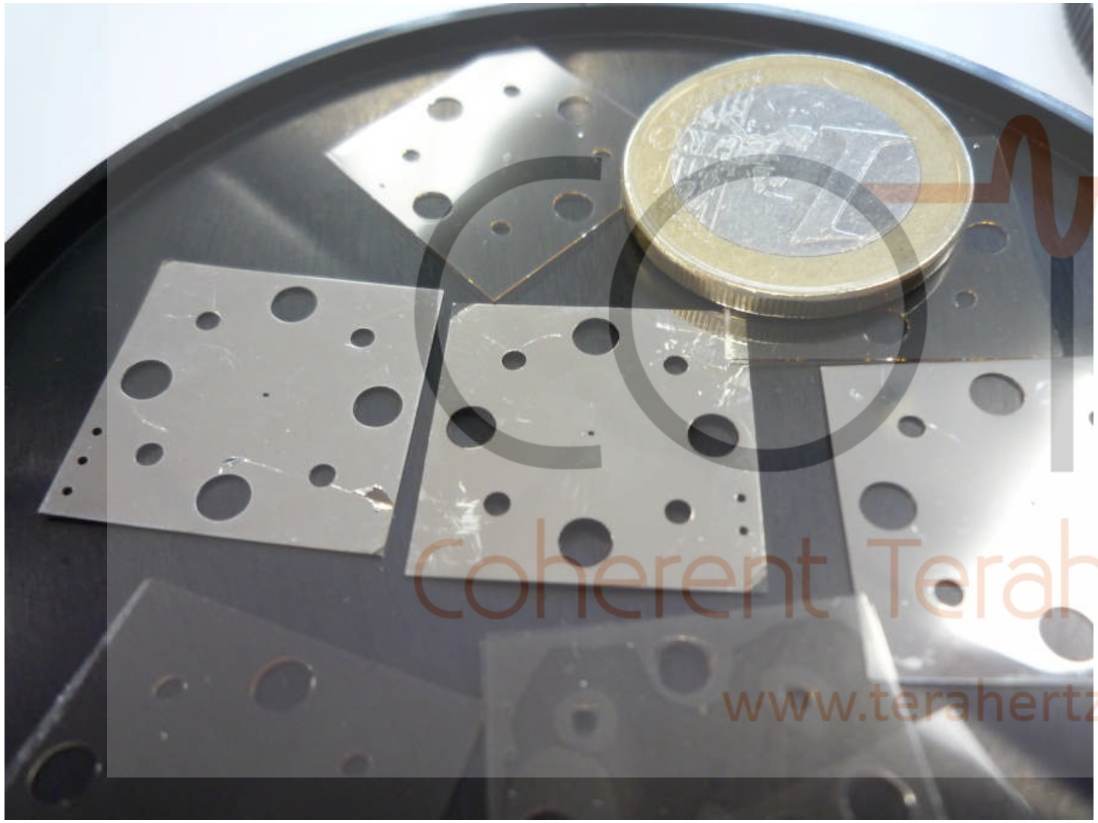
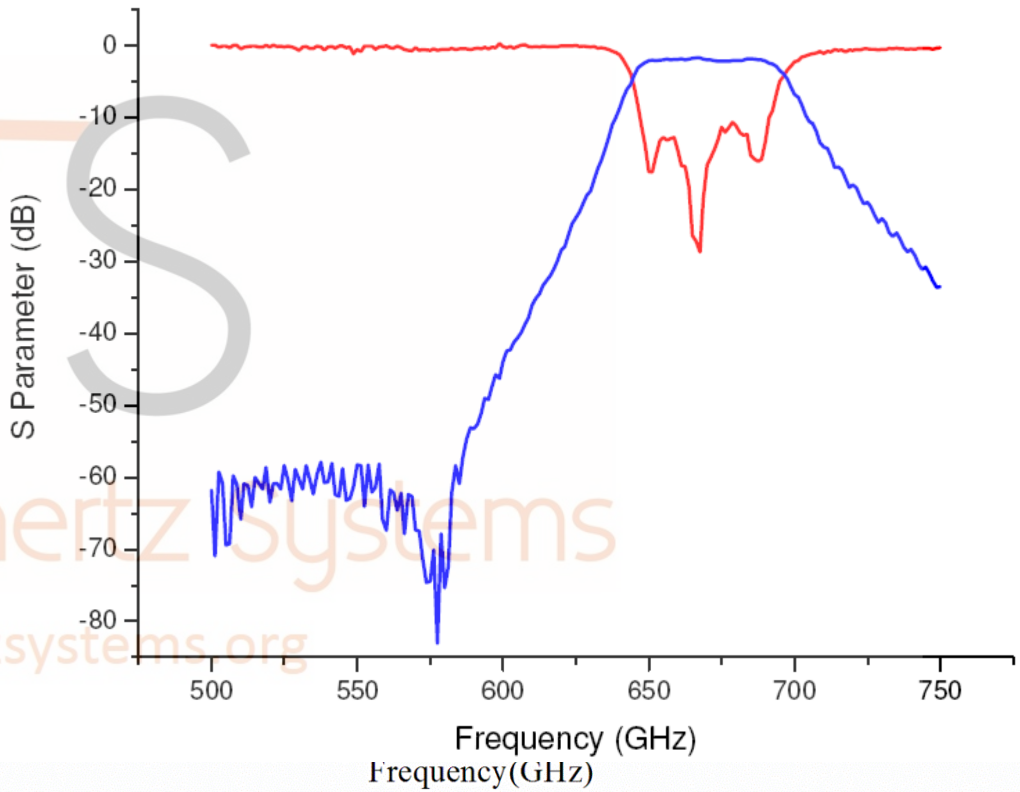
UNIVERSITY OF BIRMINGHAM

700 GHz Waveguide Filter.

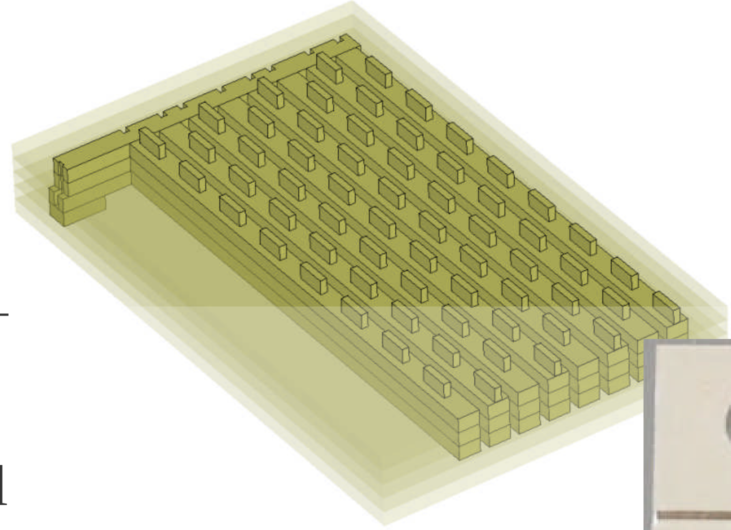
Micromachined Waveguide Filter at 300 GHz

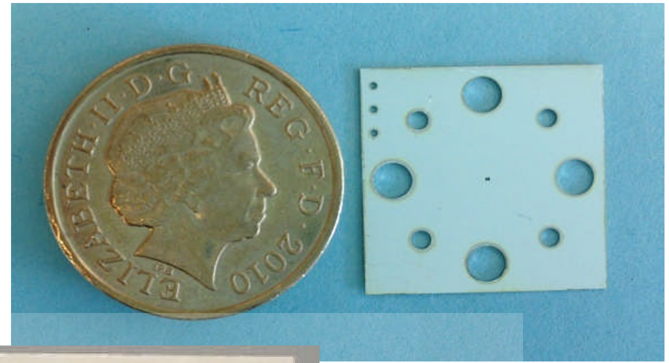


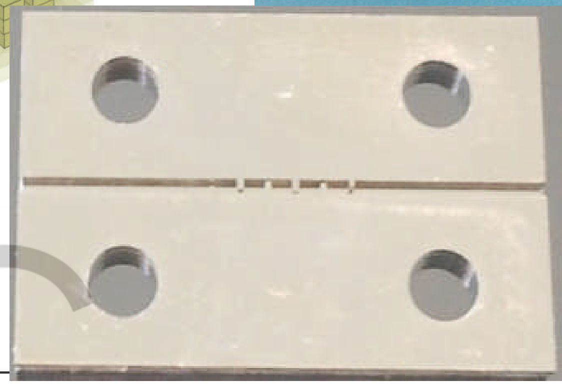


Waveguide size 430 by 220 μm

UNIVERSITY OF BIRMINGHAM

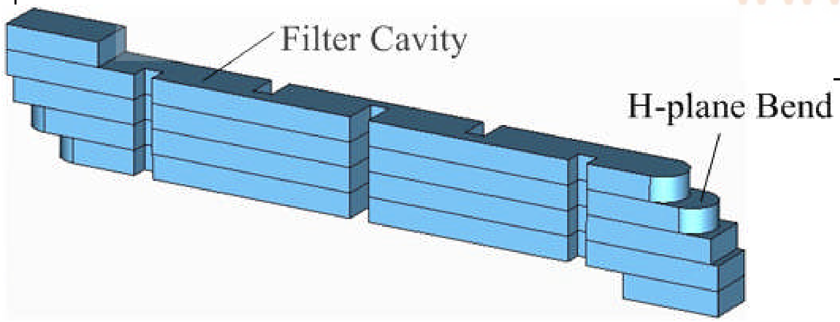






Micromachining Process:

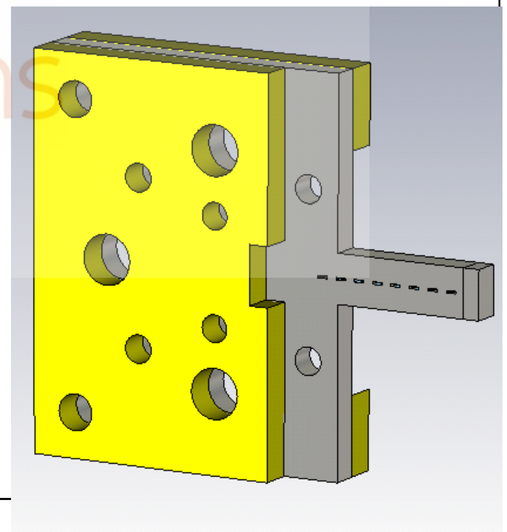
- Small accurate internal waveguide structure.
- No expensive/proprietary processes
- Batch processing possible
- No really expensive kit
- Accurate flange alignment
- Loss same as normal metal
- Large area complex structures
- Systems



40, 70, 100, 300, 700 GHz circuits demonstrated

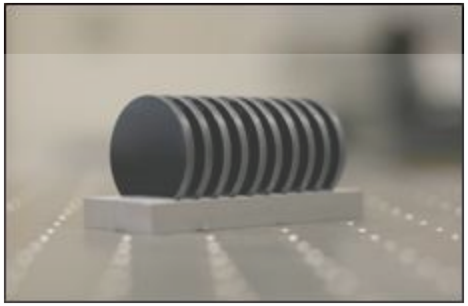
With academic collaborators and industry:

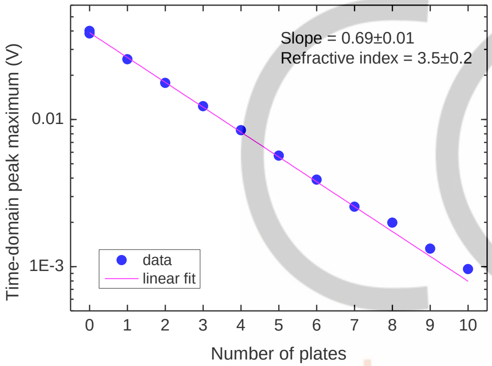
- Filters
- Diplexers
- Dual band filters
- Antenna array
- Ortho Mode transducer
- Free space mesh filter
- Butler Matrix

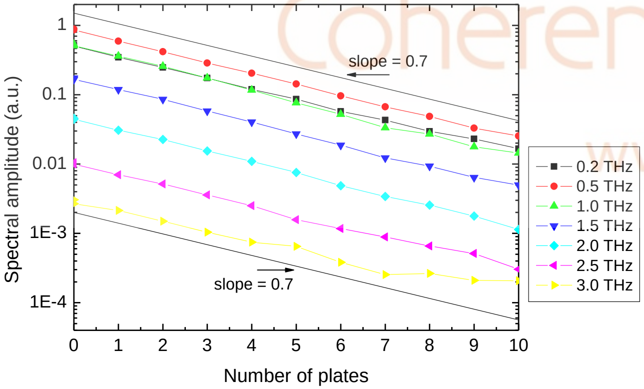


Terahertz metrology

Linearity

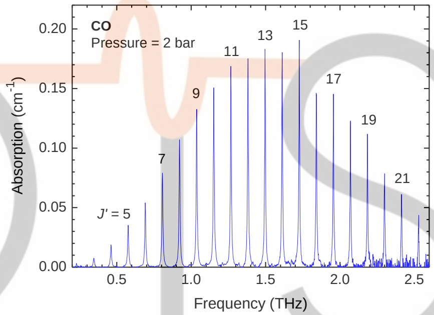




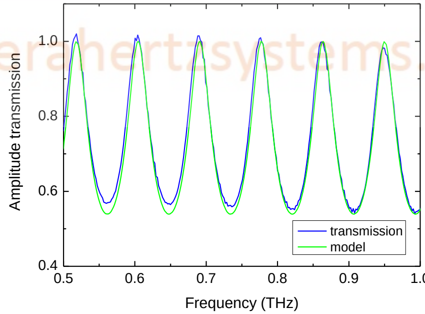


Frequency

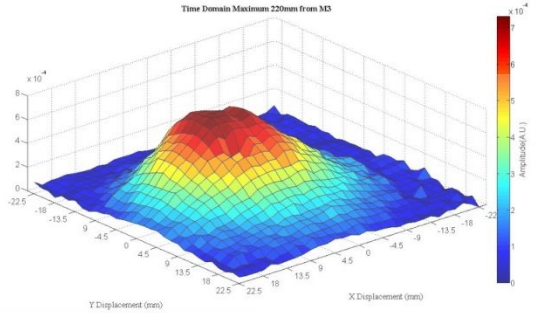
Gas cell



Etalon



Beam profile



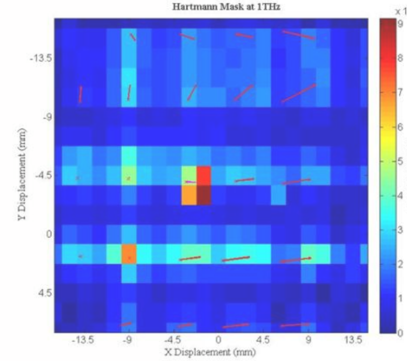
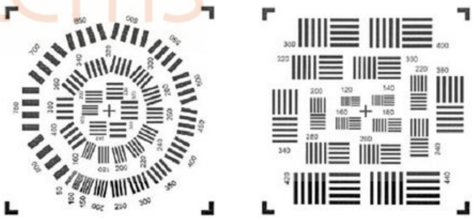


Image resolution



National Physical Laboratory

Terahertz science

New sources

THz OPO

HERIOT WATT UNIVERSITY

Institute of Monitoring of Climatic and Ecological Systems SB RAS Tomsk, Russia

MIMIC sources

University of Glasgow

Heterodyne source

UCL ENGINEERING Change the world

Materials

Liquid crystals — esa

GaSe — *Institute of Monitoring of Climatic and Ecological Systems SB RAS Tomsk, Russia*

Boron nitride — MOMENTIVE™

Clays — UNIVERSITAS COMENIANA BRATISLAVENSIS MCMXIX

Ferroelectrics — UNIVERSITY OF SURREY

Carbon nanotubes — Queen Mary University of London

Technical textiles — TechniTex

Biomedical

THz dosimetry
Hydration monitoring

Queen Mary University of London

Protein interactions

University of Reading

THz effects on cancer cells

Imperial College London

CANCER RESEARCH UK

NPL National Physical Laboratory

Centre for Terahertz Science and Engineering

Imperial College London

Science & Technology Facilities Council
Rutherford Appleton Laboratory

NPL
National Physical Laboratory

Directors: Prof N. Klein and Dr S. Lucyszyn

19 Academics / Researchers

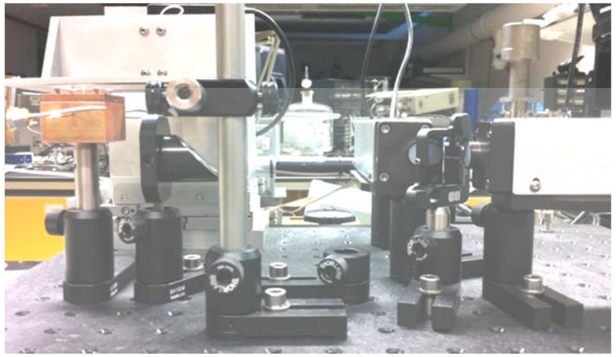
Cross Faculty Centre:

- Department of Electrical and Electronic Engineering
- Department of Materials
- Department of Physics

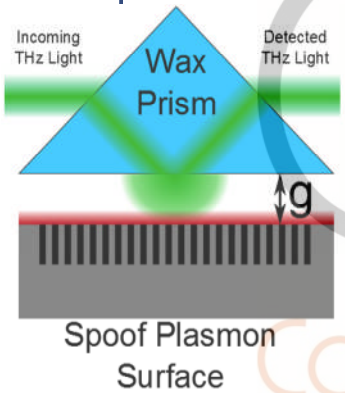
In partnership with RAL Space Millimetre Wave Technology Group
Collaborations with NPL

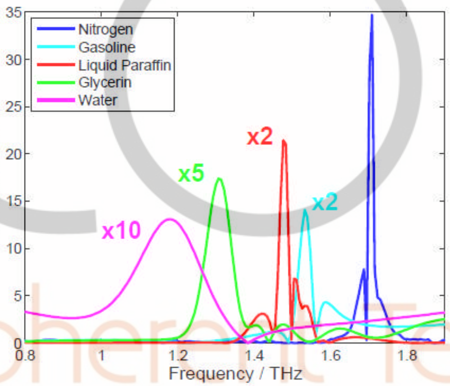
Research Areas

THz Near-field (NF) Probing System

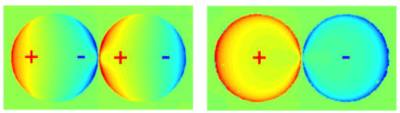


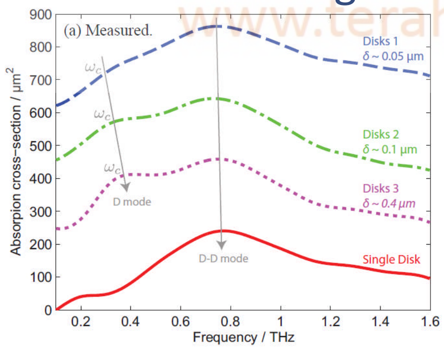
THz Spoof Plasmons for Sensing

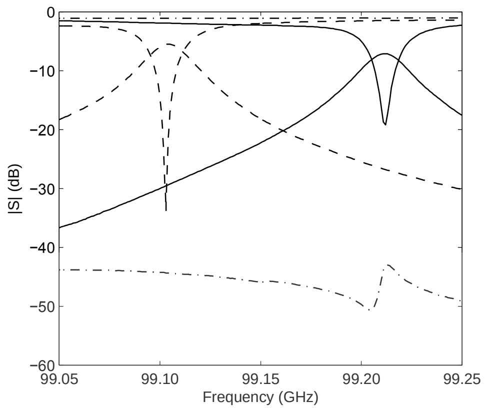




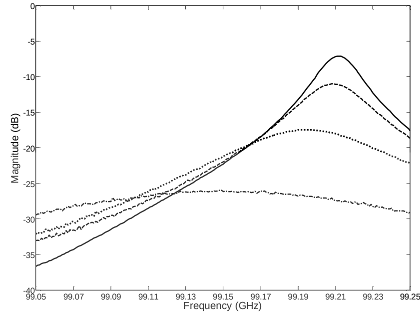
THz Plasmonic Structures for Sensing

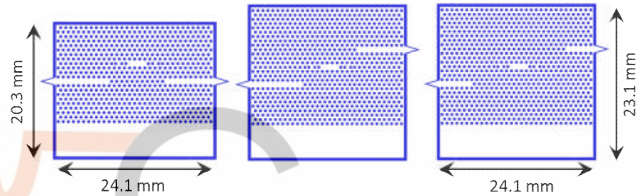


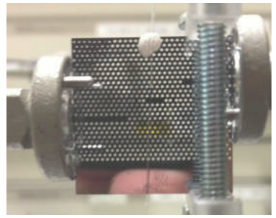




Photonic Crystals







Progress In Electromagnetics Research, PIER 101, 257–275, 2010

ENGINEERING APPROACH TO MODELLING FREQUENCY DISPERSION WITHIN NORMAL METALS AT ROOM TEMPERATURE FOR THz APPLICATIONS

S. Lucyszyn and Y. Zhou

IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY, VOL. 2, NO. 5, SEPTEMBER 2012 513

Defining Material Parameters in Commercial EM Solvers for Arbitrary Metal-Based THz Structures

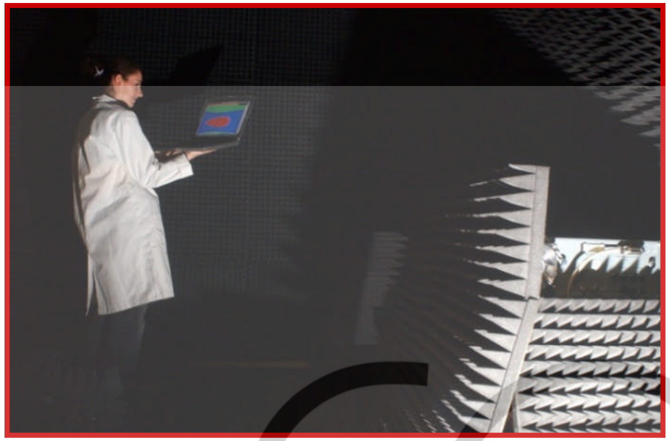
Elpida Episkopou, *Student Member, IEEE*, Stergios Papantonis, *Student Member, IEEE*, William J. Otter, *Student Member, IEEE*, and Stepan Lucyszyn, *Senior Member, IEEE*

- Low Cost THz Devices
- Communication
- Metamaterials
- Filters
- Material Characterisation

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Astronomy Instrumentation Group (AIG)

Astronomy Instrumentation Group



Dr. Carole Tucker

16th July 2013

The AIG comprises;

6.2 academics,

2 design engineers,

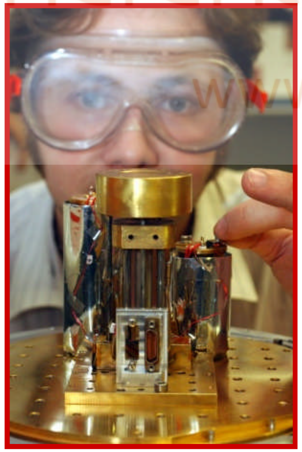
4 cleanroom technicians

11 PDRAs,

9PhD students

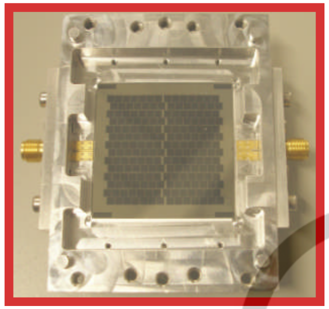
\+ Crossover with Cardiff Condensed Matter Group

\+ Staff Integration with *QMC Instruments Ltd.*



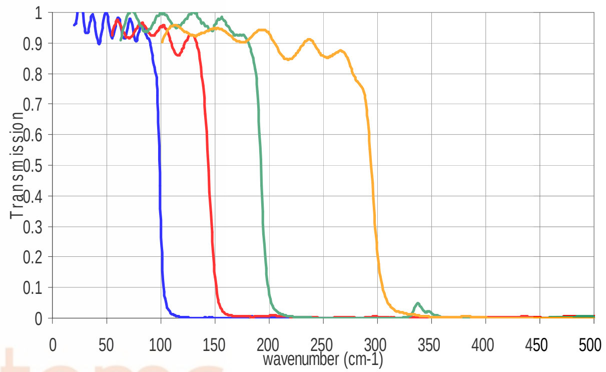
Cardiff THz expertise.

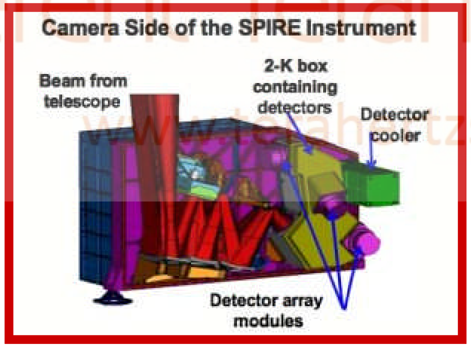
Historically we develop, manufacture and integrate THz technology for astronomical telescopes.



Ultra sensitive detectors (cold-electron bolometers, TES bolometers, LeKIDS) with NEPSs down to 10^{-18} $WHz^{-1/2}$.

Quasi optical and metamaterial filters, HWPs, lenses, AR coatings and now Flat lenses.





Integration of these technologies into low temperature systems (now cryogen-free) ultimate sensitivity and broad bandwidth. Photometric and Spectroscopic Systems.

World leading activity. Virtually all FIR telescopes in the world (and space) have AIG technology and collaboration.

Breadth of Activity

- STFC funded activity for 30 years. Grants totalling circa £15M since group relocated to Cardiff University (2001 – present).

- Academic group members now apply ultra sensitive broad-band detection/imaging to Biophysics, Medical Imaging, Optometry, Security Detection.

  2 EPSRC grants, 1 NIHR
  2 ERC grants
  External contracts for THz design and supply work
  Worldwide collaborations

- With the expansion of Cardiff CMP, activity related to THz properties of semiconductor materials.

- Well known THz Technology Spin-out company – QMC Instruments Ltd.

Graphene-controlled Terahertz Plasmonic Lasers
&
Electronically Switchable THz-over-Fibre

Subhasish Chakraborty

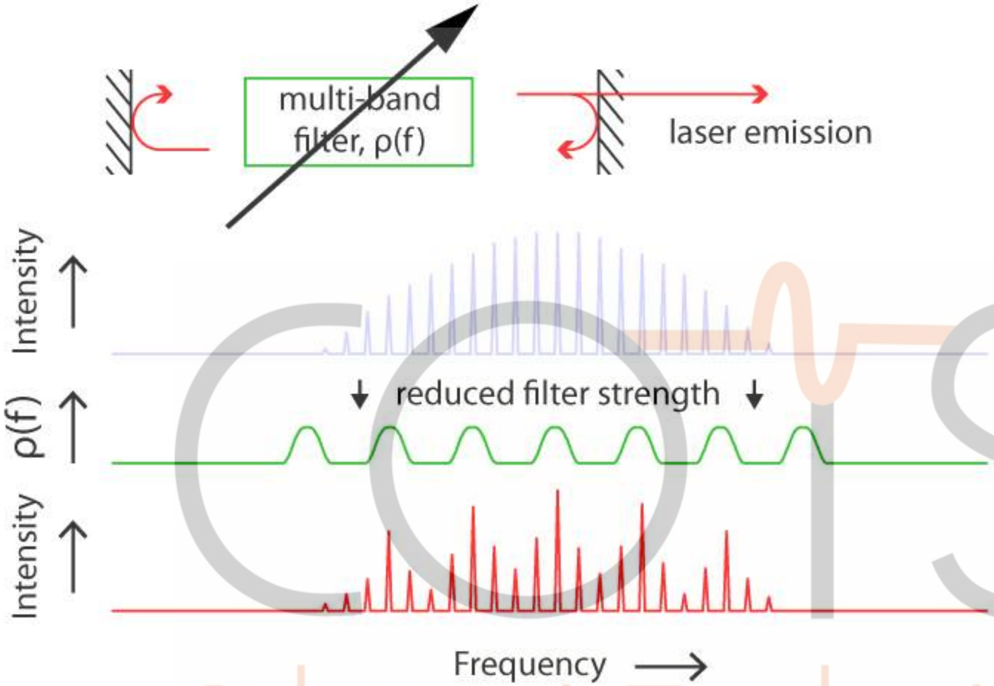
S. Chakraborty
O. P. Marshall
T. Folland
Md. Khairuzzaman
School of Electrical and Electronic Engineering
University of Manchester, UK

Y.-J. Kim
K. S. Novoselov
School of Physics and Astronomy
University of Manchester, UK

Collaborators:

H. Beere
D. Ritchie
Cavendish Laboratory
University of Cambridge

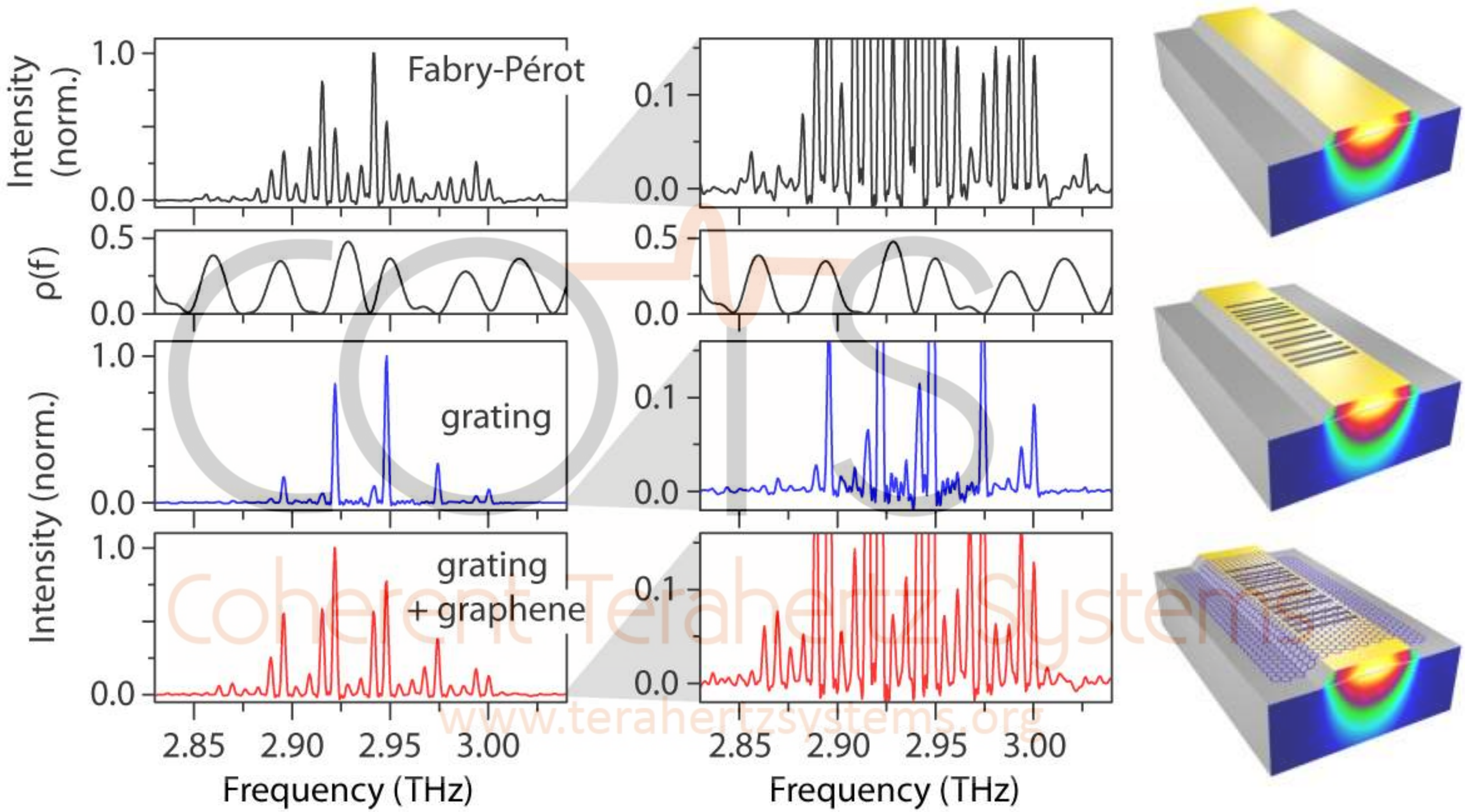
Laser emission with variable filtering strength



- Multiple lasing cavity modes in the unperturbed waveguide.
- Introduction of an aperiodic DFB filters the laser emission.
- Filtering strength dictates the emission spectra

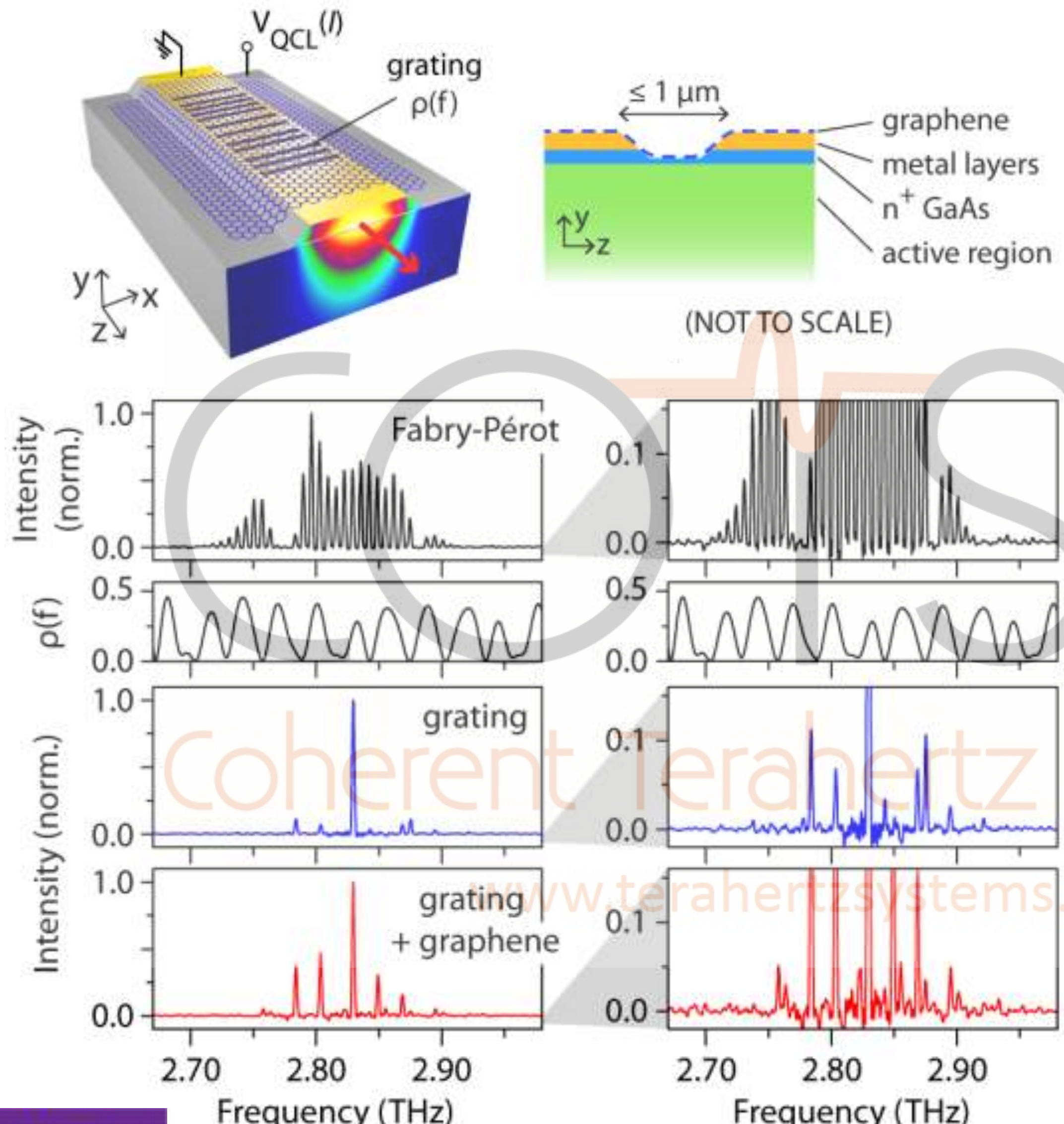
We aim to use **graphene surface plasmon mode**, and the tunable conductivity in graphene, to **control the strength** (and phase) of a **multiband filter ρ(f)**.

Filtered Laser with graphene overlayer



***Opt. Express* 20, B306 (2012)**
***J. Appl. Phys.* 113, 203103 (2013)**

Filtered Laser with graphene overlayer

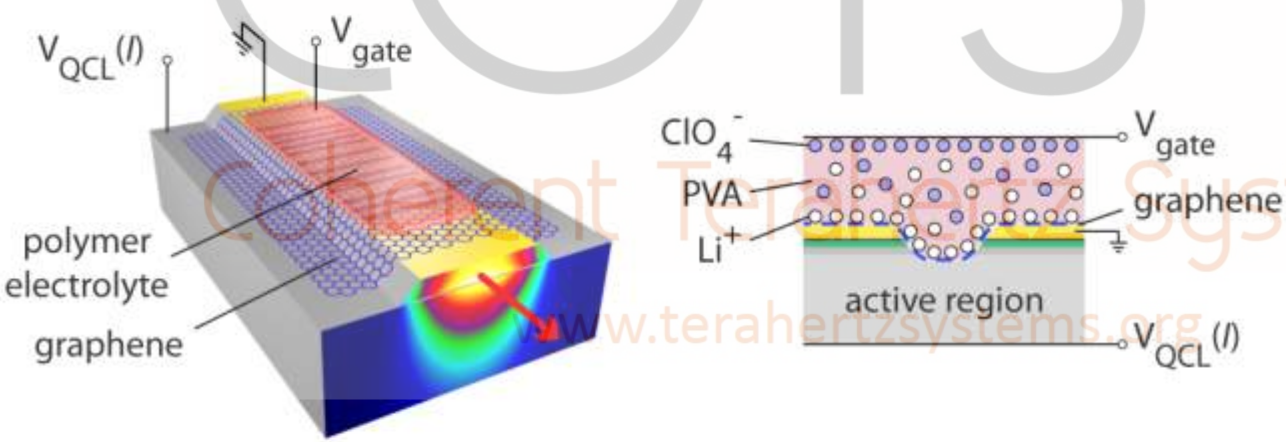


- Graphene overlayer on QCL with **stronger** aperiodic DFB **filtering**.

- Again, filtering strength reduced by graphene.

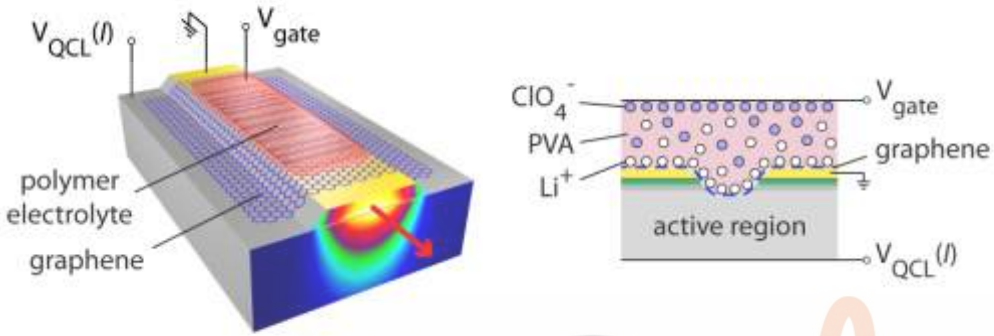
Gate Tunability of Graphene Plasmonic Laser

- **Can we tune graphene waveguide properties, changing E_f and altering QCL emission?**

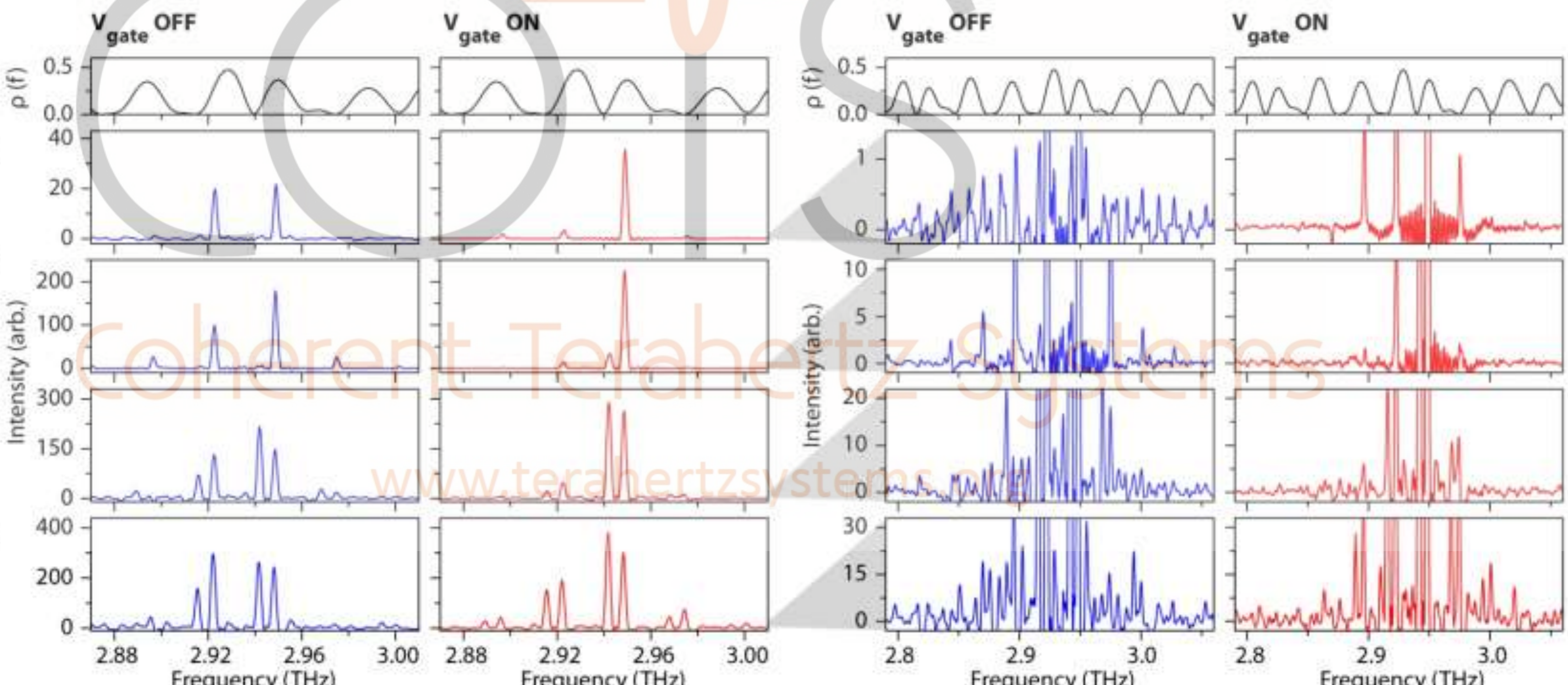


- Polymer electrolyte deposited onto graphene to electrically alter surface doping.

Gate Tunability of Graphene Plasmonic Laser



- QCL characterized with unbiased electrolyte (V_{gate} = 0).
- Filtering strength increased (|Δn| increased) with V_{gate}



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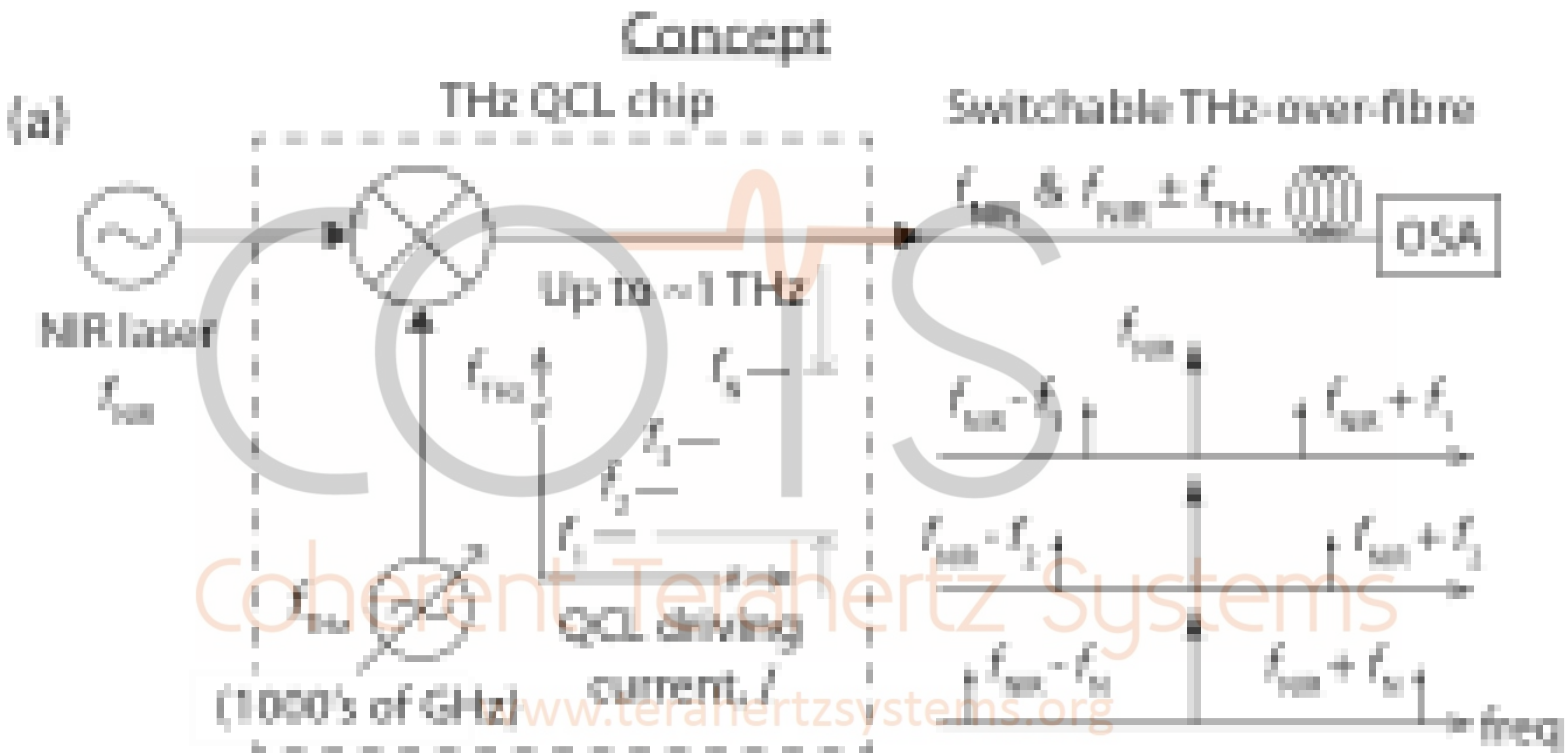
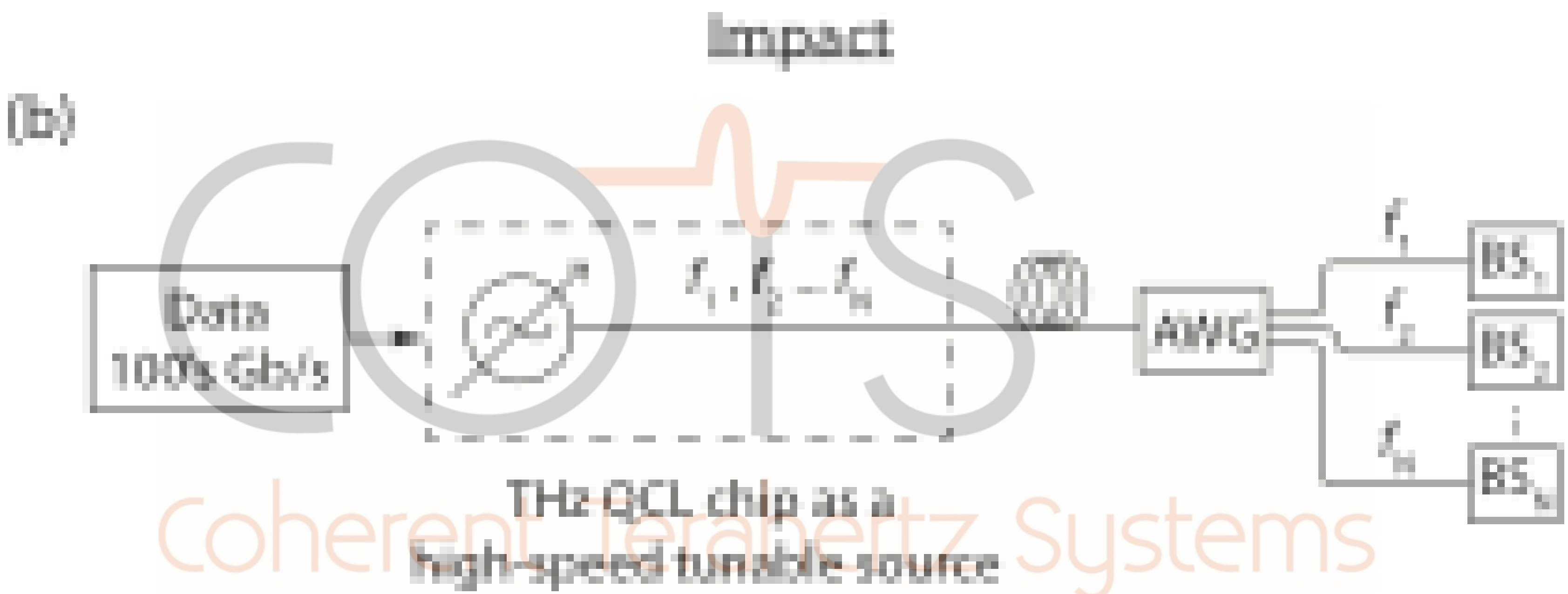
The University of Manchester

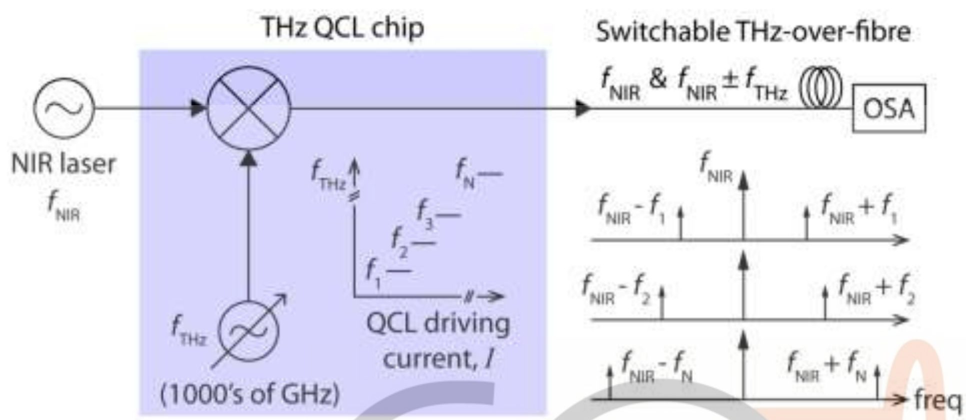
Tunable Terahertz-over-Fibre system

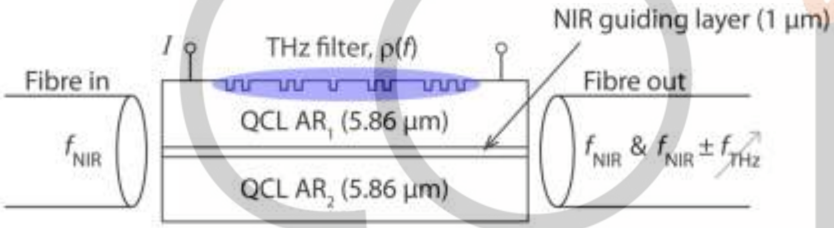


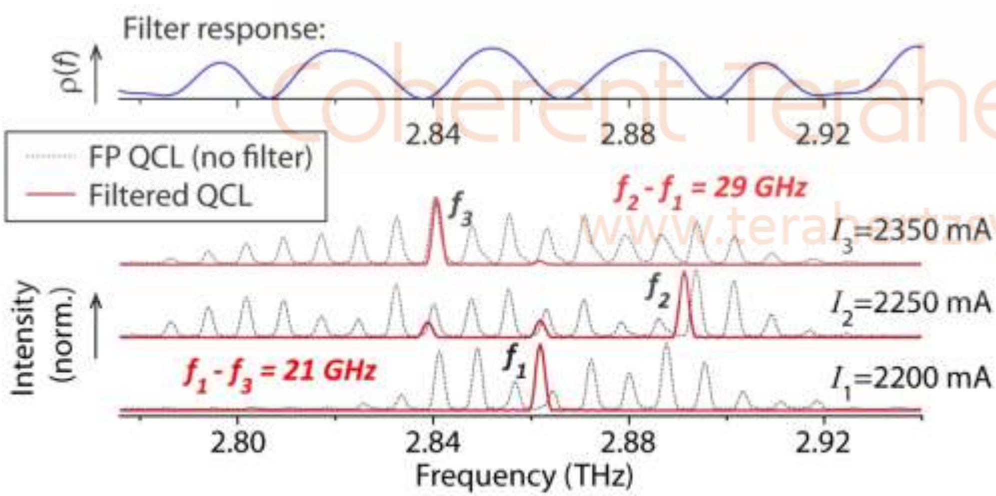
Tunable Terahertz-over-Fibre system

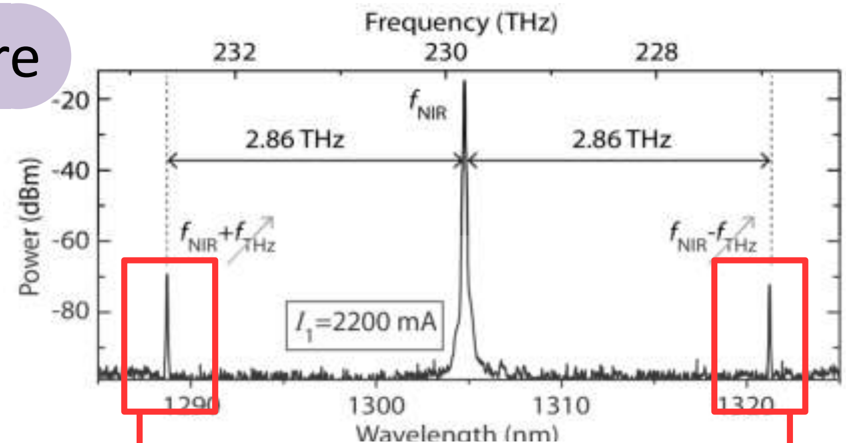


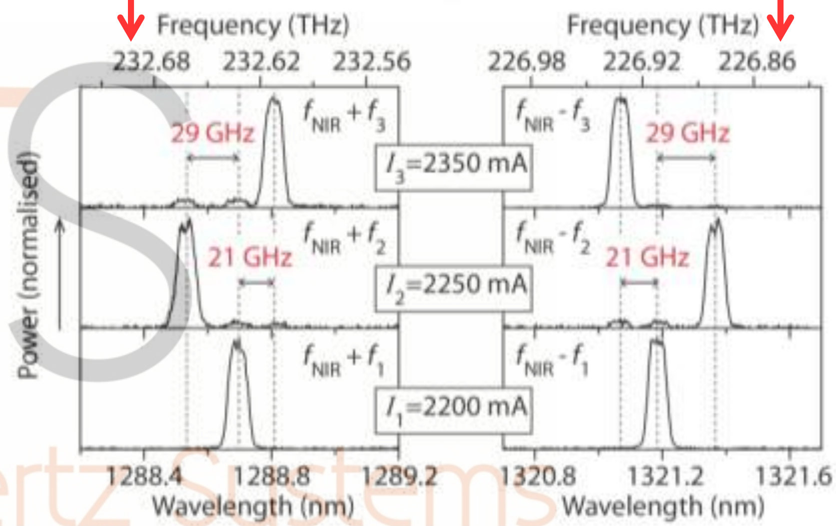
Electronically Switchable THz-over-Fibre

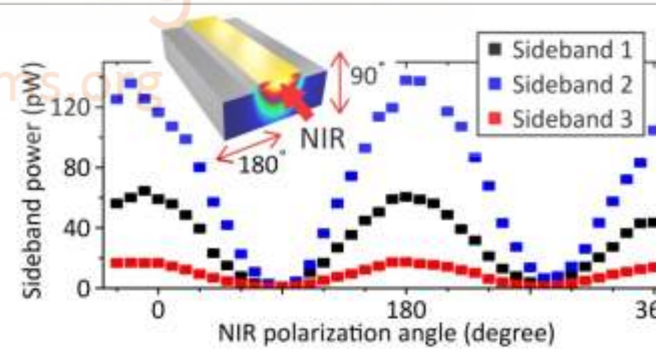












Acknowledgements and Publications

•'Aperiodic Lattices for Photonic Engineering of Terahertz Quantum Cascade Lasers'- **EPSRC First Grant (EP/G064504/1, 2009-2012)**

• 'Tunable Terahertz Quantum Cascade Lasers' - **Her Majesty's Government Communications Centre (HMGCC, 2010-2013)**

• 'New concepts for frequency tuning terahertz lasers'- **EPSRC Pathways to Impact Grant (EPSRC, 2012-2013)**

Appl. Phys. Lett. 101, 121103 (2012)

Opt. Express. 20, B306 (2012)

CLEO, post-deadline (2013)

Appl. Phys. Lett. 102, 181106 (2013)

J. Appl. Phys. 113, 203103 (2013)

Appl. Phys. Lett. 102, 111105 (2013)

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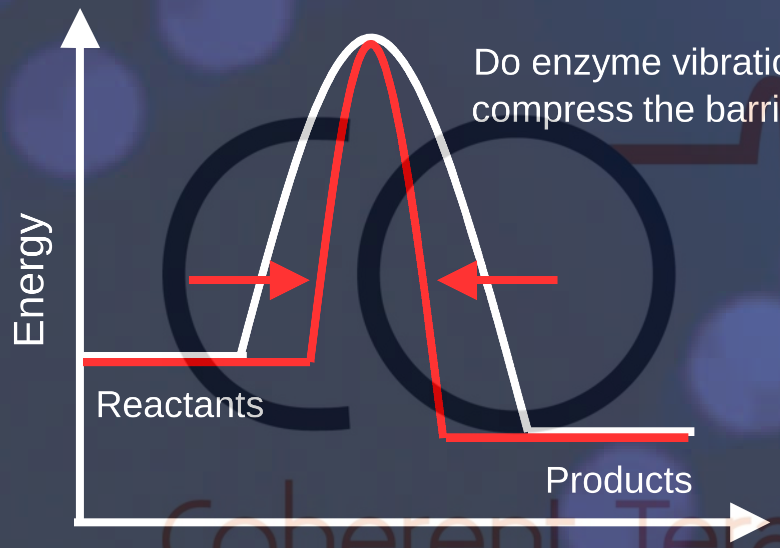
The University of Manchester

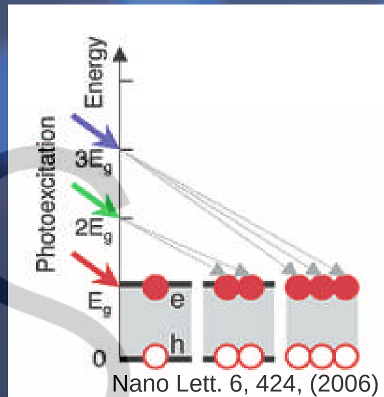
Dr Darren Graham, EPSRC Career Acceleration Fellow
School of Physics and Astronomy

Addressing the energy challenge

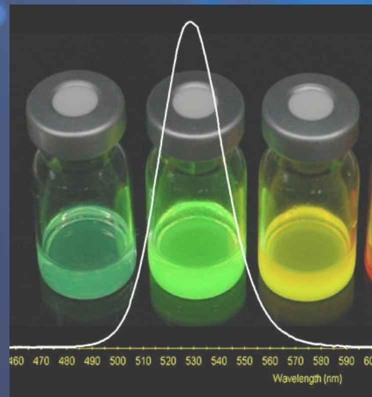
Understanding biological catalysis



Developing solar absorbers



Nano Lett. 6, 424, (2006)



NANOCO GROUP PLC

Science & Technology Facilities Council

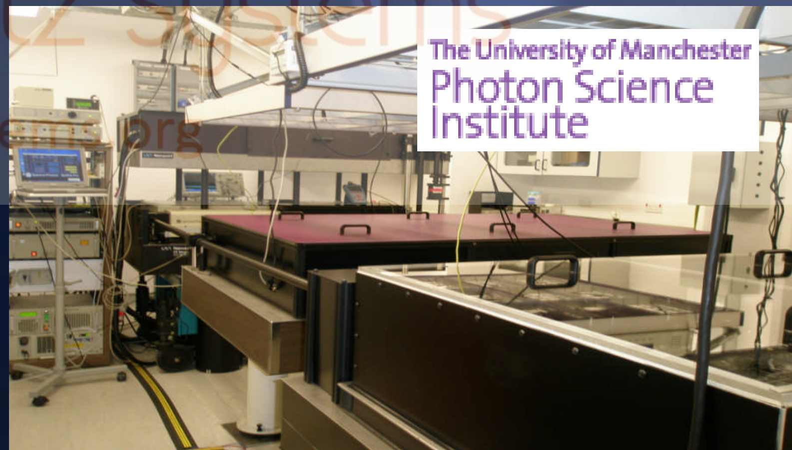
EPR National Research Facility and Service

Manchester Interdisciplinary Biocentre

EPSRC

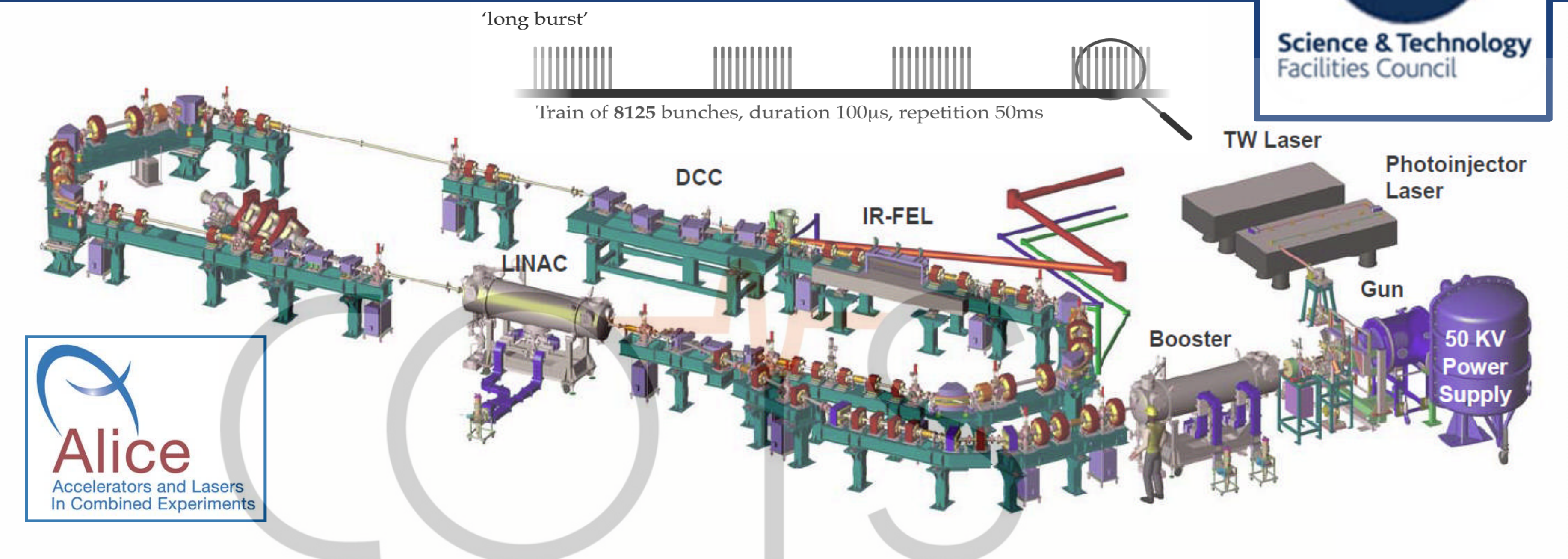
Spectra-Physics
A Division of Newport Corporation

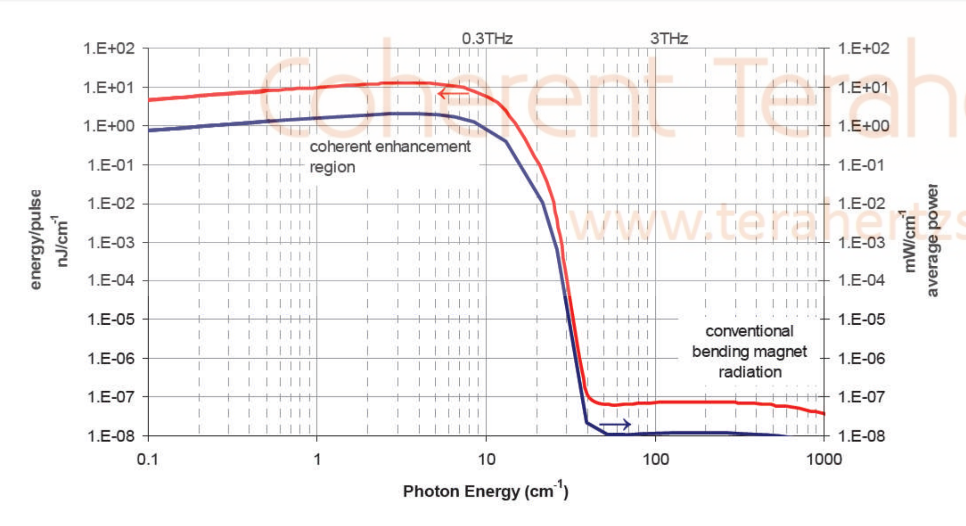
BRUKER



The University of Manchester
Photon Science Institute

ALICE energy recovery linac





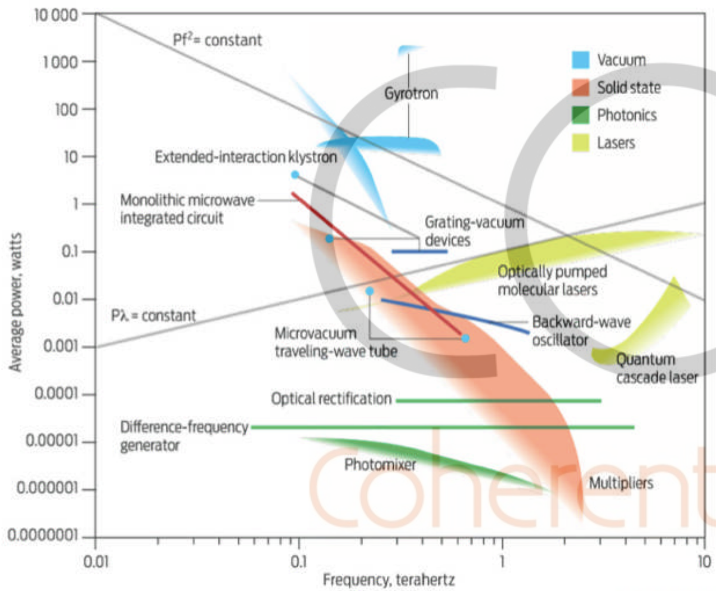
- **Broadband coherent THz radiation source**
- **600 fs duration pulses**
- **Average power in macropulse of ~ 0.6 W**

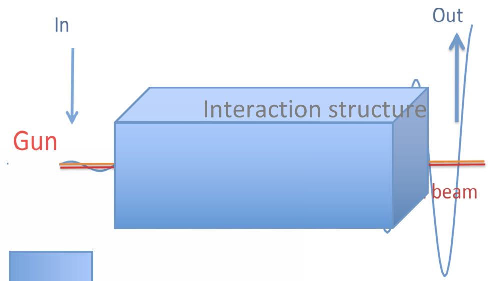
THz Vacuum Electron Devices

Claudio Paoloni
Engineering Department, Lancaster University

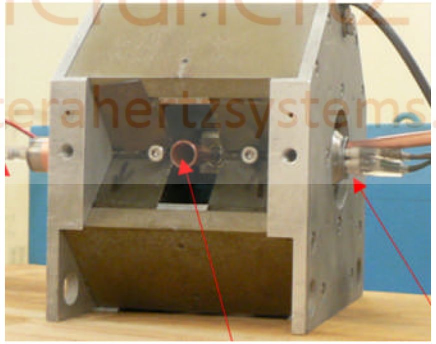
Microwave high power only by vacuum electron devices

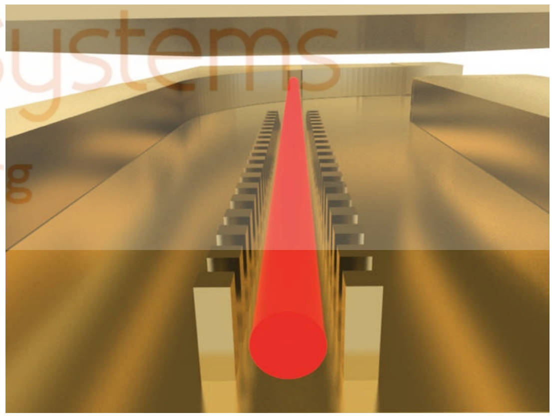
High power at THz is needed





THz vacuum electron devices are the solution

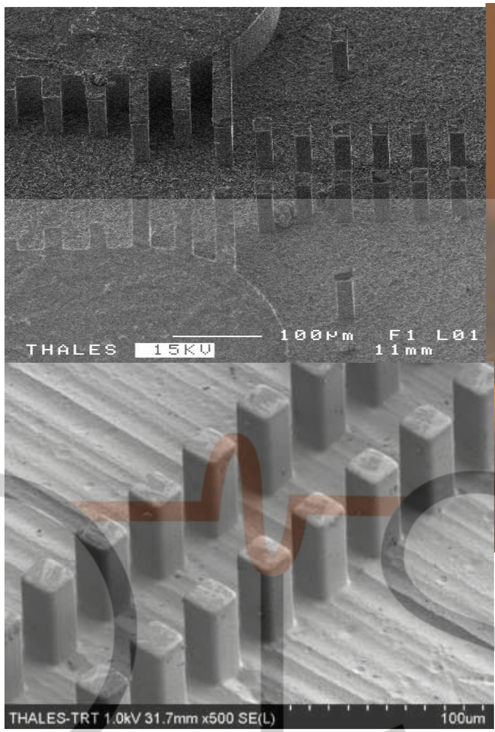


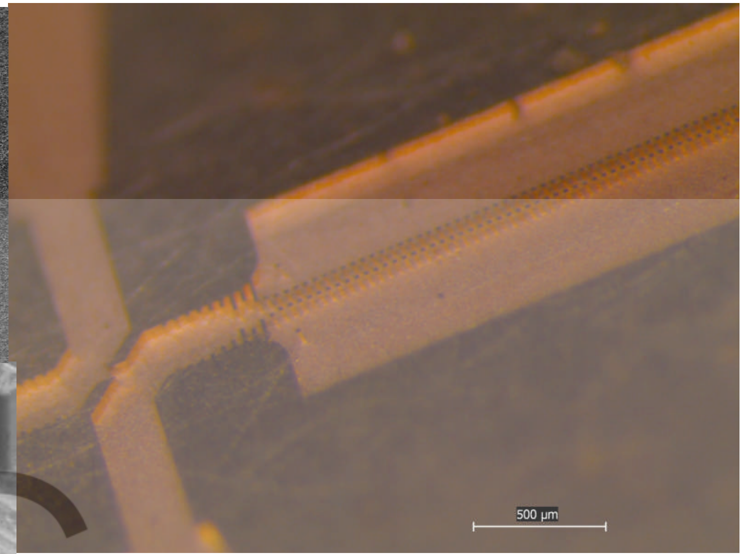


The challenges

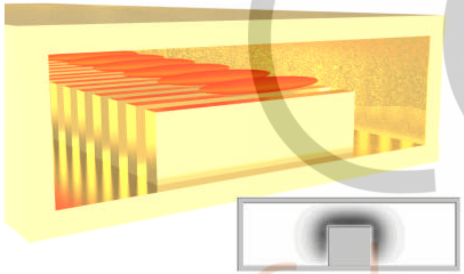
- Fabrication processes
- High current electron beam
- Assembly
- Low beam voltage (less than 15kV)
- Losses
- Simulations

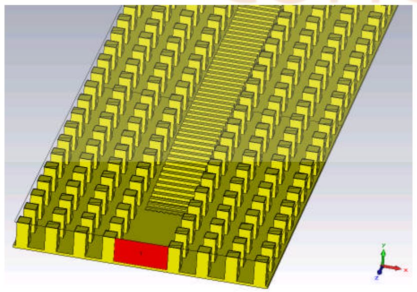
Microfabrication



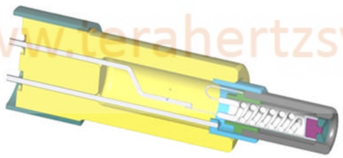


Novel interaction structures

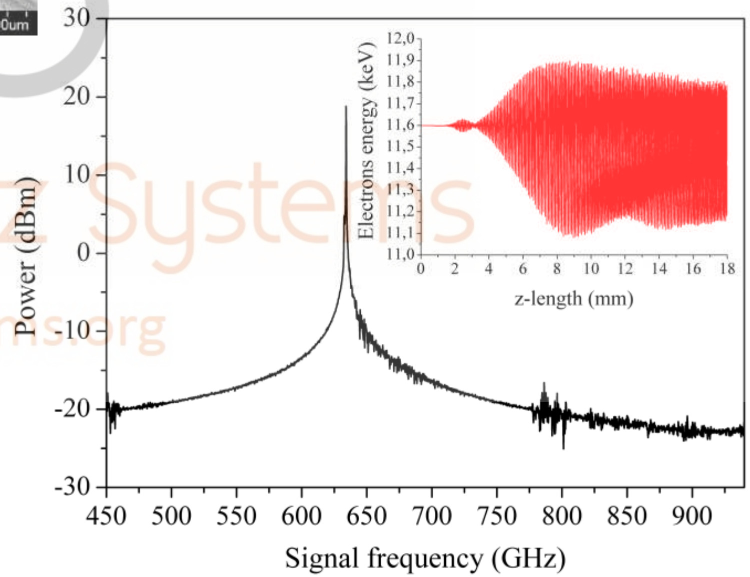




High current density electron gun



Performance



Engineering | LANCASTER UNIVERSITY

E-MIT

UCMMT 2013 ROME

2013 6th UK, Europe, China Millimeter Waves and THz Technology Workshop

IEEE

COTS
Coherent Terahertz Systems
www.terahertzsystems.org

National Roman Museum, Palazzo Massimo
9 - 11 September 2013, Rome, Italy

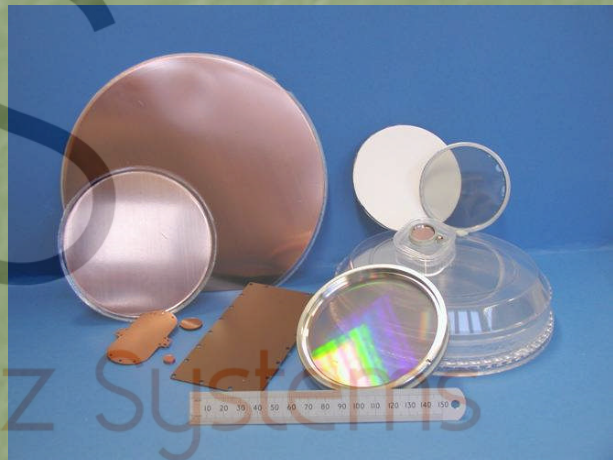
http://ucmmt2013.lancs.ac.uk/

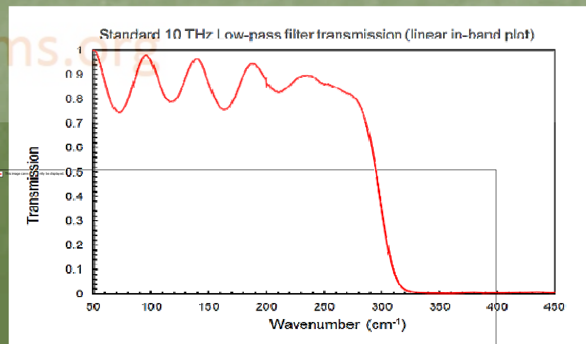
Engineering | Lancaster University

E-MIT

Ken Wood
QMC Instruments Ltd.

Cryogen-free THz Detection & Passive Imaging Technology





EPSRCTerahertzDay

QMC INSTRUMENTS

New in September 2012
Cryogen-free THz Detector Systems

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYD

New superconducting detector technology

High Sensitivity
Low external noise susceptibility
Widely deployable technology

NO LIQUID HELIUM !

KIDCAM Demonstrator

In 2011 QMC Instruments and Cardiff University agreed to build a THz camera using LEKID detectors with the following target specification:

- 170 pixel linear array
- Aluminium LEKIDs @ 250 mK
- 150 and 350 GHz Observing Frequencies
- NEΔT < 30 mK. Hz$^{-1/2}$
- Spatial resolution = 8 mm at 5 m range (350 GHz)
- Target size 2 m x 0.8 m at 5 m range (eg. A body scanner !)
- Video frame rate capability
- Cryogen-free, automatic and remote system operation and control

Portrait of the author at 150 GHz:

James Lloyd-Hughes

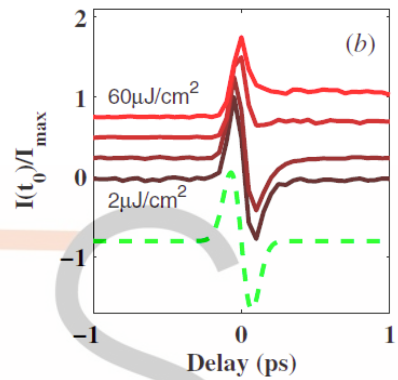
THE UNIVERSITY OF WARWICK

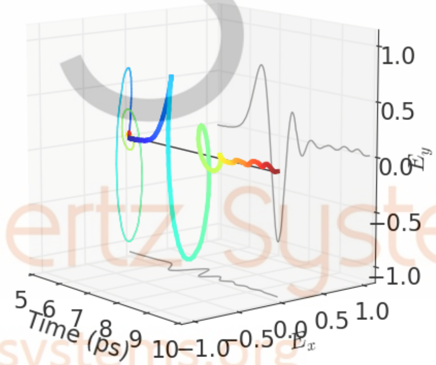
Terahertz time-domain spectroscopy

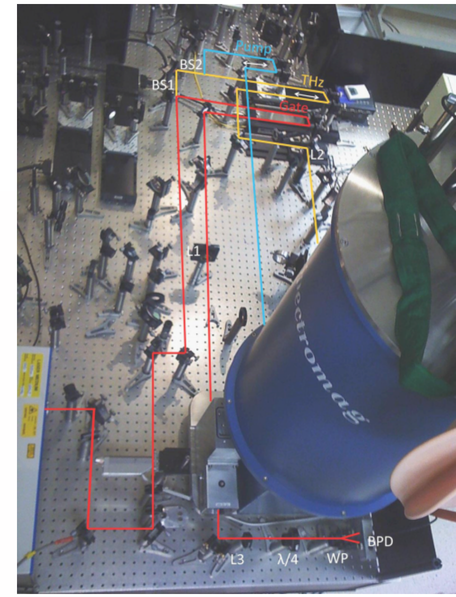
Generation and detection of THz radiation
- Photoconductive emission and detection
- Simulation and modelling
- Electro-optic and thermo-optic

Terahertz time-domain spectroscopy
- Sample temperature range 2K-400K
- Magnetic fields to 8T
- Transmission/reflection spectroscopy
- Polarisation-resolved spectroscopy

Optical pump-probe spectroscopy
- Time-resolved conductivity dynamics
- Picosecond to nanosecond timescales
- Probe electron mobility, excitons, surface plasmons.



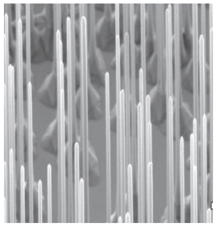


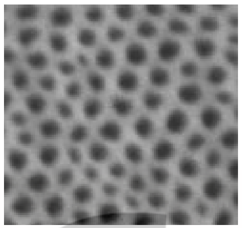


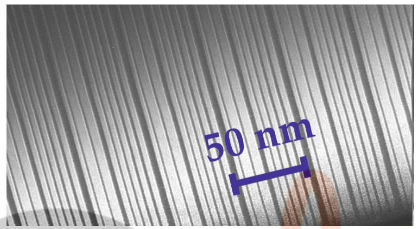
Review of terahertz time-domain spectroscopy:
Lloyd-Hughes & Jeon, J. Infrared Milli Terahz Waves, **33**:871 (2012).

Terahertz time-domain spectroscopy

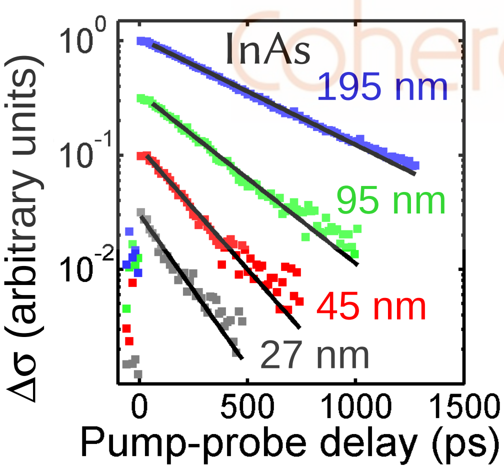
Semiconductor nanomaterials

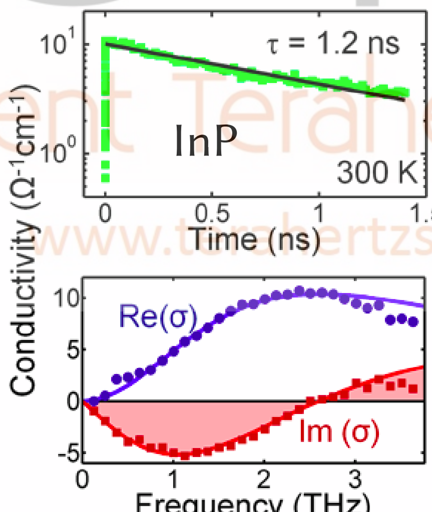






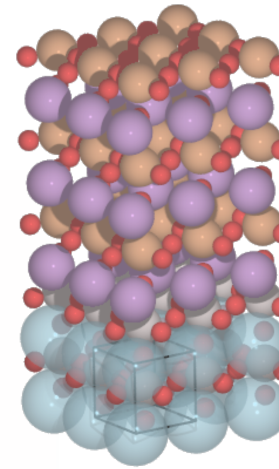
- III-V semiconductor nanowires [Nano Lett. (2012), Nanotechnology (2013)]
- Porous honeycombs [Appl. Phys. Lett. (2012)]
- Terahertz quantum cascade lasers [Opt. Expr. (2009), Appl. Phys. Lett. (2010) J. Appl. Phys. (2012)]

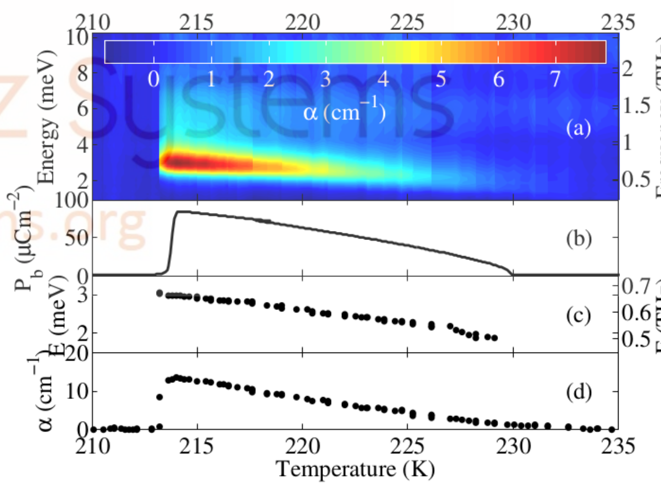




Multiferroic materials

- Dynamic response of magnetoelectrics
- Phonons and magnons in thin films
- Electrically-active spin waves at THz frequencies





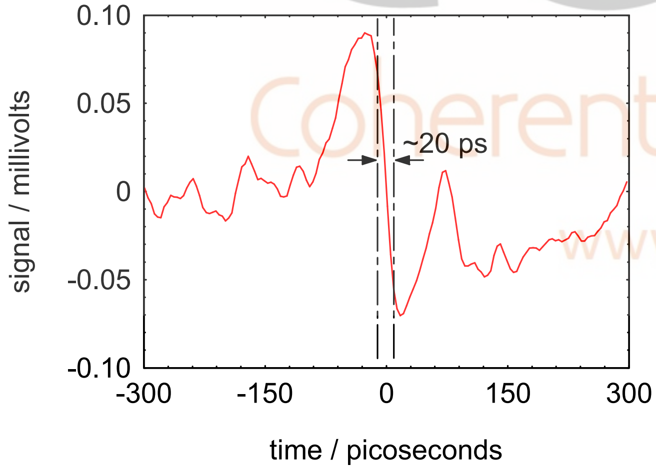
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

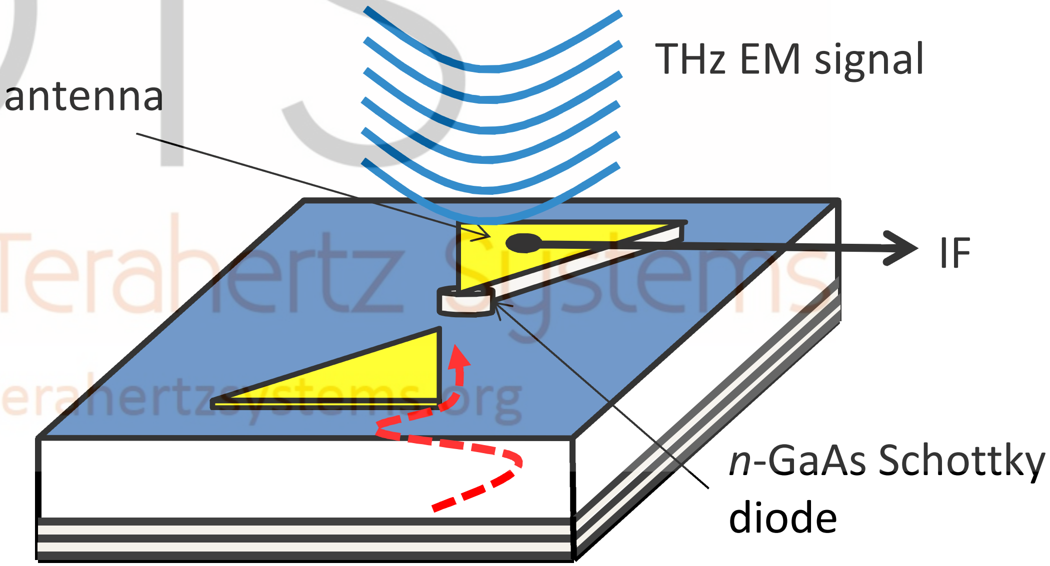
THz and sub-THz acousto-electric effects: physics and applications

- RF and microwave applications of acousto-electric effects include acoustic wave filters and delay lines.

- Our aim is to develop a new class of devices for higher frequency operation based on ultrafast acousto-electric effects in semiconductor devices, e.g. THz acoustic/EM mixer:

Acousto-electric response of *n*-GaAs Schottky diode:

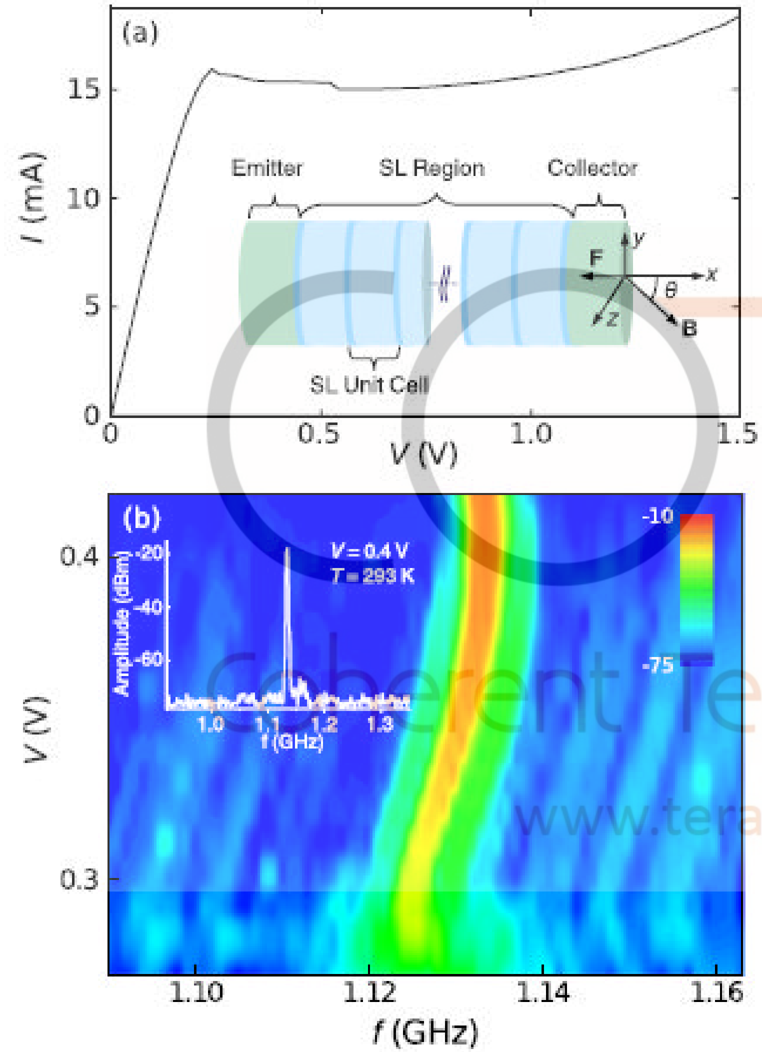




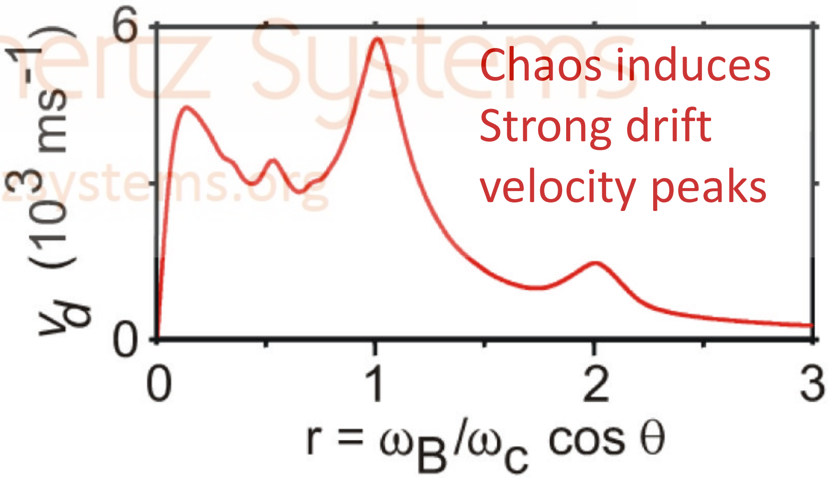
Saser oscillator (W, Maryam et al., *Nature Comms.* In press)

Superlattices, Bloch oscillations and GHz/THz dynamics

PRL 109, 024102 2012; Nature 428, 726 2004



- Enhancing GHz/THz current oscillations in SLs via chaotic electron dynamics (with Loughborough University)
- An innovative device architecture based on a **G**unn **S**uperlattice **T**erahertz **O**scillator, **GUSTO**, to enable access to ultra-fast electron speeds, power and frequency tuning in a compact, room temperature solid-state source/detector of terahertz radiation. Collaboration with **e2v technologies plc**.

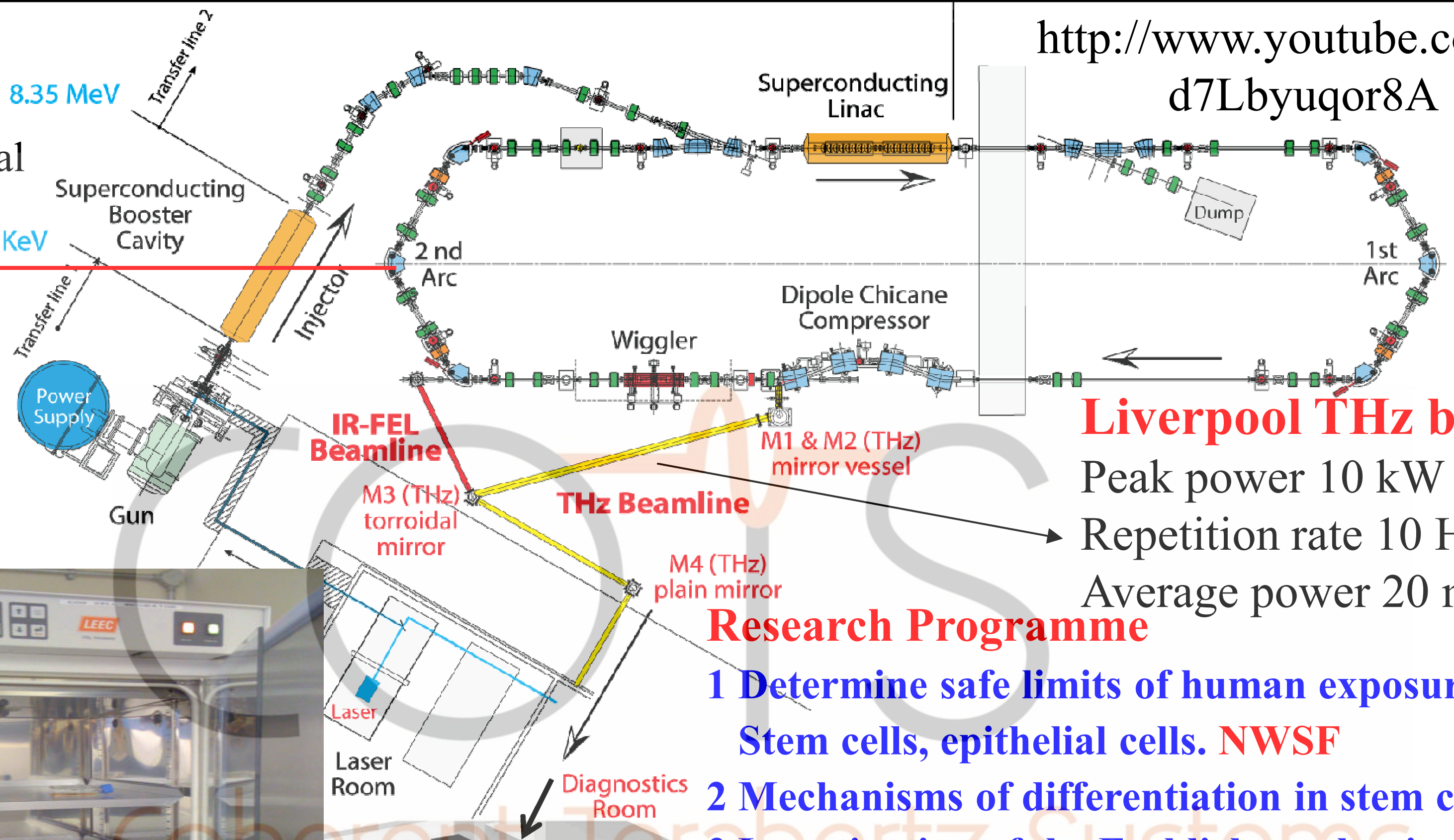


Daresbury Energy Recovery Linear Accelerator: ALICE

http://www.youtube.com/watch?v=d7Lbyuqor8A

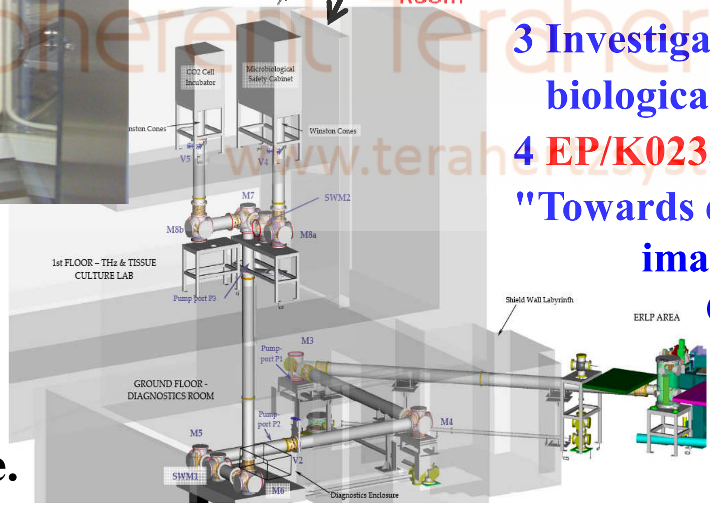
SNOM

High spatial and high spectral resolution imaging



Liverpool THz beamline

Peak power 10 kW in 0.6 psec
Repetition rate 10 Hz
Average power 20 mW



THz into CO_2 incubator.
Live tissue.
Cancer clearance.

Research Programme

1 **Determine safe limits of human exposure to THz:- Stem cells, epithelial cells. NWSF**

2 **Mechanisms of differentiation in stem cells. NWSF**

3 **Investigation of the Frohlich mechanism of biological organisation: EPSRC EP/H02235X/1**

4 **EP/K023349/1: Critical Mass £ 3.2 million 1 6 2013 "Towards disease diagnosis through spectrochemical imaging of tissue architecture."**

Cardiff, Lancaster, Manchester, Liverpool

Williams et .al. Phys. Med. Biol. **58** 373 (2013)
Smith. et. al. App. Phys. Lett. **102** 053701 (2013)
P. Weightman, Phys. Bio. **9** 053001 (2012)

ALICE as an EPSRC Midrange Facility?

Prof. M. Chamberlain and Dr A. Gallant (Engineering, Durham)

THz studies of DNA and protein interactions in solution. Origin of contrast in THz tumour images.

Dr R. Donnan, Dr. B. Yang (Queen Mary) Tuned THz control of crystal engineering on molecular scale.

Prof. D. Edgar (Cell Biology, Liverpool) Differentiation mechanism in stem cells.

Dr H. Fraser (Physics, Open University) Astrophysics.

Prof. J.G. Frey (Chemistry, Southampton) Chemical reactions.

Dr O. Kolosov (Physics, Lancaster) Nanoscale resolution spectroscopy for energy research.

Dr. S. Mackenzie (Chemistry, University of Oxford) Catalytic reactivity of transition metal clusters.

Prof. J. Marangos (Physics, Imperial College) Harmonic generation.

Prof. M. McCoustra (Chemical Physics, Heriot-Watt) Probing the Transition from Molecular to Metallic Clusters by THz Reflectivity Measurements: Metallic nature.

Prof. B. Murdin (Physics, University of Surrey) Spintronics.

Prof. C. Paoloni (Engineering University of Lancaster) ALICE as test THz source for definition of specifications of compact and affordable THz sources to enable THz applications.

Dr Jasper van Thor (Molecular Biophysics, Imperial College) Low frequency infrared spectroscopy of metal-oxygen bonds in the diffraction limit for structural measurements of biological catalysis.

Dr Martin Volk (Chemistry Liverpool) Role of H_2O in protein folding.

Prof. R. Williams (Eye and Vision Science, Liverpool)

Characterisation of substrates for controlled cell growth for tissue engineering.

Dr K. Wood (QMC Instruments Ltd.) Development of the next generation of THz instruments.

Dr A. Zeitler (Chemical Engineering, University of Cambridge) Quantum control of chemical reactions.

High Power Broadband Gyro-Devices for Terahertz Operation

Wenlong He

SUPA Department of Physics
University of Strathclyde
Glasgow, UK

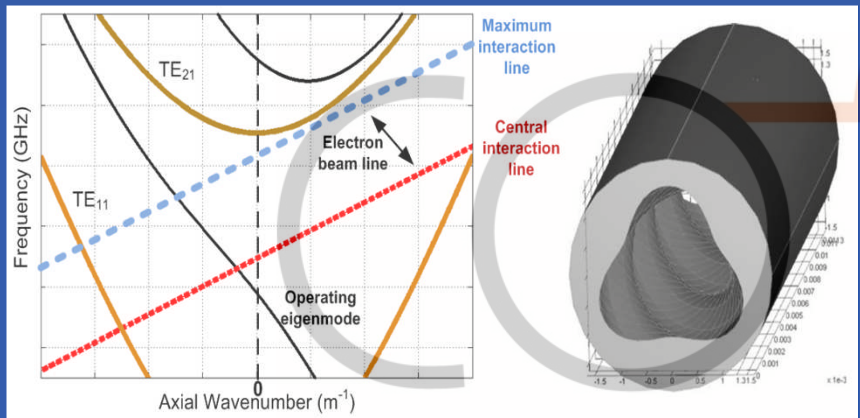
RELD Group: Vacuum Electronics for THz

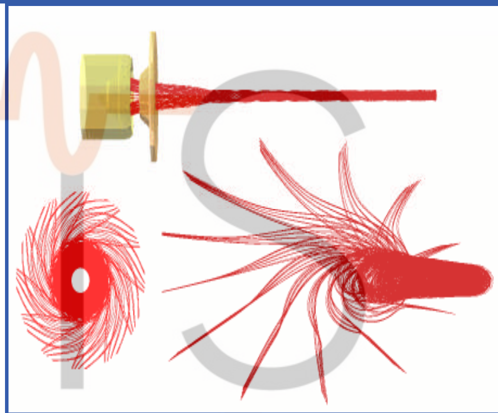
- People:
  - 14 Staff: Prof. Alan D. R. Phelps, Drs A.W. Cross, W. He, K. Ronald et al
  - 10 PhD Students, 7 masters
  - 3-5 visiting scientists/year
- Activities:
  - Over 30 years research in coherent, high power microwave & mm-wave generation
  - Theoretical, numerical, experimental and prototyping work
  - Tests, measurements, components and systems

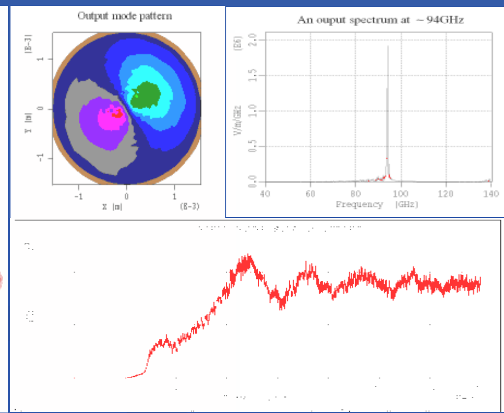
Typical process: W-band Gyro-devices

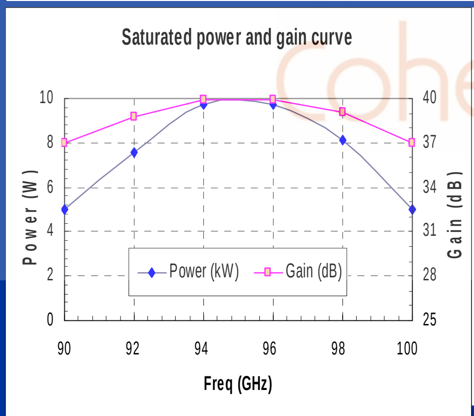
University of Strathclyde Glasgow

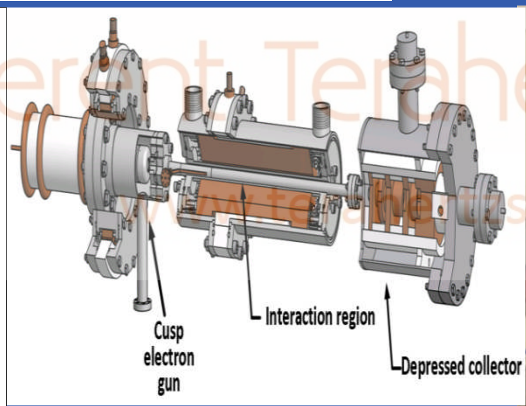
Theoretic analysis, Design, Numerical modelling & optimization
(MAGIC, KARAT, SURETRAJ, OPERA, MICROWAVE STUDIO, COMSOL, VORPAL),
Construction, measurement, publications, commercialisations

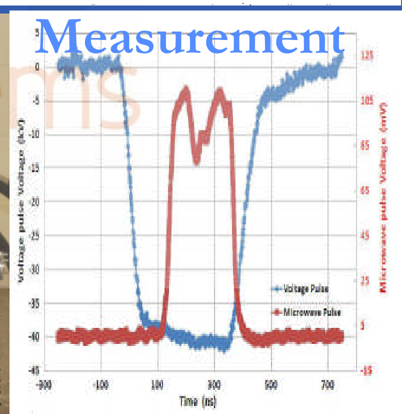






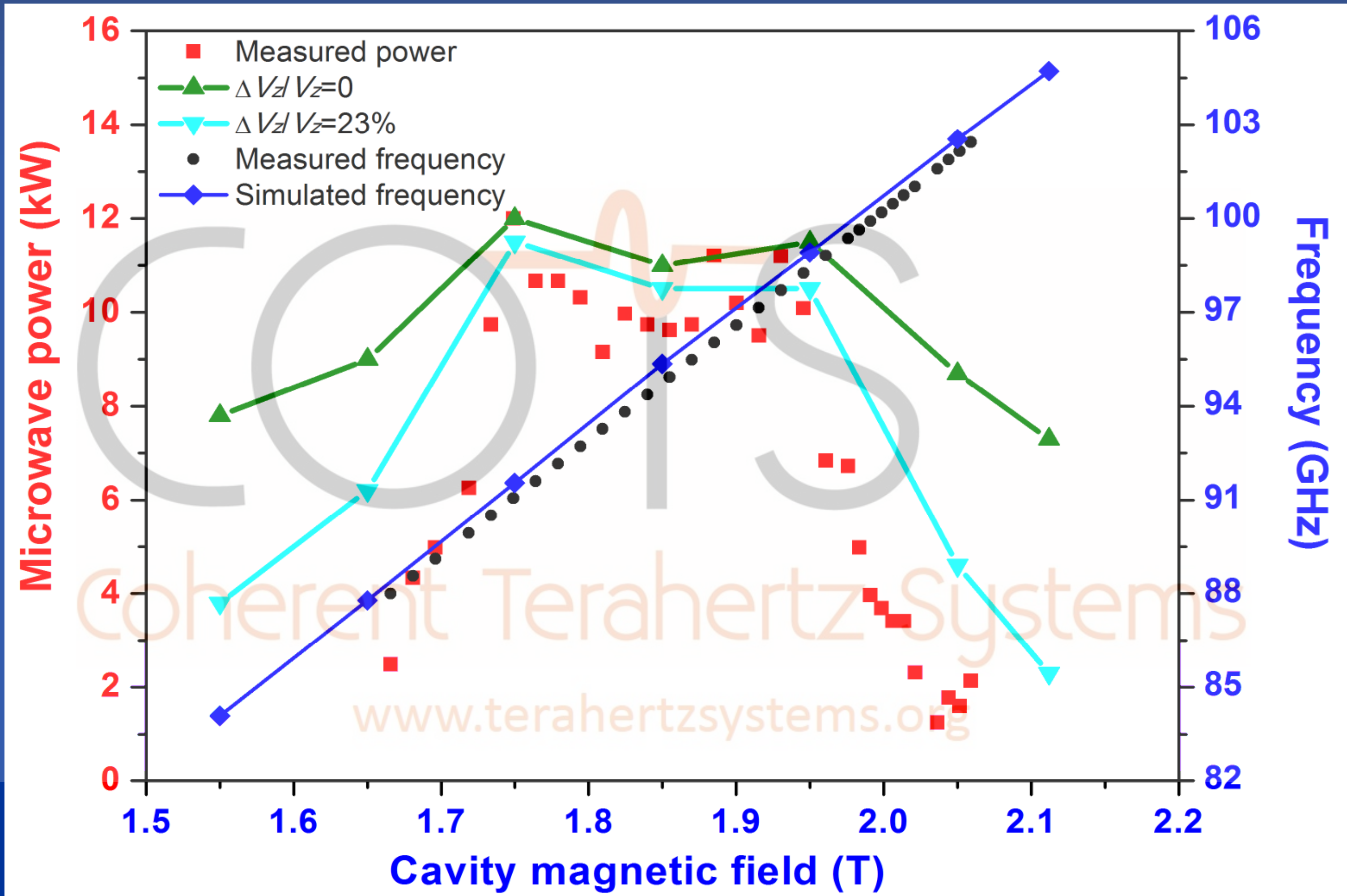






ABP

Latest measurements

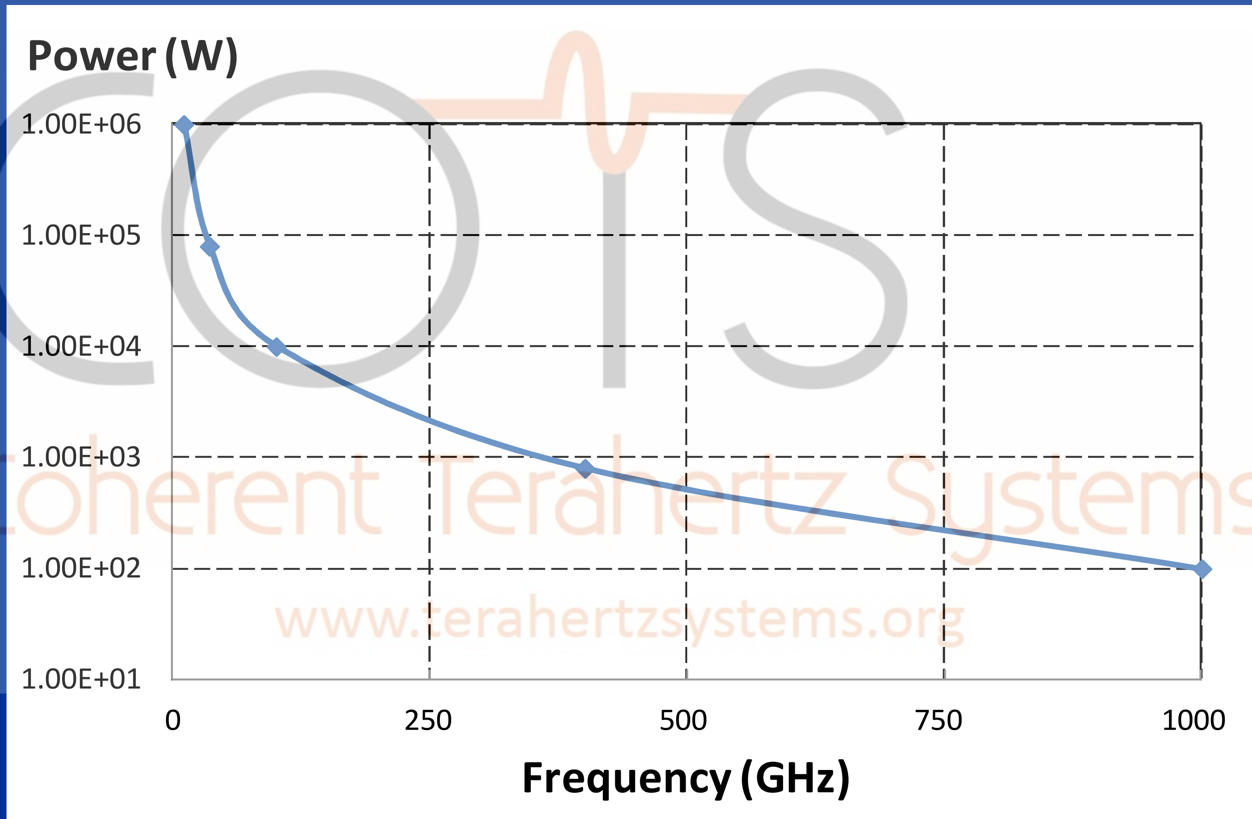


Phys. Rev. Lett., Vol. 110,165101 (2013)

Capability of Gyro-amplifier:

Frequency X Power X Bandwidth X Bandwidth

> X 50



Millimetre and THz Metrology Laboratory

QMUL

Major current theme of lab:
time-resolved polarisation spectrometry

rob donnan: head of THz Group; Antennas & Electromagnetics Laboratory

Visiting Fellow

- Dr. Wenfeng Sun (School of Physics, Capital Normal University, China)

PDRAs

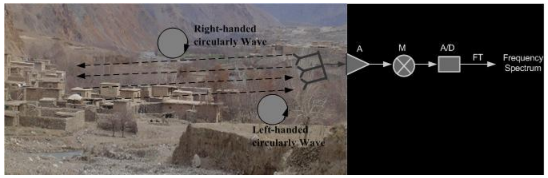
- Dr. Rost Dubrovka – Radio Physics, Antenna Metrology
- Dr. Bin Yang (EPSRC – Platform Grant, Dial-a-Molecule)
- Dr. Alex McIntosh (EPSRC – Platform Grant, Dial-a-Molecule)
- Dr. Jane Tang (EPSRC – KTA/DSTL; THz-TDS study of bacterial spores)

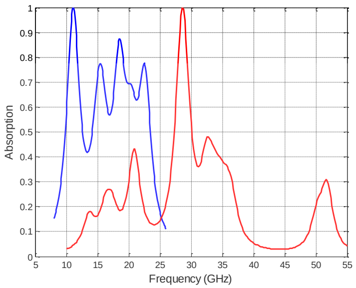
PhD Students

- Mr. Kastriot Shala (THz TDS metrology)
- Mr. Oleksandr Sushko (EPSRC – CDTA; THz TDS determination of N_A and B)
- Mr. Tom Loftus (EPSRC – CDTA; high power THz sources)
- Ms. Junyi Qui (EPSRC – CDTA; THz – TDS study of amyloidosis
- Mr. Yang Zeng (CSC; THz – TDS metrology for soft condensed matter study.

MSc (Research)

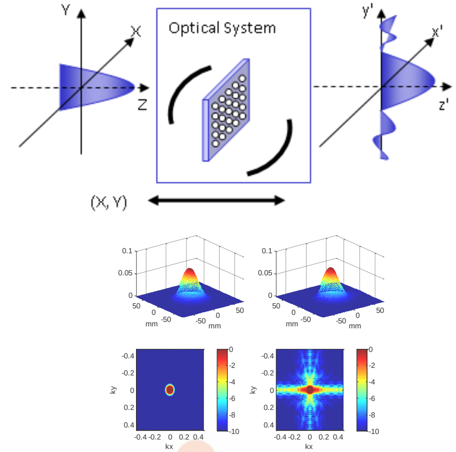
- Ms. Ana Consuelo (ERASMUS exchange – Spain; TDS of synthetic skin)
- Mr. Ajith Kuruvita (THz imaging for oncology oral healthcare)



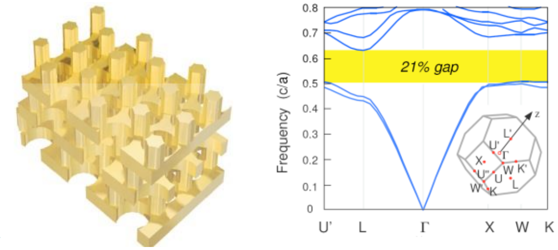


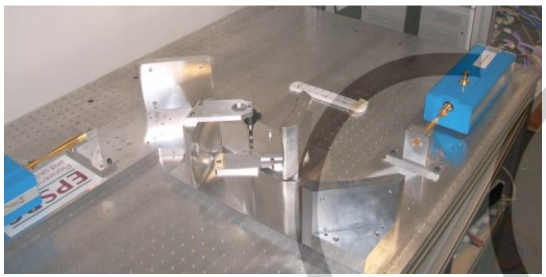
Mapping of Volatile Organic Compounds (VOCs) Using Microwave Absorption Spectroscopy

FSS aberration analysis



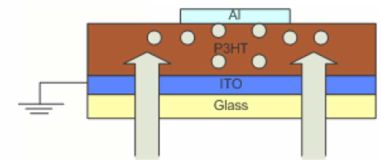
Group Theory-based selection for efficient photonic crystal design





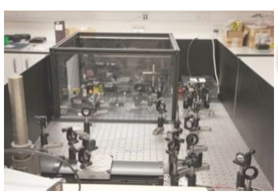
RF- directed chemistry

mm, submm & THz metrology



Non-mechanical phase-shifters: light-activated semi-conducting organic polymers

APL 91 202101 2007

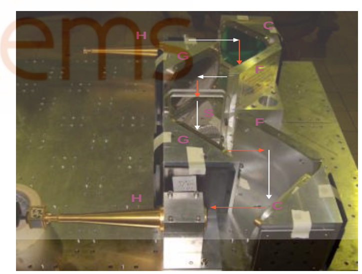


THz TDS and DFTS of bio-molecules. Development of static DFTS with fast array detectors for near-to-real-time tracking of conformation trajectory.

(application of Lagrangian dynamics to analyse and mechanically interpret measured absorption spectra)

Assessment of magnetic materials for use in quasi-optical non-reciprocal devices operating at frequencies above 90 GHz

IEEE-MTT, DOI 10.1109/MTT.2010.2086290

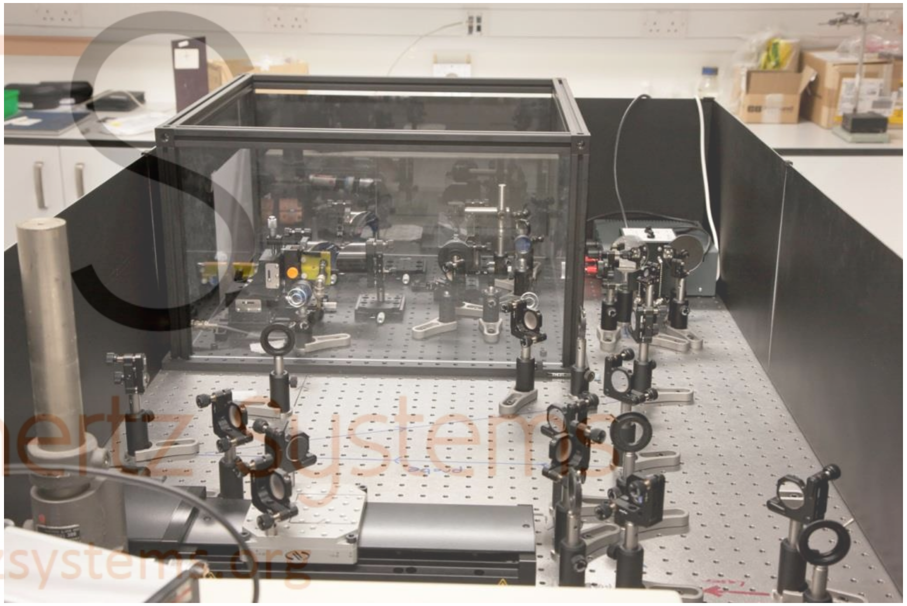


Organic materials as optically tuneable dielectrics for microwave applications

THz Laboratory

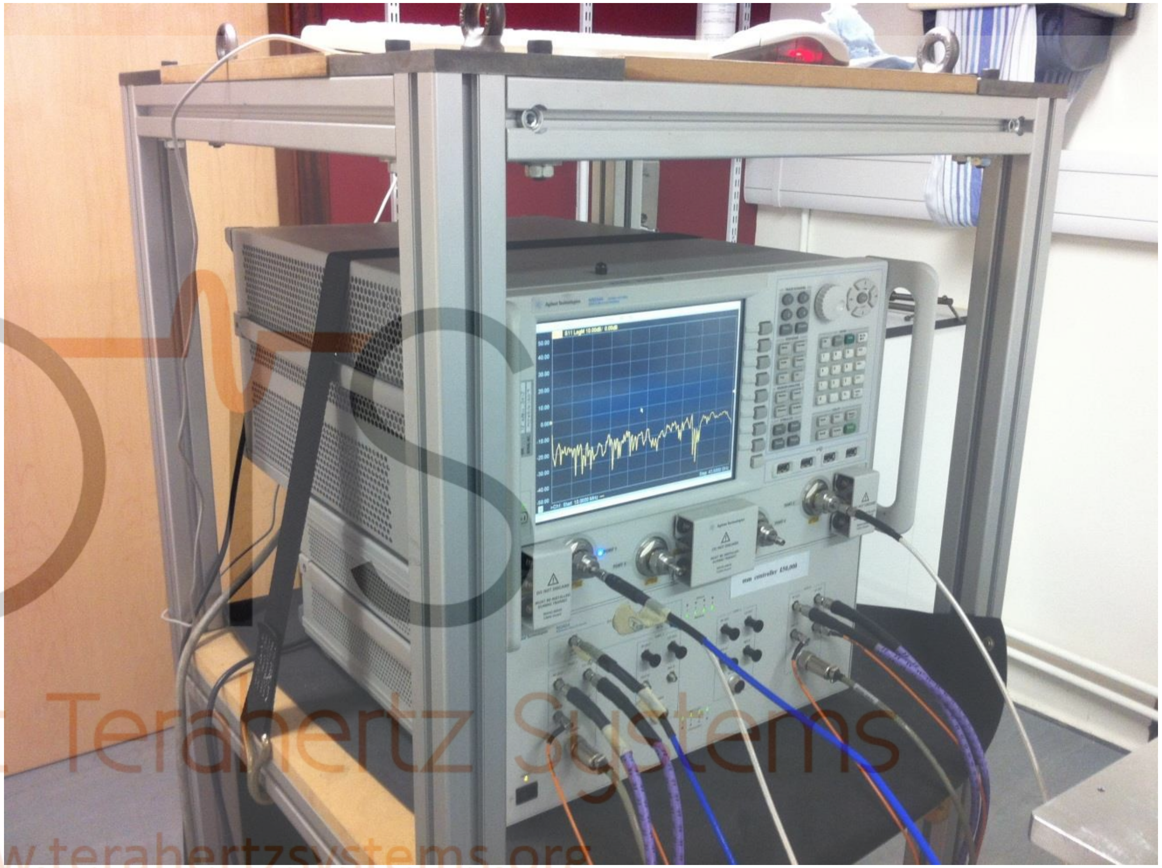
1. THz – Time-Domain spectrometer:

- Mai-Tai Ti – Sapphire laser 800 nm 1 W CW
- GaAs crystal rectifier THz source: 200 – 3000 GHz @ μW levels
- Principally transmission-mode operation.
- ATR supported
- PID temperature & humidity control

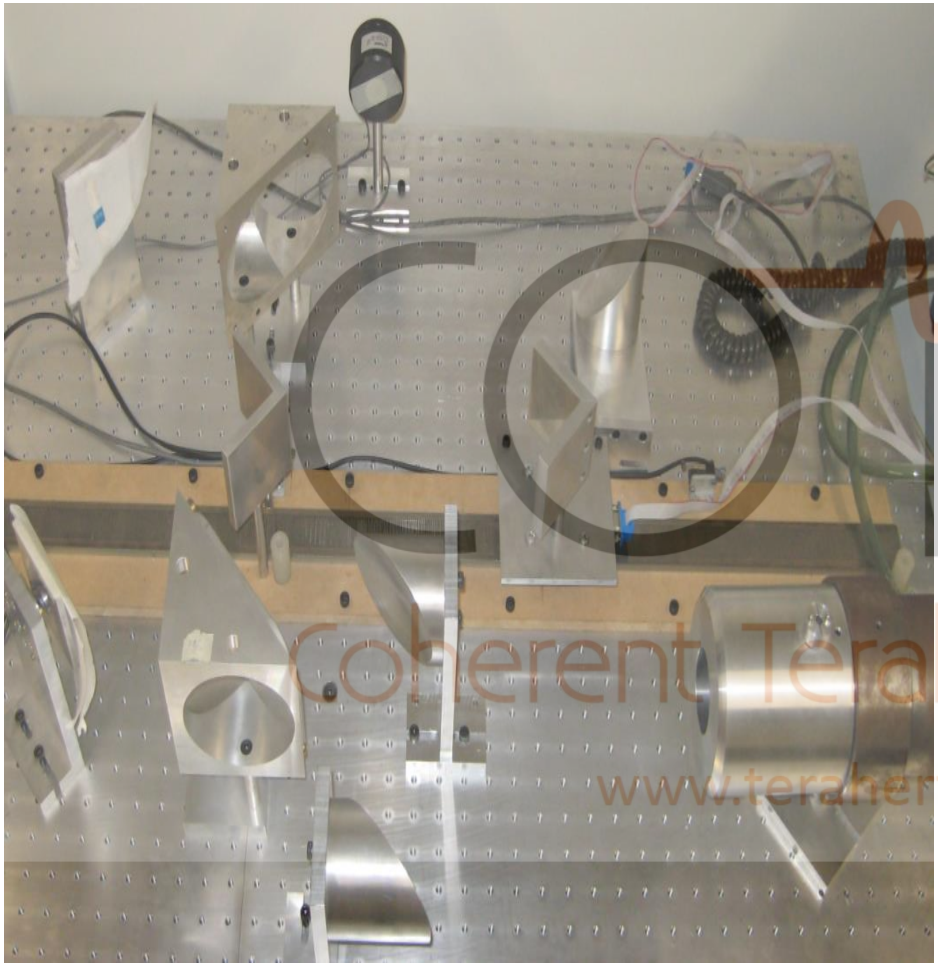


Key Features & Specifications

- 10 MHz to 43.5 GHz
- 2- or 4-ports with two built-in sources
- 126 dB system and 129 receiver dynamic range, 32,001 points, 32 channels, 5 MHz IF bandwidth
- High output power (+16 dBm), low harmonics (-60 dBc) and a wide power sweep range (41 dB)
- Best dynamic accuracy: 0.1 dB compression with +15 dBm input power at the receiver
- Low noise floor of -111 dBm at 10 Hz IF bandwidth

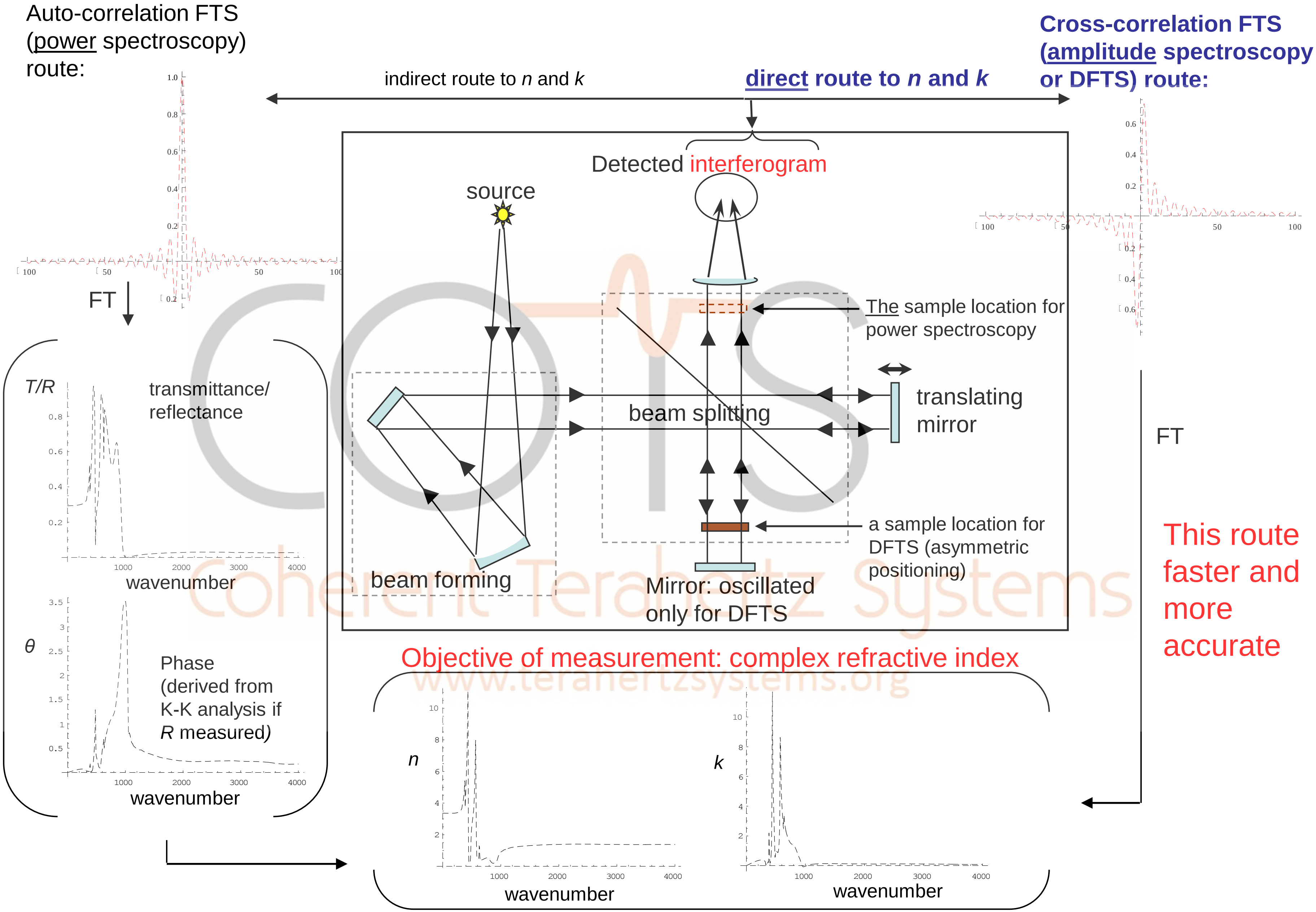


5 & 6. : FTIR, DFTS
Auto-correlation (power) and Cross-correlation (amplitude) FTS



Fourier Transform Spectroscopy

(DFTS – Dispersive Fourier Transform Spectroscopy)

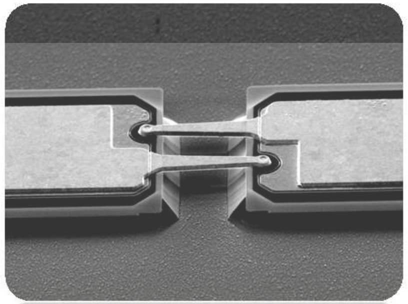


Teratech®
Components Ltd

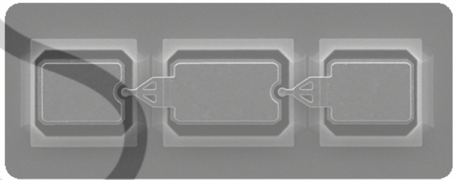
Byron Alderman
byron.alderman@teratechcomponents.com
www.teratechcomponents.com

Teratech Components Limited

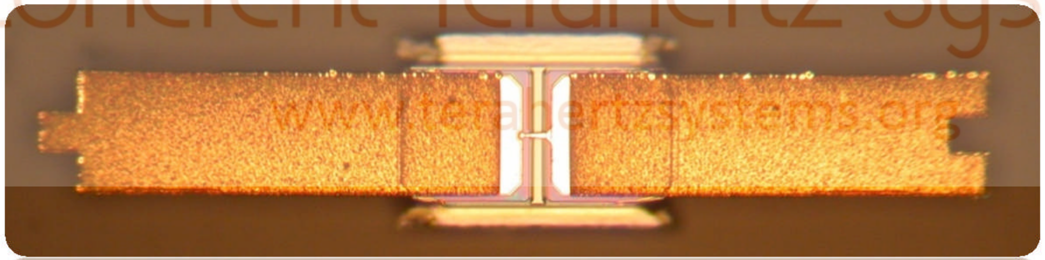
- Background
  - 2003: THz Schottky diode programme started for in-house research in the MMT Group at STFC-RAL
  - 2010: Teratech Spun-out
- Focus on commercial rather than research led development



GaAs Schottky diodes



Series pair of Schottky diodes

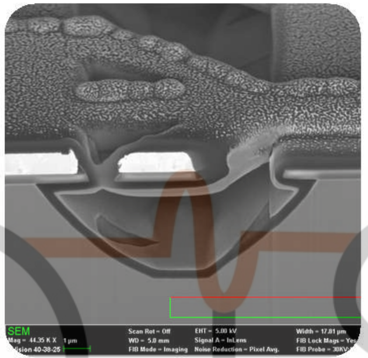


Single beam-lead diode

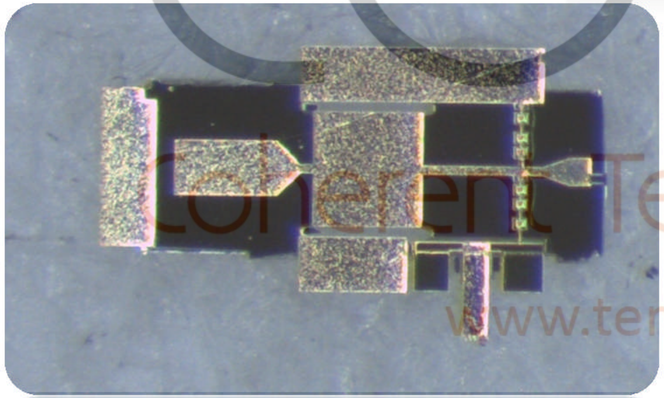
Teratech® Components Ltd

Technology Development

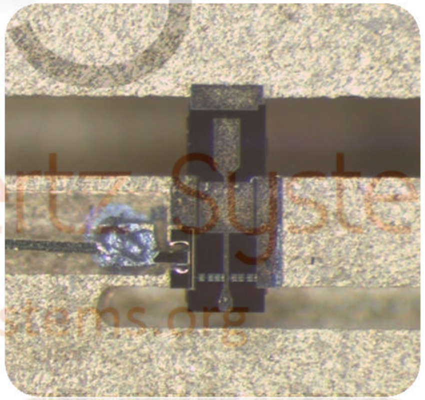
- R&D funding from FP7, TSB, ESA



FIB cross section of fully passivated air-bridge



6 GaAs Schottky diodes on a 10 µm GaAs substrate with an integrated capacitor



300 GHz frequency tripler

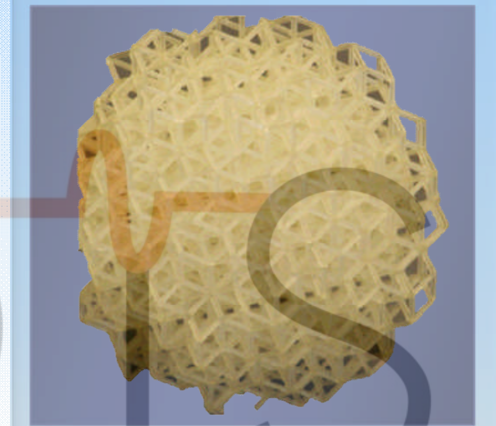
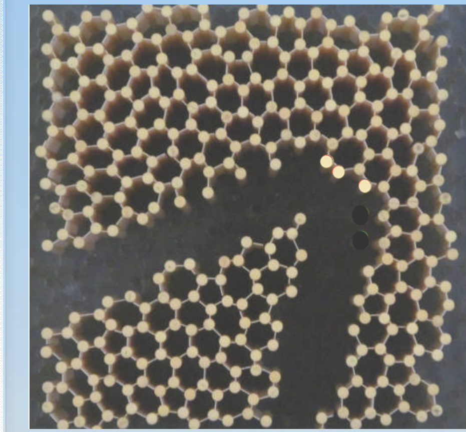
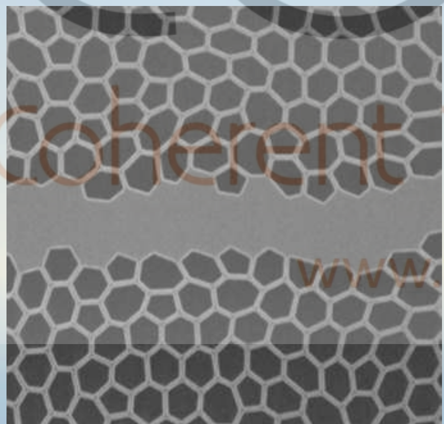
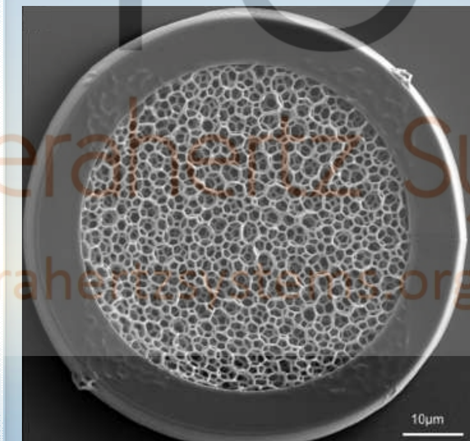
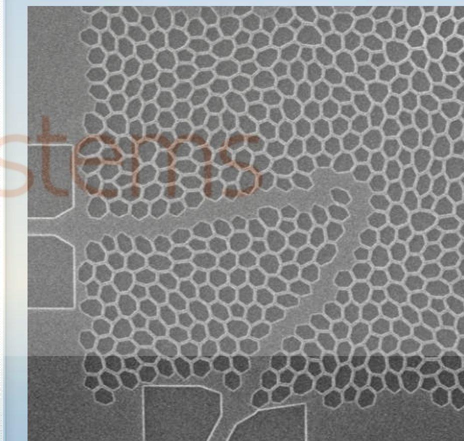
Teratech® Components Ltd

July 2013

ETAPHASE

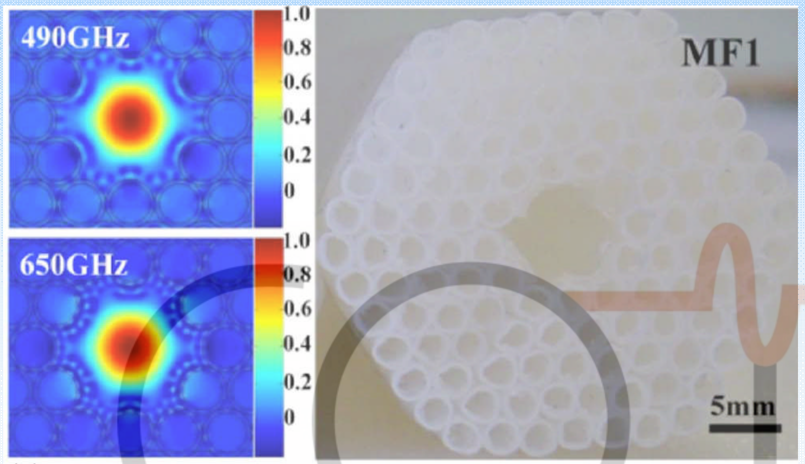
Revolutionary Designer Structures

PBGs Built and Tested at Microwave/IR Scale

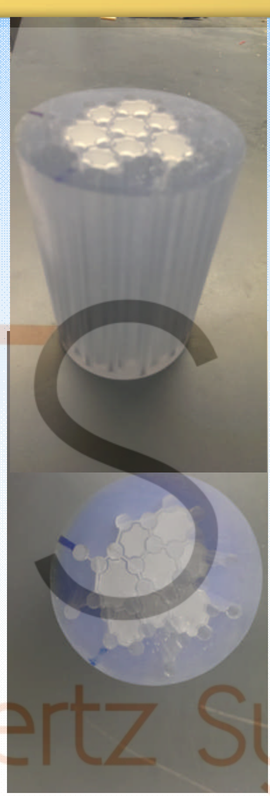
	2D linear	3D	2D bends
	Plastic	Plastic (quasicrystal)	Alumina
Large scale			
Nano scale			
	Silicon	Plastic	Silicon

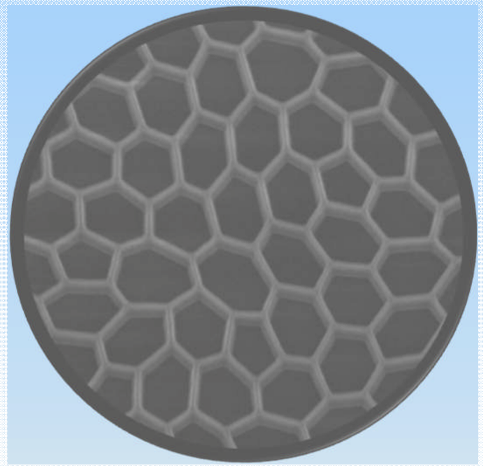
Designer PBG for Terahertz Applications

Terahertz Waveguides: Photonic Band Gap Fibers



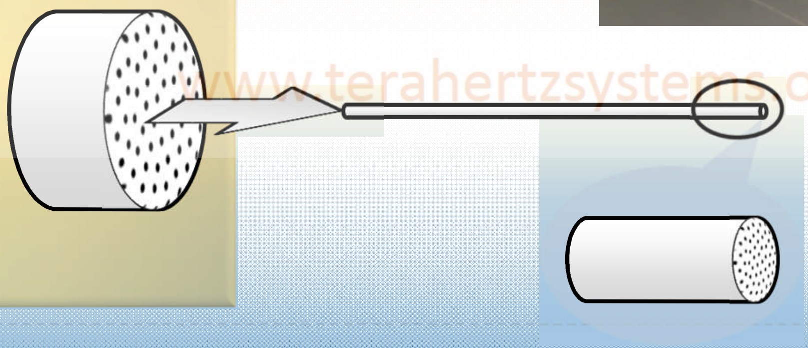
Lu, Ja-Yu et al. Appl. Phys. Lett. 92 065105 (2008)





Enables THz Devices

- Waveguides
- Splitters
- Filters
- Modulators
- Detectors
- Sources
- Other



HUDS Advantages:

- Radial isotropy
- Improved fabrication tolerance
- Design Flexibility

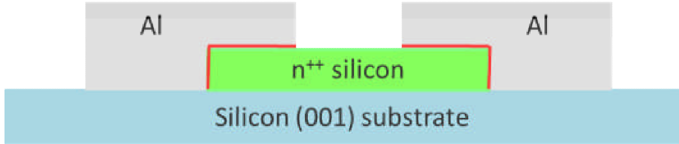
e-cooling and THz Bolometry

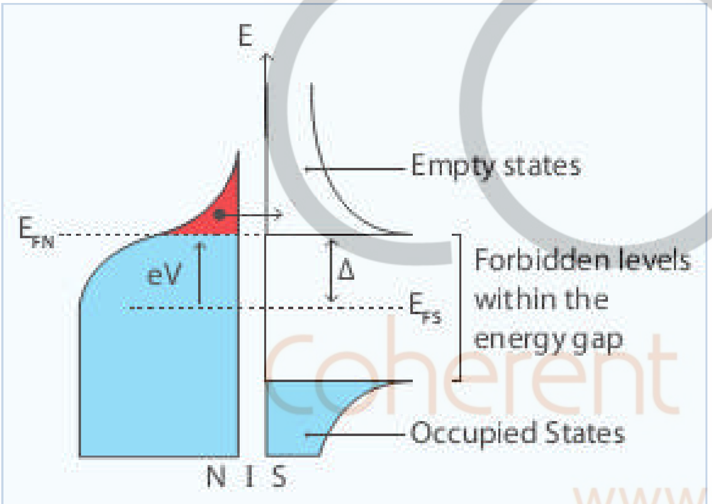
Evan Parker, Martin Prest and Terry Whall
Dept of Physics, University of Warwick

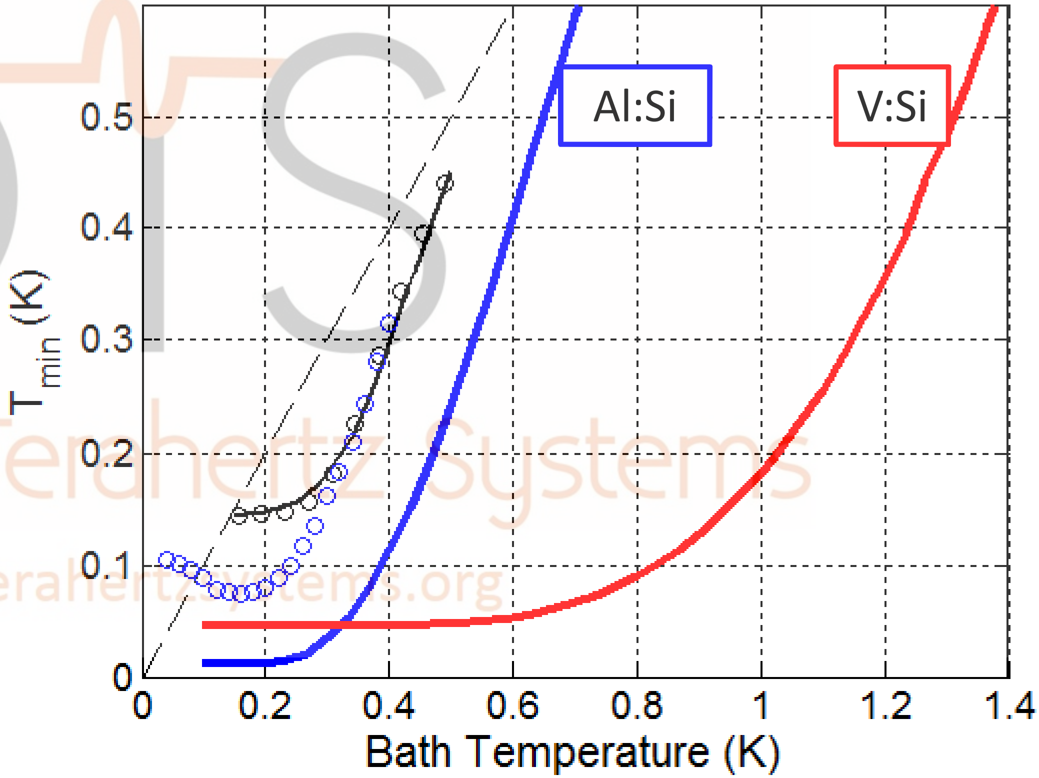
and

Tom Brien
Dept of Physics, University of Cardiff

e-cooling from 1.2 K to 50 mK



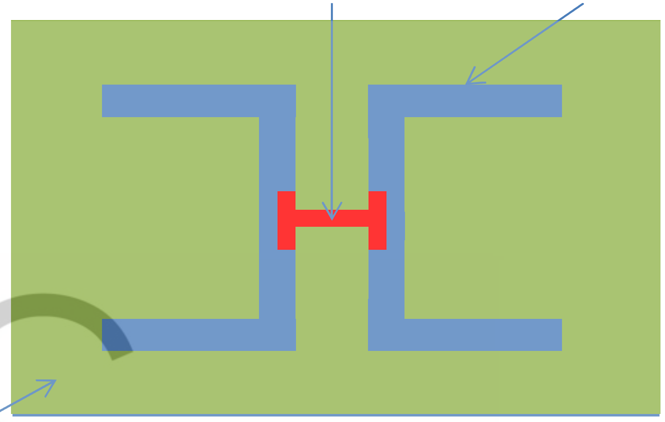




Data & model from APL 99 251908 (2011)

First Silicon THz Cold Electron Bolometer

→ Highly responsive, very quiet ,very fast



Measurements on first silicon device at 220 mK (in current bias mode):

- Responsivity of ~ 10^8 VW^{-1}
- NEP of $5x10^{-18}$ $WHz^{-0.5}$
- Response time < 1.5μs

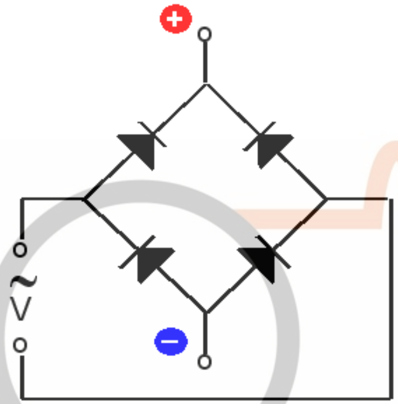
Calculations for an optimised silicon device in voltage bias mode at electron temperature 50 mK:
(Low electron-phonon coupling, $\Sigma = 2x10^6\ WK^{-6}m^{-3}$)

- **Responsivity $1x10^5$ A W^{-1}**
- **NEP = $5x10^{-21}$ $WHz^{-0.5}$**
- **Response time 0.3nS**

THz Nano-electronic Devices

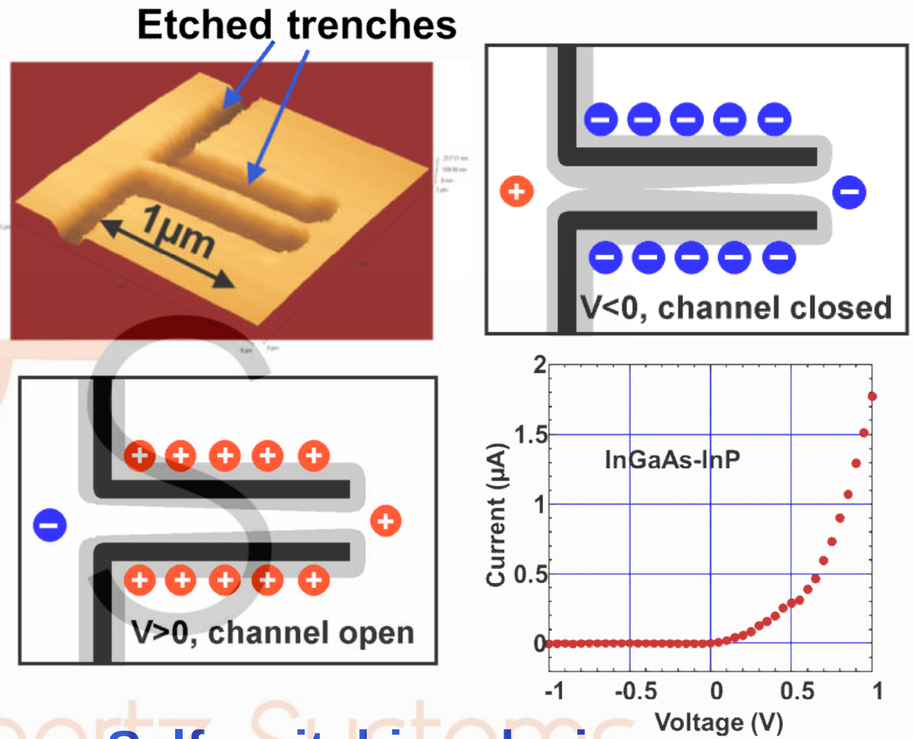
Ballistic Rectifier

Working principle in the semi-classical regime.



Functions like a **Bridge Rectifier!**

Ballistic rectifier



Self-switching device

Having zero threshold!

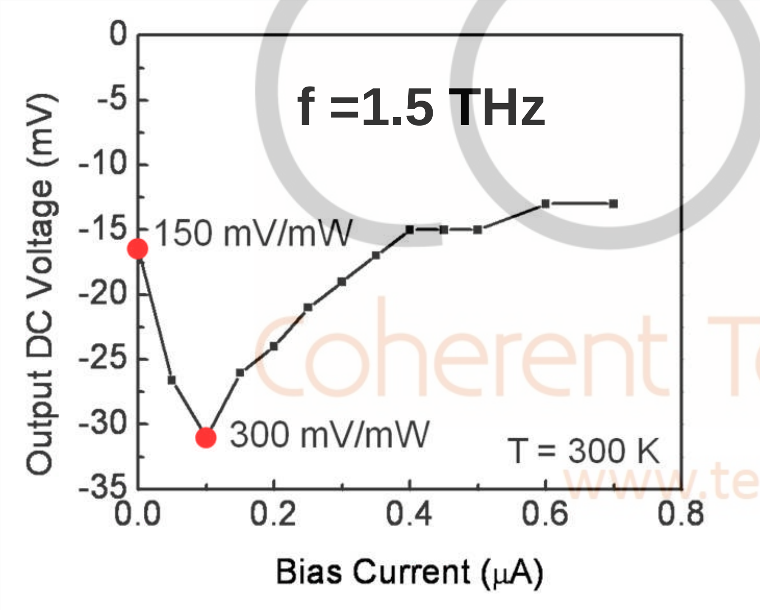
Low capacitance compared with vertical pn or Schottky diodes.

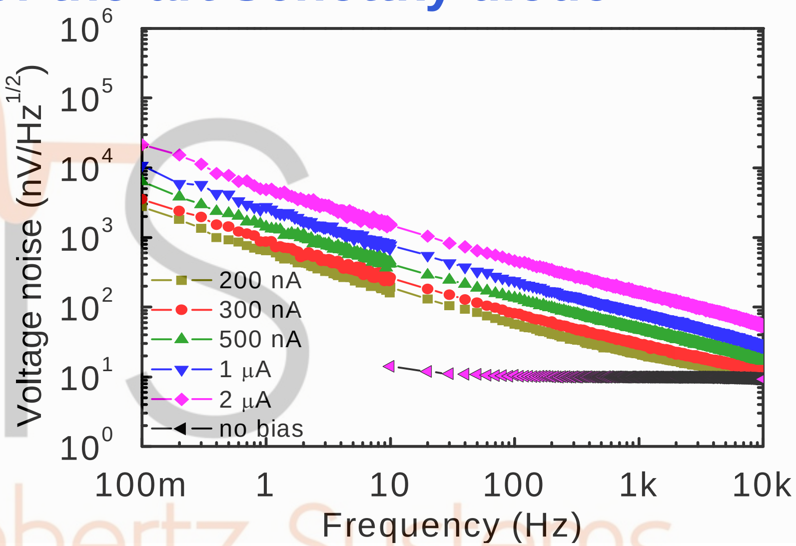
THz (1,000 GHz) speed!

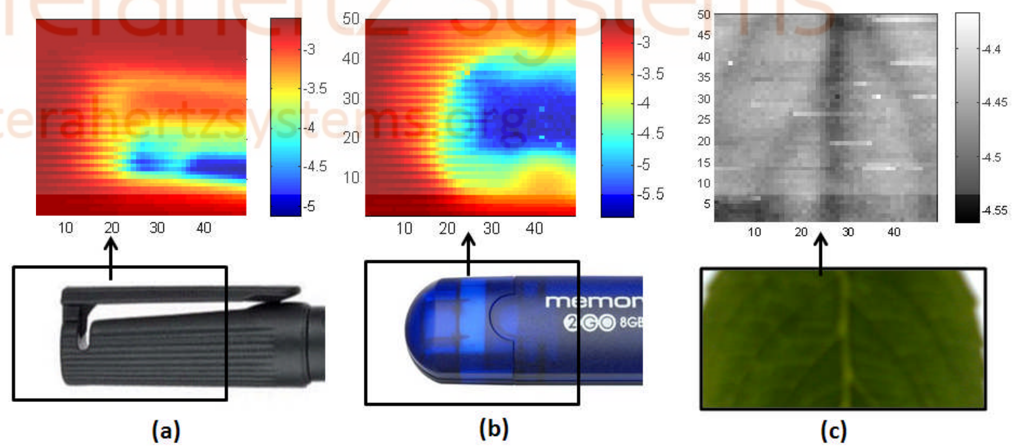
Truly planar, no need for air bridge!

Speed, noise, &THz imaging

- 1.5 THz, one of highest speeds of nanodevices to date
- Zero threshold ➔ no flicker noise! NEP= 65 pW/Hz$^{1/2}$
- Comparable/better than state-of-the-art Schottky diode
- THz emission possible
- THz imaging







THz Research Activities at Liverpool

Yaochun SHEN and Yi HUANG

High Frequency Engineering Group

Department of Electrical Engineering and Electronics

UNIVERSITY OF LIVERPOOL

1. The Group

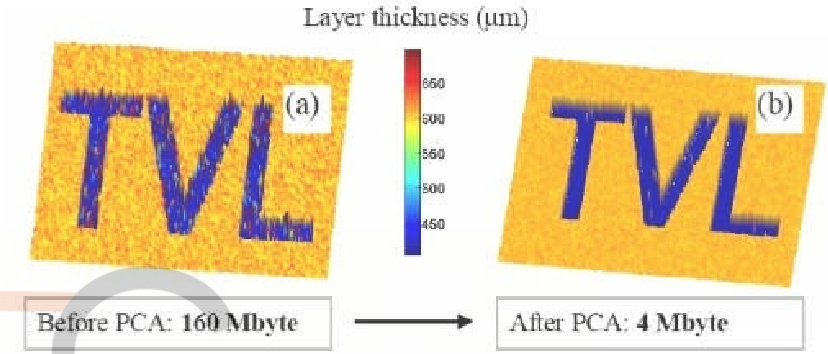
- 3+0.5+0.5 academic members of staff and over 20 PhD students
- Work on many different projects: radio comms, radar, RF -THz imaging, energy harvesting, sensors and devices linked to *High Frequency and Wireless Eng and Tech*.
- A wide range of RF/MW/THz measurement facilities

2. THz research activities

- Compressed time-domain THz imaging
- Quasi-time-domain THz imaging
- Photoconductive THz antennas

Compressed time-domain THz Imaging: to make THz technology faster

- Background
  - •THz signal is spare in time-domain
  - •THz image is spare in pixel-domain
- Initial Results
  - ✓10 time reduction in the required number of measurements thus potentially 10 time faster
  - ✓Preserve the spectral signatures for THz spectroscopic imaging.
- Further development
  - ➢3D compressed imaging--A combined pixel-domain and time-domain implementation could lead to over 100 times improvement
  - ➢Intense THz source at Daresbury



Shen etc., SPIE Proc. 5727 (2005) 24
Shen etc., Appl. Phys. Lett., 95(2009) 231112; Opt. Lett., 37(2012)46

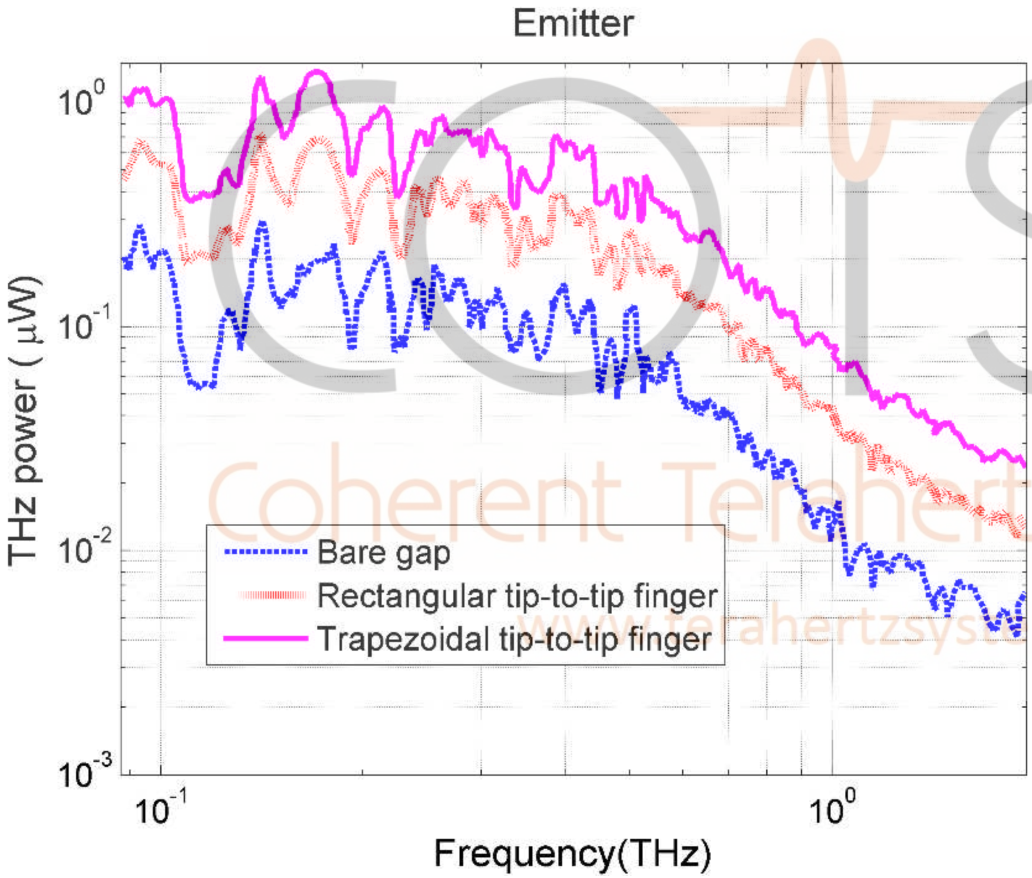
2.5% !

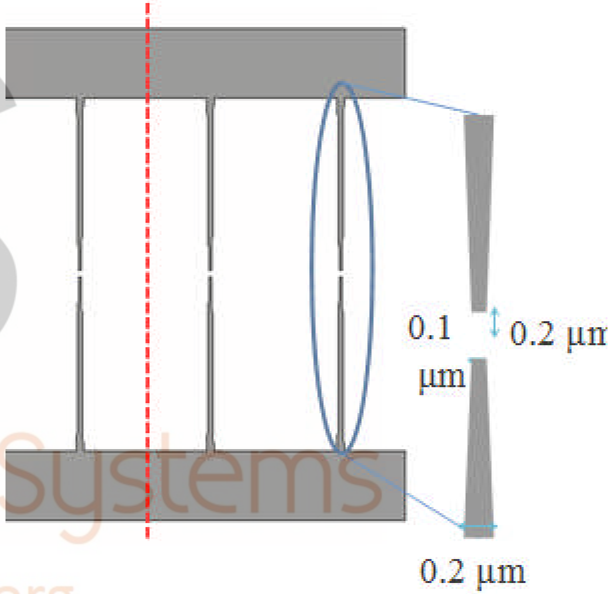
Quasi-time-domain THz Imaging: to make THz technology more affordable

- Background
  - Photoconductive emitter/receivers:
  - A femtosecond laser: $E_{THz} \propto n(t)$
  - Two tuneable cw laser diodes: $E_{THz}(\lambda_1 - \lambda_2) \propto n_1(\lambda_1); n_2(\lambda_2)$
  - Compact and works well but still very expensive
- Basic idea
  - Use conventional multimode laser diode (e.g., 850-852nm)
- Challenge
  - Total laser power is limited by the PC devices
  - Broadband with many wavelengths but Laser intensity per wavelength is small thus THz signal is very small
  - Optimised photoconductive emitter and receiver: plasmonic effects requires fabrication capability at <100 nm size features

Photoconductive antennas

- Antenna analysis, modelling and design to maximise the conversion and radiation efficiencies





The Institution of Engineering and Technology

Colloquium on

Millimetre Wave and THz Engineering and Technology

Wed 5th March, 2014

The University of Liverpool

Abstract submission deadline: **22/11/2013**

The STFC Rutherford Appleton Laboratory's

Millimetre-Wave Technology Group

B. Ellison, P. Huggard, B. Moyna, B. Alderman, S. Rea, M. Oldfield, M. Henry and H. Wang

Our 23 staff:

•*Underpin STFC's THz science objectives* in radio astronomy and remote sounding of planetary atmospheres.

•*Support UK university groups and industry* in all aspects of millimetre & sub-millimetre wave technology: design, manufacture, test

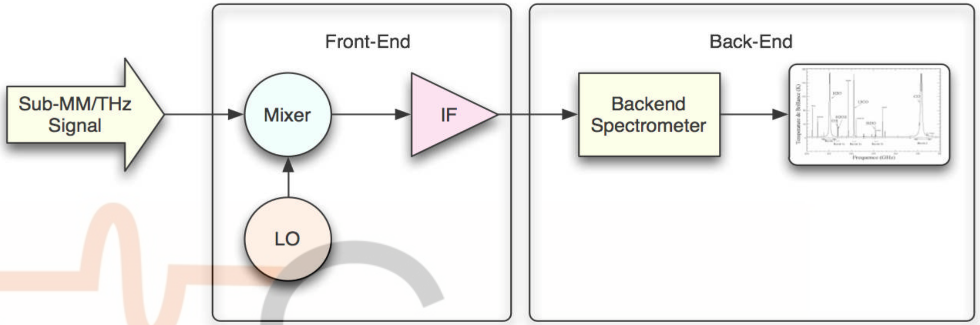
•*Innovate by developing new and novel technologies and applications* for terahertz frequencies.

MMT Group’s Role and Activities

RAL Space

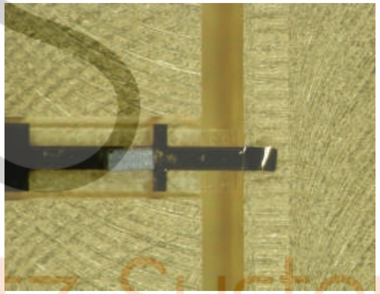
Core Business:

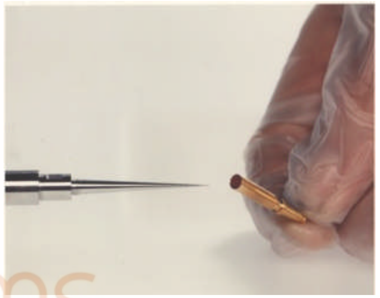
- Built about *THz heterodyne technology* from <100 GHz to >3 THz.
- *High-resolution spectroscopy*



Technical Specialisations:

- *EM simulations* of miniature waveguide embedding structures.
- *Component* manufacture - mixer, multipliers, feedhorns..
- *Detector* diode fabrication
- *Systems / Instruments* for ground, air & space deployment.
- *Field deployment* of instruments.





Examples

RAL Space

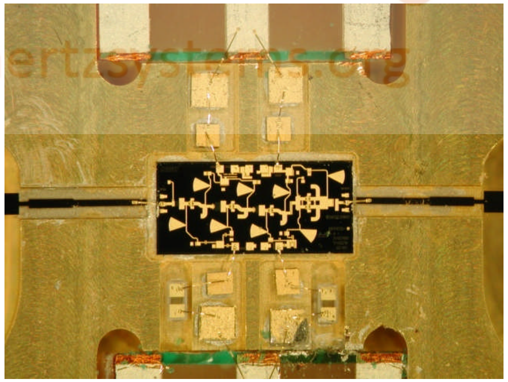
Facilities:

- Ultra-high-precision CNC manufacture:
- VNAs to 1 THz
- Polarising FTS to 3 THz
- Diode fab

Projects:

- ALMA:

- Devices



Peter.Huggard@stfc.ac.uk

Tel. (01235) 445245

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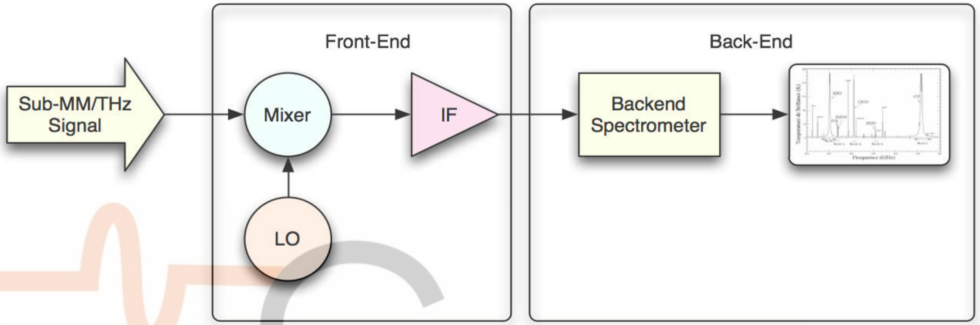

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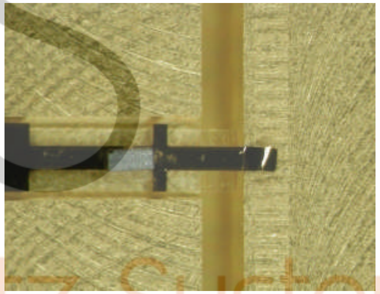

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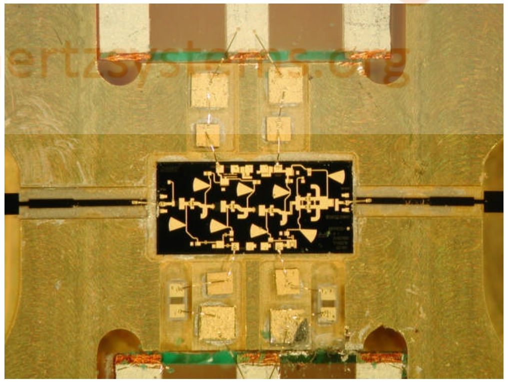

Peter.Huggard@stfc.ac.uk

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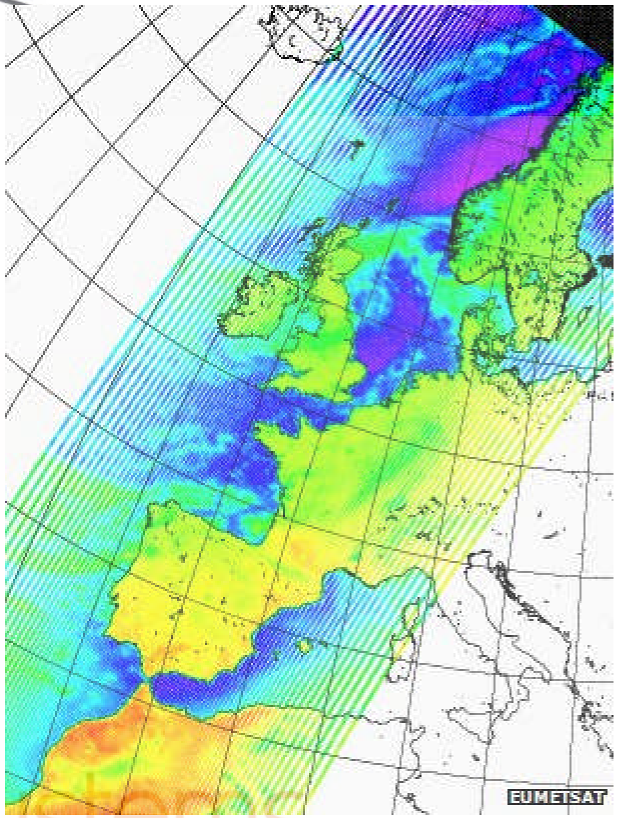
Stop Press



Science Minister, David Willets, at UK Space Conference today:

- *Microwave Sounder instrument series, on MetOp Second Generation satellites, secured for the UK.*
- *23 to 230 GHz nadir viewing of atmospheric water vapour for weather and climate*
- *Value ≈ £100M: Astrium, SMES, and UK universities*

Graphene THz Electronics

Zhirun Hu and Ernie Hill

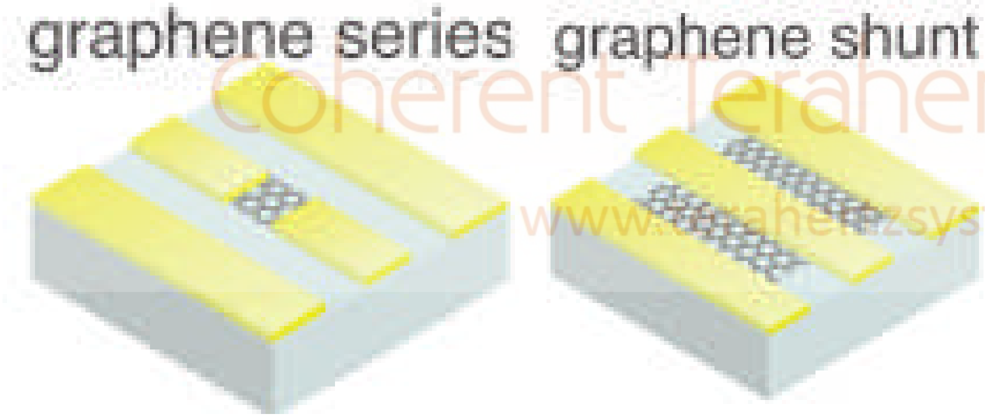
School of Electrical and Electronic Engineering

Centre for Mesoscience & Nanotechnology

University of Manchester

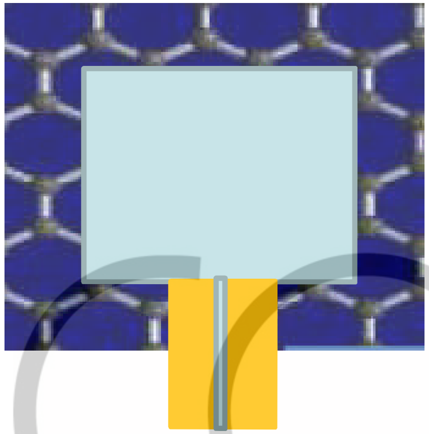
Current Research Activities

- Fabrication and measurement of graphene THz properties

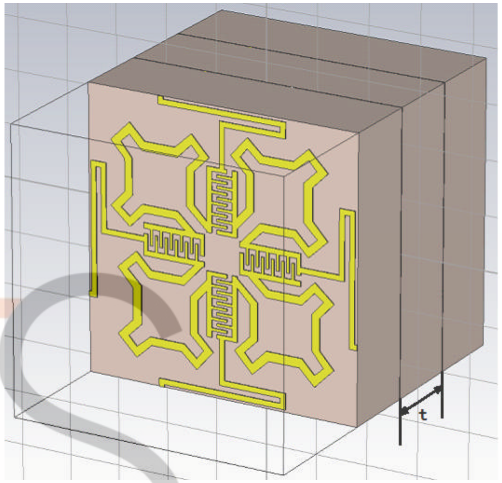


- ✓ Suspended
- ✓ on SiO_2
- ✓ hexagonal boron nitride (hBN)
- ✓ Tungsten Disulphide (WS_2).

➢ Transparent and flexble graphene THz passives and RFID

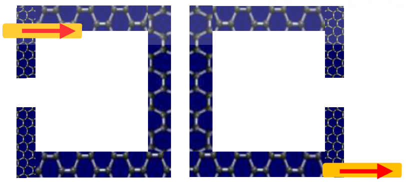


Loop antenna

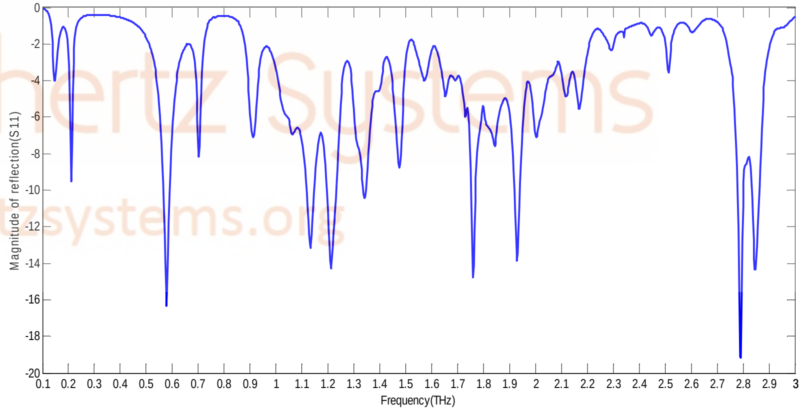


Passive graphene THz RFID

Coupled-line coupler



Filter



Preliminary simulation results

life.augmented

Sense & Power and Automotive Products (SPA)

- Analog, MEMS & Sensors (AMS)
- Automotive Product Group (APG)
- Industrial & Power Discrete (IPD)

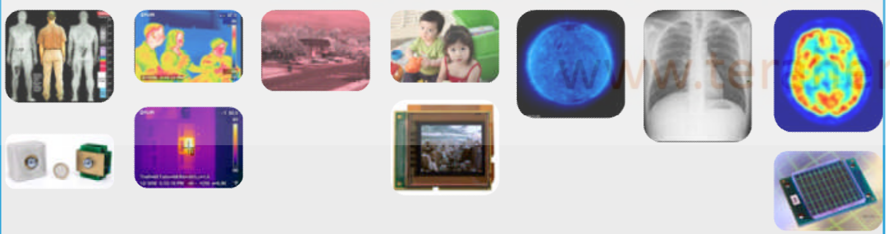
Embedded Processing Solutions (EPS)

- Digital Convergence Group (DCG)
- Imaging, BiCMOS ASIC & Silicon Photonics (IBP)
- Microcontroller, Memory & Secure MCU (MMS)
- Wireless (WPS)

Imaging Strategy, Going Beyond Visible

Applications & markets addressed

Tera	Thermal IR	Near Infrared	Visible	Ultraviolet	X-Ray	Gamma



Tera	Thermal IR / Near Infrared	Visible	Ultraviolet	X-Ray	Gamma
Security Medical	Security Home appliance Medical Automotive Consumer Industrial	Consumer Security Automotive Industrial	Consumer Medical	Medical	Medical

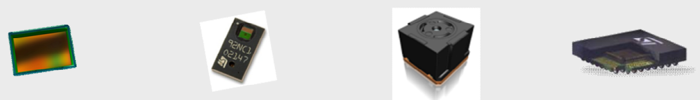
Our Product Lines

CMOS Image Sensor — Image Sensor
- Production from 1.4um to 5.6um pixel
- 1.1um development
- From VGA to 24Mpix
- 12" ST foundry
- 12" UMC second source qualified (ST process)
- 12" ST TSV foundry
- ST internal EWS

CMOS Photonic Sensor — Photonic Sensor
- User detection, Proximity, ALS, Optical navigation, Man machine interface, Automotive, Medical
- 8 & 12" ST & external foundry available
- 12" ST TSV foundry
- ST internal EWS

Camera Modules & Others — Module
- Fixed focus camera
- Wafer Level re-flowable camera
- EDoF camera
- Auto-focus camera
- Innovative optics, assembly & test technologies
- ST manufacturing
- Long term optics & supply chain partners

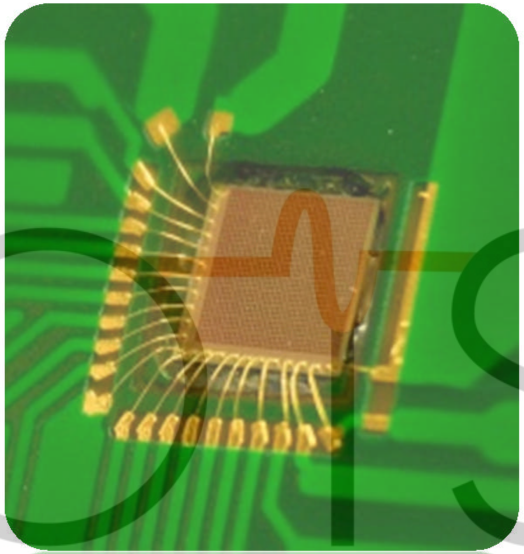
Image Signal Processing — Processor
- Stand alone ISP
- Full ST video pipe IP
- Integration of third party IP on demand
- 12" CMOS40nm ST & foundries in production
- Developing IC's in12" CMOS28nm
- ST internal BGA assembly line

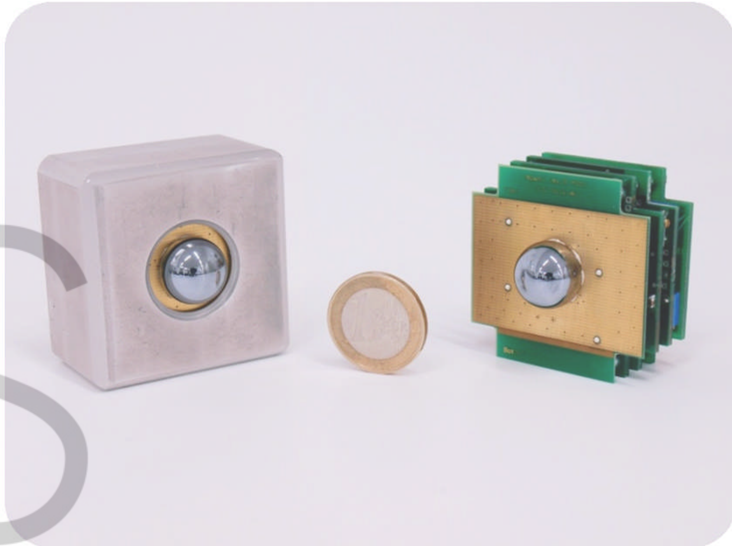


1kpixel THz CMOS Video Camera:

•STMicroelectronics, Crolles, France
•2University of Wuppertal, Wuppertal, Germany

•Hani Sherry, ISSCC 12 best European paper award (Jan Van Vessem Outstanding paper award)
•Richard Al Hadi, JSSC VOL. 47, NO. 12, Dec 2012





Si Lens

Glued to an FR4 PCB board using low-shrinkage epoxy

CMOS Chip

Glued to the back of Si-lens and wire-bonded to the board

Camera Housing

CMOS-chip + CPLD + power supply + instrumentation amplifier ($5x5x3cm^3$)

Coherent Terahertz Systems

THz Photonics @ UCL

A. J. Seeds, C. C. Renaud, O. Mitrofanov, H. Liu, M. J. Fice, C. Graham, L. Ponnampalam, H. Shams, K. Balakier, M. Natrella, R. Mueckstein

www.terahertzsystems.org

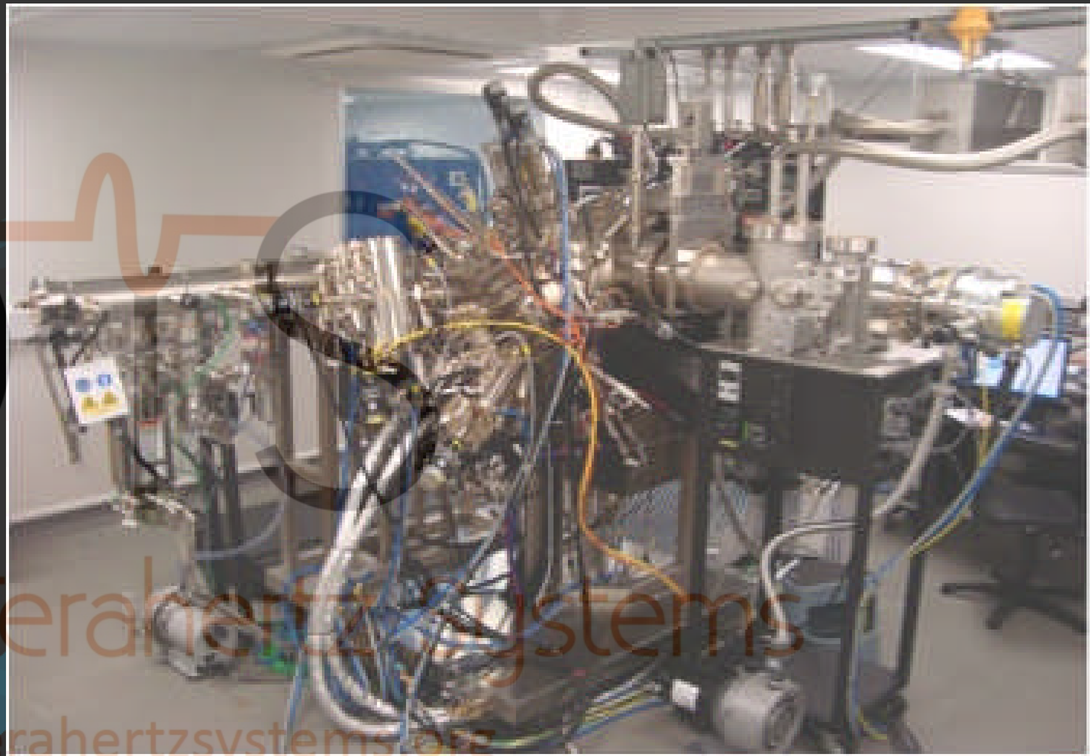
UCL · University of Cambridge · University of Leeds · LCN London Centre for Nanotechnology · EPSRC Pioneering research and skills · UCL Engineering Change the world

COTS Coherent Terahertz Systems

Range of work and Facilities

- From material to systems and applications

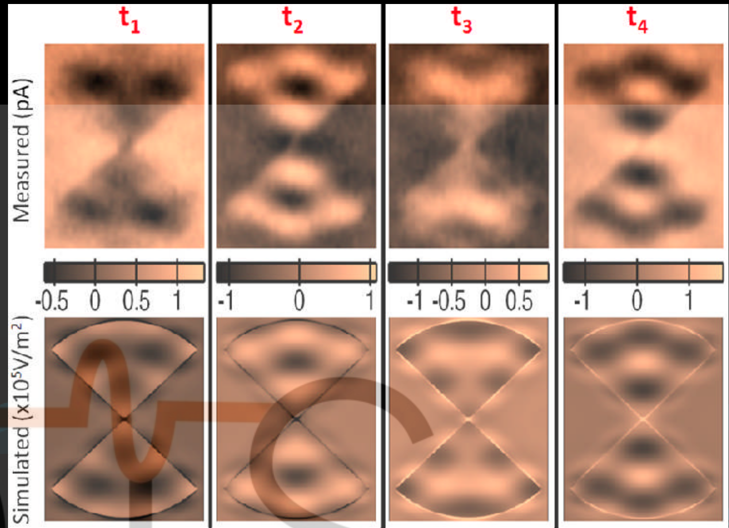
- Facilities include:
  - MBE growth
  - Cleanrooms
  - two THz lab (CW and short pulse)
  - Device characterisation lab



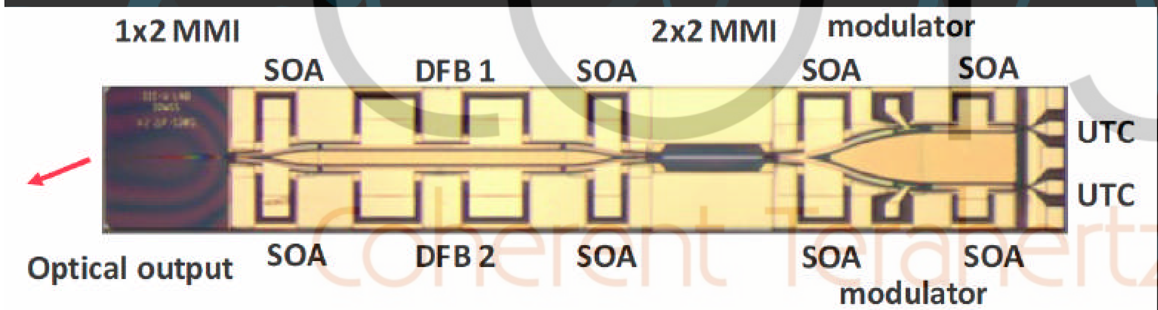
COTS
Coherent Terahertz Systems

Highlights

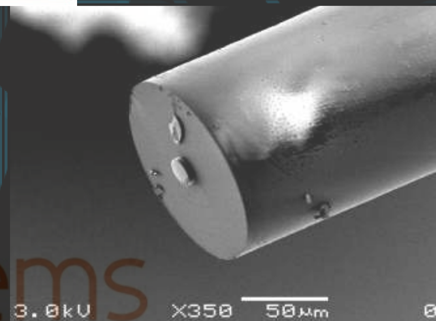
High power TW-UTC emitters /detectors



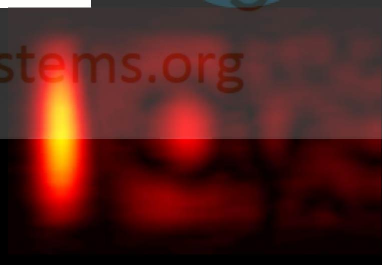
Near field imaging of plasmonic resonances on metalic structures



Fibre coupled Near Field probe



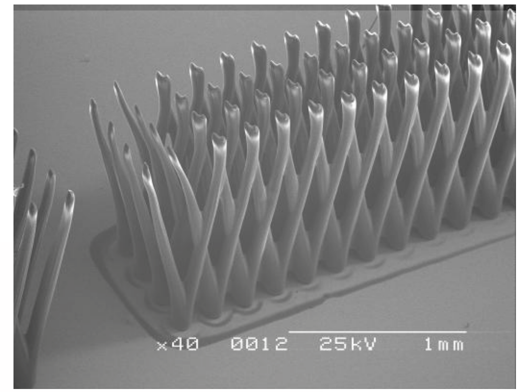
Monolithically integrated THz emitter (in collaboration with III-V Lab



Characterisation of THz waveguides

UCL UNIVERSITY OF CAMBRIDGE UNIVERSITY OF LEEDS LCN LONDON CENTRE FOR NANOTECHNOLOGY EPSRC Pioneering research and skills UCL ENGINEERING Change the world

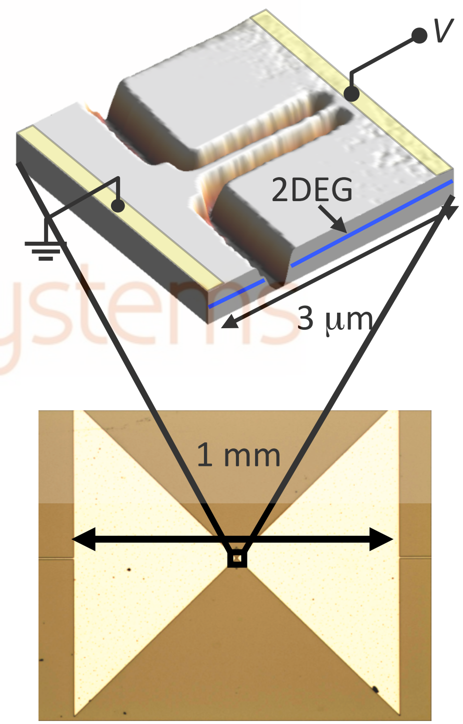
Terahertz research at Durham



- **Staff involved:** Dr Andrew Gallant, Dr Claudio Balocco and Prof. Martyn Chamberlain (emeritus)

- **Equipment:** bespoke THz TDS systems, THz VNA and extensive microfabrication & cleanroom facilities.

- **Key interests:** micro (and nano)fabricated artificial materials for imaging enhancement, sensing with microfluidic systems and the development of new receiver technology (e.g. self-switching diodes).



THz studies of atomic dynamics in glasses

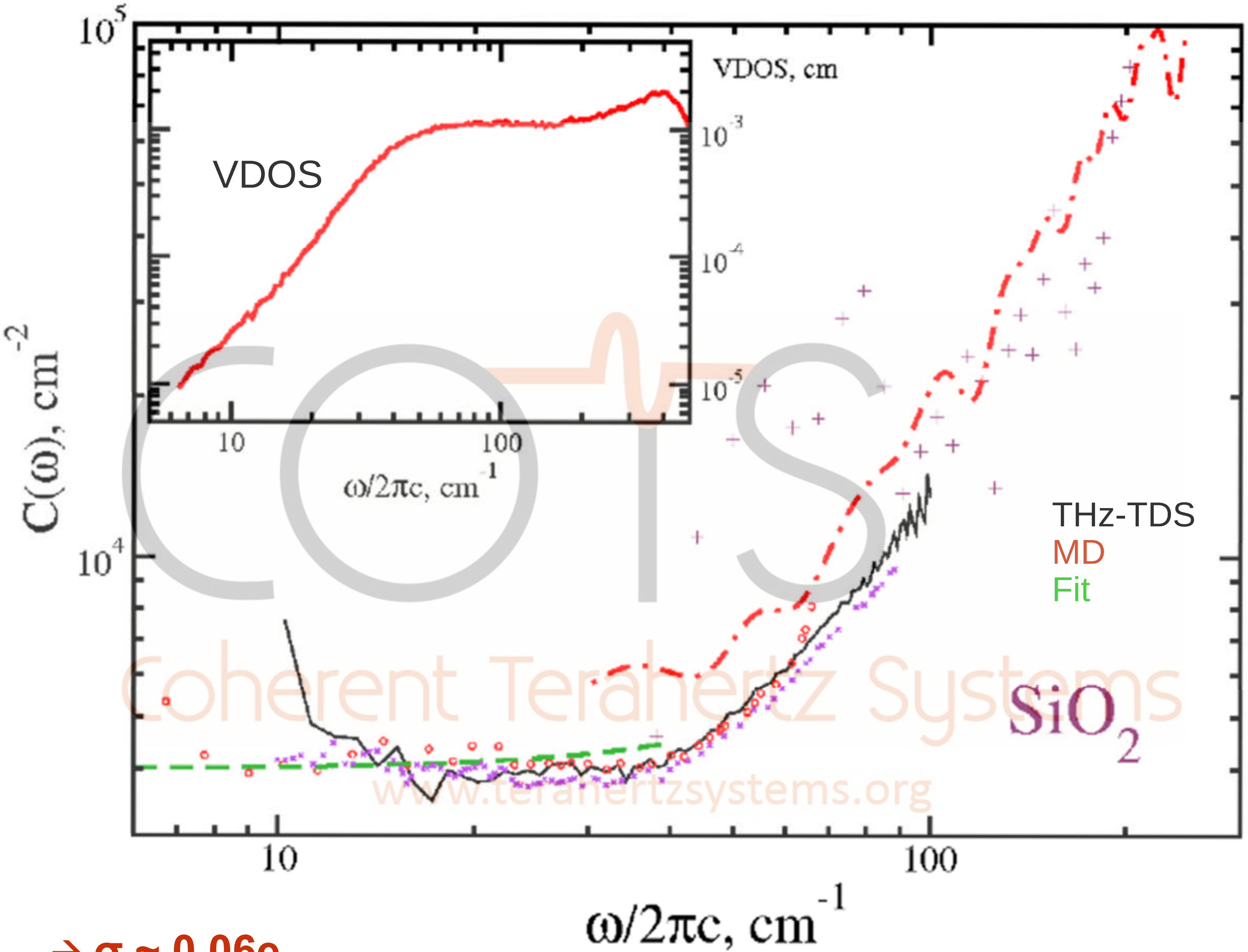
S.R. Elliott
Dept. of Chemistry
University of Cambridge
sre1@cam.ac.uk

Experimental and theoretical studies of THz atomic dynamics in glasses

- THz-TDS absorption results on SiO_2, Na_2O-SiO_2 and As_2S_3 glasses
- Theoretical model for THz absorption coupling coefficient in terms of (un)correlated atomic-charge disorder (σ)

Phys. Rev. Lett, **97**, 055504 (2006);
J. Phys. Cond. Matt. **19,** 455216 (2007);
J. Non-Cryst. Sol. **355,** 1824 (2009);
Phys. Rev. **B82,** 140203R (2010)

THz-TDS Data and MD Simulation Results for a-SiO_2



→ $\sigma \sim 0.06e$

Ultrafast Photonics Group at the University of Dundee

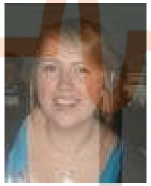
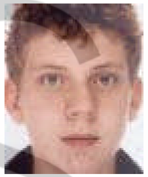
Group Leader and PI: Dr. Maria Ana Cataluna

Senior Lecturer

Royal Academy of Engineering/EPSRC Research Fellow

University of Dundee

SUPA

Post-docs		Ph.D. students		M.Sc. students	
					
Nart	Ding	David	Steph	Adam	Liang

Expertise in:

- Ultrafast semiconductor lasers: physics and technology
- Ultrafast spectroscopy of solid-state materials
- Pulsed THz generation and coherent detection

Collaborations welcome. Please contact m.a.cataluna@dundee.ac.uk

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The Royal Academy of Engineering

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Seventh Framework Programme

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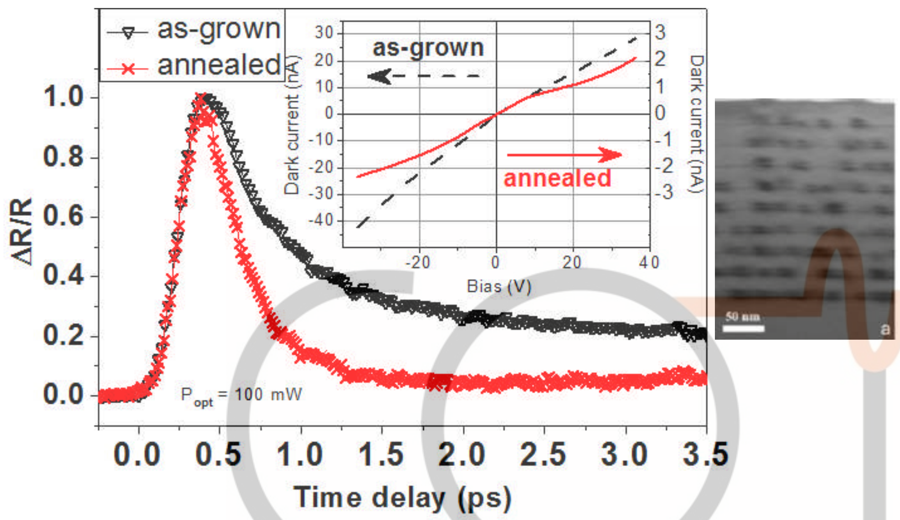
Excellence in Science The Royal Society

The Leverhulme Trust

Pulsed THz generation from QD structures



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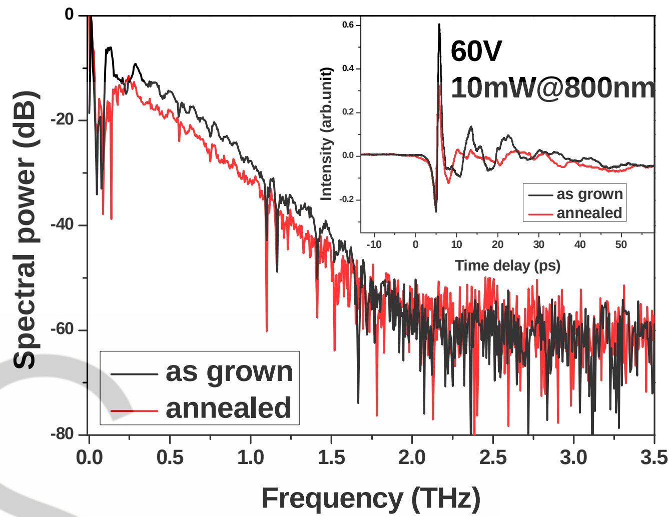

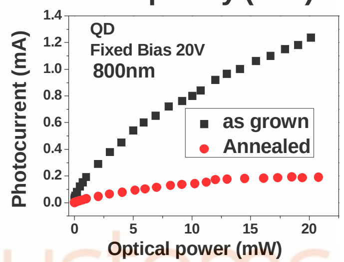

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Tyndall National Institute

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