# New sensor can take any gas and tell you what's in it

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Expert sommeliers can take a whiff of a glass of wine and tell you a lot about what's in your pinot noir or cabernet sauvignon.

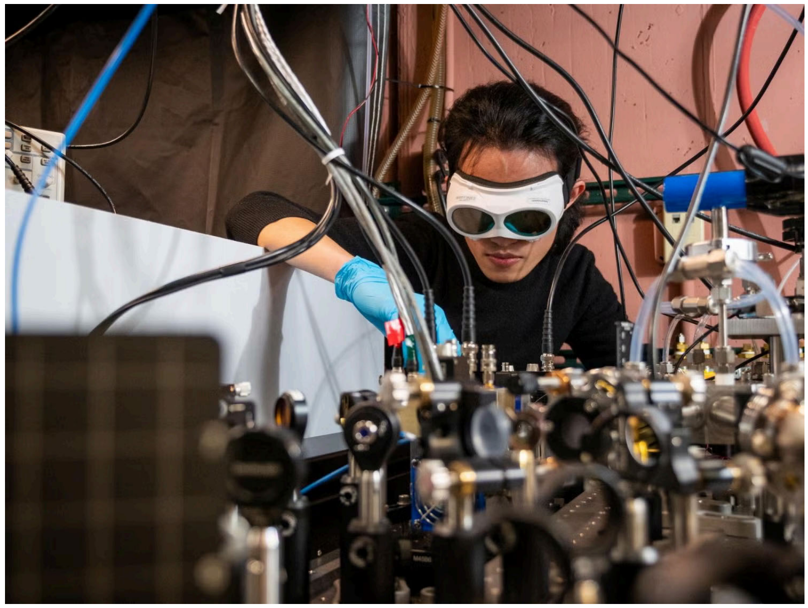
A team of physicists at CU Boulder and the National Institute of Standards and Technology (NIST) have achieved a similar feat of sensing, only for a much wider range of substances.

The group has developed a new laser-based device that can take any sample of gas and identify a huge variety of the molecules within it. It is sensitive enough to detect those molecules at minute concentrations all the way down to parts per trillion. Its design is also simple enough that researchers could employ the method quickly and at a low cost in a range of settings, from diagnosing illnesses in human patients to tracking greenhouse gas emissions from factories.

The study was led by scientists at JILA, a joint research institute between CU Boulder and NIST. The team published its findings on Feb.

19 in the journal Nature.

"Even today I still find it



Qizhong Liang in Jun Ye's lab at JILA on the CU Boulder campus. (Credit: Patrick Campbell/CU Boulder)

Jun Ye (Credit: Glenn Asakawa/CU Boulder)

unbelievable that the most capable sensing tool can in fact be built with such simplicity, using only mature technical ingredients but tied together with a clever computation algorithm," said Qizhong Liang, lead author of the research and a doctoral student at JILA.

To show what the tool is capable of, Liang and his colleagues drilled down on an important question in medicine: What's in the air you breathe out?

The researchers analyzed breath samples from real human subjects and showed that they could, for example, identify the types of bacteria living in peoples' mouths. The technique could one day help doctors diagnose lung cancer, diabetes, chronic obstructive pulmonary disease (COPD) and much more.

Physicist Jun Ye, senior author of the study, said the new work builds on nearly three decades of research into quantum physics at CU Boulder and NIST—especially around a type of specialized device known as a frequency comb laser.

"The Frequency comb laser was originally invented for optical atomic clocks, but very early on, we identified its powerful application for molecular sensing," said Ye, a fellow of JILA and NIST and professor adjoint of physics at CU Boulder. "Still, it took us 20 years to mature this technique, finally allowing universal applicability for molecular sensing."

## A shaking cavity

To understand how the team's technology works, it helps to understand that all gases, from pure carbon dioxide to your stinky breath after you eat garlic, carry a fingerprint of sorts.

If you probe those gases with a laser that spans multiple "optical frequencies," or colors, the molecules in the gas samples will absorb that light at different frequencies. It's almost like a burglar leaving behind a thumbprint at a crime scene. In a previous study, for example, Liang and his colleagues used this laser absorption detection principle to screen human breath samples for signs of SARS-CoV-2 infections.

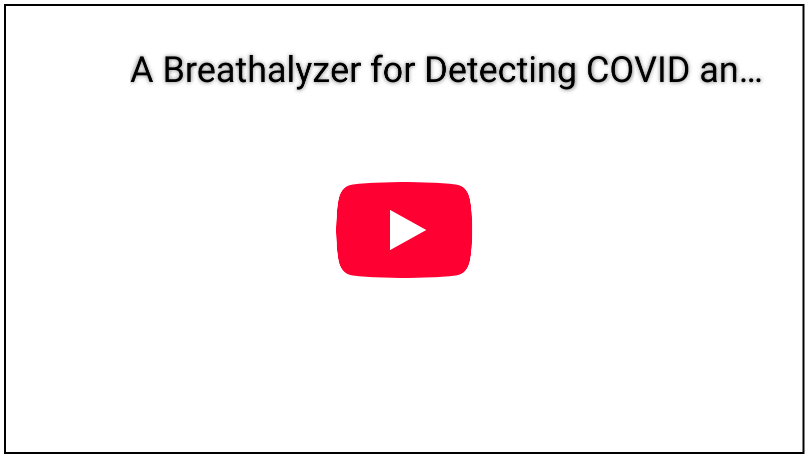
Frequency combs are well suited to that technique because, unlike traditional lasers, they emit pulses of light in thousands to millions of colors at the same time. (JILA's Jan Hall pioneered these lasers, winning the Nobel Prize in Physics for his work in 2005).

But to detect molecules at low concentrations, those lasers must also pass through the gas sample over distances of miles or more so that the molecules can absorb enough light.

To be practical, scientists must realize that distance within containers for gases that are measured on the scale of a foot.

"We enclose the gas sample with a pair of high-reflectivity mirrors, forming an 'optical cavity,'" Liang said. "The comb light can now bounce between those mirrors several thousand times to effectively increase its absorption path length with the molecules.”

Or that’s the goal. In practice, optical cavities are tricky to work with and eject laser beams if they aren’t properly matched to the resonant modes of the cavity. As a result, scientists previously could only use a narrow range of comb light, and detect a narrow range of molecules, in a single test.



In previous research, Ye, Liang and their colleagues used specialized lasers to detect signs of COVID-19 infections in human breath. (Credit: NIST)

In the new study, Liang and his colleagues overcame this longstanding challenge. They presented a new technique they named Modulated Ringdown Comb Interferometry, or MRCI (pronounced “mercy”). Rather than keep its optical cavity steady, the team periodically changed its size. This jiggling, in turn, allowed the cavity to accept a much wider spectrum of light. The team then deciphered the complicated laser intensity patterns emerging from the cavity with computational algorithms to determine the samples’ chemical contents.

“We can now use mirrors with even larger reflectivity and send in comb light with even broader spectral coverage,” Liang said. “But this is just the beginning. Even better sensing performance can be established using MRCI.”

## A sensor for breath

The team is now turning its new gas sniffer on human breath.

“Exhaled breath is one of the most challenging gas samples to be measured, but characterizing its molecular compositions is highly important for its powerful potential for medical diagnostics,” said Apoorva Bisht, co-author of the research and a doctoral student in Ye’s lab.

Bisht, Liang and Ye are now collaborating with researchers at CU Anschutz Medical Campus and Children’s Hospital Colorado to use MRCI to analyze a range of breath samples. They are examining whether MRCI can distinguish samples taken from children with pneumonia from those taken from children with asthma. The group is also analyzing the breath of lung cancer patients before and after tumor removal surgery and is exploring whether the technology can diagnose people in early stages of chronic obstructive pulmonary disease (COPD).

“It will be tremendously important to validate our approach on real world human subjects,” Ye said. “Through close collaboration with our medical colleagues at CU Anschutz, we are committed to developing the full potential of this technique for medical diagnosis.”

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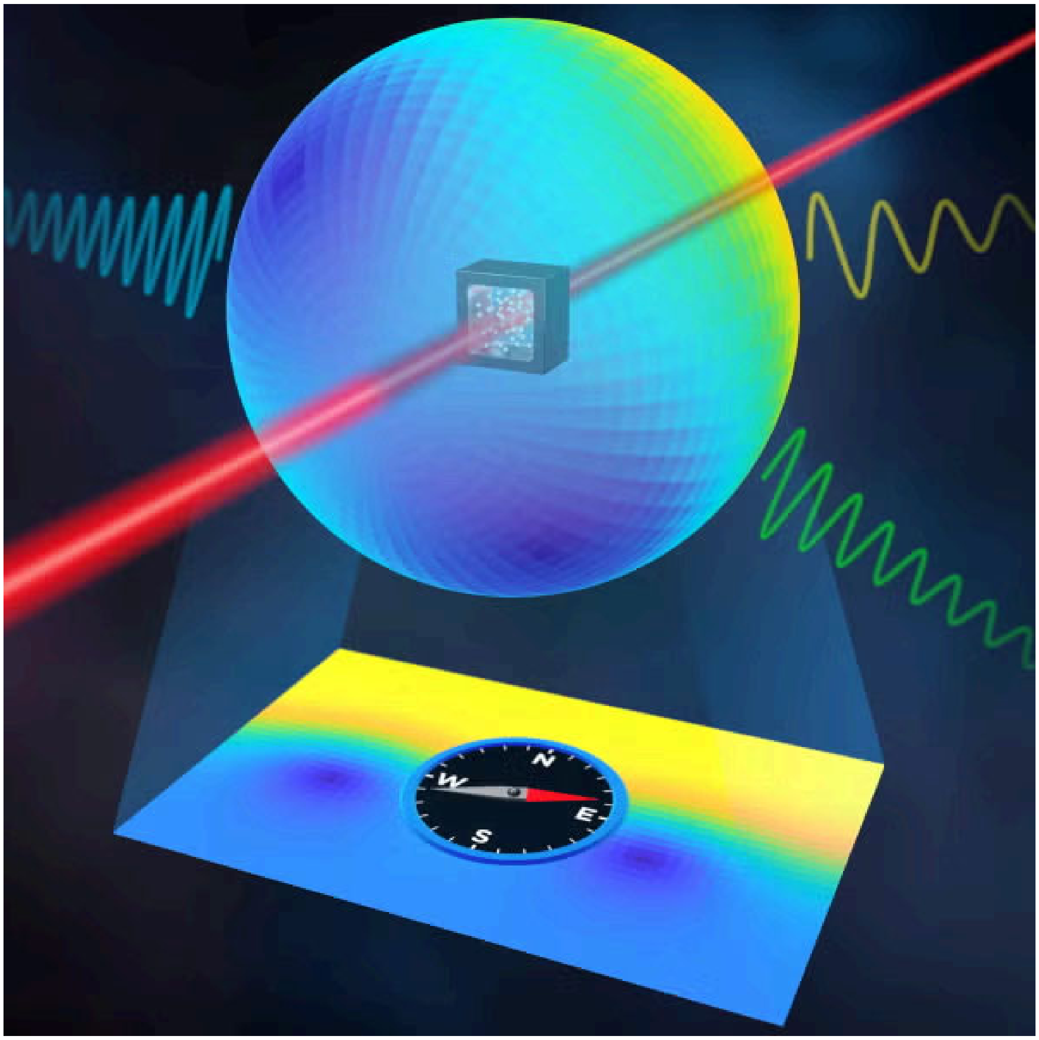


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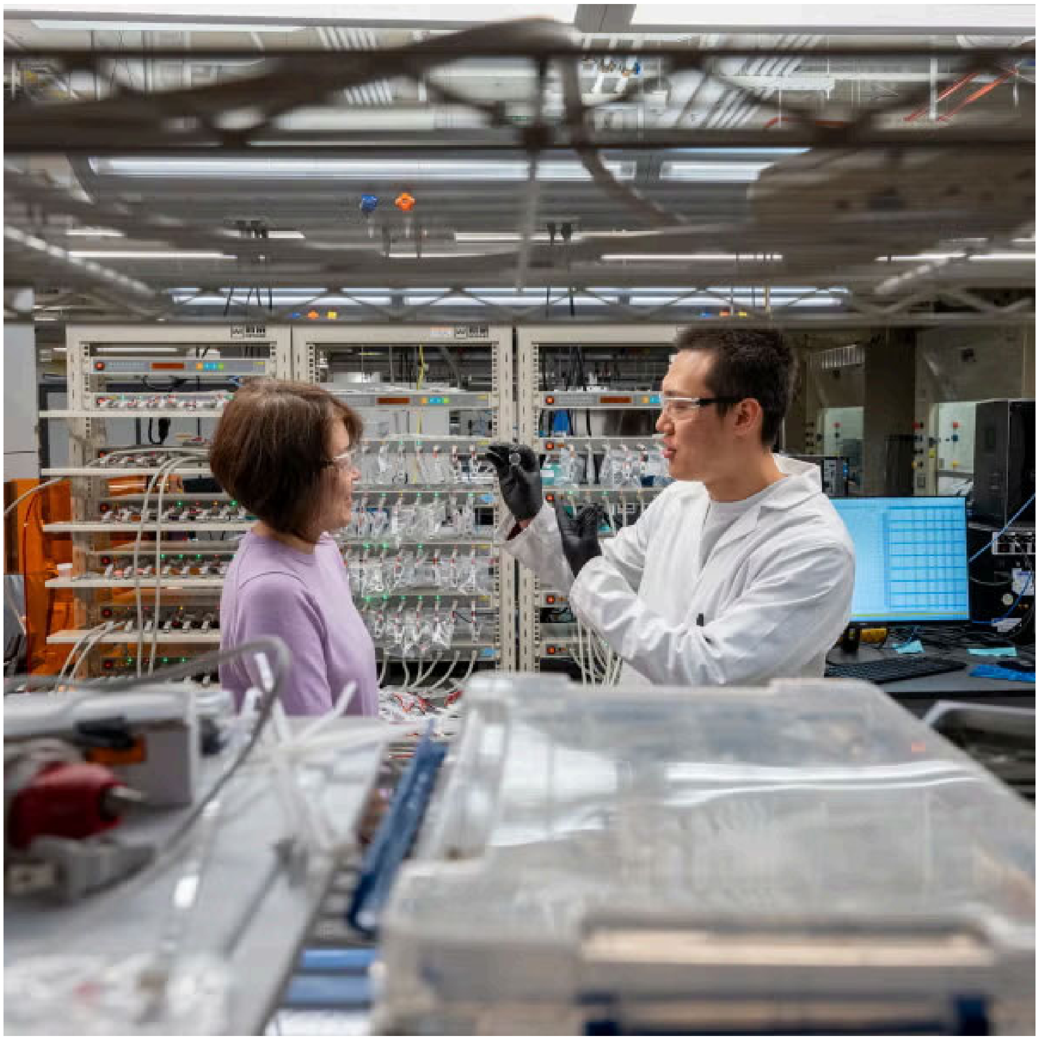

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