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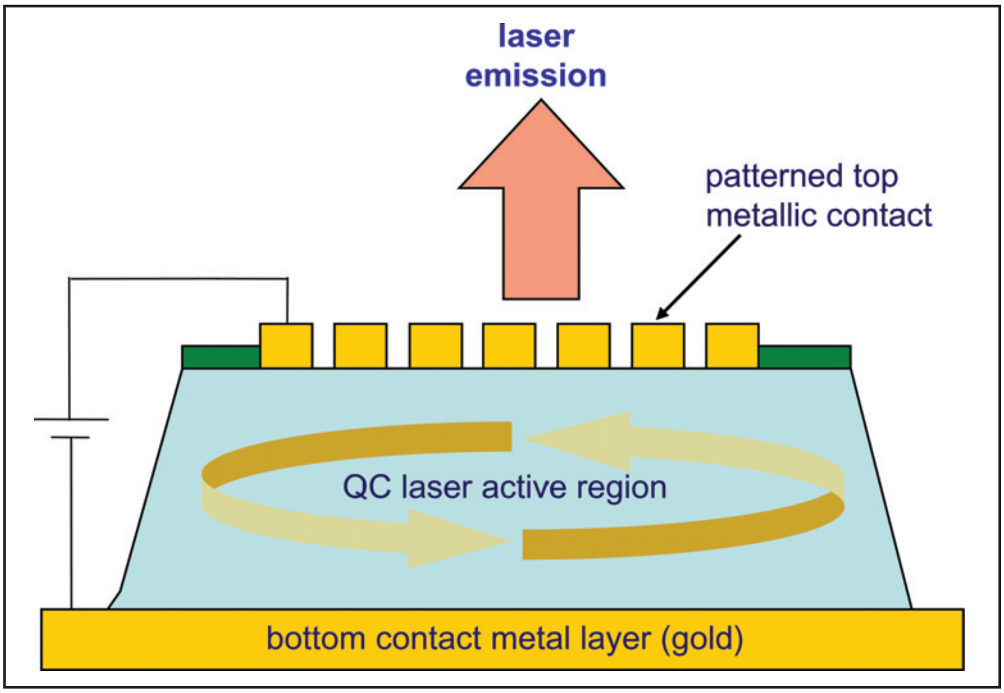
'Continuous-wave operation of 2.7 THz photonic crystal quantum cascade lasers', G. Sevin, D. Fowler, G. Xu, F. H. Julien, R. Colombelli, H. Beere and D. Ritchie

A monochromatic and highly directional THz photonic crystal quantum cascade laser that operates in CW mode has been developed for heterodyne detection

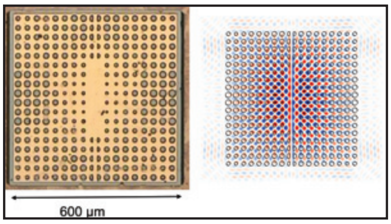
bringing THz into focus



A continuous-wave surface-emitting photonic crystal THz quantum cascade laser (QCL) with a monochromatic and low divergence output beam has been demonstrated. Researchers at the University Paris Sud in France in collaboration with Cambridge University in the UK combined their recently designed efficient photonic crystal resonator with a low-threshold quantum cascade material to produce an optimised 2.7 THz QCL which could be used for heterodyne detection applications such as in astronomy.

ABOVE: The photonic crystal THz quantum cascade laser has upper and lower gold metallic layers to provide the confinement in the active region

RIGHT: [Left] Surface view of a typical photonic crystal device before the bonding wire is applied to the central region. [Right] The electric field is distributed across the whole surface of the device



The leading source

QCLs in which the emission frequency can be set through the design of the semiconductor multi-quantum-well structure, are well established as a semiconductor-based source of coherent radiation in the mid-infrared and THz range. They are also compact, operate under electric current injection and, since one electron can emit more than one photon, they are relatively powerful. THz QCLs can be used in imaging applications, such as security screening and medical imaging for example, since paper, plastics and biological materials are often transparent in the THz range. THz QCLs could also be employed as local oscillators to provide the very precise frequency reference for heterodyne detection.

A direct approach

The Paris Sud/Cambridge team developed the characteristics of their THz QCLs with heterodyne detection applications in mind. This collaboration began a few years ago. Cambridge University performs the molecular beam epitaxy growth of the semiconductor samples whilst the University Paris Sud develops the device design, fabricates and characterises the devices. The main challenge presented by QCLs at this long wavelength is that the far-field emission pattern is, in general, extremely nondirectional. To overcome this, the researchers have developed and employed a metallic photonic crystal resonator: the top electrode of the laser is patterned with air holes to periodically modulate the light phase velocity in the device. To achieve the continuous-wave operation, the researchers employed a low-threshold quantum cascade material and, to keep the threshold current density at a resonable level, they graded the hole size in the photonic crystal resonator, hence enhancing the overall Q-factor. They also introduced a π phase shift in the centre of the photonic crystal structure to achieve the single-lobed surface emission with a very low divergence beam quality. These performance enhancements came at the expense of slightly increased waveguide losses and a reduced operating temperature, however. These QCL devices operate up to a temperature of 39 K and has an output power of 300 μW at 10 K.

Seeing stars

The properties of the developed QCLs make them suitable for THz detection in astronomy. Astronomers are particularly interested in this as a large proportion of the photons emitted after the Big Bang have a frequency in the 0.5 to 7.5 THz range. In addition, important molecules such as water can be detected by observing their spectral signals in the THz range. Whilst the cryogenic operating temperature and low output power of the developed QCLs are a disadvantage in many applications, they can be acceptable in astronomical detection. In the near future, QCL devices such as these could be useful to perform heterodyne detection for astronomy applications.

The next step in the development of the QCLs is to increase the output power; the researchers are working on new photonic crystal designs as most applications need output powers in the mW range. They are also working in collaboration with Leeds University in the UK and with other teams in France (Ecole Normale Superiéure and the University Paris Diderot) to increase the maximum operating temperature which is a very important issue for widespread application. Contrary to mid-infrared QCLs which can operate at room temperature, THz QCLs still need cryogenic cooling. The current record is 186 K (held by Professor Q. Hu's group at MIT) and, although room temperature would be ideal, reaching an operating temperature of 240 K would be a big breakthrough as Peltier-cooling systems could be used.

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