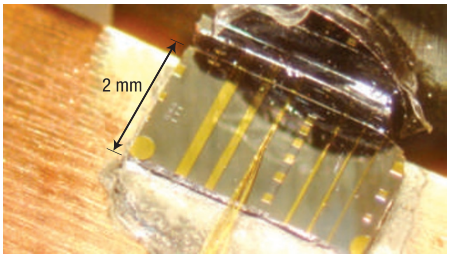
# Quantum warming

The demonstration in this issue that strong magnetic confinement of electrons can dramatically increase the operating temperature of terahertz quantum cascade lasers is good news for the dream of reaching room temperature. *Nature Photonics* spoke with Qing Hu about the result and the future prospects.

**Tell me about the origins of quantum cascade lasers in the terahertz region?**
The quantum cascade laser (QCL) concept was first proposed as early as 1971, but it took almost a quarter of a century before Capasso's group (Bell Labs) developed a QCL in the infrared. This was a major breakthrough, but the development of a counterpart device for the terahertz region has proved to be much more challenging. The terahertz region has been inaccessible because it is a range in which conventional semiconductor devices do not function. For example, electronic devices such as transistors work up to several hundred gigahertz and conventional diode lasers, even using exotic materials like lead salts, only operate above 10 THz so there is a gap of over one decade of spectra in between with no convenient solid-state sources. The terahertz gap is essentially hindering the exploration of this important area. Seven years ago, Tredicucci's group (Pisa/Cambridge) finally made a QCL that operates in the terahertz and that really opened up a great opportunity for the field.

**Where are we today in terms of performance?**
The community has made a lot of progress in recent years in terms of frequency coverage and output power. For example, my group has already achieved ~1/4 W of output power from a small device. Faist's group has developed QCLs at ~1.2 THz. Now I would say that the main challenge, the 'holy grail' if you like, is to raise the operating temperature. To put this into perspective, the highest temperature today is 178 K (which was achieved by Capasso's group) and my group has also reached 174 K. At this temperature and such a low emission frequency, the thermal energy is actually greater than the photon energy and that causes many problems. This is unprecedented for any other kind of solid-state photonics device. I come from a terahertz detector background and I lived with liquid helium as a way of life. Our first laser worked at 87 K and so to reach 225 K [see page 41 of this issue] is quite an achievement.



Q. HU

A terahertz QCL. Researchers are now striving to achieve room-temperature operation.

**So what *is* next?**
The next step is to reach even higher temperatures and open up a much wider range of applications. We have some well-defined applications such as radio astronomy and atmospheric sensing and I am working closely with those communities, but in order to have a broader range of impact we need to make these sources much more widely available and easier to use and one key factor is the operating temperature. We need to get them working at the temperature of a thermoelectric cooler — roughly speaking 240 K. Then it essentially becomes a plug-and-play device with no need for a liquid coolant. That is perhaps the single most important goal in the field and ultimately we want to reach above room temperature. If we can do that, I am confident that there will be applications that we can't even dream about today.

**Will we ever reach room temperature?**
People keep asking me that question and there are several ways of answering. One is that if we can make these type of QCLs on either silicon- or nitride-based materials with the same quality as the GaAs/AlGaAs systems, then they will operate above room temperature because the optical phonon energies of these materials are much higher, but of course these materials are far from ready. A second approach is to make a quantum-box laser with lateral confinement, and several researchers are working to achieve this. At a recent workshop on QCLs, when participants were asked whether they believe that an operating temperature of 240 K will be reached by 2010 the consensus opinion was that, yes, it will be achieved.

**How does the work of your collaboration on large magnetic fields fit in?**
This work reported in this issue with a very high magnetic field helps, as it offers a tunable way of obtaining and investigating lateral confinement. Although using a large field instead of an engineered structure is not practical for a commercial device, the end result should be the same. Our results essentially demonstrate what you can expect in terms of raised temperatures of operation if you can achieve lateral confinement by any technique. That is the key message. Theoretically, people have been expecting this kind of improved performance. but it is really nice and important to have an experimental confirmation and demonstration. The magnetic field gives you an additional tuning knob. You can learn a lot. Essentially we want to increase upper-state lifetime to help achieve lasing and we are pursing different ways, such as alternative gain media or confinement. You have to find a way to stop or quench the non-radiative decay from the upper level.

**In your paper you also report lasing a record low frequency of 0.7 THz, is this particularly important and useful?**
Five years ago I would have said yes. For sometime the goal has been to reach an emission frequency of 1 THz which is the border between electronic and photonic devices. But the field has evolved since then. Other group's such as Faist's have already demonstrated sub-terahertz operation from QCLs with a magnetic field and 1.4 THz without. On the other hand, it does demonstrate that THz QCLs can now operate over a very wide range of frequencies from around 0.7 THz (wavelength of 330 μm) to around 3 μm and that's a span of more than 2 decades. I come from electronics and there has been slow but steady progress and devices such as Schottky diodes now operate up to 850 GHz and electronics is continually pushing up and will take over below 1 THz.

INTERVIEW BY OLIVER GRAYDON

*Qing Hu is a co-author on a letter on page 41 of this issue.*