< Colorimetric gas sensors could ultimately complement the smoke detectors commonly used today. The technology can be applied to many different fields.

GROUP **INTEGRATED SENSOR SYSTEMS**

Colorimetric sensors: Colors signal toxic gases

In the future, innovative sensor systems will be capable of rapid, selective measurements of toxic gases based on the color change principle. Fraunhofer IPM is pursuing several research projects investigating materials and system concepts for colorimetric gas sensors. As part of this work, a miniaturized sensor platform is being constructed for tasks including fire gas detection.

There is no noise or odor that announces the onset of a fire. Toxic gases such as carbon monoxide (CO) and nitrogen oxide (NO_2) are produced before smoke becomes visible, and just a few breaths of these can be fatal. Despite this, standard smoke detectors do not react to such gases and only sound an alarm once smoke particles are released. Fire gas sensors can help to detect fires at an earlier stage. To date, however, these gas detectors – usually semiconductor gas sensors or infrared sensors – are virtually unheard of in private households. Depending on the technology used, they are too expensive, have a limited lifespan, consume too much power or do not reliably differentiate between different gases. Color-changing sensors put early fire detection on an entirely new technological footing, which opens up a wide range of other potential applications beyond fire gas detection – in essence, anywhere where compact, energy-efficient, durable gas detectors are required.

Sensitive, selective fire gas detection

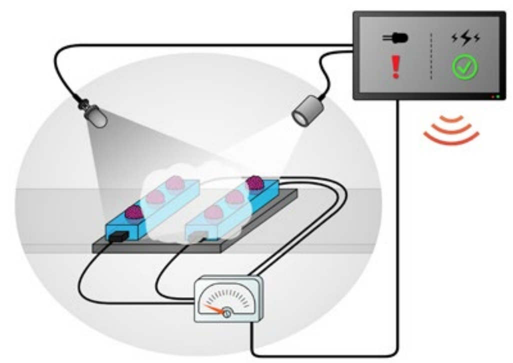
Color-changing sensors are characterized by a high degree of selectivity and sensitivity, something that is particularly crucial where fire gas detection is concerned. The gas-sensitive dye only reacts with a specific gas and, thanks to the low cross-sensitivity of colorimetric sensors, false alarms are rare. At the same time, gas sensors that operate on the color change principle work with detectable levels as low as the ppm (parts per million, 10^{-6}) range, as Fraunhofer IPM was able to demonstrate using the example of the fire gases CO and NO_2. A variety of sensor concepts are possible. For example, the researchers have combined specially designed sensor materials with optical and electrical measurement techniques. Porous substrate particles measuring just a few micrometers in diameter are coated with a dye and combined to create sensor particles. These sensor particles are constructed as so-called mole-hill structures embedded within a matrix of electrically conductive polymers, which are assembled as electrode structures. This sensor design ensures a favorable surface-to-volume ratio and facilitates the target gas's access to the gas-sensitive dye. Any light falling on the sensor particles is diffusely reflected. The reaction with the gas causes a change in the intensity of the reflected light, which is registered by a photodetector. parallel to the optical color change reading, a referenced electrical measurement of the material properties takes place in the same system. As a result, changes in environmental influences – such as high levels of atmospheric humidity or contamination from dust and fat – can be detected and offset during signal processing.

DETECTING GAS BY MEANS OF COLOR CHANGES: The presence of gases can be verified using chemical reactions that trigger color change in a specially selected sensor dye. This change in color is triggered as soon as a target gas molecule hits the gasochromic layer. Such reactions follow the lock-and-key principle – only the indicator molecule will trigger the color change, while all other gases barely react or do not react at all. The principle gained currency as early as 1937 with the introduction of Dräger tubes, which were also used to detect the presence of CO. These tubes are not suitable for everyday sensors, however, as they are only designed for single use.

Application-specific sensor concepts

Colorimetric gas sensors are of interest for a wide variety of applications. In addition to fire gas detection, Fraunhofer IPM is developing sensor systems for the detection of ammonia (NH_3), ethanol (C_2H_6O), formaldehyde (CH_2O), and hydrogen sulfide (H_2S). This involves adapting the polymer/dye structures, system configuration and readout units to each specific application. As an alternative to mole-hill structures, the dyes can, for example, be embedded in polymer matrices. Readings are then performed optically using simple transmission measurement. During this process, LED light is directed through a waveguide by total internal reflection and is focused on a photodetector on the exit side. Any color change in the gas-sensitive material leads to a measurable change in absorption. In a patented configuration, Fraunhofer IPM has optimized simple transmission measurement such that its sensitivity is comparable with waveguide-based sensors. The key to achieving this lies in folding the flexible sensor substrate. Doing so means that the light beam passes through the gas-sensitive layer multiple times, allowing the absorption path to increase in size while the sensor remains small. Large quantities of these sensors can be manufactured cheaply using roll-to-roll processing.

The team is also working on integrating the polymer/dye matrix into a sensor film. The intention is for such films to become part of standard protective equipment, where they will take the form of credit card-sized sensors that indicate critical gas concentrations, for example by emitting an audible signal. Color change can, however, also be registered by eye without any signal conversion. A visible change in color is of particular interest for applications in the food industry and food logistics sector, in air conditioning and safety technology, and in medicine. Irrespective of the application, one important feature is that gas detection based on the color change principle functions at room temperature. The technology is therefore fundamentally well suited to future integration in smart devices.



Substrate particles coated with a sensor dye are embedded in a polymer. These mole-hill structures ensure a good intake of target gas thanks to their large surface area, which ensures a high degree of sensitivity.

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