Spin Orbit Coupling in a III/V coupled quantum well 2D Topological Insulator candidate

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Introduction:

- Within 2D topological insulators, such as InAs/GaSb coupled quantum wells, transport is dominated by spin filtered edge modes, polarised out of the device plane.
- Spin orbit coupling (SOC) can disrupt that polarisation, altering the channels to have a k-dependent polarisation, termed generic helical edge modes [1].

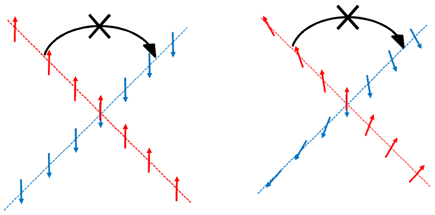

Fig. 1: Dispersion relation for the perfect helical edge states (left) and the Generic Helical edge states (right). Note that in both cases, elastic backscattering is forbidden as such an event would require a 180° spin-flip. A forbidden elastic backscattering event is marked by a black arrow [1].

- Internal potential gradients, arising from spatial asymmetries, are seen by current carrying electrons as magnetic fields, resulting in SOC.
- We investigate 2 sources of SOC within 2 similar InAs/GaSb coupled wells; Rashba SOC, where the asymmetry is caused by an asymmetric stack structure, and Dresselhaus SOC, where the asymmetry is present in the Zinc Blende crystal structure [2].

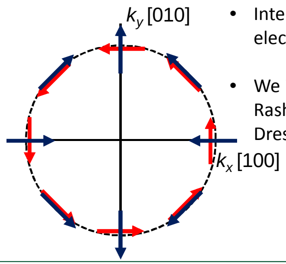

Fig. 2: Schematic of the 2D Fermi-surface, showing the relative orientations of the Rashba (red arrows) and Dresselhaus (blue arrows) SOC in a quantum well grown along the [001] axis [2]

Probing SOC through SdH Oscillations

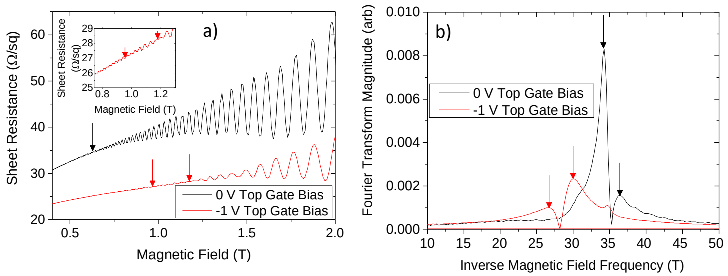

Fig. 3 a) Shubnikov- de Haas oscillations in an InAs/GaSb coupled quantum well at two different gate biases along the [010] axis. These oscillations show a clear beating pattern, highlighted in the inset for the case of -1 V gate bias, indicative of 2 separate carrier concentrations.

3 b) Discrete Fourier transform of oscillations in 3 a), showing 2 separate frequencies, the sum of which is equal to the Hall carrier density at both biases. The higher carrier concentration, n^+, (corresponding to the higher frequency) is taken to be aligned to the SOC spin splitting field within the material [3].

From [3]: $$SOC_{total} = \frac{(n^+ - n^-).\hbar^2}{m^*}.\sqrt{\frac{\pi}{2(n^+ + n^-) - 2(n^+ - n^-)}}$$

Spin Orbit Coupling: Single Carrier Case

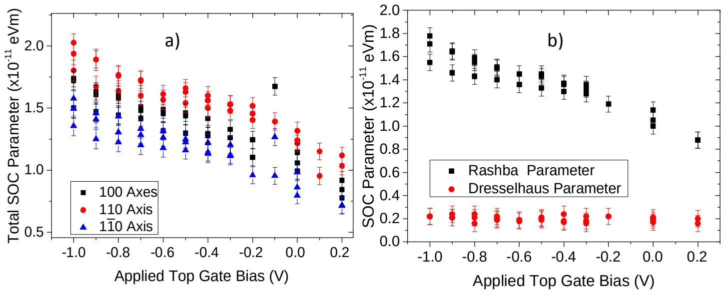

Fig. 4 a) SOC measured along 3 separate axes at a range of gate biases.

4 b) Fit of 4 a) to extract the relative strengths of the Rashba and Dresselhaus SOCs [2]. We find that the Rashba parameter contains all the gate dependence of the SOC, as expected.

From [2]: $$SOC_{total} = \sqrt{SOC_{Ras}{}^2 + SOC_{Dress}{}^2 + 2.SOC_{Ras}.SOC_{Dress}.\cos 2\theta}$$

Spin Orbit Coupling: Double Carrier Case

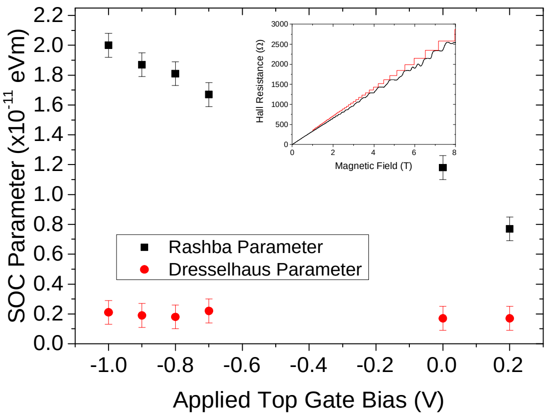

Fig.5: Relative strengths of the Rashba and Dresselhaus SOCs in a wafer in which the hole gas, localised within the GaSb layer, plays a significant part in the transport [2].

Inset, the 0 V Top gate bias quantum Hall plateaux, with the 0 K ideal plateaux in red. Note the slight bending of the low field (<1 T) Hall resistance, indicative of 2 carrier species [4].

Conclusions

- The SOC within InAs/GaSb is dominated by Rashba SOC, which is tuneable by an applied top gate bias, and by small changes in growth conditions, as the wafer in which the GaSb well plays a significant part in the 0 bias transport is found to have an elevated Rashba parameter.
- On the other hand, the Dresselhaus SOC is robust against small changes in growth conditions and top gate bias, having a value of (0.20±0.08)x10^{-11} eVm across all measured wafers and bias conditions.
- We note that the Rashba SOC increases as a more negative top gate bias is applied. We reason that, as a more negative top gate bias is applied, the carrier density within the InAs layer will be forced into closer contact with the GaSb quantum well underneath. This will create a steeper internal gradient, resulting in a higher Rashba parameter
- We also note that we have not studied the SOC close to the hybridisation gap, where topologically non-trivial behaviour is expected to play an important role in transport, future studies in this regime would, however, provide fascinating insights into the nature of the topological state seen in this class of material [1].

References

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