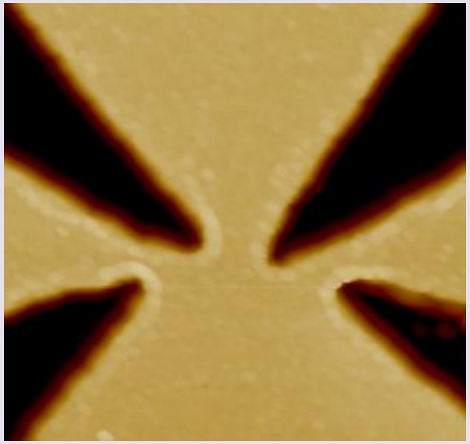
Graphene Ballistic Rectifiers for THz Rectification

Gregory Auton
Roshan Krishna Kumar
Ernie Hill
Aimin Song



Contents

- Initial device premise and design
- Low frequency operation
- High frequency operation
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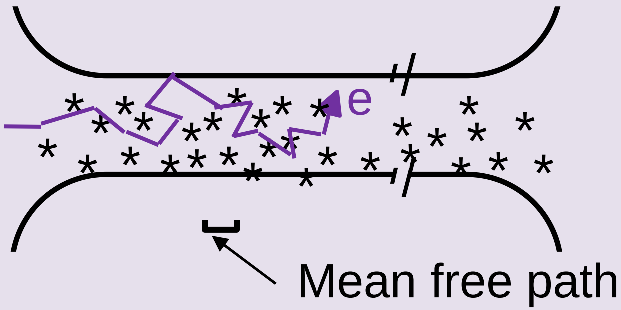
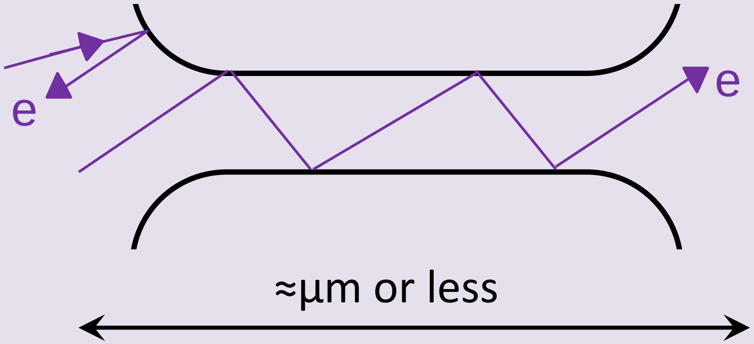
Diffusive *vs* Ballistic Transport



Diffusive transport

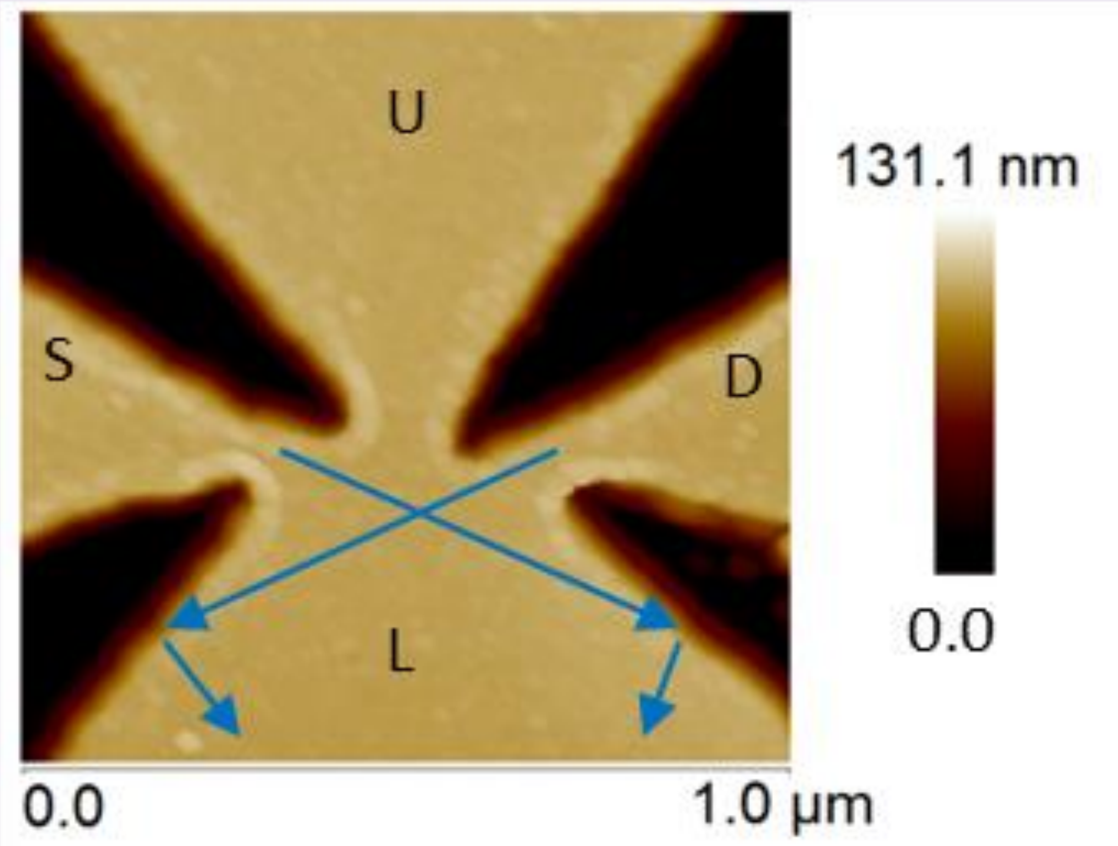


Ballistic transport
More Controllable!

- In theory, the best material for ballistic transport at RT
- But edge scattering may not be specular as in normal semiconductors
- Most literature suggests edges at least partially specular

AFMs

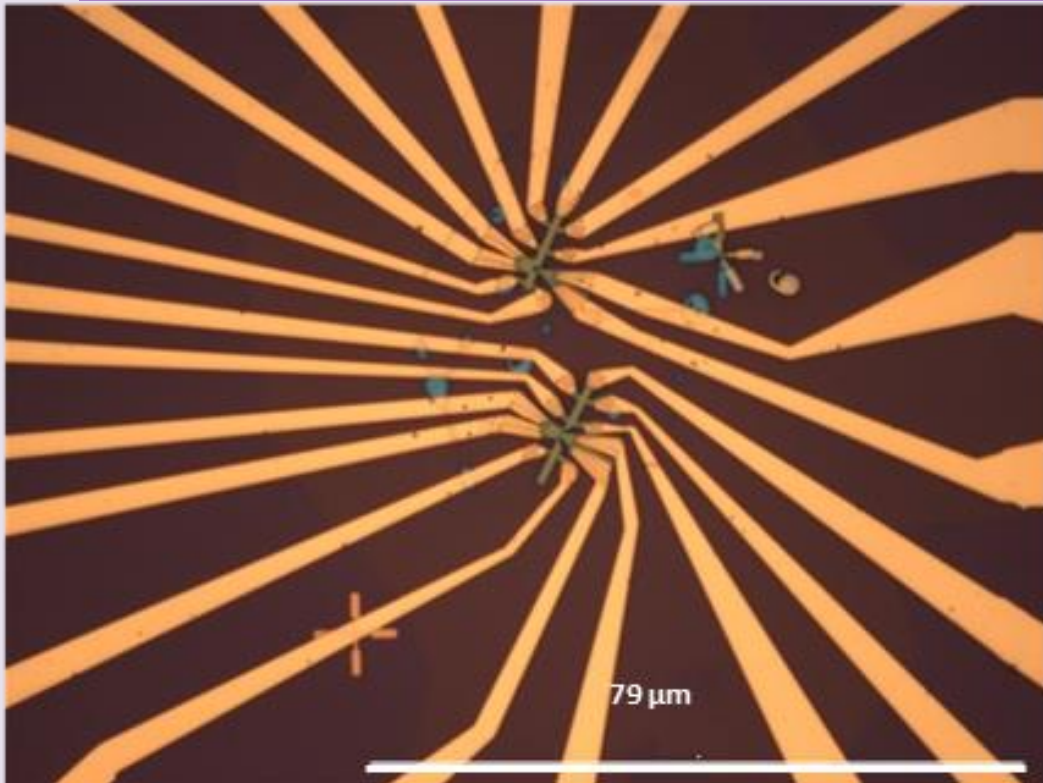
Height

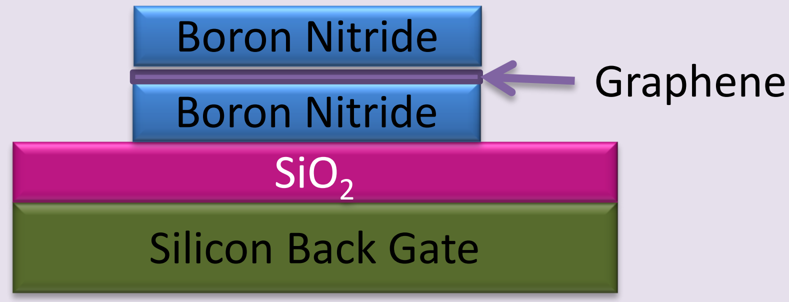


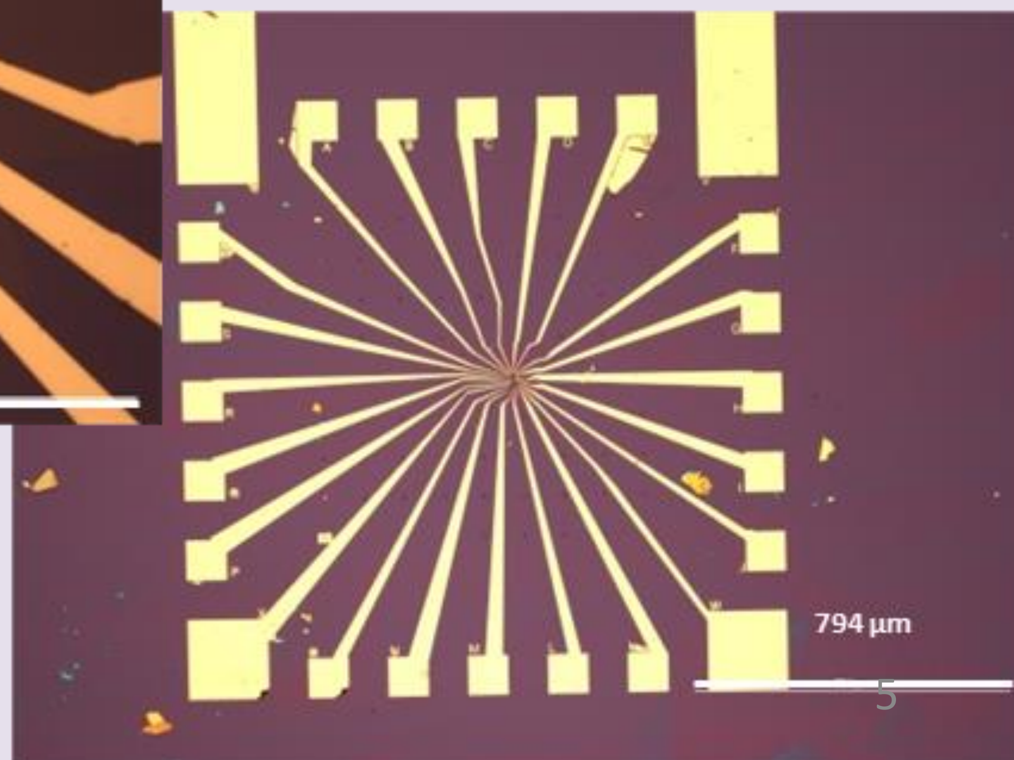
The narrow region used to redirect carriers ~ 200nm

Path length from input leads to output leads ~1µm

Low Frequency Measurements

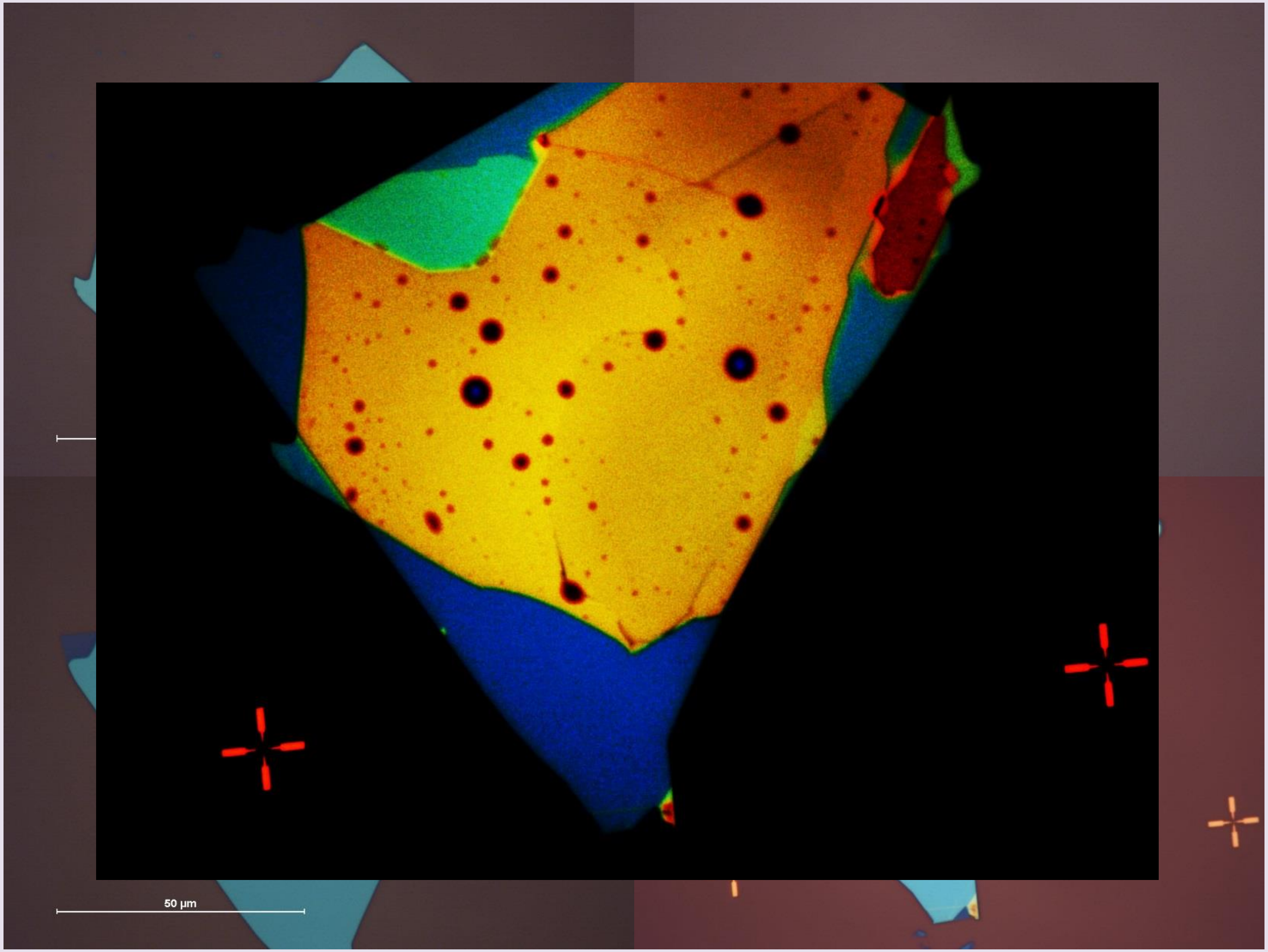






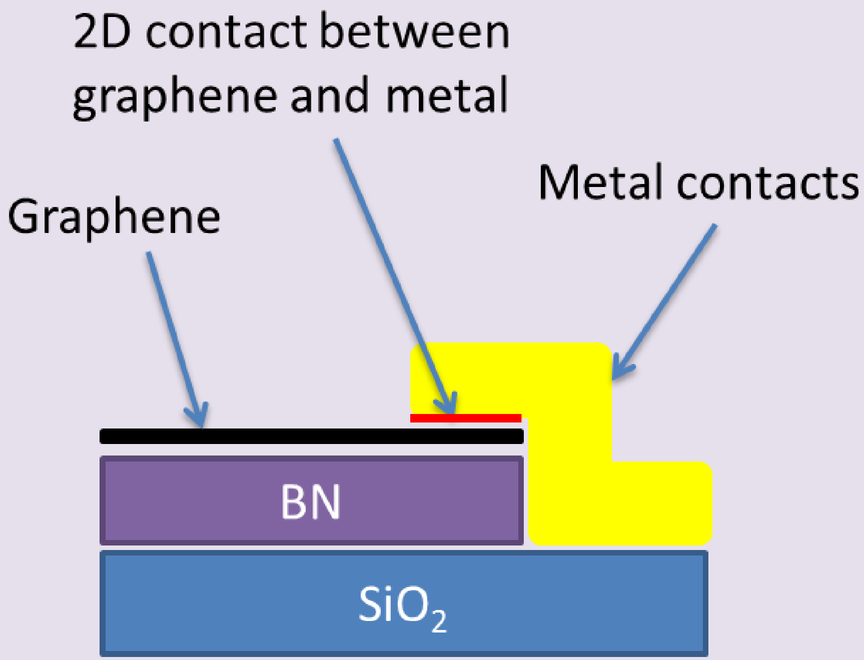
Initially we had to demonstrate/prove ballistic behaviour. Devices constructed with Hall bar structure attached

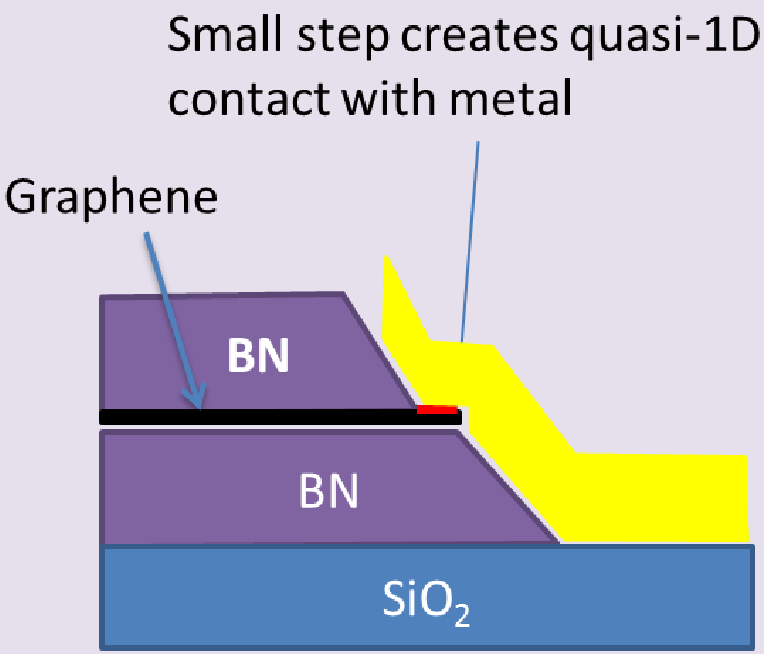
Graphene and BN transfers



Stack the flakes like LEGO!

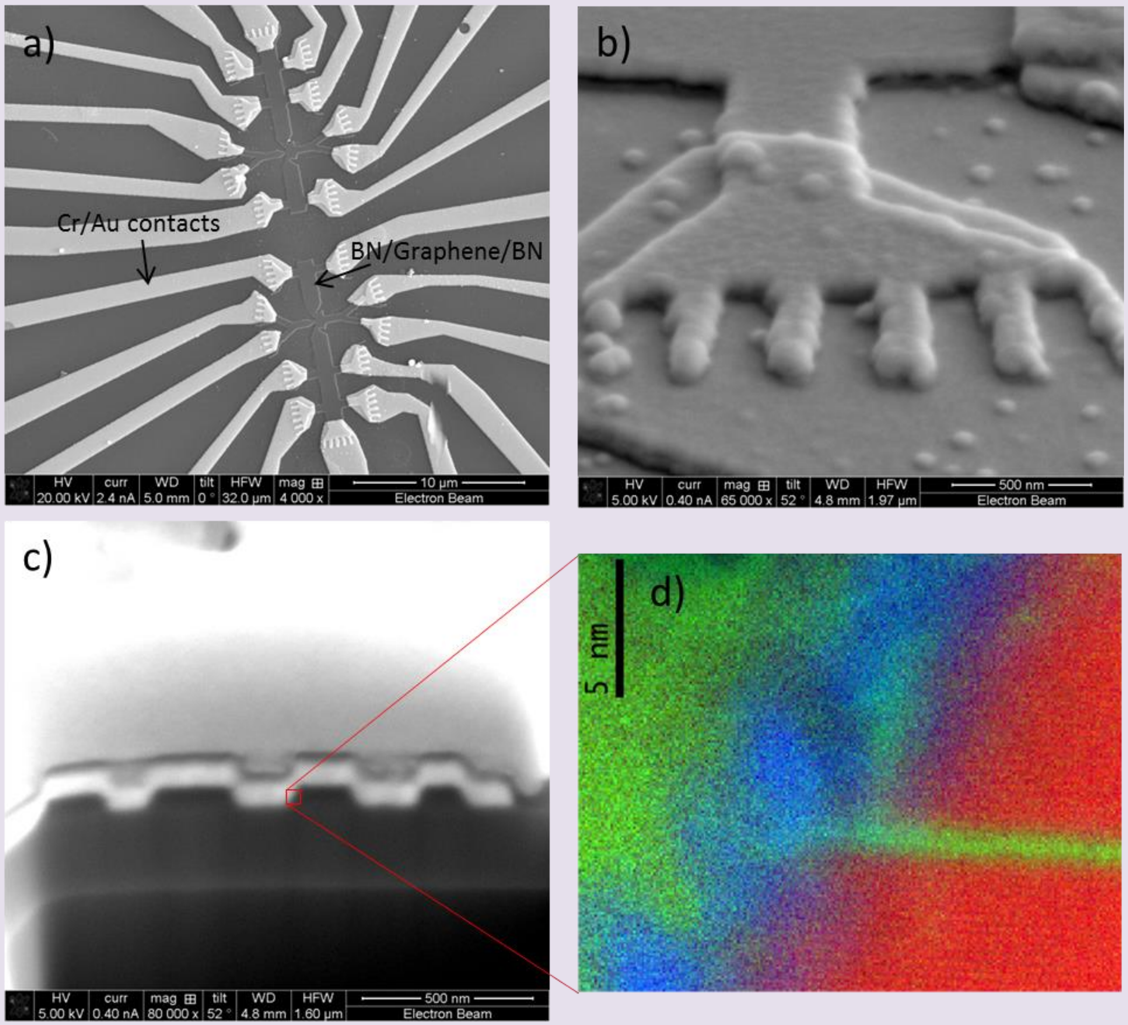
2D vs 1D contacts





L. Wang, et al. Science 342, 614 (2013).

1D Contacts



SEM images

Cross-sectional TEM

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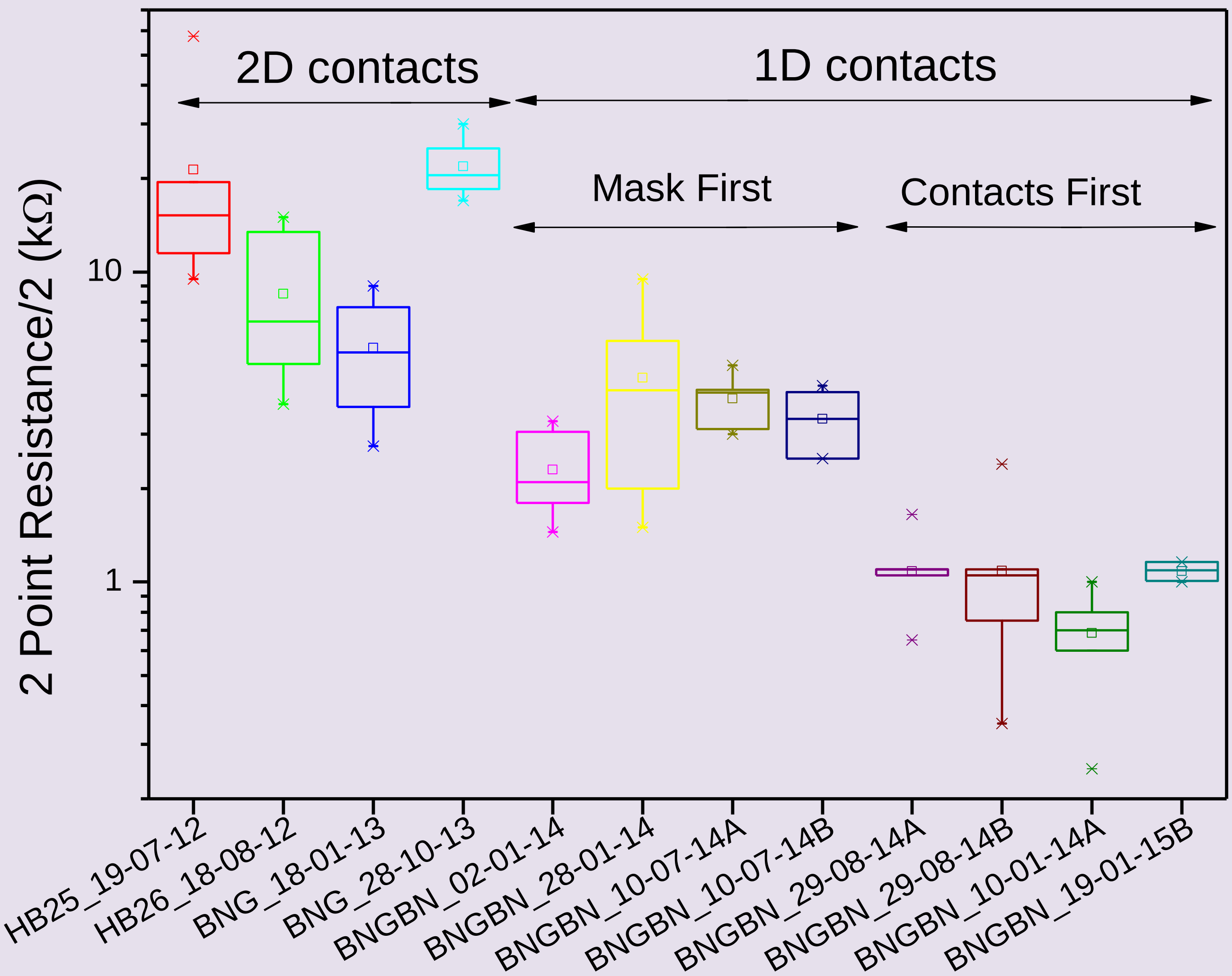
Low Contact Resistances



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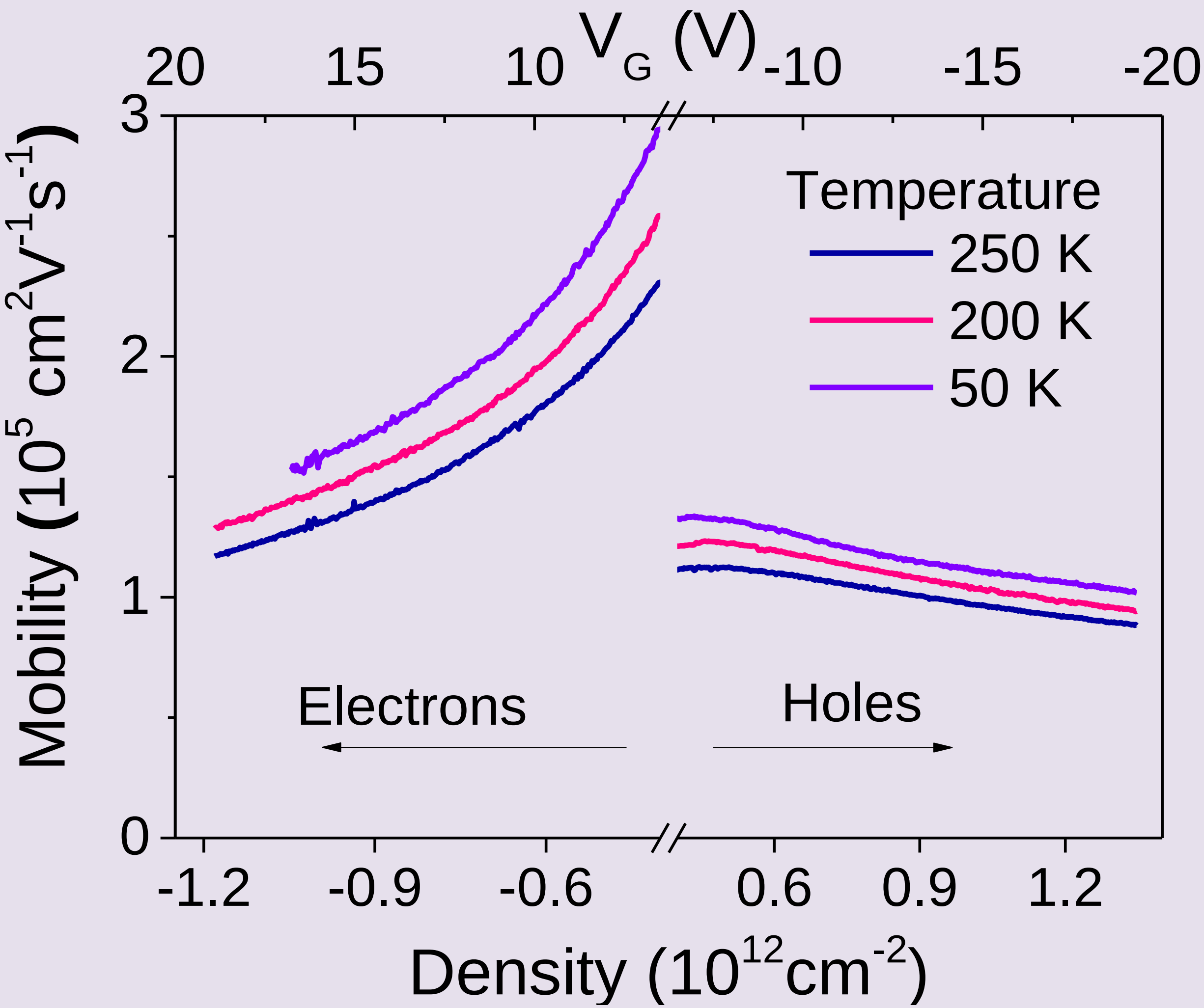
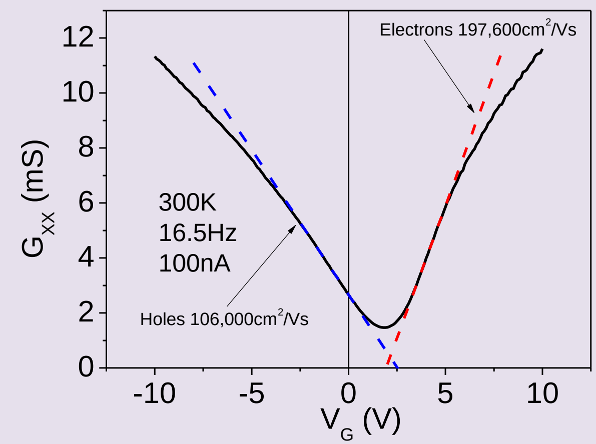
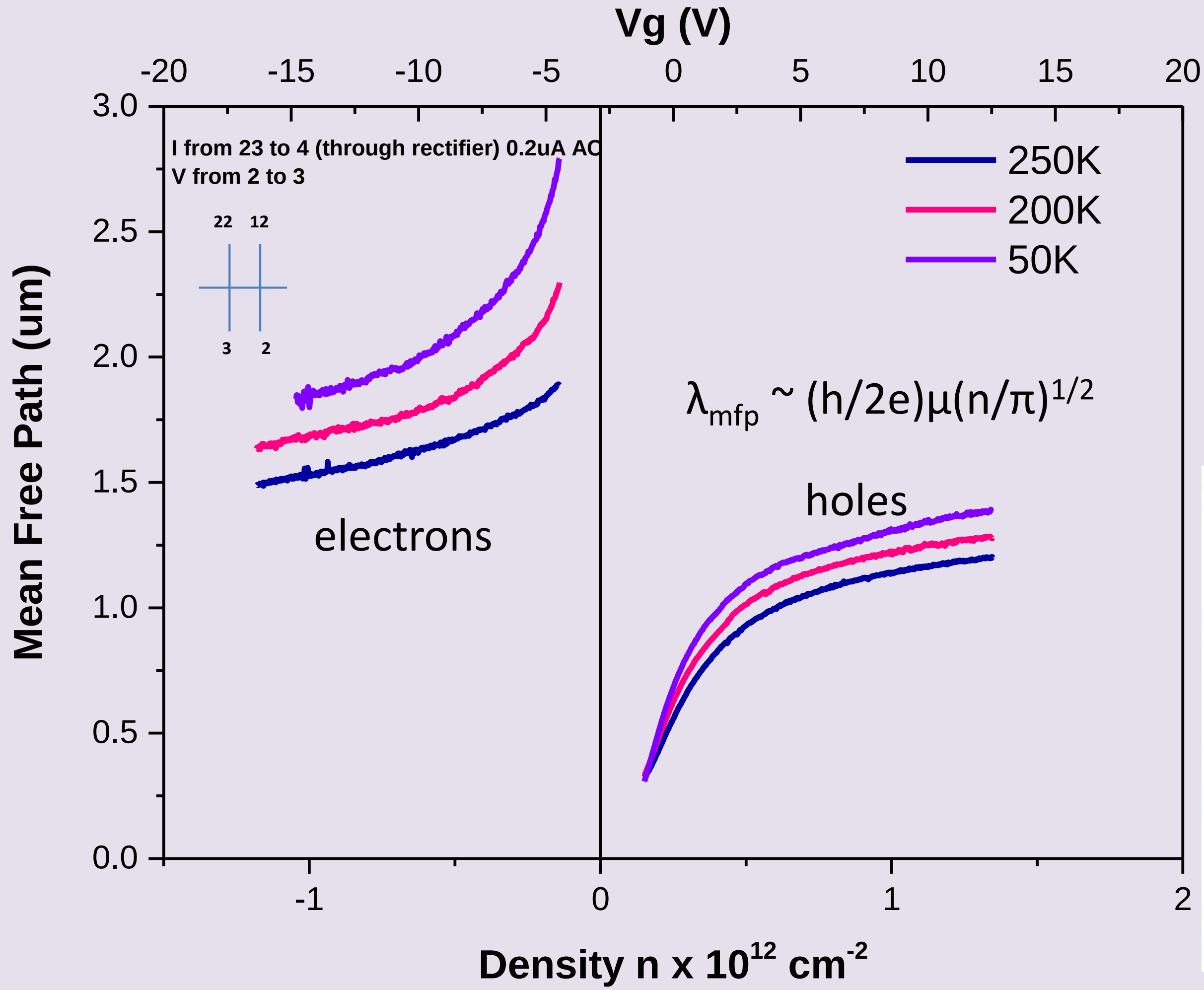
Mobility Measurements



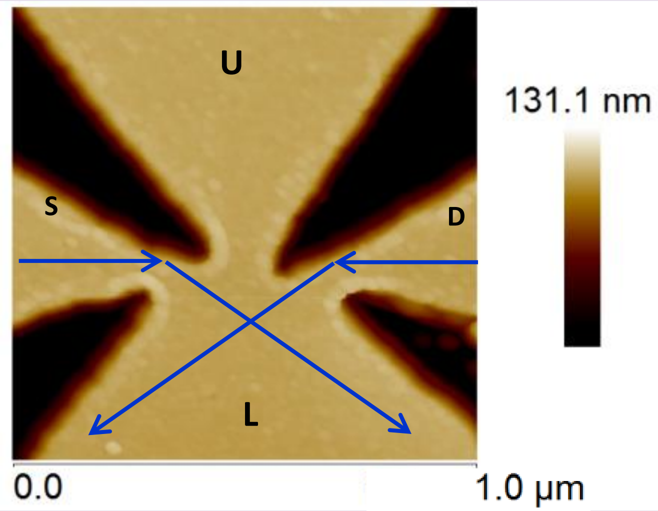
Mobility above 100,000 $cm^2V^{-1}s^{-1}$ even at room temperature and high density.



Long mean free path



- Mean free path beyond 1 μm
- Device size < mean free path



G. Auton, *et al.* Nature Communications, 7:11670 (**2016**)

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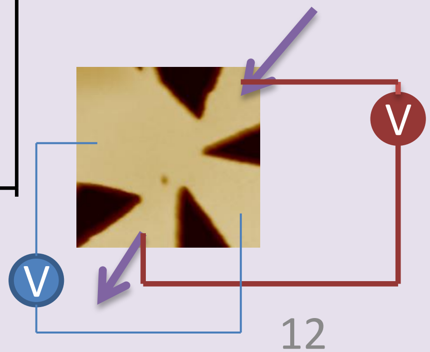
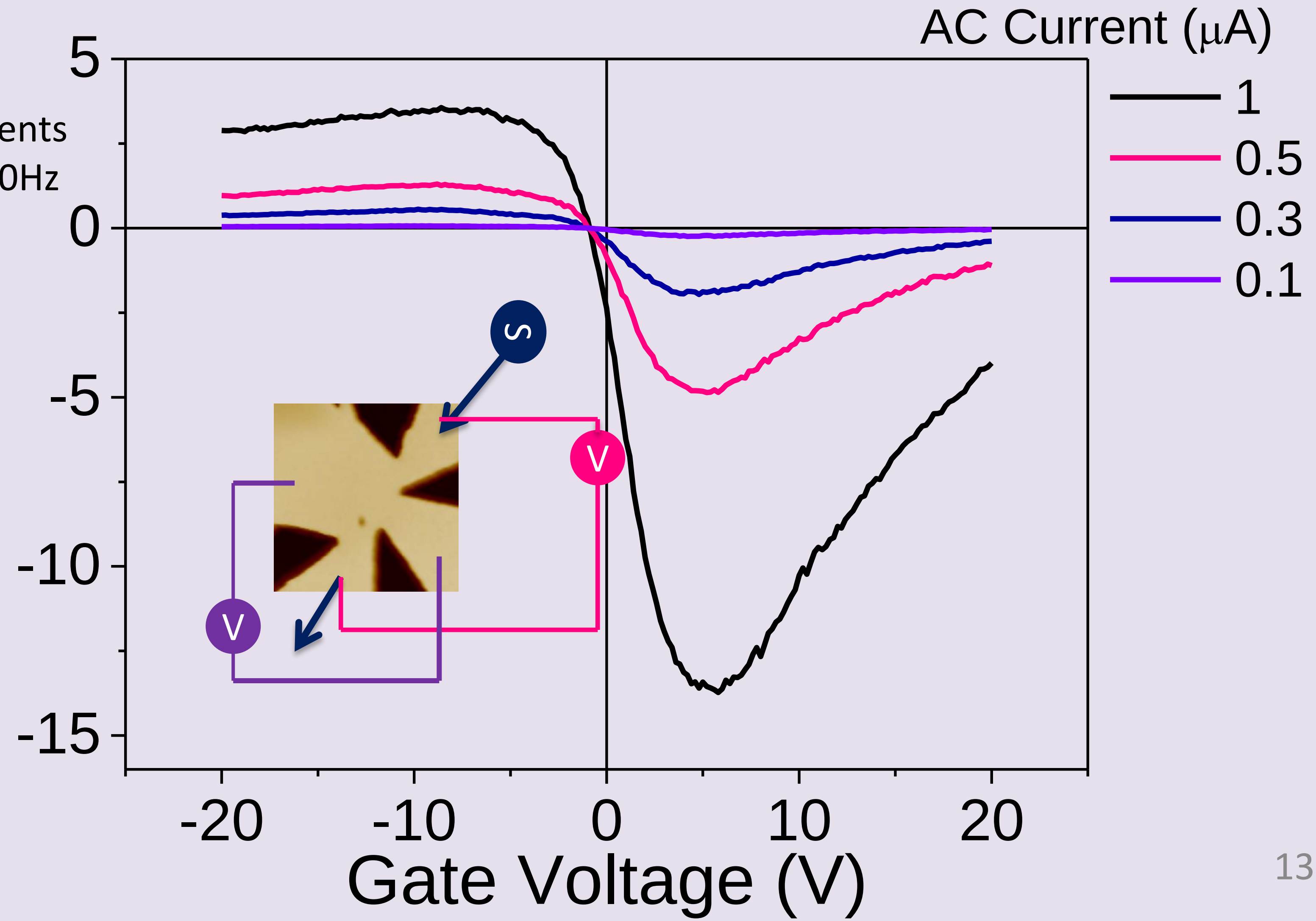
DBR Room Temperature

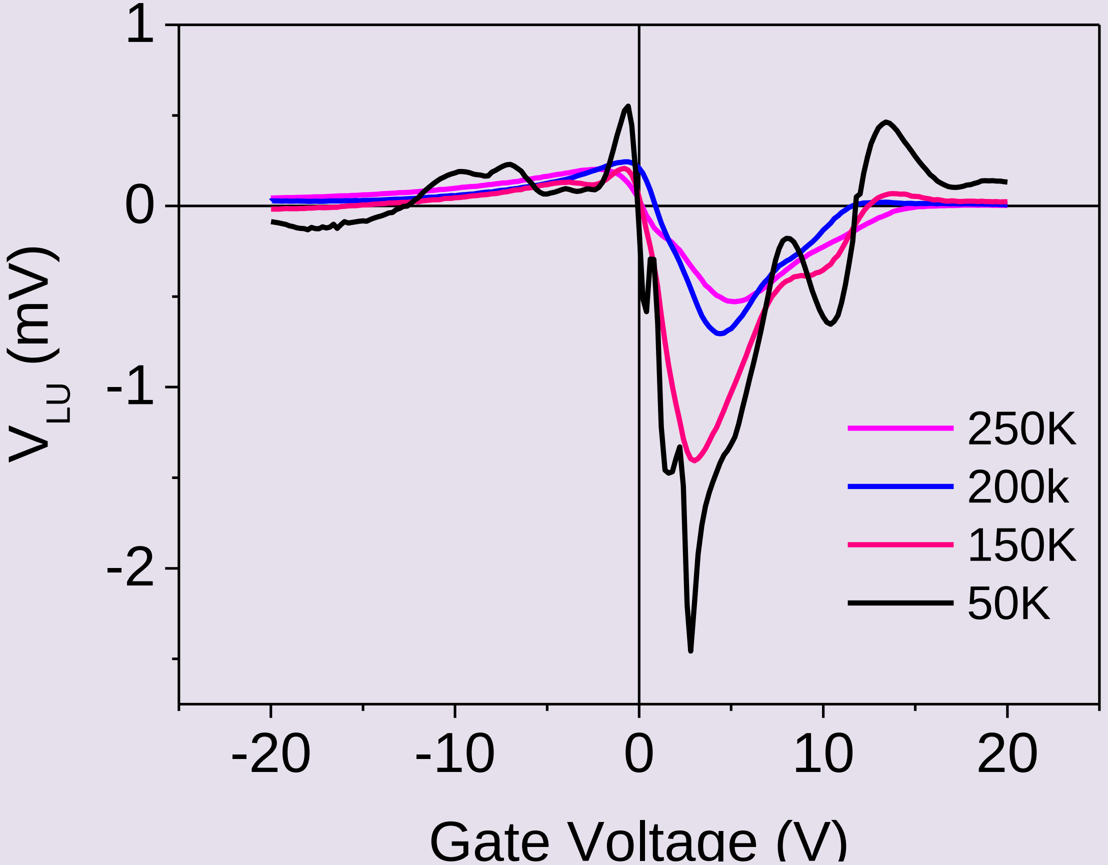


AC Response

All measurements done at 190Hz



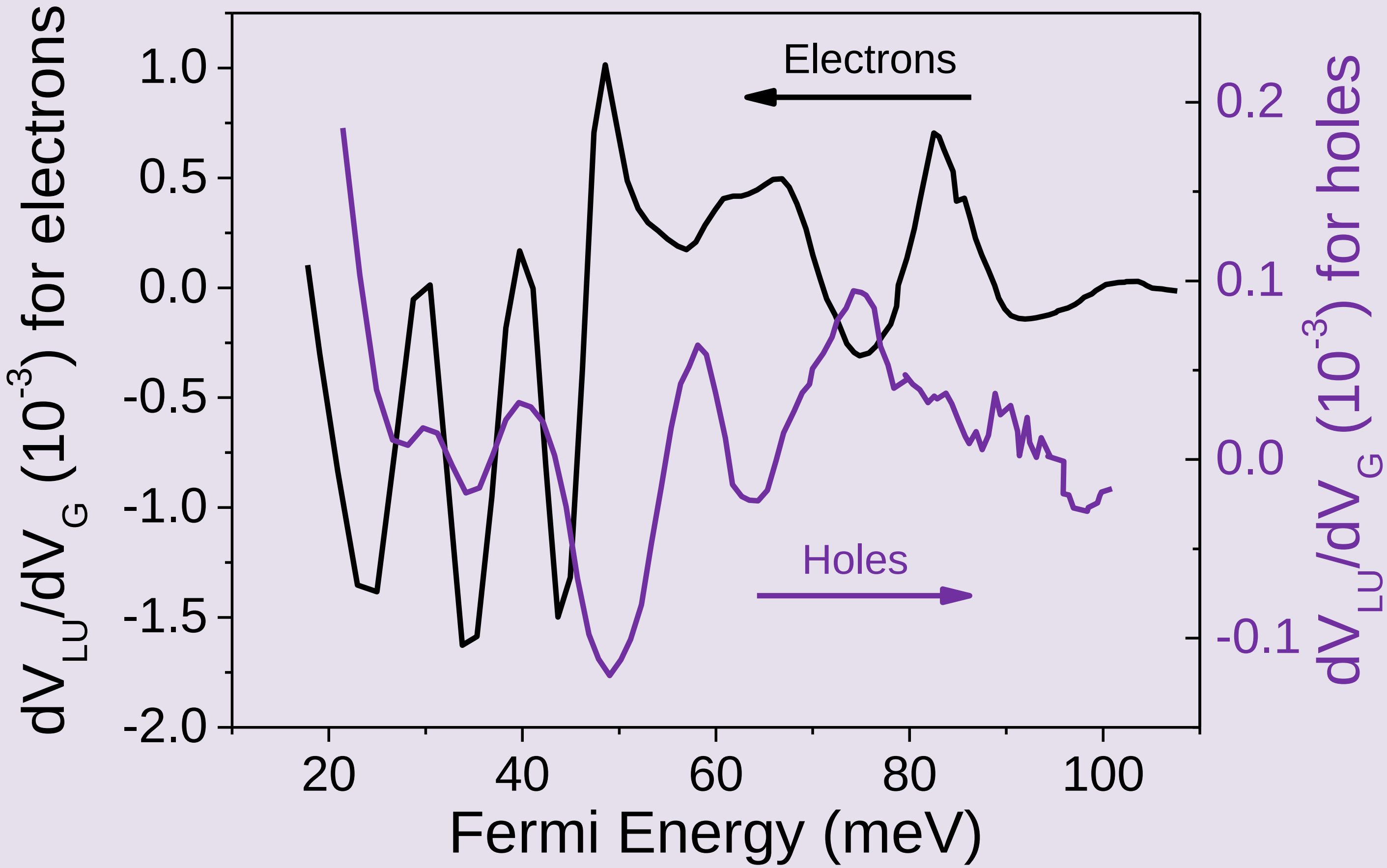
Temperature dependence



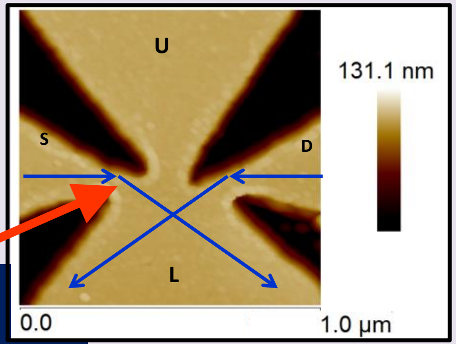
Seemingly periodic oscillation at low temperature

G. Auton, *et al.* Nature Communications, 7:11670 (**2016**)

Possible Quantum Effect



$$\Delta E = \hbar v_F \pi / W_{SD}$$



- Similar periods for electrons and holes
- Possible lateral quantisation in the narrow channels

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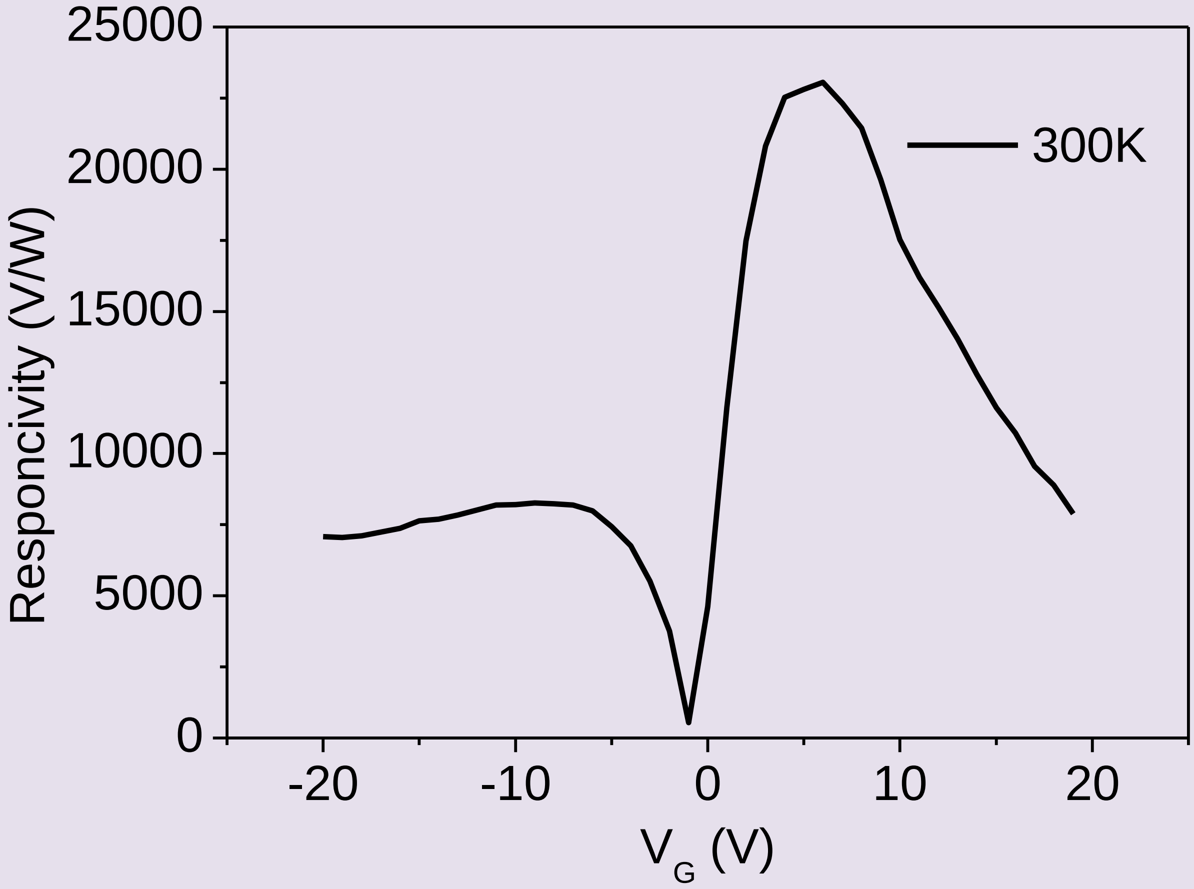
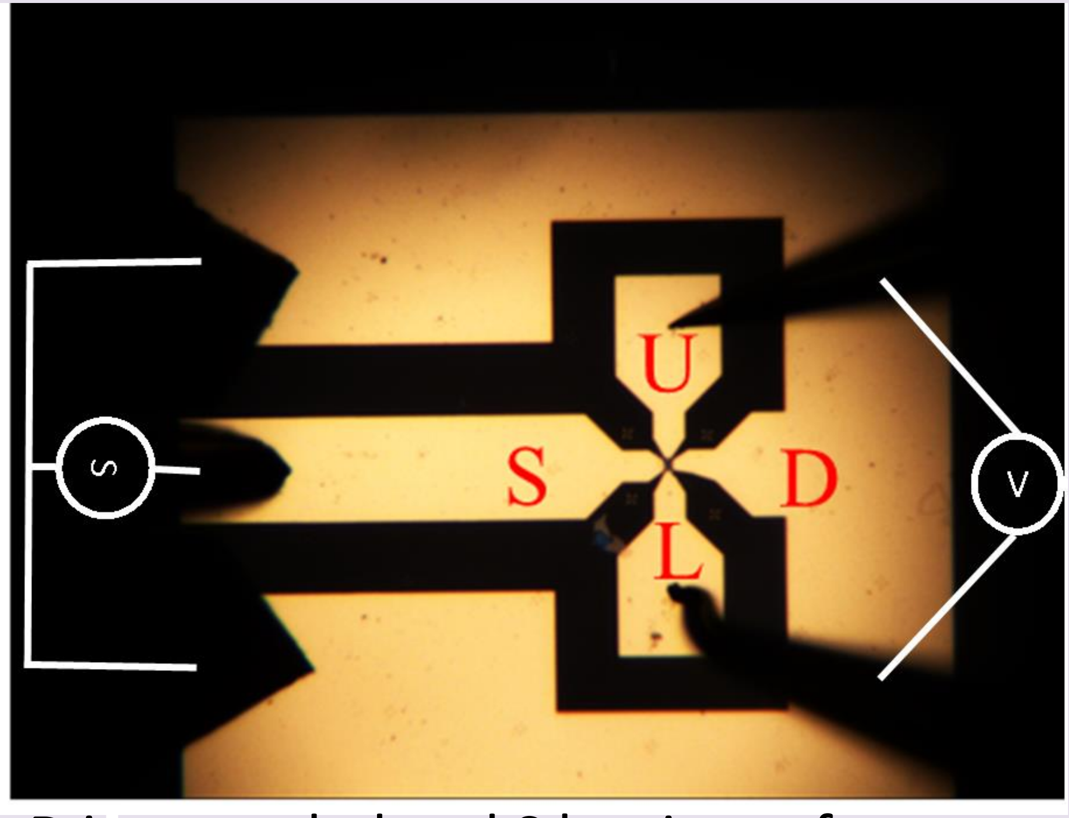
Sensitivity and responsivity



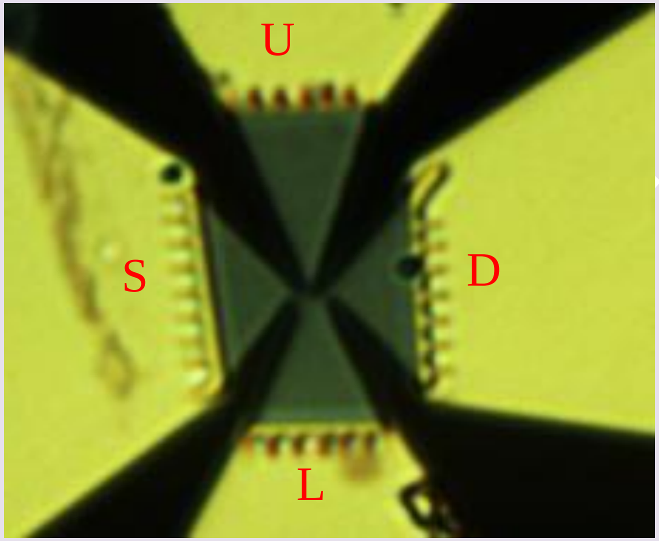
- Intrinsic Responsivity up to 23,000 mV/mW at low frequency and 300K
- One of the highest reported for diode detectors to date

G. Auton, *et al.* Nature Communications, 7:11670 (**2016**)

High Frequency Operation

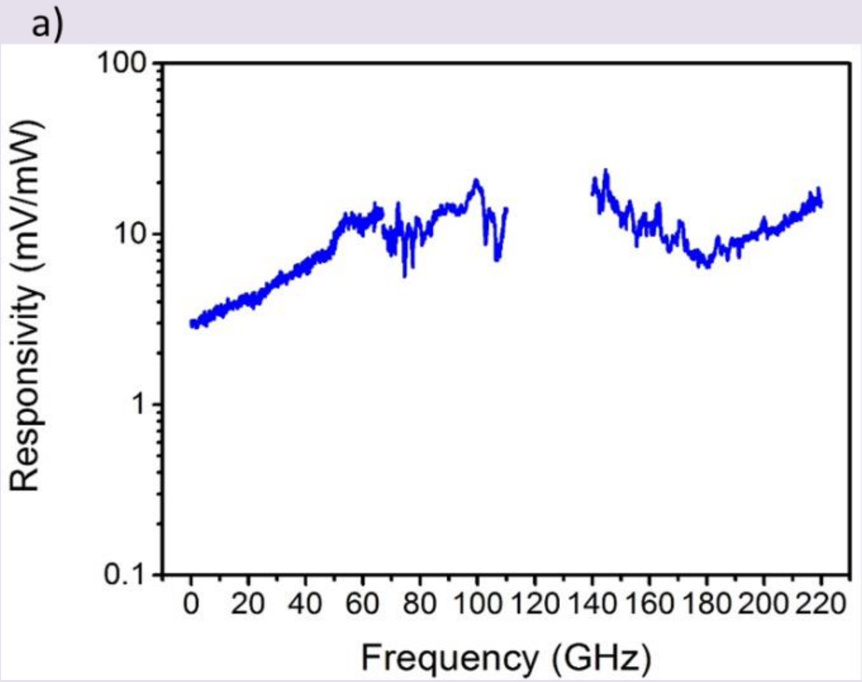


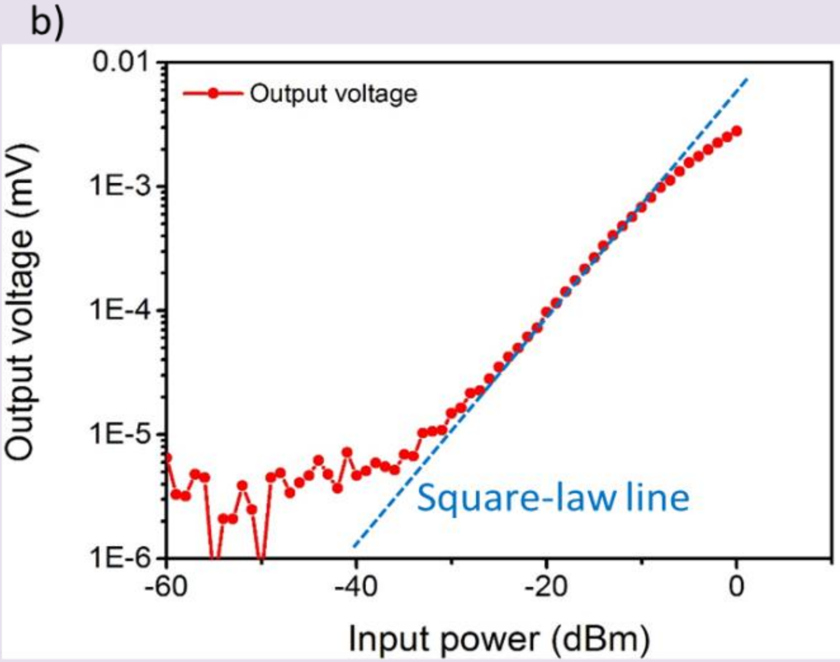
Devices where measured using a set of contacts designed for high frequency (<200GHz) on various probe set ups.



D is grounded and S has input from a vector network analyser. DC probes are used to measure output.

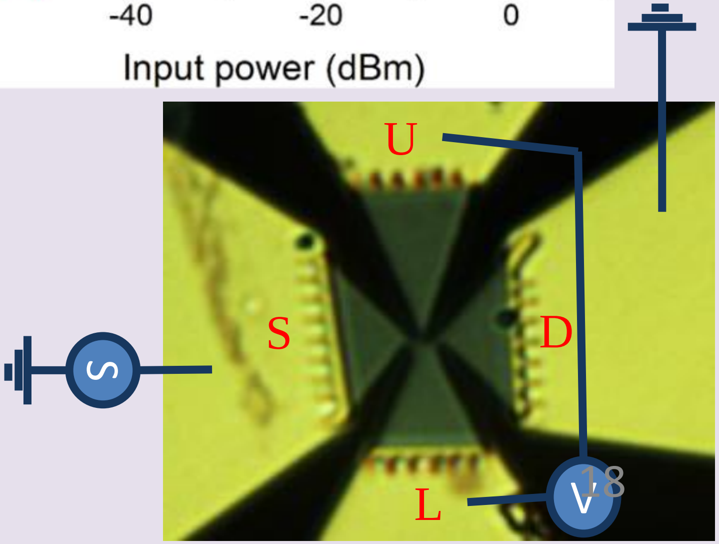
High Frequency Operation





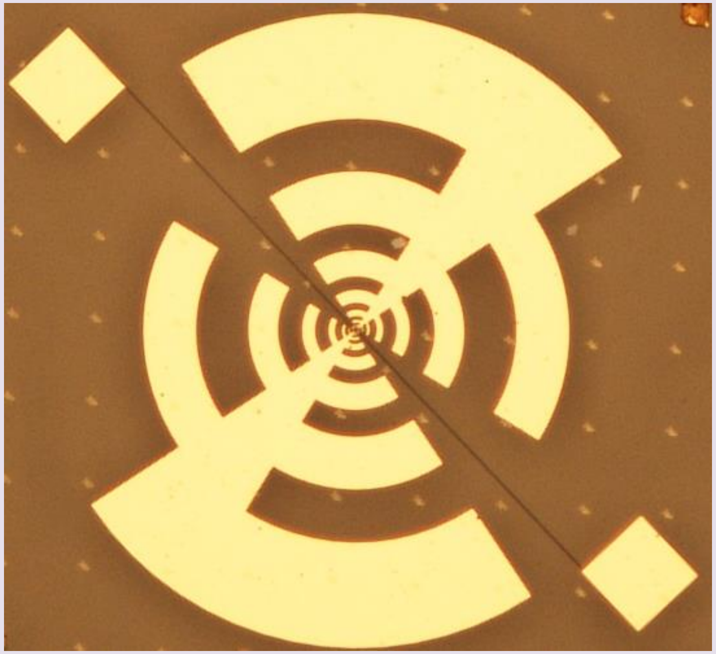
The devices where then tested up to 220GHz and show square law output

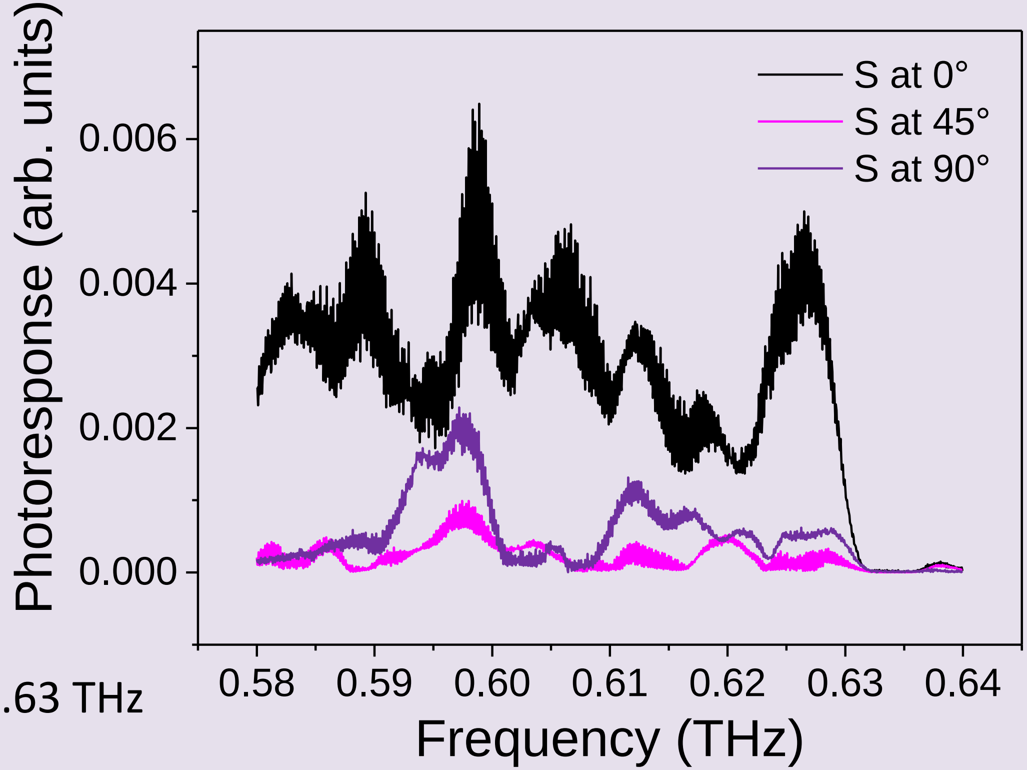
Impedence matching is a problem



Hanbin Wang, Xijian Zhang
School of Physics, Shandong University, Jinan, China

Free space measurements up to 640 GHz





Cut off from source at 0.63 THz

- Collabration with Luca Varani and Jeremie Torres at Montpellier
- No signs of a cut-off frequency up to 630 GHz
- Very initial measurements, not calibrated yet!

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Summary

- ✓ Voltage responsivity reaching 23,000 mV/mV (low freq)
- ✓ De-coupled output means very low noise
- ✓ Intrinsic NEP in the order of $pW/Hz^{1/2}$ at 300K
- ✓ Initial high-frequency measurements up to 640 GHz
- ✓ May be used as ultra-sensitive THz/microwave detector

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Thanks for your attention

Also thanks to:

Dmytro B. But
Christophe Consejo
Luca Varani
Jeremie Torres
Jiawei Zhang
Aimin Song
Hanbin Wang

Dominique Coquillat
Philippe Nouvel
Frederic Teppe
Roshan Krishna Kumar
Ernie Hill
Fred Schedin
Xijian Zhang