Selective Area Growth of InAs Nanowire Networks

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Krizek et al. https://arxiv.org/abs/1802.07808v2 (Krogrstrup group)

Vaitiekenas et al. https://arxiv.org/abs/1802.04210v2 (Marcus group)

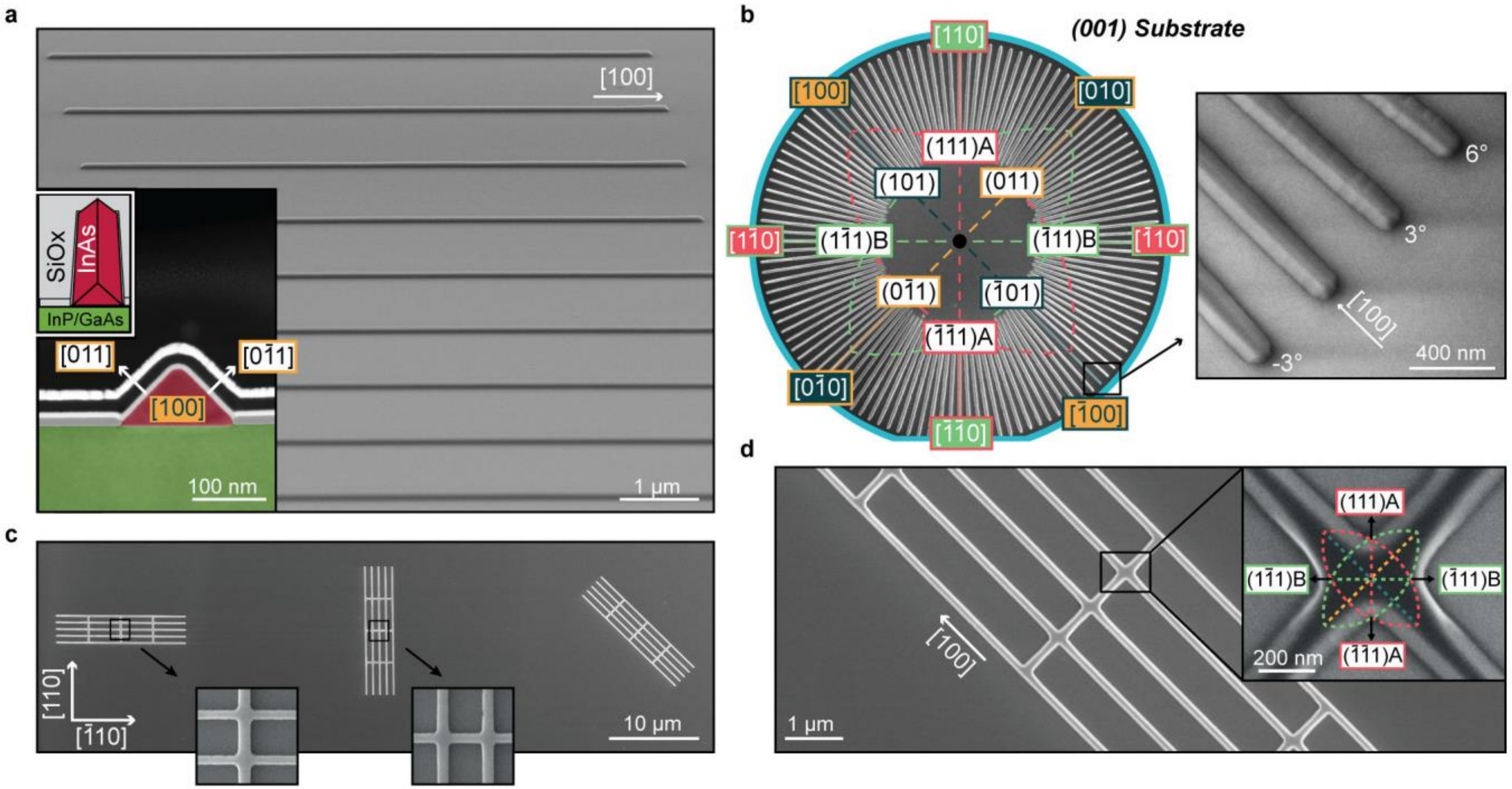
Outline

- Their system(s)
- A bit of materials science
- Experiments and results
- Conclusion

Material System (Krizek et al.)

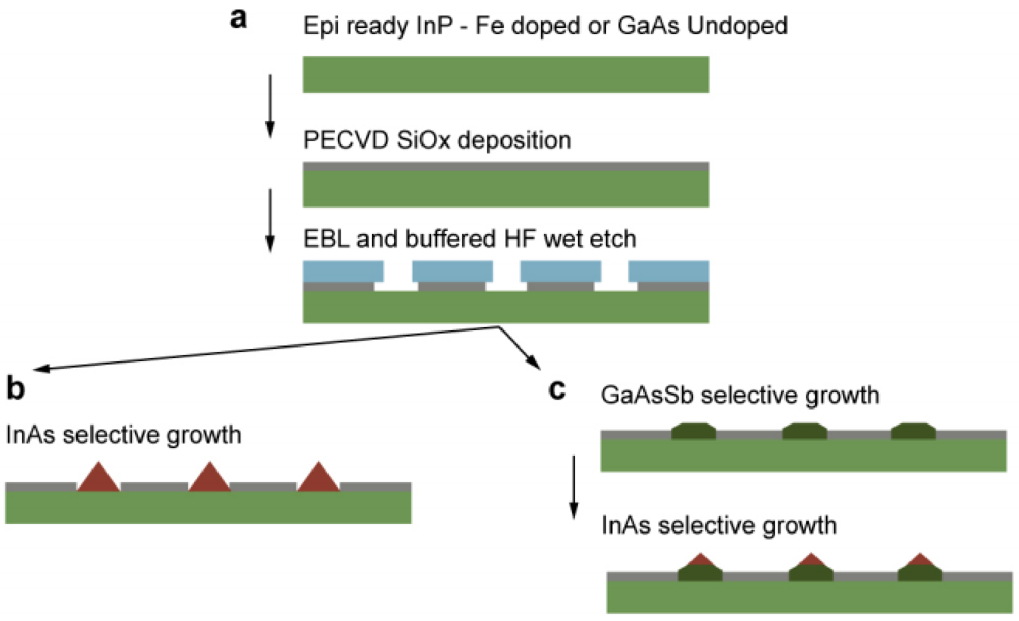
- MBE-grown InAs “wire” networks on GaAs (7% mismatch) and InP (3%) substrates ([001])

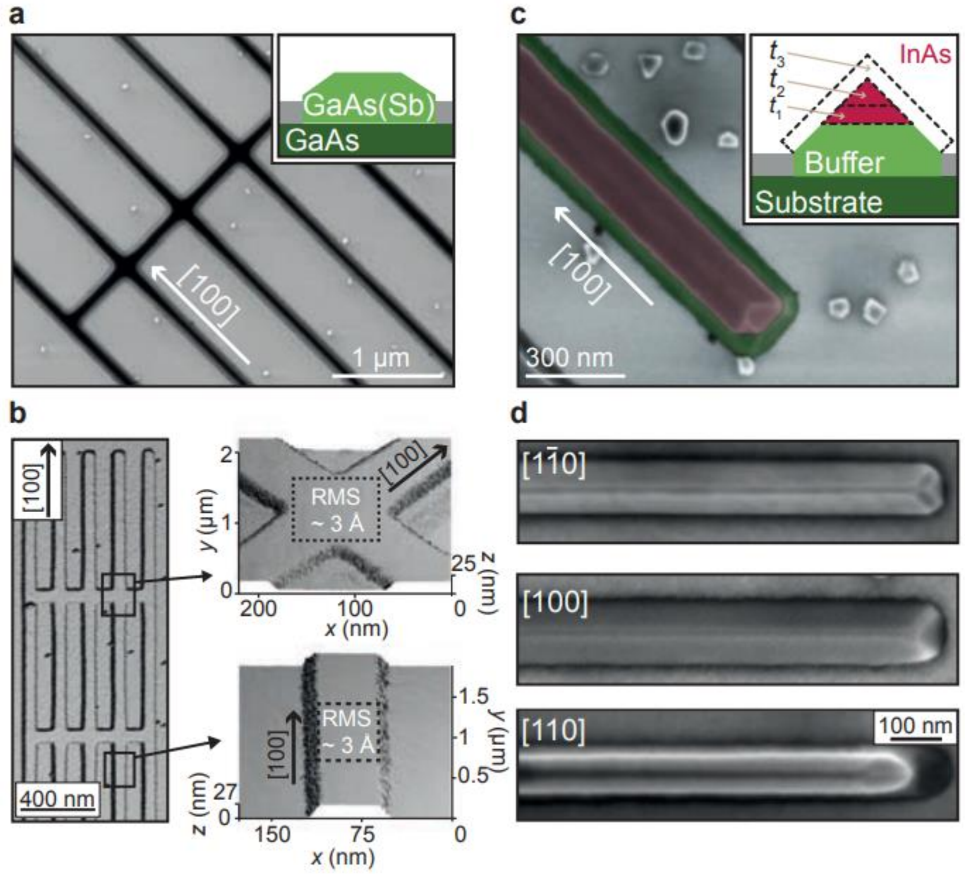
- 4 equivalent growth directions enable formation of rectangular networks



Buffer Layer

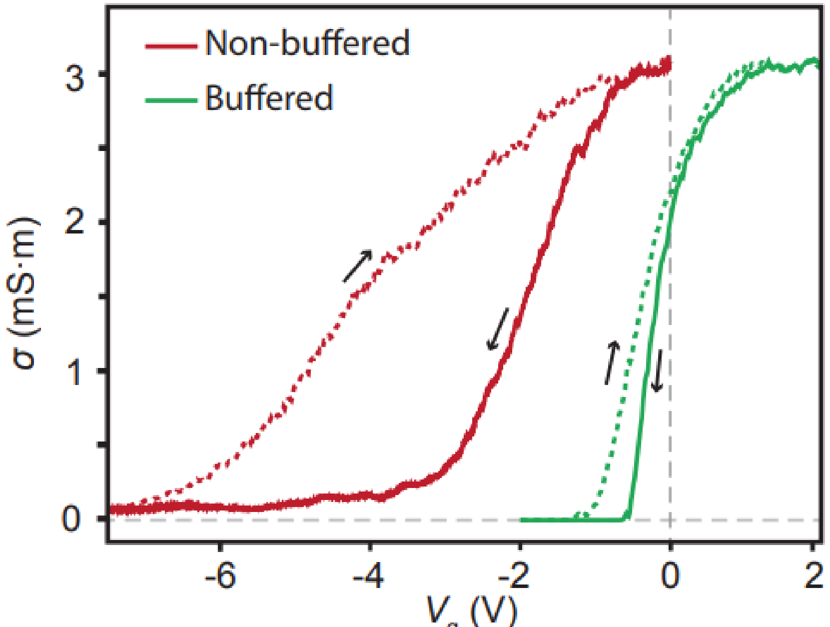
- Experiment with Sb-dilute buffer layer to improve interface
  - Improves lattice matching and strain relaxation (fewer misfit dislocations)
  - Leads to enhanced field effect response

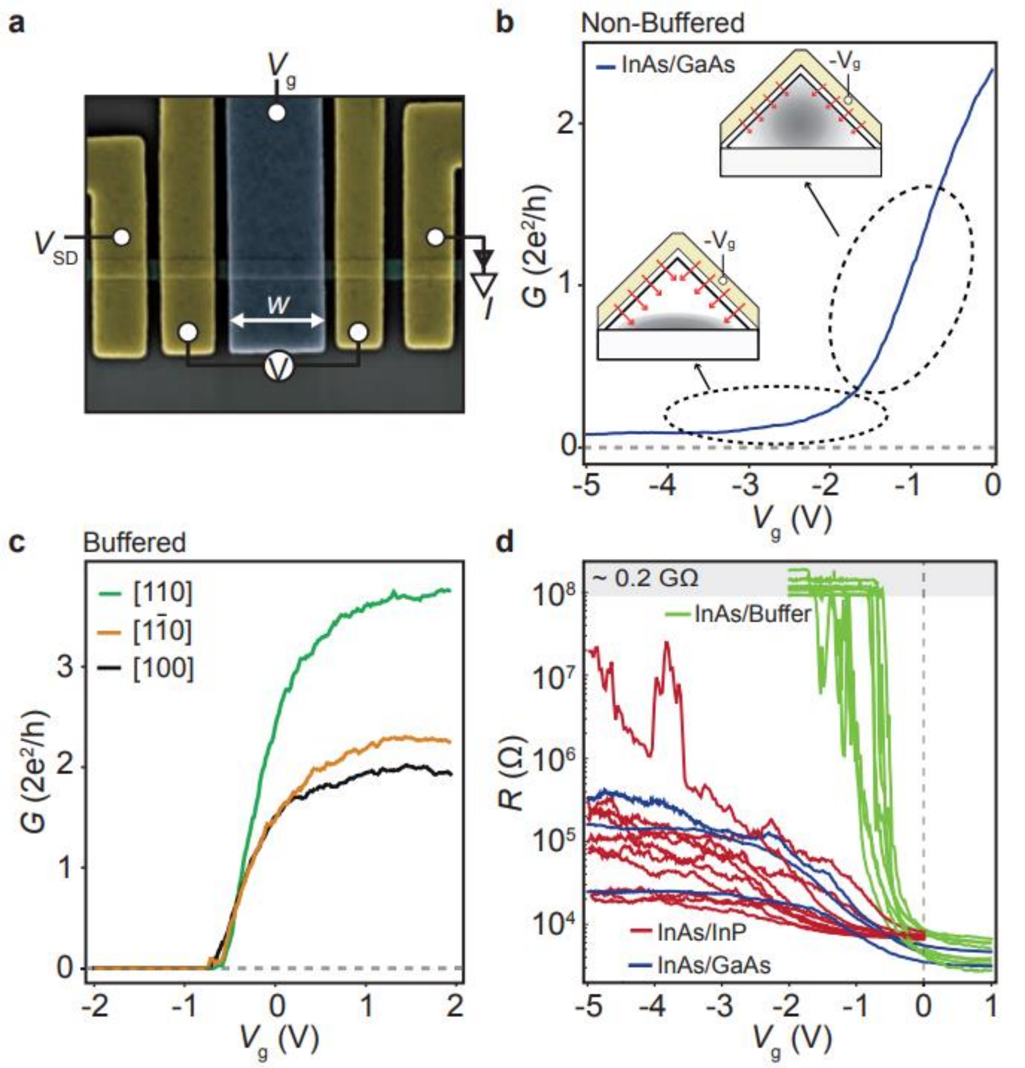




With and Without Buffer

- Without buffer no devices could completely pinch off
  - Irregular gate responses
- ***With*** buffer layer the devices pinch off reliably inside of a ~250 mV window
- Points to different transport phenomena at interface compared to bulk of wires. Better interface → better field effect response
- Sb-dilute buffer layer samples seem to have interface characteristics with no difference to the bulk.
- Greatly reduced hysteresis with buffer layer

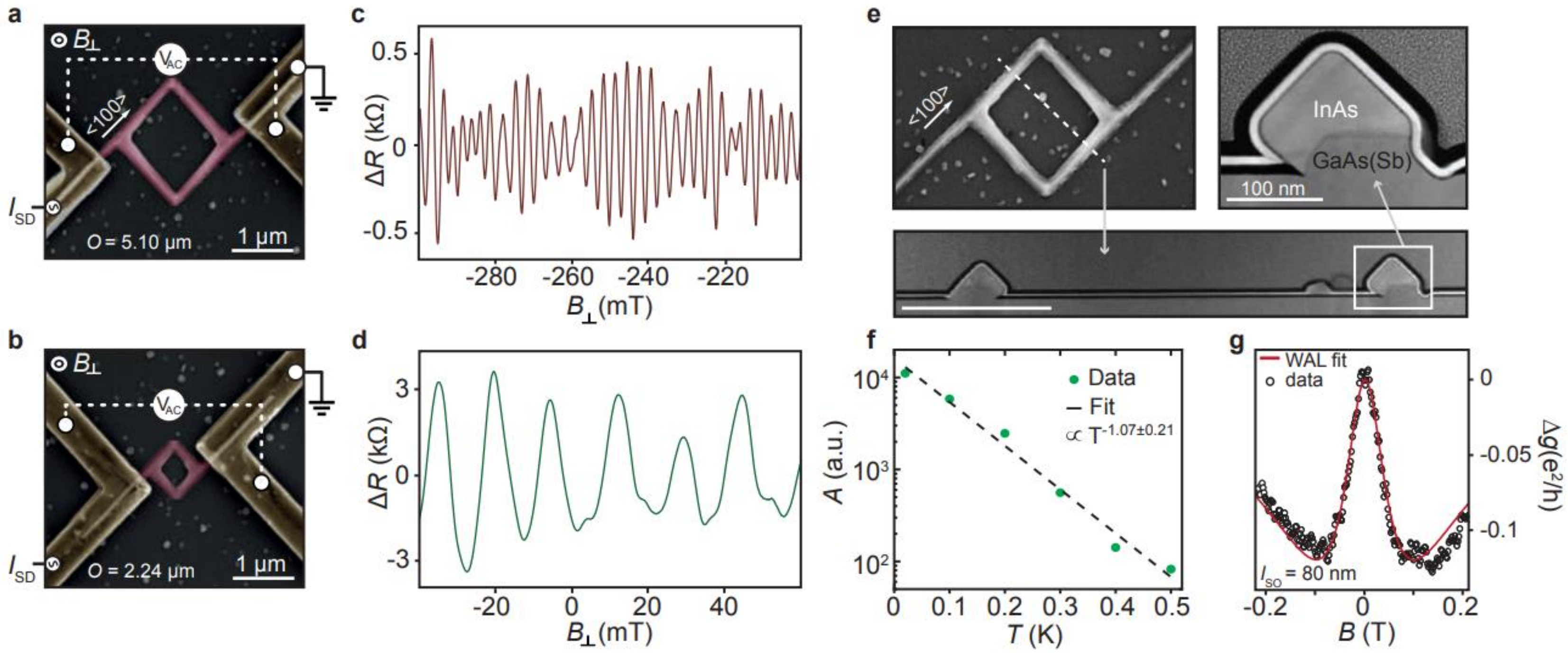




Magnetoconductance

- Sweeps of $B_\perp$ show Aharonov-Bohm oscillations with oscillation periods in good agreement with the areas of the loops
- Small loop at 20 mK: $l_\phi = 13 \pm 1\ \mu m$
- Diffusive loops have $l_\phi \propto T^{-1/2}$ → here likely in ballistic regime below 500 mK
- Single (quasi 3D) wire (not shown) fit with WAL model yields $l_\phi \sim 180\ nm, l_\phi \sim 80\ nm$; comparable to VLS-grown wires

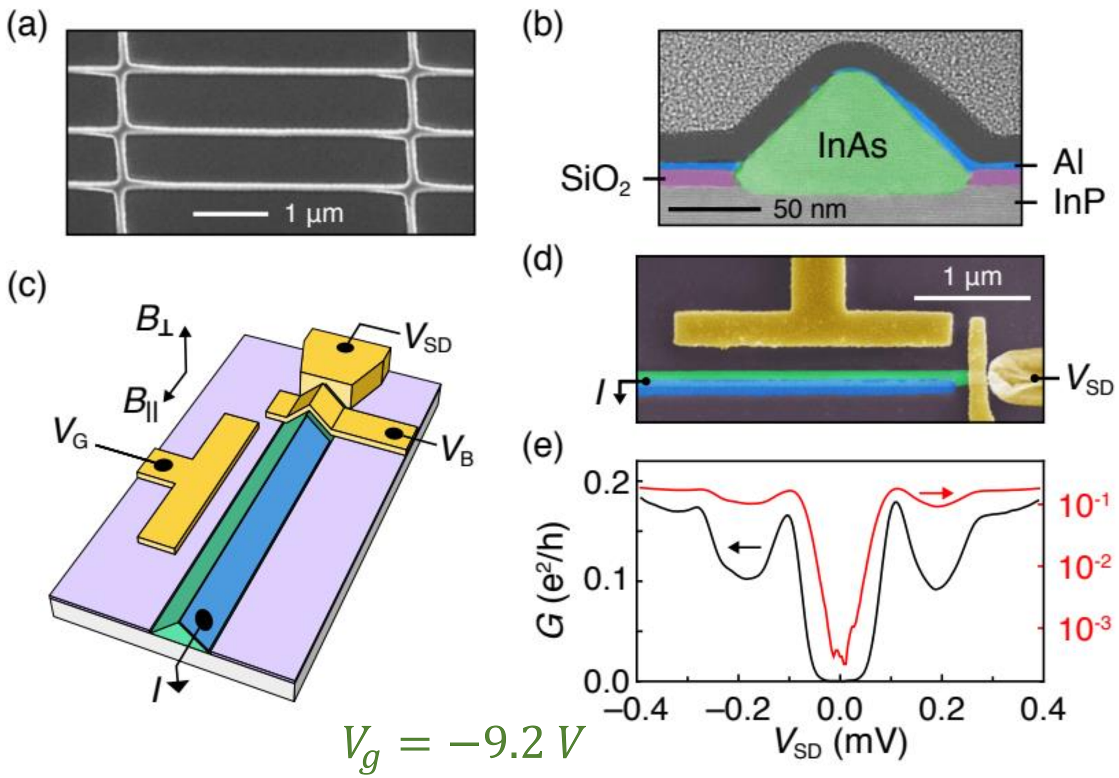
$$A(T) \propto \exp(-\frac{O}{l_\phi(T)})$$



Transport (Vaitiekenas et al.)

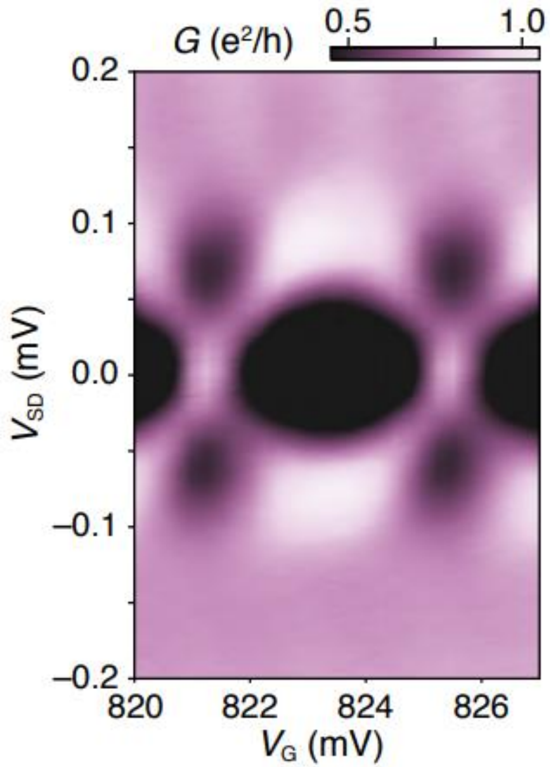
- Triangular wires on InP substrates (no buffer layer) in three different devices
- Aiming towards (of course) Majoranas
- Have:
  - Hard superconducting gap induced
  - Large phase coherence length (microns)
  - Strong spin-orbit coupling
  - Coulomb blockade peak motion compatible with interacting Majoranas
- One side of the triangle covered with in-situ MBE aluminum
- Two peaks in G tentatively identified with populations of carriers
  - Larger gap at InAs/Al interface
  - Smaller gap at InAs/InP interface
- Zero-bias G ~ 400 times lower than above-gap G (ratio better than VLS devices) → hard induced gap

Device 1



Device 2

- Hybrid QD of length 1.1 um
- 2e periodic spacing (at low temp) as function of V_g
    - Evolves to even-odd and 1e periodic with increasing T
- Coulomb diamonds give charging energy $E_c = 60\ \mu eV$ (smaller than induced gap $\Delta^* \sim 100\ \mu eV$)

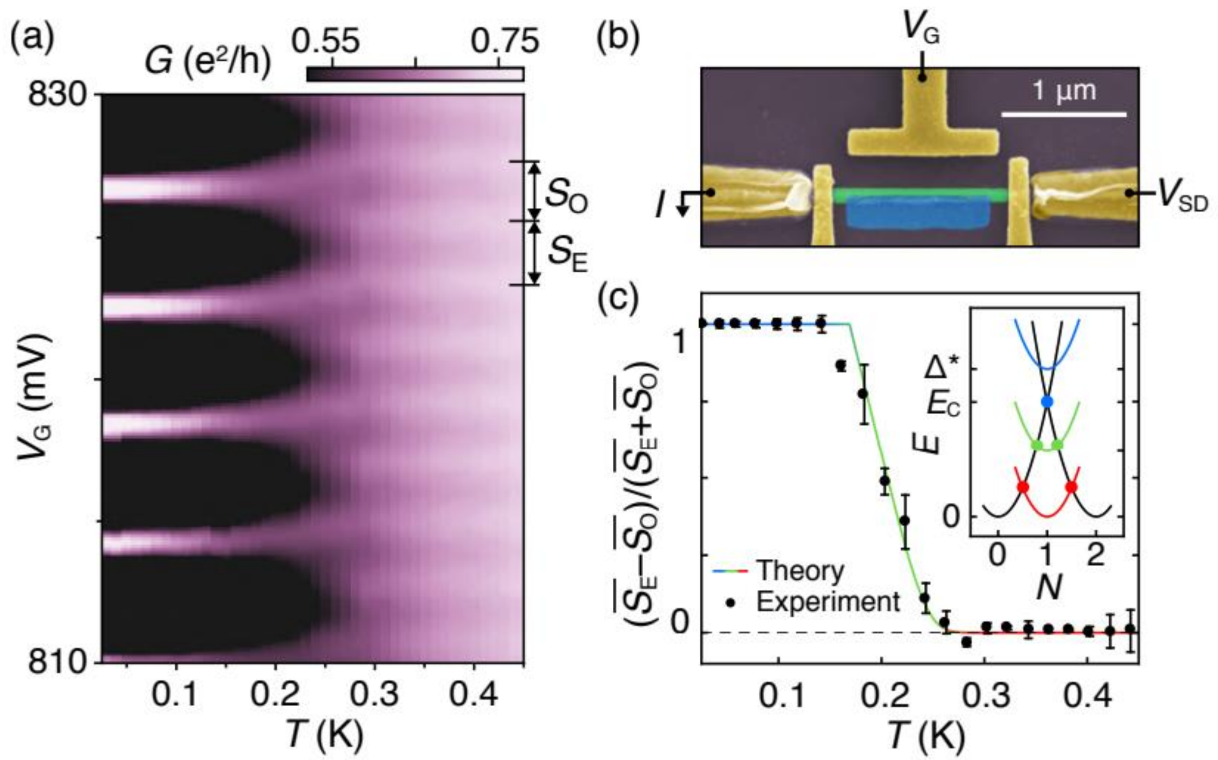


20 mK

Free Engery:
$F = F_O - F_E$

For $T \ll E_C, \Delta^*$, F → Δ^*
For $F(T) > E_C$, peaks 2e periodic
Above poisoning temp $T_p \sim 250\ mK$, F → 0
For $F(T) < E_C$, odd states occupied

Fitting to complex model yields Δ^* = 190 μeV

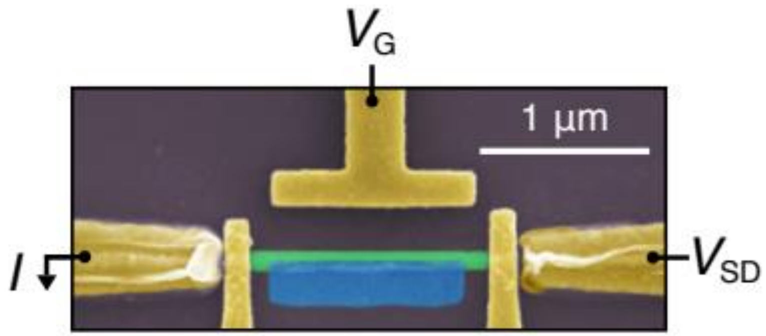


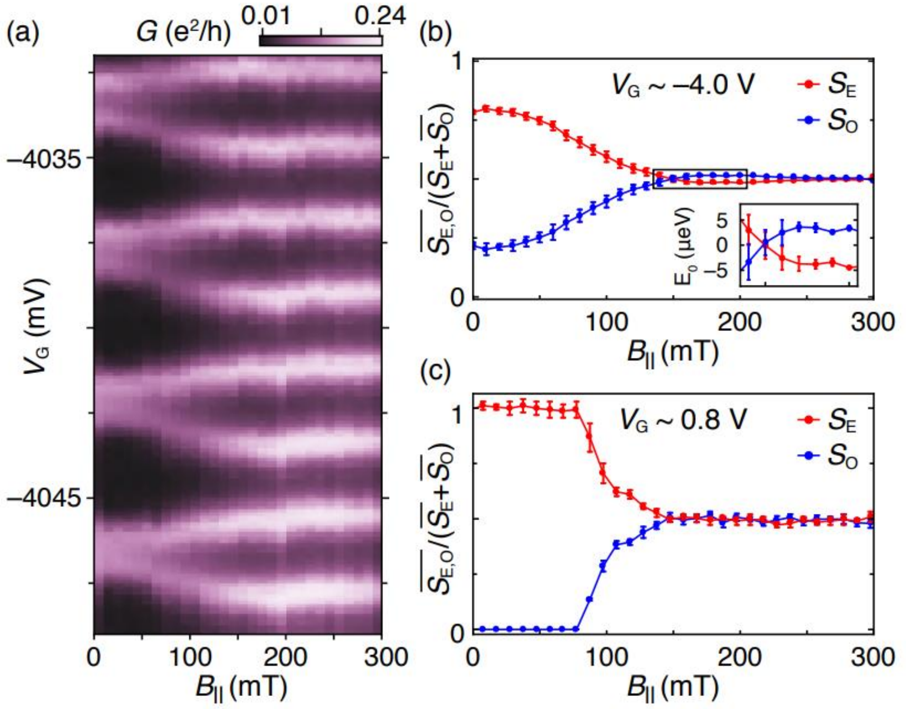
$$S_E - S_O = \frac{2}{\eta e} \min(E_C, F)$$

Evolution of CB Peaks

- Even-odd periodicity at zero bias due to bound state at E_0 less than E_c
- Overshoot in fig (b) indicates discrete subgap state crossing zero energy
    - Yields $g_{eff} \sim 13$
    - Consistent with interacting Majoranas
    - In quantitative agreement with VLS wires of similar length

$$S_{\mathrm{E,O}} = \frac{1}{\eta e}\left[E_{\mathrm{C}} \pm \min\left(E_{\mathrm{C}}, E_0\right)\right]$$
$$= \frac{S_{\mathrm{E}} + S_{\mathrm{O}}}{2}\left[1 \pm \min\left(1, E_0/E_{\mathrm{C}}\right)\right]$$





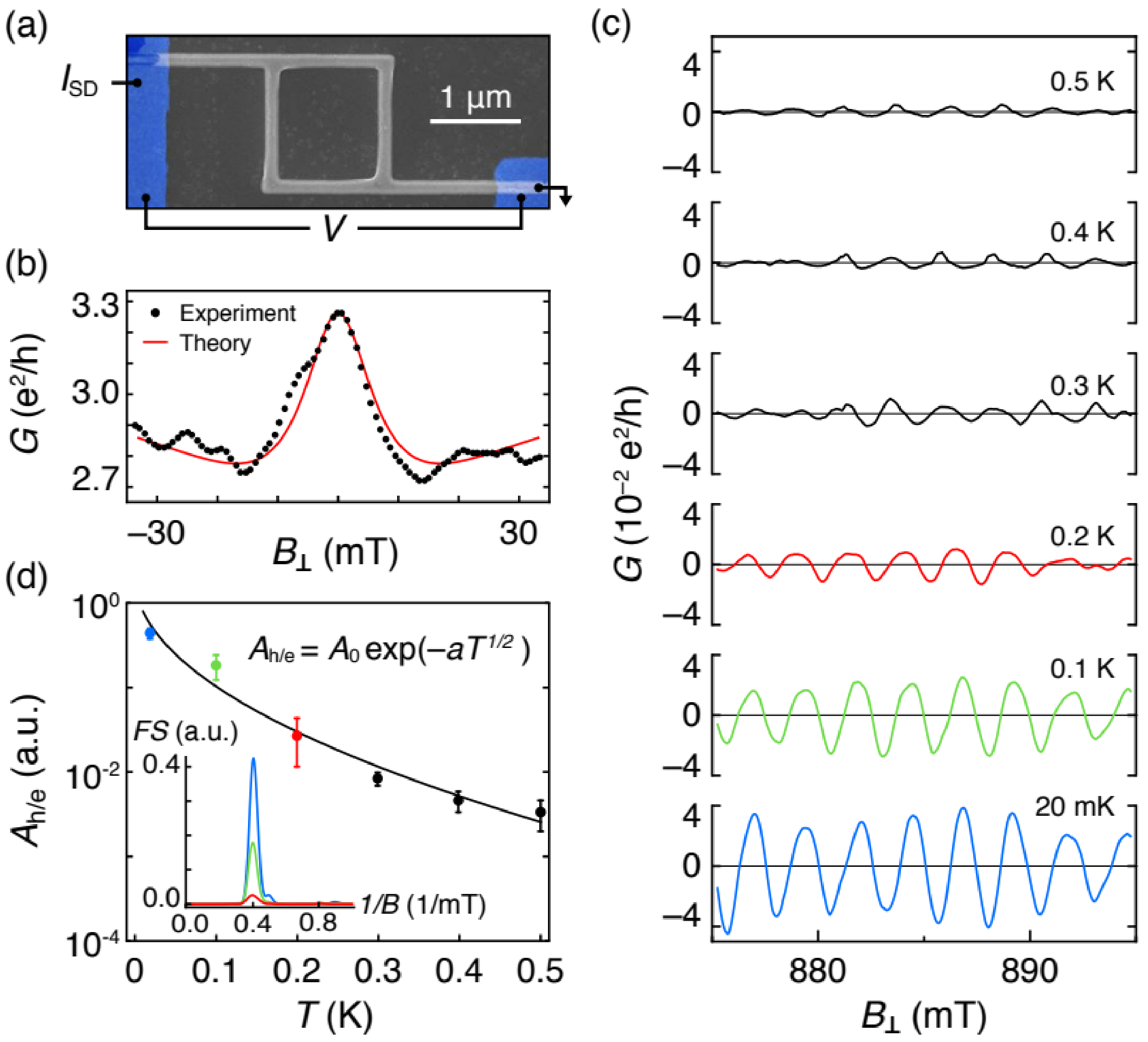
Device 3

- Al layer removed by wet etching
- WAL peak around B=0 yields $l_\phi^{WAL} \sim 1.2\ \mu m, l_{SO} \sim 400\ nm$
- At high magnetic field get AB oscillations of 2.5 mT corresponding to area of 1.7 μm^2 (area of loop)
- Temp dependence AB oscillation amplitude:

$$A_{h/e} \propto \exp\left[-\frac{L}{l_\phi^{AB}(T)}\right]$$

For diffusive ring $l_\phi^{AB} \propto T^{-1/2}$ yields l_ϕ^{AB}(20mK) ~ 4 μm

- It's been argued theoretically* that WAL and AB processes governed by different dephasing mechanisms ➔ different temp dependencies



*T. Ludwig and A. D. Mirlin, Phys. Rev. B. 69, 193306 (2004)

Conclusion

- Useful, scalable system similar to ours
- Interface quality between wires and substrate of high importance
- System allows for lots of flexibility in sample design
- May prove to be attractive long-term for Majorana physics

$$F(T) = k_B T \ln \left[\frac{\left(1+e^{-\Delta^*/k_B T}\right)^{N_{\text{eff}}} + \left(1-e^{-\Delta^*/k_B T}\right)^{N_{\text{eff}}}}{\left(1+e^{-\Delta^*/k_B T}\right)^{N_{\text{eff}}} - \left(1-e^{-\Delta^*/k_B T}\right)^{N_{\text{eff}}}} \right]$$

Neff, effective number of continuum states, = $2V_{Al}\varrho_{Al}\sqrt{2\Delta^* k_B T}$

ϱ_{Al}: density of states at Fermi energy

Tuominen, M. T., Hergenrother J. M., Tighe T. S., & M. Tinkham, Phys. Rev. Lett. 69, 1997 (1992).