CURRENT STATUS OF ELECTRONIC NOSE: THE SENSING SYSTEM

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Abstract*: Electronic/artificial noses are being developed as systems for the automated detection and classification of odours, vapours, and gases. An electronic nose is generally composed of a chemical sensing system (e.g., sensor array or spectrometer) and a pattern recognition system (e.g., artificial neural network). Today's electronic nose technology consists with* ***a****rrays of sensors that respond to a wide range of compounds, as well as advanced pattern recognition and artificial intelligence techniques, which enable users to readily extract relevant and reliable information.*

Key words*: electronic nose, sensing system, pattern recognition system*

1. INTRODUCTION

In the past decade, electronic nose instrumentation has generated much interest for its potential to solve a wide variety of problems, such us: fragrance and cosmetics production, food and beverages manufacturing, chemical engineering, environmental monitoring, and more recently, medical diagnostics.

Electronic noses are systems that can detect and identify odours, typically by linking chemical sensing devices with signal-processing and pattern recognition system. The sensing system can be an array of several different sensing elements (e.g., chemical sensors), where each element measures a different property of the sensed chemical, or it can be a single device (e.g., spectrometer) that produces an array of measurements for each chemical, or it can be a combination. Each chemical vapour presented to the sensor array produces a signature or pattern characteristic of the vapour. By presenting many different chemicals to the sensor array, a database of signatures is built up. This database of labelled signatures is used to train the pattern recognition system. The goal of this training process is to configure the recognition system to produce unique classifications of each chemical so that an automated identification can be implemented. Figure 1 shows the basic diagram of an electronic nose, [1].

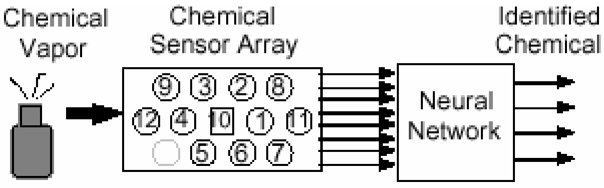

fig 1 – Schematic diagram of an electronic nose

2. THE BIOLOGICAL NOSE

Electronics noses are based on human olfactory system. To attempt to mimic the human apparatus, researchers have identified distinct steps that characterize the humans smell, figure 2, [2].

The olfaction process begins with sniffing that brings odorant molecules from the outside world into the nose. With the aid of the turbinates (bony structures in the nose which produce turbulence), sniffing also mixes the odorant molecules into a uniform concentration and delivers these molecules to the mucus layer lining the olfactory epithelium in the upper portion of the nasal cavity. Next, the odorant molecules dissolve in this thin mucus layer which then transports them to the cilia (hair like fibers) of the olfactory receptor neurons. The mucus layer also functions as a filter to remove larger particles.

Reception involves binding the odorant molecules to the olfactory receptors. These olfactory receptors respond chemically with the odorant molecules. This process involves temporarily binding the odorant molecules to proteins that transport the molecules across the receptor membrane. Once across the boundary, the odorant molecules chemically stimulate the receptors. Receptors with different binding proteins are arranged randomly throughout the olfactory epithelium.

The chemical reaction in the receptors produces an electrical stimulus. These electrical signals from the receptor neurons are then transported by the olfactory axons to the olfactory bulb (a structure in the brain located just above the nasal cavity).

From the olfactory bulb, the receptor response information is transmitted to the limbic system (a primitive portion of the brain that governs emotions, behavior, and memory). This gives rise to sub-conscious associations between odor and recalled memories. The olfactory information is also transmitted to the cerebral cortex (an advanced portion of the brain that processes high level information including conscious thought). This gives rise to the conscious sensation of smell which is also combined with taste to give the sensation of flavor.

There are no individual olfactory receptors or portions of the brain that recognize specific odors. It is the brain that associates the collection of olfactory signals with the odor.

Finally, in order for the nose to respond to new odors, the olfactory receptors must be cleansed. This involves breathing fresh air and the removal of odorant molecules from the olfactory receptors.

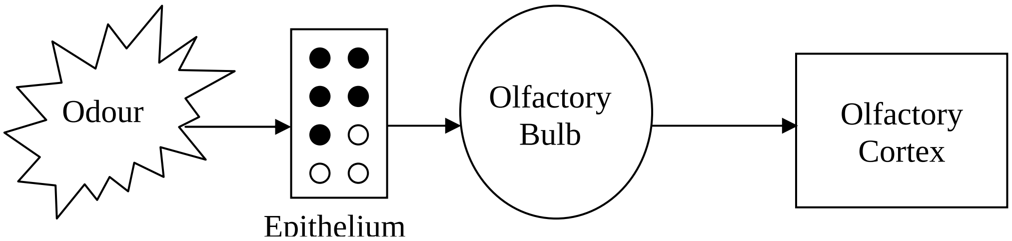

fig 2. A simplified representation of the biological olfactory system.

3. THE SENSING SYSTEM

Even though the broad selectivity of the sensors in an electronic nose is compensated by advanced information processing, the sensors still must meet key design parameters for the system. These include sensitivity, speed of operation, cost, size, manufacturability, the ability to operate in diverse environments, and the ability to be automatically and quickly cleaned. The sensors must be able to adsorb (i.e., collect and hold) large numbers of molecules of a particular species to produce a measurable change in the sensor. After the odorant is identified, the process must be reversed through a cleaning process. The choice of chemical sensors to meet these requirements is large and can be includes into five categories: conductivity sensors (e.g. metal-oxide semiconductors, MOS, conductive polymers, CP, conducting oligomers, CO), piezoelectric sensors (surface acoustic wave devices, SAW, bulk acoustic wave devices, BAW, quartz crystal microbalances, QCM), MOSFETs (chemical field effect transistors, ChemFET), optical sensors, and spectrometry-based sensing methods.

A. Chemoresistors

There are two major classes of chemiresistors: (1) high-temperature chemoresistors (200-600°C) with semiconductor metal oxide coatings, [3] and (2) low-temperature chemoresistors (room temperature) with polymeric and organic sensitive coatings, [4].

The sensitive materials used with high-temperature chemoresistors include wide-bandgap semiconducting oxides such as tin oxide, gallium oxide, indium oxide, or zinc oxide, all of which can only be operated as sensing materials at high temperature (>200°C). In general, gaseous electron donors (hydrogen) or acceptors (nitrogen oxide) adsorb on the metal oxides and form surface states, which, at high temperature, can exchange electrons with the semiconductor. An acceptor molecule will extract electrons from the semiconductor metal oxide and thus decrease its conductivity. The reaction between gases and oxide surface depends on the sensor temperature, the gas involved, and the sensor material.

Several classes of organic materials are used for application with chemoresistors at room temperature (electrode spacing typically 5 to 100 µm, applied voltage 1-5 V). Conducting Polymers such as polypyrroles, polyaniline and polythiophene are used to monitor a variety of polar organic volatiles like ethanol or methanol. Conducting carbon black can be dispersed in non-conducting polymers so that if the polymer absorbs vapor molecules and swells, the particles are, on average, further apart and the conductivity of the film is reduced (conductivity by particle-to-particle charge percolation). Applications also include organic solvents such as hydrocarbons, chlorinated compounds, and alcohols.

B. Chemocapacitors

Chemocapacitors (dielectrometers) rely on changes in the dielectric properties of a sensing, material upon analyte exposure. Two effects change the capacitance of, e.g., a polymeric sensitive layer upon absorption of an analyte: swelling and change of the dielectric constant due to incorporation of the analyte molecules into the polymer matrix. Interdigitated electrode structures are predominantly used for capacitance measurements. The devices usually are operated at an AC frequency of a few kHz up to 500 kHz. Since the nominal capacitance of microstructured capacitors is on the order of 1 pF and the expected capacitance changes are in the range of some attoFarads, an integrated solution with on-chip circuitry is usually required.

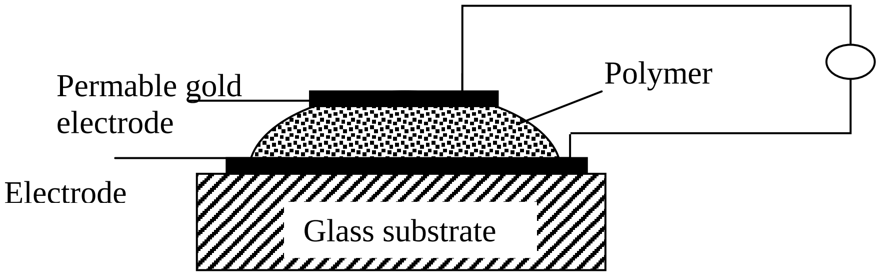

fig. 3 Schematic representation of the Chemocapacitor

C. Chemotransistors

Field-effect based transistors, which are the most common electronic components on modern IC logic chips, rely on modulation of the charge carrier density in the semiconductor surface space-charge region through an electric field perpendicular to the device surface: The source-drain current is controlled by an isolated gate-electrode. The MOSFET (metal-oxide semiconductor field-effect transistor) as used for chemical gas sensing has a p-type silicon substrate (bulk) with two n-type diffusion regions (source and drain), figure 4. The structure is covered with a silicon dioxide insulating layer on top of which a metal gate electrode is deposited [5]. The source-drain conductivity of the FET can be modulated by adjusting the strength of electrical field between the gate electrode and the silicon, or through the presence of absorbed species and the resulting polarization phenomena.

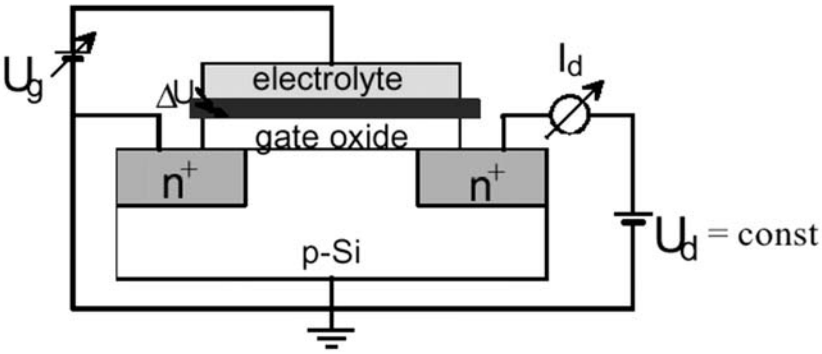

fig. 4 Schematic representation of the Field Efect Transistor for Gas Sensing

D. Optical Sensors

Optical techniques offer a great deal of selectivity already inherent in the various transduction mechanisms in comparison to other chemical sensing methods. Characteristic properties of the electromagnetic waves such as amplitude, frequency, phase, and/or state of polarization can be used to advantage. Geometric effects (scattering) can provide additional information. In addition, optical sensors like any other chemical sensor can capitalize on all the selectivity effects originating from the use of a sensitive layer.

E. Chemomechanical Sensors

Chemomechanical or mass-sensitive sensors are in the simplest case gravimetric sensors responding to the mass of species accumulated in a sensing layer, [6, 7, 8]. Any species that can be immobilized on the sensor can, in principle, be sensed. Mass changes can be monitored by either deflecting a micromechanical structure due to stress changes or mass-loading (static measurements) or by assessing the frequency changes of a resonating structure or a traveling acoustic wave upon mass loading. Both, deflection and resonance frequency vary in proportion to stress changes or mass loading on the device, figure 5.

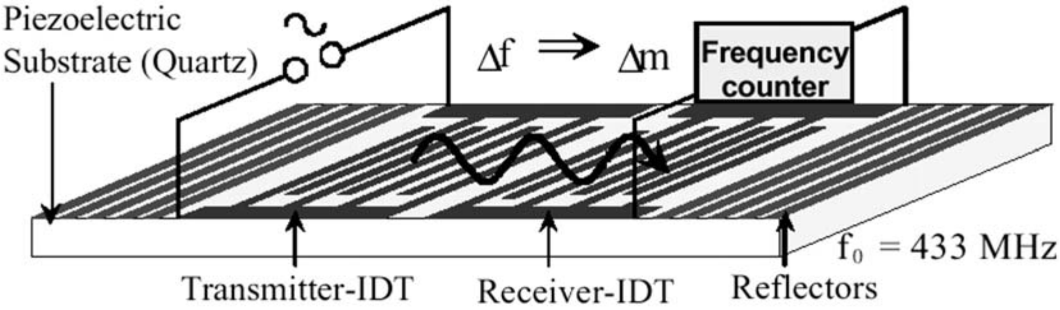

fig. 5 Schematic representation of the Chemomechanical Sensors

4. CONCLUSION

While the electronic nose can be a powerful tool, little is understood about applying it as a bio-mimic for human olfaction. This paper has briefly discussed the complexity of human olfaction and drawn a parallel with electronic nose design. Sensors and signal processing operations are analogous to human olfactory receptors and neural transduction. Coding of the neural signal and odor recognition in humans is analogous pattern recognition methods in electronic noses. The research and development thrusts go in the direction of integrating more and more electronic functions on the sensor devices such as adaptive circuits for signal evaluation and discrimination, or telemetry units for wireless communication. Telemetry functions will encompass, e.g., communication from implanted chips through the skin in medical applications or the transmission of remote and distributed chemical sensor responses to a central terminal in environmental and building control scenarios by using radio frequencies or other standards like Bluetooth.

5 REFERENCES

1. Paul E. Keller, Electronic Noses and Their Applications, IEEE Northcon Technical Applications Conference (TAC'95), Portland, Oregon, USA on 12 October 1995
2. W. Gopel, et al., Bioelectronic noses: a status report. Part I, Biosensors & Bioelectronics 13 (1998) 479–493
3. Gopel, W, Schierbaum, K., SnO_2 sensors: curent status and future prospects, Sensors and Actuators B, 26-27, 1-12, 1995
4. Hierlemann, A. et al. Polymer-based sensor arrays and multicomponent analysis for the detection of hazardous organic vapour in the environment**,** , Sensors and Actuators B, 26-27, 126-134, 1995
5. J. Hendrikse, The E MOSFET as a potentiometric transducer in an oxygen sensor, Sensors and Actuators B 47 (1998) 1–8
6. Polikar R., et al., Detection and identification of odorants using an electronic nose, Proc. of IEEE 26th Int. Conf. on Acoustics, Speech and Signal Proc.(ICASSP 2001), vol. 5, pp. 3137-3140, Salt Lake City, UT, 7-11 May 2001
7. Josse, F., et al., Guided Shear Horizontal Surface Acoustic Wave Sensors for Chemical and Biochemical Detection in Liquids, Anal. Chem.**2001,** 73, 5937-5944
8. Staples, E., et al., The zNose. A New Electronic Nose Using Acoustic Technology, Acoustical Society of America, December 2000 Paper Number 2aEA4