NANO LETTERS

Letter

Cite This: *Nano Lett.* XXXX, XXX, XXX–XXX

pubs.acs.org/NanoLett

Split-Channel Ballistic Transport in an InSb Nanowire

Juan Carlos Estrada Saldaña,[†,∇] Yann-Michel Niquet,[§] Jean-Pierre Cleuziou,[†] Eduardo J. H. Lee,[†,○] Diana Car,[⊥] Sébastien R. Plissard,[#] Erik P. A. M. Bakkers,[⊥] and Silvano De Franceschi[*,†]

[†]University Grenoble Alpes & CEA, INAC-PHELIQS, F-38000 Grenoble, France

[§]University Grenoble Alpes & CEA, INAC-MEM, F-38000 Grenoble, France

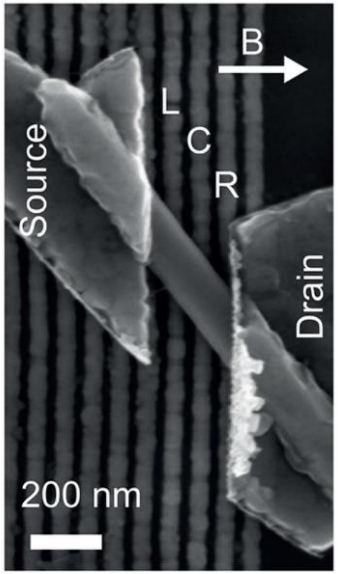
[⊥]Technische Universiteit Eindhoven, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

[#]CNRS, LAAS-CNRS, Université de Toulouse, 31400 Toulouse, France

Yemliha Bilal Kalyoncu

FAM 6 4 2018

InSb Nanowire

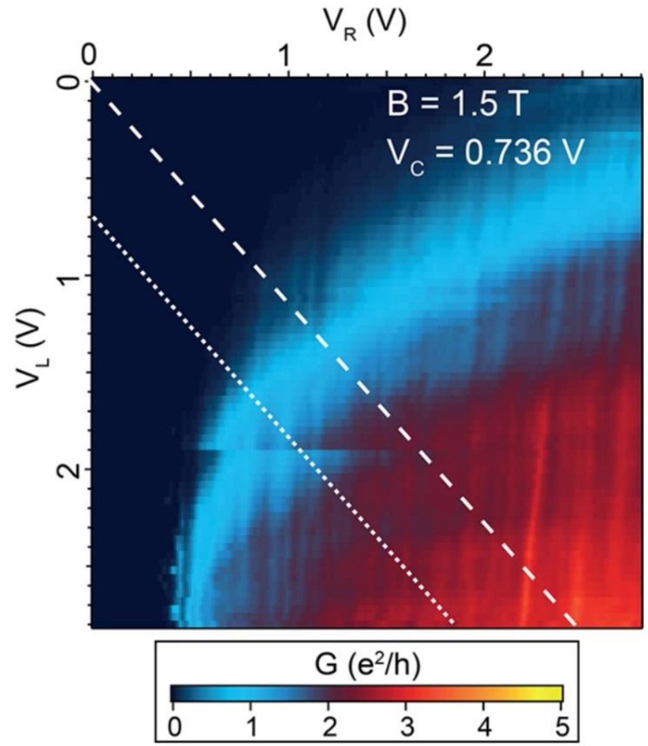


160nm diameter

10nm HfO_2

120nm Al contacts

T = 260 mK



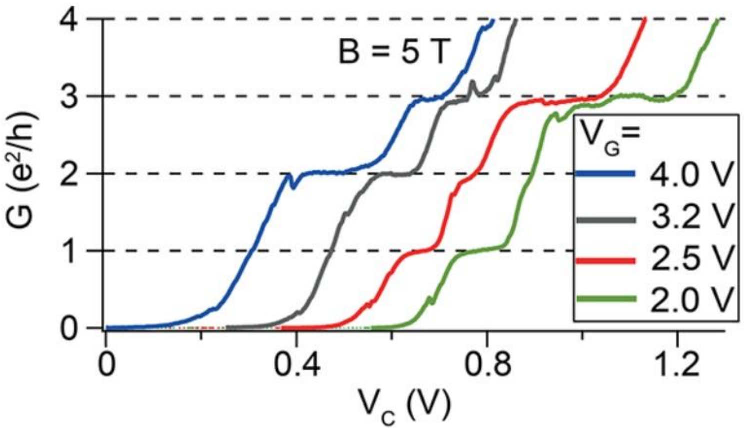
$$V_L = V_G$$

$$V_R = \alpha_{R/L}(V_L - V_{L_0})$$

$$\alpha_{R/L} = 0.875$$

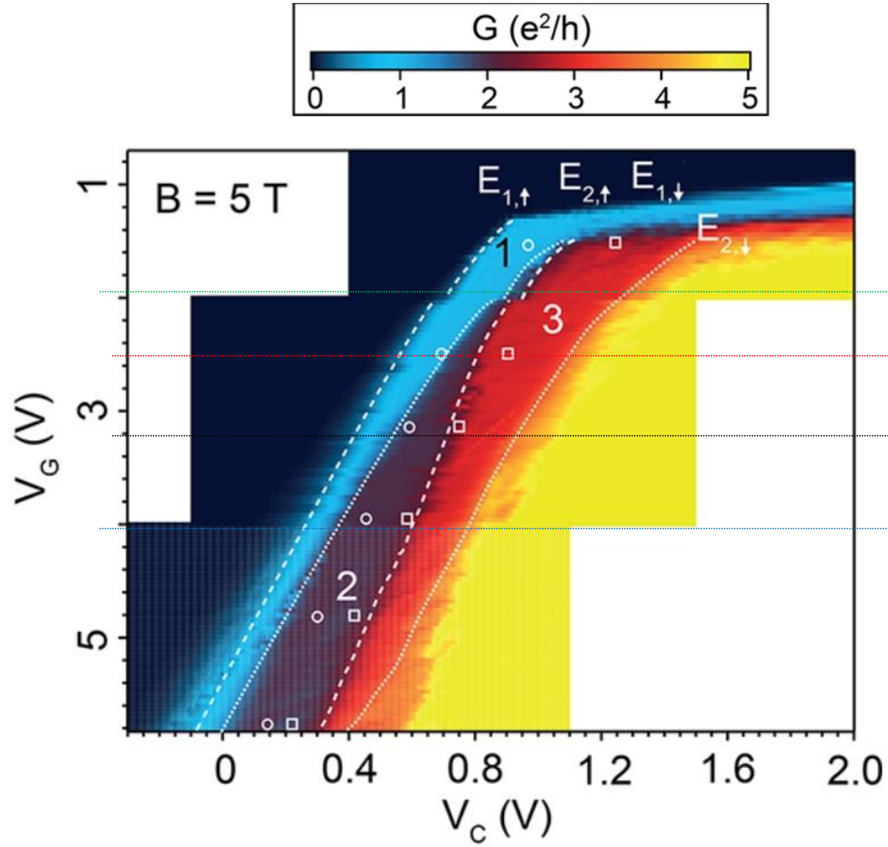
$V_{L_0} = 0.74$ V for dotted line

Quantized Conductance



Plateau width varies with V_G

@5T = fully lifted spin degeneracy



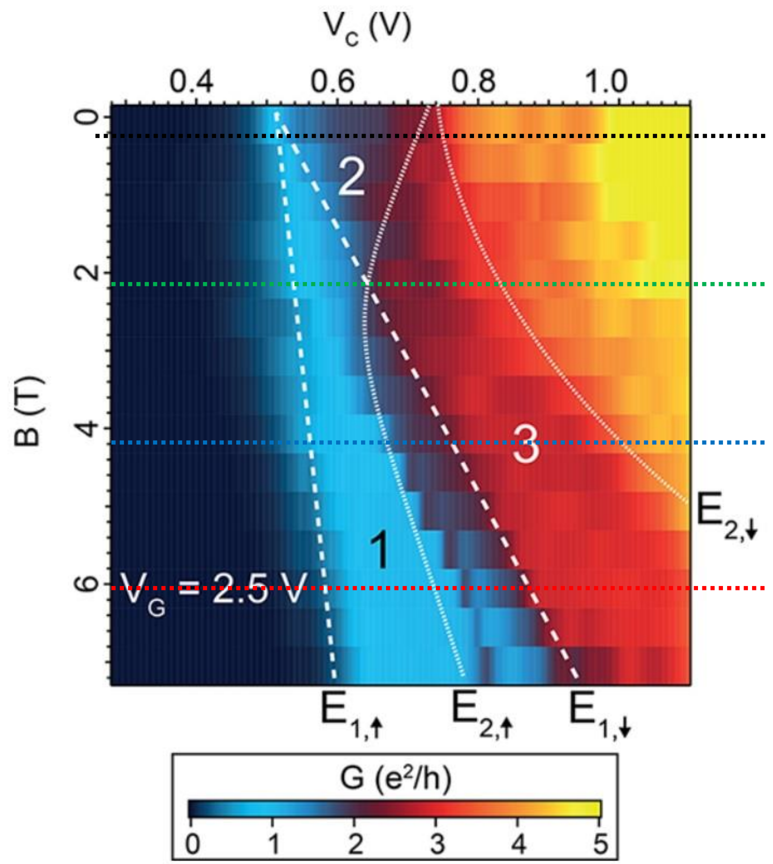
$$\Delta E = \frac{E_{2,\uparrow} + E_{2,\downarrow}}{2} - \frac{E_{1,\uparrow} + E_{1,\downarrow}}{2}$$

○ - □

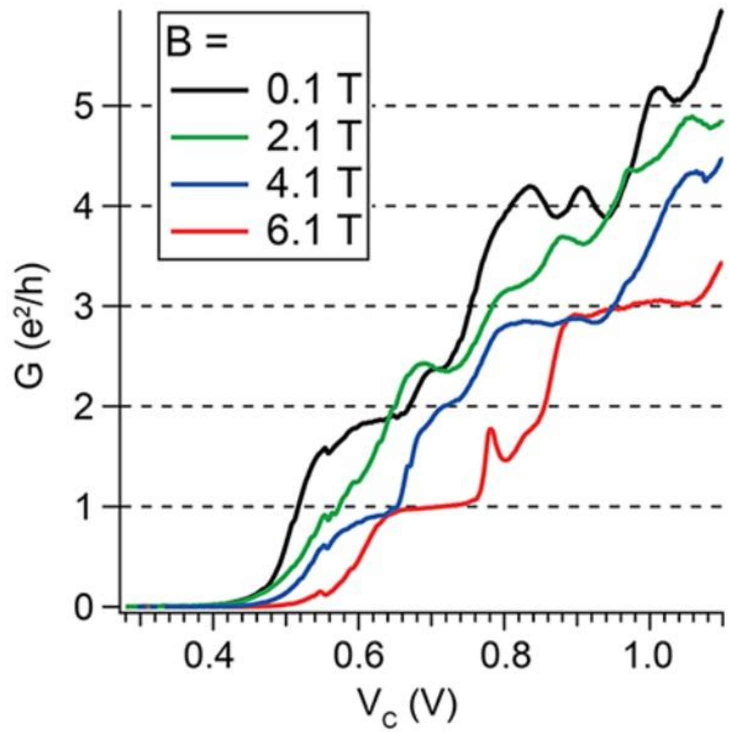
Dashed line = 1st spin-split subband
Doted line = 2nd spin-split subband

V_G (V)	α_1 (eV/V)	α_2 (eV/V)	$\lvert g_1 \rvert$	$\lvert g_2 \rvert$	ΔE (meV)
1.96	0.062 ± 0.010	0.040 ± 0.006	46 ± 7	48 ± 7	3 ± 2
2.5	0.057 ± 0.009	0.033 ± 0.006	44 ± 7	48 ± 9	11 ± 3
3.96	0.037 ± 0.008	0.029 ± 0.005	45 ± 9	44 ± 8	12.5 ± 3.5

B field Dependence



Assumptions:
B-induced orbital shifts
B-independent g-factors



Spin-split subband crossing around 2Tesla

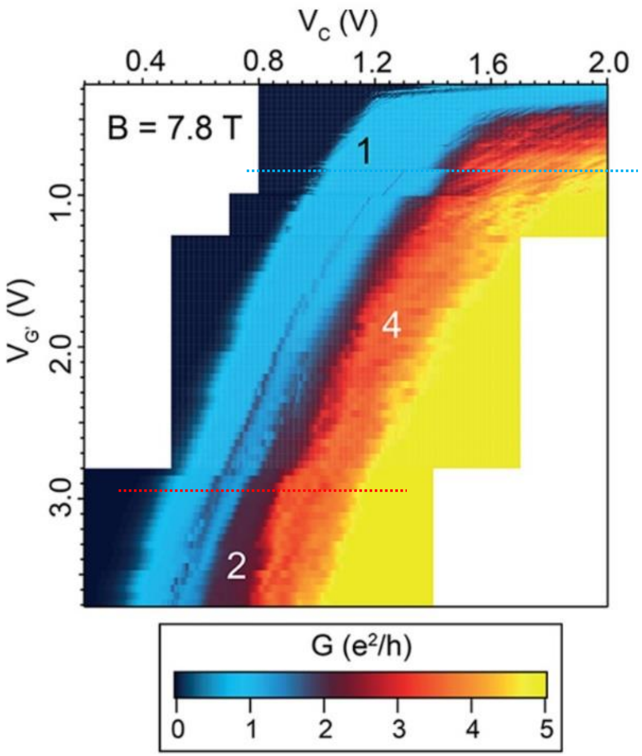
Conductance suppresion

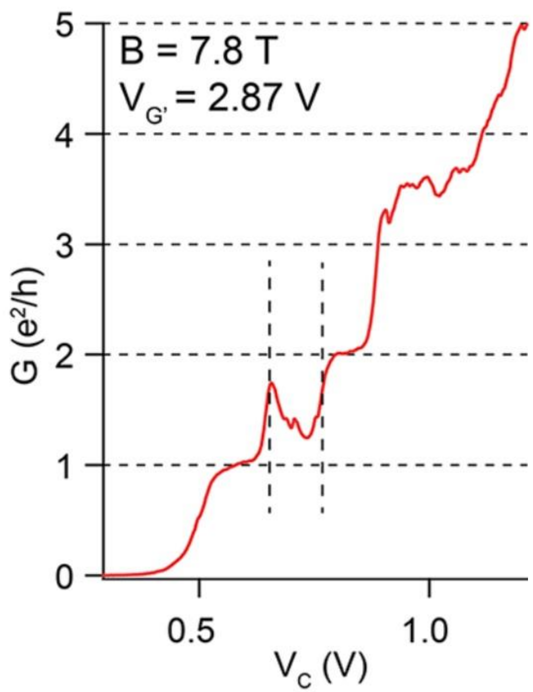
Helical gap ?

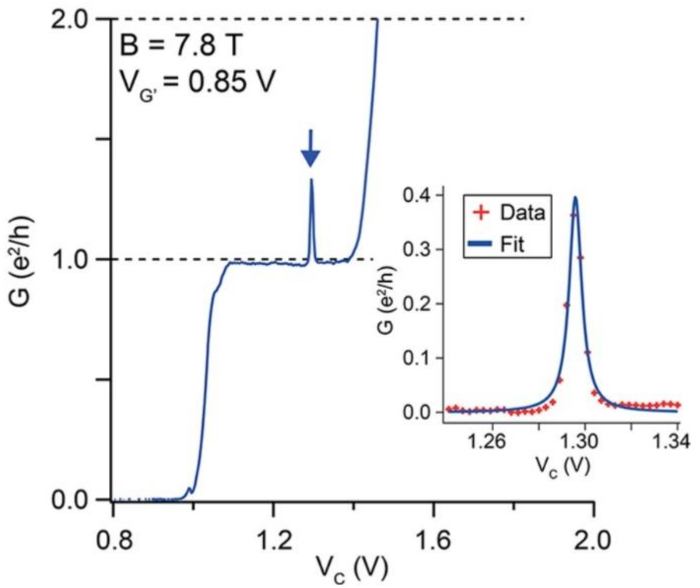
Conductance through a helical state in an InSb nanowire

J.Kammhuber et al. *Nature Communications* **8,** 478(2017)

Resonant Tunneling



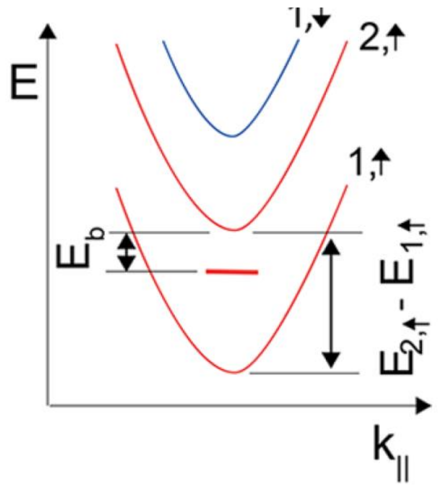




$$V_L = V_{G`}$$

$$V_R = \alpha_{R/L}\ V_L$$

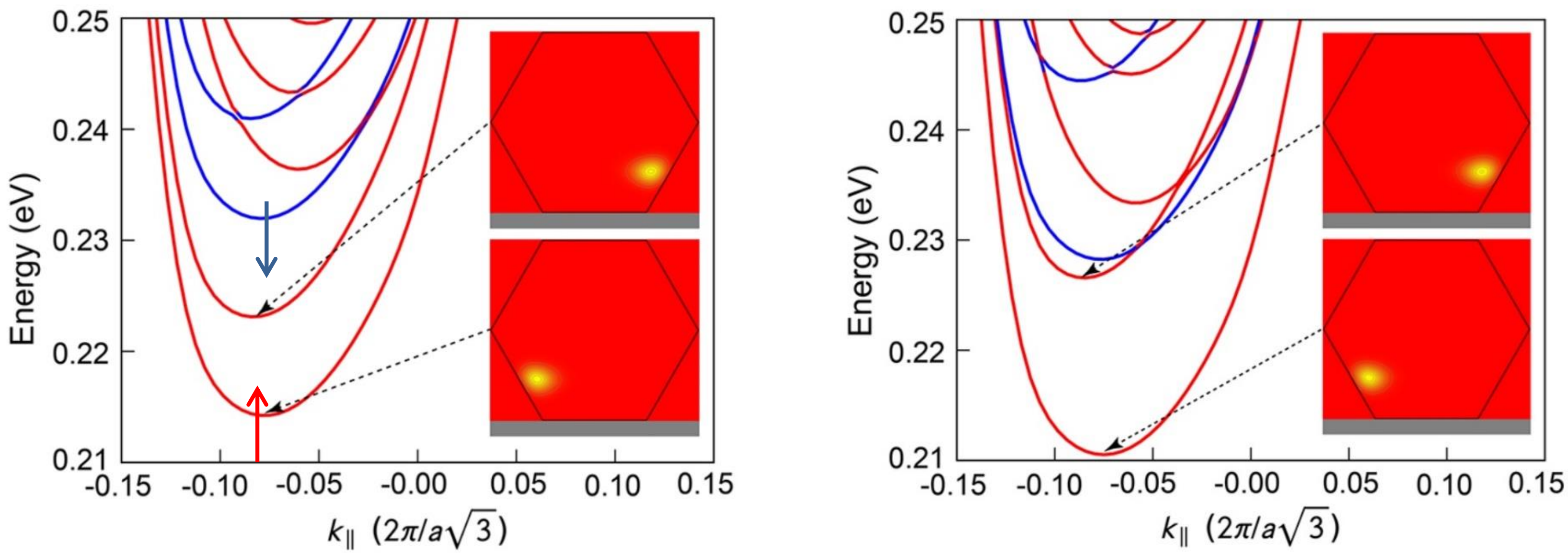
$$\alpha_{R/L} = 0.875$$



$\Gamma = 0.29 \pm 0.05$ meV

broadening of the discrete state
-tunnel coupling to the leads

Tight-binding calculations



$E_y \approx 0.1\, mV/nm$ $E_y \approx 0.18\, mV/nm$

In-plane magnetic field
Gate biasing
Negative charge distribution at the interface

Wave functions ≈ 10nm
Vertically confined by B-field
Laterally confined by E-field

E and B field confinement can form distinct uncoupled channels

Bound state due to a defect close to the location of second sub band

Summary

Conductance measurement of InSb with three bottom gates

Enhance tunability of the potential landscape

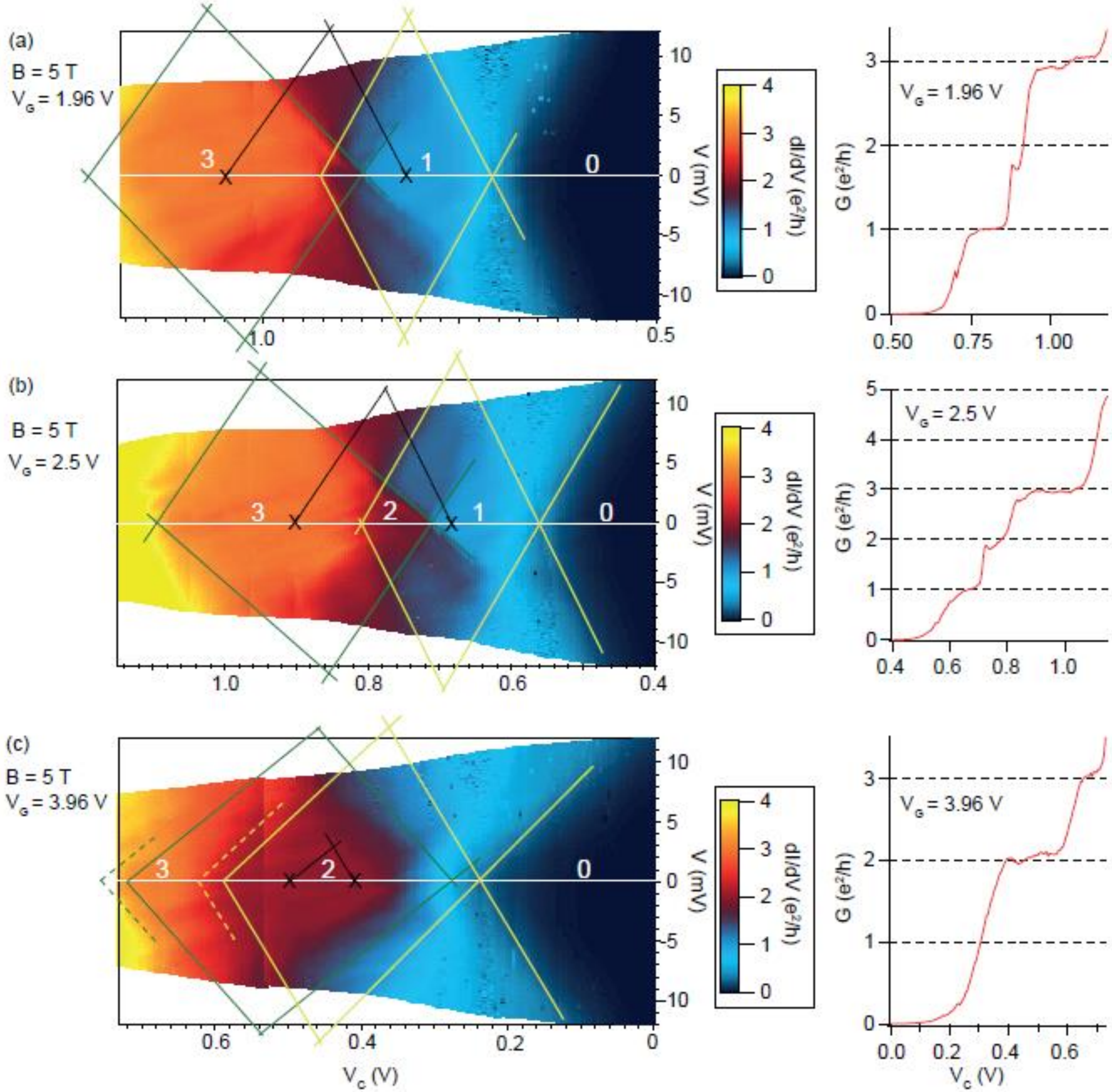
1D spin-split band structure

Gate couplings create virtual degeneracies

Crossing of the spin-resolved bands

Conductance resonances originating from localized states

Thank you



(a)
B = 5 T
V_G = 1.96 V
3
1
0
V (mV)
dI/dV (e^2/h)
G (e^2/h)
V_G = 1.96 V
(b)
B = 5 T
V_G = 2.5 V
3
2
1
0
V (mV)
dI/dV (e^2/h)
G (e^2/h)
V_G = 2.5 V
(c)
B = 5 T
V_G = 3.96 V
3
2
0
V (mV)
dI/dV (e^2/h)
G (e^2/h)
V_G = 3.96 V
V_c (V)
V_c (V)

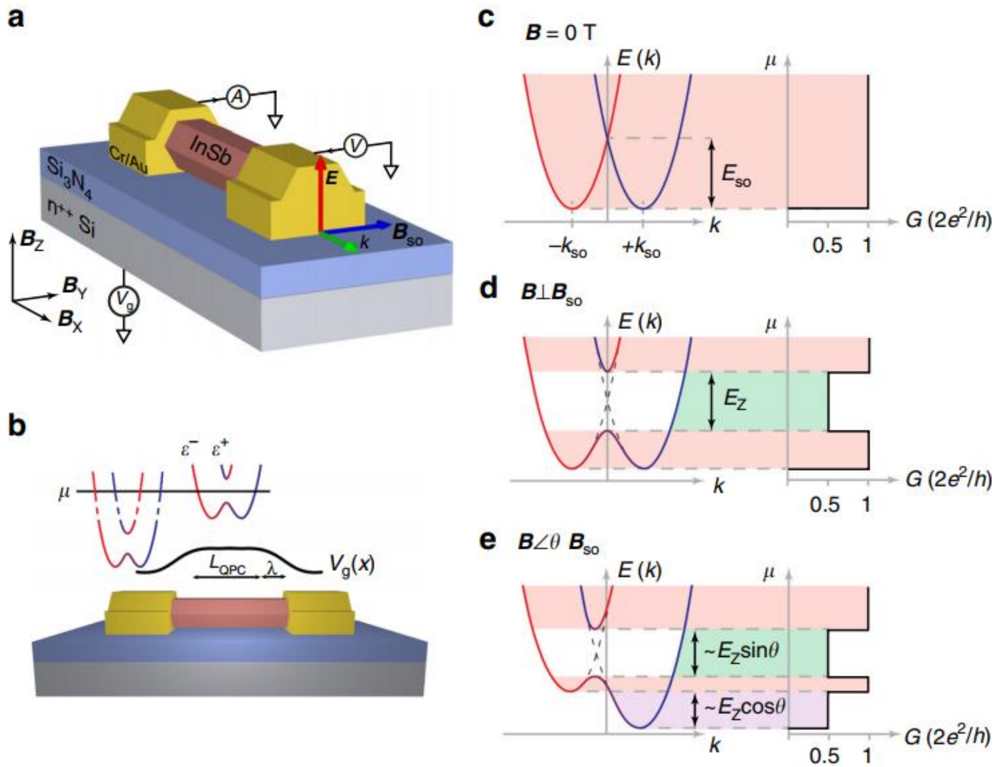


Fig. 1 The helical gap in a one-dimensional nanowire device. **a** An indium antimonide (InSb) nanowire device with a Rashba spin-orbit field $\boldsymbol{B}_{SO}$ perpendicular to the wave vector $\boldsymbol{k}$ and the electric field $\boldsymbol{E}$. A voltage is sourced to one contact, and the resulting conductance measured from the second contact. A degenerately doped wafer acts as global backgate V_g. **b** A quantum point contact (QPC) of length L is defined by the two contacts. Underneath the nanowire contacts, many subbands are occupied as the contacts screen the gate electric field. In the nanowire channel away from the contacts, the chemical potential in the wire, μ, is tuned with V_g. The onset shape of V_g with a lengthscale λ is set by the dielectric and screening of the electric field from the metallic contacts resulting in an effective QPC length $L_{QPC} = L-2\lambda$. **c** The energy dispersion of the first two subbands for a system with spin-orbit interaction (SOI) at external magnetic field $B = 0$ T. The SOI causes subbands to shift by k_{SO} in momentum space, as electrons with opposite spins carry opposite momentum. When the electrochemical potential μ in the wire is tuned conductance plateaus will occur at integer values of G_0. **d** At finite magnetic field $\boldsymbol{B}$ perpendicular to $\boldsymbol{B}_{SO}$, the spin polarized bands hybridize opening a helical gap of size E_Z (*green*). In this region the conductance reduces from $1 \cdot G_0$ to $0.5 \cdot G_0$ when μ is positioned inside the gap. **e** When the magnetic field is orientated at an angle θ to $\boldsymbol{B}_{SO}$, the size of the helical gap decreases to only include the component of the magnetic field perpendicular to $\boldsymbol{B}_{SO}$ and the two subbands split by an additional Zeeman gap (*purple*). The color scheme illustrating different conductance regimes is also used in Figs. 2d and 3b. For all angles the re-entrant conductance feature at $0.5 \cdot G_0$ in the $1 \cdot G_0$ plateau will scale linearly with Zeeman energy

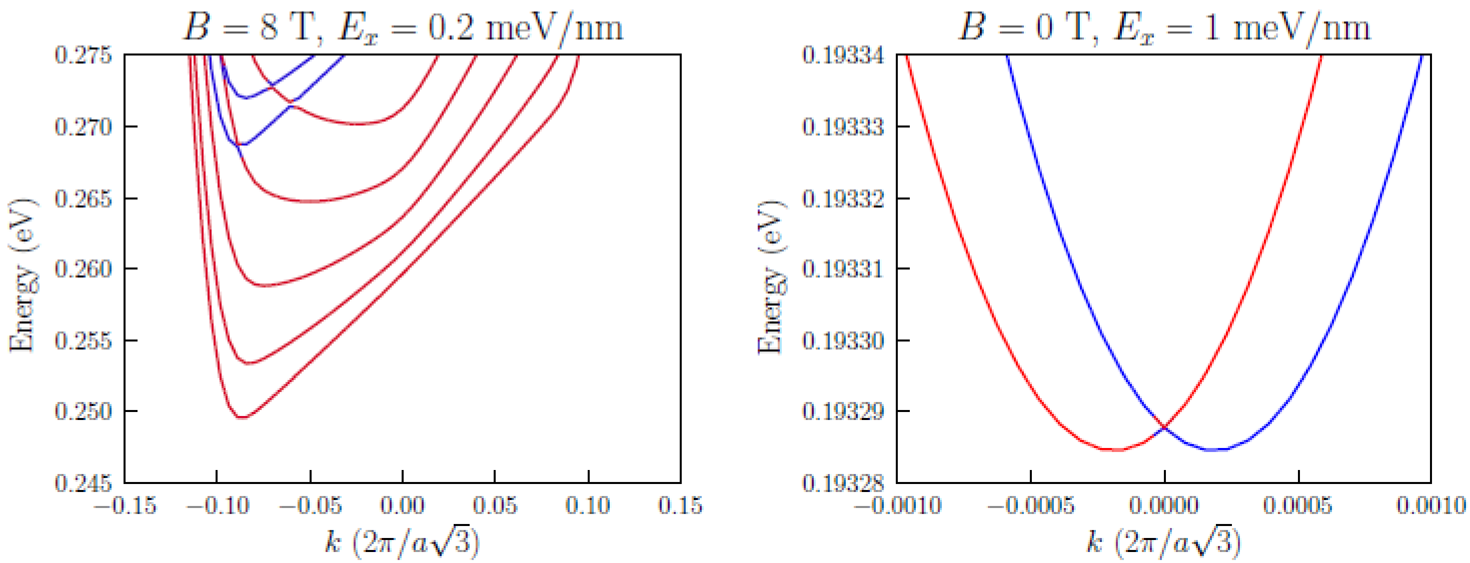


Figure S6: (left) Band structure of a 160 nm diameter hexagonal InSb NW in a magnetic field $B = 8$ T (along $(\boldsymbol{y}+\boldsymbol{z})/\sqrt{2}$), and in an electric field $E_x = 0.2$ meV/nm. (right) Band structure of 160 nm diameter hexagonal InSb NW at $B = 0$ T, in an electric field $E_x = 1$ meV/nm (close-up on the lowest subbands, showing the effects of spin-orbit coupling).

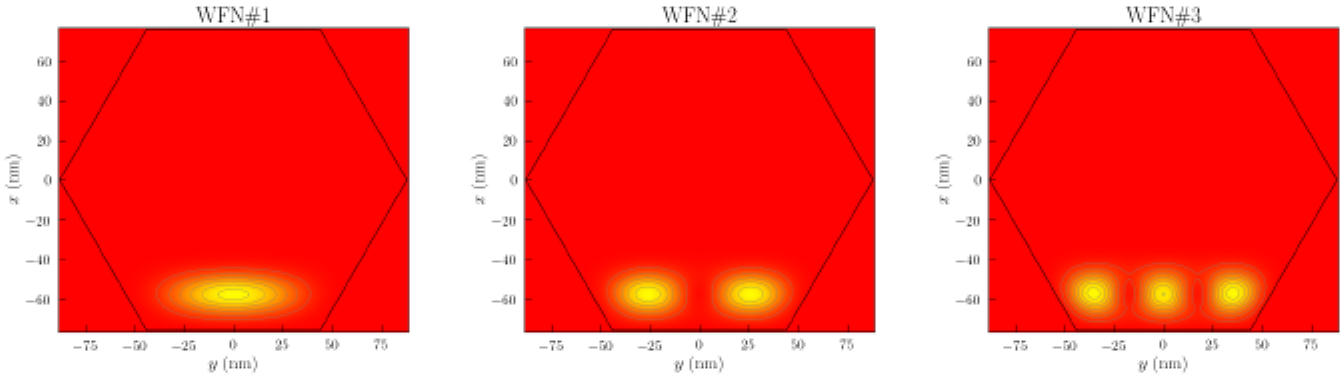


Figure S7: Squared wave functions of the first three subbands at $k = -0.089 \times 2\pi/(a\sqrt{3})$.

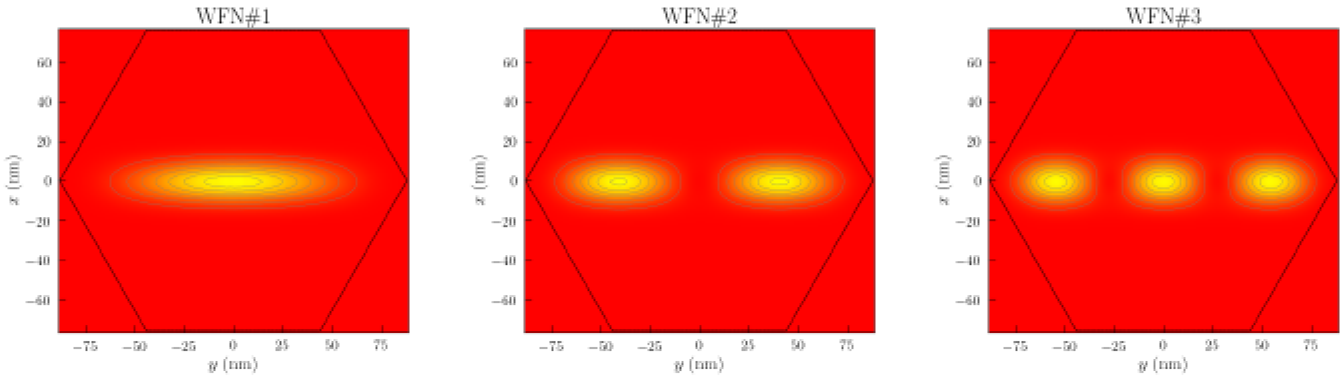


Figure S8: Squared wave functions of the first three subbands at $k = 0$.