Infrared glows out of a wide range of current news, from the capabilities of the Spitzer Space Telescope for directly detecting cool T dwarfs, to synthetic and enhanced vision to improve pilot’s awareness, or the art disclosure of a gauze-clad, hand-clenched, Mona Lisa, amazingly bonneted and veiled. Now judging by current R&D spending on medium wave infrared (MWIR) expect this part of the IR technology spectrum to start making a serious impact in primarily instrumentation and sensor fields, as well as the health and environment markets. The routes to developing MWIR devices will vary, but research is focused on the market pull and development push to low-cost, uncooled devices.

MWIR centre field in R&D

In the US, MWIR has been judged of sufficient merit to rate a new R&D centre at Princeton University. MIRTHE (Mid-Infrared Technologies for Health and the Environment) was launched in May with $15m funding from the National Science Foundation, and with corporate partners and other funding, expects to undertake some $40m worth of research and education over the next decade.

The center’s goal is to develop mid-infrared (~3–30 µm) optical trace gas sensing systems based on new technologies such as quantum cascade (QC) lasers or quartz enhanced photo-acoustic spectroscopy, with the ability to detect minute amounts of chemicals found in the environment or atmosphere, emitted from spills, combustion, or natural sources, or exhaled in human breath.

In keeping with sensor trends, MWIR developments are to be easily portable, ‘i-Pod’ sized sensors (Figure 1), rather than the current tabletop installations (Figure 2); have improved sensitivities, yet price at a fraction of current costs.

Through its fundamental research and prototyping in materials, sources, detectors, sensing systems, and application testbeds, MIRTHE will address a broad range of technologies and industry sectors – semiconductors, test and measurement, medical equipment manufacturers, chemical and petrochemical, and homeland security – as well as government labs and hospitals.

Associate Professor of Electrical Engineering at Princeton, Claire Gmachl, heads the new centre (Figure 3). “Over the last several years, QC lasers and novel mid-IR semiconductor lasers, made essentially from telecom semiconductors, have improved dramatically in performance and demonstrated their use in many different trace gas sensing applications,” she says. “Similarly sensing techniques have matured and new ideas developed, such as the miniaturised photo-acoustic cells developed by MIRTHE partner, Rice University.

“Finally, sensing in the environmental, health, and homeland security applications is becoming ever more important. All these factors came together to demonstrate the future commercial potential of mid-IR technologies, the need for more fundamental and applied R&D and the justification for the new centre.”

The centre will combine the work of some 40 faculty members, with 30 graduate students and 30 undergraduates drawn from Texas A&M, University of Maryland-Baltimore, Rice and Johns Hopkins University and City College of New York.

Gmachl notes that competition for an NSF Engineering Research Centre runs for almost two years, from the first letter of intent, roughly outlined by partner institutions in September 2004, to the award of the centre in May. “Before that we were a loose network of sometime
collaborators; during the competition process we forged new and closer ties that now allow us to function as a centre and work towards our common vision.”

“Industry,” she says, “plays an essential role. It has given the first roadmap for the technology and in July a large group of interested and involved industry discussed the first mid-IR roadmap for MIRTHE technology.”

**Industry heavyweights**


“Industry’s response to the new centre has been overwhelming; we are championing a technology that is not yet commercial in the large scale, and hence comes with some risk. Yet industry involvement and interest has exceeded our expectation by far.”

The other essential key players are III-Vs materials. “Here in particular, InGaAs/InAlAs on InP are key to the success of our centre,” says Gmachl.

“While these materials are not naturally emitting in the mid- and far-infrared wavelength range, the design of QC laser makes them do so. This way we can make a material emit at wavelengths that are otherwise unfamiliar to it.”

“Importantly, we build upon the longstanding experience in III-V materials that has been gained over the last decade and has been accelerated and refined by the demands of optical communications. We can also build upon commercial suppliers of telecom lasers to provide QC lasers for a larger market in the future.”

As the Si announcement, Gmachl’s response was: “One can imagine designing QC lasers that are made from Si-alloy heterostructure on silicon. This would be the ultimate integration, but probably quite far out in the future. Near term systems will be heterogeneous chips on boards.”

**DARPA’s funding**

Of course in the US, the establishment of such an industrial education centre is running alongside other focused MWIR research work, namely that of the Department of Defence. In its Advanced Microsystems Technology Program (AMTP), 3D IC integration and heterogeneous integration
using bonding, new materials, processes and devices for avalanche photo detectors in the IR range using the Geiger mode, and photon-counting avalanche photo detectors in array format are being worked on.

Devices and small arrays have been demonstrated in the SWIR. Now device issues, scale ups and extension to MWIR are under investigation. System applications that would benefit from these devices are also under investigation. The DARPA program manager is Dr Daniel Radack (daniel.radack@darpa.mil).

UK’s MWIR initiatives

The driving force for MWIR in the UK comes in the main from the Department of Trade and Industry, which, acknowledging the importance of photonics and the MWIR technology, has taken quite an unusual stance in placing two contracts worth some £2.1m with two consortia, working on two different routes to develop MWIR characterized devices, initially for the gas sensing requirements of industry giants Shell Global Solutions and BP.

The £1m QinetiQ-led DTI contract for MWIR involves BP, Lancaster and Surrey Universities, the Centre for Integrated Photonics, Cablefree Solutions, Procal Analytics and Anasys Instruments, developing semiconductor lasers with a wide range of potential commercial applications.

Since mid-infrared lasers operating at 3–5 µm have longer wavelengths than standard use lasers, it opens up the prospect of a range of new opportunities in healthcare, environmental monitoring, manufacturing, and free space communications, agrees QinetiQ, which sees potential healthcare applications as including the treatment of prostate and cornea disorders and the development of a new instrument for medical nanoscale imaging that could be used for stem-cell ID and early cancer detection.

Quantum wells

The commercial potential of MWIR lasers has been limited because they require cooling to ~200°C using expensive cooling techniques. A semiconductor laser consists of several layers to enable separate confinement of the charge carriers and the light.

If the middle active layer, where the charge carriers are confined, is made sufficiently thin to act as a quantum well, the laser can be made more efficient. The QinetiQ consortium will use strained-layer engineering to develop a new laser with a highly efficient active region that can operate close to room temperature without the need for expensive cooling. The QinetiQ consortium approach is to build on techniques developed for shorter wavelengths and move up into the 3–5 µm IR spectrum, which programme leader Tim Ashley from QinetiQ says, “is a very key area to a number of applications in gas sensing chemistry.”

“This programme has the potential to revolutionise the use of mid-infrared lasers, transforming them from a niche role to a pervasive technology. The three-year programme has a strong commercial focus with the emphasis on testing prototype lasers in real systems to validate potential system improvements.”

The consortium will focus on Fabry-Perot design lasers based on indium antimonide (InSb) based materials and a novel whispering gallery mode (WGM) resonator, pioneered by researchers at Lancaster University (Figure 4). Lancaster has worked with InAsSbP/InAs, InGaAs/InAs & InAsSb/GaSb materials and its particular research target is to realise room temperature lasers, which operate at 3.3 µm for molecular spectroscopy and gas analysis as well as powerful CW InAs LEDs.

The material of choice for the MWIR is highly strained InSb quantum wells in InGaAlSb-based confinement and cladding layers. Ashley says the system has already proved successful in the development of high-performance IR detectors and FETs and, most importantly, is manufacturable.

Another member of the consortium, the Centre for Integrated Photonics will provide its...
extensive expertise in optical communication laser design and fabrication. Cablefree Solutions will test the prototype lasers in free-space optical communications systems. Procal Analytics will optimise the laser devices for compact remote gas sensing instruments, which BP in turn will field-test in the petrochemical industry environment. For the medical side of the development, Anasys Instruments will test the laser devices in a photo-thermal biomedical imaging system.

Ashley says of the two DTI projects, it is unclear which approach will win. He says that although there has been great progress in quantum cascade laser (QCL) development in recent years, without cooling, these devices are restricted to wavelengths longer than 5 μm, and that achieving emission at 3.3–3.9 μm means much greater quantum well confinement will be necessary, which has proved difficult so far.

**Quantum cascade lasers**

But the QCL approach clearly has great appeal. The DTI’s award for ~£1.1m is backing just that quantum cascade laser approach to the MWIR solution. This consortium comprises Shell Global Solutions, and is led by the ‘pure play’ III-Vs optoelectronic device foundry, Compound Semiconductor Technologies Global, with the academic expertise for the QSense consortia coming from the Universities of Glasgow and Sheffield.

The other manufacturing consortium participant is Stirling-based Cascade Technologies, specialist in design and manufacture of spectroscopic gas ID and monitoring systems based on QCL technology. It has recently signed a licensing deal with Alcatel France that could reap handsome revenues for its laser-based system for detecting drugs, explosives and hazardous compounds.

Last month it also signed a £4m, three-year deal to supply greenhouse and industrial emissions monitoring systems to BP. The lasers currently used by Cascade were originally developed and patented by Lucent, which was recently acquired by Alcatel in a £10.7bn merger. The current agreement, however, enables Cascade to source its lasers from any manufacturer and to have its first major explosive-detection in place in two years.

The QCSense programme aims to develop and incorporate QCLs in a spectroscopic detection system that will measure gas traces escaping naturally from hydrocarbon reservoirs into the atmosphere. It hopes to produce the world’s most sensitive laser hydrocarbon detector and evaluate its use in exploration in large, remote areas.

Bill Hirst, Shell Global Solutions project lead notes that ‘Quantum Cascade Laser technology has the potential to dramatically enhance the LightTouch technique we currently use for rapidly screening large areas for sign of oil and gas. This way we seek to help prioritise exploration activity and focus resources to best effect.’

QCLs (**Figures 5 and 6**) perform across the 4–12 μm mid-IR spectrum. The benefit of a unipolar device is that injected electronics may be ‘recycled’ through a number of active periods and the wavelength of these photons can be controlled by varying the widths of the quantum wells in

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**Figure 5.** Electron microscope images of a QCL laser. [Courtesy: QCSense]

**Figure 6.** An integrated QCL PBG solution. [Courtesy: QCSense]
the active region, allowing a very large wavelength range to be achieved from devices within a single materials system.

Currently the shortest wavelength for QCLs is around 3.8 µm (although some record breaking is anticipated in order to deliver this project.) The depth of the QW limits the shortest wavelength achievable with the InGaAs/AlInAs/InP materials commonly used in QCL structures.

To bring the operating wavelengths to ~3.25 µm (for ethane sensing) requires innovative design in new antimonide-InP-based materials systems, with deeper QWs, and Sheffield has already demonstrated working QCLs at 4.2 µm. QCSense will require fundamental modeling and simulation to optimise the active region design; refinement of existing epitaxy growth techniques of the active growth region; use of a commercial grade device fabrication service; improved waveguide design and laser face coatings and optimisation of chip sub-mounting and thermal management.

In addition, the work will investigate integration of the devices with photonic band gaps to confine the light in 3D to give optical mode control. This offers the possibility of a very high-Q resonator, low current threshold and higher power efficient devices.

The key attraction of Photo-Acoustic Spectroscopy (used for many gases, including ethane, and giving instrument sub ppb sensitivity) is that the same instrument can be used with any laser wavelength absorbed by the gas, so a viable instrument can be based on any of the two laser wavebands under development.

For instrument development, the consortium will take a new approach to increase rejection of noise and increase the sensitivity of the final system. Multi-pass optical cells will enhance signal strength with either an optically resonant cavity or a preferred non-resonant delay line eliminating the problem of locking electronics. Appropriate instrument orientation, from a single point suspension, with seismic isolation mounts, will give significant performance benefits in view of the intended user requirements.

The Universities of Sheffield and Glasgow will establish new IP relating to design and growth of QC laser structures in terms of extended wavelength and tuning. The consortium will aim to commercialise the technology via CST’s foundry model and the Cascade product portfolio.

Glasgow University physics, in addition to collaboration with Shell, has been pioneering the use of sensitive gas detection in healthcare applications (a world market in the areas of radiotherapy, ICU (sepsis) and organ transplant worth in excess of $2.3bn). An additional outlet for the IP created in this programme will be licensing into the healthcare commercial route.

**Defence and space funding**

QinetiQ has undoubtedly gained in IR expertise from both European Space work and UK Defense funding. It designed, built, and operated an MWIR imager launched in June 2000 (Figure 7). That instrument was one of a suite of experiments on board the experimental module called ‘Space Technology Research Vehicle 2 (STRV-2)’ which was carried by the US Department of Defense Tri-Service Experiment 5 (TSX-5) spacecraft.

This year in April, QinetiQ, together with Thales UK, SELEX Sensors, and Airborne Systems, is working on a two-year MOD contract, worth around $16m, awarded to continue to develop thermal imaging technology.

The new program, ALBION, will provide TI technology with higher resolution, greater sensitivity, and lower cost, allowing detection, recognition and identification of targets in environments with low lighting and poor visibility. The material systems involved use cadmium mercury telluride (CMT) focal plane arrays and focus on affordable solutions for military applications. If all goes to plan, ALBION will move from a pilot to an operational phase in 2008.

**IR hopes in Poland**

For some, however, there has been a distinct lack of elusive European R&D funding. Talking recently at a Scottish Optical Association event, the European Commission’s project officer for Nanoelectronics & Photonics, Ronan Burgess, acknowledged that the EU was looking for
greater involvement with Central and Eastern Europe, and that more informative events on how companies could go about this would be held there.

Poland’s Vigo Systems is one company that having worked successfully on uncooled MWIR and LWIR for three decades, has not yet managed to secure Framework 7 funding. But its IR products (Figure 8) are bringing in increased sales, new orders and ever-new projects. “The performance of our uncooled and Peltier cooled devices has been steadily improved, approaching the fundamental BLIP limit,” says CEO Professor Józef Piotrowski. “Our devices are delivered to many OEM manufacturers, and one is an advanced quantum cascade laser based gas analyser of extreme sensitivity.”

“We are improving our reliability with better detector architecture, processing and packaging and working on miniaturised detector modules which integrate the detector, Peltier cooler, cooler controller, detector bias and preamplifier circuits. Some of these modules operate within the 0–1 GHz band, and we are in commercial production of thermal imagers based on microbolometer arrays.”

Vigo Systems backs the quantum cascade approach with ultra sensitive (sub ppb) gas analyser, conventional, Fourier, laser spectroscopy, optical communications, alarms, ultra fast pyrometry and plasma diagnostics, and its detectors are intended primarily for systems, but can be used as stand-alone devices.

Hopefully, such a European photonics manufacturers will play a key part in future consortia awards within the EU Framework 7 funding programme.

Gail Purvis is a freelance industrial journalist, covering the semiconductor and materials industries since 1978.

Figure 8. Vigo Systems’ VIGOcam v50 thermal imager based on micro-bolometer arrays.

MIRTHE’s lead director

Professor Claire Gmachl received her PhD from Vienna University of Technology (VUT) and has worked as technical staff at the Walter Schottky Institute in Munich, and for the Centre of Microstructures at Vienna UT and in the department of Solid State Electronics, before joining Bell Laboratories, then Lucent Technologies where she reached distinguished member status before moving to Princeton. Her major areas of research have been QC lasers for analytic spectroscopy, wireless and optical communications, microcavity lasers with chaotic resonators, non-linear optics in semiconductor heterostructures and Group III nitride devices. Her honours range from a ‘Solid State Physics Award’ from the Austrian Physical Society (1996) through NASA Group Achievement Awards in 2000, an Outstanding Performer Award under the DARPA/MTO PWASSP program in July 2001 to MacArthur Fellow in 2005.

The infrared handful to date

Near-infrared (NIR): 0.75–1.4 µm in wavelength (IR-A DIN), silicon.

Short-wave (SWIR): 1.4–3 µm (1530–1560 nm dominant spectral region for long-distance telecoms.) IR-B DIN. InGaAs.

Mid-wave IR (MWIR): IR-C DIN also intermediate-IR (IIR) 3–8 µm (IR-C DIN), InSb, HgCdTe and PbSe.

Long-wave IR (LWIR): IR-C DIN, 8–15 µm, HgCdTe.