Highly sensitive chemical detection in the field

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Optical sensing methods, in particular IR absorption spectroscopy combined with quantum-cascade lasers, enable rapid and autonomous operation in a compact and rugged package.

Many chemicals have unique absorption spectra in the IR wavelength range between 2 and 12μm, known as the molecular-fingerprint region. This region enables detection at trace-concentration levels because of strong absorption cross sections. Accordingly, IR spectroscopy can provide both highly sensitive and selective detection of gas-phase molecules, and it can be applied to environmental monitoring as well as detection of hazardous chemicals and explosives.

Fourier-transform IR spectroscopy is often used for chemical detection since it can pick up hundreds of gaseous chemicals at moderate concentrations, typically on the order of parts per million (ppm). Laser-based systems, on the other hand, offer greater sensitivity by providing higher spectral radiance. These techniques, however, have been hindered by the limited availability of laser sources in the IR. This limitation is being overcome by advances made in the field of quantum-cascade lasers (QCLs), semiconductor lasers that can be tailored to a variety of wavelengths throughout the IR.

One disadvantage of QCLs has been the spectral coverage provided by single-mode QCLs, which are often limited to a few wave numbers. Consequently, only small molecules with narrow absorption features can be detected. A grating-tuned external-cavity QCL (ECQCL) can provide a tuning range greater than 100cm⁻¹, enabling detection of multiple chemicals that have absorption features within that range, as well as sensing of large (heavy) molecules that have broad absorption features.

Although ECQCLs increase spectral coverage, they can be limited in speed and resolution. We have focused the development of our ECQCLs to tune over the entire spectral range in less than 100 milliseconds with sufficient resolution (0.2cm⁻¹) for applications in gas sensing at atmospheric pressures. This resolution is adequate for detection of most chemicals, since molecules with narrow absorption features will be pressure broadened. Figure 1 shows the tuning achieved with our ECQCL by scanning over the absorption features of acetone (a heavy molecule) and hydrogen peroxide (a light molecule), which are both precursors of the explosive triacetone triperoxide.

Combining our ECQCL with a multipass cell and custom-made low-noise electronics, we have developed a portable, cryogen-free sensor for field measurements. This system provides detection at concentration levels on the order of low parts per billion for multiple chemicals. Figure 2 shows measured concentrations for three sample chemicals, including freon-134a (1,1,1,2-tetrafluoroethane), nitrous oxide, and ammonia, in which a portable plume generator is used to release the chemicals at a distance of 200m from the sensor.

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Figure 2. Five-minute section of sensor-system results from field tests showing simultaneous detection of all three target chemicals. (a) Freon-134a, (b) nitrous oxide, and (c) ammonia. ppm: Parts per million.

Thus, detection and identification of chemicals can be accomplished using a highly sensitive and portable device, at moderate distances downwind from the source. We are currently working to reduce the size and power while maintaining sensitivity to enable stand-off detection of a larger suite of chemicals at distances greater than 200m by investigating astigmatic multipass cells, which provide a longer pathlength in a cell with a smaller volume.6,7

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References