T-ray cameras

The London bombing in July 2005, like all the previous terrorist attacks, call for even better technology for discovering hidden and concealed objects, such as weapons, explosives, knives, bombs, and the like. X-Rays are a known, but potentially harmful deep penetration imaging technique. People and passengers are not subject to X-rays at airports or train stations, only their luggage is. However the new and safe TeraHertz wavelength (hence T-ray) imaging technology is currently being intensely tested, and promises another quantum leap not only for security, but also for medical and other applications.

Compiled by V.Damjanovski

What is Terahertz?

Terahertz waves occupy a portion of the spectrum between infrared and microwaves, from 10^{11} to 10^{13} Hertz. Just a reminder for the CCTV focus readers that visible light spectrum occupies the wavelengths between 400 nm (for violet) and 700 nm (for red). The equivalent frequency for these wavelengths is between 4.2 10^{14} (for red) and 7.5 10^{14} (for violet).

Until now, the Terahertz band has been an unexplored part of the electromagnetic spectrum. However, terahertz waves are very interesting as they possess characteristics of both their neighbours: terahertz waves can pass easily through some solid materials, like walls and clothes, yet can be focused as light to create images of objects.

Scientists have known for more than a century about terahertz light, located on the light spectrum between television waves and visible rays. But until now, they've produced it only in small amounts.

The powerful nature of terahertz analysis stems from the fact that it is a coherent technique that can make both amplitude and phase measurements. Unlike common optical spectroscopic techniques that only measure the intensity of light at specific frequencies, terahertz experiments often measure the temporal electric field of terahertz pulses that have interacted with (i.e. reflected off or passed through) a sample.

A Fourier transformation of this time-domain data discloses the amplitude and phase of the pulse and reveals a wealth of information about the sample. For example, it allows precise measurements of the refractive index and absorption coefficient of a sample. Molecules also have unique rotation and vibration resonance lines in the terahertz spectrum that can be used as terahertz fingerprints.

The first Terahertz experiments

Although the majority of the initial research on terahertz imaging was carried out by Martin Nuss and colleagues at Bell Labs in the early 1990s, today the leading research group in the field is undoubtedly Xi Cheng Zhang's group at Rensselaer Polytechnic Institute, US. For more than a decade the group has been pushing back the frontiers of terahertz technology and has published a huge number of papers on the topic. The Institute has recently established a dedicated facility for terahertz studies, the Center for Terahertz Research, and has received a $1m (€1.03m) donation from the W M Keck Foundation.

At this year's CLEO conference in May in California, Zhang and co-workers from the University of Adelaide, Australia, and the New York State Department of Health, US, reported initial results on the use of terahertz waves to screen potential biohazards.

The team found that terahertz waves could detect and classify unknown powders that were sealed inside an envelope. Using a transmission terahertz imaging technique operating at 0.3 THz, the team successfully detected and distinguished between samples of flour, salt, baking soda and bacterial spores placed inside a paper envelope.

Outside academia, one of the first companies attempting to cash in on the market potential and commercialize terahertz technology is Teraview, a start-up company based in Cambridge, UK. With a headcount of 13, the firm was spun out of Toshiba Europe's Research Laboratory in April 2001 to develop equipment for medical imaging, drug development and security screening.

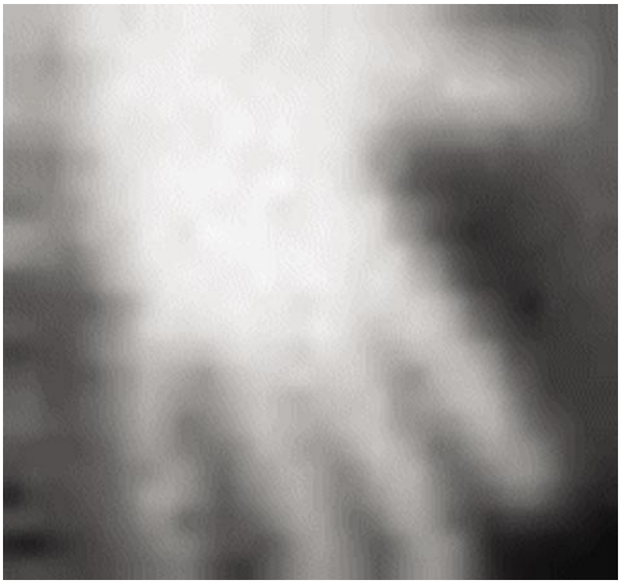
The start-up has not wasted any time. Having built prototype medical-imaging equipment, the Cambridge-based firm has tested its terahertz technique for skin-cancer detection in field trials at UK hospitals, as well as using it to image semiconductor chips for electronics companies.

Gwyn Williams, a researcher of light at Jefferson Lab, led an experiment that generated terahertz rays 20,000 times stronger than previous attempts.A Jefferson Lab scientist has produced record amounts of an invisible kind of light that could some day detect everything from anthrax to guns to skin cancer.

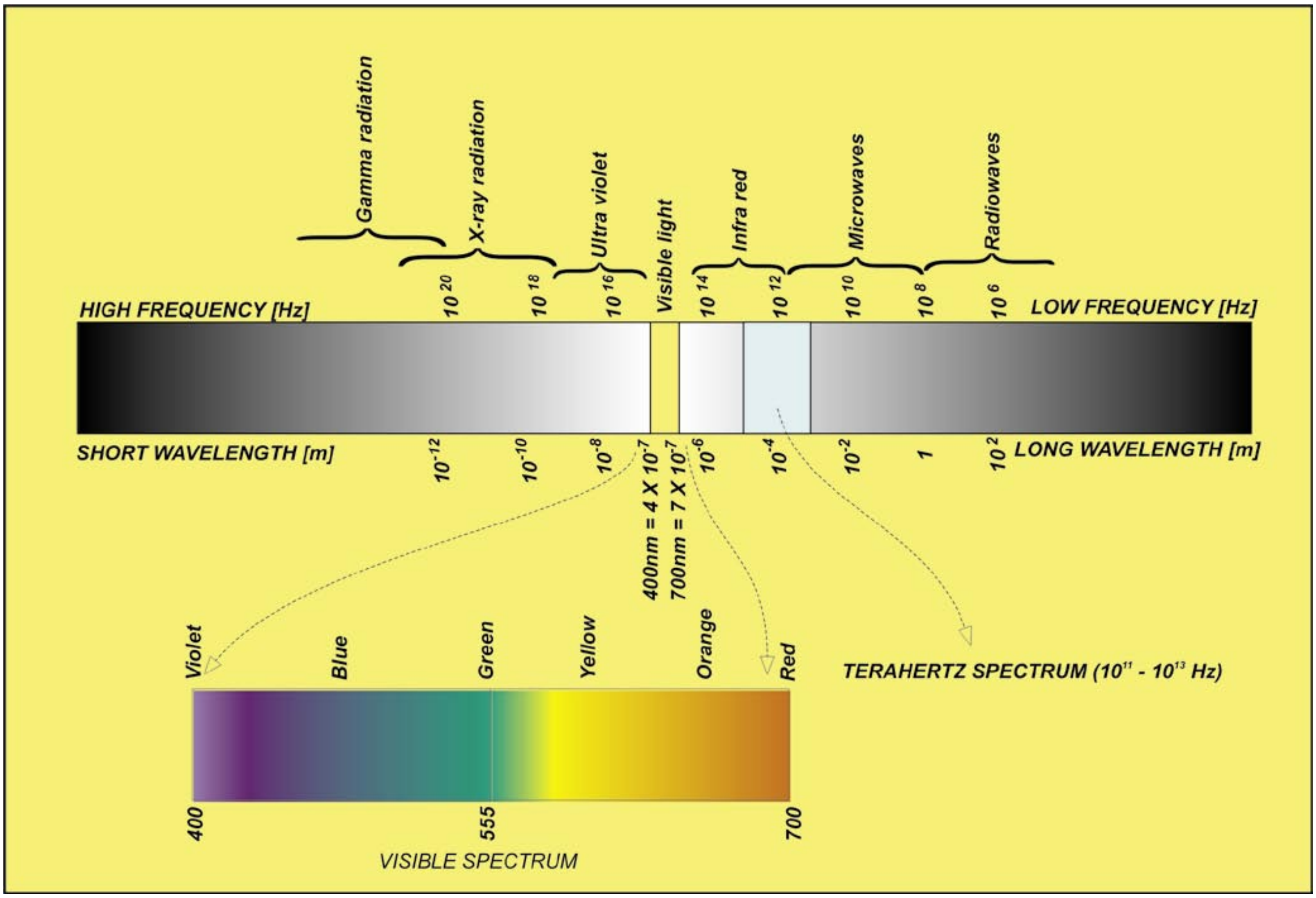
The experiment took place at Jeff Lab's free-electron laser in November 2001. Williams held off the announcement until he published it in Nature magazine. The free-electron laser produces light useful for commercial, science and defence applications. For this experiment, a portion of the laser sent a focused beam of electrons at nearly the speed of light through a magnetic field, which generated terahertz light, or T-light.

A few hospitals have used small amounts of terahertz light in medical tests. But the dim light wasn't as effective as a stronger beam would be. Now, with a much brighter light, Williams envisions doctors using tabletop T-light scanners to check patients for skin cancer. A sophisticated camera would have to be developed to allow researchers to use terahertz light, which is not visible to the eye.

"If I were looking at you in terahertz light, I would



One of the first T-ray images of a hand (2002)



know if you have any cancer on your skin," said Williams, who is the basic research project manager at the free-electron laser.

Different types of cancer, viruses and bacteria absorb T-light in unique ways, which could help doctors or even security forces pinpoint biological threats. T-light devices could fingerprint chemical and biological terror materials in envelopes, Williams said.

"You could screen mail, you could screen passengers," Williams said. T-light does not go through metal, which means terahertz devices could detect knives, guns and other weapons. "I would love if it could detect mines in the sand, because a lot of people are maimed by those," Williams said.

A fresh approach by StarTiger

StarTiger is an acronym for 'Space Technology Advancements by Resourceful, Targeted and Innovative Groups of Experts and Researchers'. It is a pioneering European Space Agency (ESA) initiative designed to facilitate innovative research, launched last year under its Basic Technology Research Programme (TRP). The aim is to reach a quantum increase in a promising technology within a short period of time.

New imaging technology came to life when the StarTiger team captured the world's first terahertz picture of a human hand. "When we started in June 2002 we set an ambitious goal: to build in four months the first compact sub millimetre-wave imager with near real time image capturing using state-of-the-art micro-machining technology," said Peter de Maagt, ESA's StarTiger Project Manager, "we reached this goal when the first terahertz images were taken in September." This breakthrough in terahertz imaging opens up the possibility for a new generation of applications, not only related to space but also in many non-space fields, including medicine, pharmaceuticals, security and aeronautics.

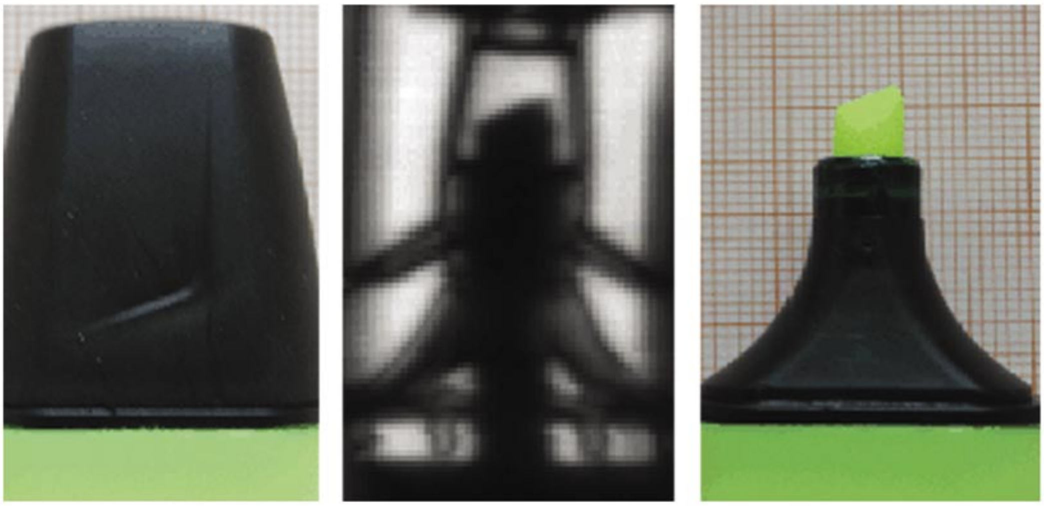
A T-ray camera image of a man wearing a gun on his right leg

StarTiger is a new approach for conducting research and development (R&D) launched a couple of years ago by ESA. The concept is to bring together a small group of highly motivated researchers, grant them full access to laboratory and production facilities, remove all administrative distractions, and let them work for an intense period of four to six months. The goal is to achieve a quantum increase in a promising and important technology within a short period of time.

The first project was started at CCLRC Rutherford Appleton Laboratory (RAL) in June 2002 and was scheduled for four months. RAL was chosen as the best location for this particular pilot project with its advanced laboratories and all support technology required, and its specific expertise in relevant fields.

The imager built by the StarTiger team takes pictures at two frequencies, 0.25 and 0.3 THz, to create a two-colour picture to create a contrast between materials with different transmission and reflection properties.

The main advantage of a terahertz imager is that it does not emit any radiation; it is a passive camera capturing pictures of the natural terahertz rays emitted by almost everything, including people, rocks, water, trees and stars.



A highlighter, with a T-ray image in the middle with the cap on

Space Applications

The imager could be applied in several areas of space science, including astronomy, atmospheric physics, and Earth and environmental monitoring by satellites. In the field of planetary, cometary and atmospheric sensing, it could have a major impact on instrumentation for monitoring issues.

In space astronomy, observing terahertz frequencies could provide answers to some key questions on how galaxies were formed in the early universe, and how stars form, and have been forming, throughout the history of the universe.

For environmental monitoring, a terahertz imager could be used to obtain data for studies on ozone depletion mechanisms. The frequencies can be selected to focus on exchanges between the troposphere and the stratosphere, adding information useful for studies on global climate changes.

“Observations from space may be on the verge of a revolution with the possibility of looking into the terahertz frequency range,” said de Maagt. He emphasized that the wide array of potential applications for such an imager must not be underestimated.

“Apart from its use on space missions, our everyday lives could soon be reaping the benefits of this innovative technology,” he added.

Non-space applications

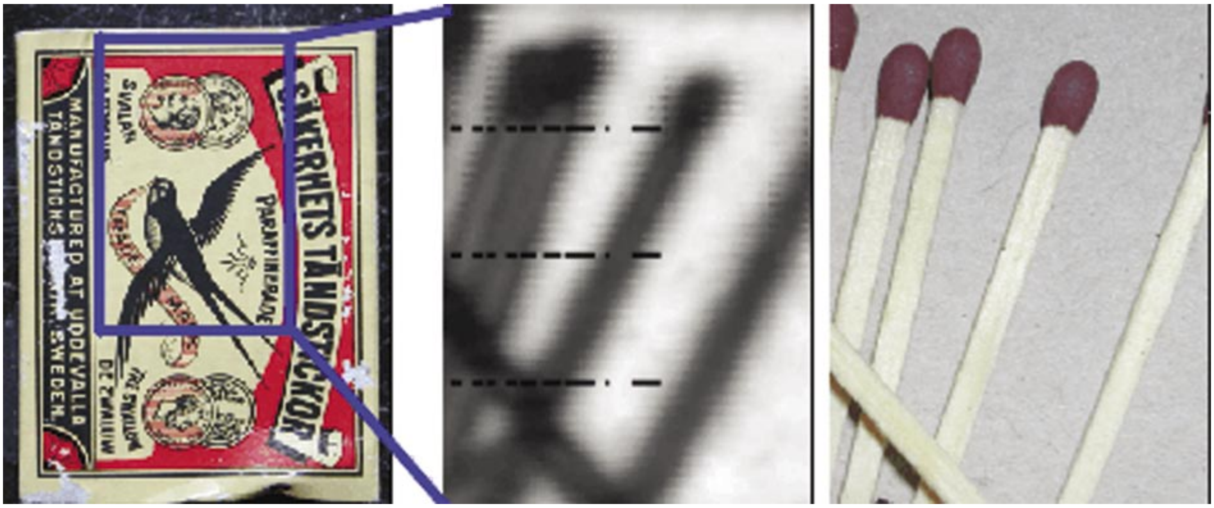
If possible space applications are numerous, many more have been identified in non-space fields for use on Earth. A terahertz imager could open up a whole new range of systems in a variety of fields on Earth.

For instance, the imager could have various uses in the medical, dermatology and cosmetic sectors. Terahertz imaging is rapidly becoming recognised as a totally new diagnostic technique. By observing these types of waves, it is possible to see through many optically opaque materials. Terahertz waves could provide an image that has X-ray-like properties without the use of potentially harmful radiation. A terahertz imager is a passive instrument and, since the source of the signals for such an imager occurs naturally, is completely safe.

A T-ray camera image of a man concealing a knife in the newspaper

X-rays are important tools for dentists to evaluate patients’ teeth and to pinpoint cavities and other signs of disease that might not be detected through only a visual examination. The terahertz imager could compliment X-ray examinations without adding further health risks. No single type of sensor can provide all the information required for most tasks; combining the use of different sensors could become a valuable tool in many medical fields.

Terahertz waves are also able to penetrate the uppermost layers of skin, making the early detection of skin cancers an interesting possibility. Skin cancer is usually curable if detected quickly enough. Looking into terahertz waves could provide earlier



A matchbox, with a T-ray image in the middle taken through the case detection than what is possible today.

What about looking behind a dressing to see if a wound is healing correctly? This again should be possible using terahertz instrument.

An application of a different nature could be the detection of chemical and biological threats. As all materials emit terahertz waves, each having it own frequency pattern as a kind of 'fingerprint', it could be possible to identify not only the existence of powder in envelopes and postal parcels, but also which kind of material is enclosed.

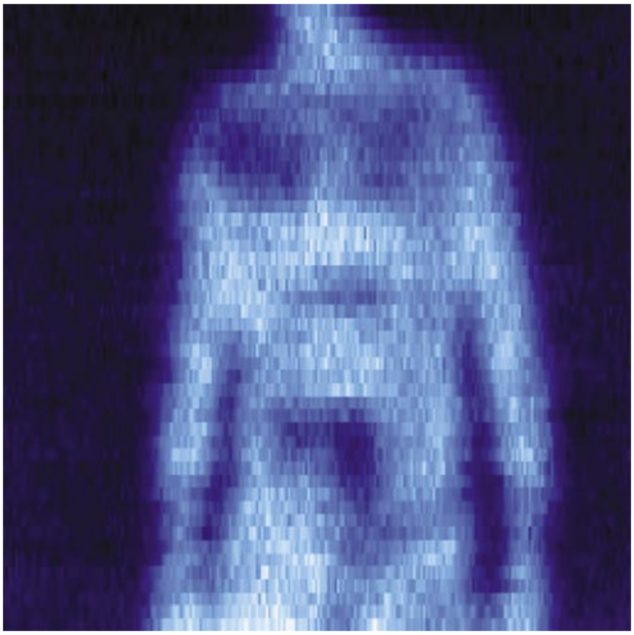
In airports, it could be possible to see through clothes and identify weapons, but not based upon the metal-detection techniques used today. Even non-metal explosives could be possible to spot since they may have their own terahertz 'fingerprint'.

"By exploiting operations at two frequencies 250 and 300 GHz, it should be possible to discriminate between materials of different types based on their optical properties e.g. reflectivity," said Roger Appleby, Technical Leader for the Passive Millimetre Wave Imaging Group at QinetiQ, a UK company. "When imaging the body, reflectivity falls and emissivity increases as the frequency is increased. These properties could be used to reduce false alarms in images of people collected for security scanning."

In aviation, terahertz frequencies could penetrate fog. When the technology is more developed, it is conceivable to build a monitor that would give a pilot a clear view ahead. Although a higher resolution imager than currently developed would be needed.

Another potential application came to light when a zoo asked the StarTiger team if a terahertz imager could look behind fur from a distance to diagnose an animal's health. Examining certain animals with thick fur, such as lions and bears, is not always easy. The team thought this was possible in future versions of an imager.

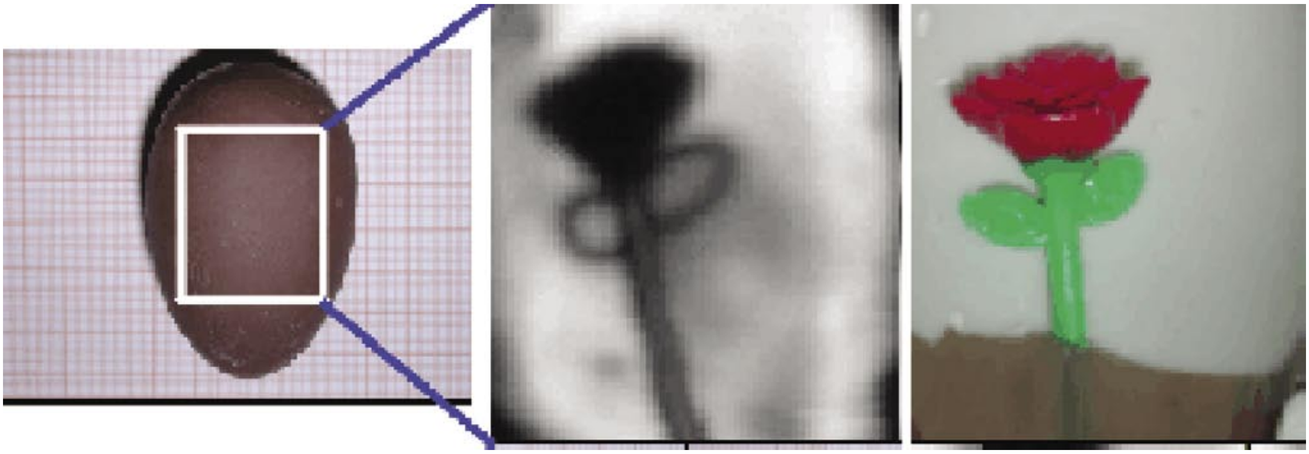
"We have recognised the huge potential in non-



space applications, and in parallel to exploring the use of terahertz waves and the StarTiger technology in space, we have kicked-off a commercialisation study to identify the best way of transferring it into terrestrial systems," said Pierre Brisson, Head of ESA's Technology Transfer and Promotion Office.

However, the resolution was low, 8-by-8 pixels, and the time needed to acquire the image was too long. The team then took the techniques further and pushed the development of a lithographically and micro-machined detector array.

"The final version was an enhanced imaging system incorporating a two-colour 16-pixel detector array, the size of a postage stamp. This advanced system incorporated revolutionary silicon micro-electrical-mechanical systems (MEMs) technology," continued Chris Mann. "The enhanced system delivered images that confirmed the mysterious nature of terahertz waves. An imager can show details of features under



A chocolate egg seen with a T-ray camera (middle) the skin, confirming the potential of this technique."

The team also tried to scan through a book, and the terahertz imager acquired pictures through different materials. Knives and even non-metallic items hidden in pockets or newspapers were clearly seen.

To reach the results in such short time was a tribute to the StarTiger R&D approach. In addition, several recent technology developments have made it possible to build the StarTiger terahertz imager at a relatively small size.

Attempts to construct a camera operating in the sub millimetre wave range have so far resulted in very bulky solutions. Such cameras have primarily been based on waveguide-based technology and usually were assembled from discrete elements.

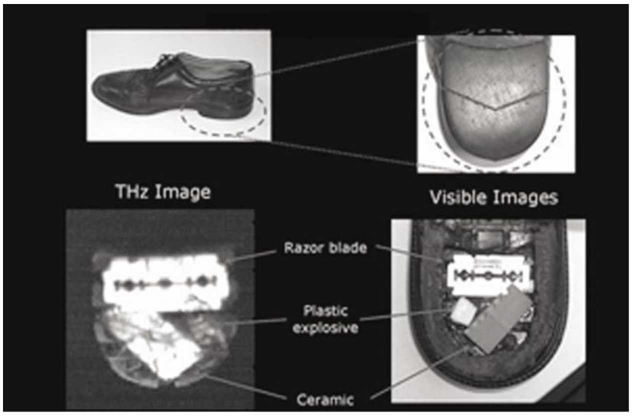
The recent advances in lithographically and micro-machining offered the potential for the realisation of the same performance with much smaller physical dimensions.

"The StarTiger imager fits within a briefcase and is easily transportable. The core of the instrument is the size of a cigarette packet," said Peter de Maagt. "Next generation instruments will go for another magnitude smaller in size, by using electronic scanning."

ThruVision too

A UK start-up company ThruVision has developed a new type of security scanner that exploits terahertz waves. They have started trialing their terahertz imaging technology at an airport in the UK. Claes Bergstedt, the firm's CEO, is confident that it will generate revenue from its security screening products within 6 to 9 months.

Founded about 1 year ago, the spin-off from the UK's Rutherford Appleton Laboratory (RAL) now has a near 25 staff located at a science park near Abingdon. They are busy commercializing CCD-style detectors of terahertz radiation developed at the lab for astronomical imaging.



T-ray cameras can see through non-metalic surfaces, as illustrated above

Although ThruVision is reluctant to discuss the details of its detector, it appears to blend high-frequency electronics with a photonic crystal microstructure.

According to Chris Mann, Thruvision's CTO, the technology can conduct image radiation from a few hundred gigahertz to several terahertz and has a sensitivity in the picowatt regime.

However, Bergstedt says that security applications are just the beginning. "We are developing a terahertz platform technology that can be applied to all kinds of imaging and material analysis," said Bergstedt. "The challenge is getting the cost of the technology down. We've now done that and can produce detector arrays on a commercial basis."

He says that the big advantage of their detector technology is that it is passive, meaning that no illumination source of terahertz waves is required. Instead the detector simply images the radiation emitted by the target object. What's more, it operates at room temperature and is capable of a sub-second refresh rate allowing real-time imaging.

What's next?

"With StarTiger we want to dramatically reduce the turnaround time for state-of-the art technology developments. We have demonstrated that this is possible with this first StarTiger project," said Niels Jensen, ESA's Head of Technology Programmes Department.

Niels Jensen continued, "Putting together a highly motivated team in the same laboratory for an intense period with everything they can possibly require, we can create a synergy not attainable to the same extent in conventional R&D. This provides a real chance to advance a well-defined key technology and reach a scientific breakthrough within a relative short period."

"We intend to use this approach for selected key technologies in the future. The location for projects will of course change from project to project. The objective is to select the best European laboratory for each specific technology, so as to provide the best support for the teams," concluded Niels Jensen. [•]

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