UK META MATERIALS NETWORK

University of Exeter
Centre for Metamaterial Research and Innovation

Metamaterials

Controlling Waves and Information through Engineered Structure.

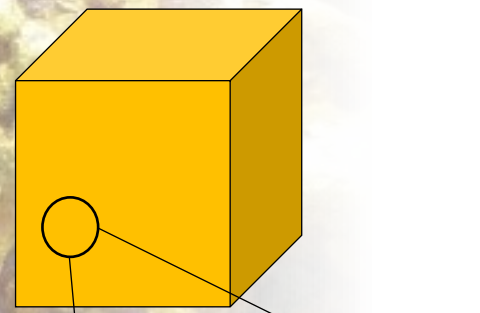
Alastair Hibbins, Professor of Metamaterial Physics
Director of the Centre for Metamaterial Research and Innovation
Joint lead of the UK Metamaterials Network
www.metamaterials.center | www.metamaterials.network

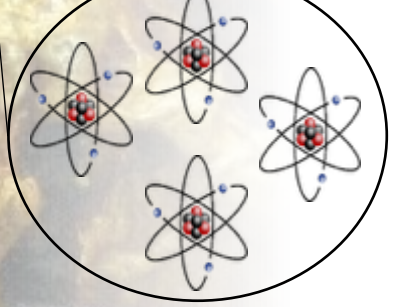
University of Exeter

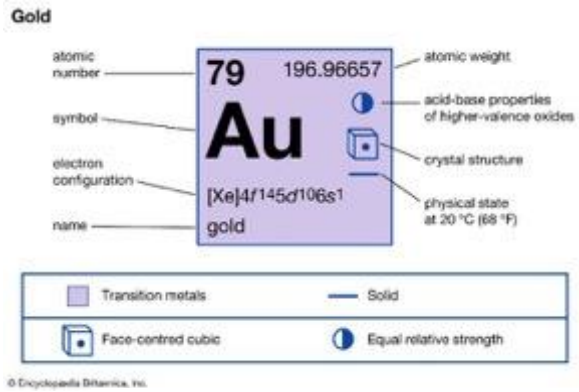
Centre for Metamaterial Research and Innovation

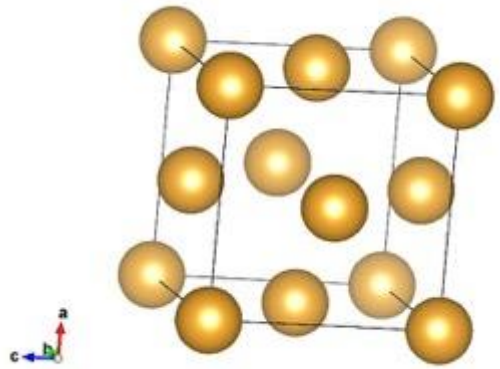
UK META MATERIALS NETWORK

Atoms are the building blocks of **Materials**









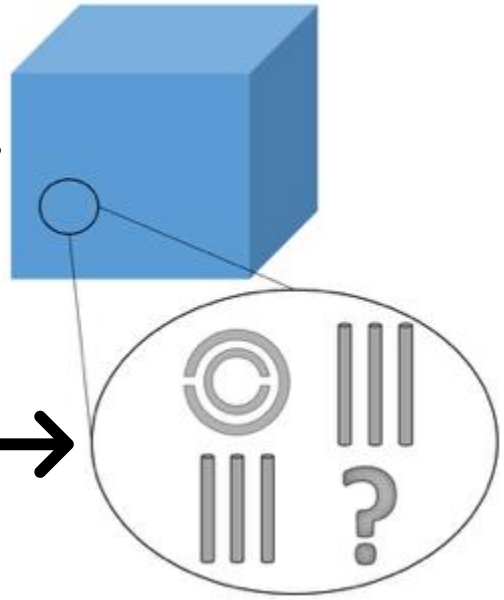
University of Exeter

Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

Meta-atoms are the building blocks of **Metamaterials**

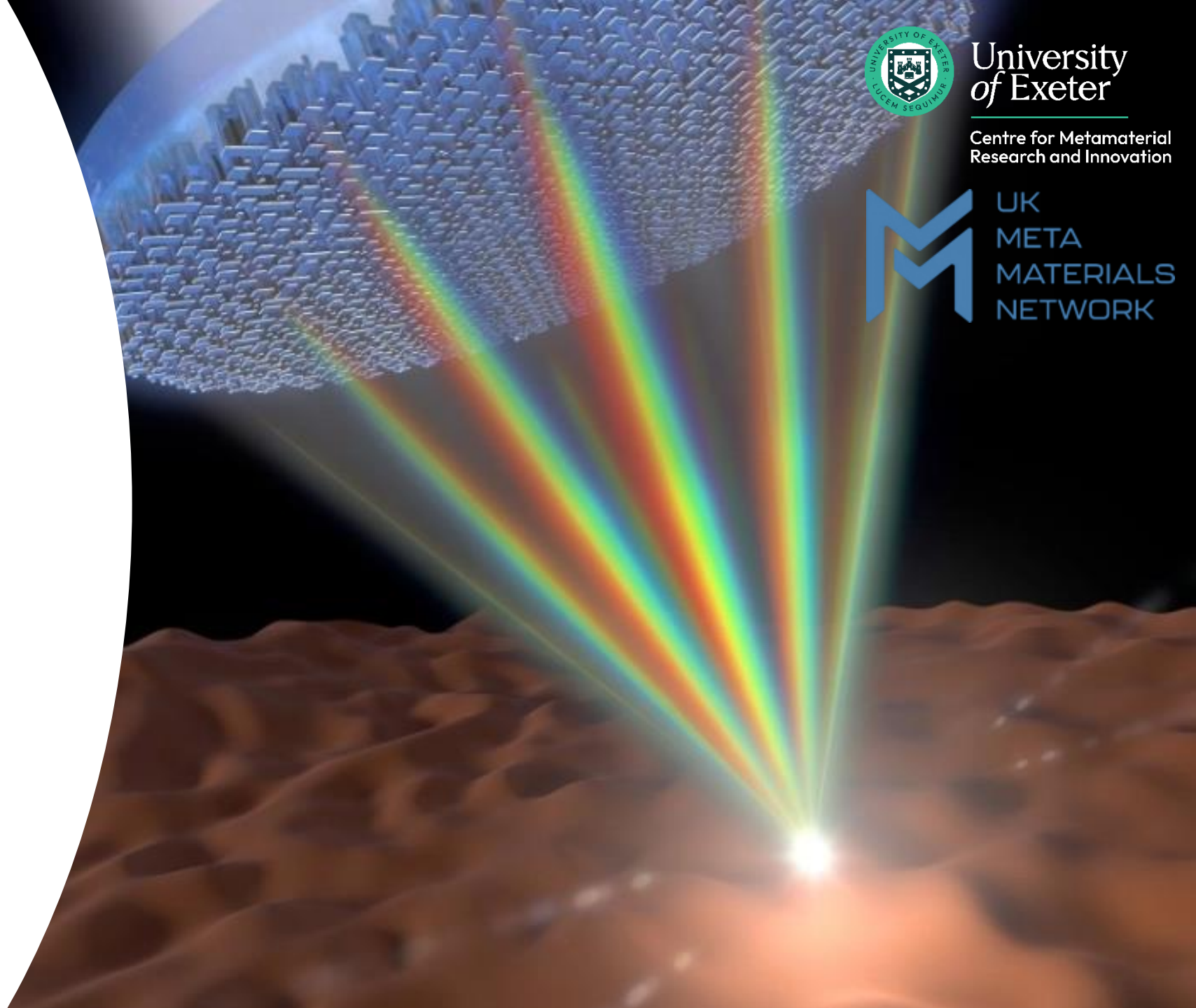
This is the metamaterial →



These are the meta-atoms →

(and are normally smaller than the wavelength – just like atoms)

‘Perfect’ and ultra-thin lenses

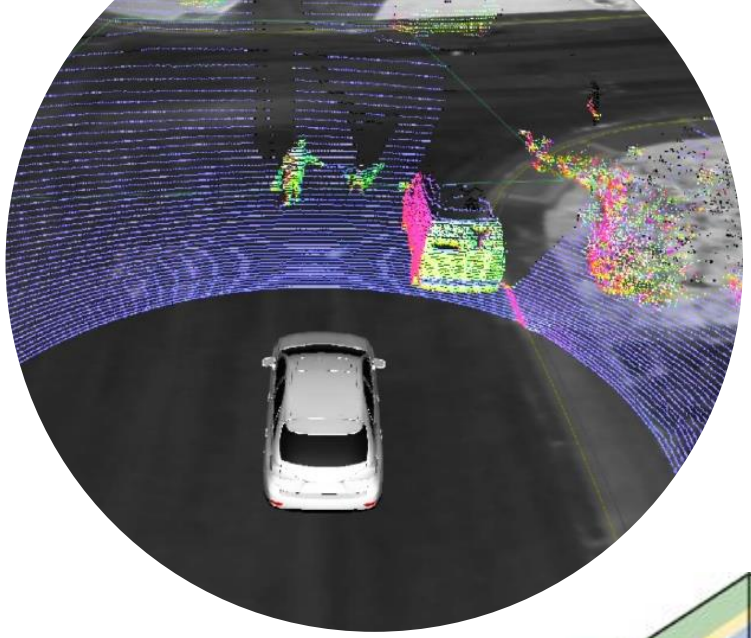


University of Exeter
Centre for Metamaterial Research and Innovation
UK META MATERIALS NETWORK

University of Exeter
Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

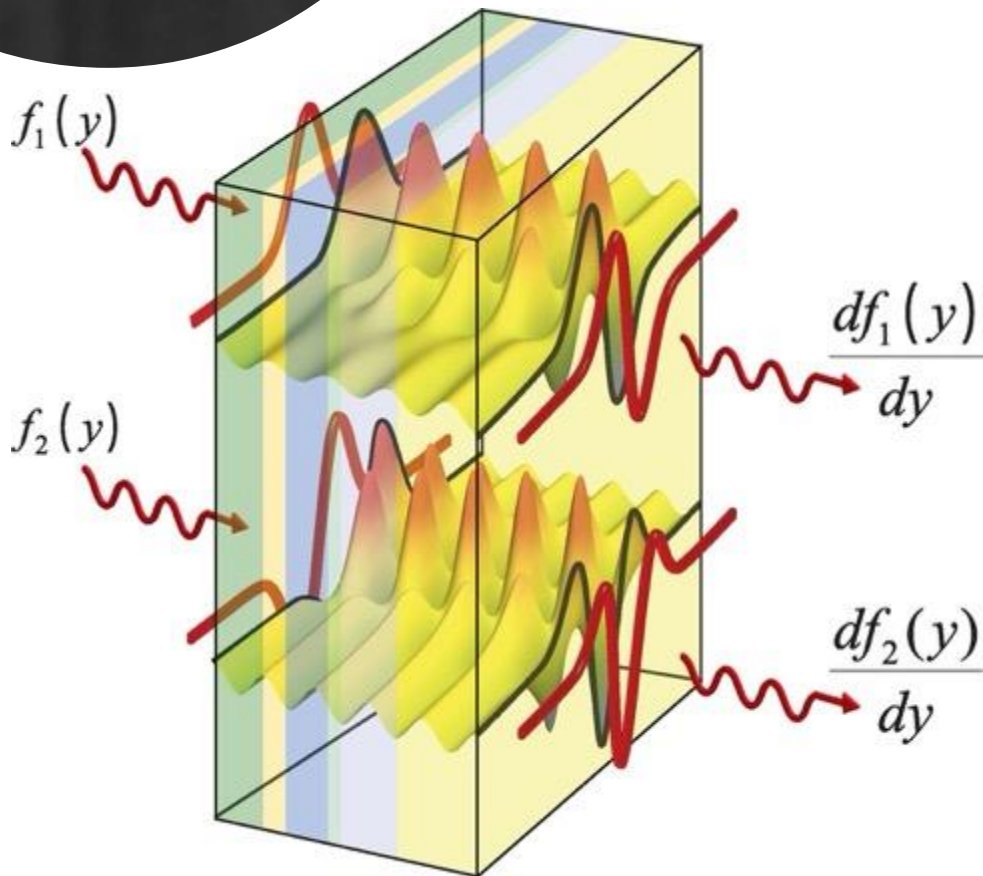
Invisibility cloaks



University of Exeter
Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

New forms of ultra-fast and efficient computing

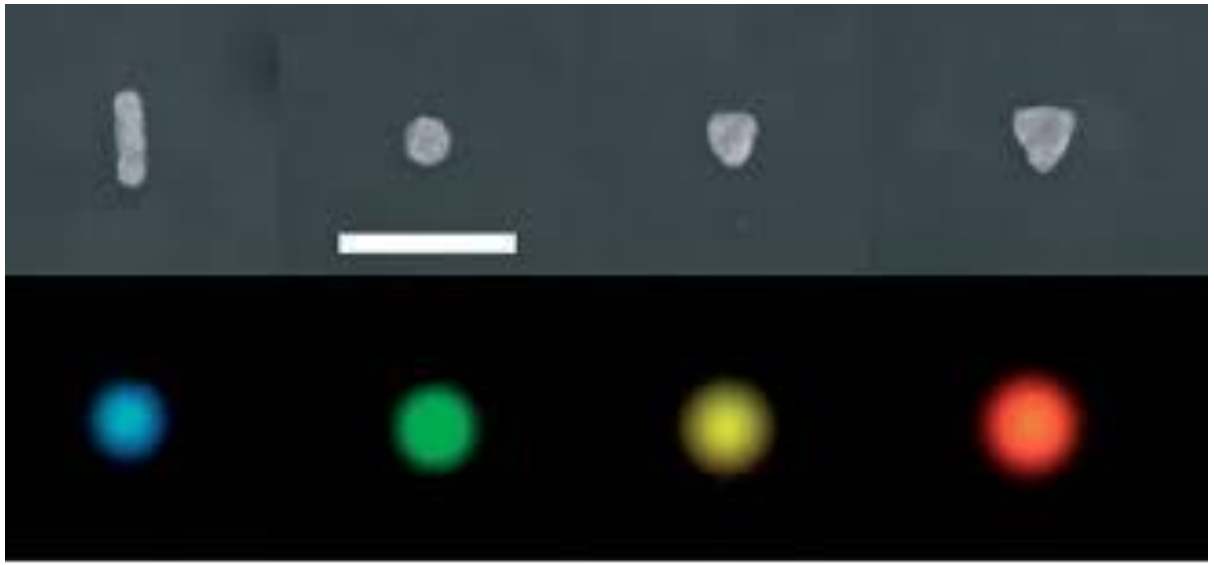


University of Exeter
Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

Exeter Cathedral

Plasmonic Meta-atoms



Gold Rush – how to make your own metamaterial

Controlling the electric fields in a material (permittivity, *e*)

University of Exeter
Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

VOLUME 76, NUMBER 25 PHYSICAL REVIEW LETTERS 17 JUNE 1996

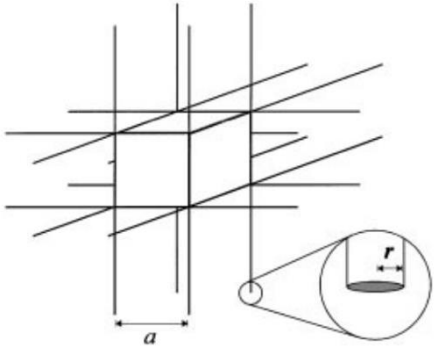
Extremely Low Frequency Plasmons in Metallic Mesostructures

J. B. Pendry
The Blackett Laboratory, Imperial College London SW7 2BZ, United Kingdom

A. J. Holden and W. J. Stewart
GEC-Marconi Materials Technology Ltd., Caswell, Towcester, Northamptonshire NN12 8EQ, United Kingdom

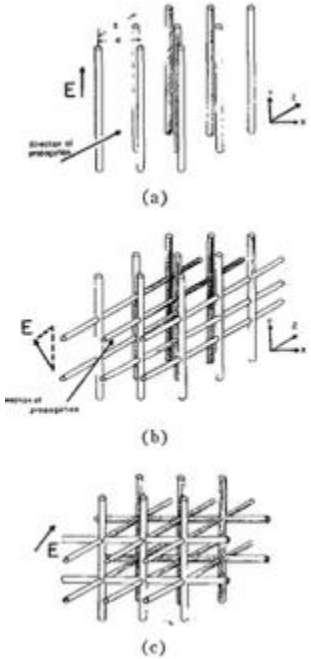
I. Youngs
Defence Research Agency Holton Heath, Poole, Dorset BH16 6JU, United Kingdom
(Received 22 December 1995)

The plasmon is a well established collective excitation of metals in the visible and near UV, but at much lower frequencies dissipation destroys all trace of the plasmon and typical Drude behavior sets in. We propose a mechanism for depression of the plasma frequency into the far infrared or even GHz band: Periodic structures built of very thin wires dilute the average concentration of electrons and considerably enhance the effective electron mass through self-inductance. Computations replicate the key features and confirm our analytic theory. The new structure has novel properties not observed before in the GHz band, including some possible impact on superconducting properties. [S0031-9007(96)00491-7]



Plasma Simulation by Artificial Dielectrics and Parallel-Plate Media*

WALTER ROTMAN†, MEMBER, IRE



IRE Transactions on Antennas and Propagation
(Volume: 10 , Issue: 1 , January 1962)

AMBITION

To design new materials with the parameters we need for devices.

i.e. control the interaction of energy and information with materials

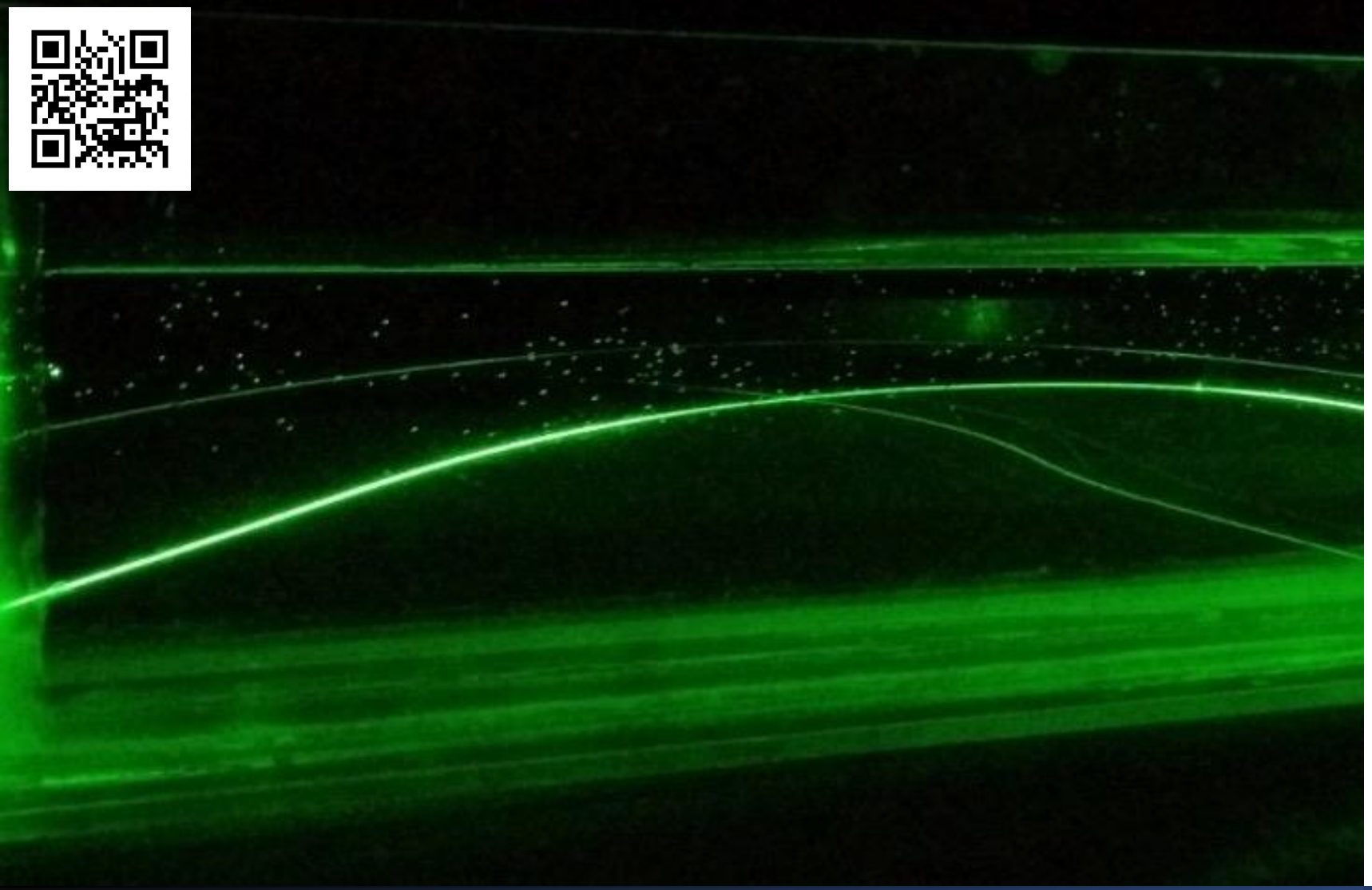
Not just light, but heat, sound, vibration, microwave, THz, …

University of Exeter

Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

Light always travels in a …
~~straight line~~



University of Exeter
Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

Light always travels in a …
~~straight line~~

Q: What is the quickest way to get from A to B?

University of Exeter
Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

B

A

Pierre de Fermat
1607-1665

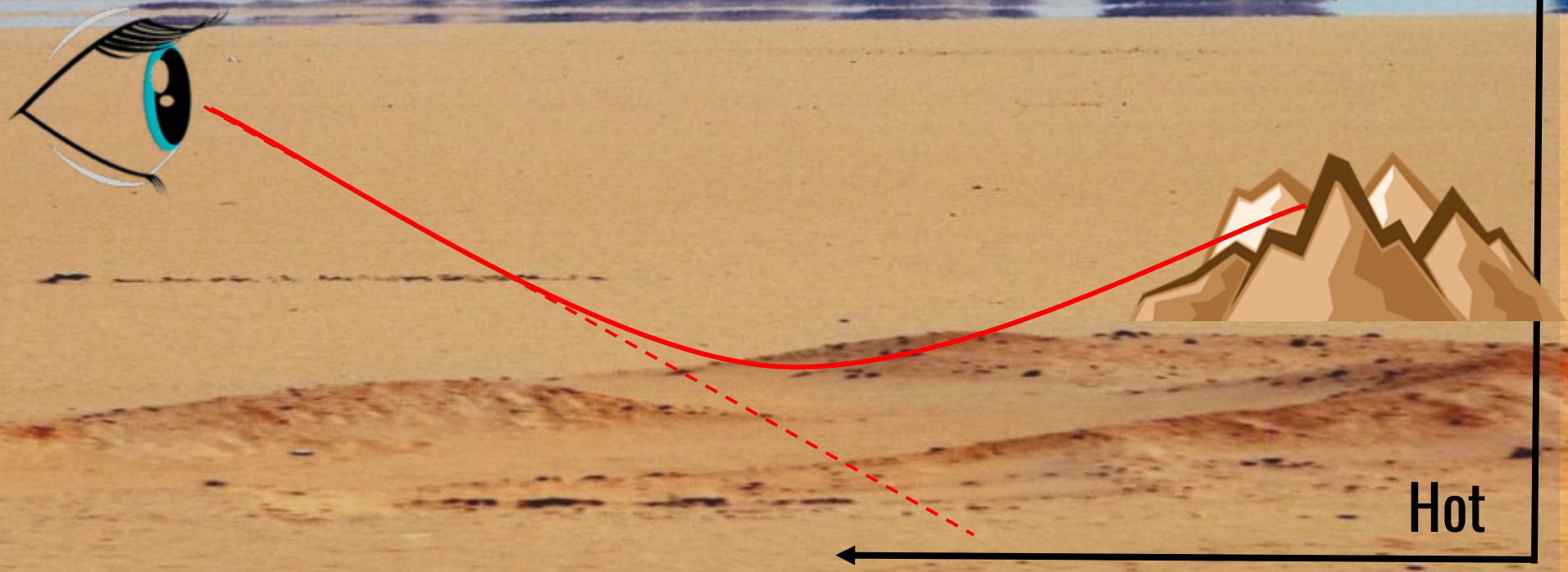
Light follows the path that takes the least amount of time i.e. Not necessarily a straight line!

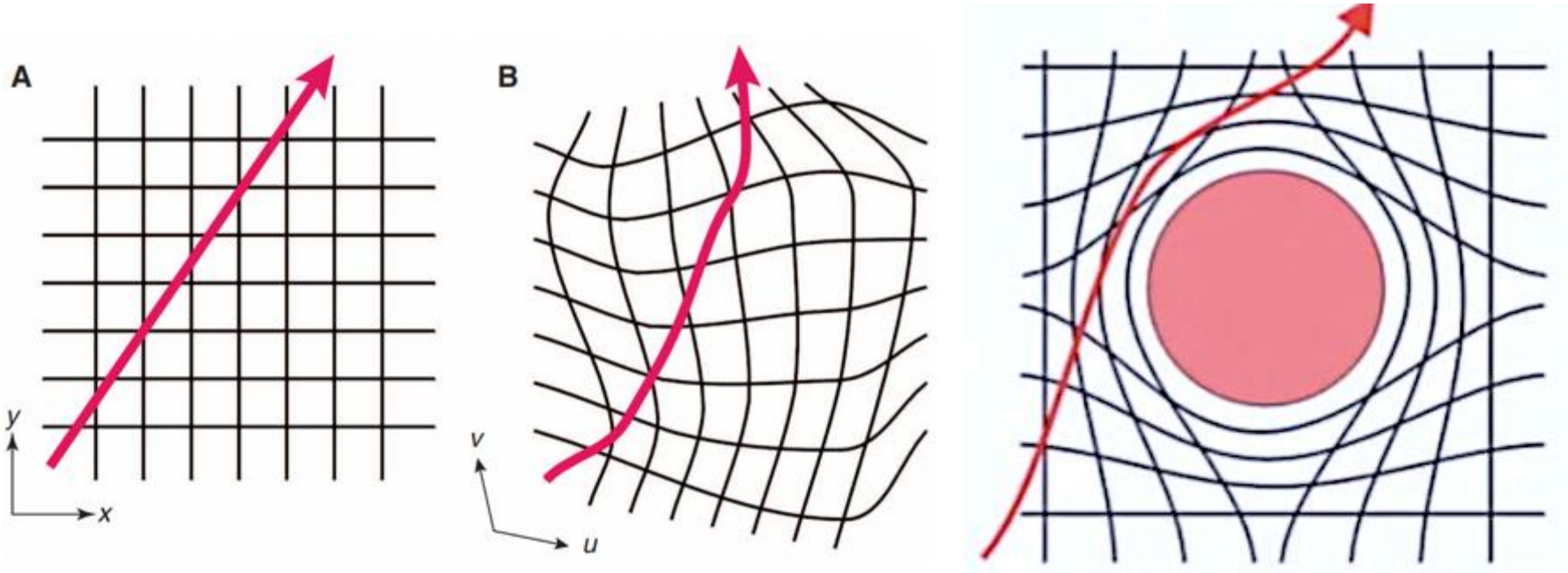
University of Exeter

Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

"The path followed by a light ray between two points is the one that takes the least amount of time"





University of Exeter
Centre for Metamaterial Research and Innovation

UK META MATERIALS NETWORK

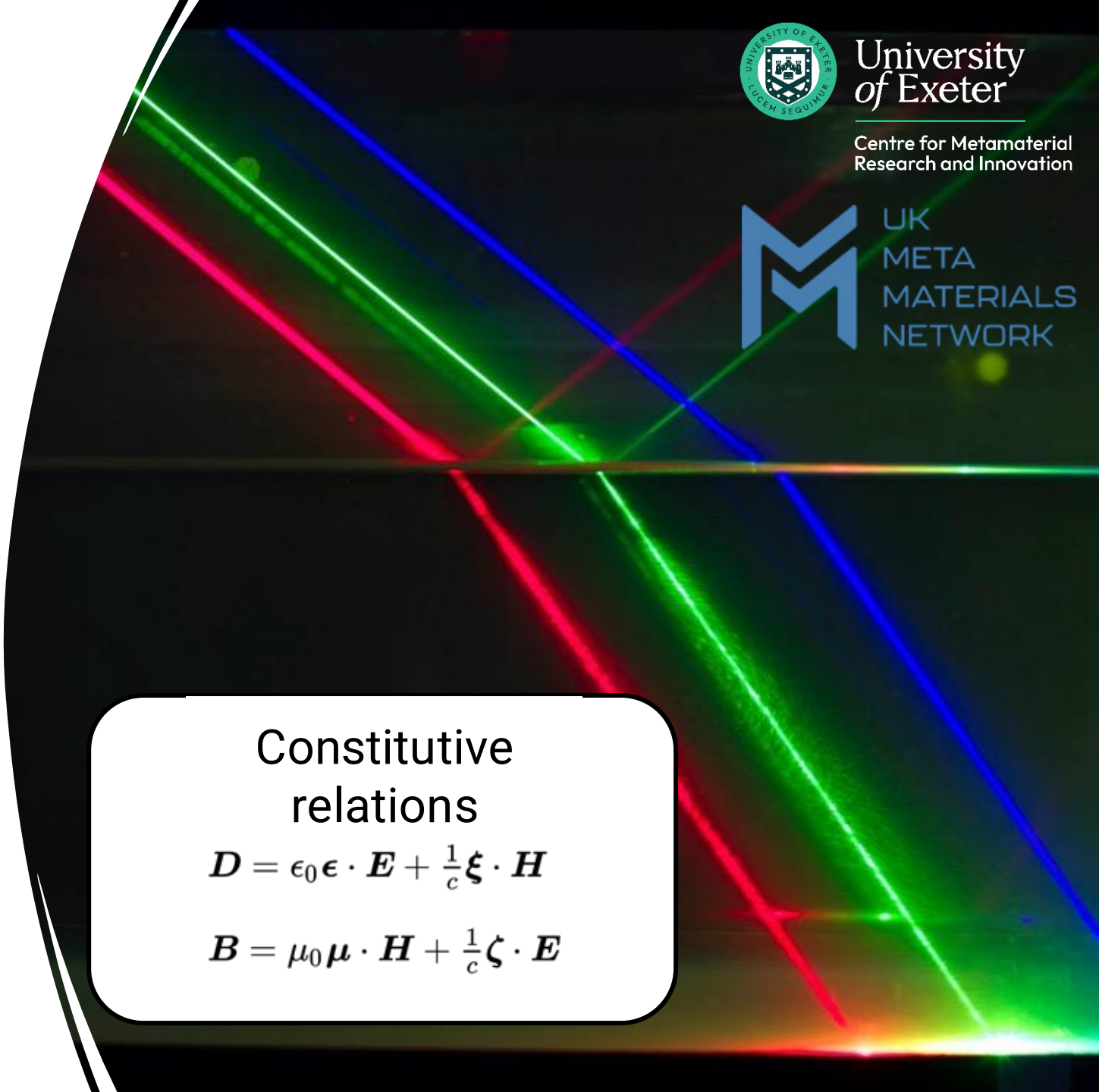
We are warping space!
There is a region of space, where rays cannot reach (invisible)!

Through engineered structuring, metamaterials enable

control of the **refractive index** and hence control the path that light takes

But REFRACTIVE INDEX alone is not enough…

- Reflections are caused by a change in **IMPEDANCE, Z**
- **Refractive index** is the **product of permittivity e** (how it responds to electric field) **and** its **permeability m** (equivalent for magnetic fields).
- **Impedance** is the **ratio** of **m** and **e**
- METAMATERIALS allow us to engineer these parameters at the point of design and fabrication



University of Exeter
Centre for Metamaterial Research and Innovation
UK META MATERIALS NETWORK

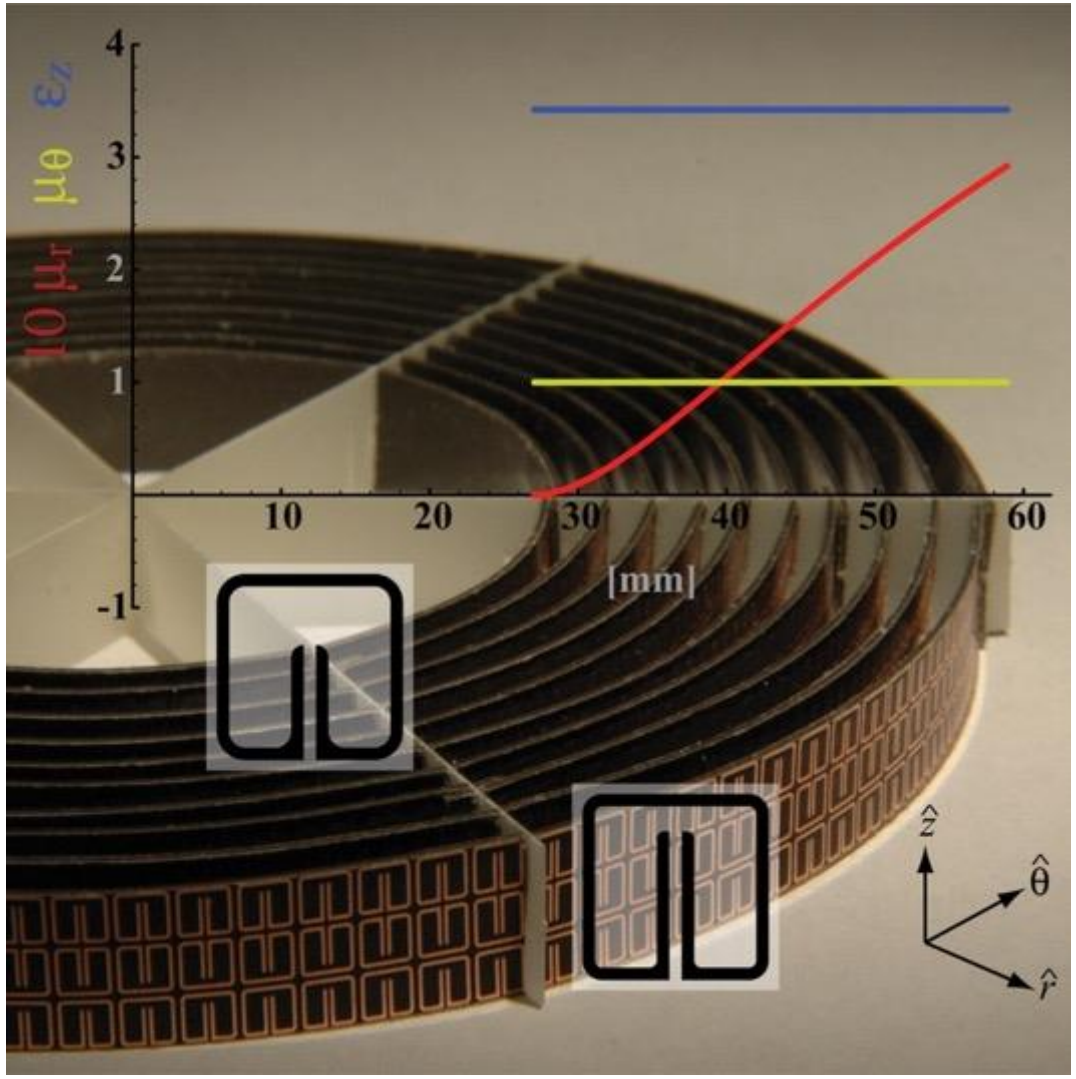
Constitutive relations

$$\boldsymbol{D} = \epsilon_0 \boldsymbol{\epsilon} \cdot \boldsymbol{E} + \frac{1}{c} \boldsymbol{\xi} \cdot \boldsymbol{H}$$

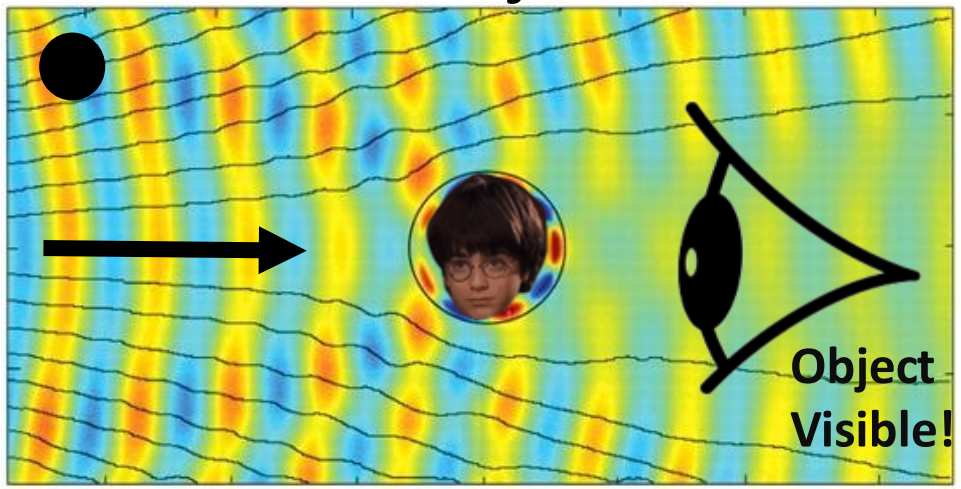
$$\boldsymbol{B} = \mu_0 \boldsymbol{\mu} \cdot \boldsymbol{H} + \frac{1}{c} \boldsymbol{\zeta} \cdot \boldsymbol{E}$$

University of Exeter
Centre for Metamaterial Research and Innovation

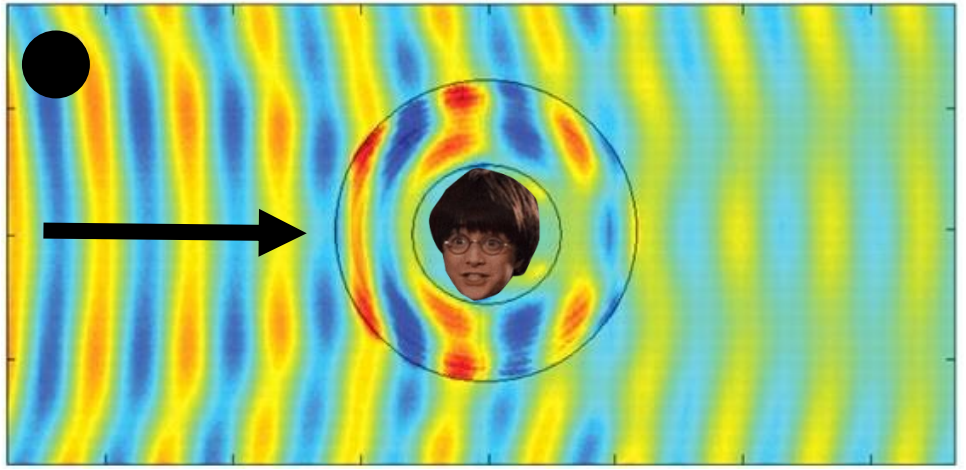
UK META MATERIALS NETWORK



Bare Object:

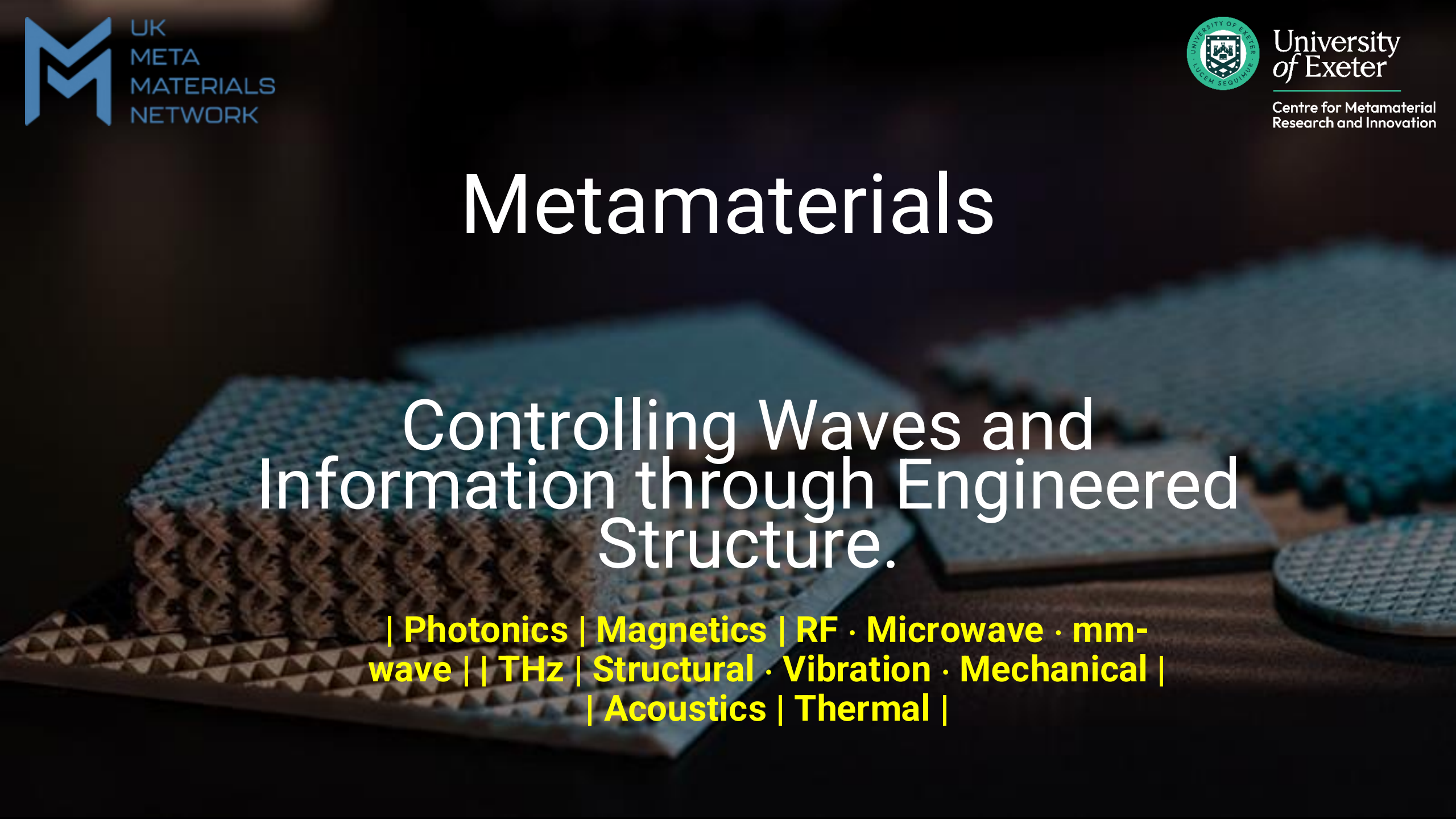


Cloak + Object:



Object Cloaked!

D. Schurig, et al. Metamaterial Electromagnetic Cloak at Microwave Frequencies. *Science* **314** (2006)


UK
META
MATERIALS
NETWORK
University of Exeter
Centre for Metamaterial Research and Innovation
Metamaterials
Controlling Waves and Information through Engineered Structure.
| Photonics | Magnetics | RF · Microwave · mm-wave | | THz | Structural · Vibration · Mechanical | | Acoustics | Thermal |

University of Exeter

Centre for Metamaterial Research and Innovation

Metamaterials at Exeter

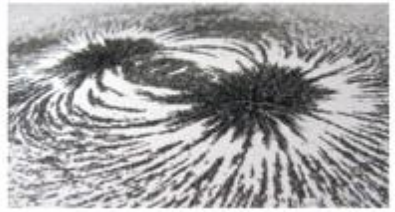
Novel solutions for today's technological problems; new science for tomorrow's challenges.

www.metamaterials.center

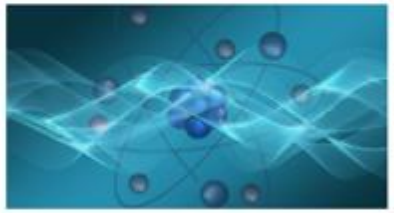
Acoustic, Fluidic and Elastic Metamaterials

Electromagnetic Metamaterials

Magnetic Materials



Quantum and 2D Materials



Theory, Modelling and Design

CMRI includes

- PhD Programme
- MetaHUB (lead)
- Meta4D (partner)
- UK Metamaterials Network (joint lead)

ICT

Management of signals and digital data: From processing, modulation, and transmission to absorption and storage.

Energy

Engineering and characterisation of improved materials to harvest, store, transmit, and save energy.

Health

From antibiotic therapy and targeted drug delivery to cancer detection and novel microscopy techniques.

Security & Defence

Materials for acoustic, biological, chemical, and electromagnetic applications to protect goods and people.

UK Metamaterials Network

Driving leadership in metamaterials for prosperity, national security and resilience

Prof Alastair Hibbins | Dr Claire Dancer | Dr Helen Rance

University of Exeter
Joint-lead UKMMN

University of Birmingham
Joint-lead UKMMN

University of Exeter
Science and Strategy Manager UKMMN

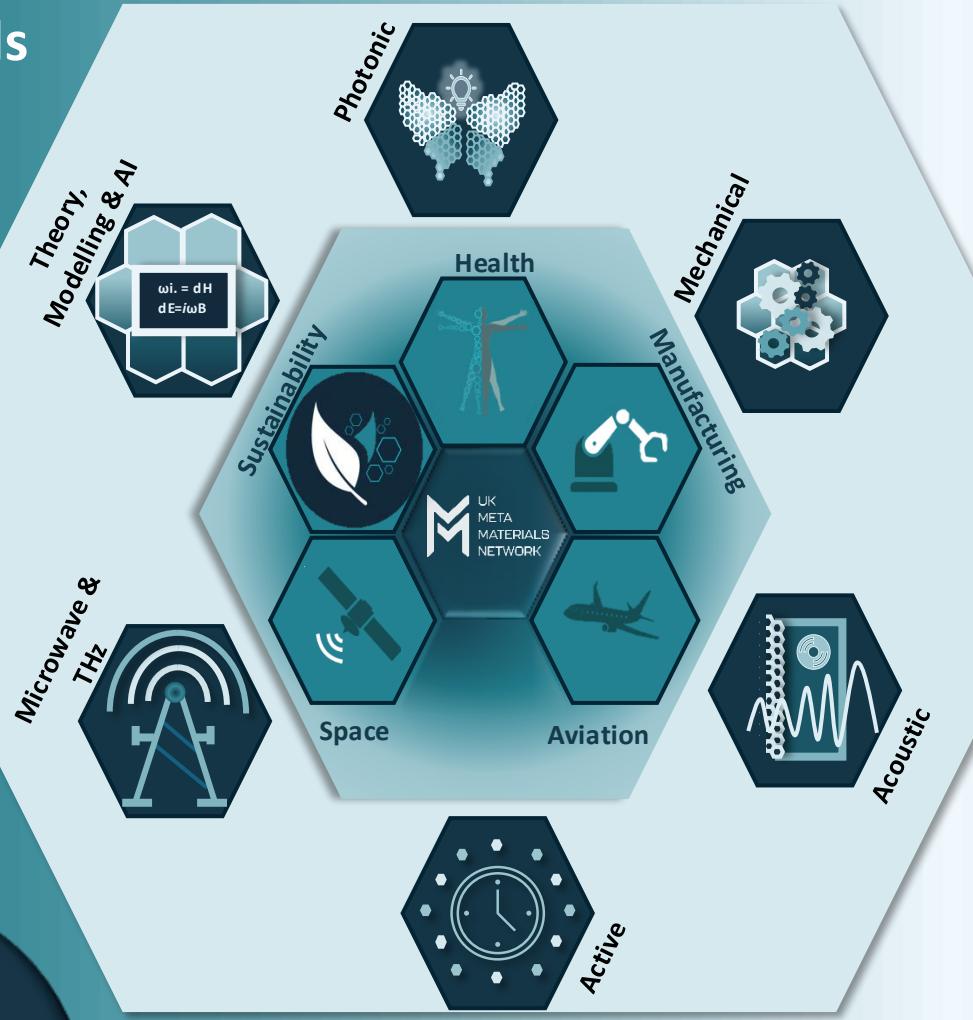
Engineering and Physical Sciences Research Council

Contact Us:

e Info@metamaterials.network | ***W*** www.metamaterials.network | **LinkedIn:** Metamaterials Network

Making the UK a Science and Innovation Leader in Metamaterials

- To provide leadership to drive the national metamaterials agenda
- To bring together metamaterials stakeholders from all domains and sectors
- To enable the full utilisation of the UK's metamaterials research and exploitation capabilities



Working with ...

dstl Delivering Mission Success

CATAPULT High Value Manufacturing

HENRY ROYCE

NPL

UKRI Innovate UK | Business Connect

875+ Academic Members |
160+ Industry Members | **145+** Other Members

Lead Institutions

University of Exeter

University of Birmingham

Manchester Metropolitan University

University of Sheffield

University of Cambridge

University of St Andrews

£1 million Flexible Fund

UKRI Engineering and Physical Sciences Research Council

UK META MATERIALS NETWORK

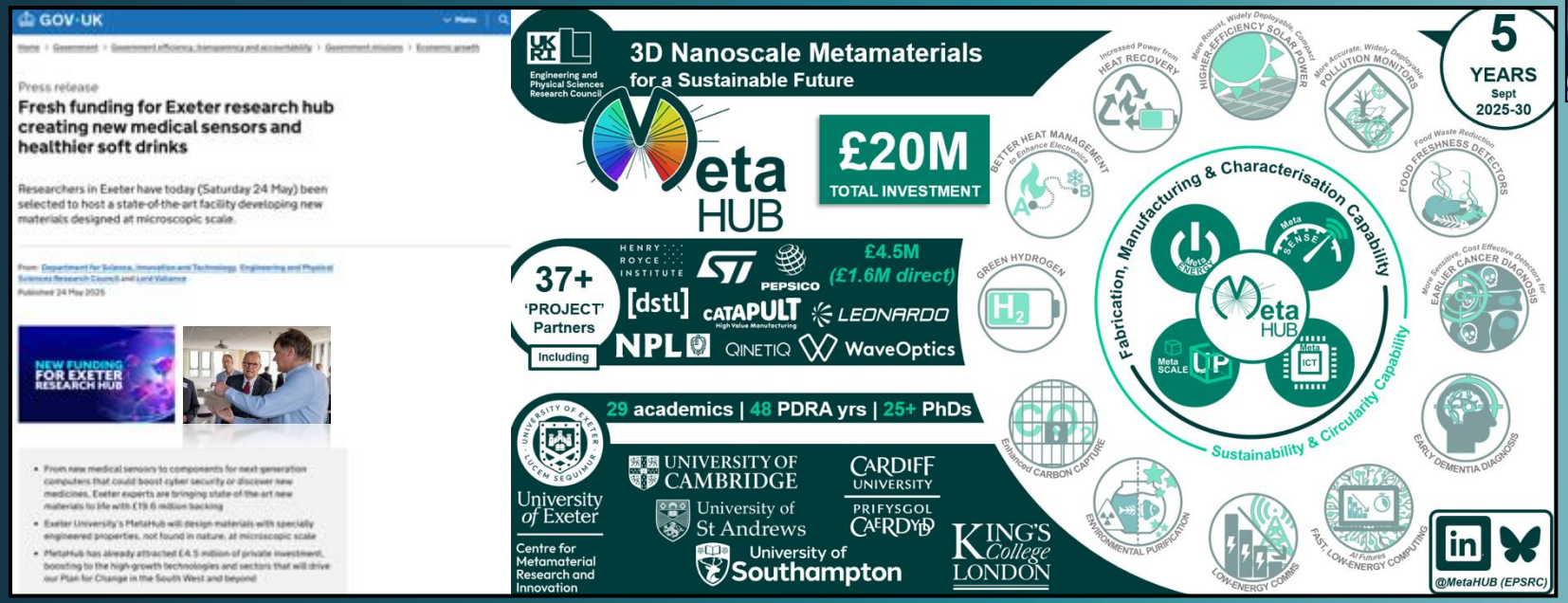
UK META MATERIALS NETWORK

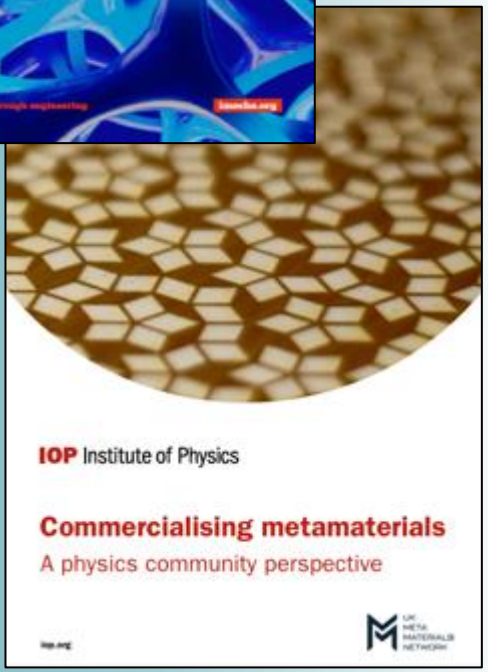
$10.7 BILLION
global market value by 2030 for metamaterials.

Reference: iuk-business-connect

1ST & 4TH
1st globally for research impact and quality by FCR 2018 - 2021.
4th globally for overall research output in 2018-2022.

Source: Dimensions FCR: Field Citation Rati



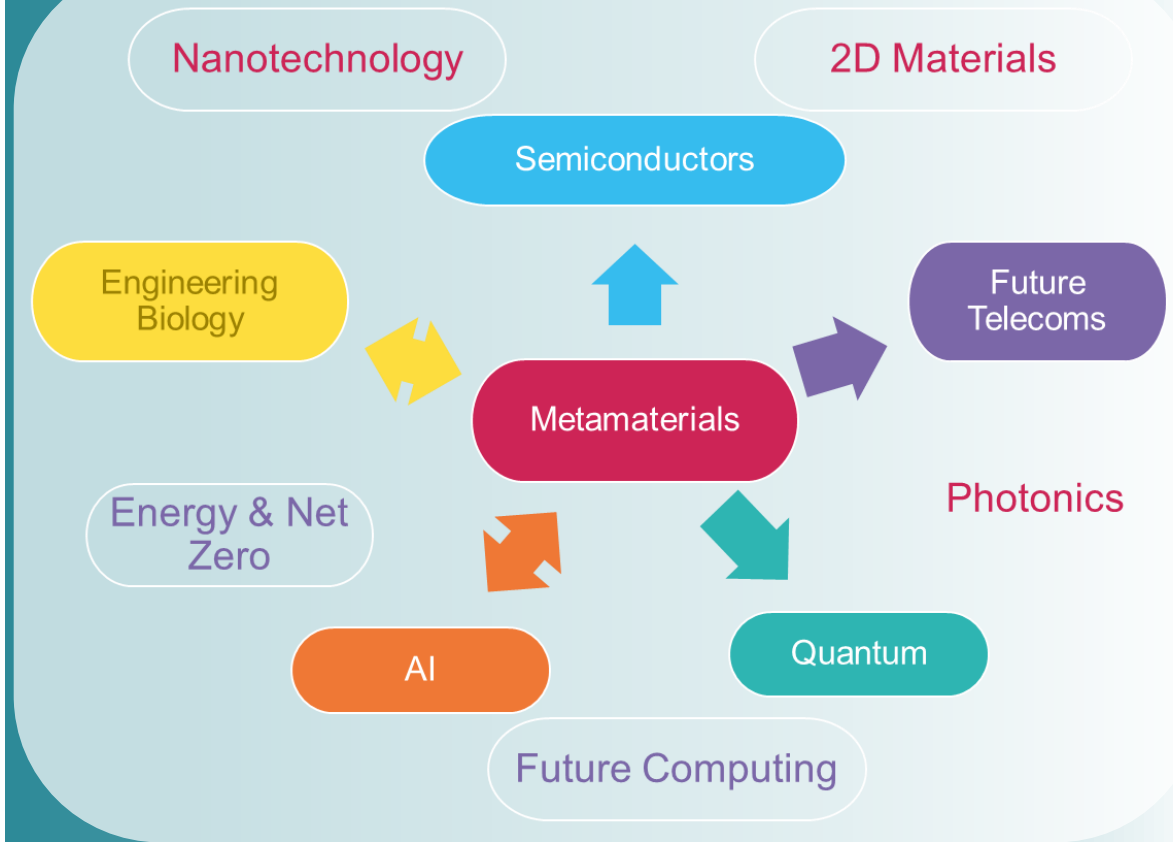


News and reports available at www.metamaterials.network and the LinkedIn pages of the Network, MetaHUB and CMRI

Opportunity Sectors & Convergence with Frontier Technologies

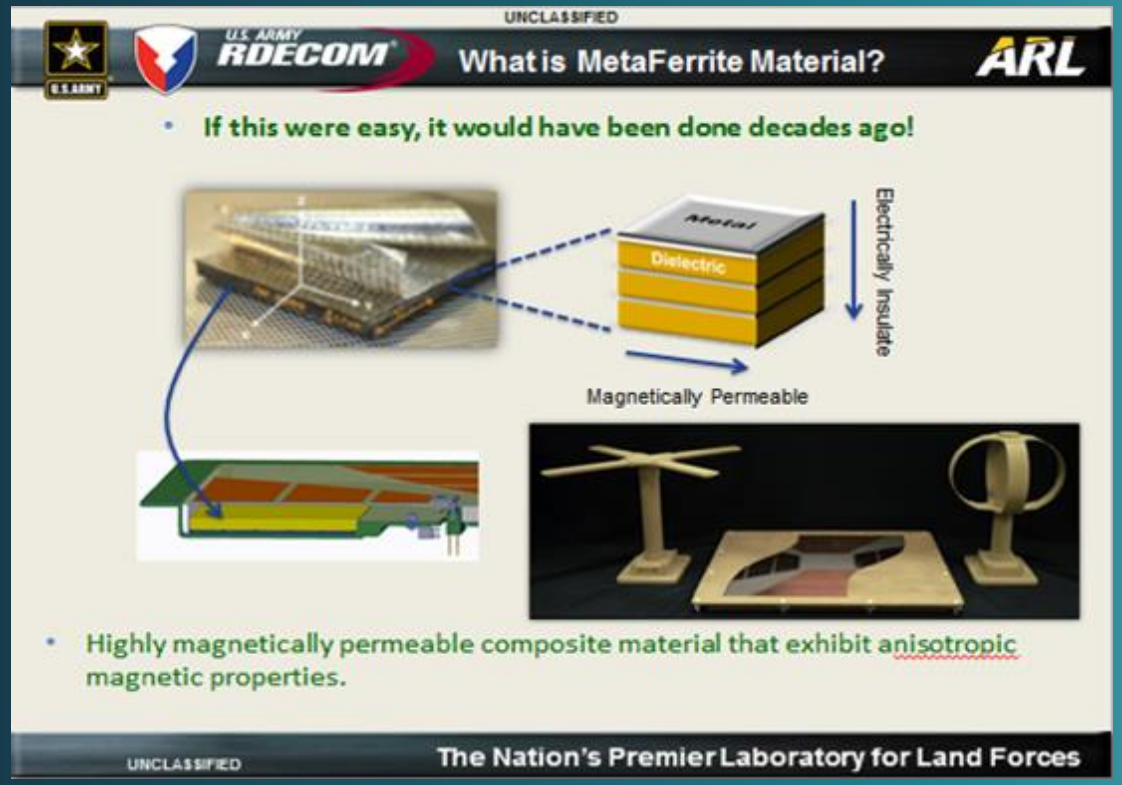
UK META MATERIALS NETWORK

	Transport	Energy & Net-zero	Aerospace & Defence	Future Telecoms	Healthcare	Photonics & Sensing
Deployment	Vibration & Noise Management	Radar-stealthy Wind Turbines	Enhanced Antennas	Wireless Power Transfer Electro-magnetic Shielding	Noise Reduction Performance/ Protective Wearables & Equipment	Filters
Development	Optical Processing - Edge Detection Compact Inconspicuous Antenna LIDAR	Solar Panel Design Passive Thermal & Noise Management	Sensing/ Targeting Space-based Solar Power Terahertz Sources	Reconfigurable intelligent surfaces High Power Efficient Radio-frequency 5G/6G Extreme Bandwidth Antenna	Point of Care Diagnostics Smart Implants, Prosthetics, and Tissue Engineering Health-sensing Wearables	Ultra-thin Lenses Anti-counterfeiting Augmented Reality
Research	Autonomous & Connected Vehicles Wide Field of View Sensing Wireless Charging	Critical Mineral Replacement Cryogenics Efficient Displays/ Signs	Signature Reduction & Management Space Nuclear Reactors & Propulsion Systems Lightweight, Ultra-stiff components	Quantum Communications	Construction Materials Antimicrobial Surfaces Drug Delivery	Single Molecule Chemical Sensing Miniaturised Cameras Quantum Computing Optical Computing

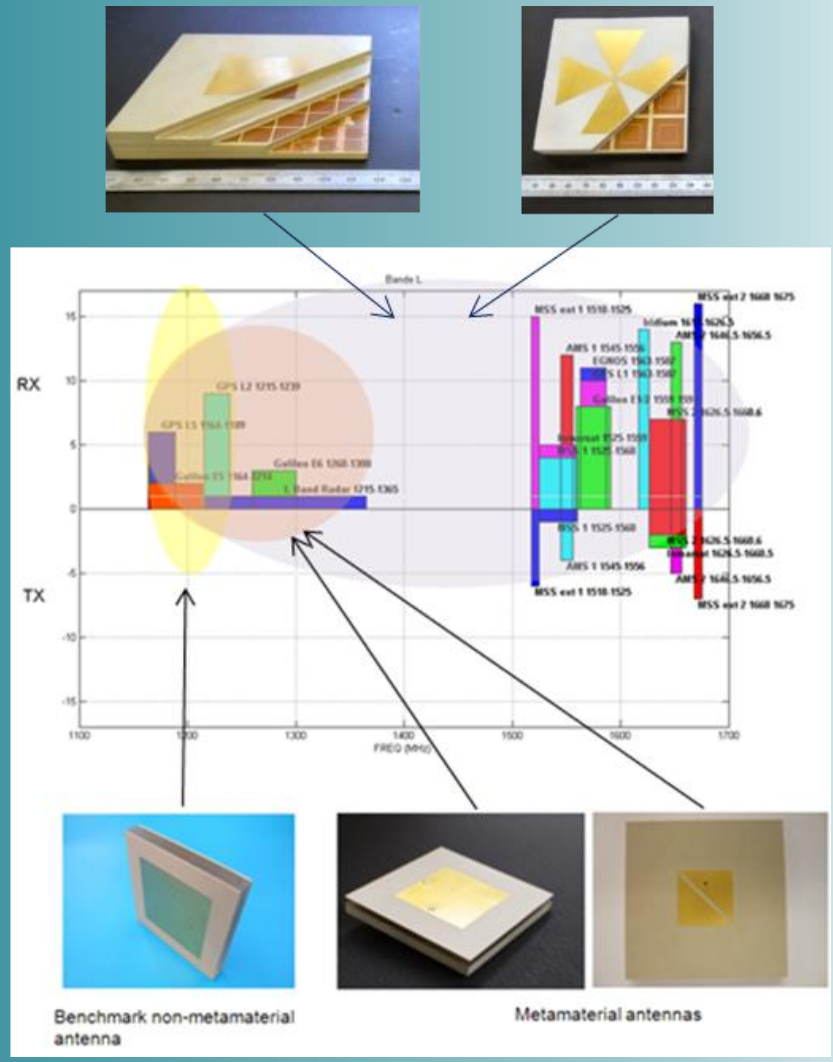


Electromagnetic Metasurfaces: Achieve better (antennas for defence)

UK META MATERIALS NETWORK



Same performance but conformal



More bandwidth & thinner

What next with Dual-Use Electromagnetic Metasurfaces?

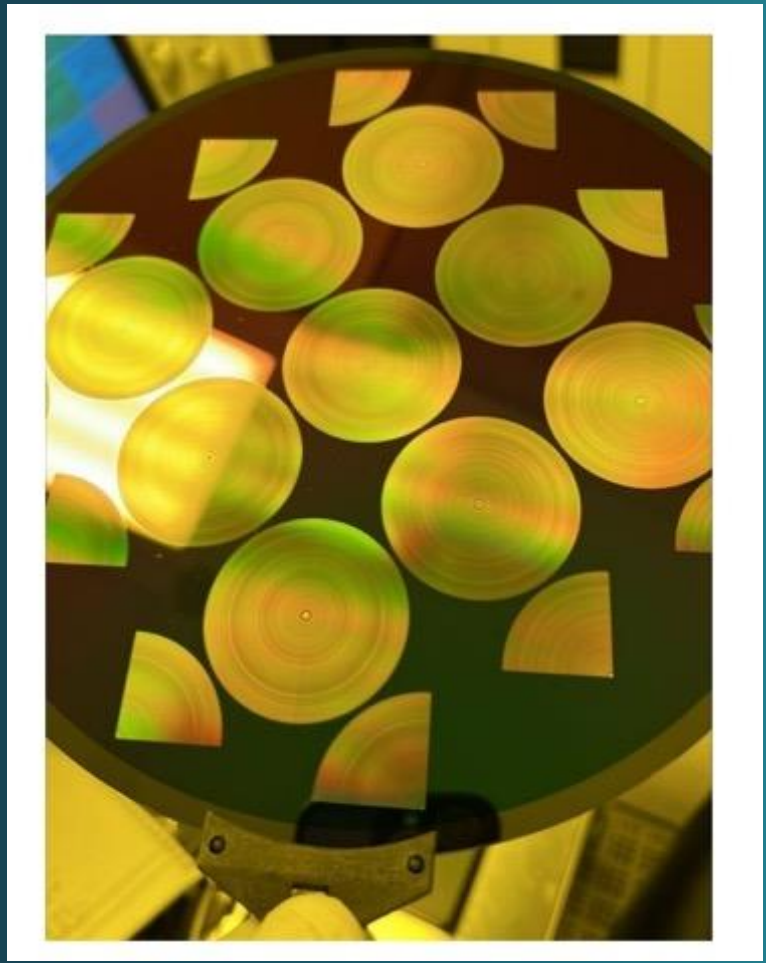
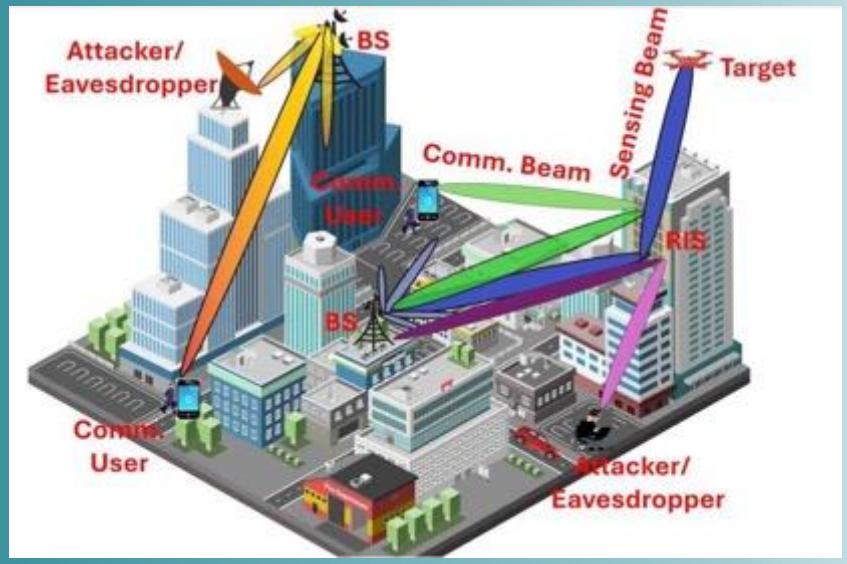
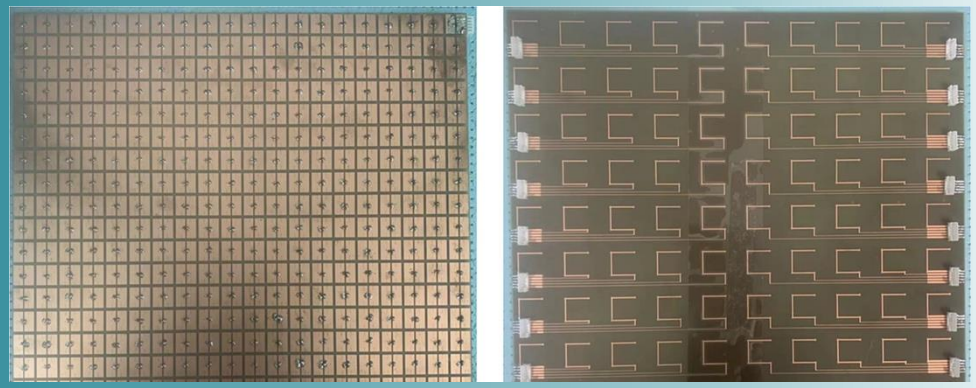


Image courtesy and copyright of Southampton University
Production-Ready Double-Sided Fabrication of Dual-Band Infrared Metaoptics
(For further information: https://pubs.acs.org/doi/10.1021/acsnano.5c11908)



https://www.electronicsforu.com/news/smart-surface-boosts-6g-reliability



Zhou Y, *International Journal of Microwave and Wireless Technologies*. 2023;15(10):1758-1767. doi:10.1017/S1759078723000466

Metamaterials for food applications

John Bows (PepsiCo R&D) and Cameron Gallagher (University of Exeter)

University of Exeter
Centre for Metamaterial Research and Innovation

pepsico
Food. Drinks. Smiles.

QINETIQ

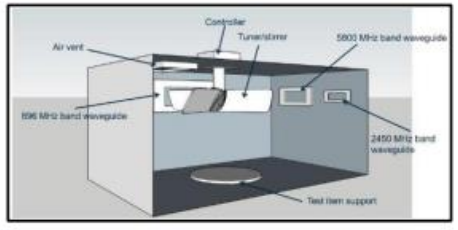
Objective. Design and validate frequency-selective metasurface for microwave heating of food

Rationale. Solid state **fixed-frequency** microwave ovens launched 2019, unlocking potential for **multi-frequency** microwave ovens and innovative food microwave active packaging opportunities

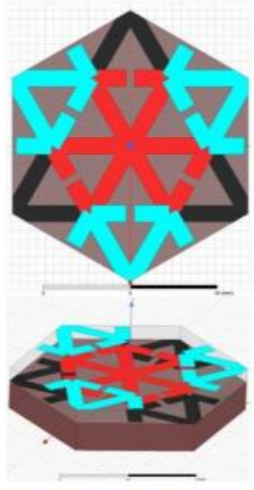
First microwave ovens to use solid state microwave energy generation instead of magnetrons

Miele Dialog 0.9 GHz

IBEX 2.45 GHz

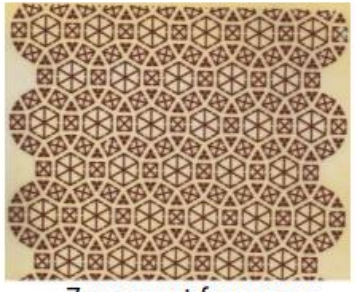


QinetiQ designed and built a 0.9 – 6.0 GHz solid state test microwave oven

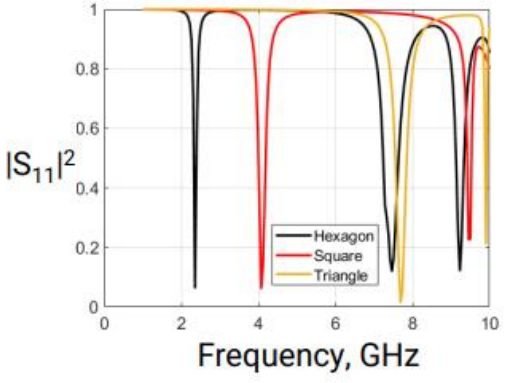


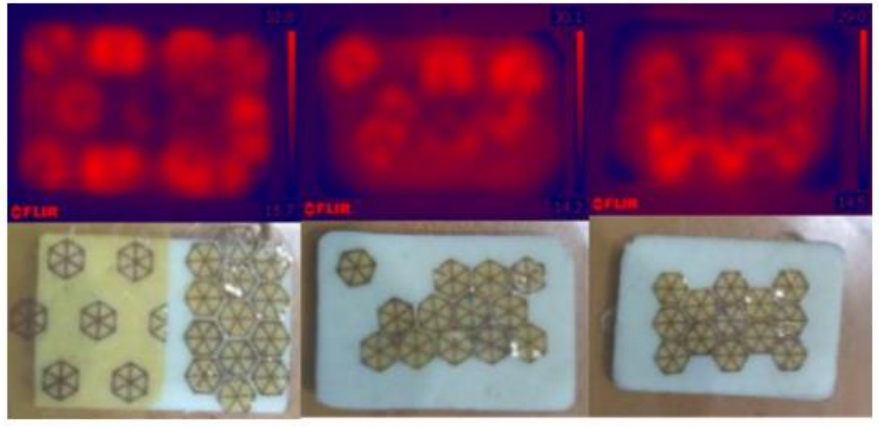
Computer-led design of metasurface

Exeter designed and prototyped frequency-selective metasurfaces



7 resonant frequency metasurface



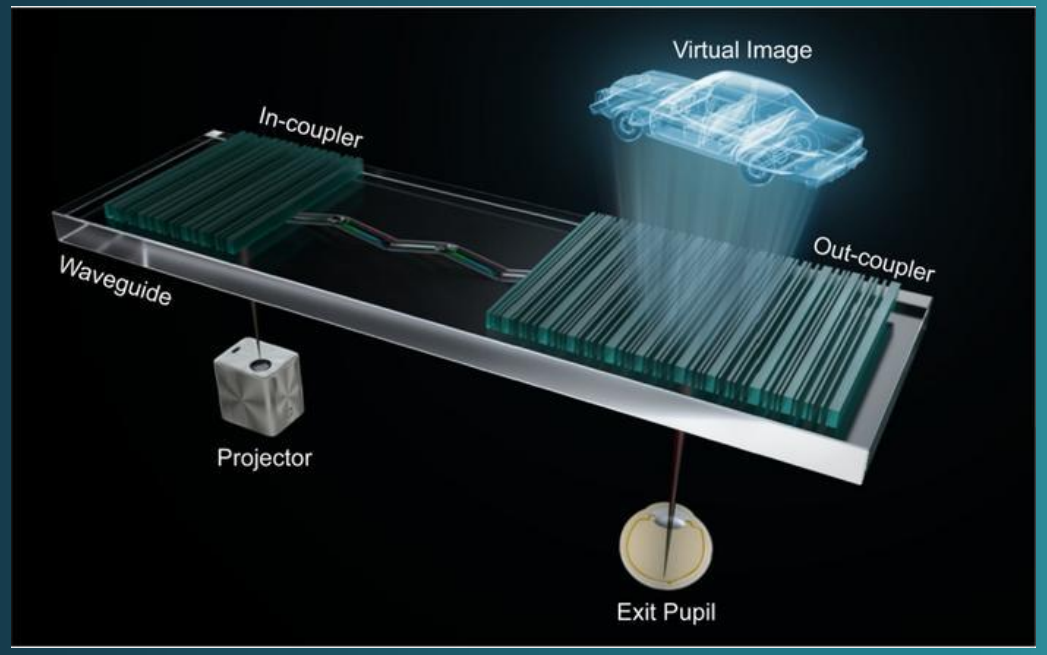


Upper. Thermal images of model food after microwave heating at 2.45 GHz in QinetiQ test oven
Lower. Metasurface cells placed on top of model food increased the heating rate of the model food underneath.

https://www.exeter.ac.uk/research/metamaterials/expertise/casestudies/cs-microwave-food/

METASURFACE WAVEGUIDE AR DISPLAY SYSTEM

UK META MATERIALS NETWORK



https://www.eurekalert.org/multimedia/1073050 by Zhongtao Tian et al.

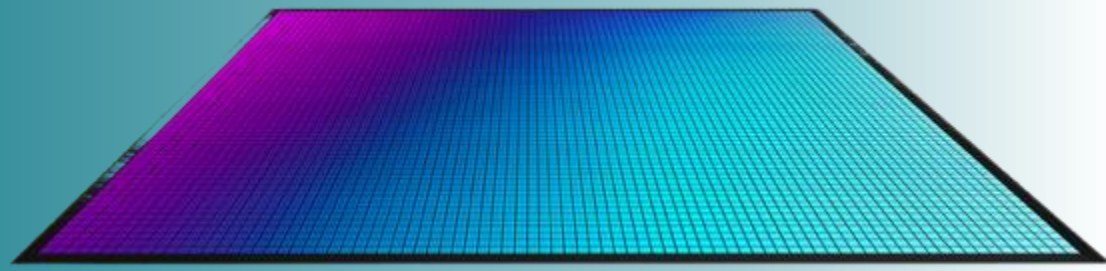
Optical functionality that would traditionally require bulky lenses and prisms is instead performed by precisely engineered metasurfaces

ADVANCED CAMERA SENSOR TECHNOLOGIES USING METASURFACES

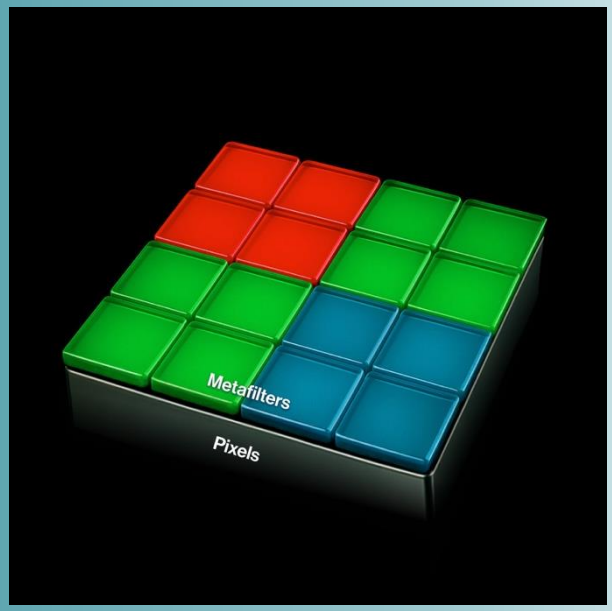
UK META MATERIALS NETWORK

metahelios

Smartphone image sensor technology



Metasurface based camera chip colour filters are set to revolutionise the industry by enhancing visual clarity and by significantly simplifying manufacturing supply chains.

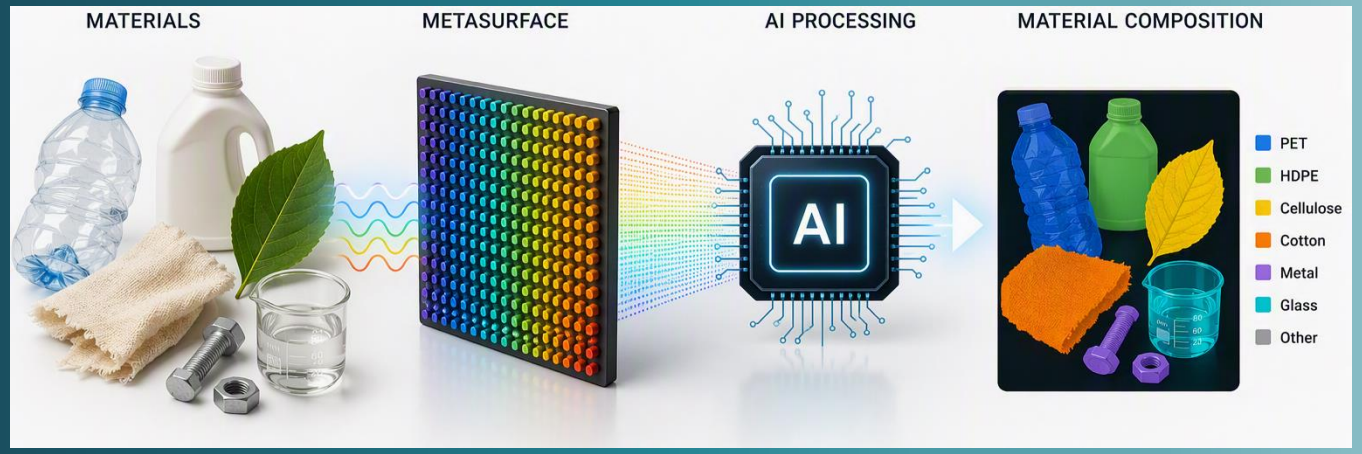


Metahelios' technology captures colours in photos with far superior colour definition

Superior sensitivity | Superior colour sharpness | Bayer filtering pixel technology

TRANSFORMING HOW MACHINES SEE

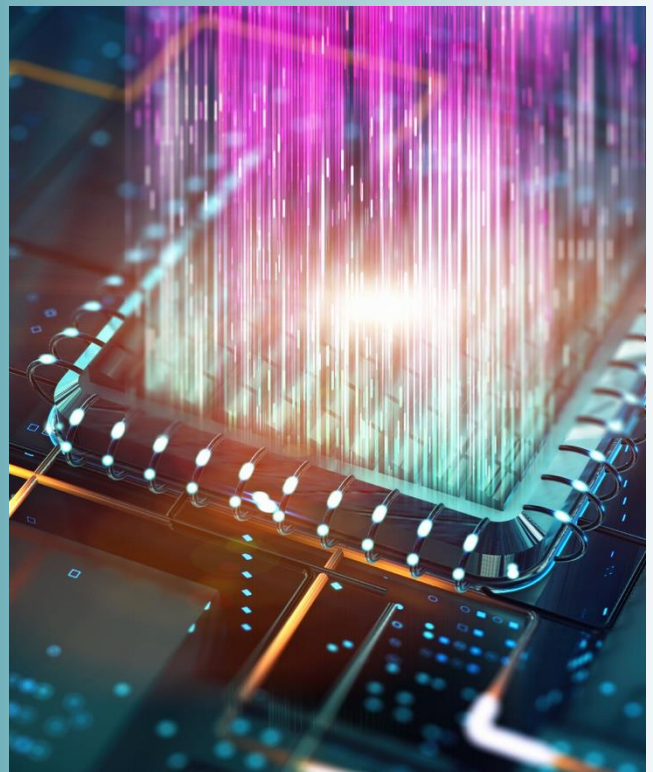
UK META MATERIALS NETWORK



Prospectral

UNIVERSITY OF CAMBRIDGE enterprise

Multimodal imaging for the next generation of computer vision



METAMATERIALS FOR HEALTH, WELLBEING & INCLUSION

UK META MATERIALS NETWORK

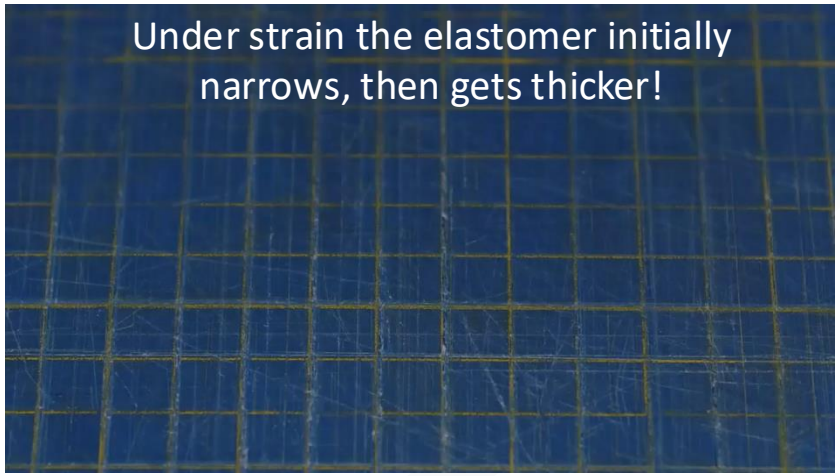
"Metamaterials have vast potential to revolutionise sports and active lifestyle products, unlocking new performance and making them more inclusive to suit a diverse range of users."

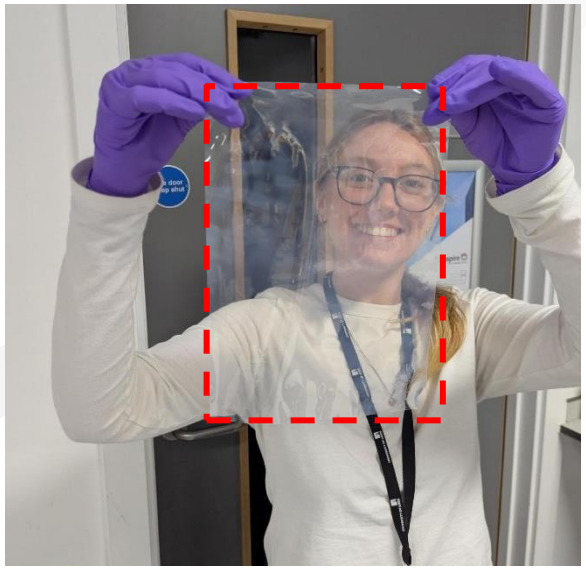
Laura O'Shea, Senior Researcher, Pentland Brands Ltd

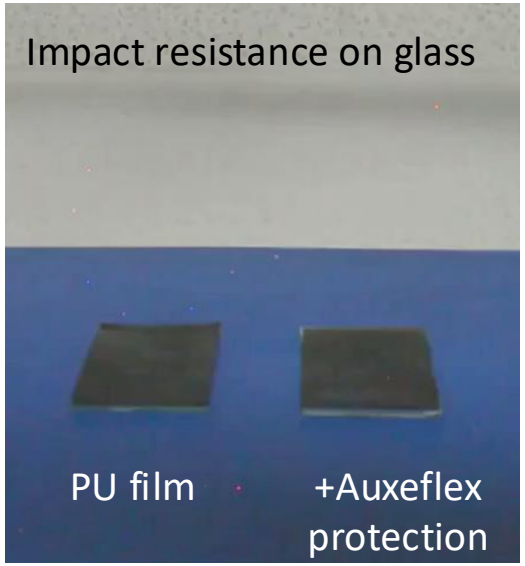
berghaus canterbury speedo Mitre ENDURA ellesse KicKers Red or Dead KangaROOS *UK licensee

RHEON

- The first synthetic molecular auxetic:
  - Impact resistance
  - Delamination resistance
- The materials are patented liquid crystal elastomers
- High optically clarity – suitable for glass
- Scalable and easily manufactured.



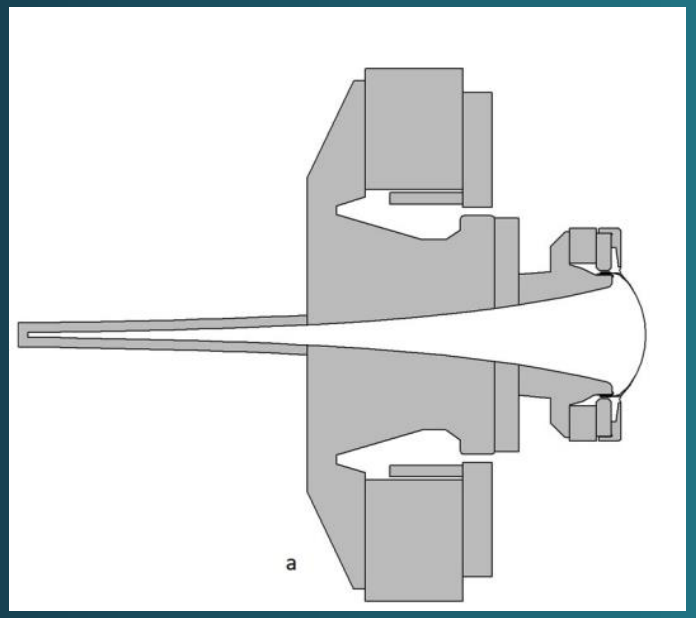


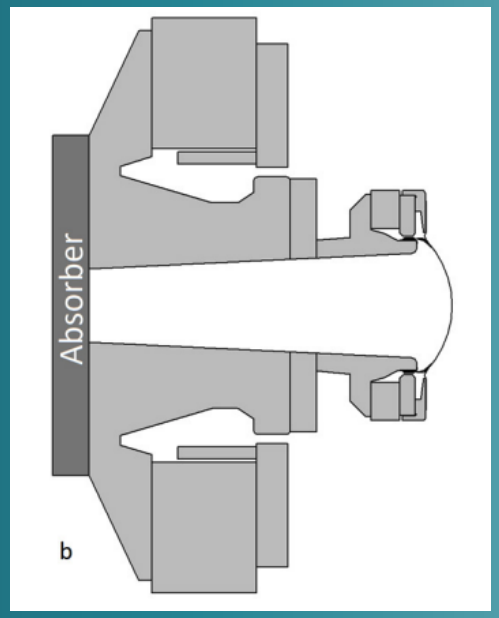


Acoustic Metamaterials

KEF
INNOVATORS IN SOUND

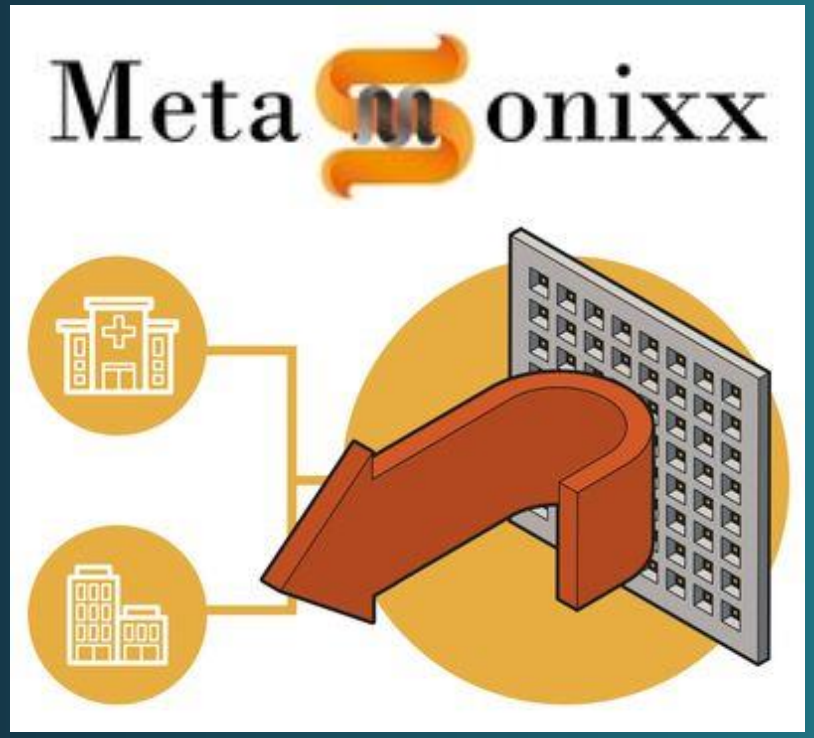
UK META MATERIALS NETWORK





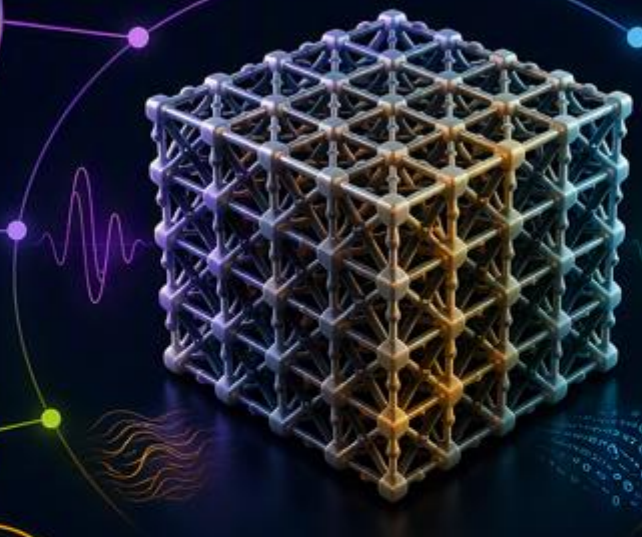
UK META MATERIALS NETWORK

ACOUSTIC METAMATERIALS FOR NOISE REDUCTION



Commercialising Metamaterials

Translating UK academic research excellence into products, companies and industrial capability



DEFENCE & SECURITY
- Conformal antennas
- Stealth & sensing
- Resilient communications

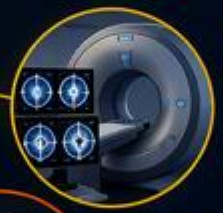
AEROSPACE & SPACE
- Embedded antennas
- Lightweight structures
- Satellite systems

ENERGY & SUSTAINABILITY
- Thermal management
- Energy harvesting
- Net zero solutions

ADVANCED MANUFACTURING
- Additive manufacturing
- Multifunctional materials
- Metamaterial composites

COMMUNICATIONS
- 5G/6G networks
- Intelligent surfaces (RIS)
- Connectivity everywhere

IMAGING & SENSING
- Compact cameras
- Spectral imaging
- Machine vision



HEALTHCARE
- Diagnostics
- Biosensing & wearables
- Medical devices

ACOUSTICS
- Noise & vibration control
- Acoustic cloaking
- High-performance sound

CONTROLLING WAVES AND INFORMATION THROUGH ENGINEERED STRUCTURE

DESIGN — Materials by design & simulation

PROTOTYPE — Demonstrate & de-risk

SCALE-UP — Validate & attract investment

MANUFACTURE — Scale, quality & supply chains

DEPLOY — Products, systems & real-world impact

UK RESEARCH EXCELLENCE | INNOVATION LEADERSHIP | PRIVATE INVESTMENT | NEW PRODUCTS & COMPANIES | HIGH VALUE JOBS & GROWTH | GLOBAL IMPACT & LEADERSHIP

UK META MATERIALS NETWORK

Join the UK **Metamaterials Network**

metamaterials.network

Work with the **Centre of Metamaterials Research & Innovation**

metamaterials.center

University of Exeter

Centre for Metamaterial Research and Innovation