
# Electrically tuneable terahertz metasurface enabled by a graphene/gold bilayer structure

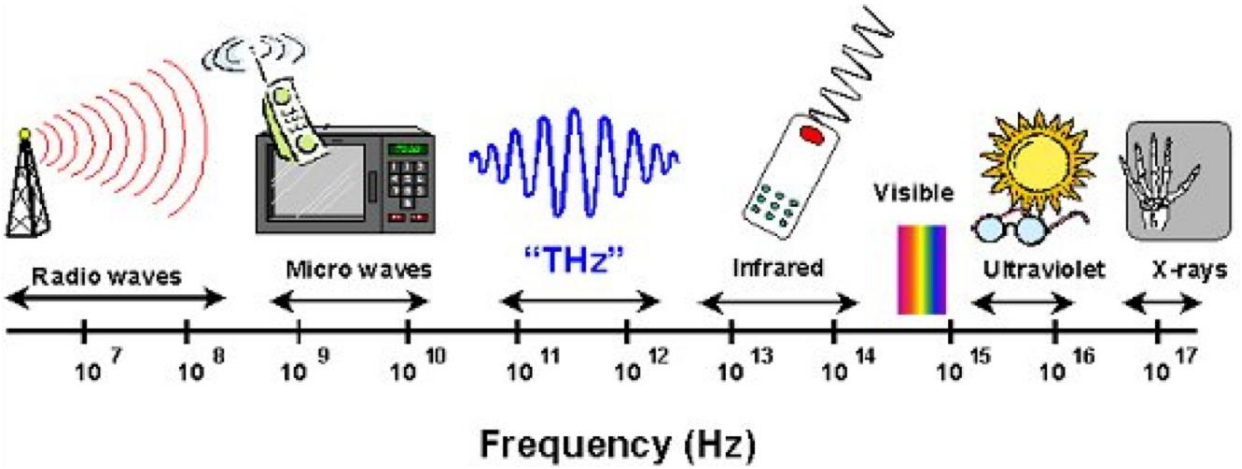
***Dr. Andrew Squires*** | CSIRO

13 Dec 2022

# Outline

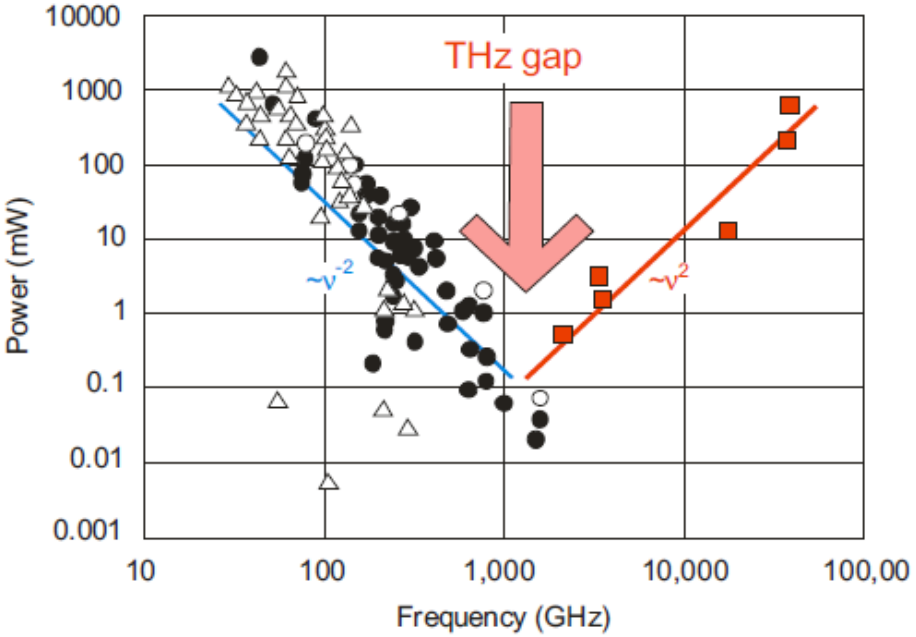
1. Introduce THz physics and graphene
2. Show where CSIRO operates in this space
3. Present details of gold THz metasurface
4. How graphene tuneability was incorporated
5. Experimental results

# High Frequency (THz) Physics




- Terahertz physics (0.1 – 10THz) represents a technological ‘gap’ between electronics and photonics

# The Fabled ‘THz Gap’

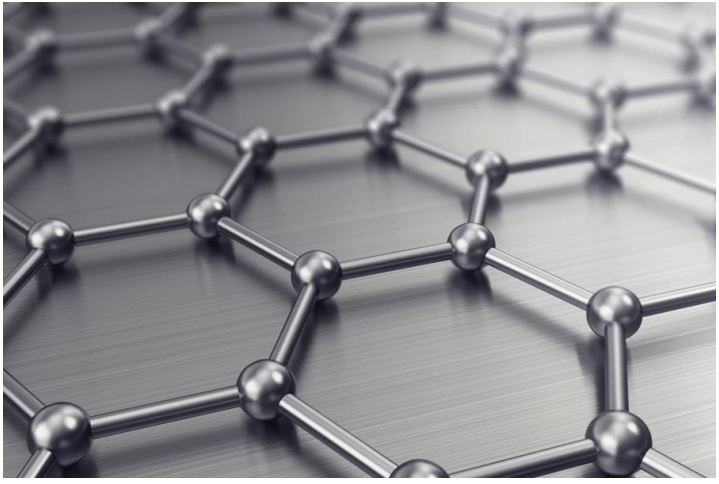



**Intrinsic limitations of current technologies requires new materials, like graphene, to access this region and ‘bridge the gap’ between electronics and optics**

https://www.uvaterahertz.com/terahertz.html

# Graphene for high frequency electronics

- 2D layer of $sp^2$ hybridized carbon atoms
- First shown experimentally in 2004 by Novoselov and Geim
- Possesses many unique and exciting electrical and electromagnetic properties



https://www.2dmaterialsmag.com/

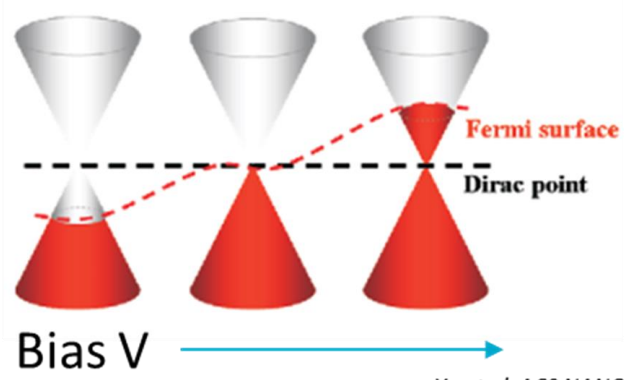
**In theory** → **FANTASTIC** 

**Experimentally** → **Not so much...** 

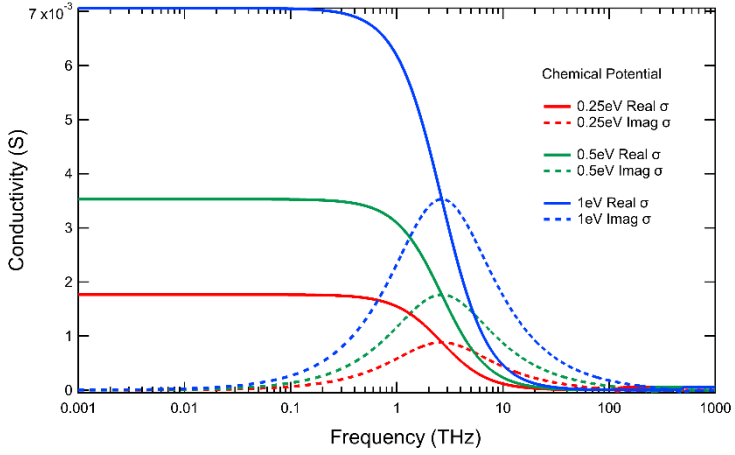
# Graphene for high frequency (THz) electronics

## High electron mobility

## Electrically tuneable conductivity




*Xu et al. ACS NANO, 2011*




Also supports plasmonic modes (not relevant for this talk)

# CSIRO's unique position

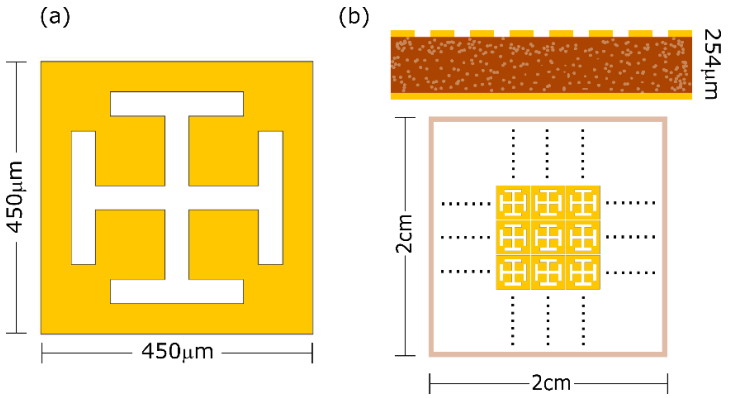
GRAPHENE

DEVICE DESIGN AND THEORY

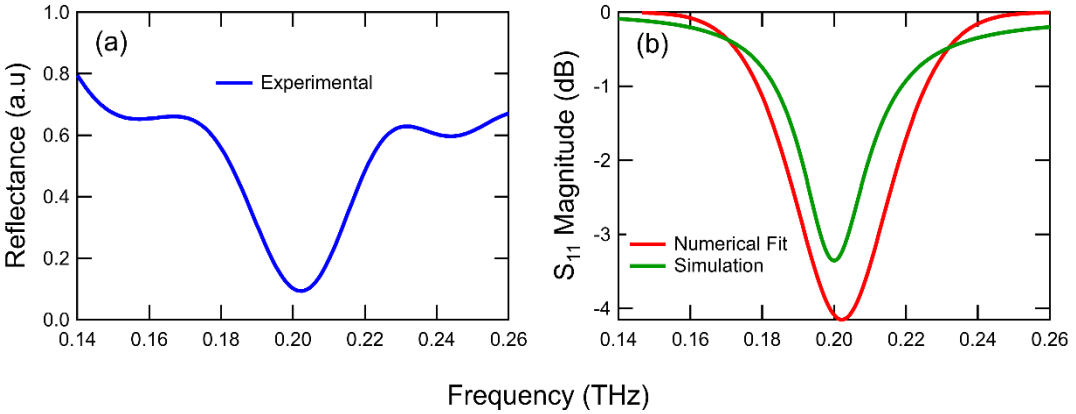
MICRO-FABRICATION

TERAHERTZ PHYSICS

# Base structure: 0.2THz metamaterial absorber



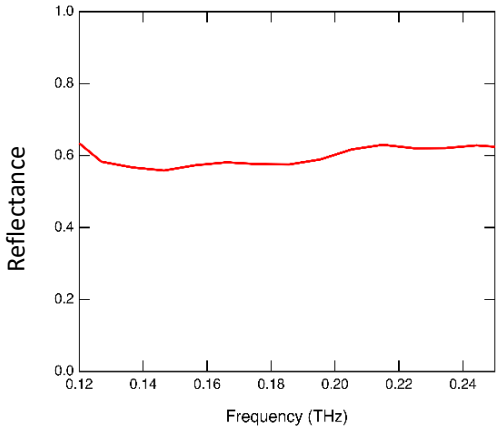

- Designed for strong (frequency selective) resonance at 0.2THz
- Uses flexible PCB board Rogers5880
- Good agreement between theory and experiment



# Introducing graphene tuning into absorber

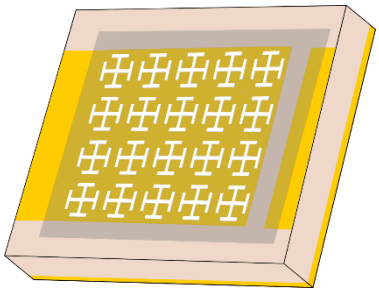
## Option 1: **Apply graphene sheet**

- Simple method
- Severely limiting
- For this device: poor response



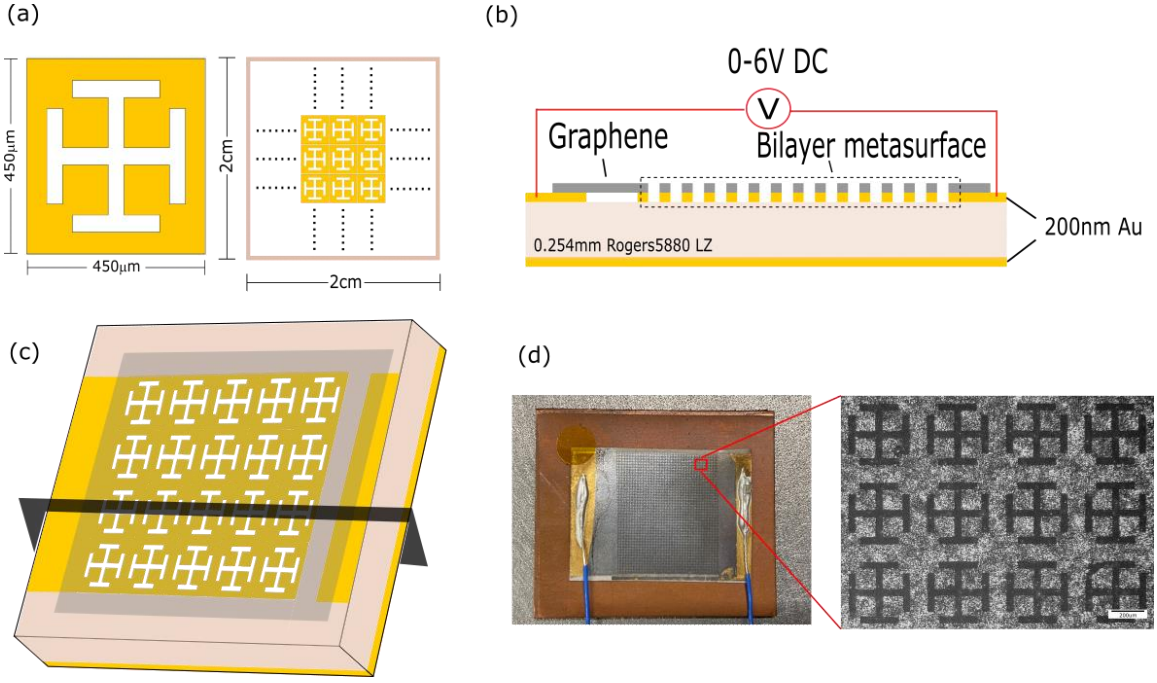

## Option 2: **Pattern graphene/gold**

- Very careful in film transfer and photolithography process
- Realisable with alternating Ar and O plasma etch.
- For this device: Great response



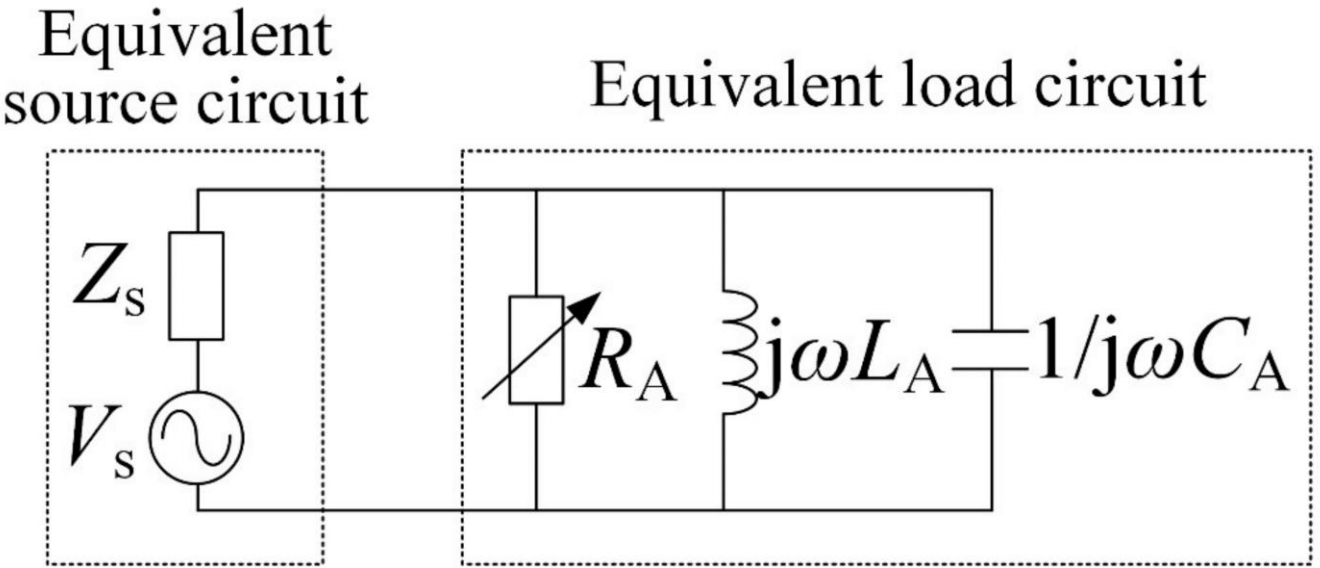
Also attempted graphene-only metasurface – No resonance

# Tuneable graphene/gold bilayer




**Details in publication**: Squires, A.D., Gao, X., Du, J. *et al.* Electrically tuneable terahertz metasurface enabled by a graphene/gold bilayer structure. *Commun Mater* **3**, 56 (2022). **https://doi.org/10.1038/s43246-022-00279-7**

# Equivalent circuit model

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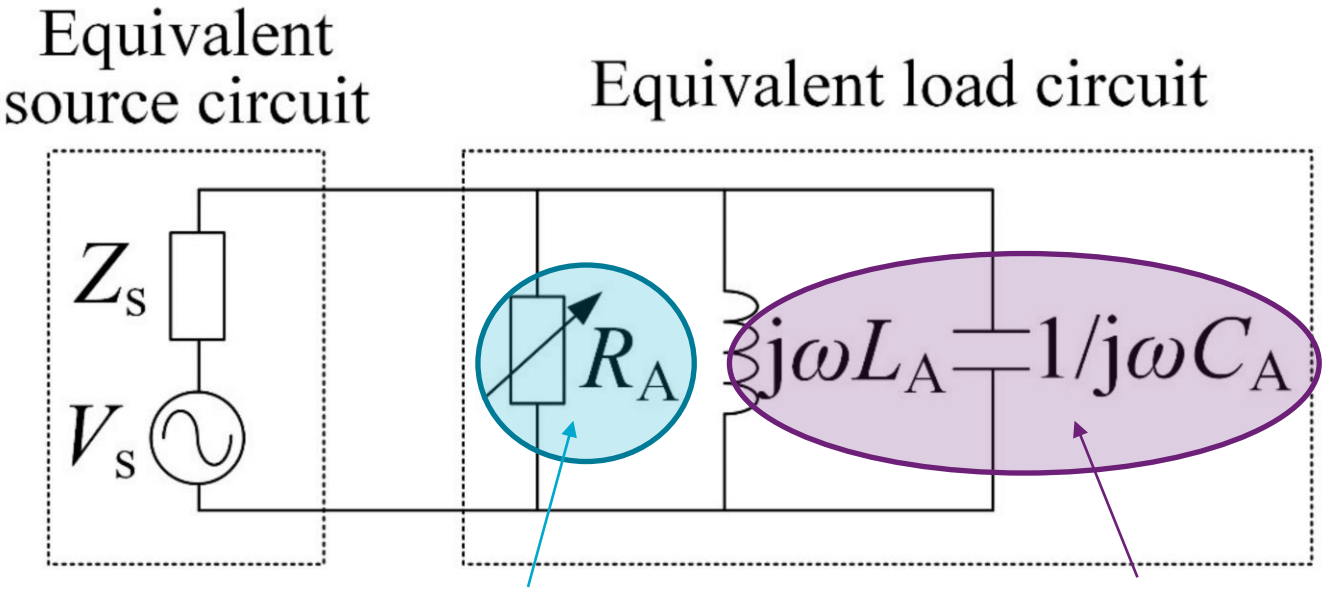


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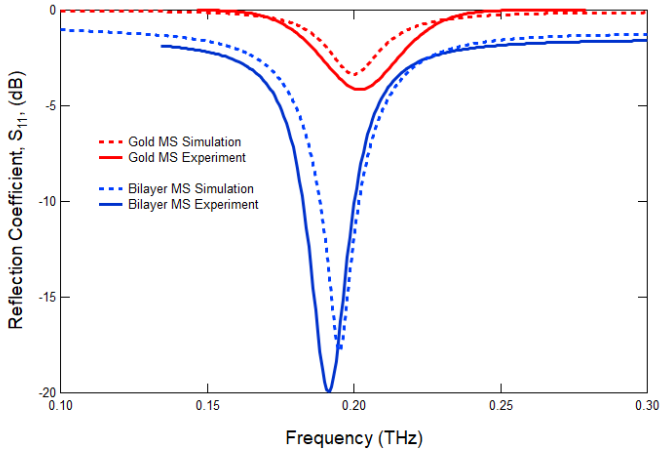
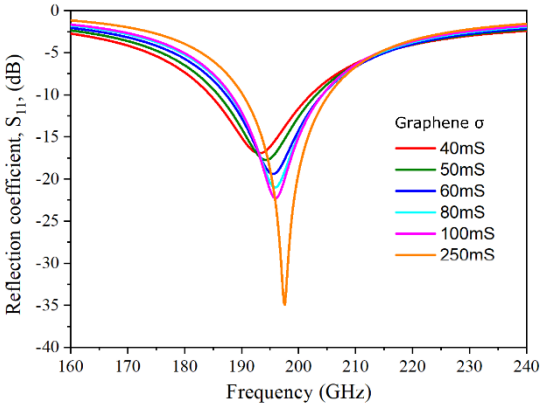
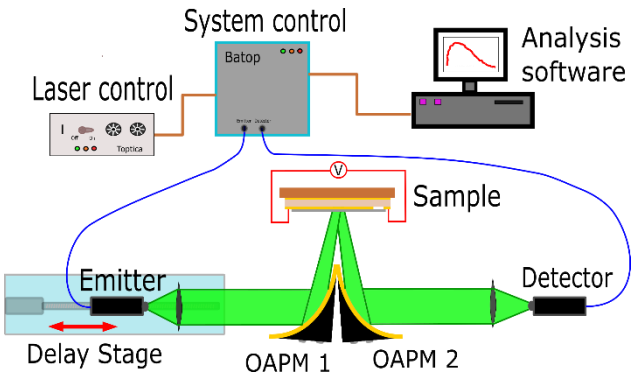
# Comparison of simulation and experiment



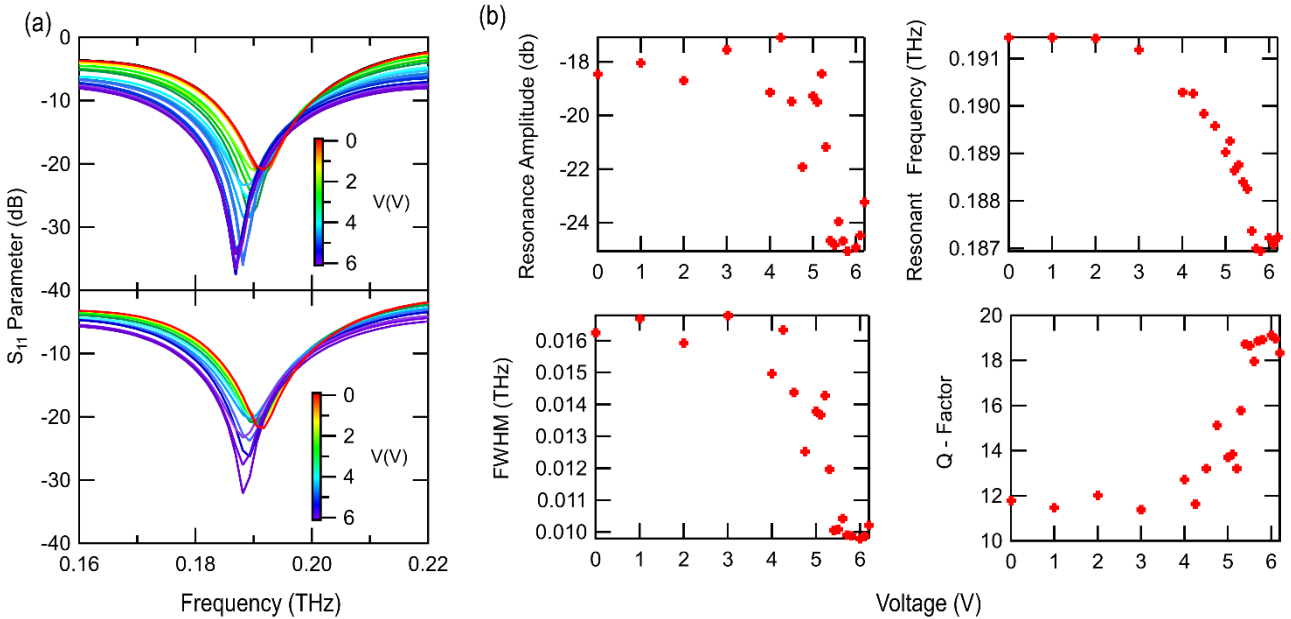




- ✓ Good agreement from gold MS (red) maintained in bilayer (blue)
- ✓ Tuning function verified theoretically




**https://doi.org/10.1038/s43246-022-00279-7**

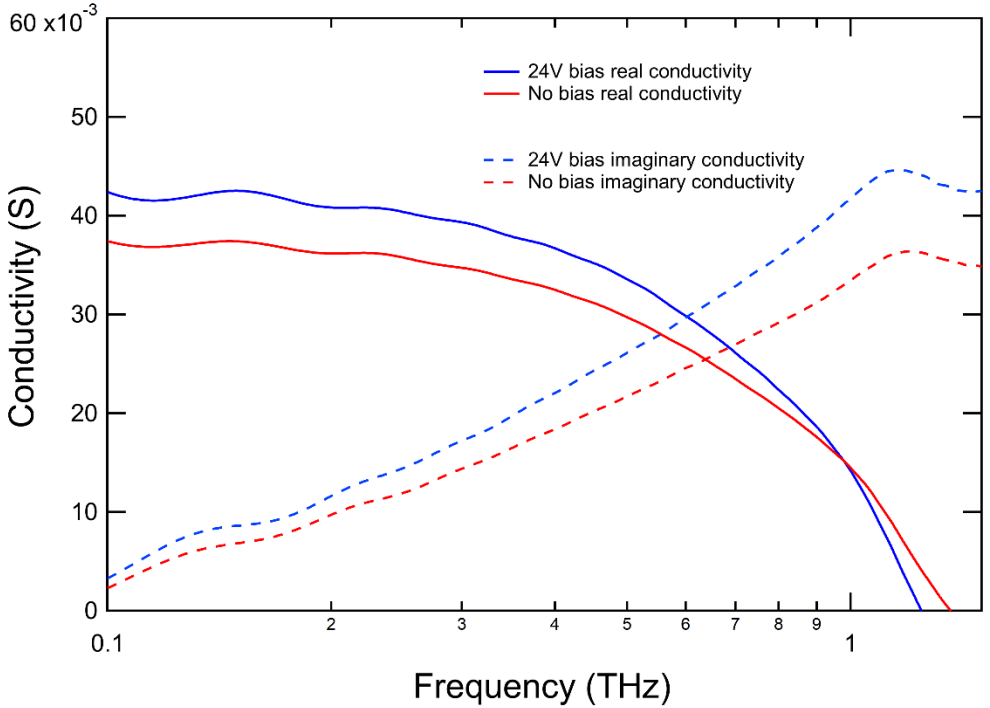
# Tuning at 0.2THz




- ✓ 16dB Amplitude tuning for 0-6V bias
- ✓ Benchmark Q-factor up to 19 (for graphene/THz MS)
- ✓ Small frequency tuning (5GHz), opposite of simulation ?

**https://doi.org/10.1038/s43246-022-00279-7**

# Graphene Conductivity Tuning

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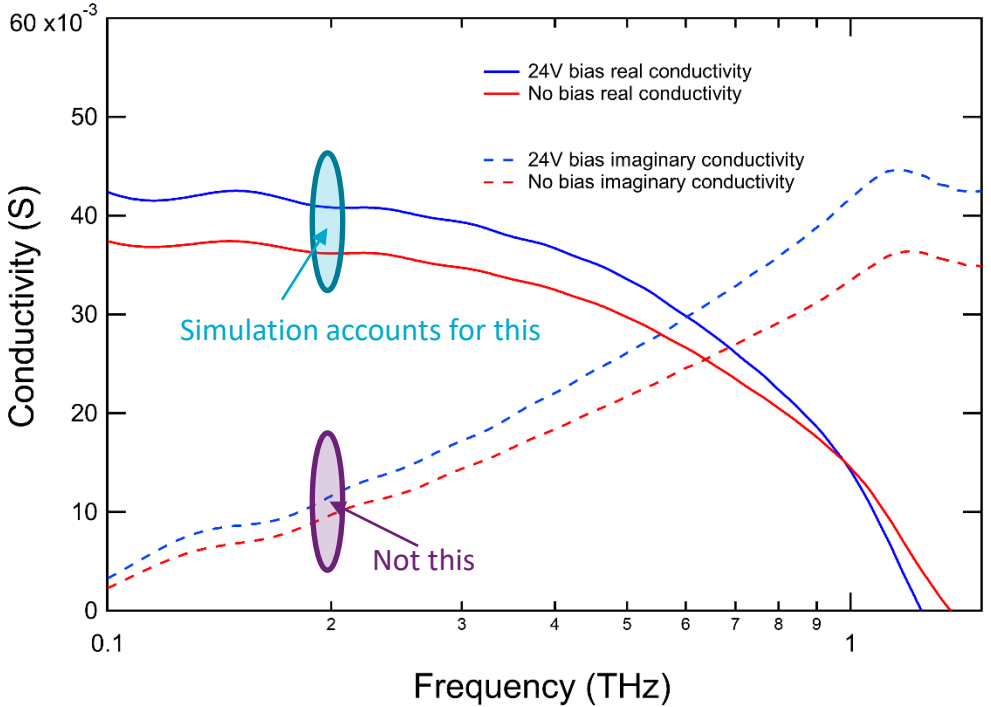


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# Tuning Mechanism

ARTICLE

Received 3 Nov 2015 | Accepted 9 Dec 2016 | Published 30 Jan 2017

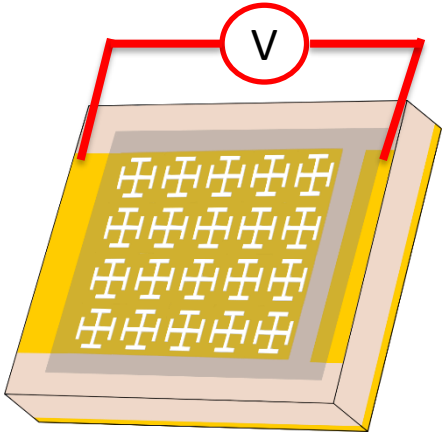
DOI: 10.1038/ncomms14217 OPEN

## Single-step ambient-air synthesis of graphene from renewable precursors as electrochemical genosensor

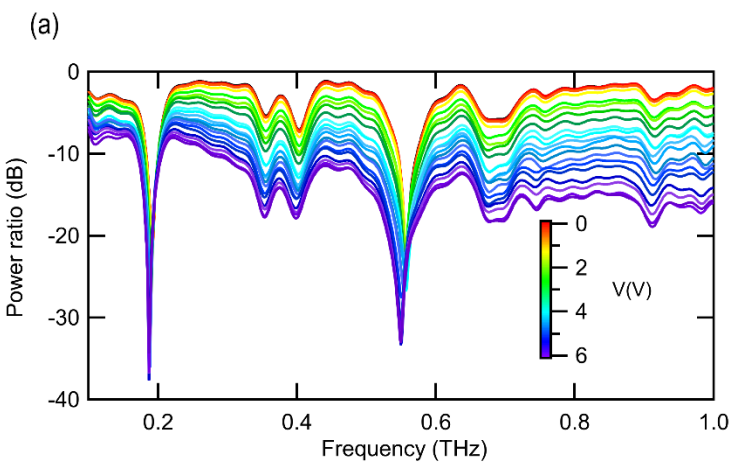
Dong Han Seo[1,*], Shafique Pineda[1,2,*], Jinghua Fang[3], Yesim Gozukara[1], Samuel Yick[1], Avi Bendavid[1], Simon Kwai Hung Lam[1], Adrian T. Murdock[1], Anthony B. Murphy[1], Zhao Jun Han[1] & Kostya (Ken) Ostrikov[1,2,4]

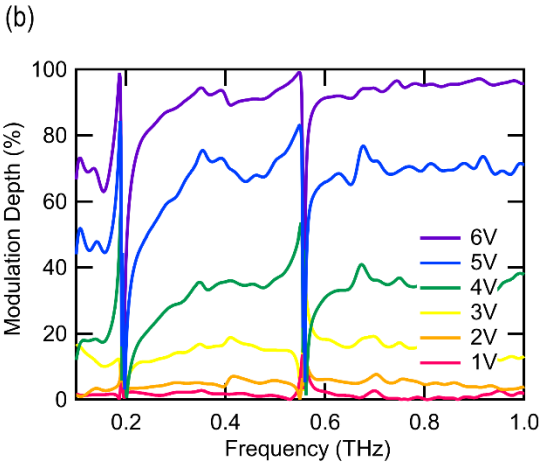
Results suggest enhanced tuning in CSIRO GraphAir films

- Still trying to understand this
- CSIRO GraphAir films highly dislocated which decouples layers in the z-direction.



# Broadband Response




**Auxiliary modes at 0.36THz, 0.40THz and 0.56THz**

- Tuneable as per the 0.2THz mode, although not as pronounced

**Broadband modulation**

- 0.23 - 0.32THz = 85%
- 0.43 - 0.50THz = 91%
- Above 0.72THz = 95%

**https://doi.org/10.1038/s43246-022-00279-7**

# Summary

- Introduced graphene and THz region of the electromagnetic spectrum
- Highlighted CSIRO's desirable position in this space
- Showed graphene/gold bilayer are useful method of producing high Q-factor tuneable resonances at THz frequencies
  - 16dB amplitude tuning at 0.2THz resonance
  - High Q-factor (19) resonance
  - Up to 95% broadband modulation

# Acknowledgments


- I would like to thank the following people involved with this project:
  - Tim van der Laan, Jia Du and Zhaojun Han (supervisors)
  - Michael Seo, Tim Van Der Laan and James Cooper (Graphene production)
  - Jeina Lazar, Wendy Purches and Simon Lam (Fabrication assistance)
  - Avi Bendavid (Mentoring and materials/fabrication assistance)
  - Xiang Gao and Ting Zhang (Device designs)


# Thank you

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