Lasers Key to Handheld Gas and Liquid Sensors

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Terrorists have just laced the water supply of a major metropolis with a chemical so lethal that only small amounts are needed to kill thousands of people. But the chemical never reaches its targets. Tiny liquid phase sensors at strategic points in the city's water mains detect the chemical as it passes and tell a computer to close down the affected pipes.

Image: Boris Mizaikoff displays a prototype of the gas phase sensor, while graduate student Christy Charlton holds the liquid phase prototype.

Current technology is too cumbersome for this kind of rapid detection and response. But new advances in liquid and gas phase chemical sensing being made at the Georgia Institute of Technology may lead to the development of palm-sized sensing tools that can provide the instant detection needed to stop such an attack.

Using small quantum cascade lasers, researchers at Tech, along with colleagues from Tel-Aviv University and OmniGuide Communications, have built and demonstrated a prototype handheld gas phase chemical sensing device and a liquid phase sensing device. The details appear in the July 15, 2005 issue of Analytical Chemistry and the May 9, 2005 issue of Applied Physics Letters.

The quantum cascade laser is the key to scaling down midinfrared chemical sensing tools to fit in the palm of the hand, said Boris Mizaikoff, associate professor in the School of Chemistry and Biochemistry at Georgia Tech.

"This diode laser light source emits midinfrared frequencies, operates at room temperature and is small – roughly the same size as the laser you use in a laser pointer or CD player," said Mizaikoff.

Almost every organic molecule has a very distinctive absorption pattern in the midinfrared range (roughly between three and 20 microns) Illuminating molecules with a laser tuned to its fingerprint frequency will cause the molecules to vibrate as they absorb radiation at that frequency.

Detecting a chemical is as simple as illuminating a small volume of gas or liquid with a laser. If the laser is tuned to a characteristic absorption frequency of benzene, for example, and benzene is present, the molecules will vibrate and absorb an amount of radiation at its characteristic absorption frequency indicating its concentration.

"The quantum cascade lasers can be designed by bandstructure engineering to emit almost anywhere in the midinfrared band," said Mizaikoff. "So, if the molecule you want to detect has an absorption at

11 microns, you design a laser that emits precisely at that frequency. With the concept of the quantum cascade laser, that's possible for the first time."

For the gas sensing modules, Mizaikoff and his student Christy Charlton use a photonic band gap hollow waveguide (developed by OmniGuide),essentially a hollow, flexible tube, to both contain very small amounts of the air being sampled and assist in sensing. The waveguide can be built to propagate only one wavelength of light very well. So when the laser illuminates the gas molecules inside the waveguide, the waveguide will propagate only the selected fingerprint frequency for detecting a specific molecule.

"In our paper, we've shown that if we take only one meter of photonic band gap hollow waveguide with an inner diameter of 700 microns coupled to a frequency-matched quantum cascade laser, we've been able to detect levels down to 30 parts-per-billion (ppb) of ethyl chloride," said Mizaikoff. "In our opinion, it's among the most sensitive measurement that's been demonstrated in gas phase sensing in a hollow wave guide to date."

Gas sensing done this way requires a sample of only one milliliter of gas, compared to few hundreds of milliliters for other techniques using regular multi-pass gas cells, he added.

One of the most promising applications for this technology is breath diagnostics, said Mizaikoff.

"A lot of diseases, like asthmatic conditions or acute lung injuries, have specific biomarkers that are contained in breath," he said. "The problem is that you have a dramatic increase of these markers, but still at very low concentration levels, so you need extremely sensitive and reliable tools to detect these changes. We believe this is one way to develop a very compact sensing device, which could provide the sensitivities needed for breath diagnostics."

Since the lasers are so small, devices could be made to sense multiple chemicals by simply adding more lasers.

For the liquid phase device, researchers use a planar silver halide waveguide, developed at Tel-Aviv University, to transmit the radiation. As with the gas devices, the quantum cascade lasers vastly increase the sensitivity of liquid phase chemical detection at the surface of this waveguide.

"By making the waveguide thinner and coupling the laser into that, we're actually increasing the amount of energy transported in the so-called evanescent field, which means the sensitivity goes up," said Mizaikoff.

Currently, there are only few techniques available that can provide an instant response at trace-levels in water monitoring. Usually, gas or liquid chromatography, which require collecting samples, is needed to detect such fine amounts.

"This might be the road to sensors that can continuously measure at ppb levels, with molecular selectivity, and instantaneously," said Mizaikoff. "We believe this technology will be the inroad to single digit ppb water quality measurement."

Link: Applied Sensors Laboratory

Source: Georgia Institute of Technology