Exploiting a neglected part of the electromagnetic spectrum

T-rays
We rely on electromagnetic radiation – from the shortest-wavelength gamma-rays and X-rays, through visible light, to longer-wave microwaves and radio waves – to observe and manipulate the world around us. Physicists and engineers have developed a wide range of sources, sensors and techniques that operate across the electromagnetic spectrum and are used in communications, imaging and analysis. However, one part of the spectrum, has stayed in the dark. Terahertz radiation, which lies between the infrared and microwave regions, covering frequencies between 300 gigahertz and 3 terahertz (3 million million cycles a second), has been little used (see spectrum above). This was because there were no practical sources or detectors of terahertz radiation – traditional optical and electronic devices work above and below this region and depend on different technologies.

Recently, however, there has been an explosion of interest in terahertz radiation, or T-rays, as UK researchers, in particular, have exploited the latest advances in physics to create and detect them. The result is a wide range of potential applications including medical imaging and security scanning, remote analysis of materials and climate monitoring, and faster wireless communications.

The advantages of T-rays are that they can partially penetrate opaque materials such as textiles, plastics, wood, and even living tissue, but are readily absorbed by metals and water. This means that images taken with T-rays can reveal concealed objects such as weapons and bombs, and can distinguish different tissues in the body by their density and the amount of water they contain. Another big benefit is that they are non-ionising so are harmless to humans. Like infrared radiation, T-rays of specific wavelengths interact with the intricate motions of molecules to give a characteristic chemical fingerprint (a spectrum) that can be used to identify a material. However, T-rays are less easily scattered than infrared radiation, so T-ray spectroscopy is more sensitive. It can also be combined with simultaneous terahertz imaging to detect drugs or analyse biological processes. As is often the case, the technological advances underpinning these applications were stimulated by the needs of basic research. Astronomers wanted to detect terahertz radiation emitted from distant galaxies, which would tell them about the evolution of the Universe, while Earth-observation scientists saw the potential for atmospheric studies. With this in mind, the European Space Agency set up a project six years ago at the Rutherford Appleton Laboratory near Oxford, to build the world’s first compact terahertz camera. Called StarTiger, the project employed state-of-the-art micro-machining technology to make a novel silicon-based detecting system.

Building on this breakthrough, a UK spin-out company, ThruVision, went on to develop passive imaging devices for customs screening. They can detect the natural terahertz radiation emitted from smuggled objects, and the system was successfully tested at a UK airport. The technology is now being applied to screening people and vehicles from a distance for materials such as explosives and drugs in a wide variety of settings including sports stadiums, office buildings and military vehicles.

Active imaging
Alongside the commercialisation of passive scanners, Cambridge physicists Sir Michael Pepper and Don Amone, have developed an active imaging and spectroscopic system – an incidental spin-off from
Professor Pepper’s more fundamental work on quantum semiconductor devices at the University of Cambridge and Toshiba Research Europe. It relies on an external source of terahertz radiation impinging on the object of interest. The absorbed or reflected/transmitted wavelengths are then converted into either a 3-D image, or a spectral fingerprint that identifies the molecular structure at a particular location within the object. Images taken in this way can, for example, reveal areas of decay and enamel thinning in teeth better than X-rays, and can also discriminate between skin cancer and normal tissue.

The researchers have since set up a company, TeraView, to market the system. The first commercial application has been in the pharmaceutical industry, where it is used to check the quality of tablets – their structural integrity and chemical formulation. This can be done even when they are in their point-of-sale blister packs. The system can tell whether a drug is in the correct crystal form, which is a crucial medicinal and patent requirement: drug companies have lost billions of dollars through this inherent problem of crystal ‘polymorphism’. Active imaging too is being adapted for homeland security. The company is working with US defence contractors to develop a handheld device that can scan airport passengers and pick up the spectroscopic signatures of any hidden weapons, plastic explosives or toxic gases.

The technique employed by TeraView relies on the production of timed terahertz pulses which are emitted by a gallium arsenide crystal when an infrared laser is fired at it. However, more powerful terahertz sources are needed – especially for cheaper, more mobile systems. A favoured candidate is the quantum cascade laser, developed in the 1990s by Federico Capasso and colleagues at Bell Laboratories. Lasers emit light as a result of electrons in, for example, a semiconductor, being excited en masse to a higher energy quantum state and then falling back to a lower level. Quantum cascade lasers consist of stacks of ultra-thin semiconducting layers precisely engineered to guide electrons so that they bounce down a staircase of decreasing quantum energy steps when an electric current is switched on (see diagram bottom right). Each time the electrons jump down a step, they emit light with a wavelength that depends on the thickness and composition of the layers.

Recently, a team funded by the EU TeraNova project, designed a quantum cascade laser tailored to emit in the terahertz range. Several UK university groups continue to work at the forefront of terahertz technology, exploring new laser schemes based on sophisticated semiconductor quantum structures and more exotic electronic materials. Novel systems for guiding the waves and modulating their intensity are also being developed, as well as new detectors. With the advent of more compact terahertz systems, we can expect to see T-rays used in industry for product quality control, and in medicine for biochemical and genetic analysis. Terahertz microscopes are another possibility being investigated. T-rays, at selected wavelengths, could even be the basis of future higher-bandwidth wireless telecommunications. The final gap in the electromagnetic spectrum is being bridged at last.

A cross-sectional image of a tablet taken with TeraView’s active terahertz system

The University of Leeds Terahertz Photonics Laboratory is one of the largest and best-equipped in the world. There is a wide range of terahertz systems available, including quantum cascade laser imaging and spectroscopy systems

The principle of the quantum cascade laser
Visions is a series of papers which highlight exciting new areas of research in physics, and their theoretical and technological implications.

AVAILABLE VISION PAPERS
1 High intensity lasers
2 Quantum information
3 Exotic nuclear beams
4 Physics and finance
5 Spintronics
6 The Large Hadron Collider
7 Particle accelerators – the next frontier
8 Flat screen displays
9 Superconductivity
10 Gravity waves
11 E-science
12 Photonics
13 Mega-telescopes
14 Technological plasmas
15 Seeing with neutrons
16 Bose-Einstein condensates
17 Free electron lasers
18 Magnetic resonance imaging
19 Dark energy
20 Solar energy conversion
21 Metamaterials

ABOUT THE INSTITUTE OF PHYSICS
The Institute of Physics is a scientific membership organisation devoted to increasing the understanding and application of physics. It has an extensive worldwide membership and is a leading communicator of physics with all audiences from specialists through government to the general public. Its publishing company, IOP Publishing, is a world leader in scientific publishing and the electronic dissemination of physics.

FOR FURTHER INFORMATION CONTACT:
Department of Higher Education and Research
The Institute of Physics
76 Portland Place, London W1B 1NT, UK
e-mail: heandresearch@iop.org
Institute website: http://www.iop.org

For more information on terahertz radiation, go to:
www.esa.int/SPECIALS/TTP2/SEMZ1R1A6BD_0.html
www.thruvision.com
www.teraview.com
http://en.wikipedia.org/wiki/Terahertz_radiation