

Types and Applications of Chemochromic Sensors

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Abstract

Smart materials, also known as responsive or intelligent materials such as chemochromic materials changes colour upon exposure to a different environment or when react with different chemicals. Chemo chromic sensors are specially designed for robustness and can be used for leak detection in the vicinity of connections, valves, or Hydrogen line outlets. They can be altered, nevertheless, for a variety of uses. These are the materials whose colors and reflective qualities vary when exposed to various substances. This is a result of several chemical reactions that the material is undergoing. When an electron that was once a component of a chemical bond dislocates and takes up a new place inside the molecule, the substance absorbs a certain color of light depending on whether the electron is there or not. The aim is to provide a simple and robust Hydrogen sensor, when exposed to Hydrogen, changes colour and is not prone to failure. The sensor can be left in place during hazardous operations and does not require any operator or power intervention. Here, we will get to know about the use of these materials as sensors in different fields like Hydrogen detecting sensor, sensor for detecting Hypergolic fuels that are hazardous in their very nature.

Keywords: Sensors, chemogenic materials, chemo chromic hydrogen sensor, NASA, hypergolic fuels.

INTRODUCTION

Chemogenic Materials

Materials that change colour in accordance with the stimuli to which they react. Materials that change colour are called Chemogenic materials, described as chemoleonic as they change colour as a response to the changes in surrounding conditions. Another word for this phenomenon is chromotropic, which describes a shift in a material's optical properties, transparency, or light diffraction as a result of microstructural alterations brought on by external chemical or physical stimuli like solvent, temperature, pressure, or electrons [1].

Types of Chemogenic materials

1. *Photochromic materials:* Materials that change colour when intensity of incident light changes.

As an illustration, photochromic sunglasses are a well-known product.

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Lenses get darker with increasing UV intensity and optimize light passing through them, when UV is lower, they become more transparent.

2. *Thermochromic materials:* These materials respond to variation in environmental temperature by changing their colour.

Example: A ceramic mug changes colour when hot drink is poured transformation is reversible.

3. *Mechanochromic/Piezochromic materials:* These materials show a change in colour when stress is applied.

Example: Potential use in stress detection, particularly in situ failure monitoring due to fracture, fatigue.

4. *Electrochromic materials:* When an electric field is applied, their optical properties change.
5. An illustration would be antiglare mirrors, which sense glare and automatically adjust for it, particularly to improve driving safety at night.
6. *Chemochromic materials:* These materials change color in response to chemical alterations in their surroundings.

Example: To develop double pane windows with ability to change colour upon contact with Hydrogen gas in the gap between panes (gas chromic).

Chemochromic Materials

These are the materials that on exposure of different chemicals show change in colour and reflection properties. This is because the substance is going through several chemical reactions. An electron that may be a part of a chemical bond previously may dis-locate itself and occupy a new position within the molecule, where its absence or presence causes the material to absorb a certain colour of light.

These compounds are versatile and have various uses; dyes are the most popular form that they take. Litmus paper uses this clever material to measure the acidity and alkalinity of various substances. It has a relatively low acidic content in dyes and varies in color according to pH. Methyl red, for example, is red at $\text{pH} < 4$ and yellow at $\text{pH} > 6$ [2].

Pregnancy tests use chemicals to identify and react to human chorionic gonadotropin (HCG) in the urine of the expectant mother. Chemochromic dyes are also used for knowing the ripeness of fruit, as a chemical reacts with gases released by fruit as it ripens [2].

Chemochromic Sensors

Hydrogen Leak Detectors

Hydrogen has a number of unusual properties compared to other combustible gases like methane (CH_4). Low ignition energy (0.017 mJ), high heat of combustion (142 kJ/g H_2), and an ignition temperature of 560 degrees are the characteristics of combustion.

Since hydrogen is an odorless, colorless, and tasteless combustible gas that cannot be detected by the human senses, other methods must be used to detect it. For the safety of nuclear reactors, hydrogen concentration monitoring is crucial. When plutonium is reprocessed in nuclear power plants, hydrogen can form in the waste tanks due to an unintentional reaction between the high-temperature core and cladding materials (zirconium and uranium oxide) and hydrogen.

Hydrogen explosion had contributed to nuclear accidents at Three Miles Island and Fukushima in 1979 and 2011 respectively. Albeit Palladium and Platinum are widely used in Hydrogen detection, these are susceptible to mechanical damage upon exposure to Hydrogen.

Hydrogen safety is a major concern for the process of space shuttling. As Hydrogen's explosion limit is lower, leaks of any level ought to be quickly recognized and addressed. To do this, chemochromic devices have been developed. As Hydrogen is odorless and colourless and it poses an explosion hazard, and emerging need for sensors to accurately and fastly detect low stages of leak of Hydrogen in fuel cells and different superior energy-producing structures herein Hydrogen is used as a fuel [3].

The tool consists of a Chemochromic pigment right into a base polymer, the item can change colour reversibly or irreversibly when exposed to Hydrogen. Chemochromic detector for sensing hydrogen gas leakage is shown in Figure 1.

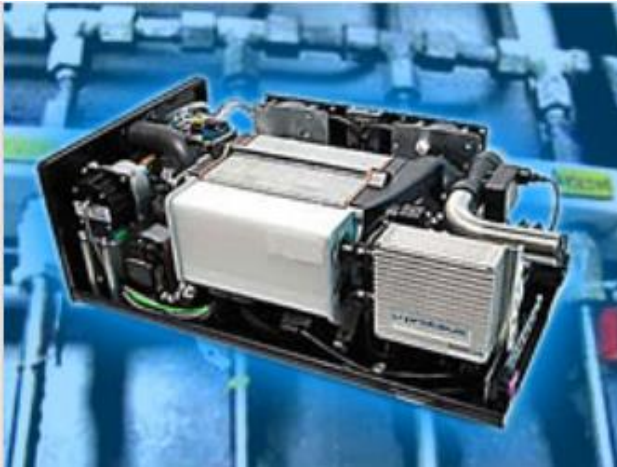


Figure 1. Chemochromic detector for sensing hydrogen gas leakage.
Source: Image Credit: NASA



Figure 2. Shuttle launch pad pipeline.

Chemochromic sensors are specially designed for robustness and can be used for leak detection in the vicinity of connections, valves, or Hydrogen line outlets. However, they can be modified for a range of applications. The aim is to provide a simple and robust Hydrogen sensor, when exposed to Hydrogen, changes colour and is not prone to failure. The sensor can be left in place during hazardous operations and does not require any operator or power intervention. Due to low flammability limit of Hydrogen, this is particularly when transporting, loading, and storing Hydrogen [4, 5].

Sensor Characteristics

Chemochromic Hydrogen sensor has been developed in two types for visual leak detection.

These can detect Hydrogen up-to as low as 330 ppm, developed in different configurations such as Hydrogen tapes, thin coatings, indicator tags for various applications [6].

The irreversible sensor changes colour from mild beige to darkish grey once exposed to Hydrogen. When staff cannot be present during dangerous activities, this is helpful.

The reversible sensor changes colour from mild grey to blue upon exposure to Hydrogen and then returning to original colour as soon as Hydrogen source is removed. This is helpful for keeping an eye on a leak in person or through a camera. This is also reusable which reduces its cost. The sensors are also available as a tape.

By manufacturing the Chemochromic sensor in the form of a tape, the size of sensor can be varied. The tape can be made in almost any width and length, which allows for custom fit. The versatility of tape allows the tape sensor to be cut into desired size. In addition to its versatility, sensor is also robust, the sensor's special matrix is flexible and malleable at room temperature, makes it durable and offer the possibility of adapting to the shape of suspected leak area [6, 7].

Detecting Defects in Membrane in Ion Exchange Membrane of Electrochemical Cell

The cell comprises of an arrangement having anode at one side and cathode at another with ion exchange membrane existing between them. To stop hydrogen from flowing between the anode and the cathode, a chemo chromic sensor is positioned above the cathode and flow isolation hardware is positioned lateral to the ion exchange membrane [8].

Anode is exposed to a first reactant fluid containing Hydrogen. Sensor is examined for a colour change after exposure. A color shift indicates the presence of at least one defect in the ion exchange membrane that permits the flow of hydrogen.

Membrane durability is limited by the development of membrane defects at the time of testing and device operation.

Example of membrane defects:

1. Pinholes, where a small hole being developed allows the Hydrogen to move from anode to cathode.
2. Crack formation, which can again permit the flow of Hydrogen to the cathode.
3. Thinning of membrane, diffusion of Hydrogen is increased because of the reduction in the thickness of material of membrane.

For each of the above case, the unexpected presence of Hydrogen reduces the performance of the fuel cell significantly and may even lead to hazardous circumstances.

Location specific detection of ion exchange membrane defects through use of chemochromic membranes as chemochromic sensors which are sensitive to Hydrogen and other reducing gases, like carbon mono-oxide. The functional of a typical chemochromic sensor is an oxidising catalyst like Palladium oxide (PdO) that is being reduced to the original metal (Metallic Palladium) with a colour change from brown to black in the case of PdO. This reduction can be gained by exposure to Hydrogen or other reducing gases with a resultant generation of water.

Infrared imaging is a well-known method for determining the location of membrane failures. The respective reactant fluids (H_2 and O_2) are both present at membrane defect locations and will exothermically react in the presence of a catalyst, producing heat, which is then detected using an infrared thermal detector, thermal imaging device, or a layer of thermally sensitive film placed in the vicinity of the membrane.

The infrared method has several important limitations. These limitations include the need to install platinum electrodes (or other catalysts) on the ion exchange membrane to generate heat during the test.

There are also safety issues because the top of the membrane electrode assembly (MEA) is exposed to environmental conditions, which may release H₂ into the environment. In addition, local heating can further damage the film [9].

The described method uses a chemical color film to locate MEA defects and has many significant advantages over known infrared methods. First, infrared imaging requires platinum electrodes (or other catalysts) on ion exchange membranes. The heat is generated because in the absence of a catalyst, H₂ will not burn with O₂. Therefore, the infrared method cannot detect MEA (membrane electrode assembly) defects outside the active area of the electrode. It is limited in this respect and does not require a catalyst bed connected to the ion exchange membrane.

Secondly, the chemical color changing film method is inherently safer than the infrared radiation method, because for the chemical color changing method, the entire device is sealed. The infrared method exposes the upper part of the OIE to environmental conditions. Third, it allows the chemical discoloration film process to be passive in nature without the risk of further damaging the OIE. The infrared method exposes the MEA to conditions that are no worse than the use of the MEA in the fuel cell, which means that the MEA suffers more damage. However, the local heat generated by the infrared method can further damage and exacerbate defects [9].

For Detection of Hypergolic Fuels

It is necessary to look for the existence of hypergolic fuels in a range of settings and circumstances due to their toxicity and degree of hazard.

Most commonly used sensors are electrochemical in nature, those have serious limitations as when used as monitoring devices. Figure 2 shows the shuttle launch pad pipeline. Chemochromic sensors have been tested for detection of hydrazine under different conditions: pure liquid, aqueous fuel solution, vapour fuel.

Sensor is made up of chemochromic pigments joined into different frameworks such as tapes, sheets, fibres, moulded parts that change colour when presented to Hypergolic fuels. At the point when set close to piping, container valves and joints, these sensors give a momentary colour change from yellow to black, which indicates the presence of hypergols at the location of the leak. Chemochromic pigments can be embedded into fibres used to fabricate fabrics for personal protection equipment as well as badge holders for use as a point leak sensor. These inexpensive, easily replaceable sensors enable continuous visual monitoring of leak-prone areas and personnel working in those locations for the presence of dangerous hypergols [10].

- *Precision:* sensors that come into contact with exposed hardware may pinpoint the exact site of hypergol leaks, greatly simplifying and speeding up the process of leak localization and repair for maintenance personnel.
- *Versatility:* Technology can be employed as a point source or an area monitoring sensor. One can customize the size and shape of sensors for tasks. Another method for finding hydrazine in a solution is by using sensors.
- *Affordability:* Incorporation of the technology into various matrices can be accomplished with a very low implementation cost.
- *Safety:* A visual and immediate alert of the presence of hypergols is provided by a color shift in the sensors. This warning facilitates an immediate evacuation of personnel from the contaminated area to a safe distance. Pigment in the sensor traps hypergols, thus helping prevent escape of the hypergol into the surrounding atmosphere.

Hypergol detection is tough due to low level of detection required, time response of sensors and reactivity of the commodity. These fuels often stick inside the lines or react with water, effecting the detection level possible with traditional sensors [10].

CONCLUSION

Chemochromic materials shows colour change upon exposure to changing environment pH. Chemochromic sensors are used by NASA for detecting Hydrogen leaks at the space shuttle processing which is very much in need as Hydrogen is flammable and poses explosion hazard that can cause great damage to the environment at NASA. The detectors are inexpensive, portable, and simple which makes them easier for use. More advancement is to come, and research is still going onto develop more efficient materials and devices keeping in mind the future demands.

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