Demonstration of Tunable Antenna-Coupled Intersubband Terahertz (TACIT) Mixer

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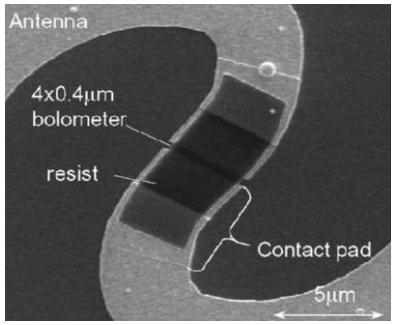
Motivation

Sensitive THz mixer for 2-5 THz that works at relatively high temperature (50-70 K)

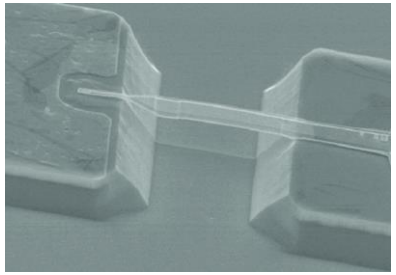
- high-resolution THz spectroscopy in deep space, etc

Superconducting hot-electron bolometer



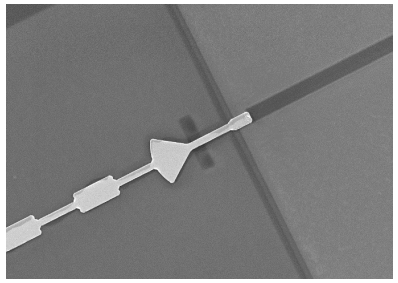
T_N ~ 10* quantum limit
IF Bandwidth ~ 3 GHz
LO power ~ 1 μW
Works below 4 K

Schottky diode



Works at ambient T
T_N ~ 50* quantum limit
LO power ~ 1 mW

TACIT



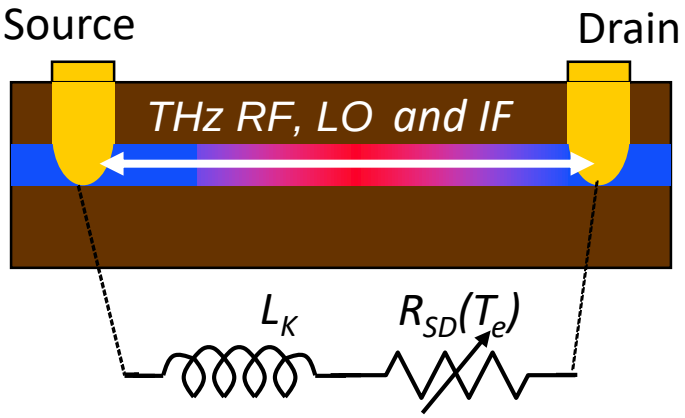
T_N ~ 10* quantum limit
LO power ~ 1μW
Works at 50-70 K
IF bandwidth > 6 GHz
+ Tunability!

Demonstrated ☺

J. J. A. Baselmans *et al.*, *IEEE Transactions on Applied Superconductivity*, **15,** 484-495 (2005)
Giovine et al, *MICROELECTRONIC ENGINEERING*, **88,** 2544-2546. (2011)

Hot-electron Bolometer Based on High-mobility 2DEG in GaAs/AlGaAs QW

Two-terminal Hot-electron Bolometer (HEB) based on high-mobility 2DEG[1]:



Mixing demonstrated at ~ 100 GHz with wide IF bandwidths:

~ 3 GHz for phonon-cooled device[2,3] @ 77 K

~ 20 GHz for diffusion-cooled device[4] @ 77 K

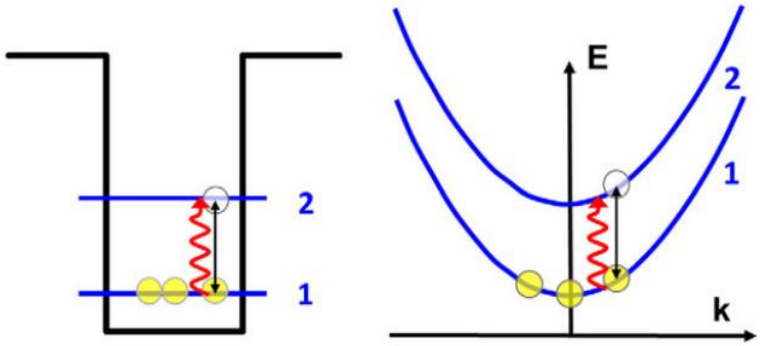
~ 40 GHz for ballistically cooled device[5] @ 1.5 K

But, due to large kinetic inductance, RF coupling efficiency significantly degrades above ~500 GHz.

[1] Ynvesson, Appl. Phys. Lett. **76**, 777 (2000)
[2] J. X. Yang et al, Appl. Phys. Lett. **66**, 1983 (1995)
[3] D. V. Morozov et al, Semiconductors **39**, 1082 (2005)
[4] M. Lee et al, Appl. Phys. Lett. **78**, 2999 (2001)
[5] M. Lee et al, Appl. Phys. Lett. **81**, 1243 (2002)

There's another way of absorbing THz radiation!

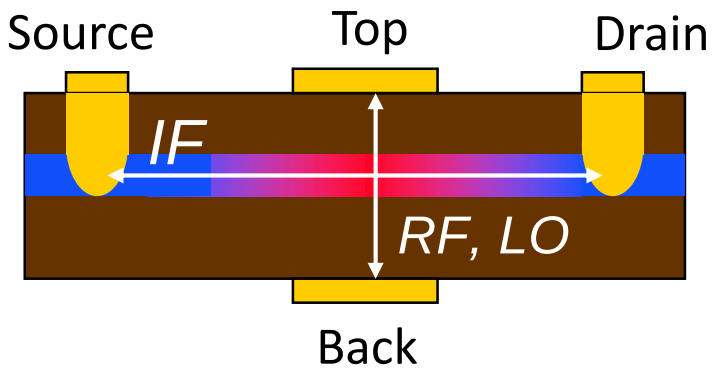
Intersubband transitions[1]:



[1] Figure from A. Vasanelli et al. C. R. Physique **17**, 861-873 (2016)

No photocurrent generated!
1 wide (~40 nm) QW

This requires THz E-fields oriented perpendicular to 2DEG plane:

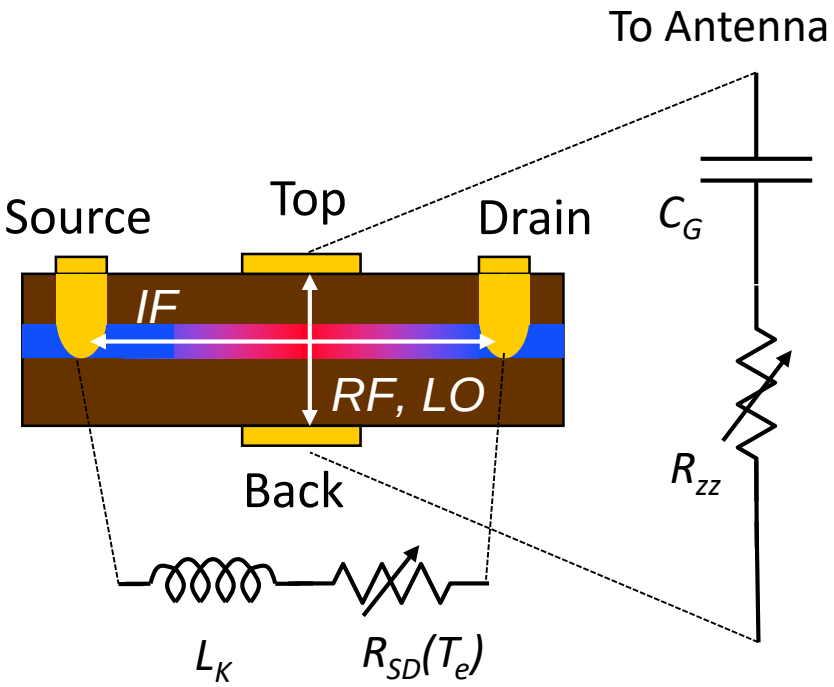


Independent tuning of n_s and E_{DC} is possible:

$$n_s \propto (V_T + V_B)$$
$$E_{DC} \propto (V_T - V_B)$$

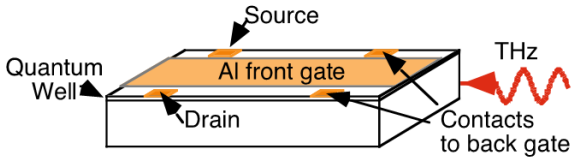
Two Advantages

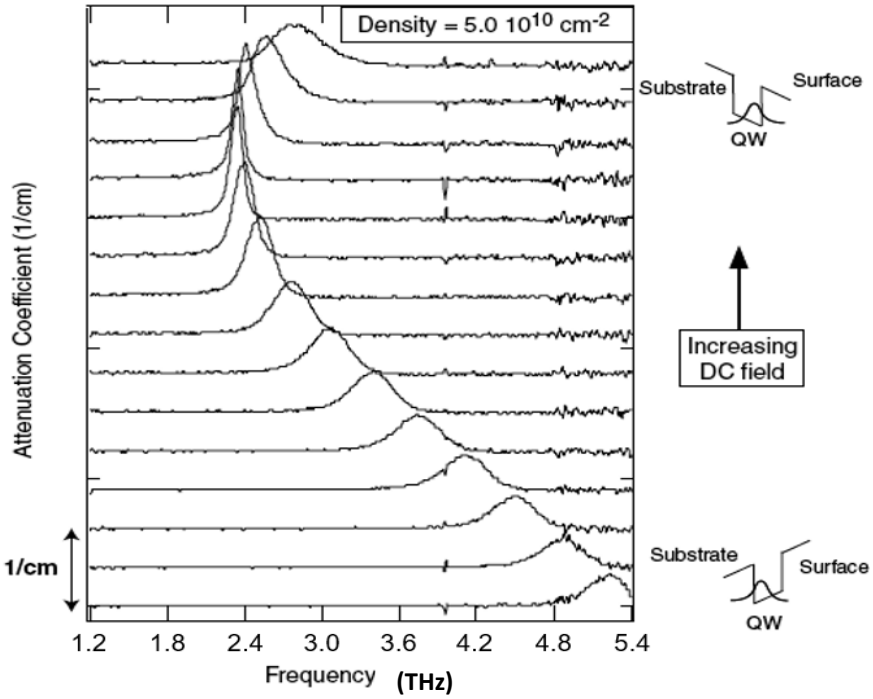
n_s tunes RF impedance:



$$R_{zz} \propto n_s$$

E_{DC} tunes detection frequency:

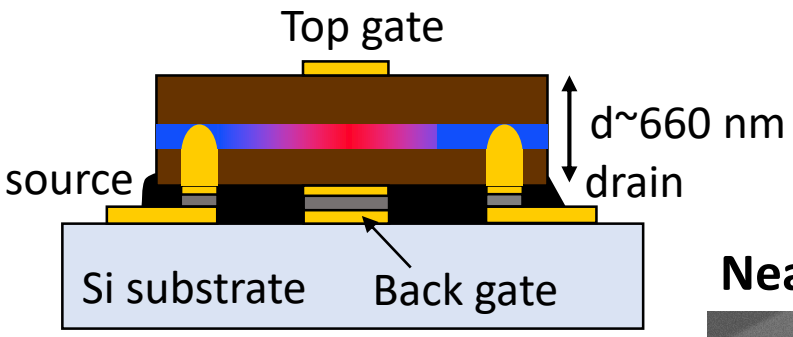




J. B. Williams et al, PRL, **87**, 3 (2001)

Fabricated Prototype Device

Vertical Profile:

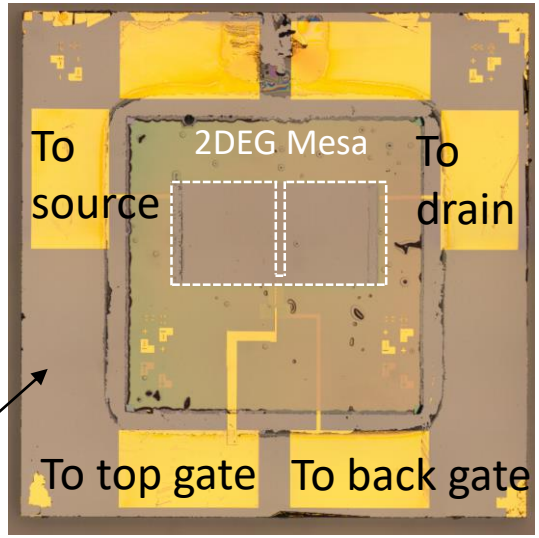


QW structure:

Grown in MBE @ Princeton

1 QW
40 nm GaAs
$n_s \sim 2 \times 10^{11}$ cm^{-2}
$\mu \sim 10^7$ cm^2/V-s at 2 K

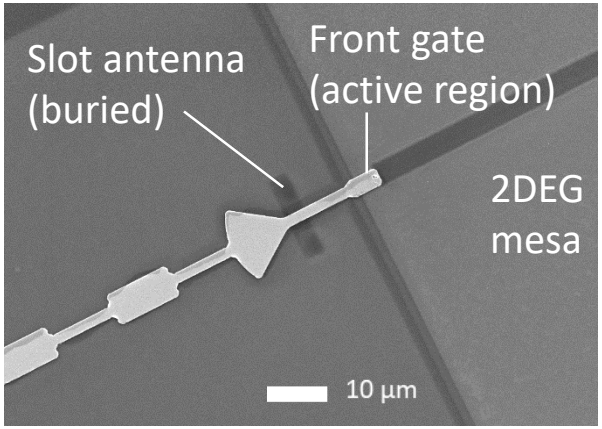
Top-down View:



Si substrate

5 mm

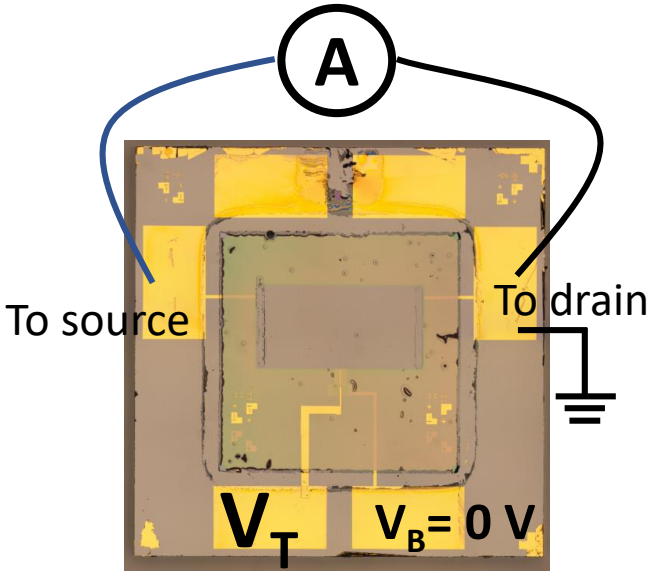
Near active region:

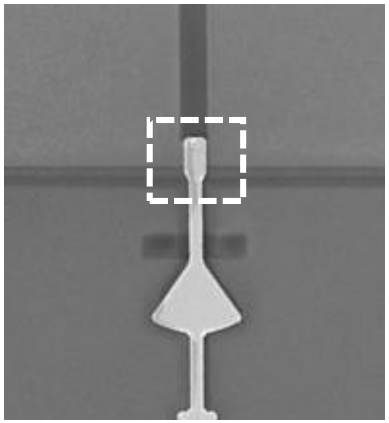


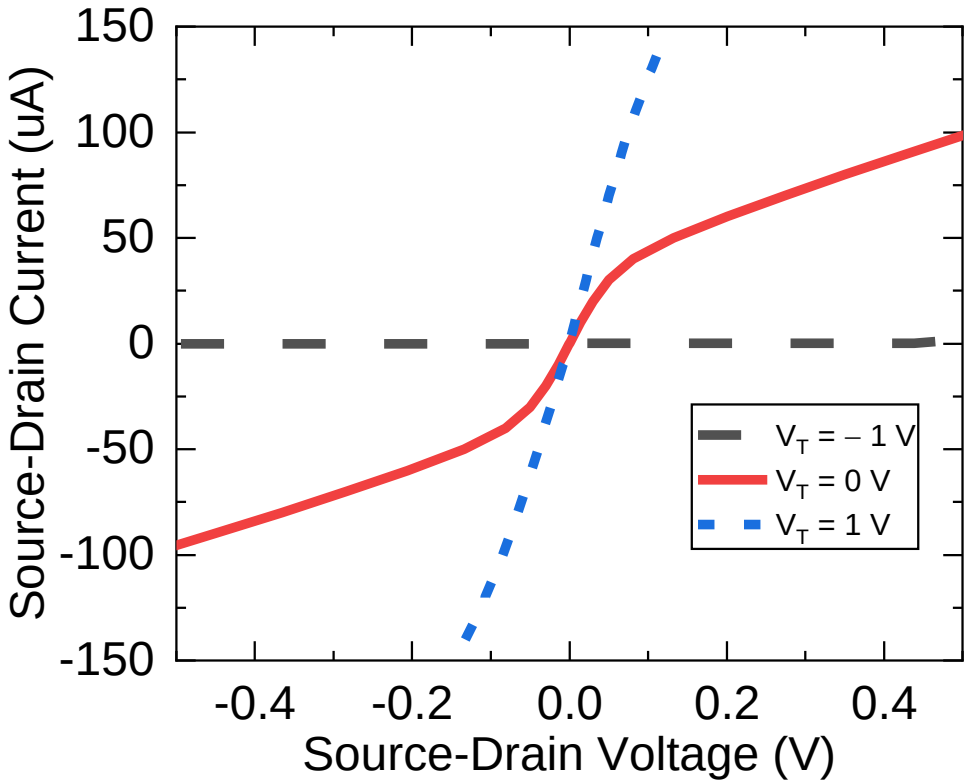
Side View:

THz E field

Bolometric Response at 50 K



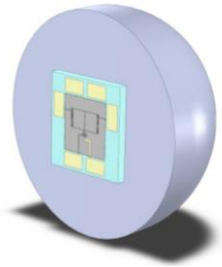


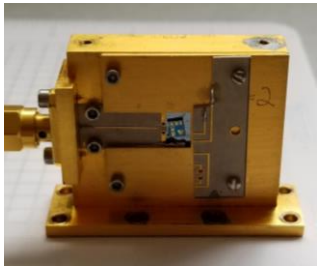


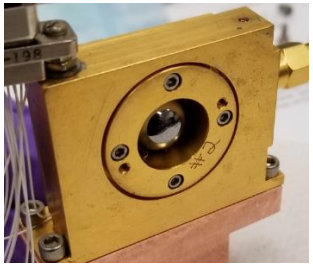
Gate works!

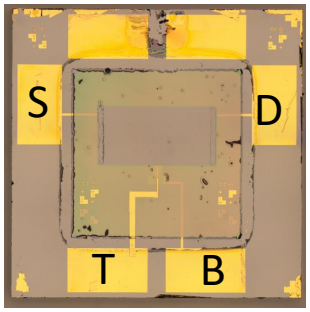
Direct Detection at 36 K

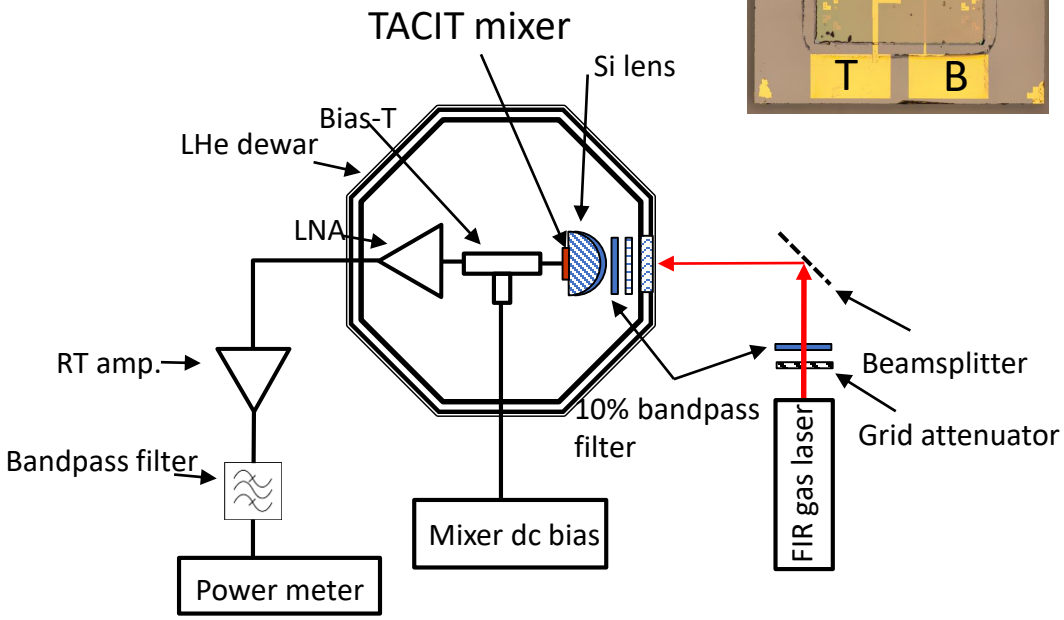
Quasi-optical coupling:

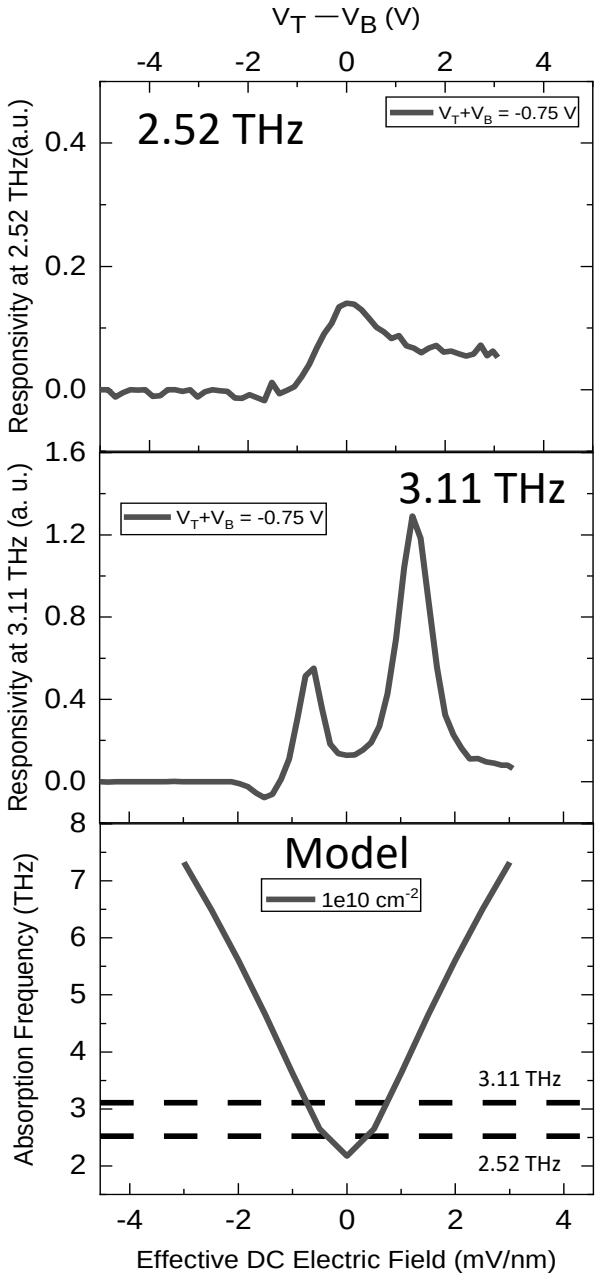






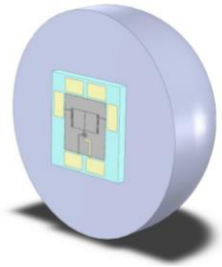


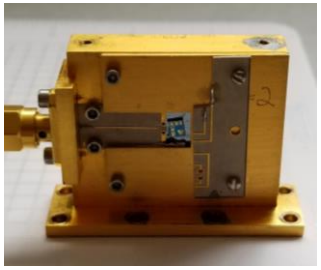


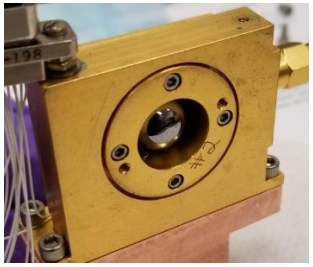


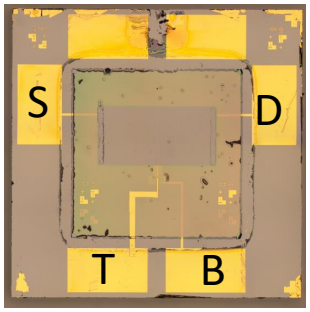
Direct Detection at 36 K

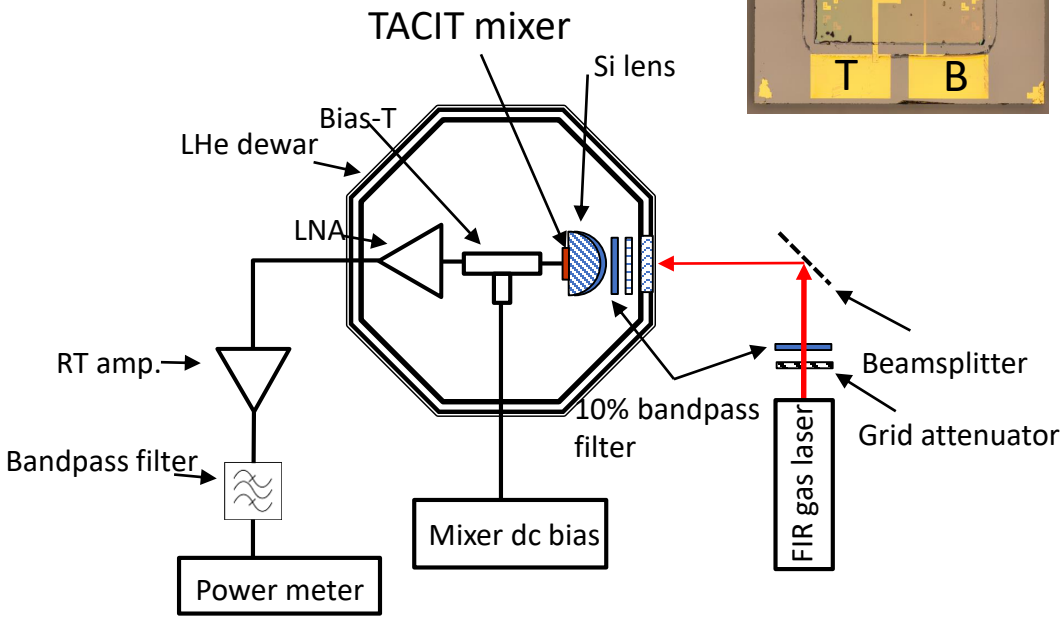
Quasi-optical coupling:

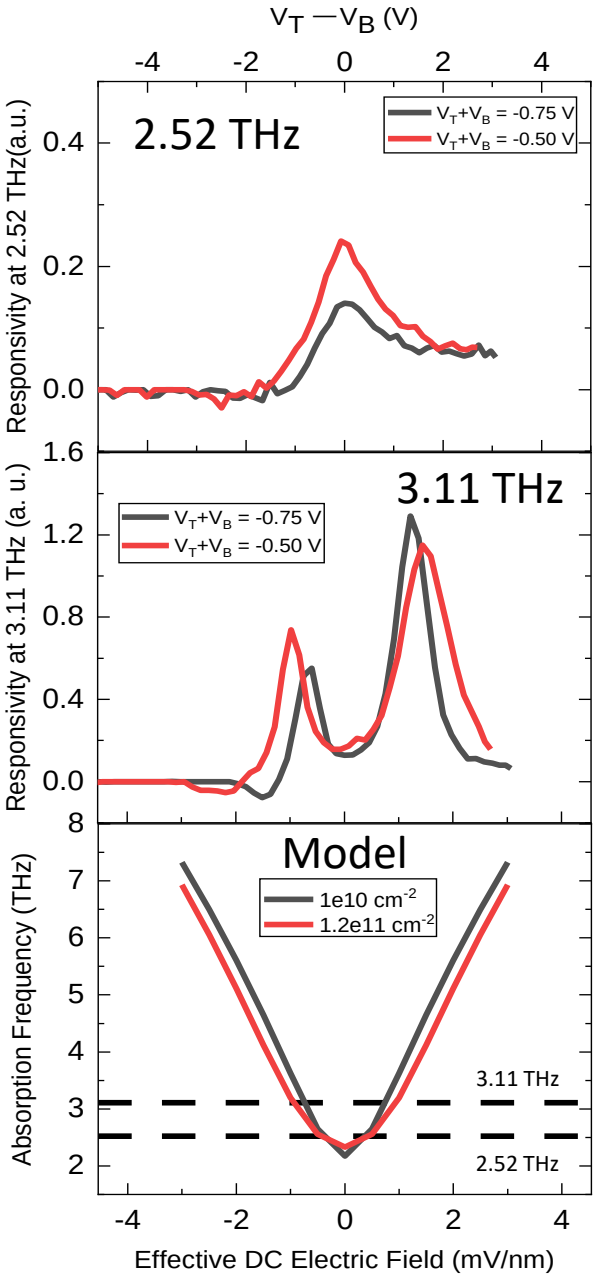






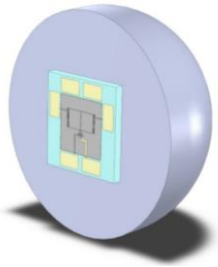


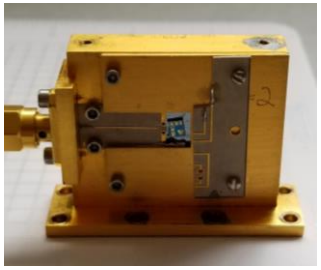


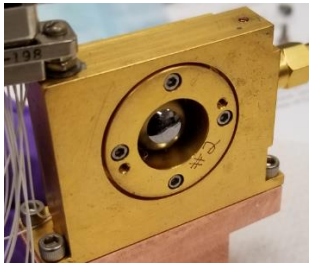


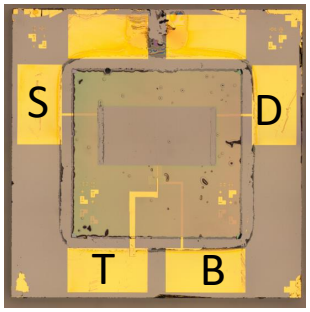
Direct Detection at 36 K

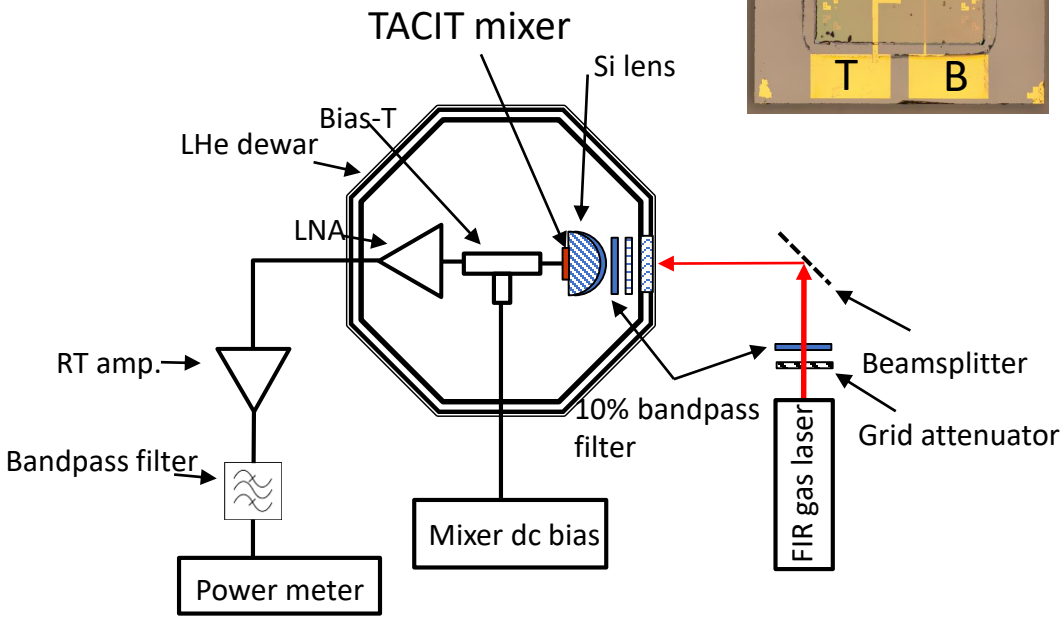
Quasi-optical coupling:

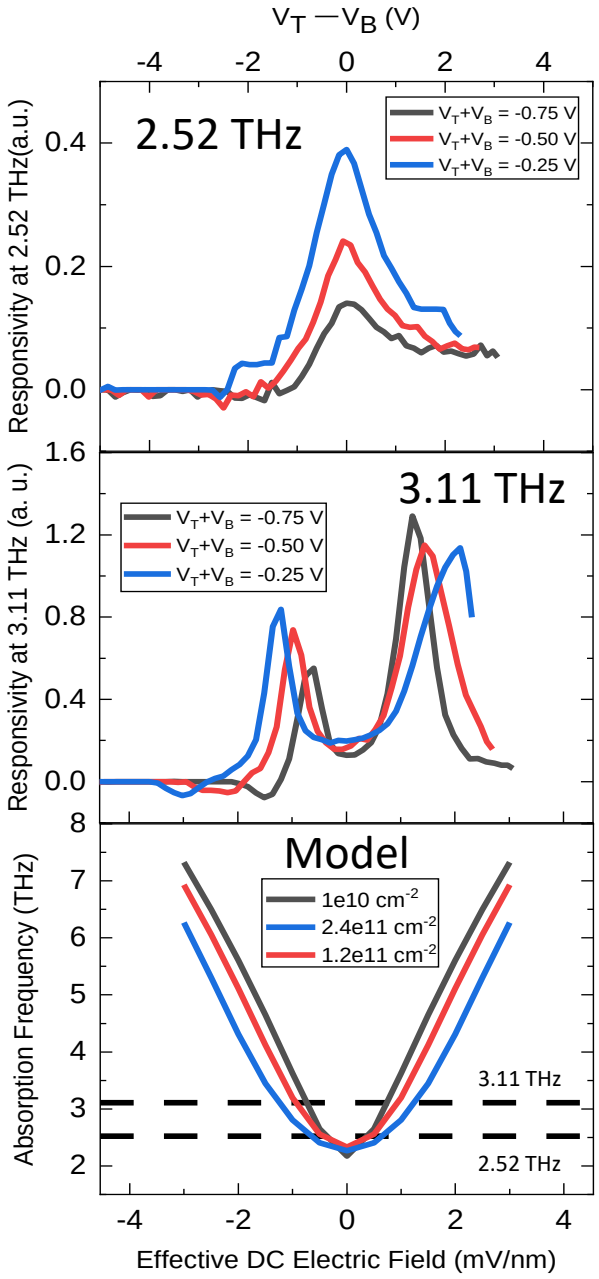




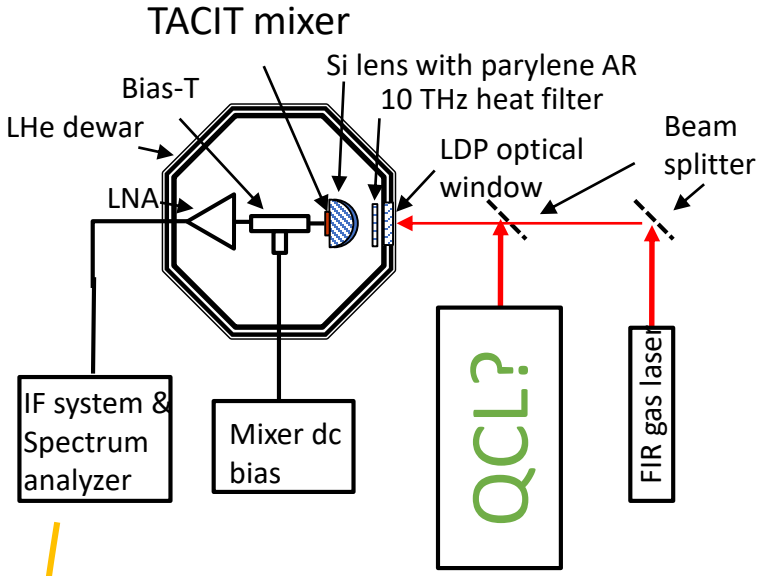


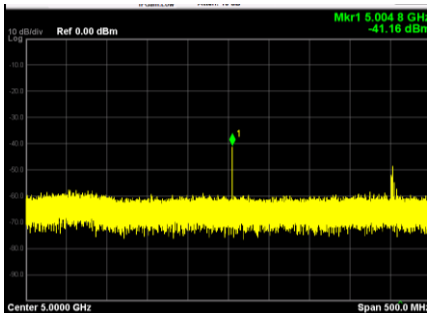




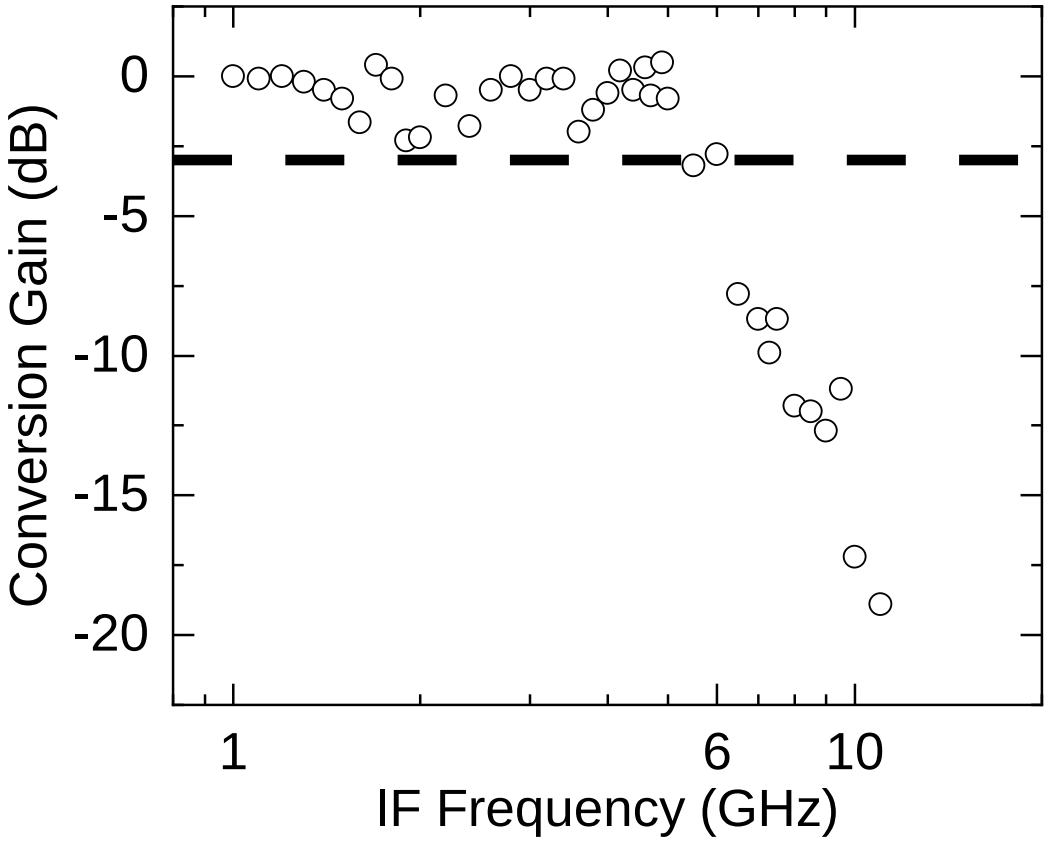


Heterodyne Detection at 60 K (2.52 THz)





IF signal at 5 GHz



-12dB/octave roll-off due to high-order filtering in IF circuit

Summary and Outlook

Prototype TACIT mixer

- tunability

- THz mixing at 60 K

- IF bandwidth > 6 GHz

Outlook

- Response beyond 3.11 THz (QCL?)

- Noise temperature measurement

Acknowledgement

High-mobility 2DEG growth@ Princeton

Dr. Ken West (Princeton)

Prof. Loren Pfeiffer (Princeton)

QW design, device fabrication, and DC characterization @ UCSB

Dr. Mengchen Huang

Prof. Mark Sherwin

Antenna Design and THz measurements @ JPL

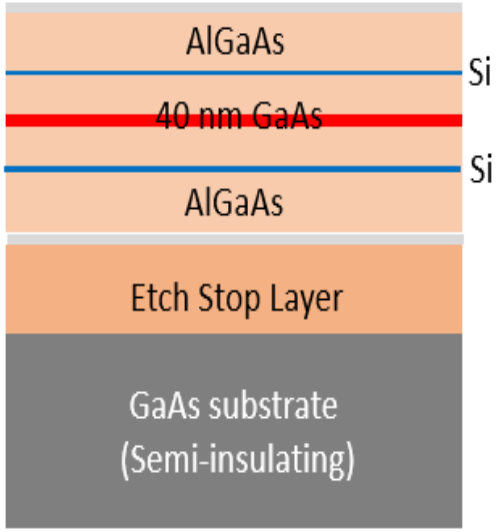
Dr. Jonathan Kawamura

Dr. Boris Karasik

Funded by NASA PICASSO program

Prototype TACIT Mixer

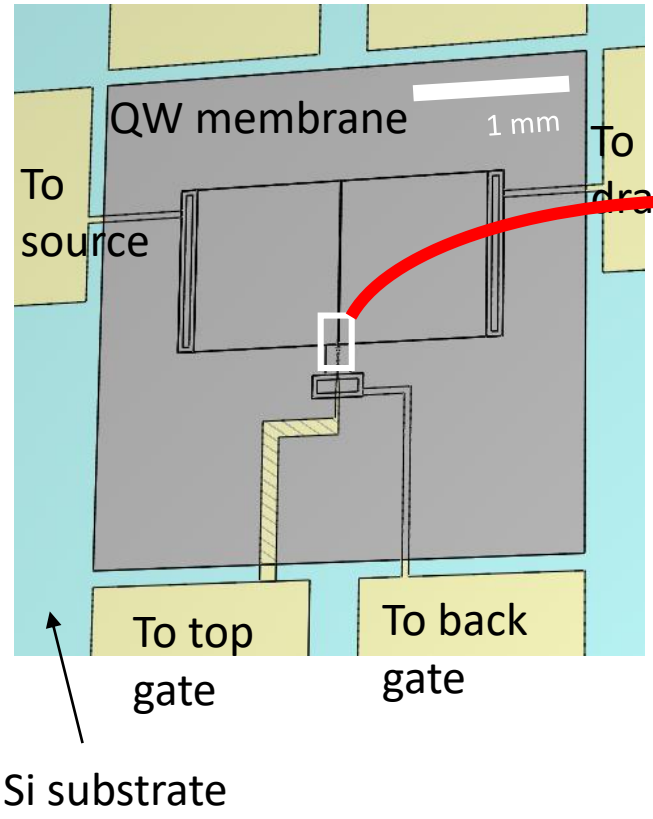
Sample structure:



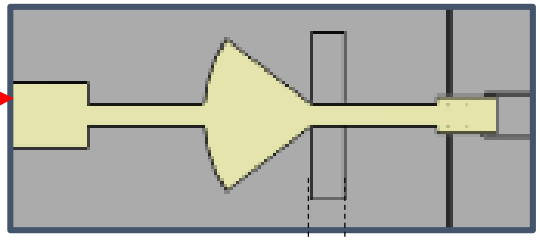
Grown in MBE @ Princeton

1 QW
40 nm GaAs
$\mu \sim 10^7$ cm^2/V-s at 2 K
$n_s \sim 2\times10^{11}$ cm^{-2}

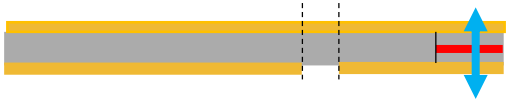
Prototype Design:



Top-down View:



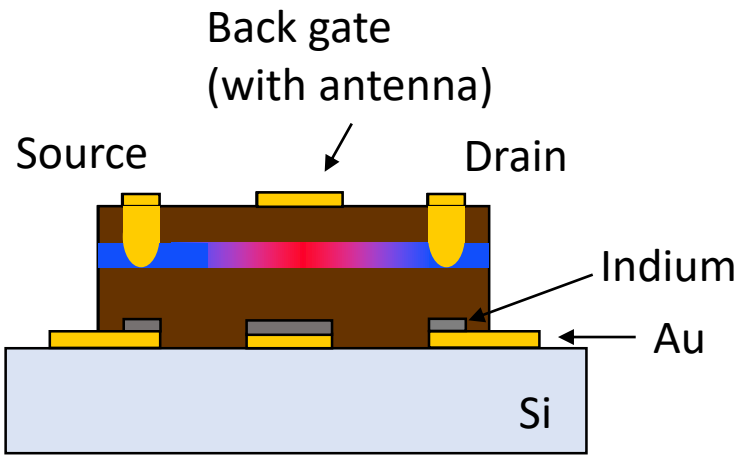
Side View:



THz E field

Fabrication

We use a modified version of Epoxy-Bond-And-Stop-Etch (EBASE) flip-chip process[1]:

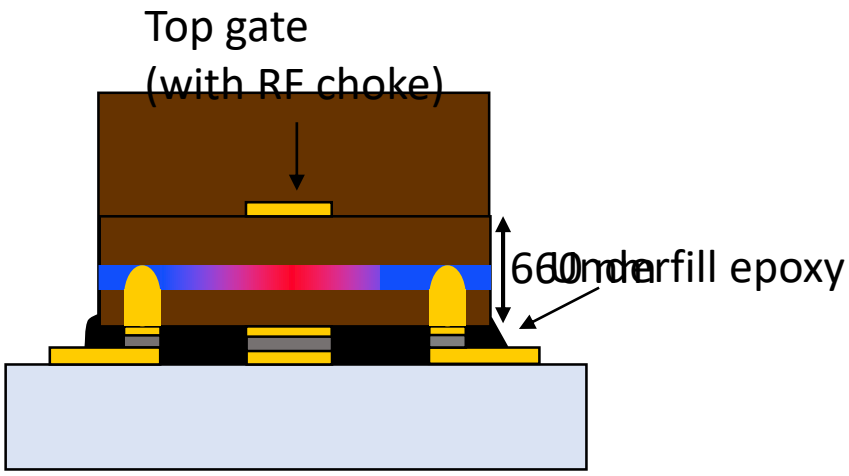


Definition of 2DEG Mesa

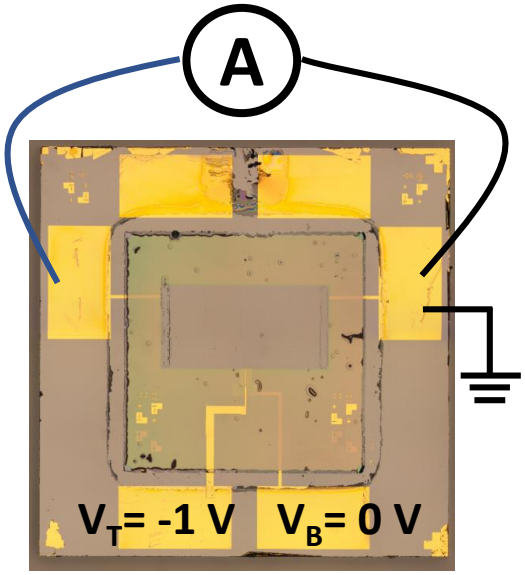
Flip-chip bonding and underfilling

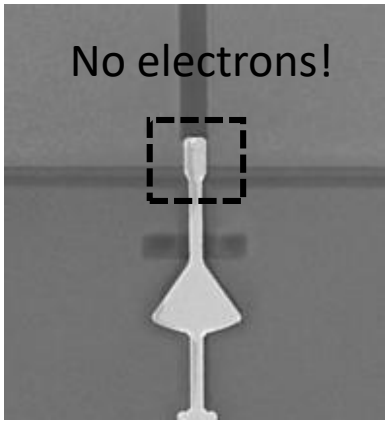
[1]Weckwerth et al. *Superlattices and Microstructures,* **20,** 4 (1996)

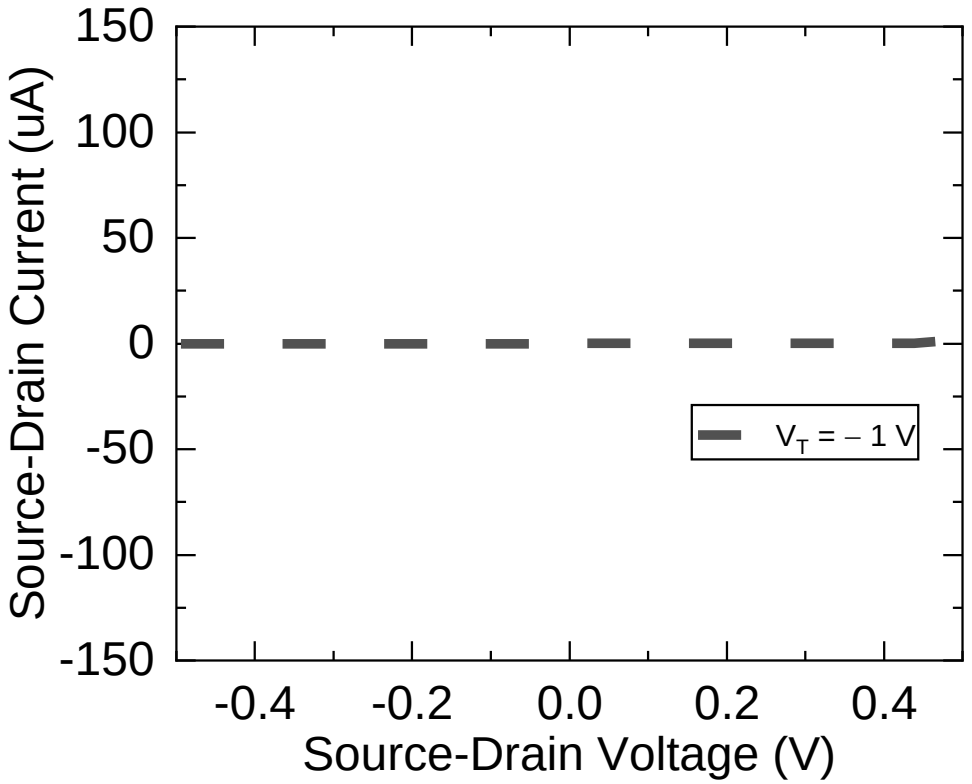
Fabrication



Bolometric Response at 50 K

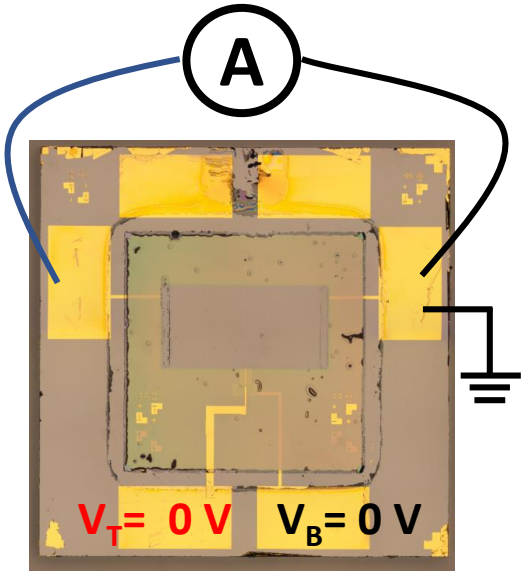


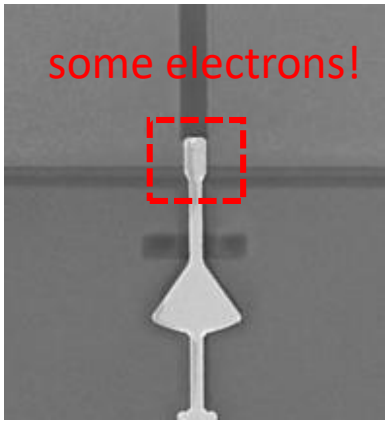


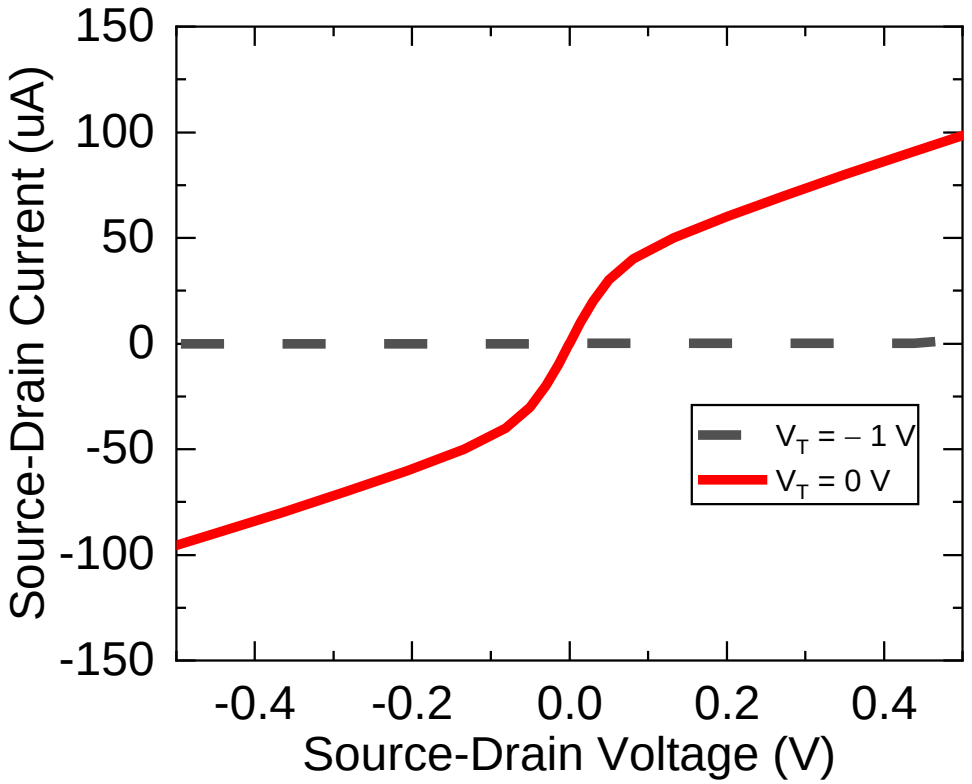


Electrons are all depleted and no current flows in the source-drain channel

Bolometric Response at 50 K







There are some electrons in the active region that become hot