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Lasers & Sources

Efficient laser arrays for infrared spectroscopy

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New high-power quantum cascade lasers show continuous-wave operation and wide tunability at room temperature.

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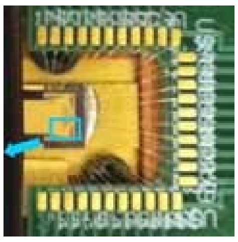

All molecules absorb infrared radiation at characteristic frequencies, with most substances preferring the mid-infrared band (roughly, the 3–16μm wavelength range). Hence, infrared spectroscopy can be applied to the study and identification of chemicals. In fact, this technique is used for manufacturing quality control of a variety of products that we interact with daily, including food and beverages, plastics, pharmaceuticals, and textiles. It is also useful in detecting the presence of unwanted or toxic chemicals such as pollutants, explosives, nerve gas, and others.

In general, infrared spectroscopy is a very specific technique (capable of identifying a particular substance and not have false detections due to the existence of a similar chemical in the sample) that can be done quickly and on-site. However, detecting trace amounts (parts-per-billion) of chemicals is often challenging. The reason is that traditional broadband infrared light sources do not have the necessary characteristics for use with high-sensitivity detection techniques such as cavity ring-down spectroscopy or photoacoustic spectroscopy. These require a long light-path length (or, equivalently, a laser source that is highly directional) or high average power at a specific wavelength. On the other hand, tunable lasers can have these characteristics, which makes them an enabling technology for trace detection of harmful chemicals.

The choice of lasers, however, is limited. Large systems based on carbon dioxide lasers and optical parametric oscillators have been used for a while, but suffer limitations due to size and cost. Semiconductor laser diode sources, which are inherently compact and durable, would be preferable. Unfortunately, this development has been hindered by intrinsic physical limitations of the technology. These include the need to cryogenically cool the laser or deal with pulsed operation, which broadens linewidths, reduces spectroscopic resolution, and limits average power delivery.

The indium-phosphide (InP) system[1] is well suited for many types of semiconductor devices, and it is already predominant in telecommunications. An added benefit is that it can be used to make high-power mid-infrared quantum cascade lasers (QCLs).[2,3] Because this technology is compact and can often be used directly at room temperature, it is being investigated for a variety of spectroscopic applications. Wide tunability in low power devices has been demonstrated using external cavity optical feedback.

Recently, there have been tremendous improvements in mid-infrared QCL technology in terms of output power and efficiency.[4,5] To date, we have demonstrated room temperature continuous-wave operation with 5W output power and wall-plug efficiency above 20% at a wavelength around 5μm. In addition, we continue to explore possibilities of combining high power capability with tunable single mode (single wavelength) devices since a laser array with these characteristics is particularly attractive for chemical sensing applications. This effort led us to demonstrate 34W peak power in a single mode with a photonic crystal (PC) distributed feedback (DFB) coupling mechanism.[6] The PCDFB approach allows for simultaneous manipulation of the spectrum and the far field using a two-dimensional grating that is monolithically integrated inside the laser waveguide.

Although pulsed-mode operation is sufficient for some applications, photoacoustic sensors prefer a high-power continuous-wave laser source for both sensitivity and ease of operation. By adding a surface DFB grating and high-fidelity thermal packaging, we recently demonstrated a single mode laser at a wavelength of approximately 4.75μm with a power output of 1.1W in room temperature continuous operation.[7] Further optimization has successfully brought this value to 2.4W.

In terms of tunability, the gain bandwidth of a QCL is usually quite broad (several hundred cm^{-1}). Although this limits the maximum value of the material gain, it also provides the possibility of one device to emit over a wide spectral range, which is the foundation of all tunable QCLs.

Rather than use external optics and a diffraction grating to tune the laser (as in an external cavity system), an all-electrical tuning mechanism is more attractive in terms of size, speed, and robustness. An array of DFB lasers is much more compact and robust, and it has been demonstrated previously for near-infrared and long wavelength QCLs. In this case, each laser in the array can emit its own individual wavelength and can be electrically tuned by changing the driving current. Although the tuning range of each laser is limited, combining an array of tens of DFB lasers can cover a wide range of the electromagnetic spectrum. We have recently demonstrated the first DFB QCL array working in continuous-wave mode at room temperature that covers a wide spectral range from 4.5 to 4.7μm ($95cm^{-1}$). This chip can deliver up to 150mW continuous-wave output power with low fidelity thermal packaging (see Figure 1).

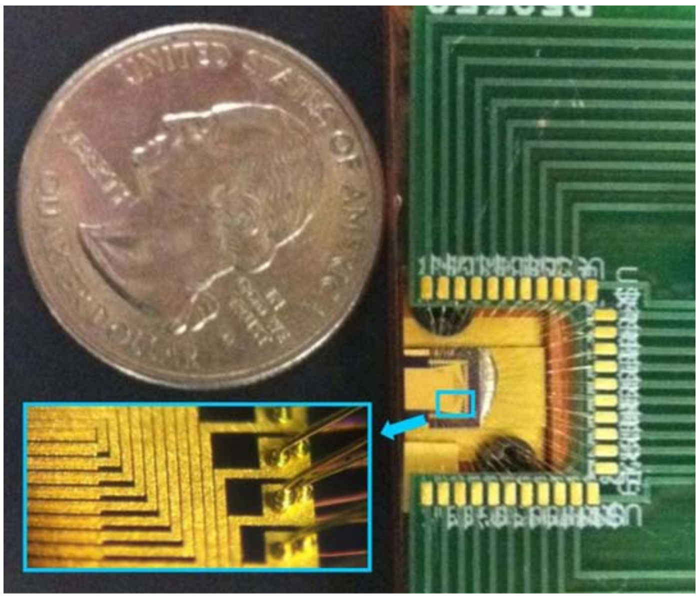

Figure 1. *Fully packaged distributed feedback quantum cascade laser array compared with a US quarter. This device can operate in continuous-wave mode with a wavelength coverage of 4.5–4.7μm at room temperature.*

In conclusion, with the improvement of quantum cascade gain media, a widely tunable, high-power DFB-QCL array is realized for the first time with the capability of room-temperature continuous-wave operation. Future work includes improving the thermal packaging and implementing a compact design that includes diffraction gratings to combine the output beam of all the emitters into a single spot. The finished product is anticipated to be highly attractive for chemical sensing applications.

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Manijeh Razeghi joined Northwestern in 1991 as a Walter P. Murphy professor and as the director of the Center for Quantum Devices. She is an elected fellow of the Society of Women Engineers (1995), SPIE (2000), the International Engineering Consortium (2003), the Optical Society of America (2004), the American Physical Society (2004), the Institute of Physics (2005), the Institute of Electrical & Electronics Engineers (2005) and the Materials Research Society (2008).

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