Commercialising Metamaterials:

The benefits to your business

KTN-UK.org

Introduction

This informative document is aimed at businesses developing devices and products for the following sectors:

5G & Communications

Antenna, Electromagnetic, Metasurfaces

Aerospace

Antenna, Electromagnetic, Metasurfaces, Radar

Automotive / Autonomous Vehicles

Acoustic, Antenna, Electromagnetic, Lidar, Radar, Thermal

Construction / Built Environment

Acoustic, Mechanical, Metasurfaces, Thermal

Consumer Electronics

Electromagnetic, Metasurfaces

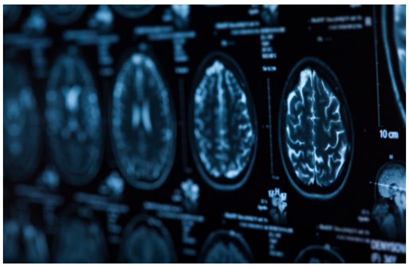
Defence & Security

Acoustic, Antenna, Electromagnetic, Lidar, Mechanical, Metasurfaces, Photonic, Radar, Tuneable

Energy & Power

Photonics, Metasurfaces, Electromagnetic

Medical



Acoustic, Electromagnetic, Photonic, Tuneable

Rail

Acoustic, Electromagnetic, Thermal

It is also aimed at engineering companies developing new manufacturing processes to help with the challenges and potential solutions that would enable metamaterials to be used on a large scale.

1. What are metamaterials?

We are aware of the accepted definitions of metamaterials and the various types that include mechanical, photonic, electromagnetic, plasmonic, thermal and acoustic metamaterials and metasurfaces.

We would like to exemplify them, because of their diversity of form and application, through a series of real examples as follows:

- Acoustic metamaterials are the result of a patterned surface on the side of a surface, and they can reduce noise associated with air (or fluid) flow across them. It is like completely redesigning a surface because it can also be applied retrospectively.
- An acoustic metamaterial is a metamaterial that can cancel noise selectively but let air and light through if needed. It is like traditional solutions for noise management but much better, because it weighs less and lets air through.

Figure 1: A metamaterial-based panel for controlling acoustics courtesy of Sonobex

- Thermal metamaterials can provide cooling of buildings much as air conditioning does, however they are much better because it is a passive system and requires no energy.
- Auxetic metamaterials expand in the vertical direction when you pull the structure horizontally. It is like an anti-plasticine and can be used for many applications including body armour and other protective devices, the impact of the projectile resisting through expansion against the impact.
- Auxetic foam is a metamaterial that can expand in all directions when pulled along one. It is like a polymeric foam but much better, because it absorbs more energy and provides more comfort for cushions.

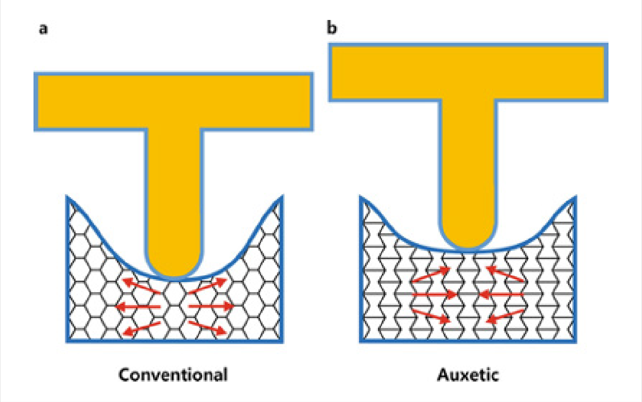


Figure 2: Mechanical metamaterials as auxetics

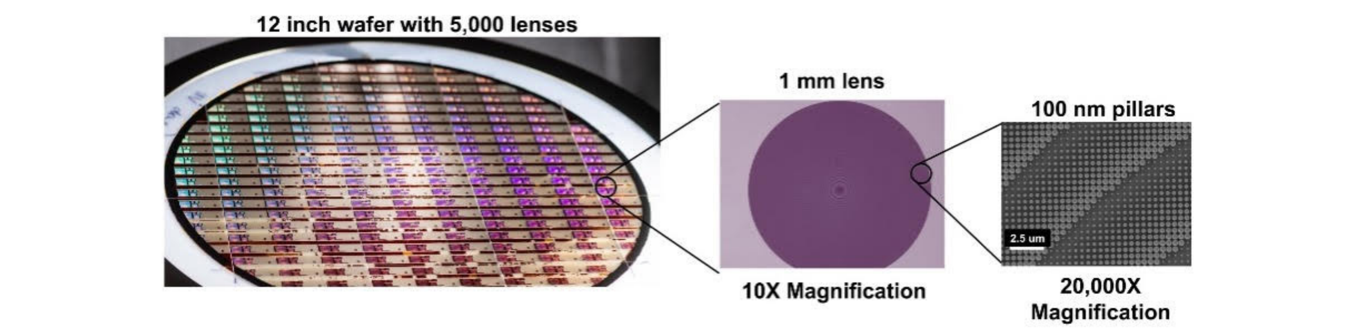


Figure 3: Metalenz' flat lens construction

- A patterned metamaterials surface can modify the reflection or transmission of microwave radiation so it is like a regular antenna but much better, because we can introduce an active element to the design permitting beam steering or stealth/camouflage.
- A metamaterial-based antenna printed onto a window can redirect 5G and mm waves like beam redirectors but much better, because it can improve 5G reception while being transparent for integration onto windows and buildings.
- Metalenses are metasurfaces that can bend light like conventional lenses and prisms, but they are much better because they are flat, light and can provide a greater level of control over the bending of the light, as well as offer a combination of multiple features such as polarisation, focusing and holographic imaging in the same lens.

- Metamaterial-based non-invasive glucose testing can make skin "transparent" to 40GHz radio waves in order to measure capillary blood glucose for people with diabetes. It is like other non-invasive blood glucose sensor approaches but much better, because of increased tissue penetration and therefore improved measurement.

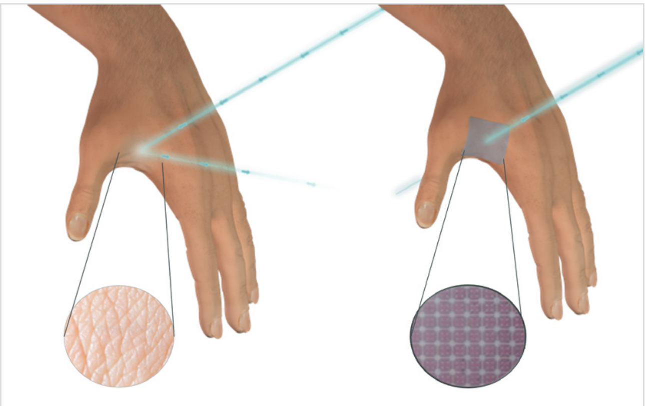


Figure 4: The principle of META's non-invasive glucose testing

The Commercialising Metamaterials Innovation Network and the role of Innovate UK KTN

The strategic objective of the Commercialising Metamaterial Innovation Network is to catalyse pockets of cross sector activity and establish a single metamaterials community with a common goal to enable the coordination of effort in addressing the challenge of commercially exploiting metamaterials.

The overall aim is to facilitate successful commercial exploitation and technology transfer of metamaterials through brokered or encouraged collaboration. This is being achieved by assembling a community of stakeholders from industry, academia and government, undertaking a series of activities to connect experts and potential users to share knowledge, deploy KTN tools to prepare metamaterial researchers to present their developments to investors and to generate wealth via commercial exploitation.

Significant investment (both public and some private) since the year 2000 has unlocked a series of basic science innovations and provided key understanding of the potential offered by metamaterial research – and novel supply chains are required to deliver the breakthroughs.

For example, BAe Systems are currently investing tens of millions of pounds sterling per annum into novel metamaterial developments but struggle to secure and recruit/retain trained and skilled suppliers into their own supply chains. KTN, with a clear understanding of the key strengths of the UK academic community and potential access to known and identified (but not active) industrial participants, is well placed to help address this dilemma.

Metamaterials have a phenomenal range of potential applications with the potential to transform the way we do things in important areas, from energy to ICT, defence, security, aerospace, and healthcare.

Numerous market research studies predict very significant growth over the next decade, for example, the metamaterial device market is expected to reach a value of over $10bn. The University of Exeter Centre for Doctoral Training in metamaterials is now releasing new high-skilled PhD researchers with freshly minted knowledge into the UK sector. A dedicated support-mechanism is needed to ensure this work is successfully exploited and commercialised.

The intervention that this network is providing is ensuring that the UK is part of this growth, providing the stimulation of a virtuous enterprise cycle to meet desired outcomes for prosperity and consequentially, society, defence and security in the UK.

KTN is seeking to join the dots within the potential value chain by identifying the technology ideas and their likely opportunity in terms of adding value to a sector/applications. KTN is helping researchers to understand that potential value through understanding the features and benefits of their technology aligned to the needs and challenges of the market, pitching to investors and collaborators as they seek to upscale and develop prototypes and demonstrators and ultimately find that commercial space and promote and develop that product.

2. The science behind metamaterials

The strength of the UK in the research of metamaterials is well known with them holding the position of third in the global activity:

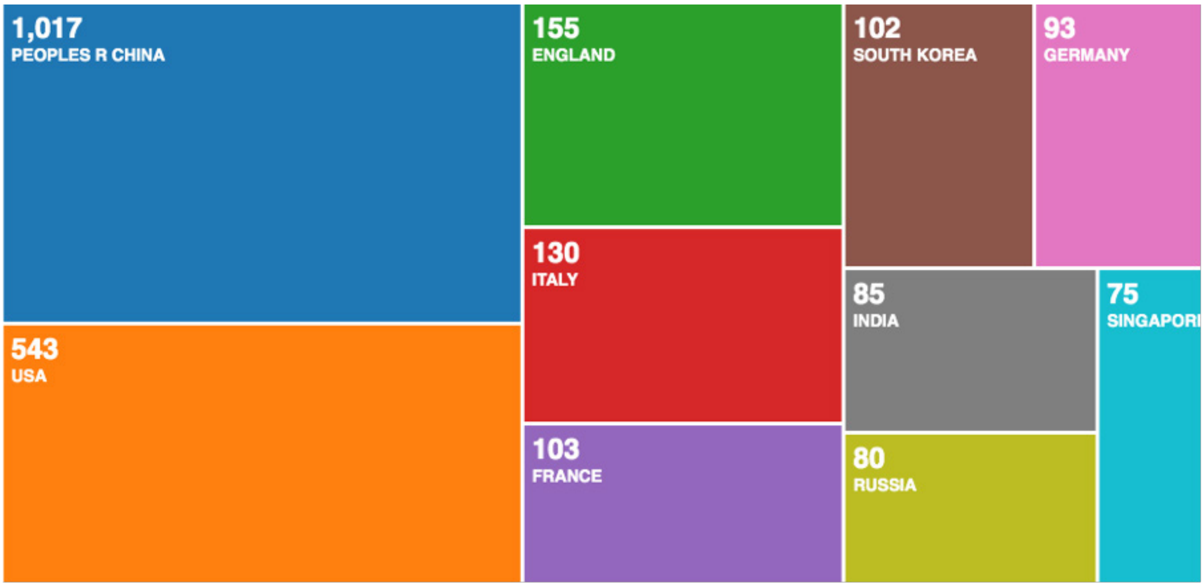


Figure 5: The number of metamaterials papers by country in 2020 courtesy of QinetiQ

Similarly the activity related to patents:

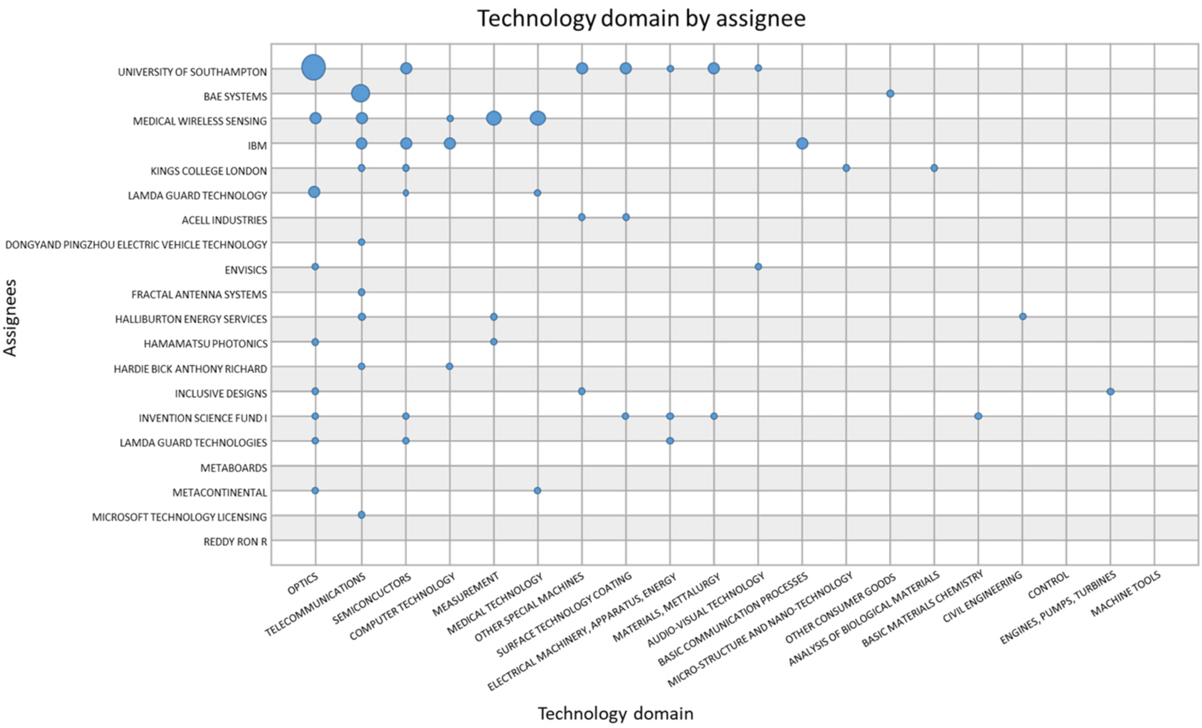


Figure 6: Metamaterials patents by organisation and technology courtesy of QinetiQ

The UK Government funding in research has recently seen the launch of a UK Metamaterials Network. Within this network, there are a series of Special Interest Groups focused on the UK strengths in acoustic metamaterials, active metamaterials, flexible and conformable metasurfaces, mechanical metamaterials, nanophotonic and plasmonic metamaterials and wireless and microwave metamaterials, as well as supporting groups of manufacturing and scale up and modelling and AI-Design.

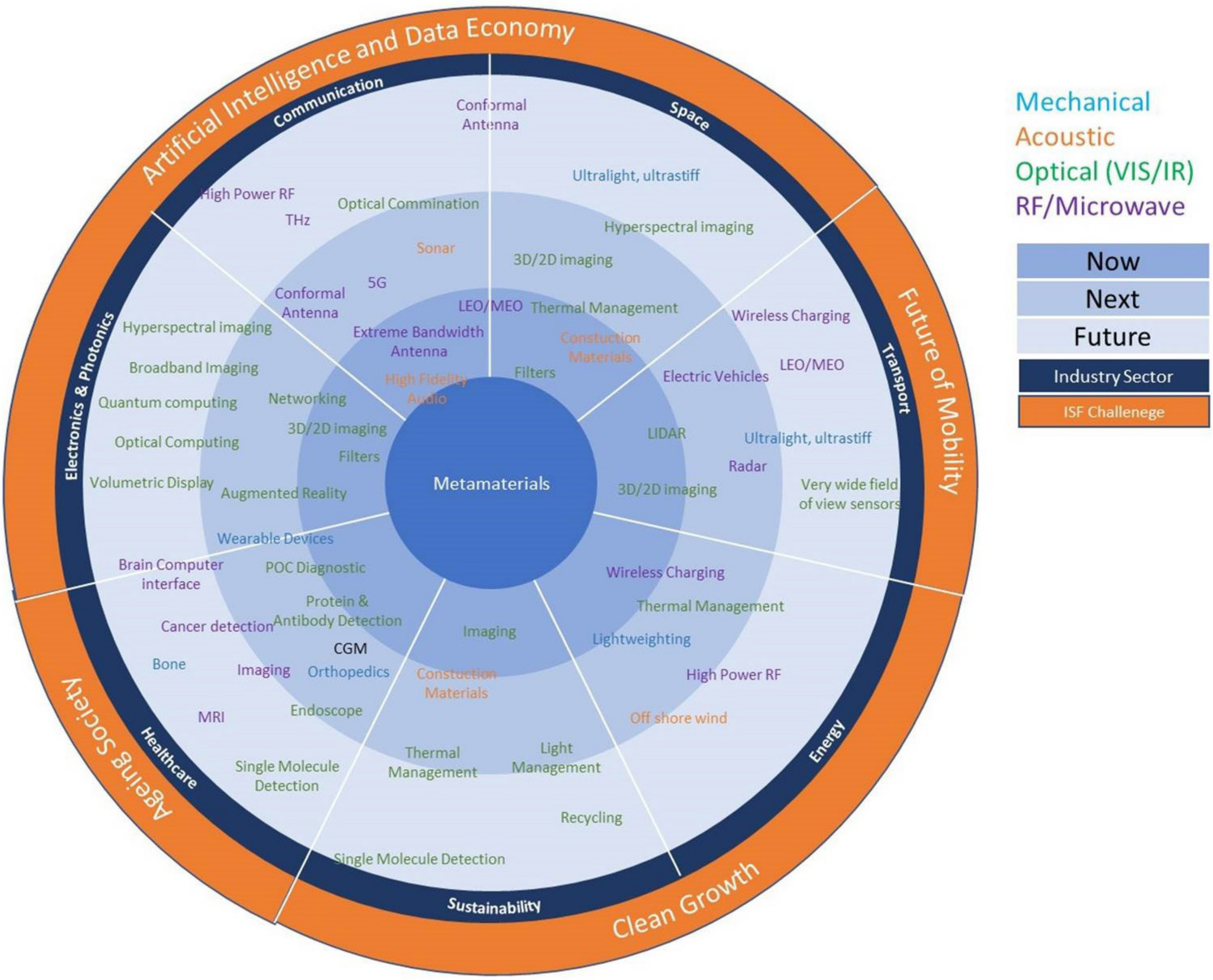


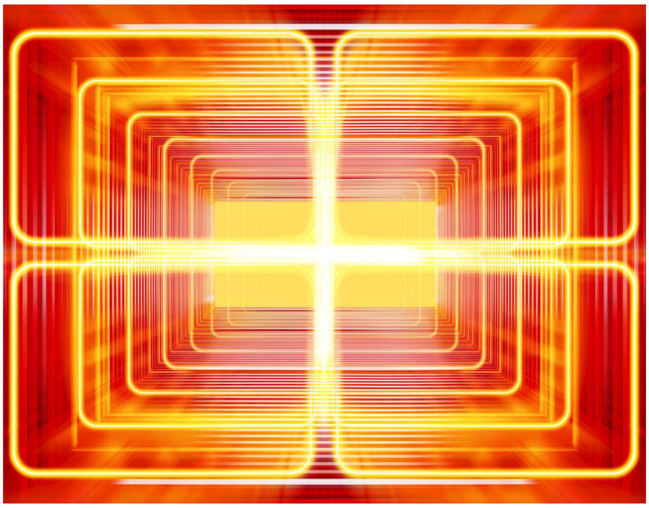
Figure 7: Metamaterials technologies and applications courtesy of UK Metamaterials Network

3. Metamaterials: Present and future

So, what do metamaterials bring to the device or systems? That depends very much on the device or system that we are considering, however in the main they can direct radiation in a particular direction.

If we are considering electromagnetic radiation, then radiation falling on an object can be redirected to pass around an object and effectively make it invisible to the detector. This is the classic "Harry Potter invisibility cloak", although the use of metamaterials to make objects disappear to the naked eye are still a thing of science fiction. There are examples of manipulating radiation in the microwave region and work is being done in the infra-red region to disguise heat signatures.

In terms of examples of the use of metamaterials and why they are used, here are some current commercial uses:



3.1 Metasurface technologies and applications

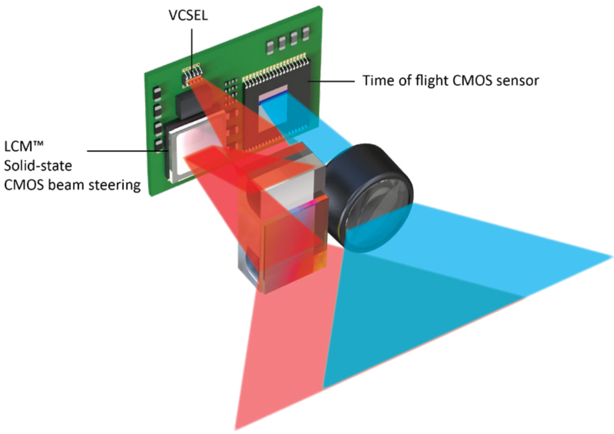


Figure 8: Beam steering principle using metamaterials courtesy of Lumotive

3.1.1 Lumotive and Lidar

Lumotive is developing lidar systems based a metamaterial solid-state beam steering technology. Their chips are tunable optical metasurfaces that allow them to dynamically steer the direction of laser beams without any moving parts.

This revolutionary technology was enabled by metamaterial design principles being applied to conventional semiconductor manufacturing.

3.1.2 Metaboards and wireless charging of multiple items

Metaboards' Evenlode surface is roughly the size of a tablet. At the heart of its magic is a dynamically-controlled metasurface – a careful arrangement of mutually-coupled inductive elements that propagate waves carrying both power and communication signals from the single power input point to the areas where the receiving devices are placed. Evenlode continuously probe the state of the metasurface from the same power input point to detect and localise the receiving devices wherever they are placed on its surface. It then proceeds to selecting the most efficient power routes that propagate energy across the surface towards the receiving device.

Figure 9: Metaboards' Evenlode charging surface

3.1.3 Metalenz and 3D Environmental Imaging

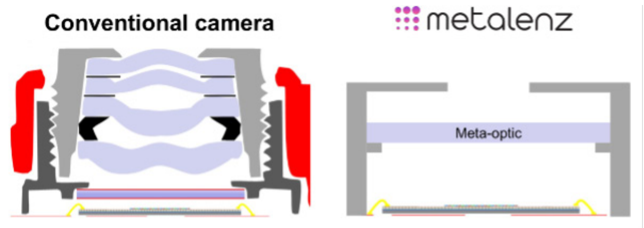


Figure 10: Graphic of Metalenz' flat lens in comparison to a conventional one

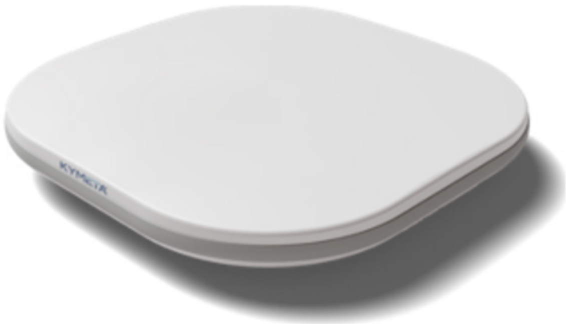
Metalenz are using metamaterials as a metasurface in existing compound semiconductor technology allowing the focusing of laser beams in a single layer and delivering 3D images of the environment. The imaging is simpler and the images brighter using standard consumer electronics technology which allows mass production at scale.

3.2 Metamaterials for improved antennas and communications

3.2.1 Kymeta and SATCOM

Kymeta has developed and commercialised a holographic metamaterial-based SATCOM user terminal to address the surging need for an antenna solution that meets performance, size, weight, cost and power requirements for mobile and fixed use cases. A reconfigurable diffractive metasurface (shown below) builds the core of the antenna and implements the hardware required for holographic beam forming.

The metasurface approach and the holographic beam forming algorithm along with flat panel display technology provide a complementary solution that meets all the above-mentioned requirements. The result is a full duplex antenna with wide tunable bandwidth, switchable polarisation, and wide scan range with an excellent scan roll off.



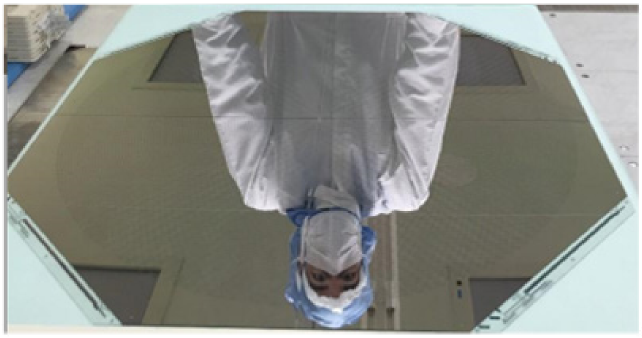


Figure 11: Kymeta's Ku band user terminal and the metasurface glass segments manufactured using flat panel display technology.

3.2.2 Technical Composite Systems and aircraft antennas

Technical Composite Systems (TCS) set out to reduce the mass and the physical size of the composite baseplate for a communication antenna to be used on commercial aircraft. Mass was lost through the replacement of the aluminium structure with composite materials, however the operational requirements of the antenna meant that the baseplate was still too large.

This was addressed using metamaterials in conjunction with the composite structure to act as a mirror for the Electromagnetic radiation. Unlike a conventional "mirror", the metamaterial design allowed the antenna to be used in much closer proximity, and so significantly reduced the size of the entire antenna system.

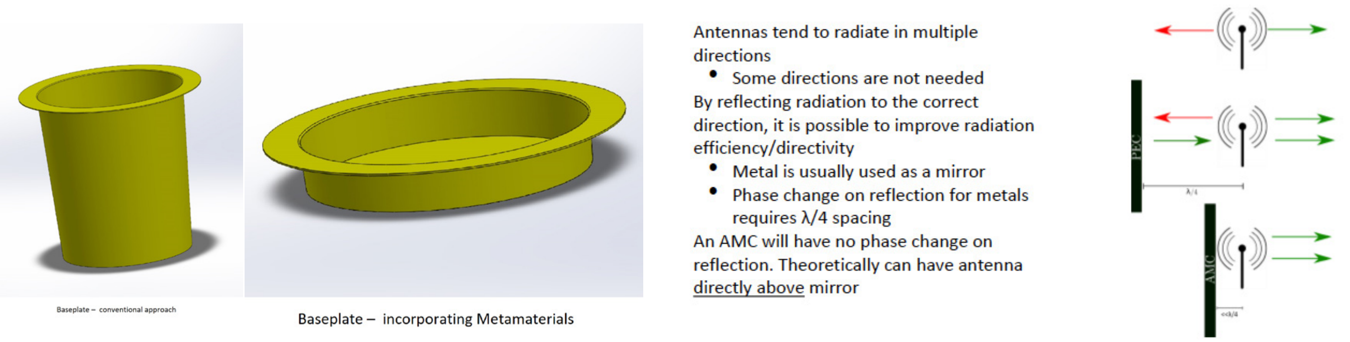


Figure 12: The use of metamaterials to reduce the size of antenna courtesy of Technical Composite Systems

3.2.2 Meta and transparent antennas

At META, metamaterials are at the core of the business, as they design, fabricate and test advanced functional devices and components. They use metamaterials as well as other nano- and micro-structured surfaces to achieve system properties that are not normally achievable with conventional materials. This might include higher performance enhancement, improved control of electromagnetic waves, more compact size, fewer raw materials used, or a combination of these. As an example, they produce in large scale a nanostructured transparent metal conductive film, Nanoweb, that appears transparent to visible light, but its sub-micron metal wire design provides very high conductivity. By adjusting the wire pattern of the film, radio frequency communication signals can be redirected at will, for example to non-specularly reflect an incoming 5G signal off windows and walls, and towards areas with poor reception. This type of customisation is unachievable with conventional transparent conductors such as ITO, which have fewer degrees of freedom available to the systems designer.

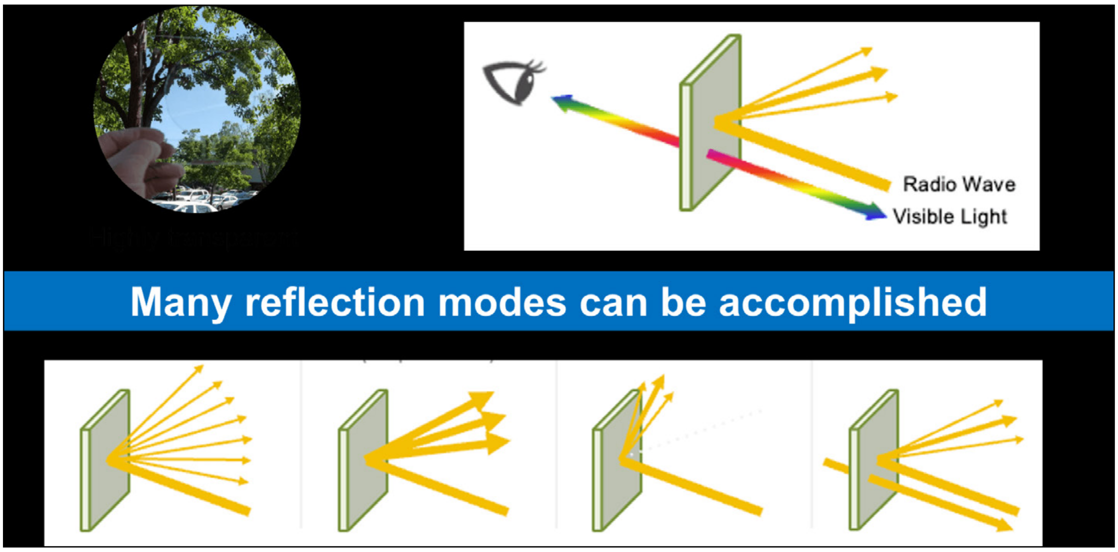


Figure 13: The use of metamaterials to control electromagnetic radiation courtesy of META

3.3 Metamaterials and the control of sound and air

3.3.1 Sonobex and Acoustics for Industrial Machinery

Sonobex have developed a range of acoustic metamaterial-based noise control solutions – NoiseTrap® LF Acoustic Panels – that have been successfully used in mitigating low frequency noise, primarily used in electricity substation and power transformer applications.

They design and manufacture a range of modular engineered systems that incorporate NoiseTrap® acoustic metamaterial-based panels, from noise enclosures to acoustic barriers, that are better performing at low frequencies, lightweight and modular.

By tuning the periodic structures and resonant dampers to the specific frequency ranges of troublesome noise sources, optimised noise abatement can be obtained.

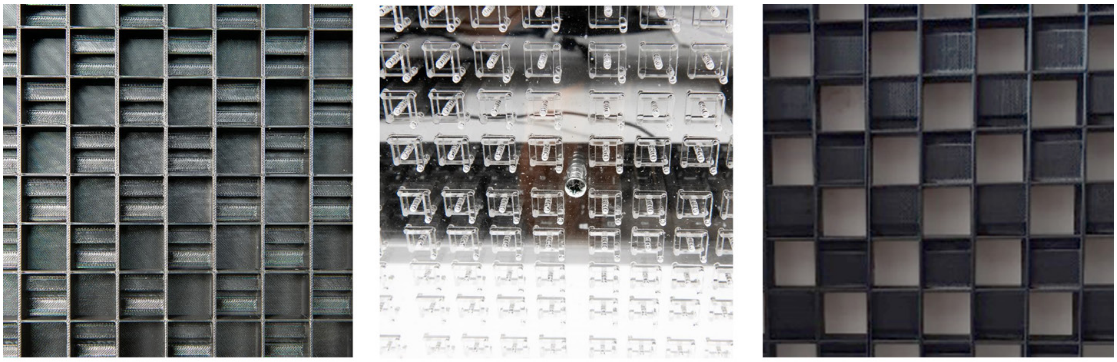
Continued development has led to providing solutions using their latest product, NoiseTrap® Box, that provides significant low frequency attenuation whilst providing passive ventilation replacing typical acoustic louvre and silencer solutions. This has led to the development of the NoiseTrap® ACE heat pump enclosure.

Figure 14: Controlling noise from industrial machinery using metamaterials courtesy of Sonobex

3.3.2 Metasonixx and Acoustic Barriers

Acoustic metamaterials are made up of unit cells that are smaller than the (acoustic) wavelength, which typically means they are a few mm in size. They can be used for sound manipulation and obtain effects only possible for light until a few years ago, like acoustic lensing and holograms. Crucially, they can be also used to cancel an external noise, while air is allowed to flow.

This is finding application in the built environment for managing noise and ventilation i.e., through coatings on windows and blinds for internal use in open offices. In the NHS, metamaterials have been used within light and easily movable panels to manage noise in A&Es and intensive care wards.



Panel with no airflow | Panel with some airflow | Maximum airflow

Figure 15: Metamaterials panels for controlling acoustics

On a window | In an empty hospital ward

Figure 16: Application of metamaterial panels to control sound through windows and curtains

Metasonixx was incorporated in 2019 and has since established a revenue collaborating with companies interested in managing road noise due to traffic and white goods. They are now looking for investment to transform their panels into a line of products, SonoBlind®, for the simultaneous management of noise and airflow. Prototypes have been tested in hospitals, funded by Innovate UK, and in peoples' homes, funded by the Venture Prize of the Armourers and Braziers.

3.4 Metamaterials for sustainable energy generation

QinetiQ and radar-invisible Wind Turbines

QinetiQ's innovative patented technology is enhanced with a well-established material supply chain and represents a breakthrough for the wind energy sector. Radar weather stations are just one example of a system that could be detrimentally impacted by wind farms; other objections come from military and airfields where radar is essential – their technology can diminish this threat by making the apparent radar signature size of the turbine much smaller, giving stealth wind turbines a chance to thrive in what were previously unobtainable areas, and coexist with existing facilities.

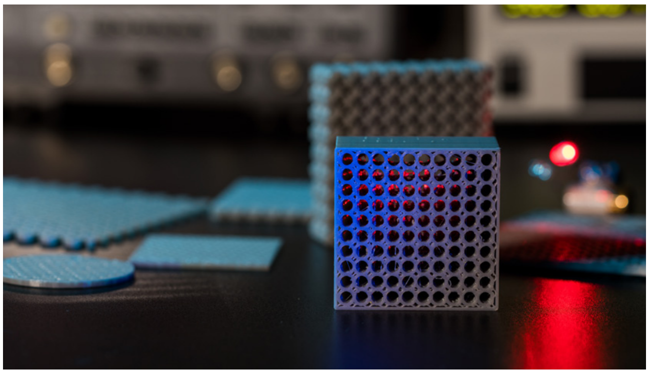
QinetiQ integrated an innovative material that is applied without structural change to wind turbines to reduce their radar signature by up to 99%. This technology enabled France's largest wind farm to be installed without significant interference to the weather radar located nearby-a world first.

Figure 17: Wind turbine blades incorporating metamaterials to reduce interference with radar

4. Challenges and Potential Solutions

The major challenge with metamaterials lies with the size of the enabling feature or function in relation to the scale of the system or device that they are being used in.

Metamaterials are generally fabricated with feature sizes in the micrometre and nanometre scale whereas the products, devices, components and coatings employing them are in the macroscale and could be many metres. Not only does that pose a challenge for manufacturing, but also for process and product quality control, behaviour and existing modelling, simulation and design tools; and there is a need to update and develop new standards.



In the manufacturing process there are several areas that need attention in moving metamaterials into scalable commercial applications:

Current manufacturing:

- Some applications like Lidar and 3D imaging can use CMOS and other semiconductor fabrication processes to deliver the metasurface technologies for improved performance.

Potential manufacturing

- For applications that require large area metasurfaces (m2) in the form of coatings to deliver their functionality, such as radar-invisible wind turbines and the cloaking of military platforms there is a challenge of scaling the production. The UK has the capability in transitioning from the laboratory scale to small scale commercial through the RTOs and the Catapults, but industry needs to take the next step.
- In some applications like acoustics, and to obtain enhanced performance and effects, the ability to produce large scale 3D metamaterials is needed. Additive Layer Manufacturing methods offer opportunities, but these are currently limited by build volumes of current machines and the limitations on different feedstock materials.

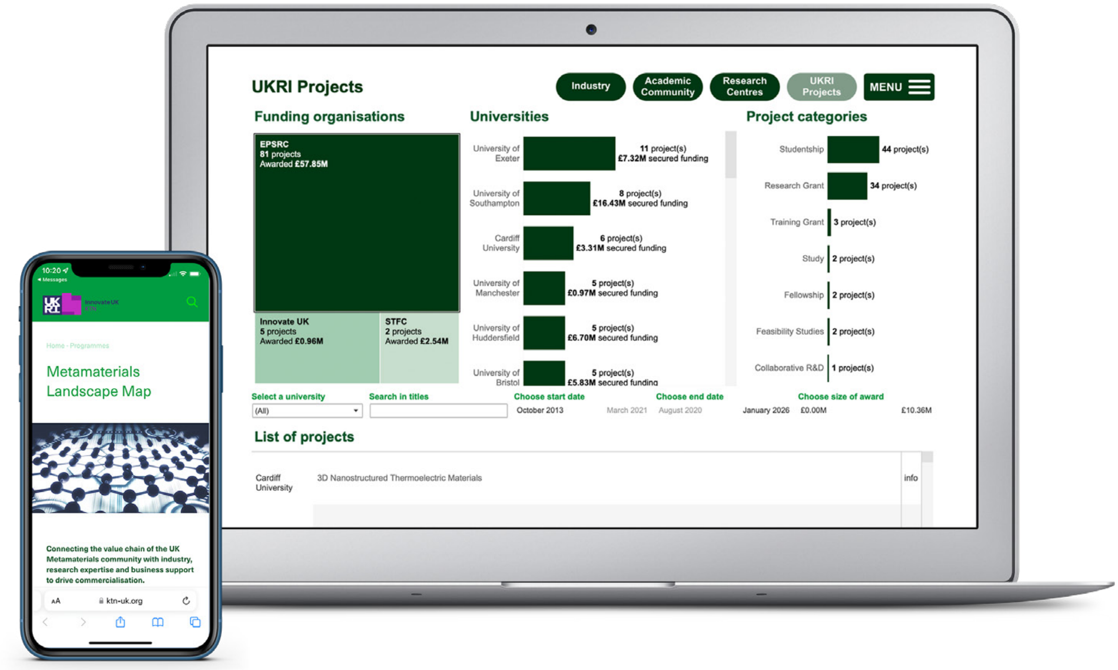
Future manufacturing

- Bottom-up or self-assembly processes may offer alternative approaches, including the application of engineering or synthetic biology routes to manufacture. The desired characteristics of the building blocks of metamaterials may also be realisable through novel engineering of complex micro and nano-scale particles, such as coated and tailored shape particles.
- Functional materials are important to specific and often higher value applications of metamaterials, including for example in sensing, finding ways to include optimised functional materials within metamaterial fabrication will be important. Alternatively, new materials and different material classes may further facilitate manufacturing.
- Advanced computational techniques to model metamaterials (both manufacturing process and manufactured metamaterials) will be an important enabler.

In terms of testing and standards there may be a need for Government policy:

- To consider standards that are applied to technologies in certain sectors and whether there are current or future accreditation processes required to allow the use of metamaterials
- In approvals for new products, particularly in aerospace, defence and healthcare which have stringent requirements for performance and safety. Any regulatory bodies could influence the manufacturing process to mitigate risk
- Where no standards are available. It will be worth considering if there are existing sector/ performance/ safety /manufacturing standards that are applicable or easily modified.
- Are there common issues metamaterials have that require a centralised standards activity? Would a terminology document help?
- In acoustics, measurement standards are specific to the types of materials used now and they simply do not work for metamaterials. In contrast, many measurements are more generic to any materials but what specific measurements are unique to metamaterials?

Connect with other UK businesses to commercialise Metamaterials



Visit the interactive landscape map to explore the UK's thriving metamaterial community:

View Map

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