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Microwave Response in a Topological Superconducting Quantum Interference Device

Wei Pan

In collaboration with Daniel Soh, Wenlong Yu, Paul Davids, and Tina Nenoff

Sandia National Labs

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Single photon detection at microwave frequencies:

- Entanglement of superconducting qubits
- Secure quantum communications
- Quantum sensing
- Radioastronomy, dark-matter searches
- …

Graphene-Based Josephson-Junction Single-Photon Detector

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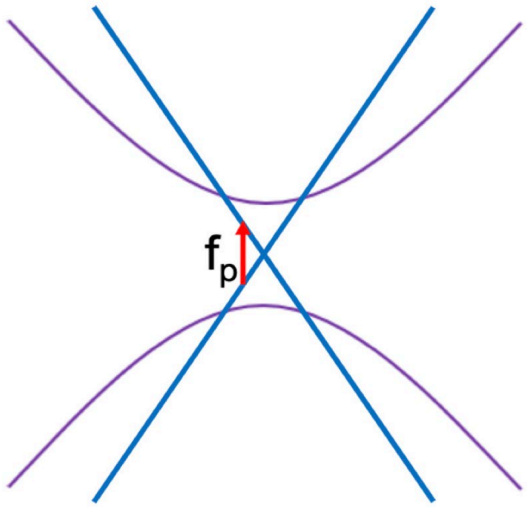
astronomy. As an example, we present our device concepts for GJJ single-photon detectors in both the microwave and infrared regimes. The dark count rate and intrinsic quantum efficiency are

Dirac semimetal is promising for microwave photon detection

-- Surface states → two dimensional electrons

-- Dirac energy dispersion relationship

-- High electron mobility



PHYSICAL REVIEW RESEARCH **3**, 023046 (2021)

Microwave photon number resolving detector using the topological surface state of superconducting cadmium arsenide

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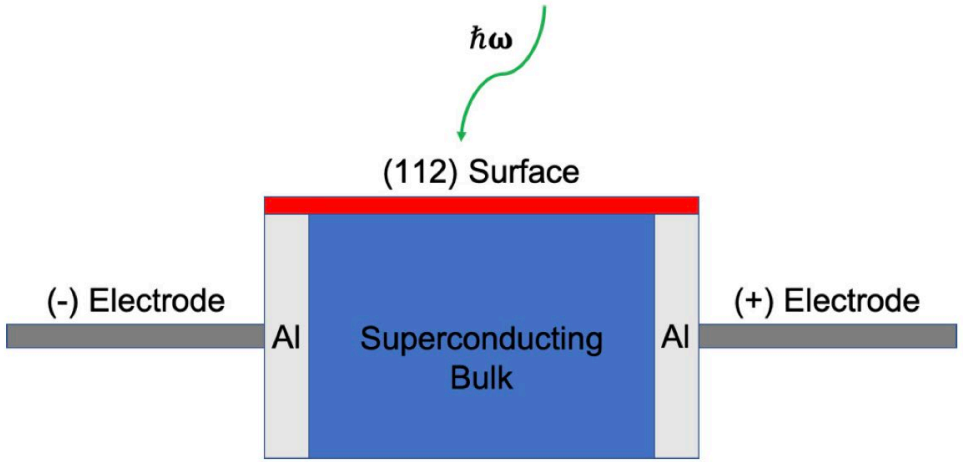
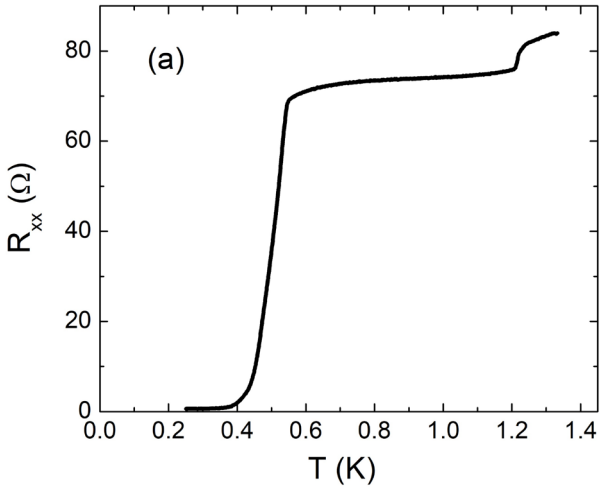
Photon number resolving detectors play a central role in quantum optics. A key challenge in resolving the number of absorbed photons in the microwave frequency range is finding a suitable material that provides not only an appropriate band structure for absorbing low-energy photons but also a means of detecting a discrete photoelectron excitation. To this end, we propose to measure the temperature gain after absorbing a photon using superconducting cadmium arsenide (Cd_3As_2) with a topological semimetallic surface state as the detector. The

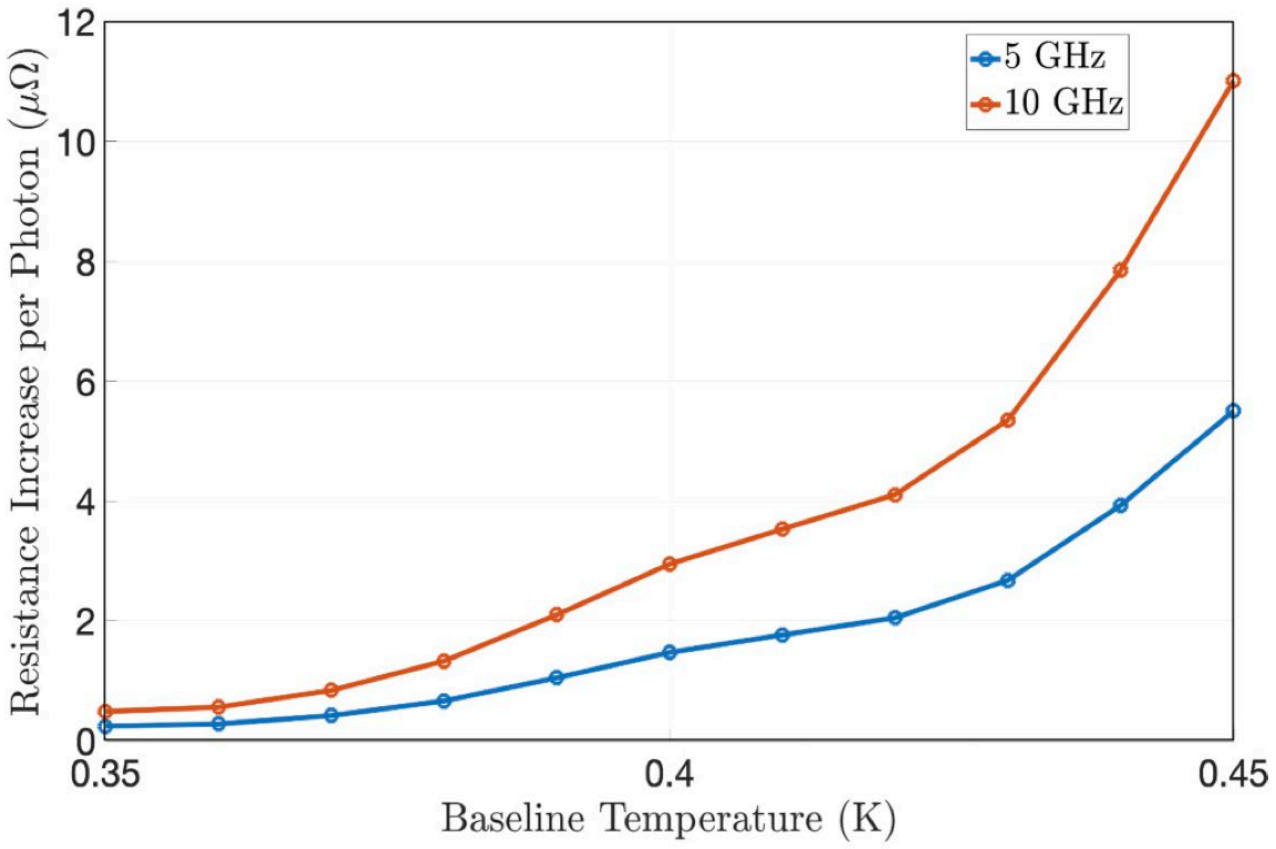
Complete quantum model of photon-number-resolving (PNR) RF single-photon detector

- Working principle of our proposed PNR-RF-SP detector:
  - Surface mode absorbs incoming RF photons.
  - Excited surface mode transfers energy to bulk phonons.
  - Bulk phonons increase the superconductor's temperature, which changes the bulk resistance.
  - Increased resistance resolves the number of photons absorbed.



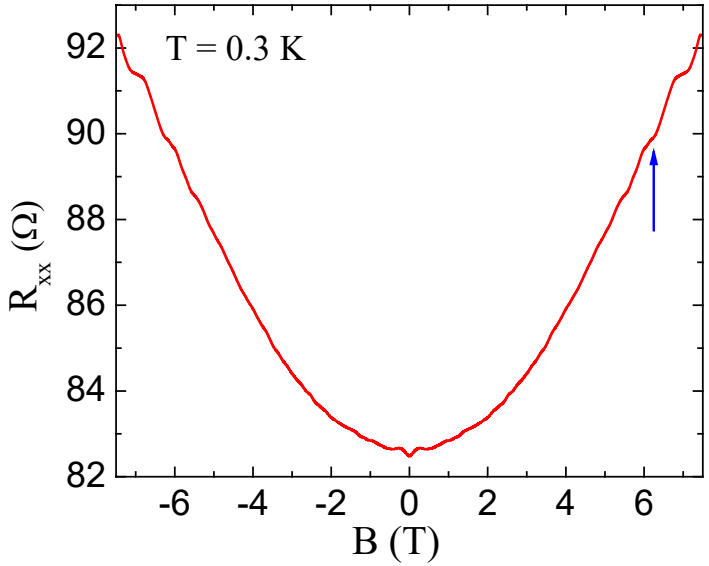
Superconducting Cd_3As_2 material

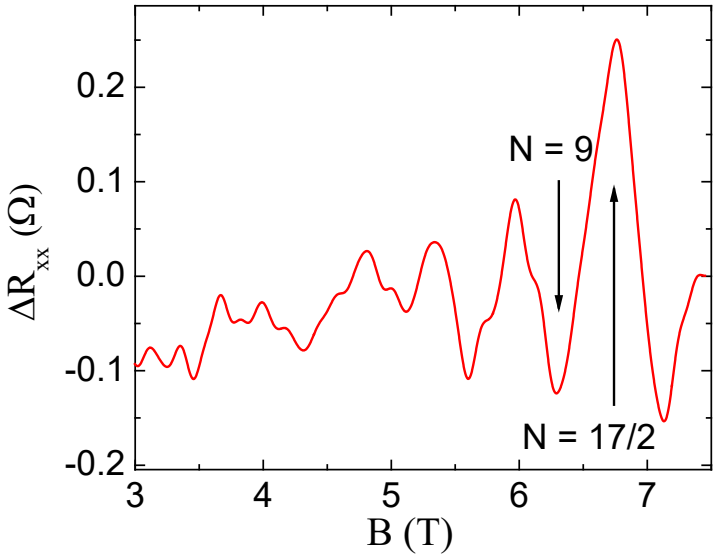


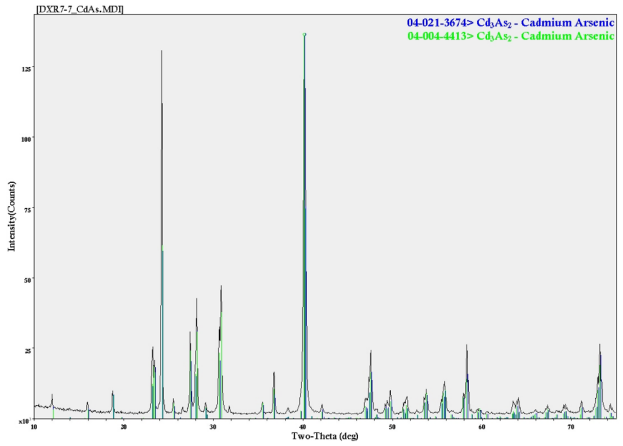


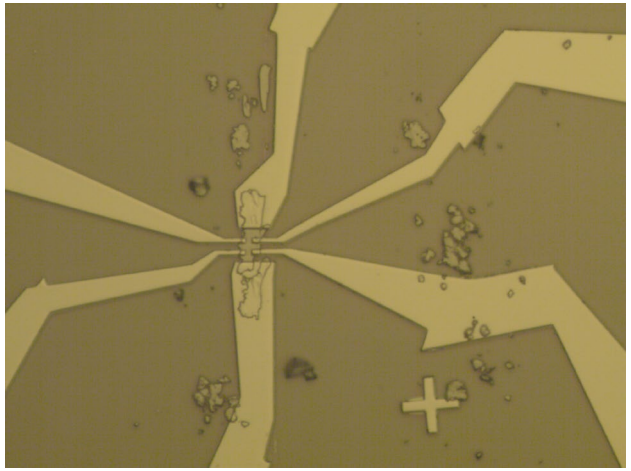
- Measurable resistance change upon absorbing one microwave photon.
- Depending on the “parking” temperature, one can resolve the number of absorbed RF photons by observing resistivity increase.
- Number resolving capability.

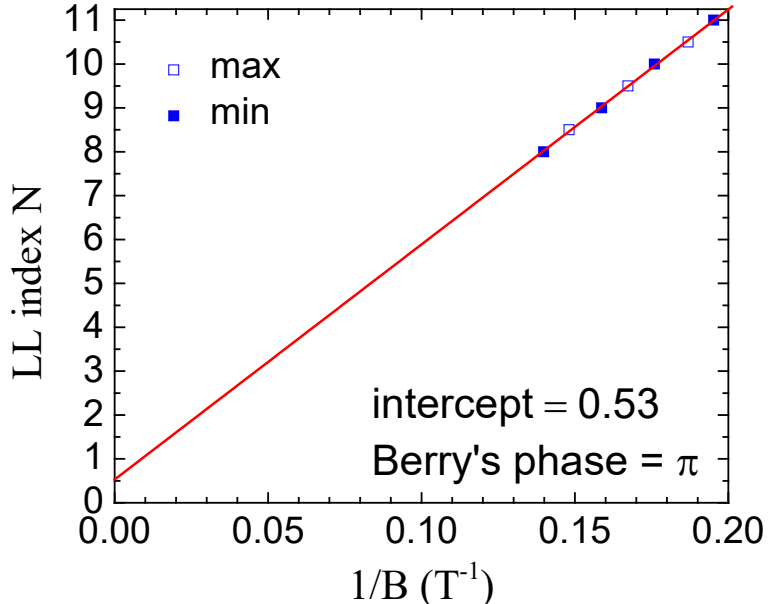
High quality Cd_3As_2



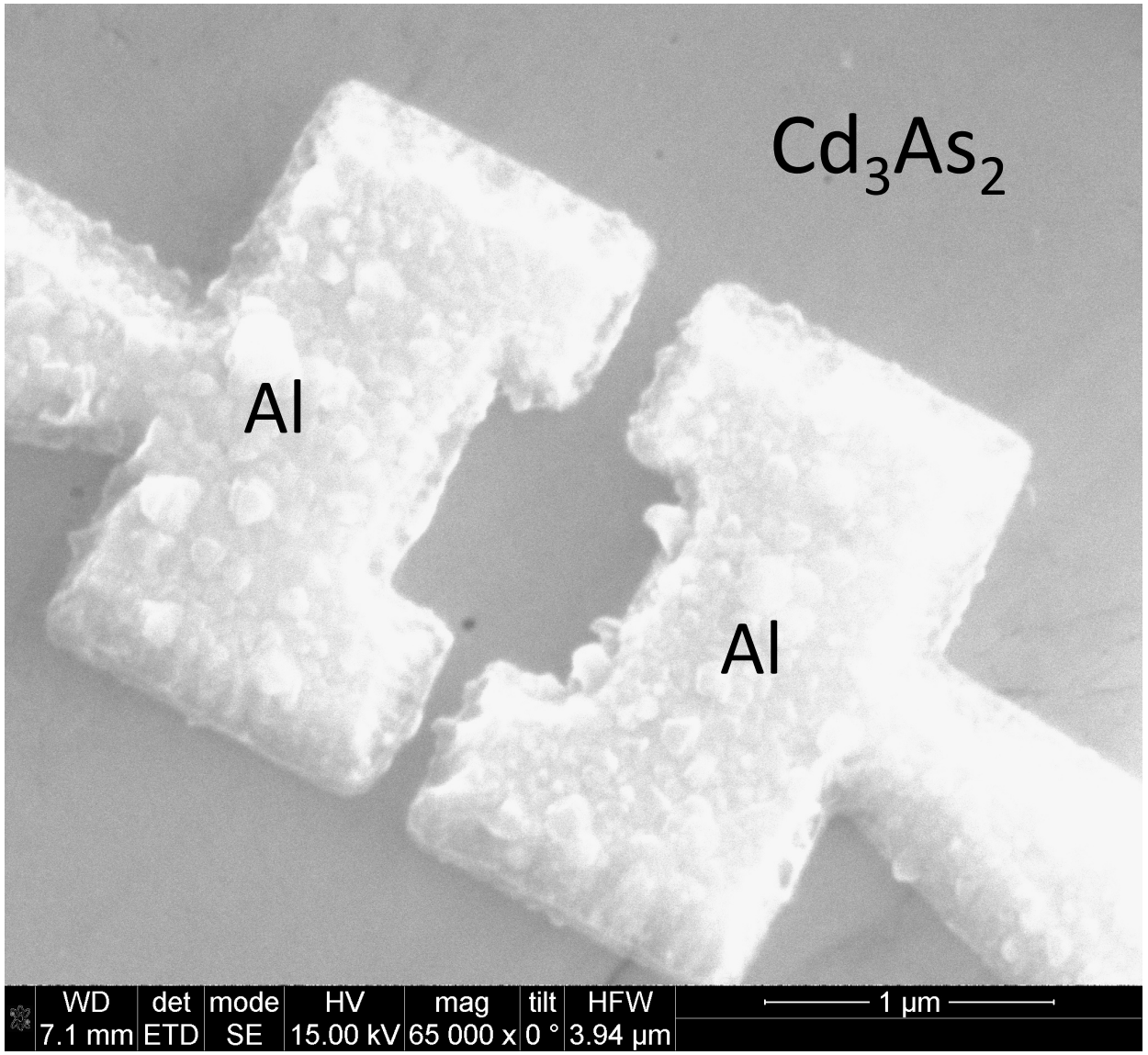


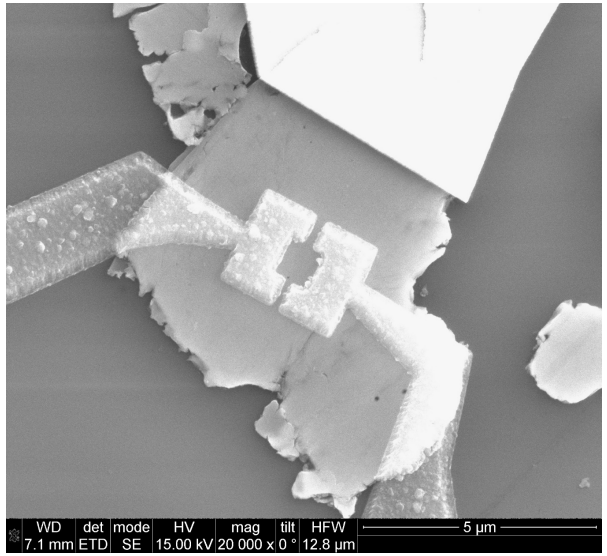


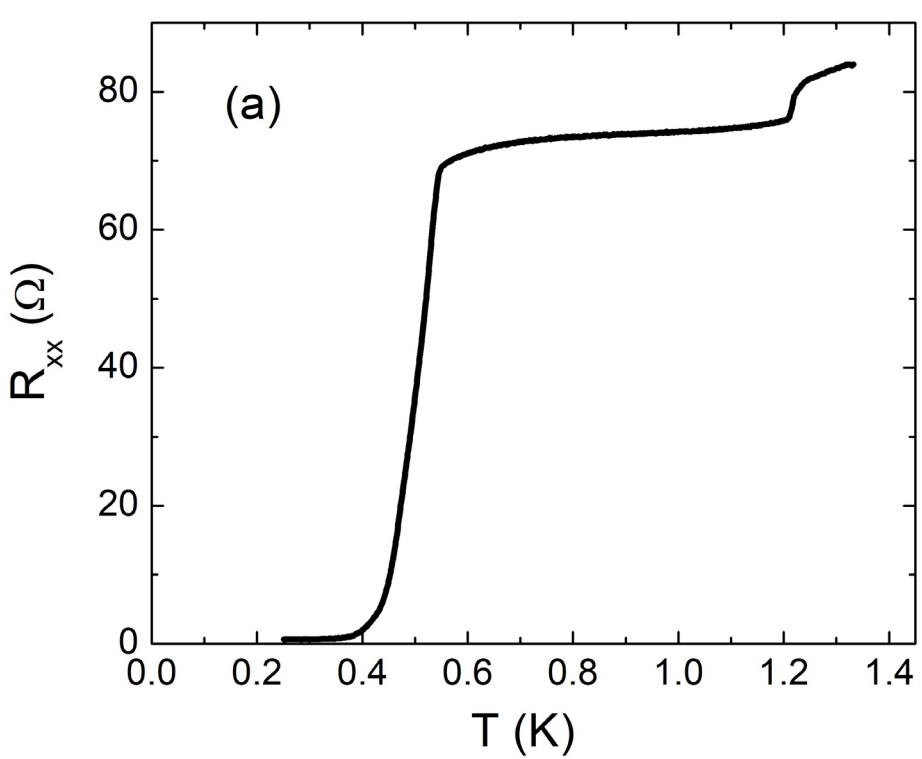


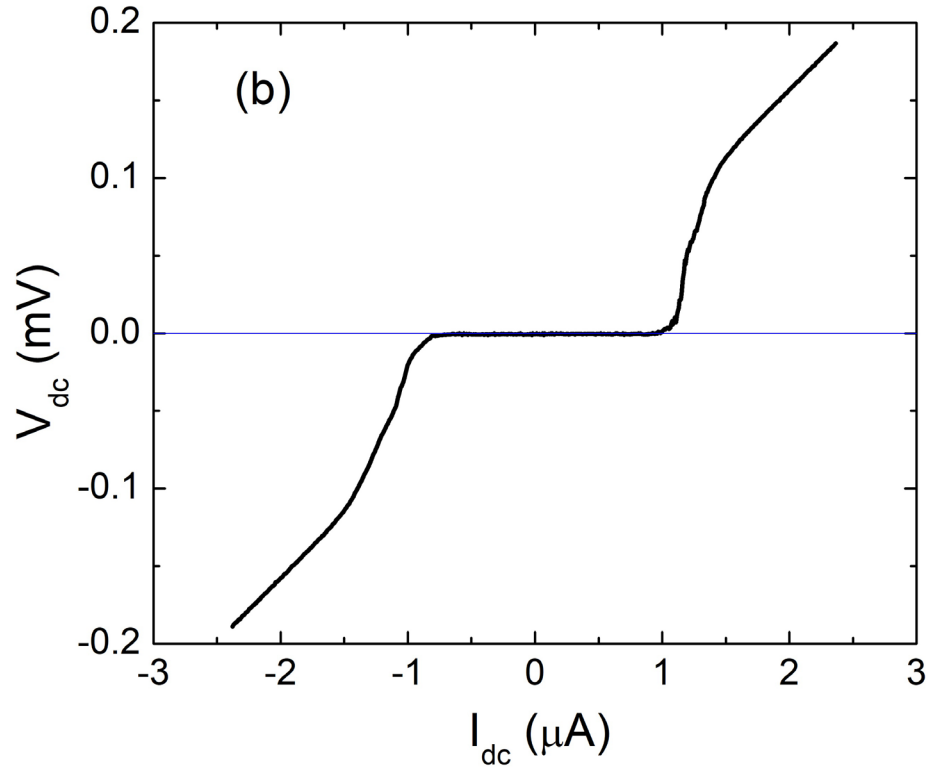


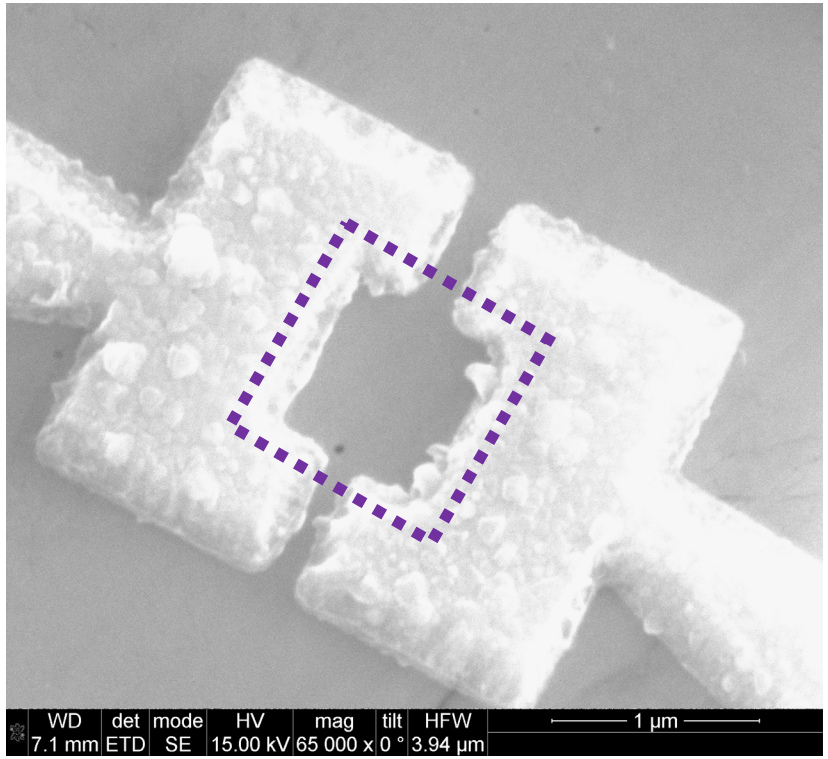
SQUID Device to study microwave response

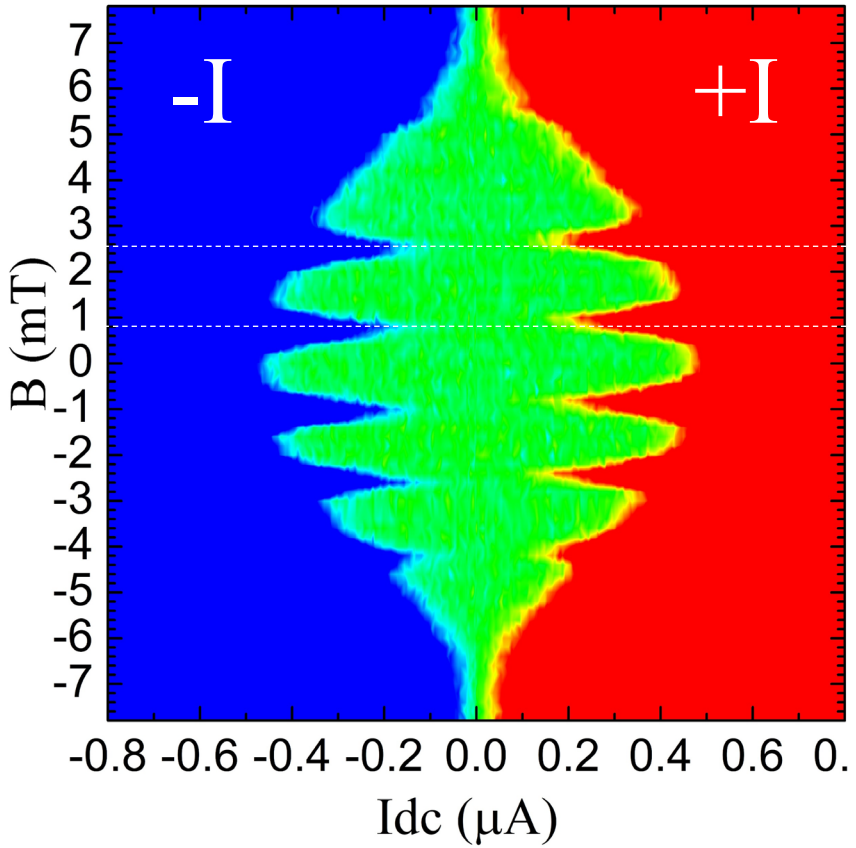


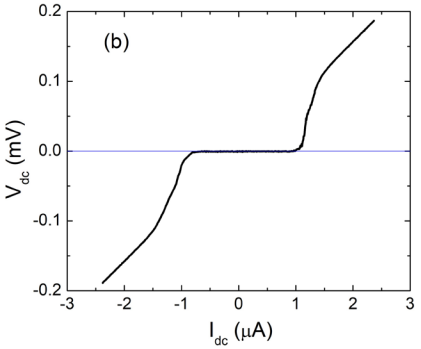



(a)
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
R_xx (Ω)
T (K)

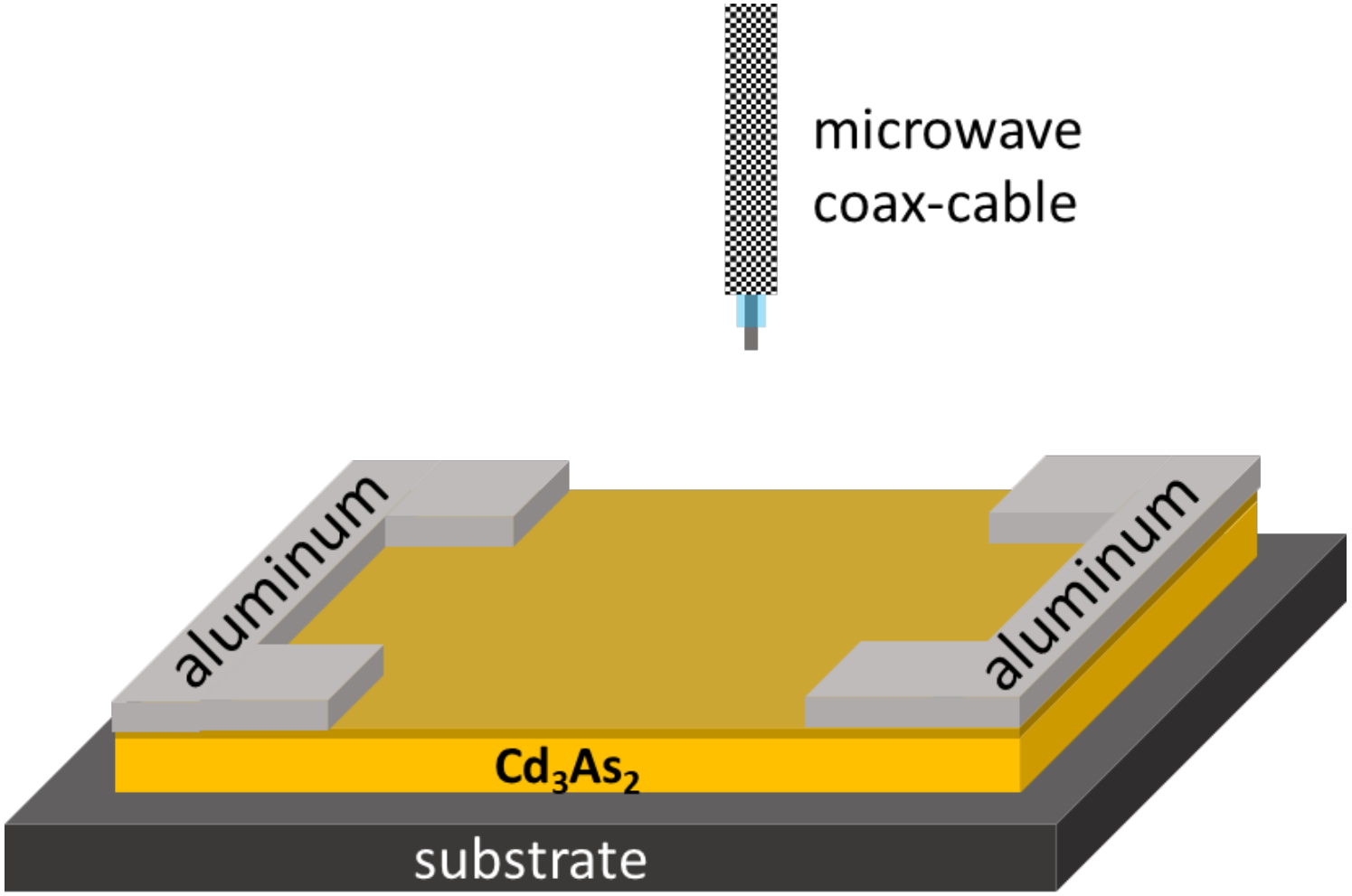

(b)
0.2
0.1
0.0
-0.1
-0.2
-3
-2
-1
0
1
2
3
V_dc (mV)
I_dc (μA)

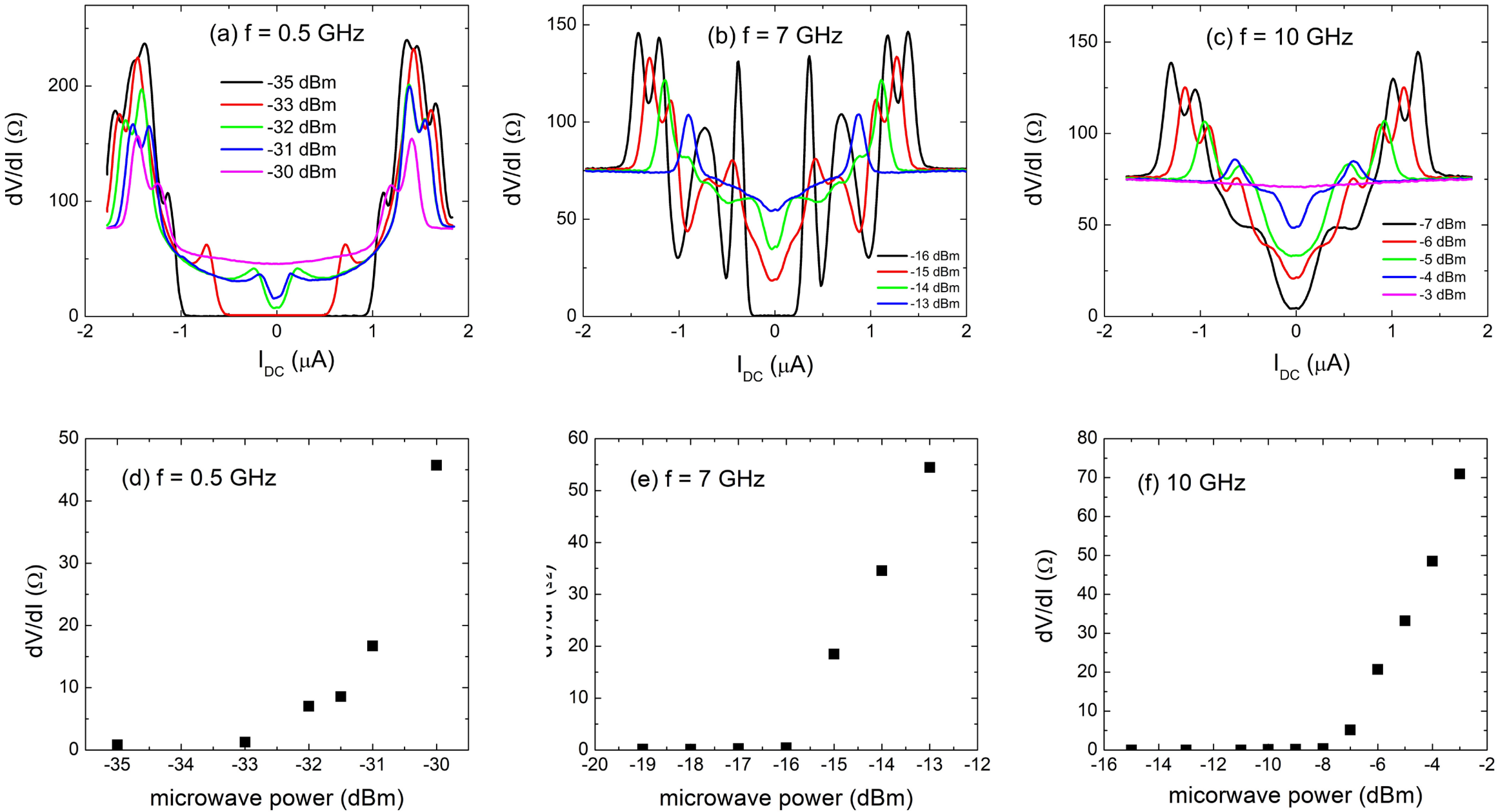

WD det mode HV mag tilt HFW
7.1 mm ETD SE 15.00 kV 65 000 x 0 ° 3.94 µm
1 µm

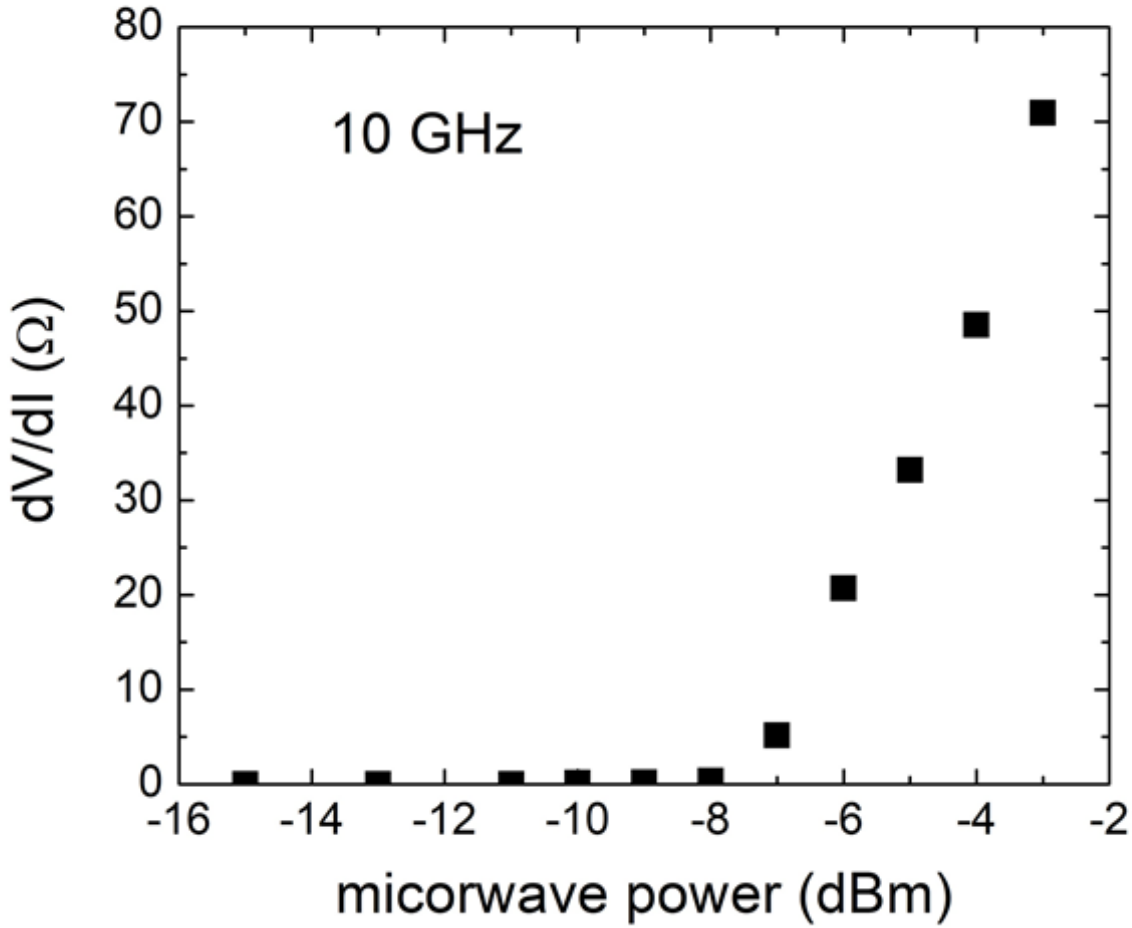

-I
+I
B (mT)
7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7
-0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.
Idc (µA)

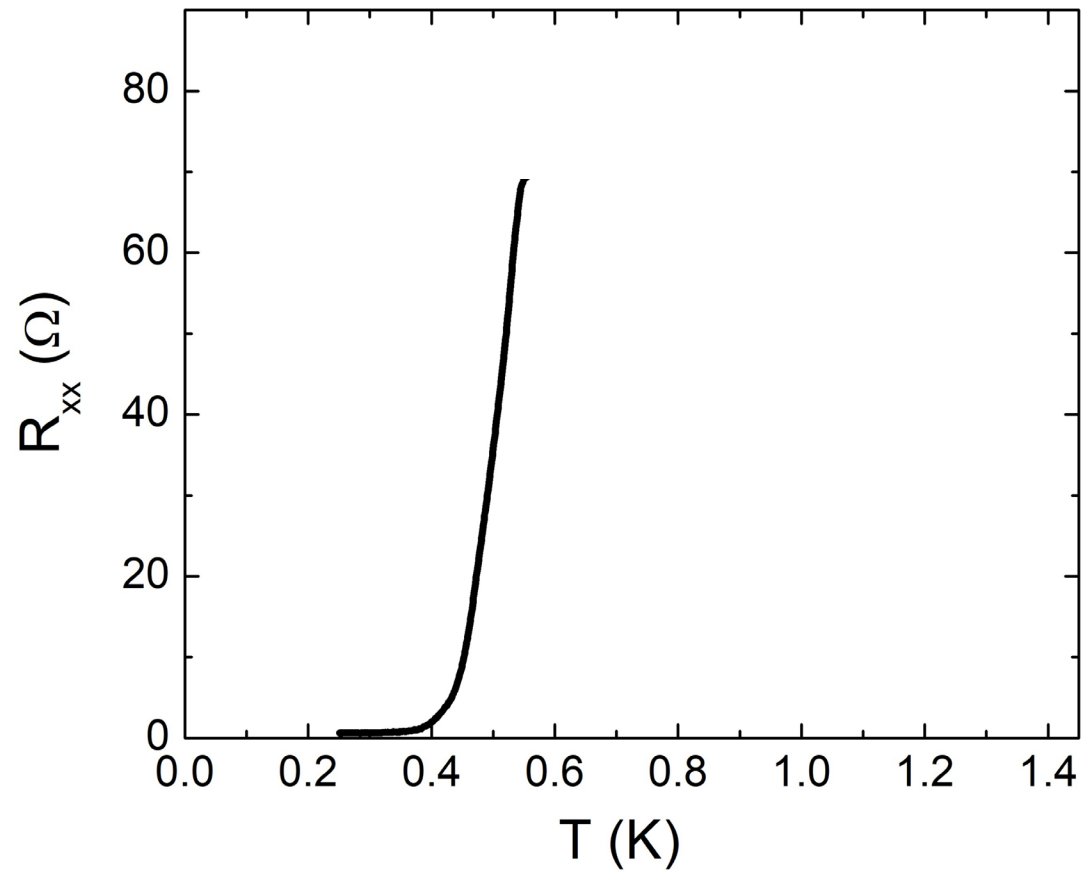

(b)
0.2 0.1 0.0 -0.1 -0.2
V_dc (mV)
-3 -2 -1 0 1 2 3
I_dc (µA)

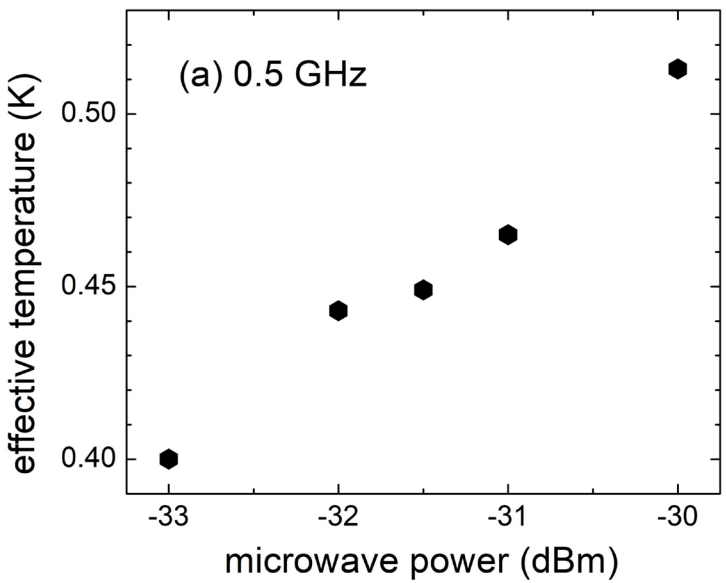
Microwave response setup

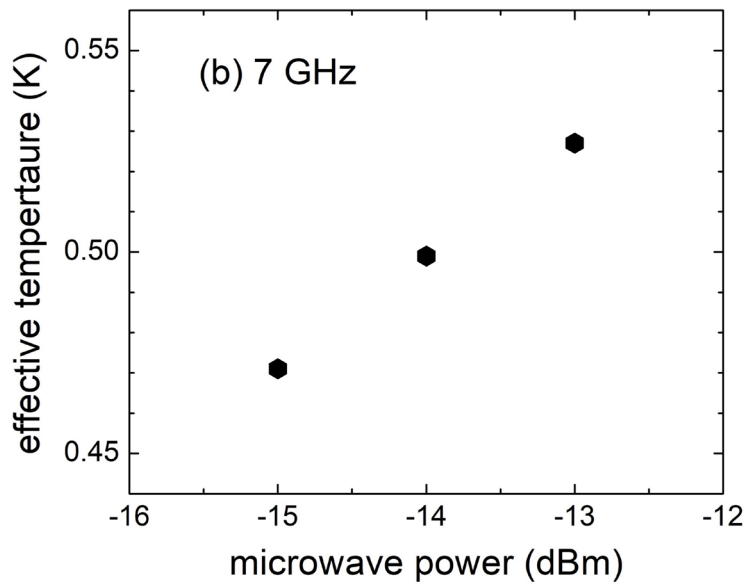


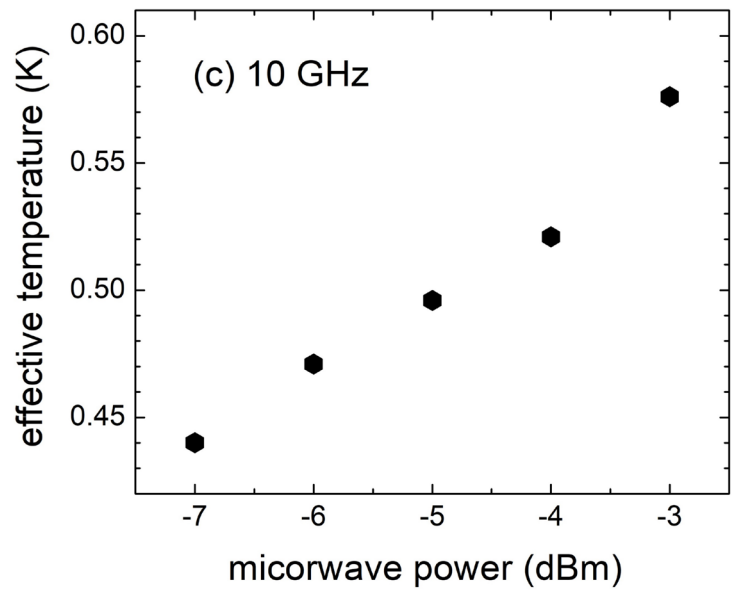

(a) f = 0.5 GHz
-35 dBm
-33 dBm
-32 dBm
-31 dBm
-30 dBm
dV/dI (Ω)
I_DC (μA)
(b) f = 7 GHz
-16 dBm
-15 dBm
-14 dBm
-13 dBm
dV/dI (Ω)
I_DC (μA)
(c) f = 10 GHz
-7 dBm
-6 dBm
-5 dBm
-4 dBm
-3 dBm
dV/dI (Ω)
I_DC (μA)
(d) f = 0.5 GHz
dV/dI (Ω)
microwave power (dBm)
(e) f = 7 GHz
microwave power (dBm)
(f) 10 GHz
dV/dI (Ω)
micorwave power (dBm)


10 GHz
dV/dI (Ω)
micorwave power (dBm)
80
70
60
50
40
30
20
10
0
-16
-14
-12
-10
-8
-6
-4
-2


R_{xx} (Ω)
T (K)
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4


(a) 0.5 GHz
effective temperature (K)
0.40
0.45
0.50
-33
-32
-31
-30
microwave power (dBm)

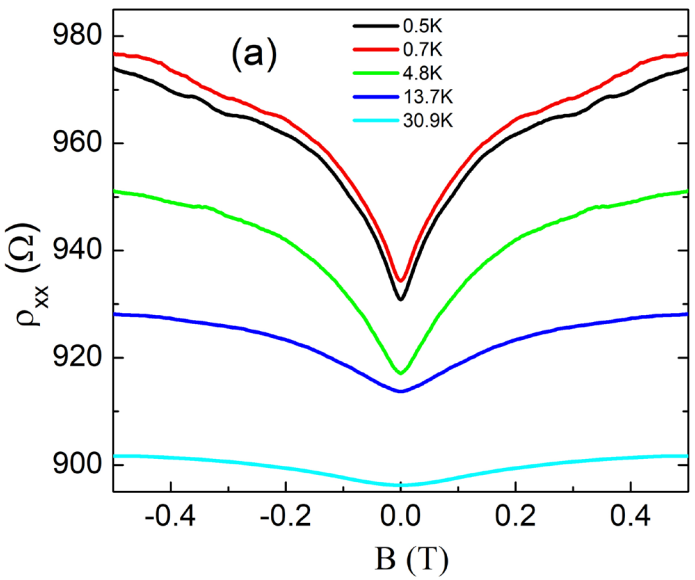

(b) 7 GHz
effective tempertaure (K)
0.45
0.50
0.55
-16
-15
-14
-13
-12
microwave power (dBm)

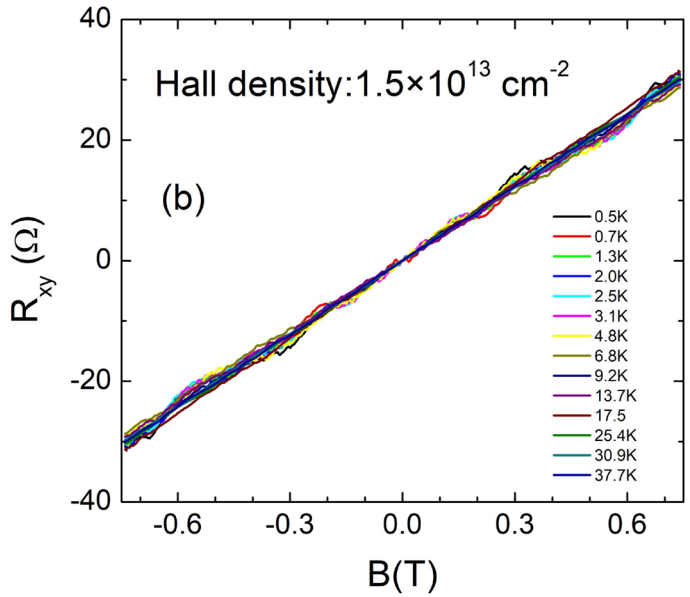

(c) 10 GHz
effective temperature (K)
0.45
0.50
0.55
0.60
-7
-6
-5
-4
-3
micorwave power (dBm)

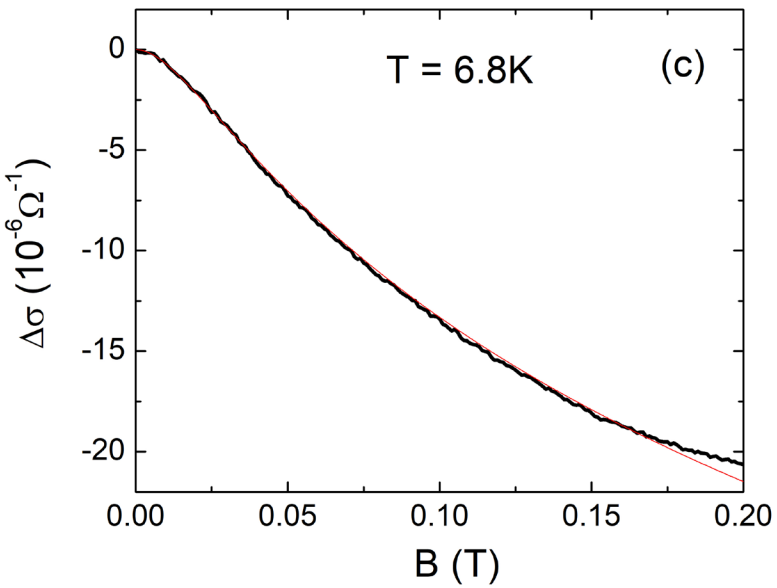
- Large microwave response in topological SQUID
- Promising for single photon detection at microwave frequencies

Thank you for your attention!

Weak antilocalization in Cd3As2

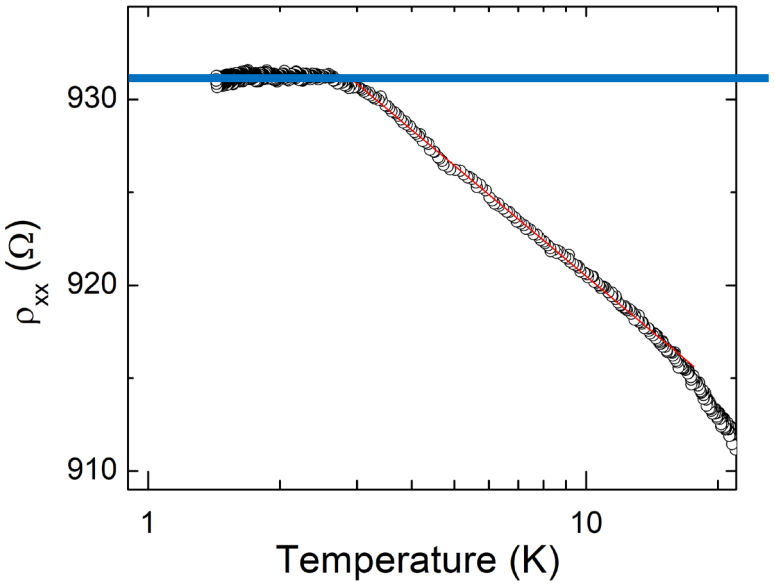


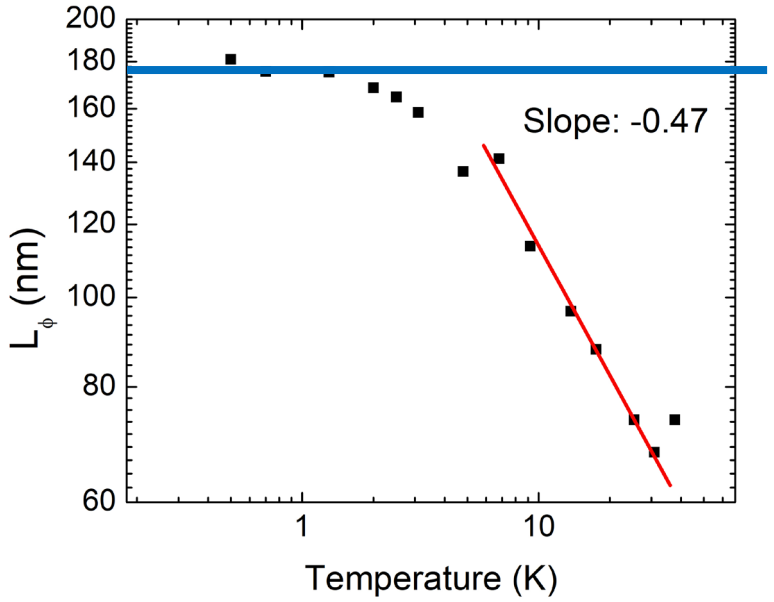


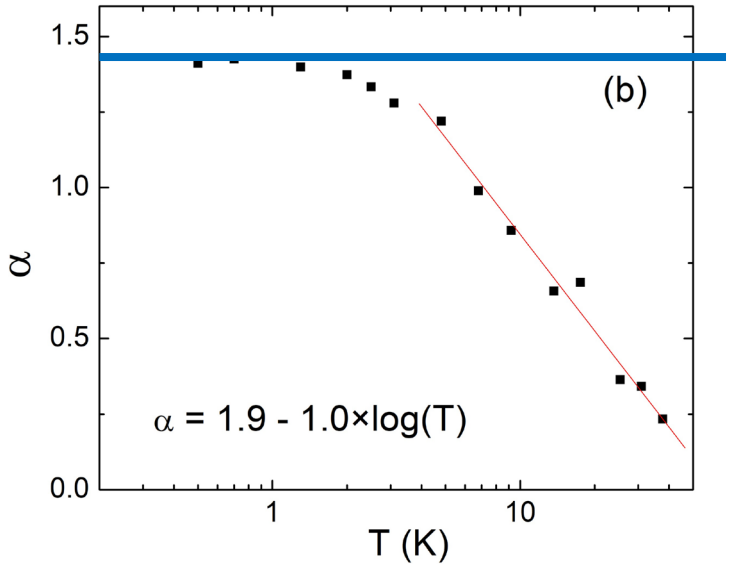


$$\Delta\sigma_{\perp}(B) \cong \alpha \frac{-e^2}{2\pi^2\hbar}\left[\Psi\left(\frac{1}{2}+\frac{B_{\varphi}}{B}\right)-ln\left(\frac{B_{\varphi}}{B}\right)\right]$$

Saturation of ρ_{xx}, L_ϕ, and α – decoupling of surface and bulk states







$$\Delta\sigma_{\perp}(B) \cong \alpha \frac{-e^2}{2\pi^2\hbar}\left[\Psi\left(\frac{1}{2}+\frac{B_\varphi}{B}\right) - ln\left(\frac{B_\varphi}{B}\right)\right]$$

$\alpha \sim 1.5 = 0.5+0.5+0.5$