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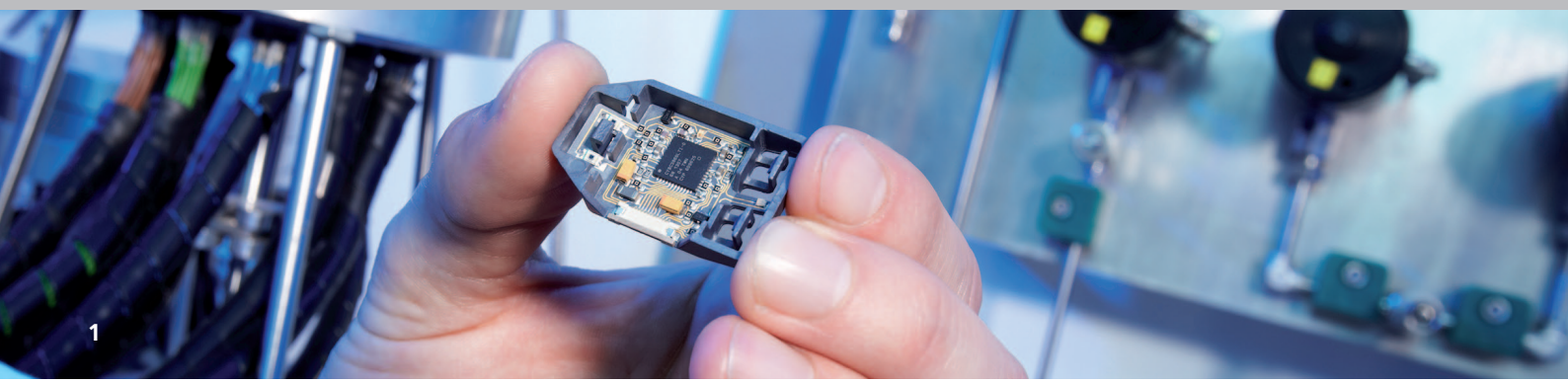
FRAUNHOFER INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES IPM



1 *Small, colorimetric and low-cost: gas sensors, manufactured using a roll-to-roll process, reliably measure various gases.*

COLORIMETRIC GAS SENSORS

Small, flexible, low-cost

Colorimetric gas sensors are used in all applications where there is only a limited amount of energy available and low-cost sensors are required. For example, this situation applies to operation in fire detectors, in Food Chain Management or in RFID labels. In such applications, colorimetric sensors can reliably detect gases such as carbon monoxide, nitrogen dioxide or ethylene. The low-cost sensors can be integrated in sensor networks and combined with other sensor principles.

Low-power gas sensors

Fraunhofer IPM is developing new types of low-power gas sensors based on the color change principle. A dye in combination with a polymer reacts when it comes into contact with the target gas and changes its color. This color change correlates with the concentration of the gas and has no interaction with other gases. The reaction takes place at room temperature thus meaning that no heating power is required. The power consumption is in the region of a few milliwatts. This means that, depending on measurement cycle, the system consequently operates for several years without battery changes.

Sensor design

The principle of the sensor is based on a change in color of the gas sensitive layer when it comes into contact with the target gas. A special sensor concept has been developed in order to be able to detect a color change automatically: the central element is an optical waveguide. The color change material is deposited on the surface of this waveguide. Light, coupled into the front of the waveguide, passes by total internal reflection and is focused on a photodetector at the opposite side. A change in color of the gas sensitive material corresponds directly to the change in absorption of the light. This reaction occurs in the visible wavelength range. The measurement

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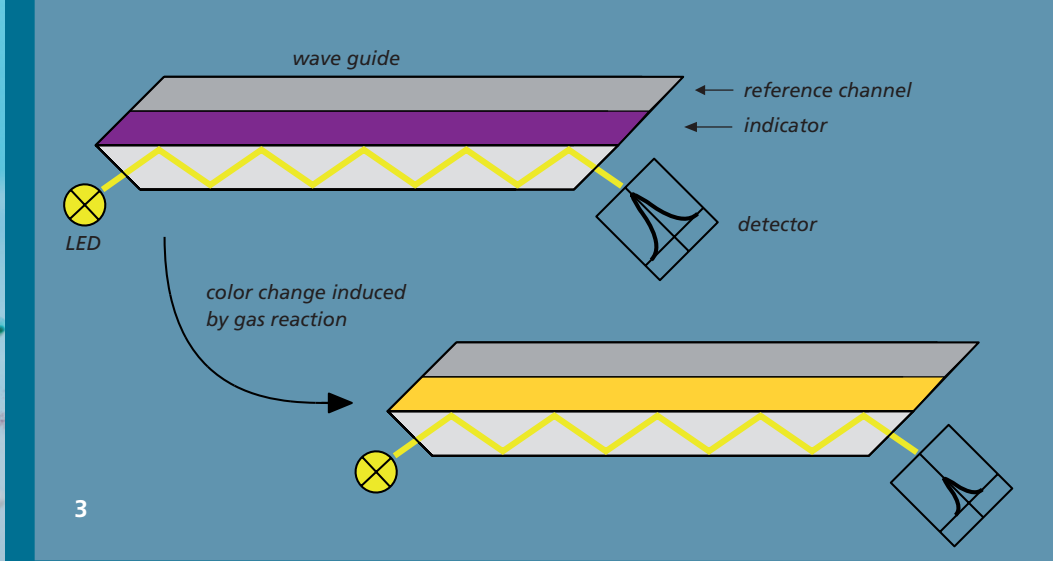


signal is generated from the change in voltage in the photodiode. For the purposes of stabilization, the sensitive material is embedded in a polymer. This polymer dye matrix is applied to the waveguide using microsystem technology methods – e.g. spin coating, screen printing or inkjet printing. The research focus at Fraunhofer IPM is on the development of colorimetric sensors with reversible color reaction.

Gasochromic dyes

Various dyes such as metal complexes, quinonimines or pH indicators are used to measure gases such as carbon monoxide, nitrogen dioxide, ammonia or ethylene.

Carbon monoxide (CO)

The gasochromic reaction of a binuclear rhodium complex is used for the CO reaction: the CO reaction takes place through a two-stage ligand substitution of the axially bound acetate groups. The color change runs from purple (initial condition) through orange (unilateral substitution) to yellow (bilateral substitution) (Fig. 4). The measuring range of these CO sensors is between 10 and 1,000 ppm.

Nitrogen dioxide (NO_2)

Dye N,N,N′,N′-tetramethyl-p-phenylenediamine allows detection of NO_2. The para-phenylenediamine is classified in the quinone family. Oxidation with NO_2 leads to the formation of »Wurster's blue«. The color change is from brown to blue. The measuring range of these NO_2 sensors is between 100 ppb and 5 ppm.

Ammonia (NH_3)

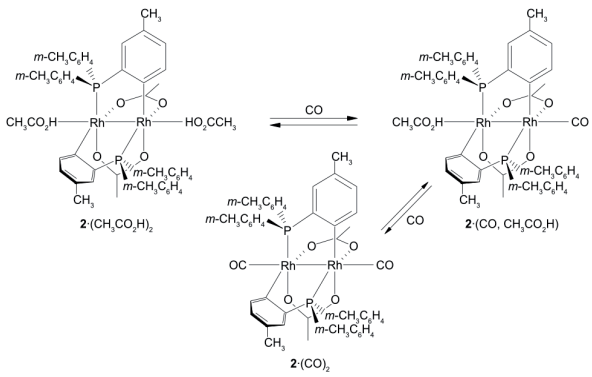
Fraunhofer IPM uses bromophenol blue for detecting NH_3. This dye is used primarily as a pH indicator. The acid-base reaction splits off the proton of the hydroxy group. The protonated form then has a different color than the deprotonated form. In the case of bromophenol blue, the protonated form is yellow and the deprotonated form is blue. The measuring range of these NH_3 sensors is between 0.5 and 50 ppm.

Ethylene (C_2H_4)

Fraunhofer IPM uses the redox reaction of ethylene with ammonium molybdate for detecting C_2H_4. This produces the mixed-valence, deep-blue pigment molybdenum blue. The color reaction is from clear to blue. The measuring range of these C_2H_4 sensors is between 0.5 and 100 ppm.

Low-cost production

The colorimetric gas sensors can be manufactured with a special-purpose roll-to-roll process owing to their simple design. The MIDs (Molded Interconnect Devices) are pressed into carrier plates and connected to form a 15 m-long roll. All components are manufactured by endless injection molding. The sensors consecutively pass through all process steps for the electronic components on the roll such as laser structuring, galvanization and SMD component assembly. The coated waveguide is pressed onto the carrier using a backend process.



2 *Various dye granulates are used for detection.*

3 *Basic mode of operation of the colorimetric gas sensor.*

4 *Color change reaction of the rhodium complex when it comes into contact with carbon monoxide.*