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Carrier mobility and band structure within the bulk of a III/V topological insulator candidate

C.S. Knox^{1,2}, L.H. Li^{2}, M.C. Rosamond^{2}, E.H. Linfield^{2}, C.H. Marrows^{1}

UNIVERSITY OF LEEDS

1. School of Physics and Astronomy, University of Leeds, LS2 9JT, UK. 2. School of Electronic and Electrical Engineering, University of Leeds, LS2 9JT, UK.

Introduction:

- Within InAs/GaSb coupled quantum wells, tunnelling between the two wells creates a so-called "inverted" bandstructure, shown in Fig. 1 as solid lines.
- The gap created by this hybridisation is so radically different to the vacuum that there must be a transition at the edge of the material, characterised by helical, gap closing modes (Shown in Figs 1 and 2), protected against disorder by the topology of the system. [1]
- However, scattering reduces tunnelling probability, destroying the inverted bandstructure, leading to some trivial mid-gap states that mask the interesting edge modes, shown in Fig. 1 as dotted lines

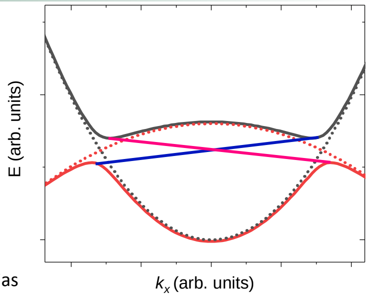


Fig. 1: "Inverted" bandstructure of an InAs /GaSb coupled quantum well. The electron-like states are shown in black, whereas the hole-like states are shown in red. The topologically protected edge modes are shown in blue and pink.

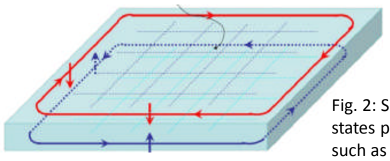


Fig. 2: Schematic of the helical, spin filtered edge states present within a 2D Topological insulator such as InAs/GaSb. From [1]

- Therefore, a detailed study of the scattering within this interesting material is of experimental interest. Particularly interesting is how an applied gate bias changes the scattering within the system.

Effects of a Gate Bias on Carrier Mobility

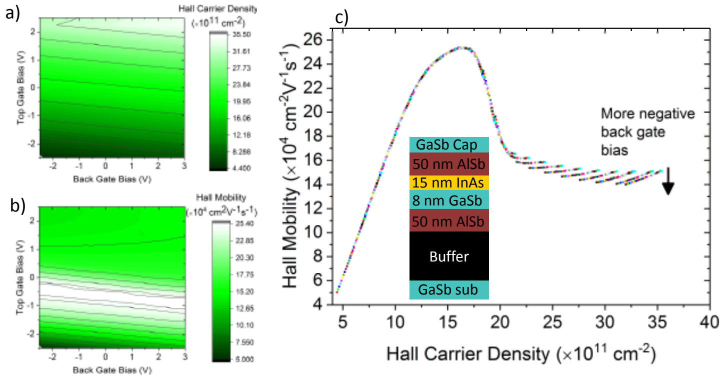


Fig. 3 a) Carrier density within an InAs /GaSb coupled quantum well, grown by MBE, as a function of top and back gate bias. b) Hall mobility within the same well over the same range of gate biases as a). c) The data in b) plotted as a function of Hall carrier density. The inset shows the quantum well stack structure. In all cases, data was taken between ±0.2 T applied, out of plane, magnetic fields at 1.5 K.

Multiple Anticrossings and Delayed Subband Occupation

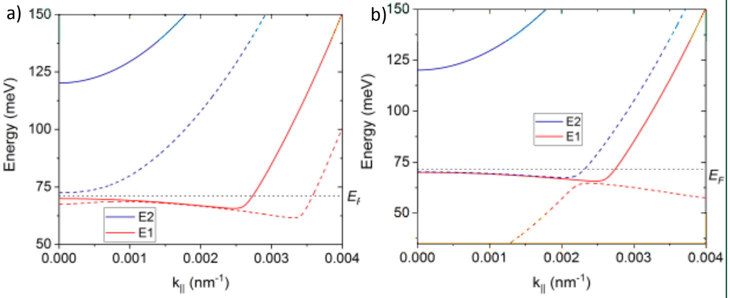


Fig. 5 Schematic dispersions of the first (red) and second (blue) electron-like subbands within a hybridised InAs/GaSb quantum well in the absence of an applied gate bias (solid lines) and shifted down by an applied gate bias (dashed lines). In a) the dispersions have been shifted down by 50 meV, whereas in b) the dispersions have been shifted down by 100 meV [3]. These dispersions were arrived at by diagonalising a 3 band Hamiltonian, including the highest energy hole subband and two electron-like subbands. These bands are assumed to be parabolic, and the coupling between the electron and hole subbands is assumed to be independent of k.

In a) the second electron like subband (E2) should touch the first (E1), but instead a new anticrossing gap opens. This will prevent the second electron-like subband (E2) from being occupied until an even greater bias is applied, as in b).

Selective Screening of Low Angle Scattering Events

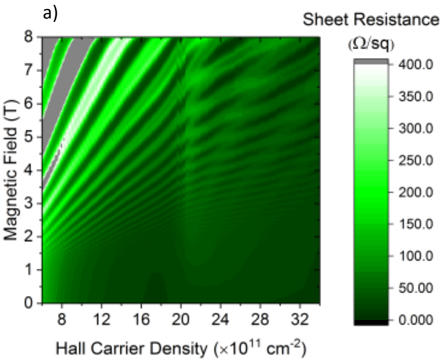
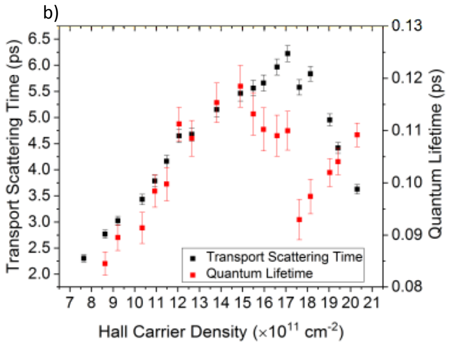


Fig. 4 a) SdH oscillations as a function of Carrier density within the same InAs/GaSb coupled quantum well as in Fig. 3 at 1.5 K. Note the change in envelope function at a carrier density of (21.7±0.2)×10^{11} cm^{-2}, indicating that two subbands are present.



b) Scattering timescales in an InAs/GaSb quantum well as a function of Hall carrier density. By analysing the temperature dependent amplitudes of SdH oscillations, the quantum lifetime (a sum over all scattering events) can be deconvoluted from the classical Drude scattering time (weighted towards large angle scattering).

The fact that the quantum lifetime rises as the transport scattering time falls indicates that low angle scattering events are selectively screened against [2].

Conclusions

- Contrary to previous assumptions [4], we have shown that a back gate bias acting on the GaSb layer has a distinct effect on the transport when compared to a top gate acting on the InAs layer at all carrier densities.
- Additionally, anticrossing between the second excited electron subband and the highest heavy hole subband results in the population of that subband being delayed until a higher carrier density is reached.
- The states at the bottom of the hybridised, second electron-like subband will follow a hole dispersion relation, resulting in their low mobility, so they do not appear in the SdH oscillations in Fig. 4 a), but their screening is visible in the change in quantum lifetime in 4b) [2].
- The proportion of these states within this new, hybridised subband with a hole like dispersion could be controlled by shifting the energies of the GaSb layer with a back gate, resulting in the behaviour seen at high carrier densities in Fig. 3c).

References

[1]:B. A. Bernevig and S. C. Zhang. "Quantum spin hall effect". In: *Physical Review Letters* **96**.10 (2006), p. 106802.
[2]:G. Q. Hai et al. "Intersubband-coupling and screening effects on the electron transport in a quasi-two-dimensional δ-doped semiconductor system". In: *Journal of Applied Physics* 80.10 (1996), pp. 5809–5814.
[3]:I. Lapushkin et al. "A self-consistent investigation of the semimetal-semiconductor transition in InAs/GaSb quantum wells under external electric fields". In: *Journal of Physics-Condensed Matter* **16**.26 (2004), pp. 4677–4684.
[4]: I. Knez, R. R. Du and G. Sullivan. "Finite conductivity in mesoscopic Hall bars of inverted InAs/GaSb quantum wells". In: *Physical Review B* **81**.20 (2010), p. 201301.