Modern IR diode lasers enable novel photoacoustic sensors

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Using a single, continuously tunable laser provides better molecular discrimination and enables simultaneous detection of several molecules.

The global war on terror and escalating environmental awareness have made rapid detection and identification of hazardous materials a priority. Detecting a diverse range of chemical and biological agents requires an adaptable sensor platform capable of identifying threats before they cause harm. Research and development in hazardous-materials detection technology focuses on increasing speed and sensitivity, while reducing size and cost.

Currently, the US army is using ion-mobility-spectrometry-based products to assess threats. While they are useful for certain applications, they have limitations, including poor specificity and little adaptability in combination with other chemical systems. We are studying photoacoustic spectroscopy (PAS) to improve current technologies and address the latest sensor-system requirements.

PAS is a highly sensitive technique that can be used for detection of trace levels of gases. It uses optical absorption and subsequent measurement of a pressure wave produced from a photo-induced change in the sample’s thermal state (see Figure 1). To generate acoustic waves in gases, the sample must be heated periodically to produce pressure fluctuations. This is accomplished using modulated or pulsed excitation sources. Although previous research has demonstrated the sensitivity of photoacoustic sensors at parts per trillion,$^{1,2}$ the total system size represents a large logistics burden in terms of bulk, cost, and power consumption.

To date, limited research has been done to demonstrate the feasibility of a miniaturized photoacoustic sensor.$^{3–5}$ Initial examination of PAS scaling principles with respect to micro-electromechanical-systems (MEMS) dimensions indicated that photoacoustic signals would remain at similar sensitivities or even surpass those commonly found in macro-scale devices.$^{3–5}$ However, these investigations used relatively bulky carbon dioxide laser sources. To realize the full advantage of evolving...
MEMS photoacoustic-cell designs, we are using quantum-cascade lasers (QCLs) with small package sizes, increased wavelength tunability, and room-temperature operation.

We have examined the efficacy of PAS applied to military and environmental problems. Specifically, we have demonstrated QCL-based, MEMS-scale photoacoustic sensors with detection limits at parts-per-billion levels for the nerve-gas simulant dimethyl methyl phosphonate (DMMP), as well as chlorobenzene, a propellant analog and an intermediate in the manufacture of pesticides such as dichlorodiphenyltrichloroethane (better known as DDT) and hexafluoroethane (Freon 116), and DMMP, and 1,4-dioxane are different. Data points for each chemical are encircled in colored lobes. PC 1, 2, 3: Principal components.

Figure 3. (A) Laser photoacoustic (——) and Fourier-transform IR (FTIR) data (— - -) for vinyl acetate, acetic acid, acetone, and 1,4-dioxane. The photoacoustic and FTIR spectra are in excellent agreement. (B) Partial least-squares (PLS) model data illustrating that the photoacoustic spectral features for vinyl acetate, acetic acid, acetone, and 1,4-dioxane are different. Data points for each chemical are encircled in colored lobes. PC 1, 2, 3: Principal components.

In summary, the next-generation PAS sensor using broadly tunable QCL sources shows promise to meet the requirements for environmental and military applications. We have successfully demonstrated a QCL-based, MEMS-scale photoacoustic sensing platform capable of both trace-vapor detection and molecular discrimination. We believe that this sensor platform is an important step towards development of a portable prototype. Our next step will be to use multiphysics modeling to better understand the acoustics of MEMS-scale, photoacoustic gas sensors. Other investigations will take advantage of the QCL-based photoacoustic motif and examine it for detection of solid samples.

The authors thank Nancy Stoffel and Almon Fisher from Infotonics Technology Center.

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References

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