Edge-mode Superconductivity in a Two Dimensional Topological Insulator

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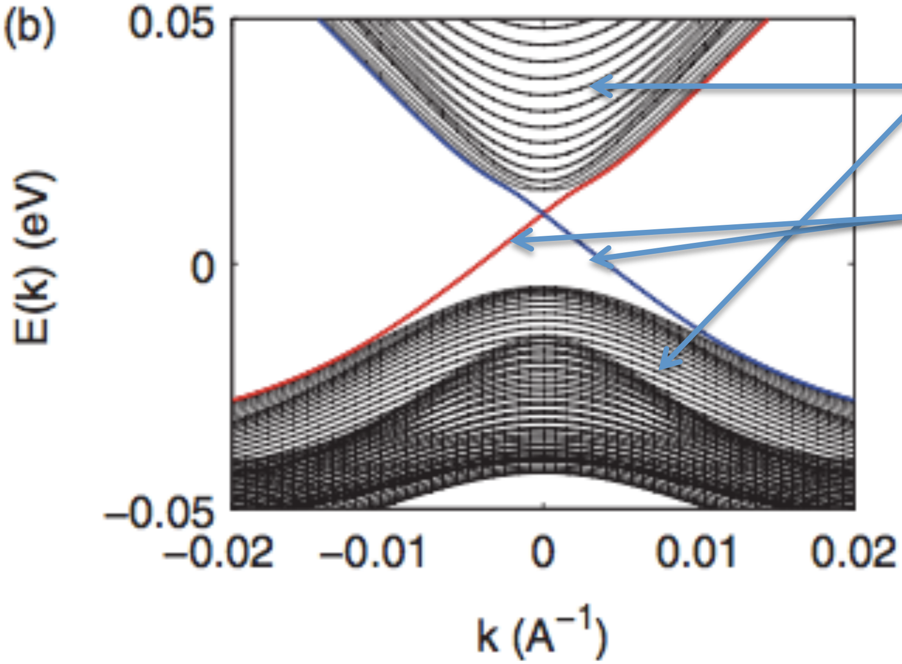
Topological superconductivity is an exotic state of matter that supports Majorana zero-modes, which are surface modes in 3D, edge modes in 2D or localized end states in 1D [1, 2]. In the case of complete localization these Majorana modes obey non-Abelian exchange statistics making them interesting building blocks for topological quantum computing [3, 4]. Here we report superconductivity induced into the edge modes of semiconducting InAs/GaSb quantum wells, a two-dimensional topological insulator [5–10]. Using superconducting quantum interference, we demonstrate gate-tuning between edge-dominated and bulk-dominated regimes of superconducting transport. The edge-dominated regime arises only under conditions of high-bulk resistivity, which we associate with the 2D topological phase. These experiments establish InAs/GaSb as a robust platform for further confinement of Majoranas into localized states enabling future investigations of non-Abelian statistics.

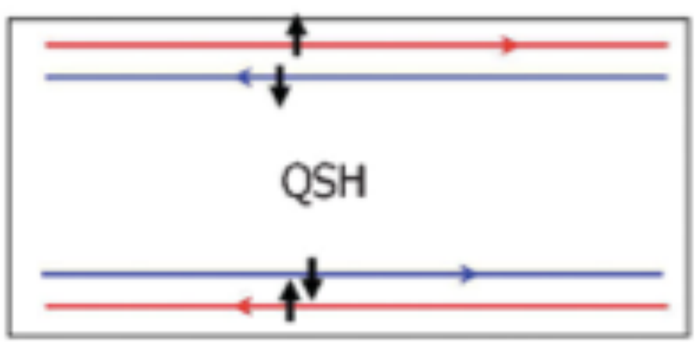
Silas Hoffman
Journal club
14.8.14

2D Topological Insulators



Bulk states

In-gap helical states

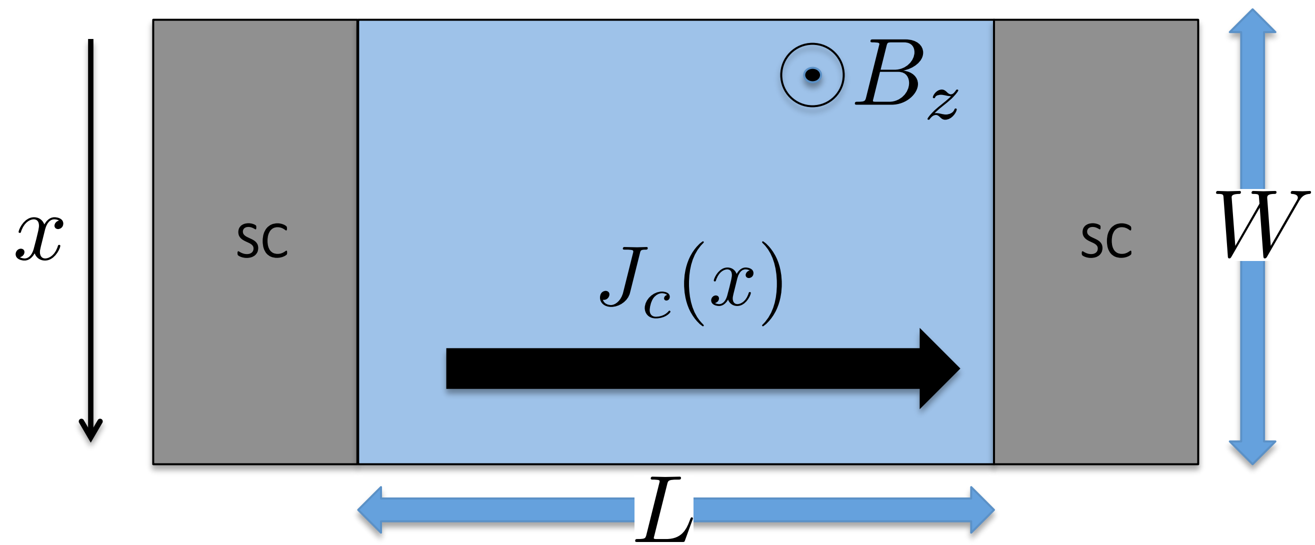


CdTe|HgTe|CdTe

InAs|GaSb

Qi and Zhang, 2010

Superconducting Quantum Interference



The critical current through a superconductor as a function of magnetic field depends on the density distribution of current:

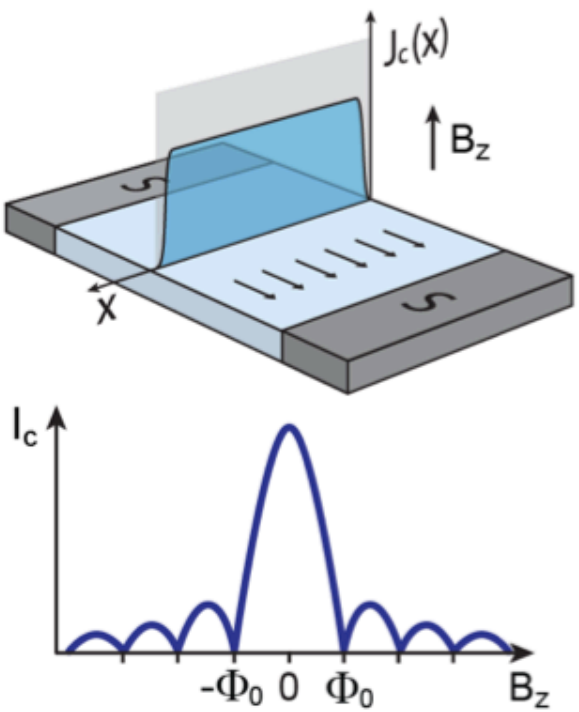
$$I_c(B_z) = \left\| \int_{-\infty}^{\infty} J_c(x) e^{ikx} dx \right\|.$$

$$k = 2\pi L B_z / \Phi_0$$

Dynes and Fulton, 1973

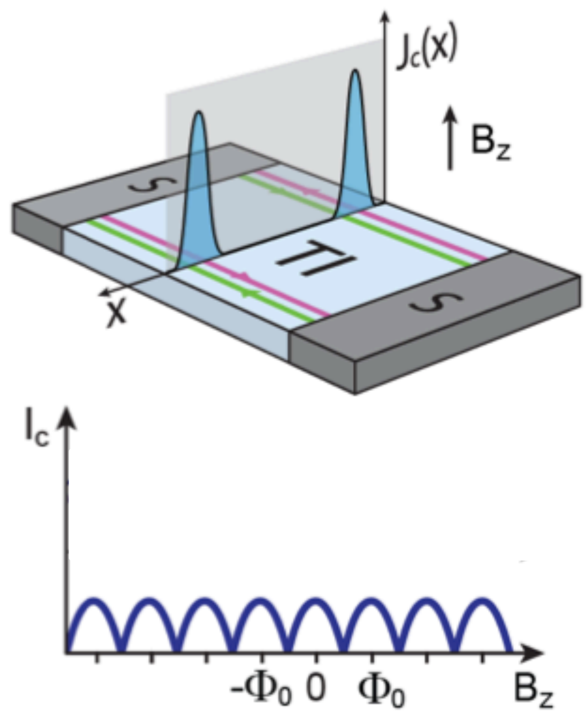
Bulk vs Edge

$$J_c(x) = \text{const}$$



$$I_c \sim \left| \frac{\sin(\pi\Phi/\Phi_0)}{\Phi/\Phi_0} \right|$$

$$J_c(x) = \delta(0) + \delta(W)$$



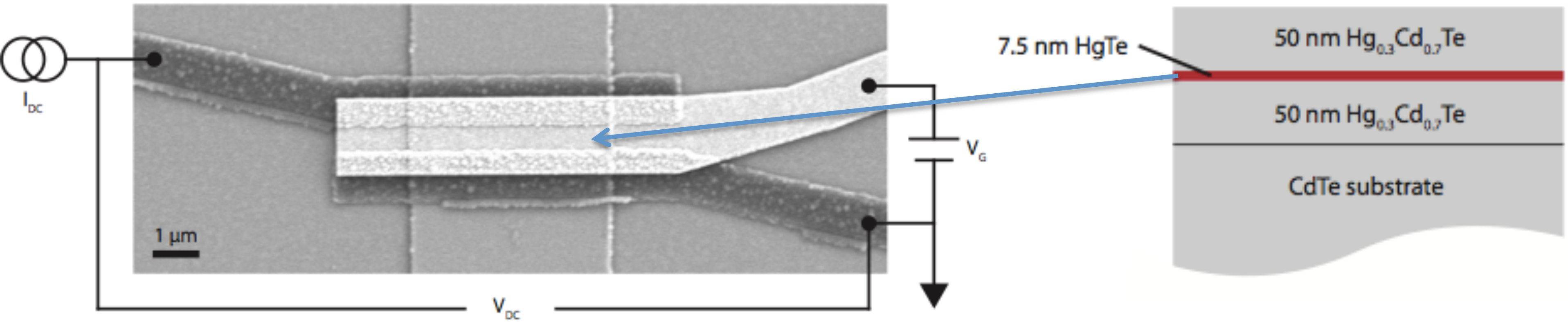
$$I_c \sim |\cos(\pi\Phi/\Phi_0)|$$

Theory: The interference pattern can differ between superconducting current carried in the bulk and by edge modes.

Experiment: Measure superconducting interference pattern in bulk and in the topological regime and determine the current distribution

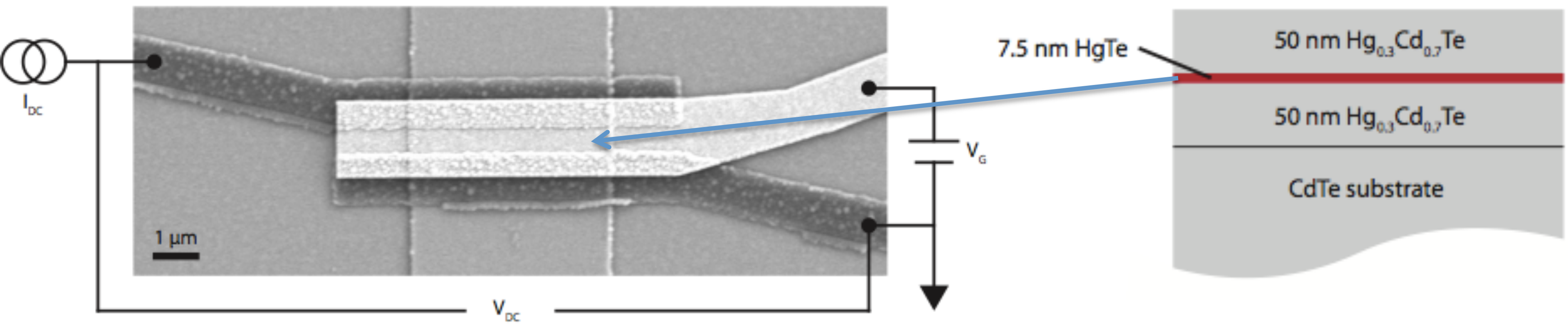
HgCdTe|HgTe|HgCdTe

Hart et al., 2014

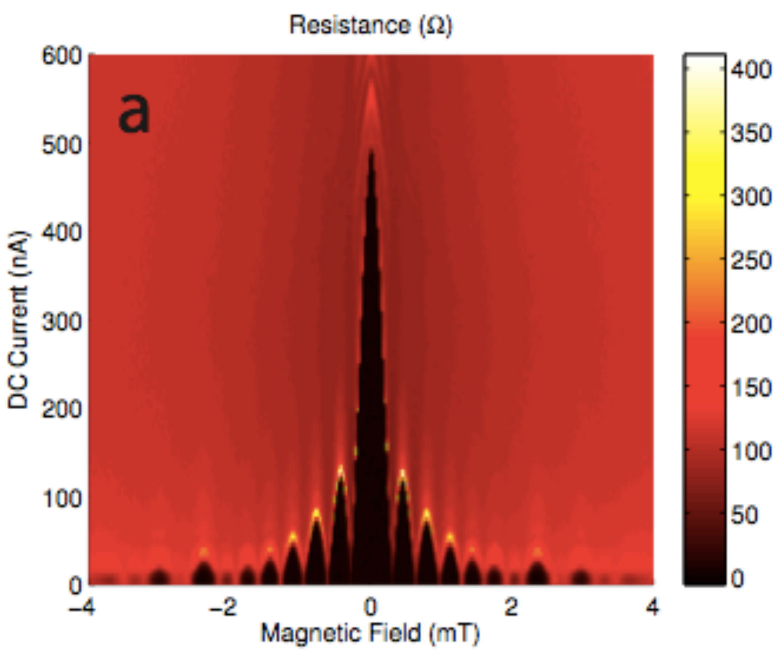


HgCdTe|HgTe|HgCdTe

Hart et al., 2014

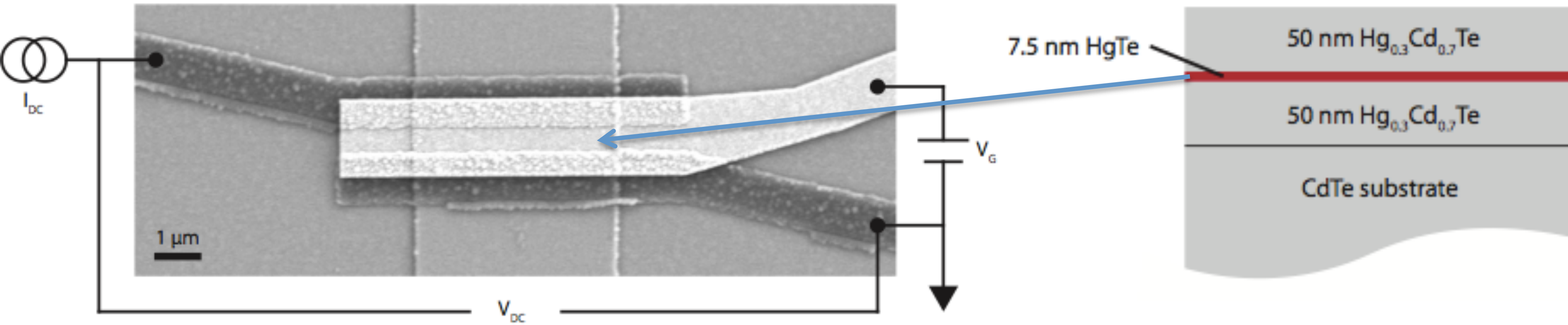


Bulk



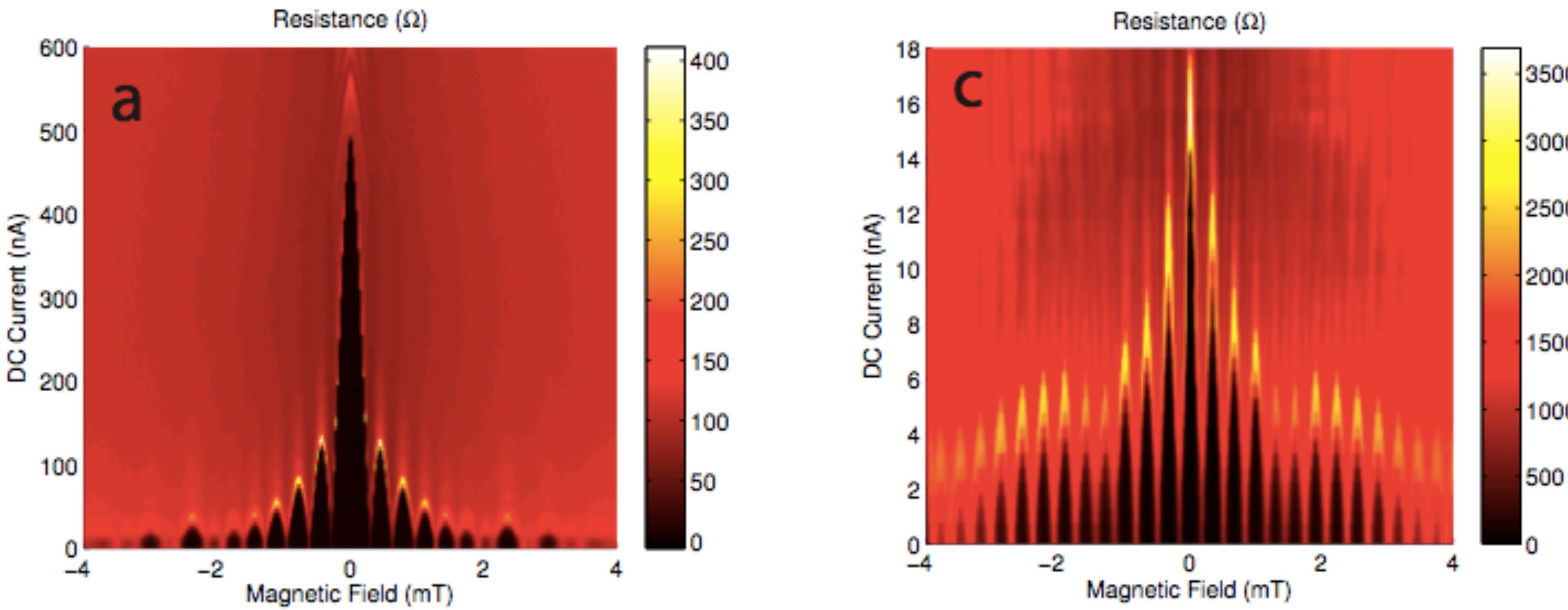
HgCdTe|HgTe|HgCdTe

Hart et al., 2014



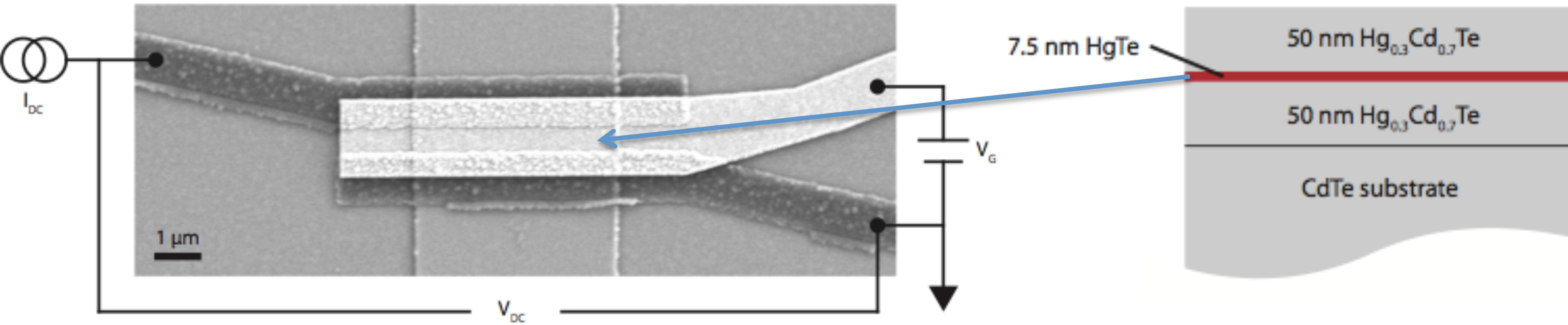
Bulk

Gap

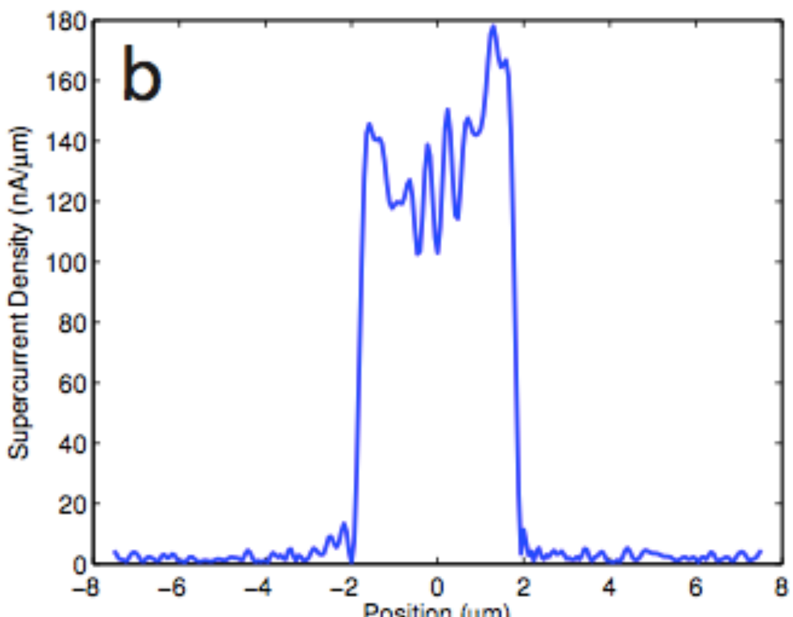


HgCdTe|HgTe|HgCdTe

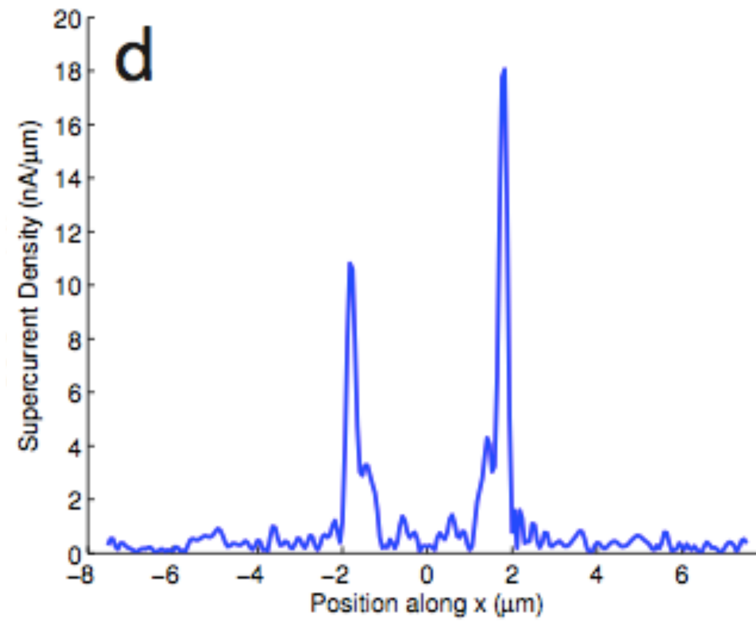
Hart et al., 2014



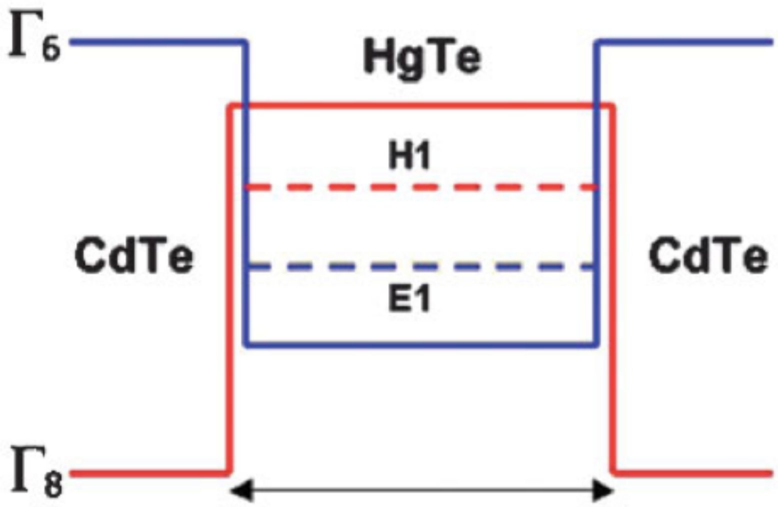
Bulk



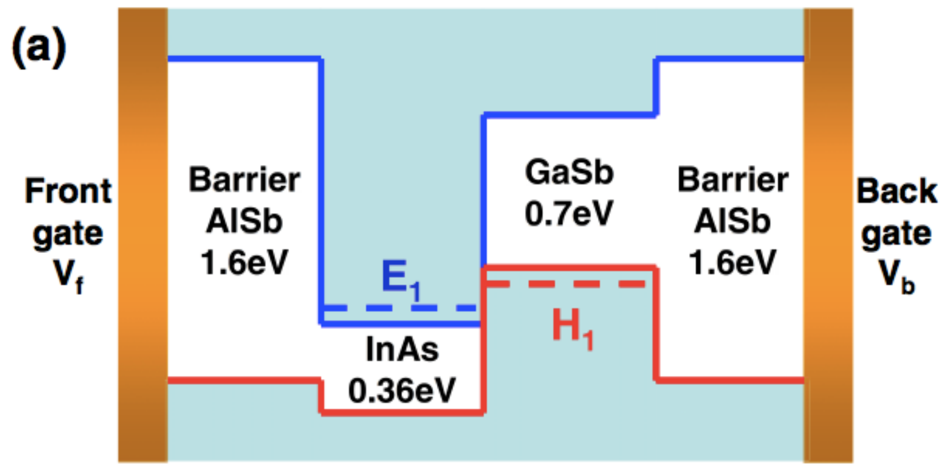
Gap



How is InAr|GaSb different from HgCdTe|HgTe?

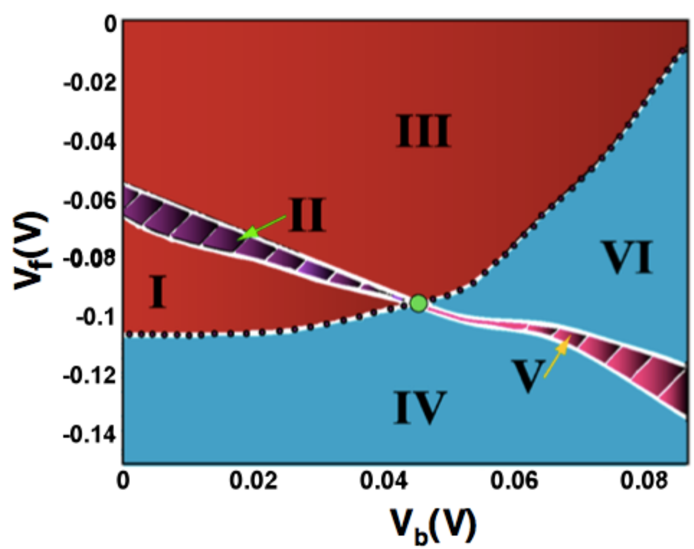


Bernevig et al., 2006

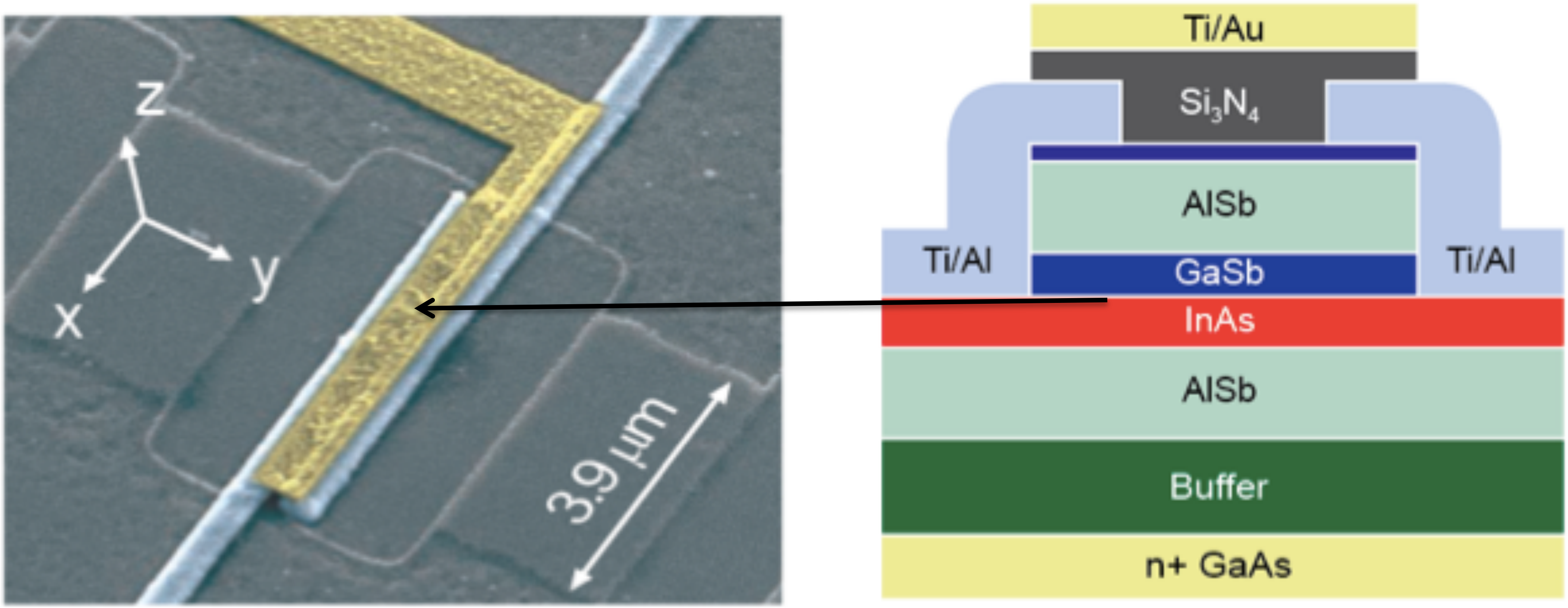


Liu et al., 2008

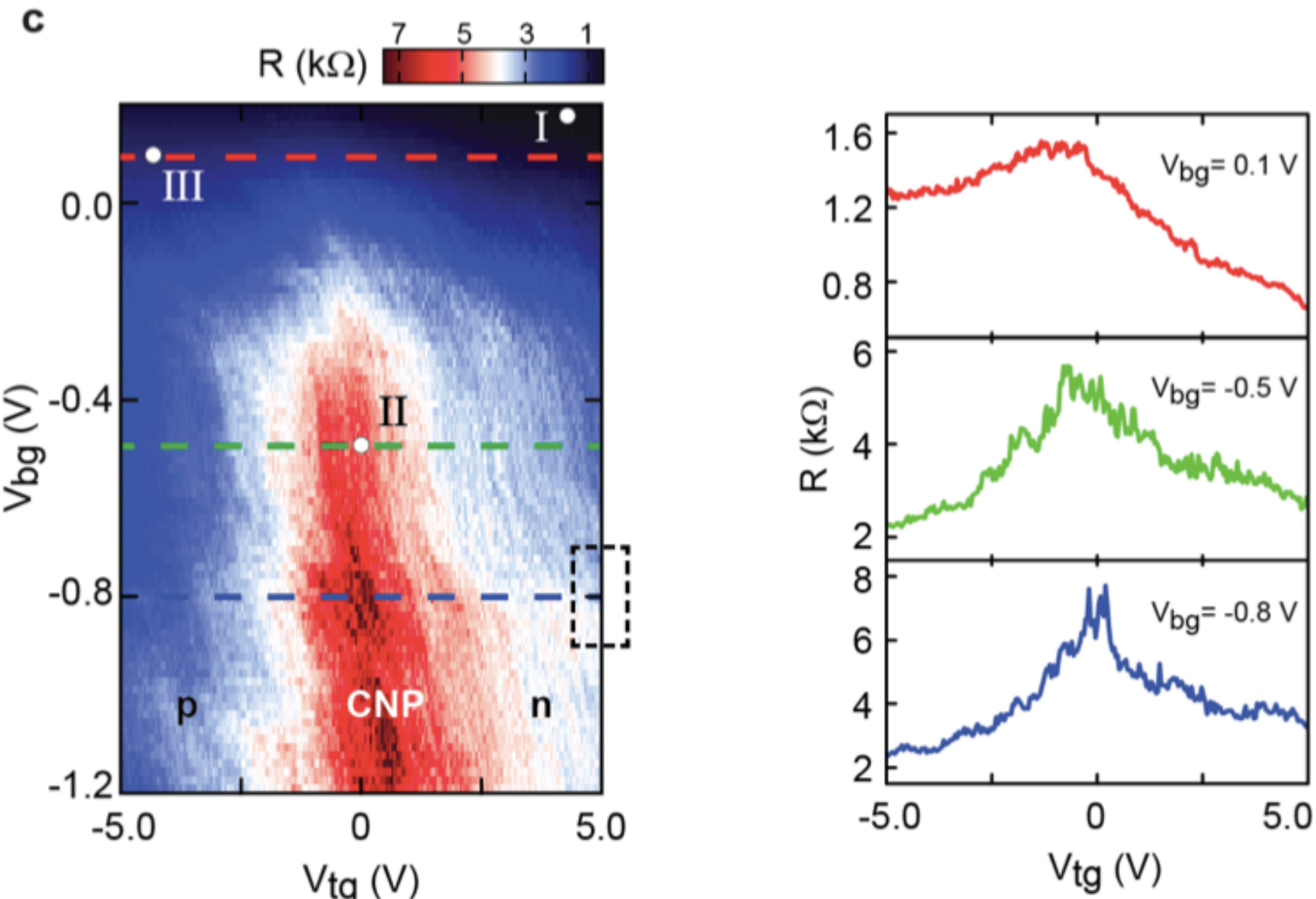
- Because of the lack of inversion symmetry, there is a SIA term in the
- Electron and hole bands reside in different materials
  - Bands can be gated independently
  - Can tune between TI and normal regime with voltage!



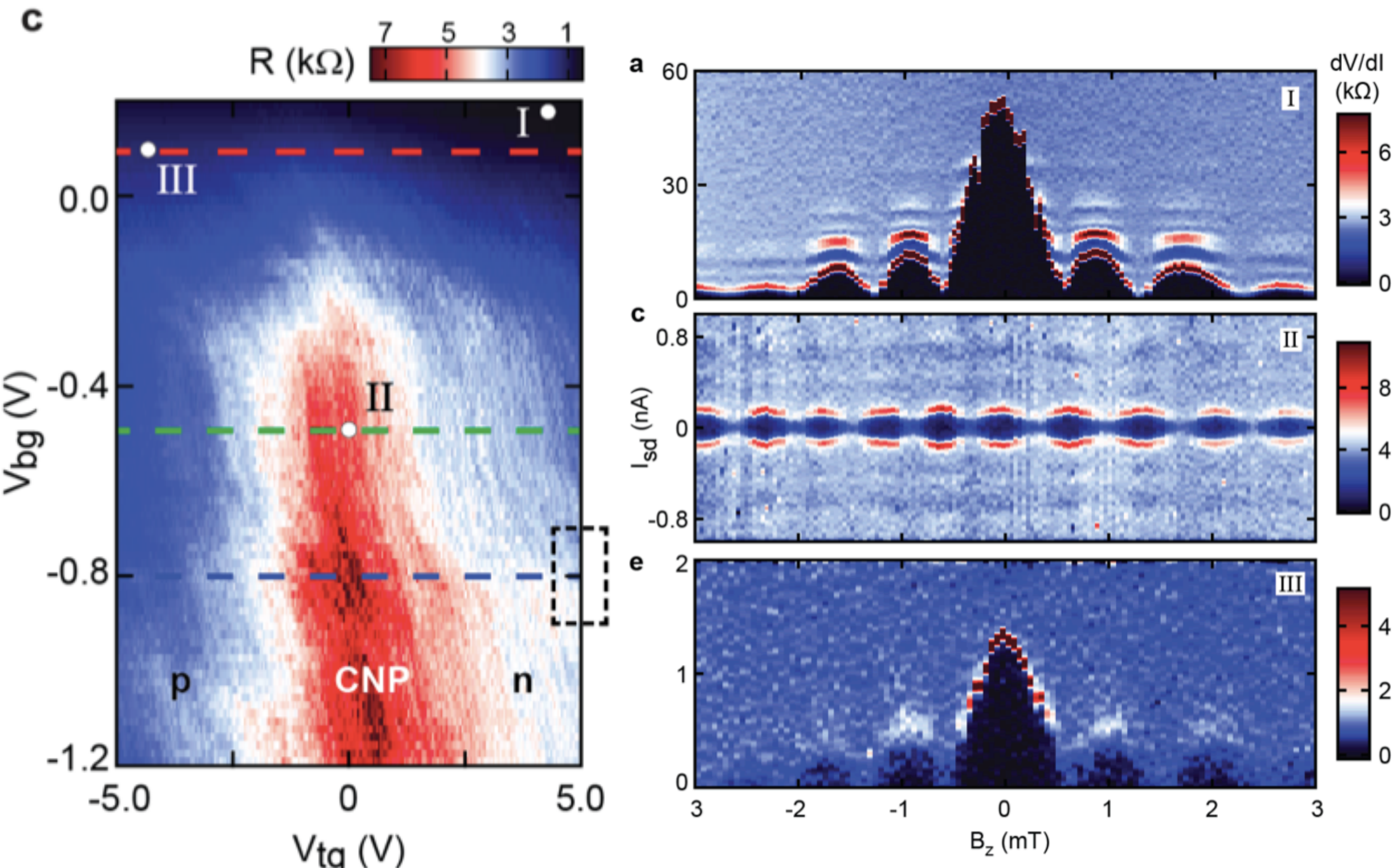
InAr|GaSb - setup



InAr|GaSb

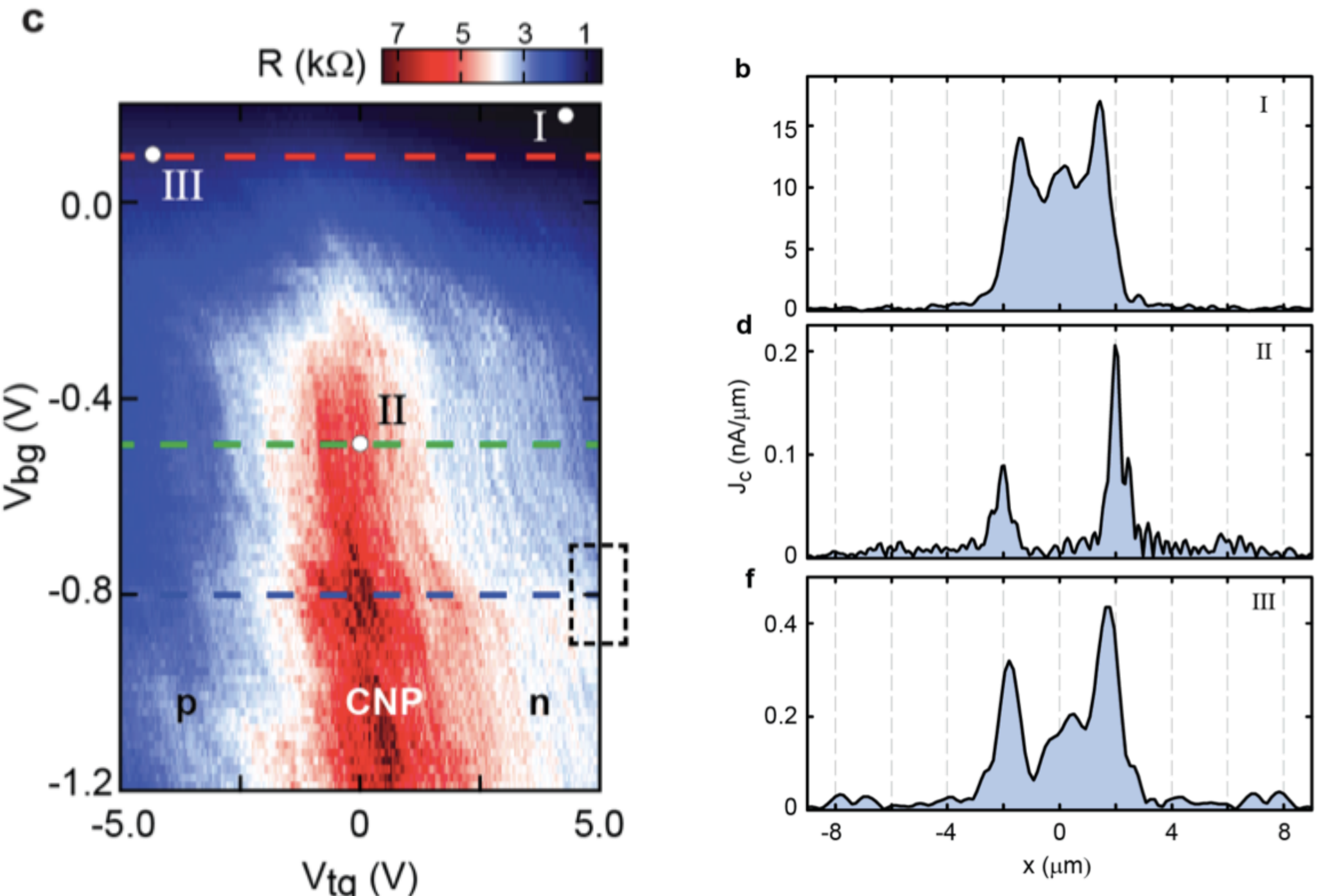

c
R (kΩ)
7
5
3
1
I
III
II
CNP
p
n
Vbg (V)
0.0
-0.4
-0.8
-1.2
-5.0
0
5.0
Vtg (V)
1.6
1.2
0.8
Vbg= 0.1 V
6
4
2
Vbg= -0.5 V
8
6
4
2
Vbg= -0.8 V
R (kΩ)
-5.0
0
5.0
Vtg (V)

InAr|GaSb

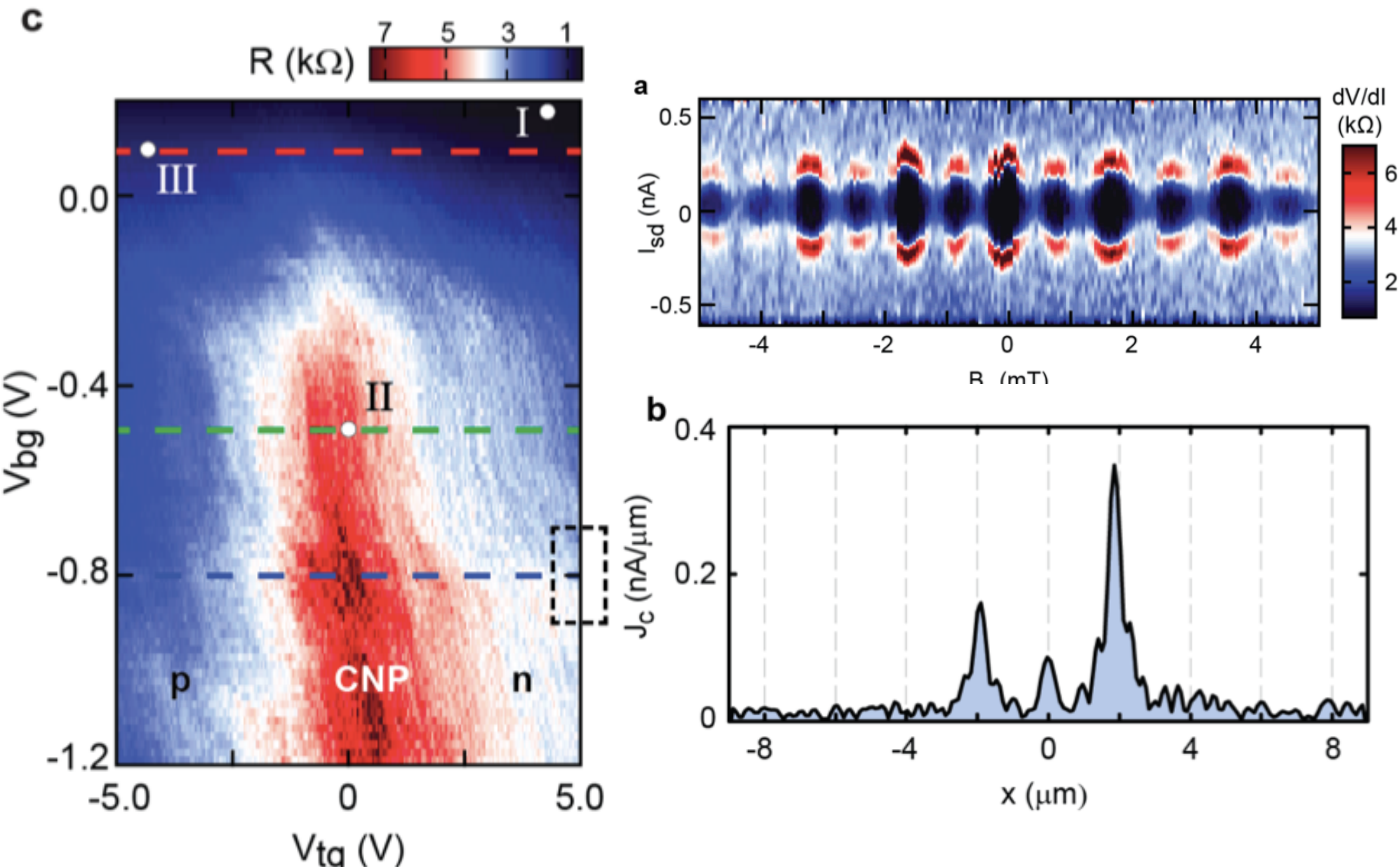


c
R (kΩ)
7 5 3 1
I
III
II
CNP
p
n
0.0
-0.4
-0.8
-1.2
Vbg (V)
-5.0
0
5.0
Vtg (V)
a
60
30
0
dV/dI
(kΩ)
6
3
0
c
0.8
0
-0.8
Isd (nA)
8
4
0
e
2
1
0
4
2
0
3
-2
-1
0
1
2
3
Bz (mT)

InAr|GaSb


c
R (kΩ)
7
5
3
1
I
III
II
CNP
p
n
0.0
-0.4
-0.8
-1.2
Vbg (V)
-5.0
0
5.0
Vtg (V)
b
15
10
5
0
d
0.2
0.1
0
J_c (nA/μm)
f
0.4
0.2
0
-8
-4
0
4
8
x (μm)

InAr|GaSb



c
R (kΩ)
7 5 3 1
I
III
II
CNP
p
n
0.0
-0.4
-0.8
-1.2
Vbg (V)
-5.0 0 5.0
Vtg (V)
a
dV/dI (kΩ)
6 4 2
0.5 0 -0.5
Isd (nA)
-4 -2 0 2 4
b
0.4 0.2 0
Jc (nA/μm)
-8 -4 0 4 8
x (μm)

Conclusions

- Tuning the top/back gate voltage changes the Fraunhofer pattern

- Consistent (?) with edge modes carrying superconducting current