Absolute measurement of the exchange interaction in InSb quantum wells

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BACKGROUND

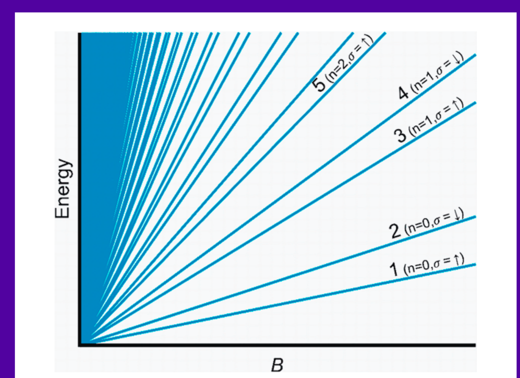
InSb is a particularly interesting material due to its extreme properties, such as:

- Small bandgap
- High room-temperature electron mobility
- Small effective mass
- Strong spin-orbit interaction
- Large Lande g-factor

Electrons within InSb quantum wells form Landau Levels - the quantization of cyclotron orbits in the presence of a magnetic field - which then become spin-split due to the Zeeman interaction. This results in Landau Levels corresponding to spin-up and spin-down states. Landau Levels can be described by the equation:

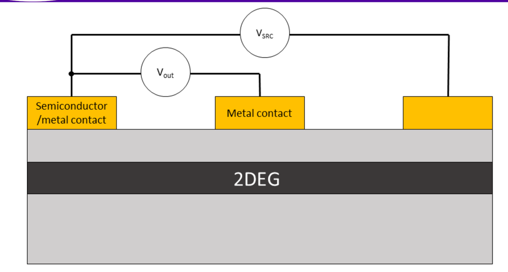
$$E = \hbar\omega_c\left(n + \frac{1}{2}\right) \pm \frac{1}{2} g^* \mu_B B$$

When we plot energy as a function of magnetic field, we can produce a 'fan plot' where spin-split Landau Levels can be seen:



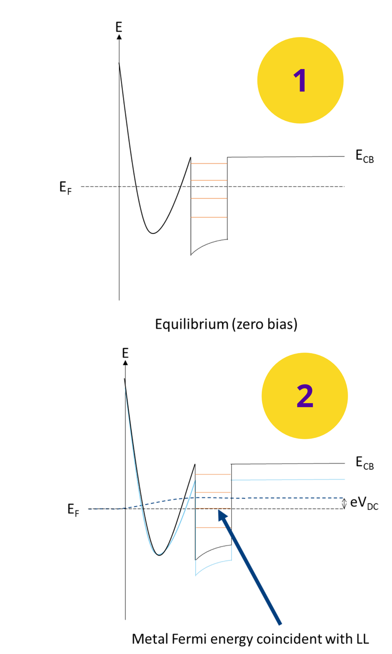
Previous work has focused on measuring Landau Levels by tunnelling through a quantum dot, but...
Can we directly measure Landau Level energies in a simple 2DEG system?

METHODS

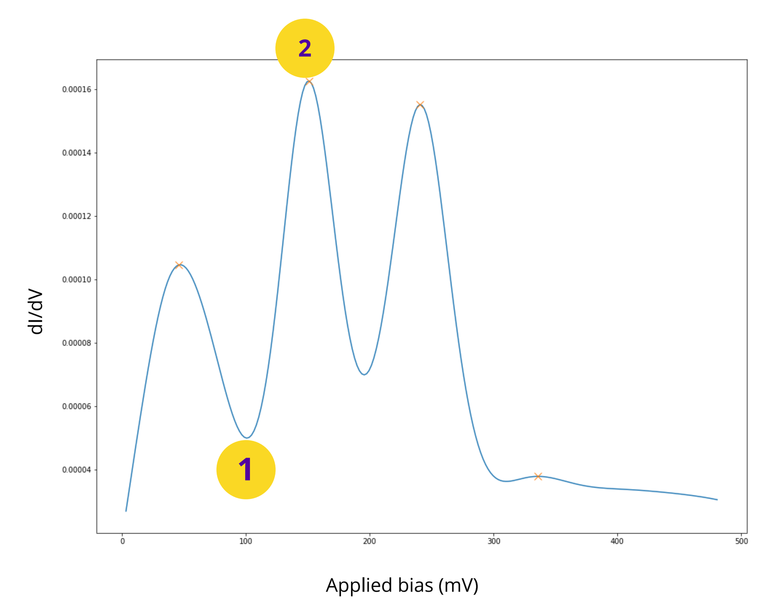


A schematic of the differential conductance measurement set-up. Three mental contacts on top of the quantum well material are used, with a current applied across two contacts and the voltage measured between a common and the final contact.

To measure the Landau level spectrum, we use a three terminal differential conductance measurement. Here, we apply a current across two contacts and measure the voltage across a common and a further contact, measuring the local gradient using a lock-in technique.



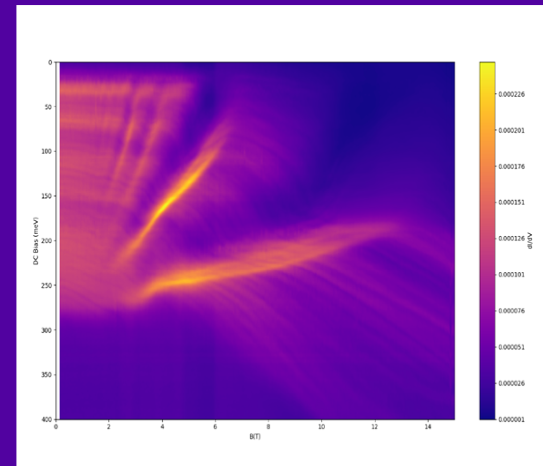
Band structure schematics showing the conduction band energy for the delta-doped quantum well, metal Fermi energy and Landau Level energies.



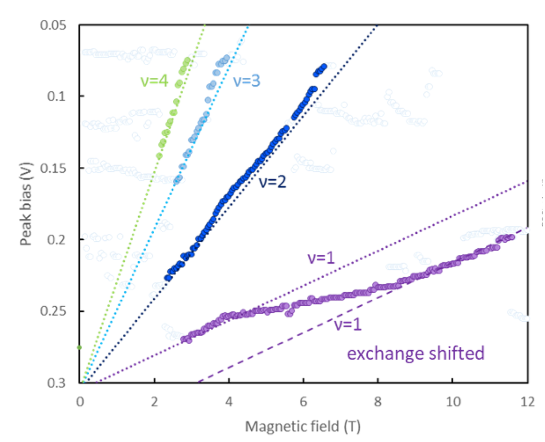
An example of a differential conductance measurement showing dI/dV peaks at various biases.

When the Landau Level energy is coincident with the Fermi energy of the metal contact, there is a sudden increase in current flow when electrons in the Landau Level have enough energy to tunnel into the contact, resulting in a dI/dV peak. dI/dV can be plotted as a heat map as a function of magnetic field and applied bias.

KEY RESULTS

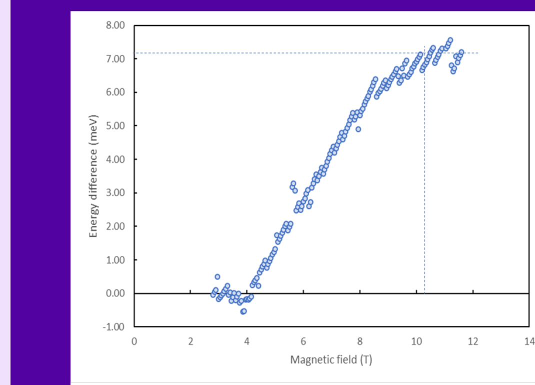


A colourmap of the field against the DC bias swept across the device, with the differential conductance indicated by the colour bar.



The extracted peak positions at each measured magnetic field value along with the spin-split Landau fan fitting results.

- The first four spin-split Landau Levels are clearly resolved on the colourmap plot, demonstrating that a resonant quantum dot level is not required
- The fit produces a g-factor of 62, with a leverage factor of 5.5 and an offset of 0.305V
- The first level starts to diverge from its initial trend around 4T and then re-aligns with the original trend and gradient at a shifted energy at higher fields



The difference between the Landau fan fit and the measured data for the first Landau level, showing a sudden divergence at around 4T which recovers and plateaus at around 10.3T.

- The onset of the decrease in energy due to the exchange interaction corresponds to the point at which the second Landau Level begins to empty
- The data plateaus as the first Landau level becomes fully polarized at around 10.3T
- From this, we can extract an exchange energy of 7.2meV

TAKE-AWAY

Rather than a persisent exchange 'enhancement', and associated g-factor increase, our results indicate an energy **shift** caused by the exchange interaction in strongly spin-orbit coupled materials.

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