state in which, apart from the energy gap in the bulk material there is a continuum of states localized on the edge of the system with energies closing the energy gap.[1] These states give rise to the counter propagating helical channels leading to the so called quantum spin Hall (QSH) effect. In this respect InN/GaN QWs provide a novel example of yet another 2D TI system which may be compared to the existing structures such as HgTe/CdTe and InAs/GaSb QWs realized so far. [2] The band structure inversion in narrow InN/GaN QWs grown along (0001) crystallographic direction is caused mostly by the extremely large built-in electric field originating from piezoelectric effect and spontaneous polarization but also, by the specific band structure of these materials related to their wurtzite structure symmetry. So, although the InN/GaN is a direct gap (type I) quantum well, the wave functions in the conduction and valence band are quite well spatially separated in this structure and therefore one should expect some analogy to the type II broken-gap InAs/GaSb QWs. The topological insulator state is protected by the time reversal symmetry, but it turns out that the helical edge states may persist even at strong magnetic field, as it was demonstrated for the case of HgTe quantum wells. [3] The situation is slightly different in type II broken-gap quantum wells, in which the crossing of Landau levels at some rather low critical value of the magnetic field closes the bulk gap and opens the way for the bulk conduction.

In the present paper we consider the edge states in the infinite stripe geometry of InN/GaN QWs in the magnetic field perpendicular to the stripe plane. Our effective 6x6, two-dimensional Hamiltonian obtained from the full eight-band k.p model incorporates one conduction, one heavy hole and one light hole QW subbands in the vicinity of the energy gap. The magnetic field is accounted for by using the Peierls substitution and by solving the resulting finite difference eigen-problem for a 1000 nm wide stripe of a 14 nm wide QW layer for a range of magnetic fields from B=0 T to B=15 T. In this structure the negative (inverted) energy gap of about 4 meV occurs between the heavy hole and light hole levels at B=0 T. It is observed that the first crossing of the Landau levels originating from the heavy and light-hole bands closes the bulk band gap at about B=6 T. Up to this magnetic field, the dispersion and spin polarization of helical edge states are not very sensitive to the increasing magnetic field. Even after the crossing, up to B=15 T, both edge channels exist, although with much lower degree of spin polarization. One may therefore conclude, that despite the spatial separation of the conduction and valence band states the TI InN/GaN QWs is similar to HgTe system in that the helical edge states are quite robust against the external magnetic field

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