Combing light for tell-tale chemical fingerprints

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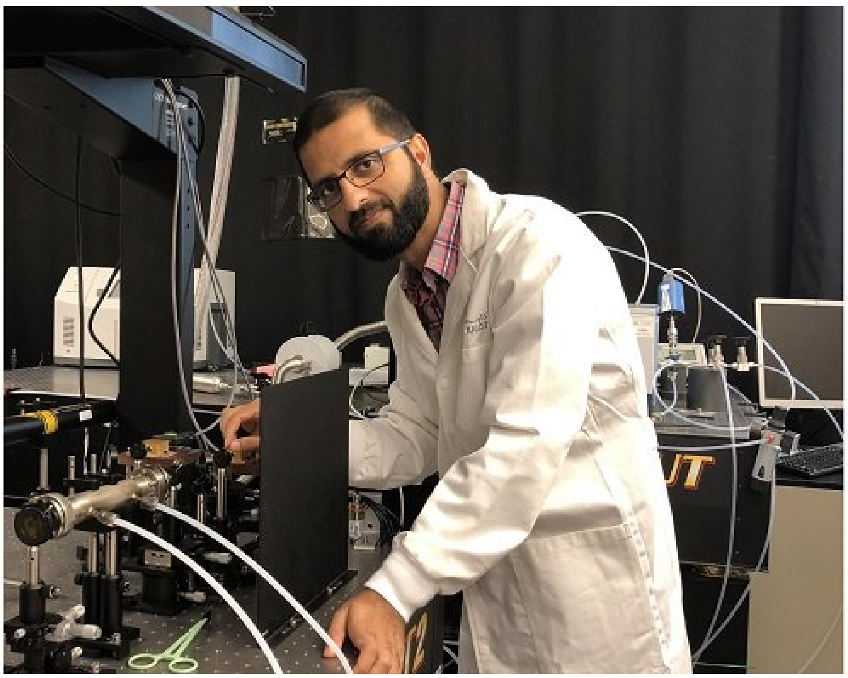

Associate Professor Aamir Farooq working with a quantum cascade laser: his team's work could help identify pollutants and improve optical sensors. Credit: KAUST

A laser-based technique that can scan and lock on to molecular vibrational signals that are normally too complex to resolve clearly could enable production of sensors for multi-species identification in harsh environments, including industrial emissions.

The spring-like characteristics of chemical bonds cause molecules to shake and rotate when stimulated by infrared light. The patterns resulting from these excitations can uniquely identify substances, particularly in the fingerprint region—a frequency band covering the mid-infrared spectrum. In realistic environments, however, vibrations in the fingerprint region become blurred and hard to resolve because of overlapping signals.

One way to detect individual molecular signatures is with high-precision lasers, but these light sources normally operate either at fixed frequencies or scan a very limited frequency range in the mid-infrared band. Now, a research team, including Bidoor AlSaif and Aamir Farooq from KAUST, reports having overcome these restrictions with a tunable laser that can be calibrated through equally spaced optical lines known as frequency combs.

Quantum cascade lasers use tunneling transitions between fabricated nanostructures to generate mid-infrared light. By constructing the devices so that optical amplification occurs in an external, mirror-controlled cavity, frequency emissions can cover the entire fingerprint region. Implementing these features into spectrometers that scan and record molecular vibrations has been hindered, however, by the natural electrical noise of tunneling electrons.

"External cavity quantum cascade lasers tend to have a high jittering behavior, which is problematic for precision spectroscopy applications," explains AlSaif. "That's why we developed an idea to lock the mid-infrared quantum cascade laser to a near-infrared frequency comb."

The KAUST team and coworkers from Italy combined the emission of quantum cascade laser and frequency comb using a nonlinear optical process called sum-frequency generation that only appears when two photons interact strongly. Jitter effects could be stabilized by monitoring for beat-note signals caused by differences in optical frequencies between the frequency comb and the calibrated beam.

To demonstrate potential applications of the spectrometer, the researchers tested the device on nitrous-oxide gas (N2O), an atmospheric component linked to both ozone depletion and global warming. Overcoming the systematic jitter limitations provided striking molecular resolution—even faint rotational signals that occur when N2O absorbs light were observed superimposed on the vibrational fingerprints.

"Accurate spectroscopic data are very scarce in the mid-infrared range," says Farooq. "This type of device has the opportunity to not only do broad spectral surveys, but will also be very useful in optical sensors."

More information: Marco Lamperti et al. Absolute spectroscopy near 7.8 μm with a comb-locked extended-cavity quantum-cascade-laser, *Scientific Reports* (2018). DOI: 10.1038/s41598-018-19188-2

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