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Uncovering the Modern Aspects of Chemical Sensors

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Abstract

Chemical sensors are becoming more and more critical in any area where the measurement of concentrations of volatile compounds is related for both control and analytical purposes. They have also observed various applications in sensor systems called electronic noses and tongues. This chapter will primarily discuss fundamentals of sensor science comprising a brief discussion on the main terms encountered in practical applications, such as: sensor, transducer, response curve, differential sensitivity, noise, resolution and drift. Basic electronic circuits employed in the sensor area will be discussed with a particular emphasis on the noise aspects, which are important for realizing high resolution values in that background where measurement of the lowest concentration values of chemicals is the main purpose. Noise is related to high resolution as it is necessary for accurate result. All the most relevant transducers such as: MOSFET (metal-oxide-semiconductor field-effect transistor), CMOS (complementary metal- oxide-semiconductor), Surface Plasmon Resonance device, Optical Fibre, ISFET (ion-selective field effect transistor), will be covered in some detail including their intrinsic operating mechanisms and showing their limitation and performance. Shrinking effects of these transducers will also be stated. The electronic nose and electronic tongue will be stated as systems able to provide olfactory and chemical images, respectively, in a diversity of application fields, including medicine, environment, food and agriculture. Finally, some future trends will be outlined in order to predict potential applications derived from today's micro and nanotechnology developments.

Keywords: sensors; chemicals, electronic noses, CMOS, MOSFET

1. Introduction

A chemical sensor is a device that obtains signals or stimuli and responds in the type of an electrical signal. Now the sensors receiving chemical signals are called chemical sensors. The output signals correspond to some kinds of electrical signal, such as current or voltage. The sensors are classified into distinct types based on the applications, input signal, and conversion mechanism, material utilized in sensor characteristics such as cost, accuracy or range.

A chemical sensor is a device that transforms chemical information, varying from the concentration of a specific sample component to total composition analysis, into an analytically useful signal. The chemical information, cited above, may be created from a chemical reaction of the analyte or from a

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physical property of the system investigated [1].

It can also be defined as an analyzer that has to respond to a particular analyte in a selective and reversible way, transforming a chemical concentration into an electrical signal, with its key element being the sensing material.

Humphrey *et. al.* has built up a new group of lanthanide-based materials, which could form the basis of a new generation of rapid chemical sensors that could be utilized for these applications. Due to their light-emitting – or 'photo luminescent' – properties (Figure 1), molecules comprising lanthanide (Ln) ions (charged atoms) have been increasingly explored as chemical sensors. The term 'lanthanide' refers to the group of elements with atomic numbers 57 to 71, from lanthanum (La) to lutetium (Lu) [2].

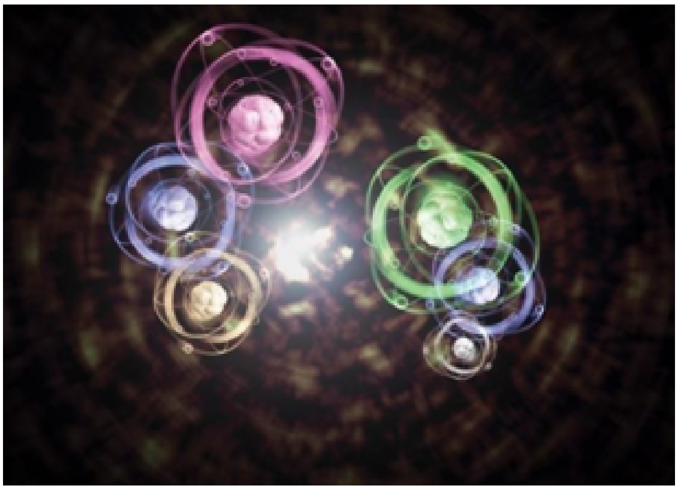


Figure 1: Photoluminescence of Lanthanide ions which have been increasingly explored by chemical sensors.

After absorbing light, lanthanide ions emit visible and infrared light at specific frequencies. This signifies that a solid-state sensor (for example, a dipstick) could be easily read either using the naked eye or a UV-reader to detect chemical impurities in a sample. Each kind of lanthanide ion (for example Europium or Terbium) emits a very diverse frequency of light that is characteristic of that particular element. This means that lanthanide-based chemical sensors can be tuned to sense an exact impurity.

2. Components of a chemical sensor

The chemical sensor fundamentally has two basic components in the form of **a chemical resonance system** (Figure 2) known as

- the receptor and
- a physical chemical transducer [3].

The receptor makes interaction with analytic molecules whereas the transducer transmits the electric signal. A test sample is listed to the receptor which checks composition connected with the transducer. The transducer gathers the information from the receptor and sends it to the signal amplifier. This amplifies the signal from the transducer and sends it as output signals. The figure below provides a clear perspective on the components of a chemical sensor.

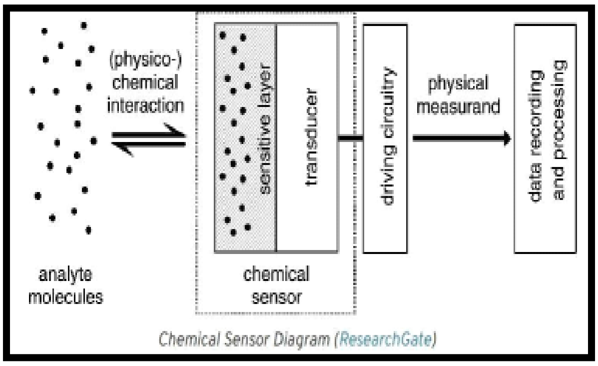
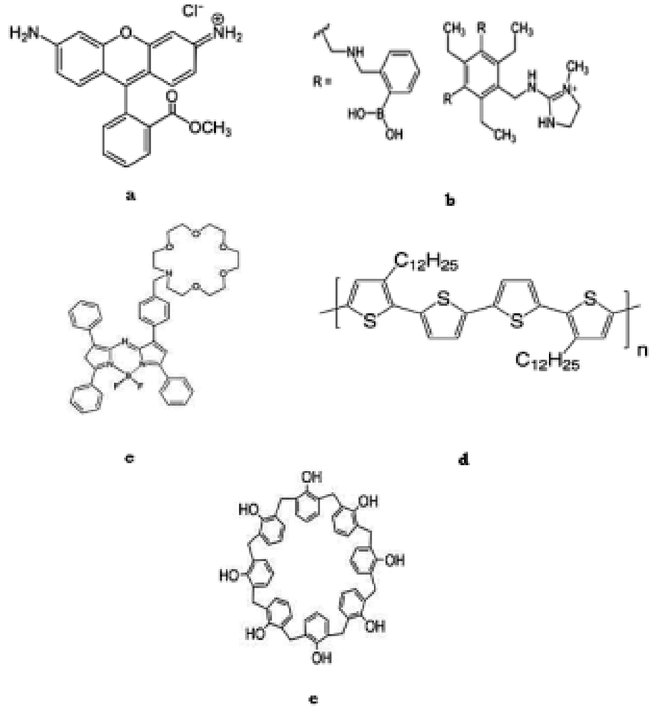


Figure 2: Chemical sensor diagram [4]

Organic chemicals used in sensors

The following names are of some organic chemicals which are utilized in chemical sensors: i) Rhodamine dyes (Scheme 1a) were making use of to build fluorescent sensors because of their excellent spectroscopic properties, for example long absorption and emission wavelength, high fluorescent quantum yield, large extinction coefficient, and great photo stability, ii) Tannic acid and Saxitoxin (Scheme 1b and 1c respectively) are utilized in fluorescence-based chemosensors, iii) Poly(3,3‴-didodecyl[2,2′:5′,2″:5″,2‴-quaterthiophene]-,5‴diyl),Poly(4,4″didodecyl[2,2′:5′,2″:5″,2‴-quaterthiophene]-5,5‴-diyl) (PQT-12) (Scheme 1d) is utilized in high sensitivity chemical sensors based on organic thin film transistors. It can also be employed as donor material in organic solar cells, iv) Calix-8-arene (Scheme 1e) is utilized in sensor for the direct assay of haphazard ephedrine content of weight loss herbal preparations.



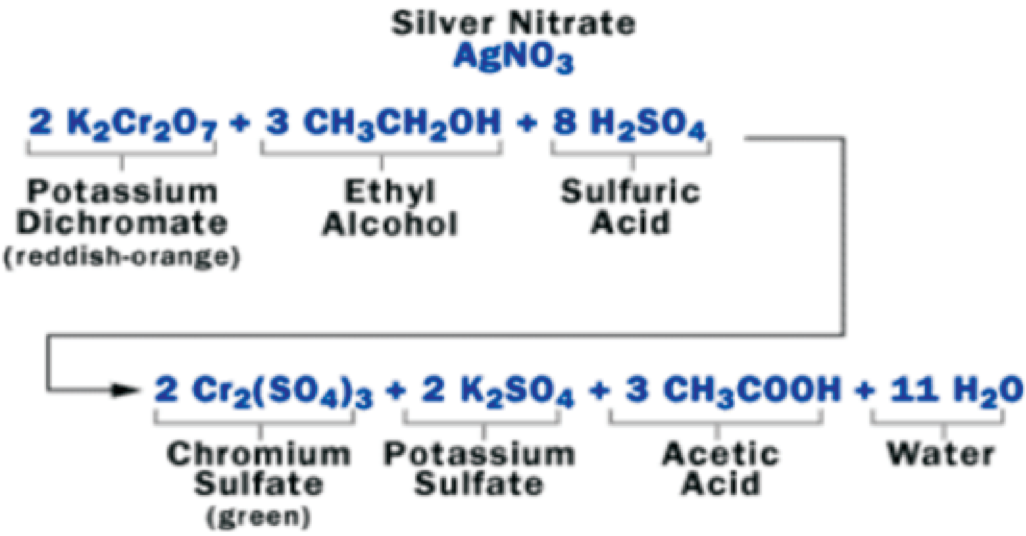
Scheme 1: The structures of Rhodamine dye (a), Tannic acid (b), Saxitoxin (c), PQT-12 (d), Calix-8-arene (e)

3. Applications of chemical sensors

I. Breath Analyzer: When people consume alcohol, they breathe out an amount of alcohol molecules straight proportional to the amount they drink. A breathalyzer is a chemical sensor that is specifically designed to determine a person′s blood alcohol content (BAC), often to conclude whether or not they are safely capable of driving a vehicle. When the alcohol molecules interact with the receptor, they encounter another chemical substance contained in the receptor (namely: sulphuric acid, potassium dichromate, silver nitrate and water). This triggers a chemical reaction, and when the chemical disparity between the two chambers (one not influenced by the reaction) is perceived, an electric signal is produced and it indicates via screen or needles the suspect's BAC. Memorize the next time you drive after consuming alcohol; else the cops may catch you utilizing a breathalyzer (Figure 3).

Figure 3: This picture shows a Breathalyzer [5]

Silver nitrate catalyses the reaction in which alcohol, in the presence of sulfuric acid, transforms orange potassium dichromate solution green owing to conversion of potassium dichromate into chromium sulphate. The intensity of the green colour can be utilized to estimate the amount of alcohol in the exhaled air.



II. Chemical sensors are utilized for to detect toxins and determining the presence and amount of nitrogen and phosphorus mixed in the air and liquid (Figure 4).

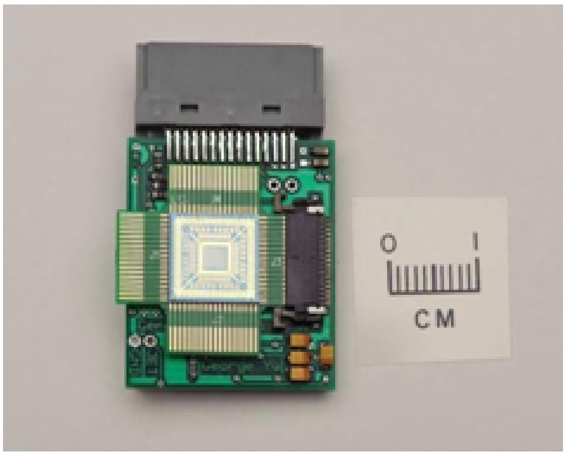


Figure 4: Gas detection sensor [6]

III. Amperometric sensors are a type of chemical sensor which is utilized to monitor air quality by using liquid electrolytes (Figure 5a and 5b).

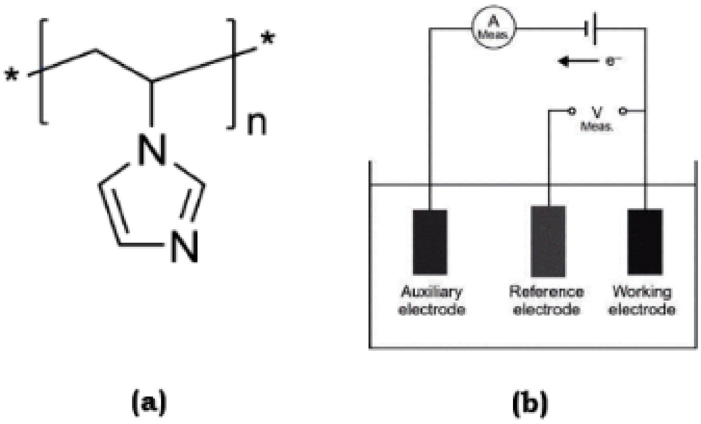
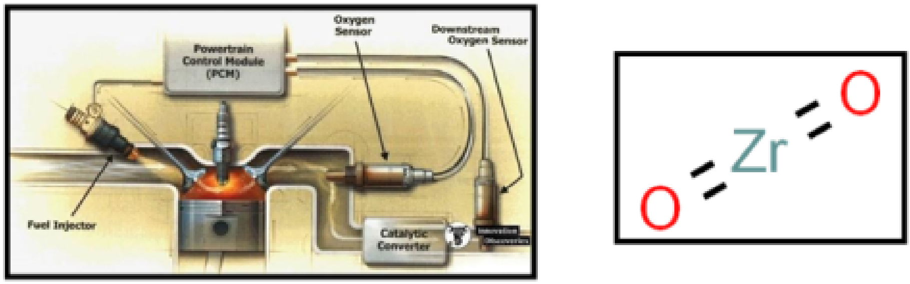


Figure 5: (a) Polyvinyl imidazole: A chemical applied in Amperometric sensor [6], (b) Amperometric sensor [6]

IV. The **LAMBDA** sensor, also called an oxygen sensor (Figure 6a), is a tiny probe situated on the car exhaust, between the exhaust manifold and the catalytic converter. It was developed by Volvo in the 70s. If you own a newer car, it will be equipped with two lambda sensors. In that case, the second sensor will be situated right behind the catalytic converter. The lambda probe will adjust the fuel quantity that is sent to the engine cylinders by optimizing the air and fuel mixture, which in turn will build the engine to work properly. This will also affect the harmful gas emissions rate by generating sure the catalytic converter is working correctly. As the lambda sensor is placed before the catalytic converter, it can measure the amount of air and fuel in the unburnt hydrocarbons after combustion. That way, the vehicle's Electronic

Control Unit (ECU) which regulates some functionalities of the engine, will get the correct data on the emissions, and it will then release the exact quantity of gas needed. This is necessary in decreasing polluting emissions. Lambda sensors usually construct applications of Zirconia (Figure 6b) [7].



(a) (b)

Figure 6: (a) The Figure beside shows the setup of oxygen sensor (b) Zirconia: Used in Lambda sensors.

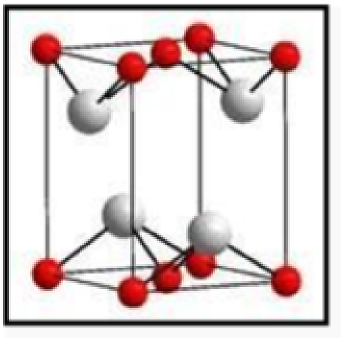
V. High-tech sensor for blood glucose measurement

The new blood glucose measurement with the high-tech Free Style Libre sensor is made to make life much easier for diabetics who require insulin. The sensor is attached to the upper arm and enables blood glucose measurement with a discrete scan (Figure 7). The sensor makes the typical stinging obsolete and also gives considerably more insight into the course of glucose than before [8].

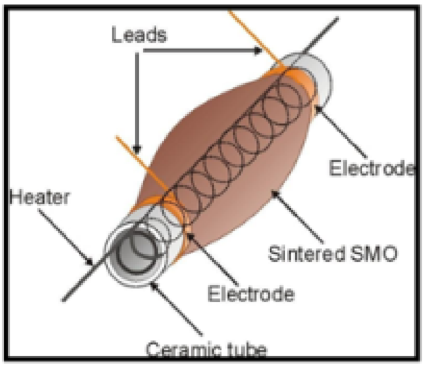
Figure 7: A glucose sensor [9]

VI. TAGUCHI SnO Sensor

This kind of gas sensors utilizers varies in their resistance or conductance in identifying a target gas originating from electronic interactions between the semiconductor sensor materials and the target gas. After the numeral attempts to improve gas-sensing performance, SnO-based (Figure 8a) semiconductor gas sensors were put on the market as gas leakage monitors for town gas and liquid petroleum gas in 1968 (Figure 8b). Since then, SnO has been the most attractive semiconductor gas sensor material among various types of semiconductor metal oxides so far developed and/or illustrated to date as sensor materials.



(a)



(b)

Figure 8: (a) Structure of SnO [10], (b) A Taguchi-type sensor where the heater is embedded in a ceramic tube and semiconductor material is mounted on the tube with two pre-printed electrodes [11].

VII. TITRATION is one of the conventional techniques of analytical chemistry. The titrant, a reagent solution of exactly known concentration (a standard solution) is added stepwise under continuous stirring to the sample solution, until equivalence has recognized, i.e., until reagent and sample have reacted to a degree of approximately 100 percent. In an acid-base titration (Figure 9), this point is attained if the sample (which was either acidic or alkaline before) reacts neutral, i.e., if it is neutralized. The indicator is saying this state. The amount of titrant consumed up to this point can be derived from the scale of the burette. The consumed volume is utilized to calculate the result. Titrations were performed long before sensors had been accessible. Usually, indicator substances have been adopted i.e., dissolved dyes which transform their colour markedly in the vicinity of the equivalence point. Beginning in the 1930s, instrumental signal by means of electrochemical probes also became more and more accepted [12].

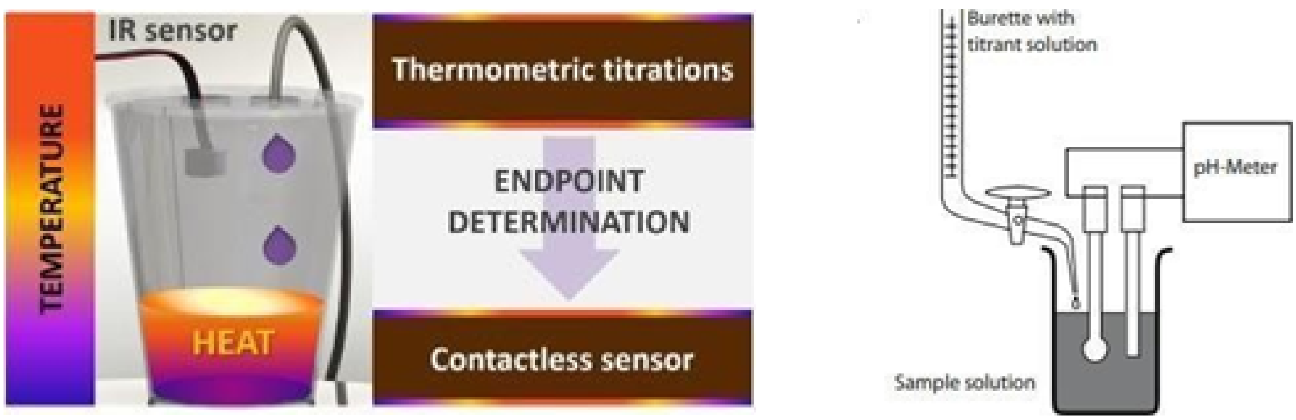


Figure 9: Low-cost device for thermometric titration

Chemical sensors also find their used in:

The following detectors are also found for the chemical sensors as follows:

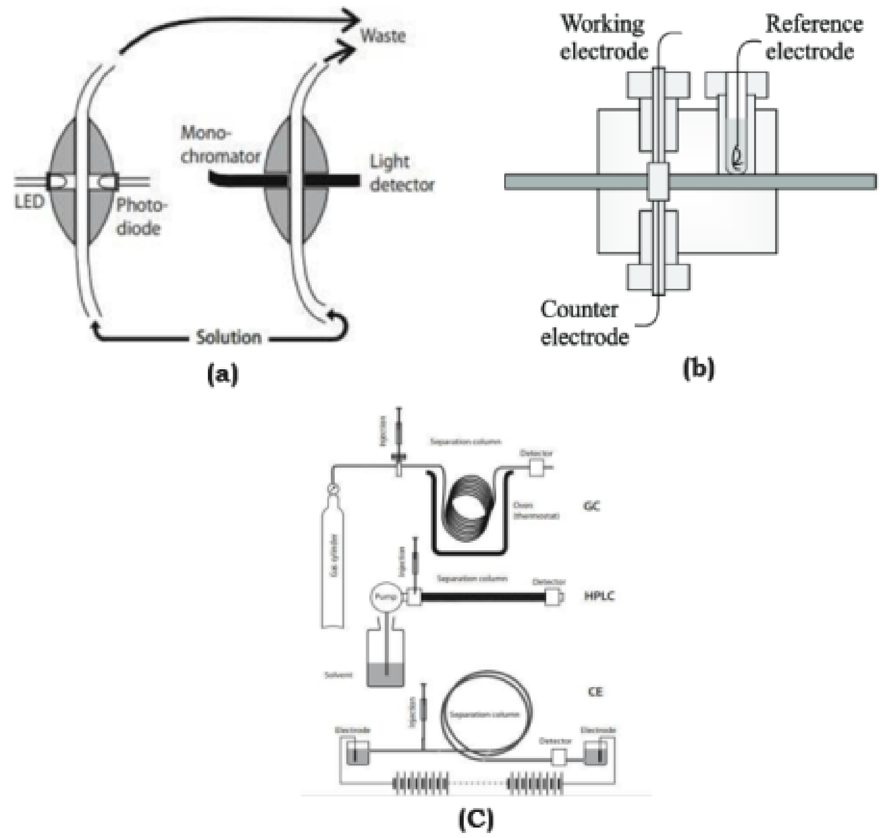


Figure 10: (a) Photometric detectors for flow injection analysis [13], (b) Electrochemical flow-through detectors [13], (c) Chromatography [13]

4. Conclusion

The use of chemical sensors is rapidly increasing with the incoming of nanomaterials. Chemical industries are now more dependent on chemical sensors owing to their detection abilities. The rising levels of pollution have supported the need for chemical sensors. In view of the future improvement of sensors driven by increasing need for accuracy and precision, and by the opening of current fields close to the biological area (which is oriented toward nano-biosensor fabrication), it is now significant to suitably utilize the most relevant sensor keywords, such as: response curve, sensitivity, noise, drift, resolution, and selectivity. The proper understanding of these words and their inferences is of fundamental significance for the scientific and industrial community interested in sensor science progress, since it allows the correct dissemination of both experimental and theoretic results. Some basic transducers have also been considered to illustrate intrinsic sensing and sensitivity mechanisms, without disregarding comments on noise which are primary to the determination of resolution.

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