nature physics

LETTERS

https://doi.org/10.1038/s41567-020-1017-3

Check for updates

Zero-bias peaks at zero magnetic field in ferromagnetic hybrid nanowires

S. Vaitiekėnas[1,2], Y. Liu[1,3], P. Krogstrup[1,3] and C. M. Marcus[1,2] ✉

Outline

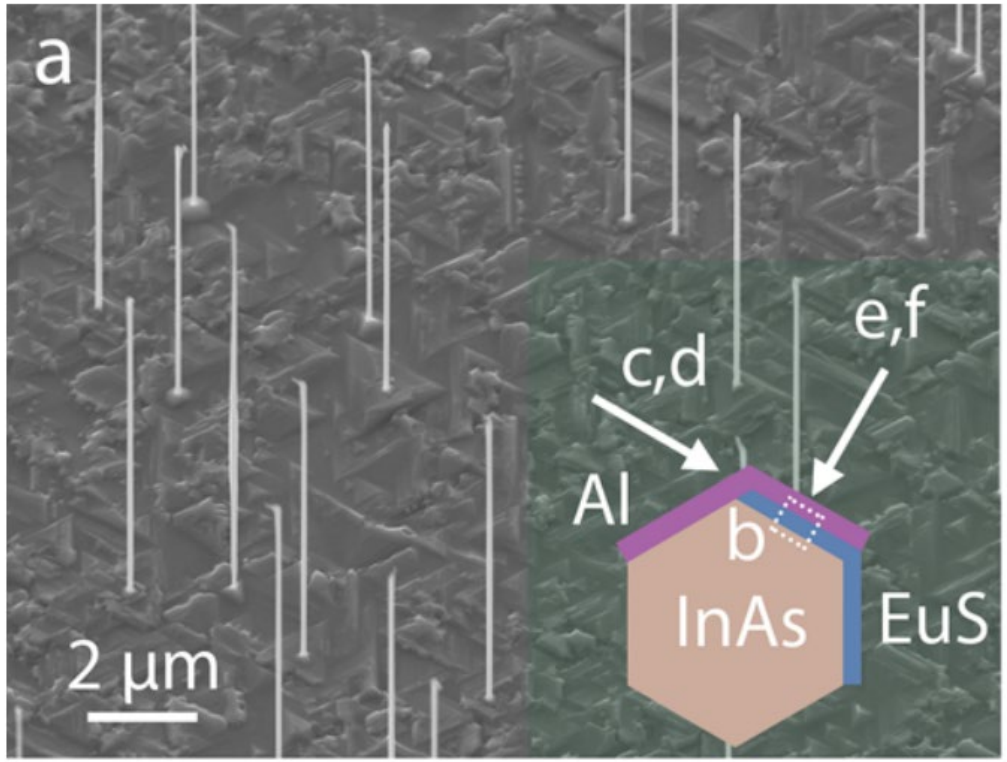
- Growth of the devices
- Device Architectures
- Non-overlapping devices
- Overlapping devices
- Results
- Conclusions

Motivation

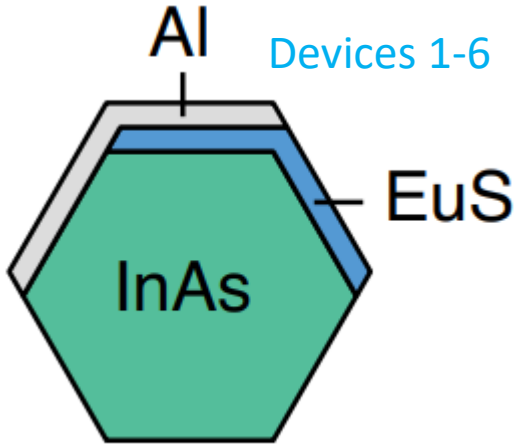
- Microsoft wants Majoranas (to exist)
- Requires: 1D wire, strong SOI, coupled SC, *strong B-field parallel to wire*
- Applying external B-field is detrimental to SC and places strong limits on a number of device parameters
- It would be great to have an alternative source of the Zeeman splitting
- They have a source of InAs NWs grown with epitaxial EuS (ferromagnetic insulator) and Aluminum, which could avoid the aforementioned problem
- SC-FMI hybrids exhibit spin splitting of SC DOS with zero applied B-field due to ferromagnetic exchange coupling [1]
- Novel system to explore complex interactions between SOI, SC and FMI (could yield topological state)

[1] E. Strambini et al., PRM **1**, 054402

How It's Made



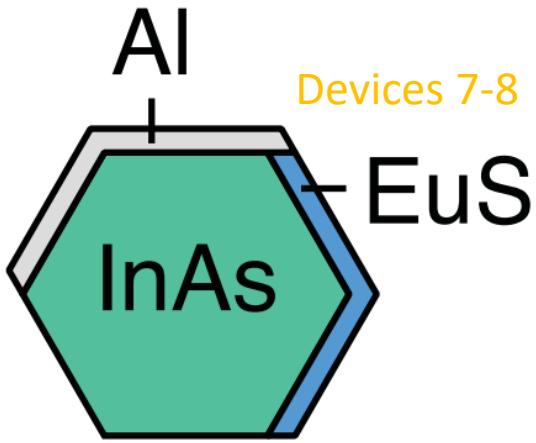
10 nm Al shell



= *Europium Sulfide*

(Ferromagnetic below T_{Curie} = 16 K)

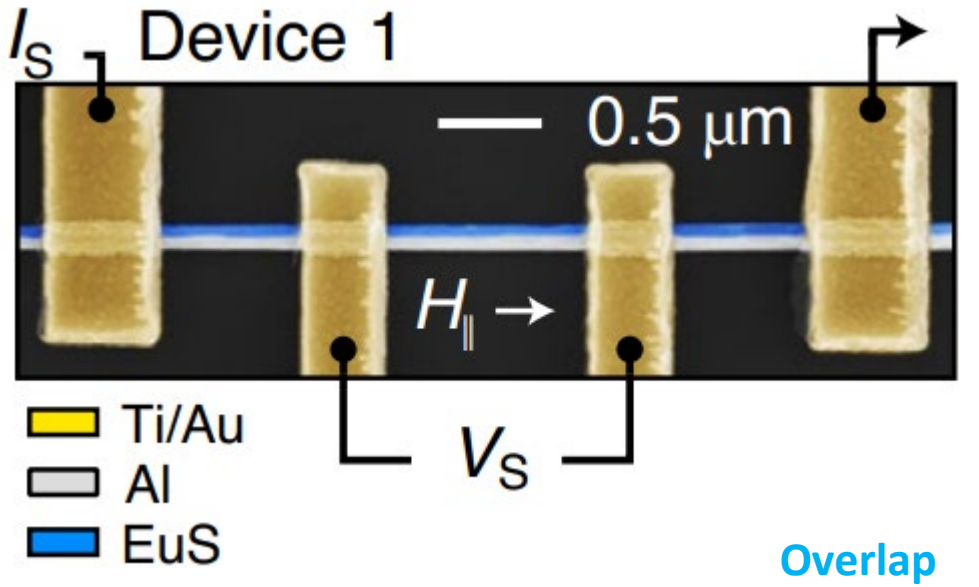
8 nm shell



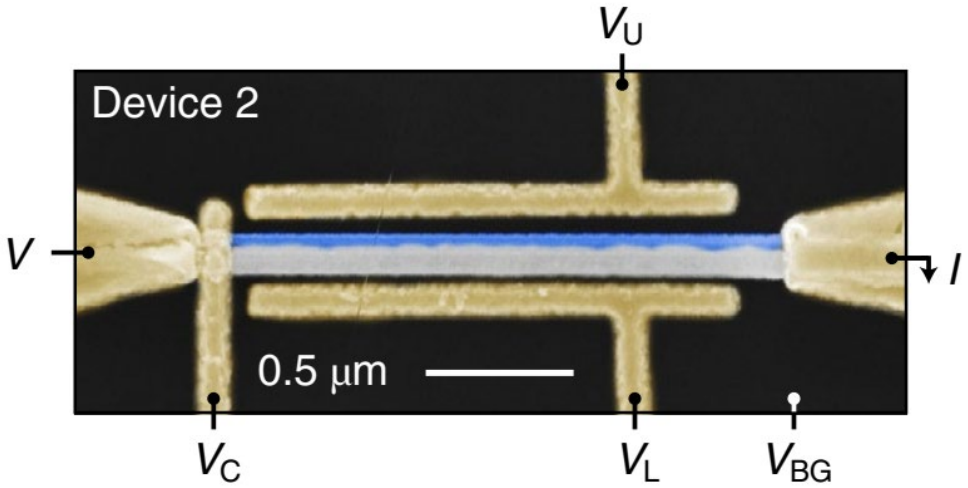
d_{InAs} = 120 nm

[2] Yu Liu et al., Nano Lett. 2020, 20, 456-462

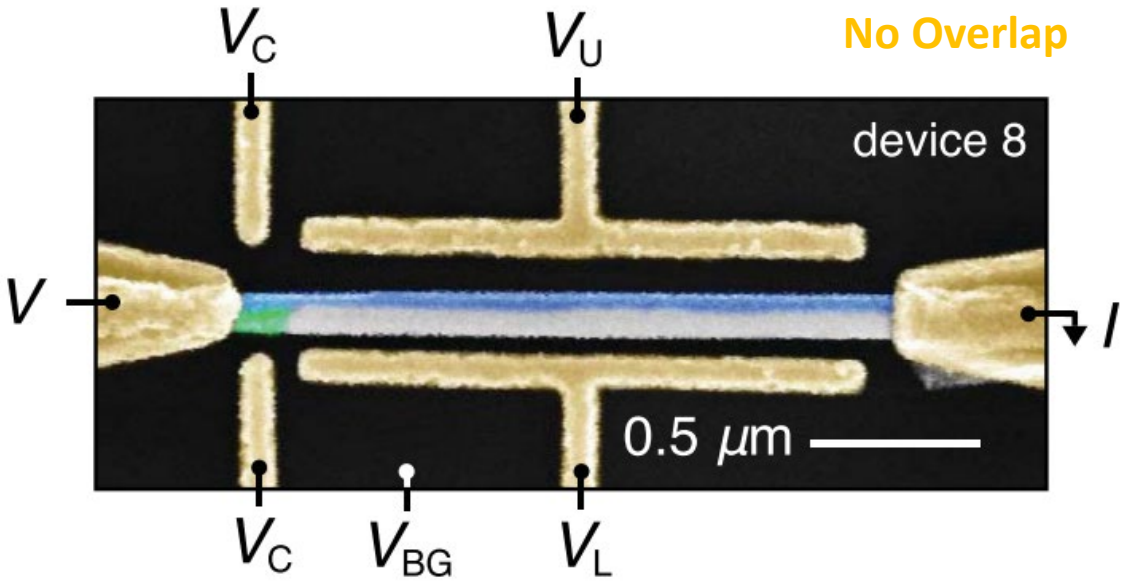
Device Architectures

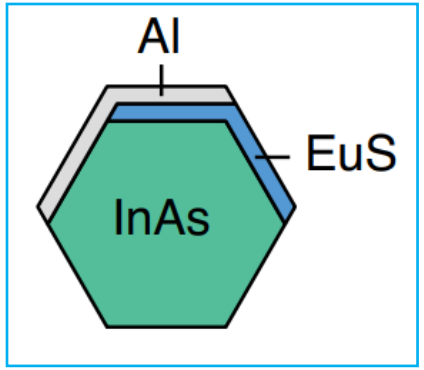


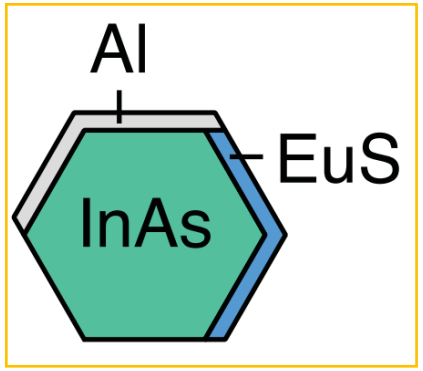
Overlap



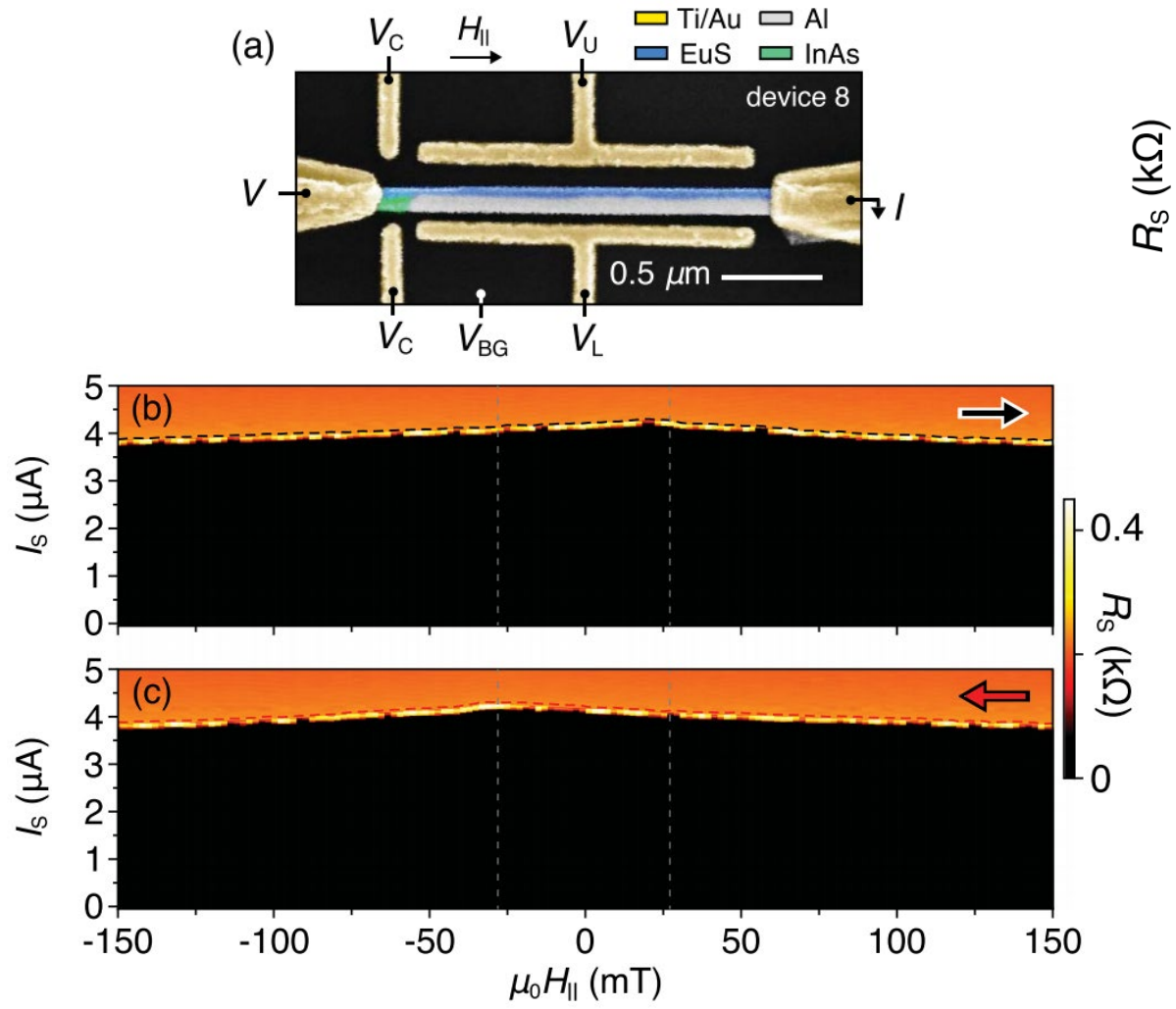
No Overlap

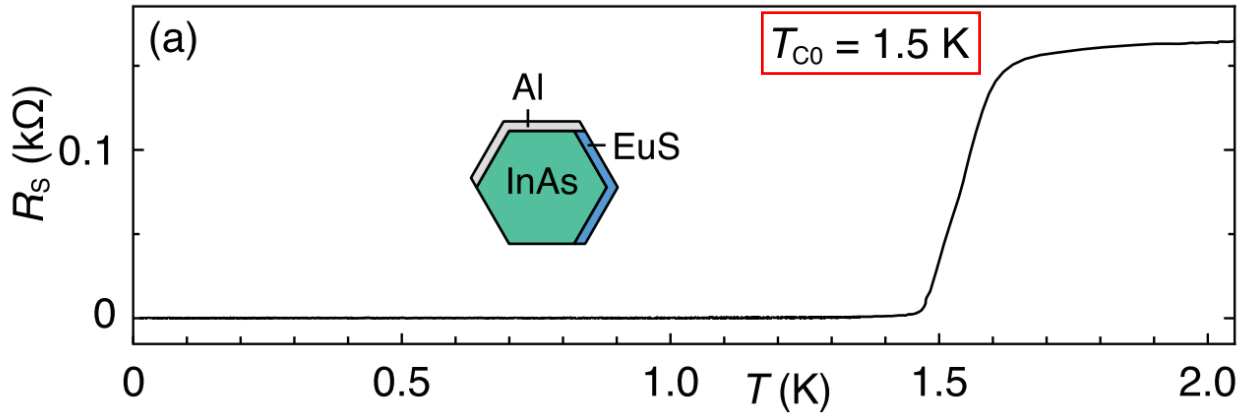


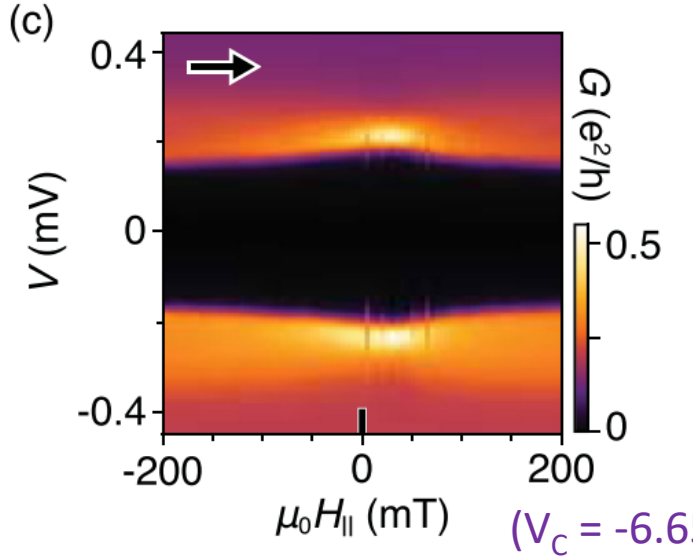


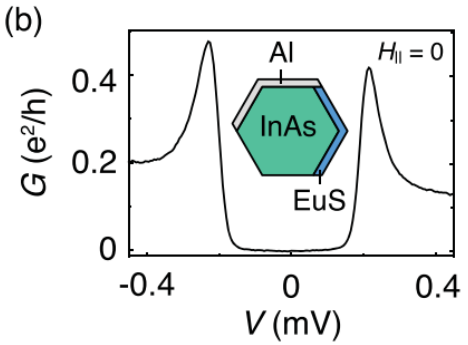


Non-Overlapping Al/EuS Shell Characteristics



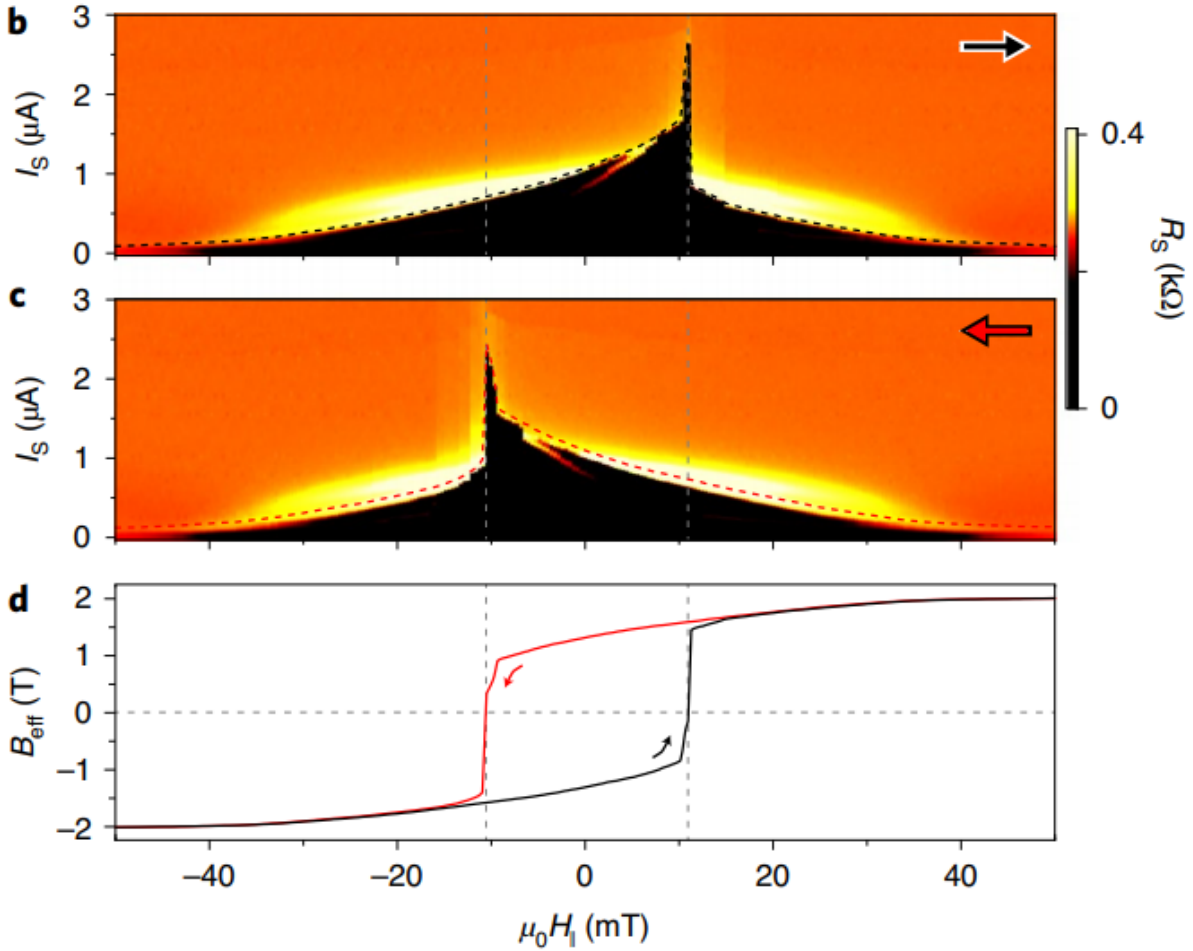


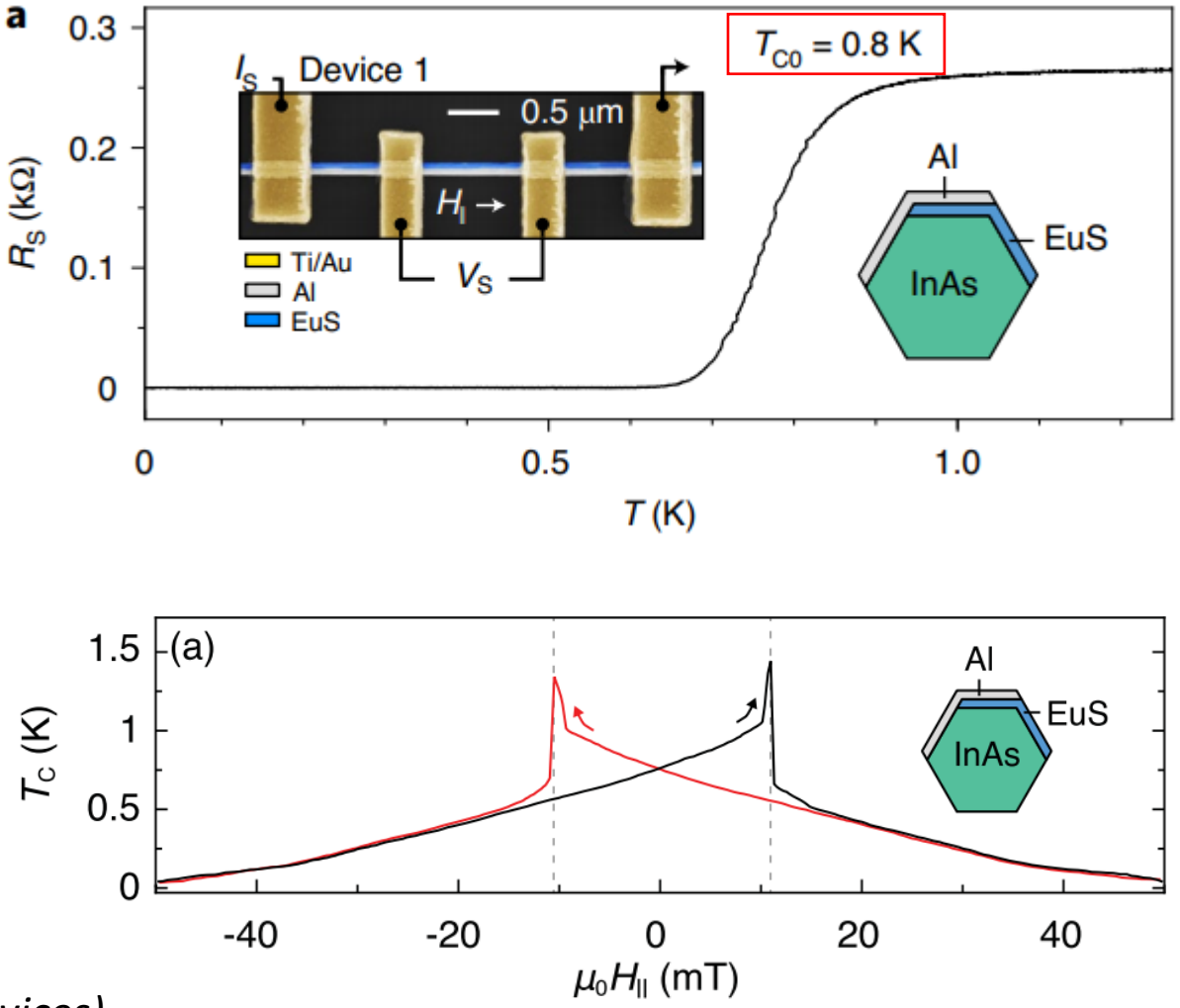




(V_C = -6.65 V, V_U = -7 V, V_L = 1.65 V)

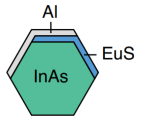
Overlapping Al/EuS Shell Characteristics



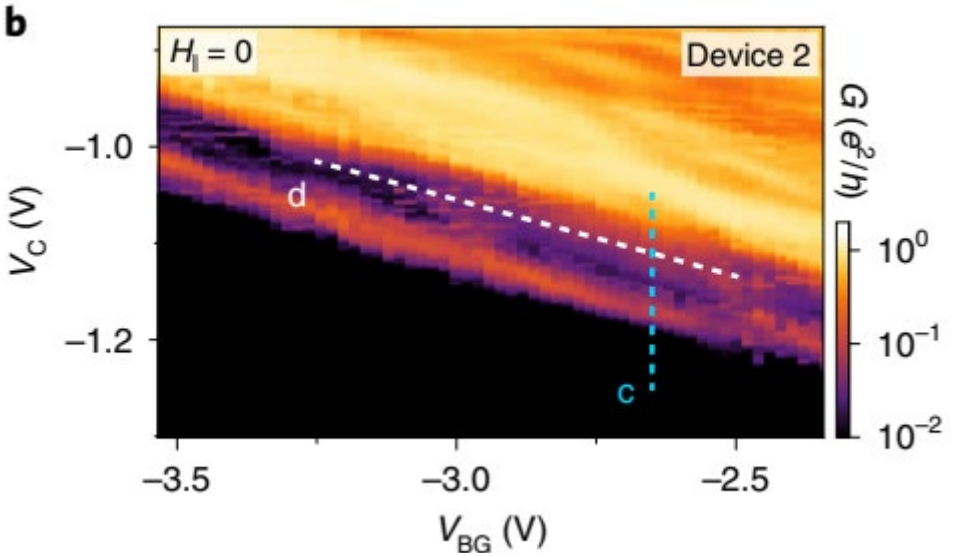


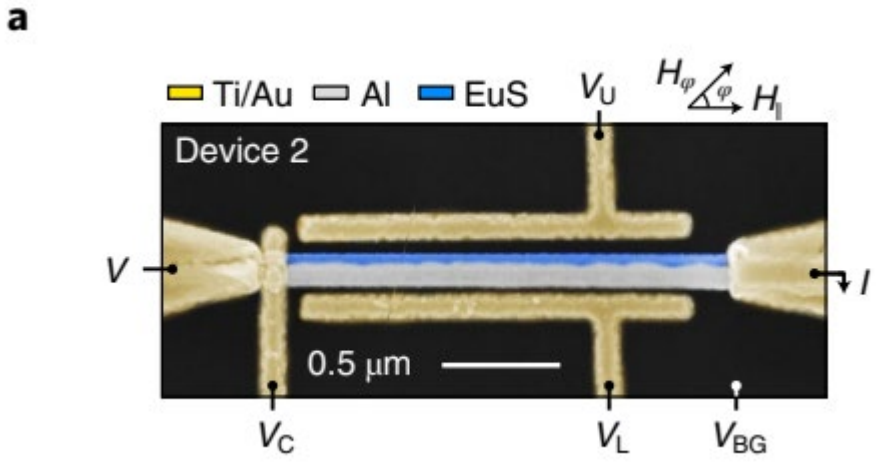
➔ *B_{eff} = +/- 1.3 T (previously > 1 T sufficient for TSC in hybrid devices)*

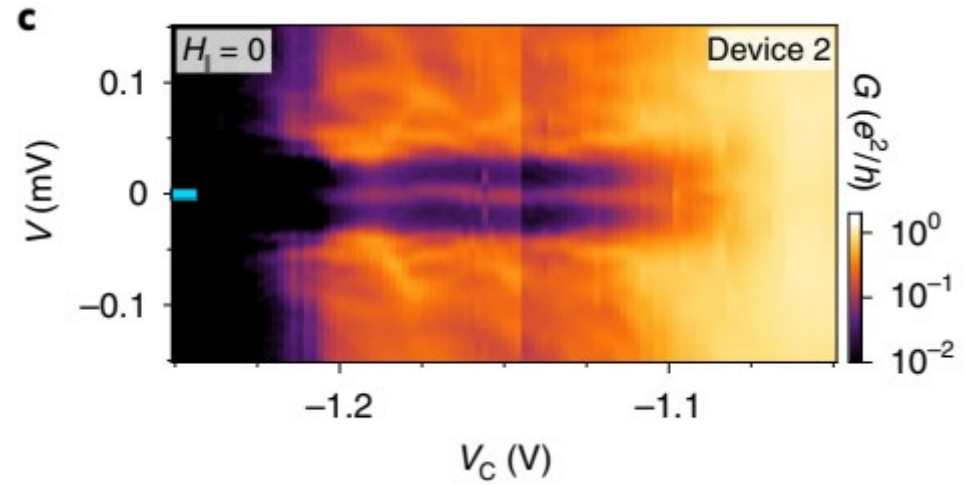
Zero-Bias Peaks!!



Principle: utilize the ferromagnet (EuS) for the effective Zeeman field instead of using an applied in-plane external magnetic field

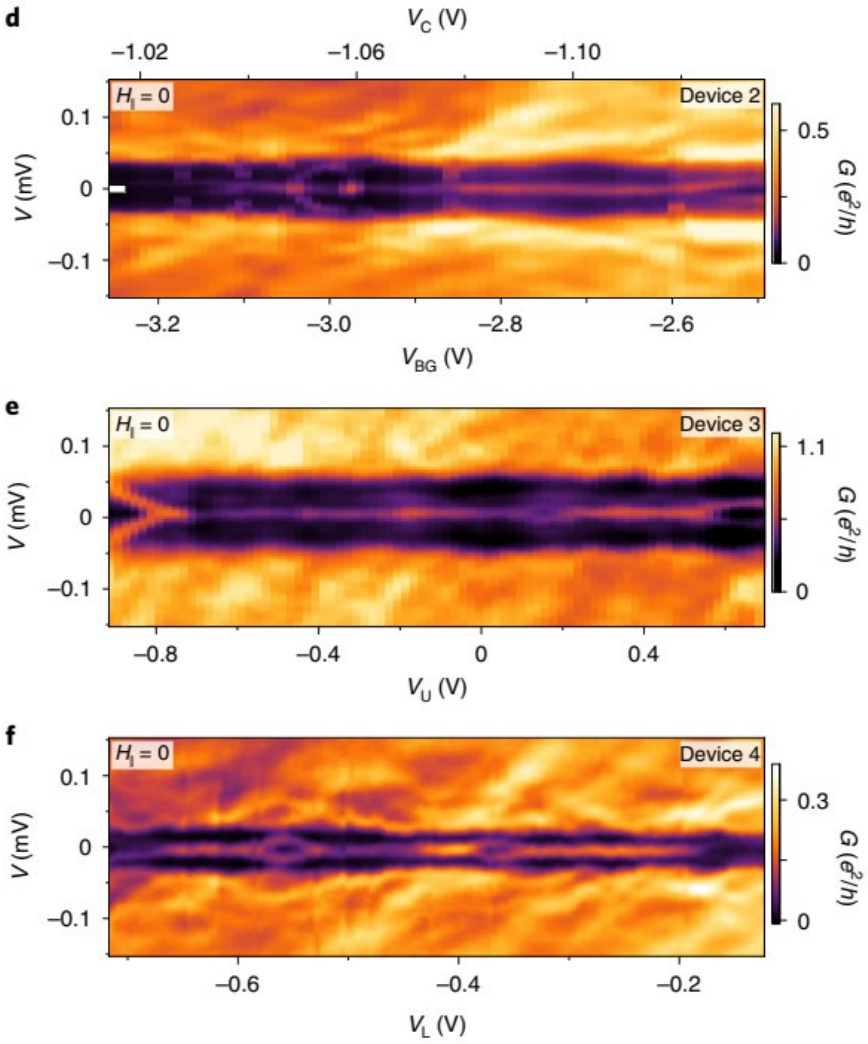


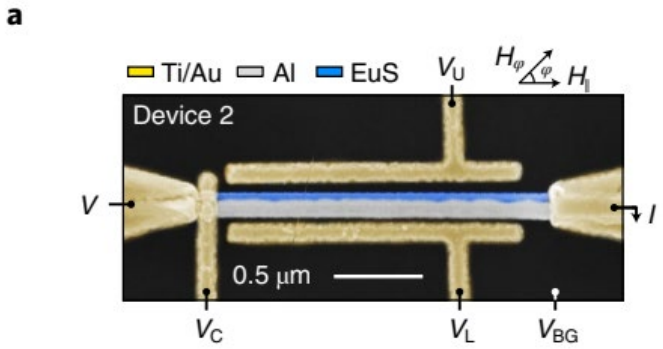


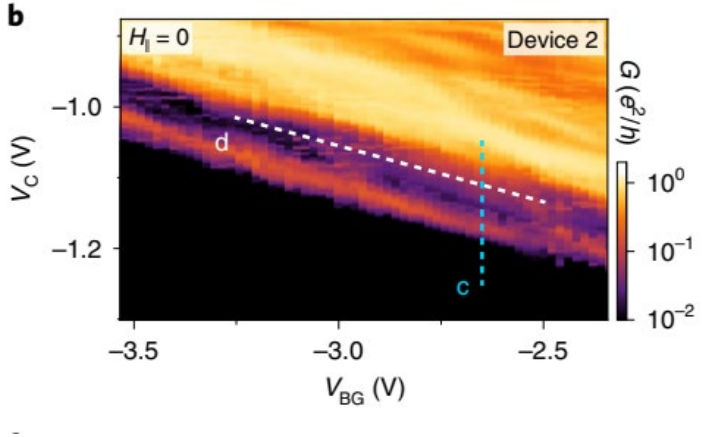


Note: ~1/2 of devices fabricated showed subgap states

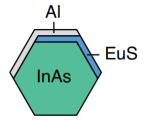
More ZBPs!

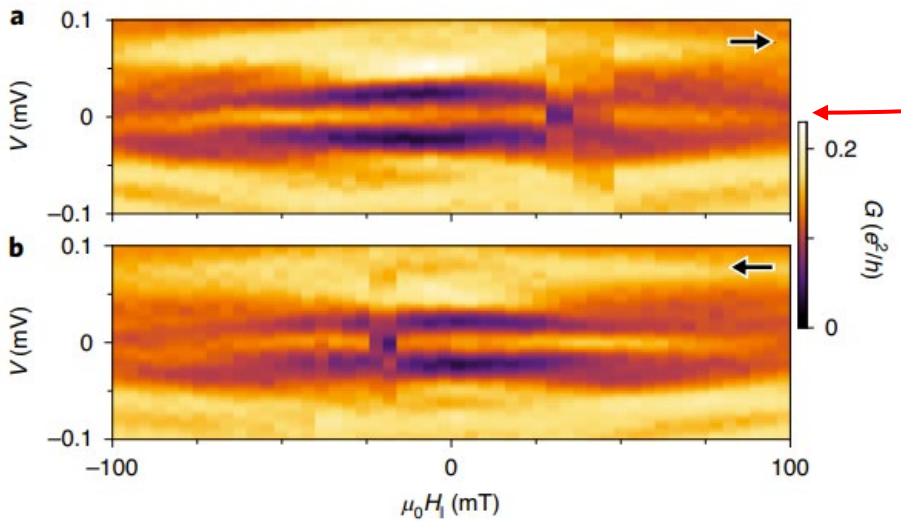

d
V_C (V)
−1.02
−1.06
−1.10
$H_\parallel = 0$
Device 2
0.1
0
−0.1
V (mV)
0.5
0
G (e^2/h)
−3.2
−3.0
−2.8
−2.6
V_{BG} (V)
e
$H_\parallel = 0$
Device 3
1.1
−0.8
−0.4
0
0.4
V_U (V)
f
$H_\parallel = 0$
Device 4
0.3
−0.6
−0.4
−0.2
V_L (V)

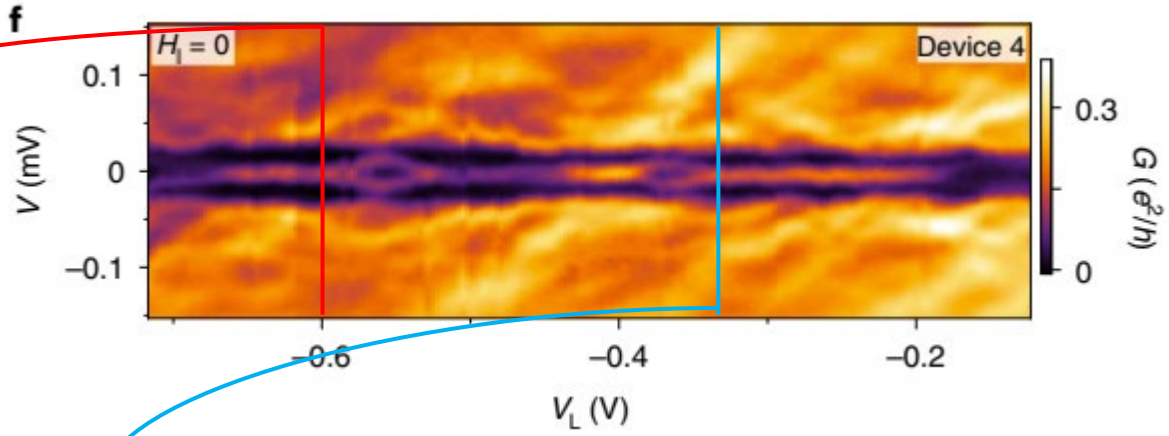

a
Ti/Au
Al
EuS
V_U
H_φ
$H_\parallel$
Device 2
V
I
0.5 μm
V_C
V_L
V_{BG}

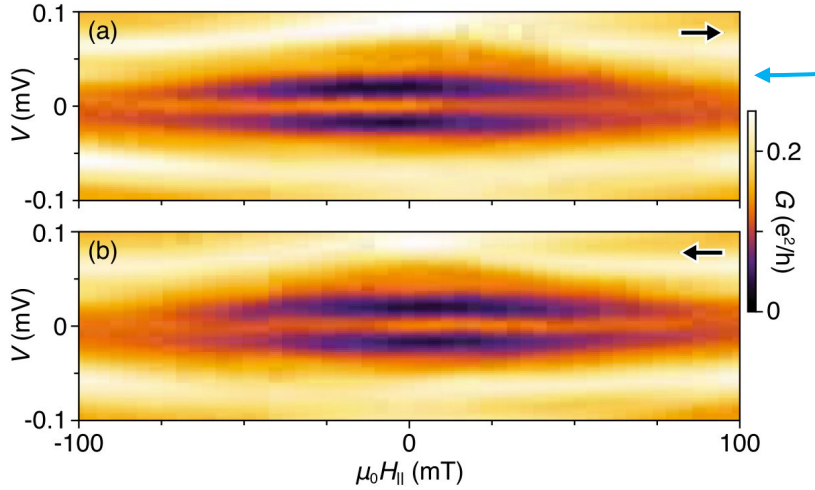

b
$H_\parallel = 0$
Device 2
−1.0
−1.2
V_C (V)
d
c
G (e^2/h)
10^0
10^{-1}
10^{-2}
−3.5
−3.0
−2.5
V_{BG} (V)

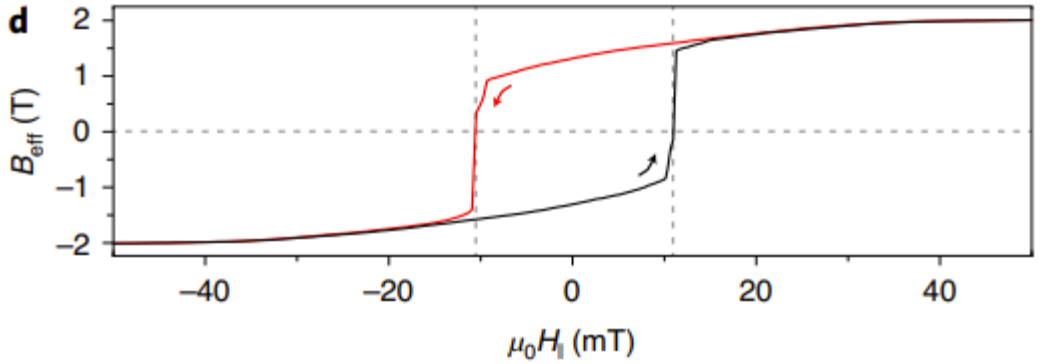
Loss of ZBP at Coercive Fields











(Coercive field for device 4 ≈ $\pm$ 25 mT)

[3] Nijholt, Akhmerov, PRB **93**, 23524 (2016)

Conclusion

- Microsoft wants Majoranas (to exist)
- Requires: 1D wire, strong SOI, coupled SC, *strong B-field parallel to wire*
- Applying external B-field is detrimental to SC and places strong limits on a number of device parameters
- Epitaxial EuS (ferromagnetic insulator) and Aluminum grown epitaxially on InAs wires
- SC-FMI hybrids exhibit spin splitting of SC DOS with zero applied B-field due to ferromagnetic exchange coupling
- Novel system to explore complex interactions between SOI, SC and FMI (could yield topological state)

Thanks for listening!

Determination of $B_{eff}(H_{\parallel}=0)$

$$\ln\left(\frac{T_C(\alpha)}{T_C(\alpha=0)}\right) = \Psi\left(\frac{1}{2}\right) - \Psi\left(\frac{1}{2}+\frac{\alpha}{2\pi k_B T_C(\alpha)}\right)$$

$$\alpha = \mu_B B_{eff}$$

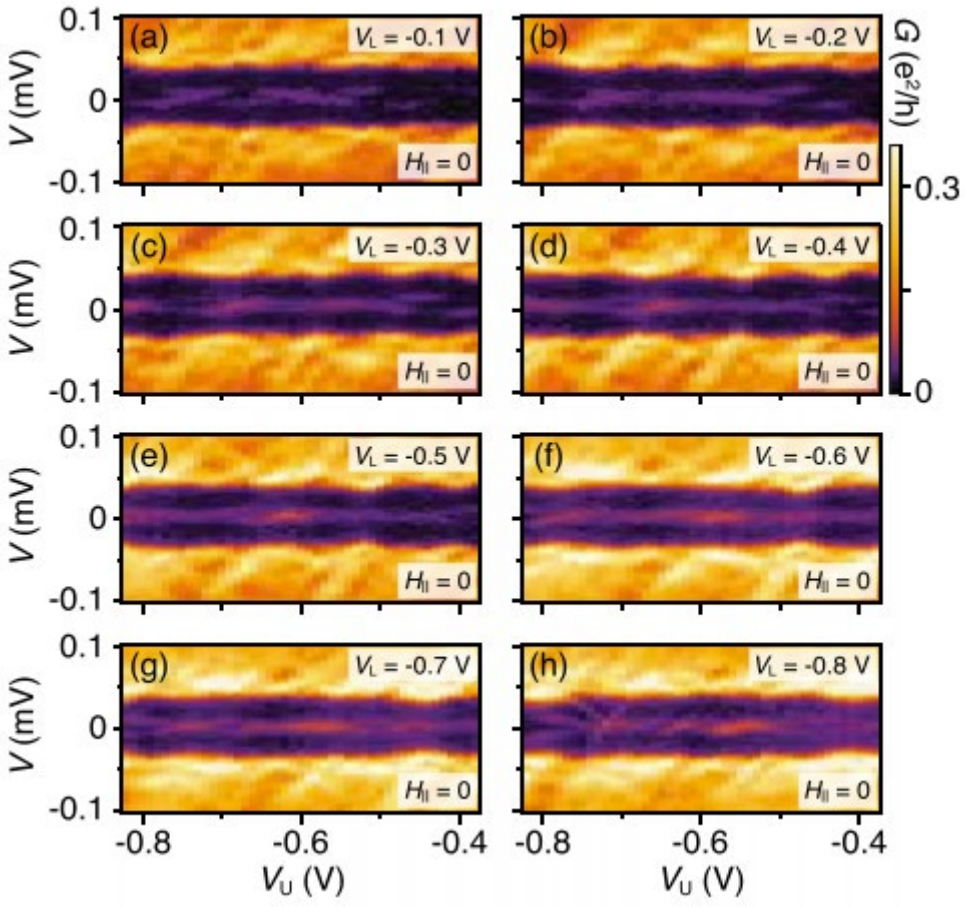
$$B_{eff} = \mu_0 (M + H_{\parallel})$$

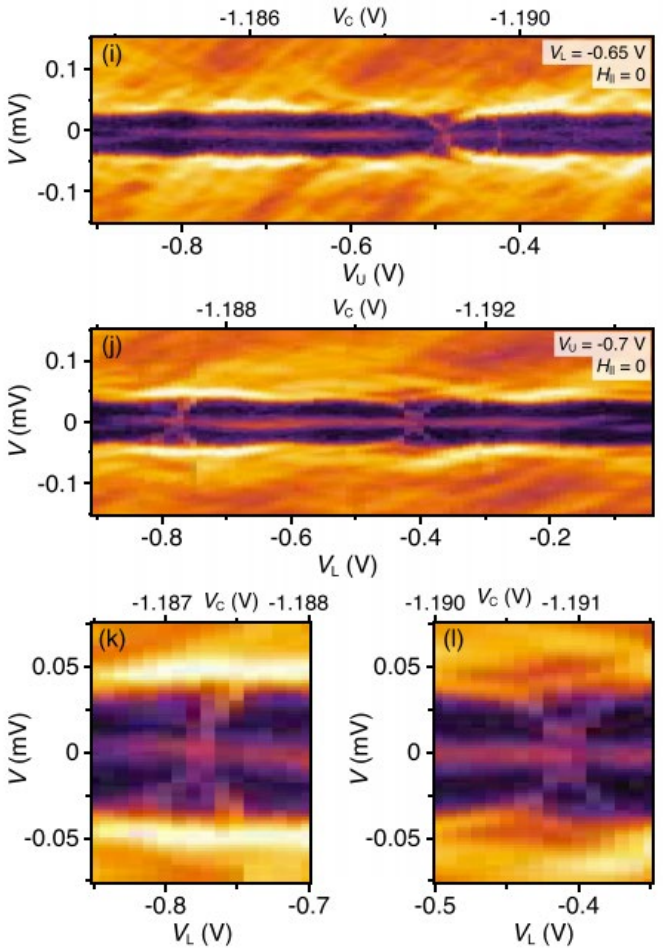
$$T_C(H_{\parallel}) = T_{C0}\left(\frac{I_C(H_{\parallel})}{I_{C0}}\right)^{2/3}$$

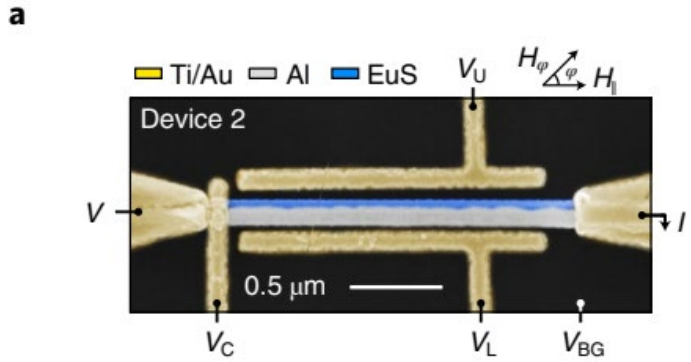
$$T_C(\alpha=0) = 1.5\,\mathrm{K}$$

$$T_{C0} = 0.8\,\mathrm{K}$$

Still More!!


(a) V_L = -0.1 V
(b) V_L = -0.2 V
(c) V_L = -0.3 V
(d) V_L = -0.4 V
(e) V_L = -0.5 V
(f) V_L = -0.6 V
(g) V_L = -0.7 V
(h) V_L = -0.8 V
$H_{||}$ = 0
G (e^2/h)
0.3
0
V (mV)
0.1
0
-0.1
-0.8
-0.6
-0.4
V_U (V)


(i) V_L = -0.65 V
$H_{||}$ = 0
-1.186 V_C (V) -1.190
V (mV)
V_U (V)
(j) V_U = -0.7 V
$H_{||}$ = 0
-1.188 V_C (V) -1.192
V_L (V)
(k)
-1.187 V_C (V) -1.188
(l)
-1.190 V_C (V) -1.191
0.05
0
-0.05


a
Ti/Au
Al
EuS
V_U
H_φ
$H_{||}$
Device 2
V
I
0.5 µm
V_C
V_L
V_{BG}

Other Devices!