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Chapter 1

Introductory Chapter: What is Chemical Sensor?

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1. Introduction

The chemical sensor is an analyzer that responds to a particular analyte in a selective and reversible way and transforms input chemical quantity, ranging from the concentration of a specific sample component to a total composition analysis, into an analytically electrical signal [1, 2], as depicted in **Figure 1**. The chemical information may originate from a chemical reaction by a biomaterial, chemical compound, or a combination of both attached onto the surface of a physical transducer toward the analyte. The chemical sensor subject is an emerging discipline formed by the multidisciplinary study among chemistry, biology, electricity, optics, mechanics, acoustics, thermology, semiconductor technology, microelectronics technology, and membrane technology.

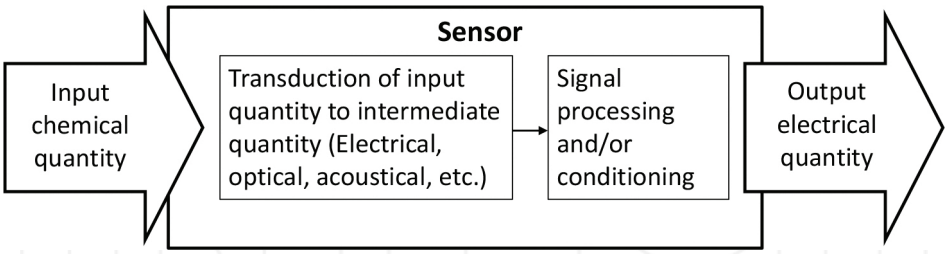

Figure 1. Sensor principle. Schematic diagram of a sensor that produces an electrical output in response to the presence of an input quantity.

Although the history of chemical sensor dates back not long ago, it has gained increasing attraction for applications in environmental monitoring, industrial process monitoring, gas composition analysis, medicine, national defense and public security, and on-site emergency

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disposal owing to its many excellent properties such as small size, satisfactory sensitivity, larger dynamic range, low cost, and easy to realize automatic measurement and online or in situ and continuous detection. Hence, the chemical sensor becomes one of the most active and effective directions of modern sensor technology.

2. Classification of chemical sensor

According to the working principle, the chemical sensor can be classified into many types such as optical, electrochemical, mass, magnetic, and thermal. The optical chemical sensor is based on the changes in optical phenomena analysis arising from the interaction between the analyte and the receiver. The electrochemical sensor utilizes electrochemical effect among the analytes and featured electrodes. The working principle of the mass sensor depends on the quality change induced by the mass loading from the adsorption toward the analyte by the special modification of sensor surface. The magnetic device is based on the magnetic properties in analyte adsorption, whereas the thermal sensor utilizes the thermal effect generated by the specific chemical reaction or adsorption process.

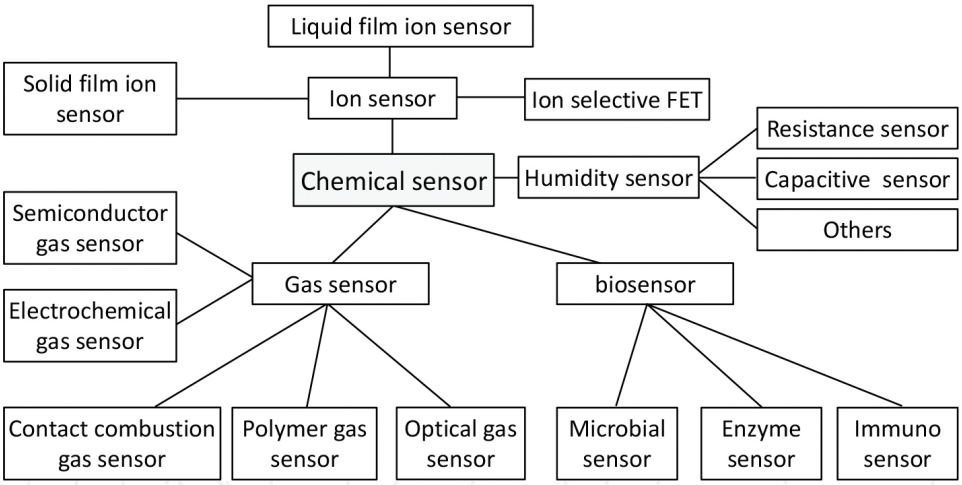

Figure 2. Classification of chemical sensors based on sensing objects.

Another way to categorize the chemical sensors is based on the object to be detected, that is, the chemical sensors can be classified as gas sensors for trace gas analysis and monitoring, various ion sensors represented by the pH sensor, humidity sensor, and biosensors made by biological characteristics. **Figure 2** lists the main categories of chemical sensors toward various objects.

It is well known that the environment monitoring is the major application field of the chemical sensor, therein, the gas sensor plays a pivotal role. The key performance indicators of the gas

sensor include sensitivity, selectivity, and stability, which are determined mainly by the characteristics of the sensing material and mechanism. By utilizing the advanced materials and the new response mechanism, the gas sensitive characteristic of the sensor can be improved significantly. Generally speaking, the gas sensor is categorized mainly by its working principle as a semiconductor type, an electrochemical type, a solid electrolyte type, a contact combustion type, a photochemical type, and a polymer type. Each type is introduced in the paragraphs below.

2.1. Semiconductor gas sensor

Semiconductor gas sensor is a sensitive element made by metal oxides or metal semiconductor oxide materials [3]. As regards the electrical conductivity sensors, the resistance of their active sensing layer changes due to contact with the gas to be detected. Since the first semiconductor metal-oxide-ceramic gas sensor was reported in 1962, the semiconductor gas sensors have become the most comprehensive and widely used gas sensors.

2.2. Electrochemical gas sensor

The electrochemical gas sensor can be categorized into galvanic cell type, controlled potential electrolysis type, coulometric type, and ion-selective electrode type [4]. The galvanic cell gas sensor evaluates the target gas composition by measuring the shift in current. The controlled potential electrolysis gas sensor senses the target gas by measuring the electrolytic current and is different from the galvanic cell sensor, and a specific voltage should be imposed externally. Furthermore, the oxygen in blood can also be detected in addition to CO, NO, NO_2, and SO_2. The coulometric gas sensor detects the target species by measuring the current generated by the interaction between the gas and the electrolyte. The ion-selective electrode gas sensor has appeared earlier, and it detects the gas by measuring the ion current with high sensitivity and excellent selectivity.

2.3. Contact combustion gas sensor

The contact combustion gas sensor includes direct contact sensor with the combustion and catalysis combustion sensor [5]. Its working principle is that oxidative combustion of the combustible gas occurs directly or by using catalysts in the energized state, accordingly, the burning gas sensitive material (Pt wire) is heated up, resulting in the shift in the resistance value. By evaluating the resistance shift, the gas concentration can be extracted. Sometimes, such a sensor is called a thermal conductivity sensor, which is widely used for sensing combustible gas in petroleum chemical plant, shipyards, mine tunnels, kitchens, and bathrooms.

2.4. Optical gas sensor

Optical gas sensors include infrared absorption sensors, spectrum absorptive sensors, fluorescence sensors, and fiber sensors [6], in which, the infrared absorption sensor is the most widely used for sensing gas by measuring and analyzing the infrared absorption peak from various gas adsorption. Such a sensor has a lot of outstanding advantages of excellent

antivibration and antipollution ability, autocorrection, and possibility of continuous and longer dynamic monitoring.

2.5. Polymer gas sensor

The polymer gas sensitive materials have grown enormously in the past several years, which plays an important role in sensing trace poisonous gas because of its easy operation, simple process, good selectivity at normal temperature, low price, and easy to combine with the micro structure or surface acoustic wave (SAW) devices [7].

3. Development trend of chemical sensors

Environmental protection and monitoring, prevention and treatment of disease and the continuous improvement of people's quality of life are still the main application areas of the chemical sensors in the foreseeable future. Nowadays, with new challenges as well as new opportunities, the features of the chemical sensors trend are as follows:

1. A variety of gas sensors used widely in environmental protection and monitoring are highly valued, which are the mainstays of three mainstreams of chemical sensors. High sensitivity, miniaturization, integration, and low cost are still the development tendency of the gas sensors.

2. Biosensor ranks second in three mainstream of current chemical sensors. The twenty-first century is the century of biology. As an important part of biology, the biosensor provides the important support for the biological technology. It is not only an important aspect of the international competition of high-tech but also a window to evaluate the biological level of a country. Nowadays, the research on biosensor is strengthened in many countries to adapt to rapid development of biology. Among them, the microarray technology dominated by the DNA or cDNA biochip is one of the emphases for biosensor research. Nanobiosensing technology formed by a combination of biosensing technology and nanotechnology would be a new growth point of the biosensors, and a unprecedented new situation will be created based on the new applications of the silicon and nonsilicon-based micro biosensor in biomedical, environmental monitoring and instrumentation industries.

3. Electrochemical sensor ranks only the third in the mainstream of current chemical sensors, but it is very active. The electromechanical sensor dominated by ion selective electrode (ISE) will continue to trend to high sensitivity, low detection limit, fast response, and long-operating life. The appearance of the new materials such as organometallic compound, organometallic polymer, and macrocyclic compounds and their complexes represented by the metal porphyrin (metalloporphyrins) offers a solid foundation for gradual perfection of all solid-state ion-selective electrode, electrochemiluminescence (ECL), and photoelectrochemical sensor. Some new technologies such as nanoparticle LB films, molecular imprinting technology (MIT), and nanoelectrode arrays, and appearance of

scanning electrochemical microscopy (SECM) and electrochemical impedance spectroscopy (EIS) will make the electrochemical sensor vigorous and exuberant and expand some new applications in environmental protection, food industry, biology, and medicine.

4. A new generation of bionic sensors, such as electronic nose and electronic tongue, will be a new growth point of chemical sensor in the coming century. It is an important aspect of artificial intelligence study to simulate the function of human bodies and facial features (five human senses) to recognize various substances and environments effectively. Since the breakthrough in taste sensor was obtained in the 1990s, the substances with five major tastes of sweetness, sourness, bitterness, spiciness, and saltiness can be detected quantitatively by using the multichannel technology. Further improvement of the taste sensor in selectivity, repeatability, and durability will lead to more applications in the food industry to improve the quality and quality control of beverages, fruits, and vegetables. Electronic nose is a multichannel gas sensor array that provides an effective way to detect toxic gas, explosive gas, as well as the released smell of drugs, explosives, and food.

5. The emergence of the microchemical sensor and its array is an important sign of the chemical sensor with excellent performance entering the new century. With the development of solid-state and microelectronic technology and the appearance of the MEMS sensors aiming for high precision, low driving, low power consumption, small size and fast response, the chemical sensor will be turned over a new leaf, and enters into an unprecedented "Micro world."

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