PRESS RELEASE

Hugo Geiger Price (2nd place)

Cost-effective photoacoustic sensors for comprehensive trace gas detection

Photoacoustic sensors are highly sensitive to low gas concentrations. Thanks to innovative light sources and microphone chips, these sensors can be made into cost-effective, compact, energy-efficient systems. This enables them to monitor gases across large areas. As part of his doctoral thesis, Dr. Christian Weber from Fraunhofer IPM developed two sensor architectures to monitor carbon dioxide and nitrogen dioxide, for which he was awarded the Hugo Geiger Prize.

The dose makes the poison – this also applies to air pollutants. Air contains many gases in addition to its main components, oxygen and nitrogen, some of which are present in very low concentrations. Increased levels of these trace gases can impair our well-being and damage our health. For example, carbon dioxide (CO_2) causes poor concentration and discomfort at concentrations as low as 0.5 percent by volume. The World Health Organization has set a limit of only 5 ppb for toxic nitrogen oxide (NO_2), which is produced during combustion processes, among other things. This corresponds to 5 molecules of NO_2 per billion air molecules. Comprehensive monitoring of critical trace gases in indoor spaces, tunnels, underground parking garages, and traffic-heavy urban or industrial areas has so far failed due to expensive, complex, or insufficiently sensitive measurement technology.

Classic measuring principle – modern components

Dr. Christian Weber of the Fraunhofer Institute for Physical Measurement Techniques IPM developed miniature photoacoustic sensors using the principle of photoacoustic spectroscopy (PAS). These sensors can detect CO_2 and NO_2 gases at very low concentrations for a fraction of the cost of previous systems. „In my doctoral thesis, I essentially revived the 150-year-old photoacoustic measurement principle," says Weber. „Today, high-performance LEDs or semiconductor lasers are available as light sources, and inexpensive micromechanical microphone chips serve as detectors. This makes it possible to build small, low-cost sensors that require little energy."

Editorial notes
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Turning light into sound: the photoacoustic effect

Photoacoustic gas detection involves irradiating the gas with light of a suitable wavelength, which the gas then partially absorbs. The amount of light energy absorbed is proportional to the number of absorbing molecules in the gas mixture. This energy is then converted into heat energy via several processes. The gas expands, causing an increase in air pressure and the generation of a sound wave. This sound wave can be measured using a microphone. If pulsed light is used, a periodic signal is generated, equivalent to an acoustic tone. The higher the gas concentration, the louder the acoustic signal. This allows precise statements to be made about the gas concentration.

CO2 detector: significantly higher sensitivity due to indirect photoacoustics

For his doctoral research, Weber developed two sensor architectures for the target gases CO_2 and NO_2. He relies on an indirect photoacoustic method for CO_2 detection. An LED sends infrared light through a short measurement path into a hermetically sealed photoacoustic detector filled with CO_2. The catch: As its concentration rises, the CO_2 in the measuring volume between the light source and the detector cell absorbs the exact wavelengths of light that would usually activate the detector. Consequently, the signal becomes weaker. The detector thus precisely detects the narrow absorption lines to which CO_2 reacts. „This design makes our sensor four to six times more sensitive than classic filter photometric solutions and allows us to shorten the light path to eight millimeters," says Weber. The sensor module, measuring 8 mm × 7 mm × 17 mm, is smaller than most optical gas sensors on the market. With a one-minute measurement interval and an average power consumption of only 24 µW, the sensor can operate on a battery for several years without drift or calibration.

Resonant photoacoustics: NO_2 detection limit of 3 ppb

The nitrogen dioxide detection sensor is based on direct photoacoustics. NO_2 absorbs light in the violet-to-blue spectrum. Although strong LED light sources can generate a measurable signal, it is very weak at low concentrations. Weber uses an acoustic resonator to amplify the signal and generate an audible tone. The pitch at which the resonance oscillates is influenced by environmental parameters, such as pressure and temperature. To avoid measurement errors, the excitation frequency must exactly match the resonance frequency of the measuring cell. Weber has found an elegant solution to this problem. Instead of generating the sound via a loudspeaker, he uses a second LED that focuses its light directly onto the wall of the resonant cell. Absorption of the radiation on the wall transfers some heat to the gas, creating a sound wave that excites the cell resonance. This method is completely linear and free of its own resonances and can be easily and inexpensively integrated into sensor technology. The process has already been patented and licensed. In test measurements, the sensor achieved a detection limit of 3 ppb, a sensitivity previously only possible with complex, expensive laser or chemiluminescence measurement systems.

The principles of photoacoustic trace gas detection can be adapted to detect other gases. Based on these findings, a methane leak detection system has been developed and is now in productive use.

Further information

The Hugo Geiger Prize

On March 26, 1949, the inaugural meeting of the Fraunhofer-Gesellschaft was held at the Bavarian Ministry of Economic Affairs under the patronage of State Secretary Hugo Geiger. On the occasion of Fraunhofer's 50th anniversary, the Bavarian Ministry of Economic Affairs, Regional Development and Energy launched the Hugo Geiger Prize for the next generation of research scientists. Awarded each year to three young researchers, the prize honors outstanding doctoral theses in the field of applied research that have been completed in close collaboration with a Fraunhofer institute. The individual prizes amount to 5,000, 3,000 and 2,000 euros. The submissions are assessed by an expert panel of judges made up of representatives from the worlds of research, development and industry. The assessment criteria are scientific quality, relevance to industry, originality and use of interdisciplinary methods

Dr. Christian Weber, the winner of the Hugo Geiger Award from Fraunhofer IPM, developed a photoacoustic sensor for NO_2 detection. With a detection limit of 3 ppb, this compact sensor is as sensitive as complex, much more expensive measuring systems.
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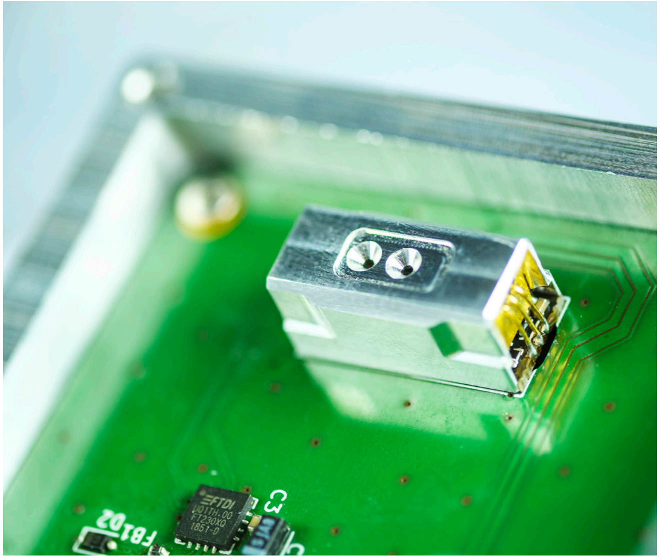

The photoacoustic sensor is energy-efficient and no bigger than a piece of chewing gum. It monitors the carbon dioxide concentration in room air and can operate maintenance-free for several years using a battery.
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