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Sensors, Chemical Sensors, Electrochemical Sensors, and ECS

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The growing branch of science and technology known as sensors has permeated virtually all professional science and engineering organizations. Sensor science generates thousands of new publications each year, in publications ranging from magazines such as *Popular Mechanics* and *Discover* to learned journals like the *Journal of The Electrochemical Society (JES)*. The Electrochemical Society (ECS), which has declared itself the society for solid state and electrochemical science and technology, and its worldwide membership, have been vitally instrumental in contributions to both the science and technology underlying sensors. This article is about a few of the chemical sensors that have evolved, those still now evolving, and the continuing role of ECS in advancement of sensor science and engineering.
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Chemical sensors have been widely used in such applications as critical care, safety, industrial hygiene, process controls, product quality controls, human comfort controls, emissions monitoring, automotive, clinical diagnostics, home safety alarms, and, more recently, homeland security. In these applications, chemical sensors have resulted in both economic and social benefits. Some examples of market areas are summarized in Table I. Indoor air quality (IAQ), volatile organic compounds (VOCs), and the lower explosive limit of combustible hydrocarbons (HCs) have all become targets for new sensor developments that seek to monitor and help improve the quality of the air we breathe. The range of detection for sensors can be percent levels in process streams with O_2 sensors to single molecule or unique organism detection with carbon nanotubes.

ECS Sensor Related Symposia and Publications

The Electrochemical Society formally recognized its role in chemical sensor technology and the importance of sensors with the formation of the Sensor Group in 1987. This grew into the Sensor Division founded in 1993 by Dennis Turner and co-organizers. The new Group organized a successful Chemical Sensors symposium for the 1987 ECS Fall meeting in Honolulu, a joint international meeting with the Electrochemical Society of Japan (ECSJ). Subsequently, the symposium was continued as a series in the 1993 and 1999 Fall meetings in Honolulu. Norboru Yamazoe, a founder of the International Meeting on Chemical Sensors (IMCS), was co-chairman and contributed significantly to obtaining many papers from Japan and the East for these symposia.

Sensor research takes place in virtually every ECS division (see Table II), and these listed 80 or so symposia represent about 7% of all ECS symposia. A series of state of the art conferences have been organized by the Sensor Division over the past 10 years and progress in this field can be found in ECS publications, including proceedings volumes.[1-11] The ECS sensor symposia span diverse topics, including biosensors, luminescent materials, ion-selective electrodes, and high-temperature ceramic sensors. General broad coverage symposia on chemical sensors provide opportunity for interdisciplinary discussions on both fundamental and applied aspects of all kinds of chemical sensors, while most symposia have dedicated topics that focus on solving special problems of significance at that time. Table III provides a classification of the ECS sensor symposia according to topics, and most topical symposia were launched to discuss special applications like industrial, medical, or environmental sensors. This focus supports the strong connection between sensors and practical problems in technology, industry, and society. The second largest category of symposia concerns materials. Sensor technology is dependent on progress in materials science and technology, and whenever a new material is discovered it is soon investigated for applications to sensors. Conducting polymers, solid ionic materials, and nano-materials (nano-particles, nano-wires, nanotubes) are all examples.

The Society has proven to be an ideal organization for sensor research because of its long tradition of providing a home for science and technology at the interface of many disciplines. Through the pages of its respected journals, *JES* and *Electrochemical and Solid-State Letters* (ESL), ECS has chronicled developments for many types of sensors including amperometric sensors, potentiometric sensors, and chemiresistors. JES has published more than 200 papers on chemical sensors since 1990 (Vol. 137-149), and ESL has reached 26 chemical sensor papers since its inception in 1998. Of the 26 sensor-related papers in ESL, more than 60% discuss solid electrolyte sensors. The interest in this type of sensor is growing and is the topic of a joint meeting of the ECS Sensor Division and the American Ceramic Society (ACerS) to be held in the Fall of 2003 in Orlando.

More and more ECS members are interested in microfluidics, microsystems, and nanodevices, many of which are considered physical sensors as well as being part of chemical and biochemical devices. The physical sensors which detect physical properties of mass, force, pressure, strain, temperature, flow, position, distance, and acceleration have been directly enabled by advances in electronic fabrication processes. Hybrid physical-chemical systems open new areas for sensor design and bring the promise of advanced analytical systems capability on a single chip.

Sensors, Chemical Sensors, and Electrochemical Sensors

The world seems to have a natural division between chemical and physical sensors. However, there are those that do not classify easily, like relative humidity sensors, a chemical sensor traditionally lumped with physical sensors. Also, sensors are often discussed along with the topic of actuators. Chemical sensors have a chemical or molecular target to be measured. Biosensors are defined as sensors that use biomolecules and/or structures to measure something with biological significance or bioactivity. More appropriately, biosensors target a biomolecule of interest for measurement. The biosensor can usually be considered a subset of chemical sensors because the transduction methods, sometimes referred to as the sensor platforms, are the same as those for chemical sensors. Chemical sensor arrays with instrumentation, having popular names like the electronic nose or electronic tongue,[5] have been constructed to address chemically complex analytes like taste, odor, toxicity, or freshness.

A useful definition for a chemical sensor is ''a small device that as the result of a chemical interaction or process between the analyte gas and the sensor device, transforms chemical or biochemical information of a quantitative or qualitative type into an analytically useful signal.'' The definition is illustrated in Fig. 1a and compared to two other sensor devices, specifically, the microinstrument (Fig. 1b) and the ''lab-on-a-chip'' sensor concept (Fig. 1c). The microinstrument using the physical sensor for light or heat would have a similar definition to the chemical sensor except there is no interac-

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Table I. Exemplary Applications and Markets for Chemical Sensors.

Market/application	Examples of detected chemical compounds and classes
Automotive	O_2, H_2, CO, NO_x, HCs,
IAQ	CO, CH_4, humidity, CO_2, VOCs,
Food	Bactreria, biologicals, chemicals, fungal toxins, humidity, pH, CO_2,
Agriculture	NH_3, amines, humidity, CO_2, pesticides, herbicides,
Medical	O_2, glucose, urea, CO_2, pH, Na^+, K^+, Ca^{2+}, Cl^-, bio-molecules, H_2S, Infectious disease, ketones, anesthesia gases,
Water treatment	pH, Cl_2, CO_2, O_2, O_3, H_2S,
Environmental	SO_x, CO_2, NO_x, HC_s, NH_3, H_2S, pH, heavy metal ions
Industrial safety	Indoor air quality, toxic gases, combustible gases, O_2,
Utilities [gas, electric]	O_2, CO, HC_s, NO_x, SO_x, CO_2,
Petrochemical	HC_x, conventional pollutants,
Steel	O_2, H_2, CO, conventional pollutants,
Military	Agents, explosives, propellants,
Aerospace	H_2, O_2, CO_2, humidity,

tion of the analyte gas with the sensor device, but rather the analyte modulates the energy absorbed or emitted by the physical sensor. The lab-on-a-chip or μ-TAS (micro-Total Analytical System) is considered a sensor in only the broadest of definitions and is really a complete analytical system.

The signal from a sensor is typically electronic in nature, being a current, voltage, or impedance/conductance change caused by changing analyte composition or quality. While chemical sensors contain a physical transducer and a chemically sensitive layer or recognition layer, the microinstrument or spectrometer (Fig. 1b) sends out an energy signal, be it thermal, electrical, or optical, and reads the change in this same property caused by the intervening chemical and this is akin to molecular spectroscopy in the above example. In μ-TAS, the system, Fig. 1c, can include sampling system, separation or fluidic instrumentation system, as well as a detector. The users of sensors, of course, do not care about this division, but this paradigm is helpful in explaining the types of systems that exist and understanding how they work, why they have certain properties and analytical performance, and how new developments are made. ECS has had conferences that have included all of these types of sensors. A few types of electrochemical sensors are included in the following discussions.

While the topic of sensors of interest to the Society is too broad to cover here, we can discuss a few electrochemical sensors by conventional definition, assigned to three categories: potentiometric, amperometric, and impedance or admittance based devices. Biosensors, while directed toward analysis for a specific or significant biological material or bio-endpoint[3] will utilize one or more of these principles. Optical and acoustic or similar approaches are also included in electrochemical sensors if a broad definition of these terms is used. Electrochemical sensors can be applied for solid, liquid, or gaseous analytes with the latter two most common. High temperatures can be accommodated using solid electrolytes and high-temperature materials for sensor device construction. In the following brief discussion, we outline some common electrochemical sensors (see Table IV), and, by illustration, the continued ECS interest in sensors.

Semiconducting oxide sensors.—The heated metal oxide sensor is probably the most investigated and widely produced chemical sensor and has always been a very popular topic for ECS symposia. The working principle of this type of sensor is that the resistance of the metal oxide semiconductor changes when it is exposed to the target gas because the target gas reacts with the metal oxide surface and changes its electronic properties. Such devices are now sometimes called chemiresistors. The sensor usually can be produced simply by coating a metal oxide layer on a substrate with two electrodes pre-embedded on it. Two typical designs with tubular and planar structures are shown in Fig. 2a and b. For the tubular design, the sensor comprises an alumina support tube containing a Pt heater.

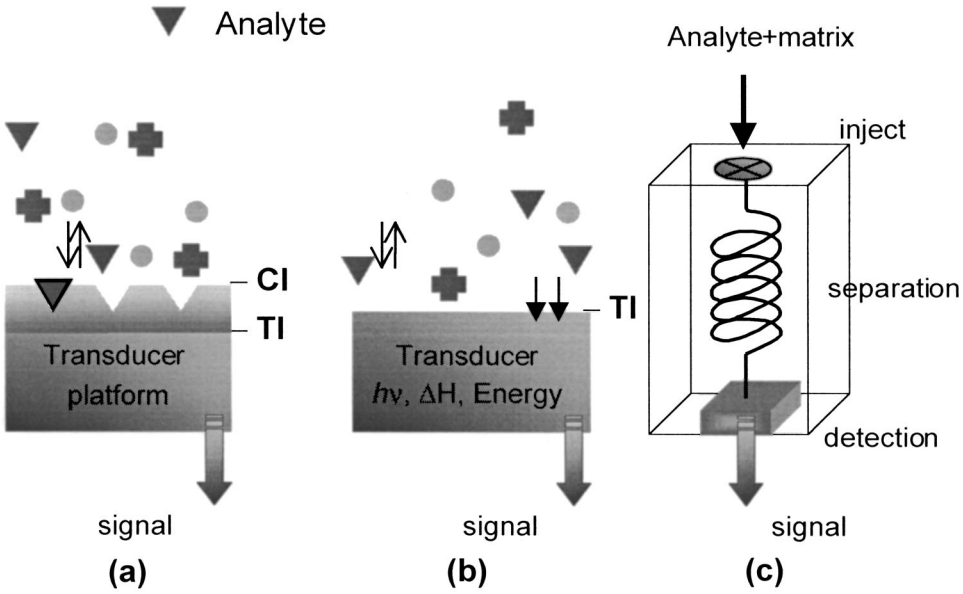

Figure 1. Three types of sensor design and operating principle. CI: chemical interface, TI: transducer interface. (a) Chemical or biochemical sensor (analyte reacts at interface); (b) Physical sensor for chemical analysis, e.g., molecular or atomic spectroscopy; (c) Micro-Total Analytical System, μ-TAS (lab-on-a-chip technologies).

Table II. Chemical Sensor Related Symposia Supported by the Sensor and Other ECS Divisions.

Year[a]	Division[b]	Symposium[c]
2002/F	HT/SS/BA	Solid-State Ionic Devices III[d]
2002/F	SS	Acoustic Wave Based Sensors
2002/S	SS/DS/EN	Microfabricated Systems & MEMS VI[d]
2002/S	SS/IE	Sensing in Industrial & Extreme Applications
2002/S	PE/OB/SS	Chemically Modified Electrodes
2002/S	PE/OB/SS	Microanalytical Devices & Instrumentation
2002/S	EN/SS	Wide Bandgap Semiconductors for Photonic & Electronic Devices & Sensors II[d]
2002/S	HT	High Temperature Materials Symposium in Honor of the 65th Birthday of Prof. W. L. Worrell[d]
2001/F	SS/PE/OB	Chemical & Biological Sensors & Analytical Methods II[d]
2001/S	SS/OB/NT	DNA Sensors
2001/S	SS	8th International Symposium on Olfaction & the Electronic Nose (ISOEN8)[d]
2001/S	CR/SS	Corrosion Sensors
2000/F	SS/IE	Microsensor Systems for Gas & Vapor Analysis
2000/F	SS/DS/EN	Microfabricated Systems & MEMS V[d]
2000/F	SS	Acoustic Wave-Based Sensors
2000/F	HT/SS/BA	Solid State Ionic Devices II-Ceramic Sensors[d]
2000/S	SS	Advances in Sensors for Diabetes Monitoring
2000/S	SS	Polymer Manufacturing Process Sensors II
2000/S	SS/PE	Electrochemical Impedance for Analysis of Chemical & Electrochemical Processes & Mechanisms
1999/F	SS	Chemical Sensors IV[d]
1999/F	OB/SS	Biosensors & Biomolecular Electronics
1999/S	SS	Transportation Sensors
1999/S	PE/SS/OB	New Directions in Electroanalytical Chemistry
1999/S	HT/SS/BA	Solid State Ionic Devices I[d]
1998/F	SS/PE	Acoustic Wave-based Sensors
1998/F	SS/DS/EN	Microstructures & Microfabricated Systems IV[d]
1998/F	SS	Sensors for Polymer Manufacturing Process Monitoring I
1998/S	SS	Sensors for Environmental Monitoring & Occupational Safety
1998/S	HT	Ceramic Sensors
1998/S	HT	High Temperature Corrosion & Materials Chemistry Ceramic Sensors
1998/S	ET	Applications of Electronically & Ionically Conducting Membranes
1997/F	SS	Chemical & Biological Sensors & Analytical Electrochemical Methods I[d]
1997/S	SS	Immuno & Bio-Sensors
1997/S	SS	Microstructures & Microfabricated Systems III[d]
1997/S	LD	Sensors Based on Optical Spectroscopy
1997/S	IE	Sensing, Control & Treatment for Pollution Prevention
1997/S	ET	Application of Sensors in Energy Technology
1996/F	SS	Acoustic Wave-Based Sensors
1996/F	HT	Ceramic Sensors III[d]
1996/S	SS	Automotive Sensors
1996/S	SS	Surface & Films for Sensing
1995/F	SS/NT	Environmental Sensors
1995/F	SS/DS/EN	Microstructures & Microfabricated Systems II[d]
1995/F	ET	Thin-Film Solid Ionic Devices & Materials[d]
1995/F	EN	Wide Bandgap Semiconductor and Devices I
1995/S	SS	Sensors for Industrial Processes Monitoring & Control
1994/F	SS	Acoustic Wave-based Sensors
1994/F	SS	Biosensors & Their Applications in Medical Science
1994/F	HT	Solid Electrolyte Sensors
1994/S	SS	Microstructures & Microfabricated Systems I[d]
1993/F	SS	Fundamental Processes in Ion-Selective Electrodes & Other Ion-Sensors
1993/S	SS	Chemical Sensors II[d]
1992/F	SS	Piezoelectric Sensors
1992/S	SS	Electrochemical Sensors in Medical Science
1992/S	HT	High Temperature Sensors
1992/S	BA	Development of Applications of Sensors for Emerging Energy Technology Conversion
1991/F	CR	Acoustic Wave Sensors for Corrosion Studies
1991/S	SS	Environmental Sensors
1991/S	SS	Sensors Based on Organic Electroactive Materials
1990/F	SS	Optical & Piezoelectric Sensors
1990/F	SS	Sensors for the Transportation Industry
1990/S	SS	High Temperature Sensors
1990/S	SS	Sensors for Chemical Industry
1990/S	OB	In Vivo Electroanalytical Chemistry & Biosensors
1989/F	SS	Fundamental Processes in Electrochemical Sensors
1989/F	SS	Materials & New Processing Technologies for Sensors
1989/S	SS	Electronic Biomedical Sensors
1988/F	LD	Optical Sensors
1987/F	HT	Electro-Ceramics & Solid-State Ionics
1987/F	SS	Chemical Sensor I
1986/F	PE	Solid Electrolytes
1986/F	LD	Sensors for Robot Applications
1986/F	EN	Microstructured Sensors
1986/S	EN	Electrochemical Sensors for Biomedical Applications[d]
1985/F	EN	Fiber Optics Sensors
1985/S	EN	On-line Solid-State Sensors for Process Monitoring
1984/F	LD	Sensors for Robot Applications
1984/F	EN	Electrochemical, Optical, & Solid-State Sensors
1984/F	BA	Solid Electrolytes: Fundamentals & Applications
1979/F	NT	Ion Selective Electrodes

[a] ECS semiannual meetings are held in May and October (with few exceptions) with odd and even meeting numbers, respectively.
[b] Some symposia were sponsored by multiple ECS divisions. Above are often just given the first sponsor. ECS currently has 14 divisions or group: Battery Division (BT); Corrosion Division (CR); Dielectric Science & Technology Division (DS); Electrodeposition Division (ED); Electronics Division (EN); Energy Technology Division (ET); Fullerenes Group (FU); High Temperature Materials Division (HT); Industrial Electrolysis & Electrochemical Engineering Division (IE); Luminescence and Display Materials Division (LD); Organic and Biological Electrochemistry Division (OB); Physical Electrochemistry Division (PE); Sensor Division (SS); New Technology Subcommittee (NT).
[c] Chemical sensor related symposia and
[d] Indicates symposia producing proceedings volumes.

Table III. Classification of ECS Sensor-Related Symposia.

Application	Automotive, transportation, polymer manufacturing process, process control, energy technology, pollution prevention, environmental monitoring, occupational safety, industrial & extreme applications, gas & vapor analysis, chemical industry, robot applications, diabetes monitoring, medical science, biomedical application,
Materials	Semiconductor, ceramic, solid-state ionic or solid electrolyte, high temperature materials, fiber optics, organic electroactive materials,
Principle	Acoustic wave, piezoelectric, optical, electrochemical impedance,
Fabrication	MEMS, chemical modification,
Analytical target	Ion, gas, bio, immuno, DNA,

The sintered SnO_2 powder is painted on the outside surface of the tube. For the planar design, a substrate, such as alumina or silica, can be used. An advantage of planar design is that the SnO_2 film can be prepared by many techniques, such as silk-screen printing, dip-coating, sputtering, or chemical vapor deposition (CVD). Planar designs are especially promising in the design of a microsensor, a mass production approach, or a sensor array device. As listed in Table IV, many metal oxides have been investigated for gas sensing, however, the most widely used is SnO_2 or doped SnO_2 for the active layer. New materials such as the rare earth oxides or gallium oxide are being used as the active sensor elements. Recent reviews[12,13] include many examples of this type of gas sensors.

A new set of devices using conductive polymers, either those with intrinsic conductivity[14,15] or those that are insulating that have conductive particles inside a matrix that is nonconductive.[16-18] Again these sensors depend upon the interaction between the coating and the analyte and as such will age, clear (reverse), selectively respond, and obtain their analytical characteristics largely from those of the polymer used for the coating. Some polymers are more stable than others and some will change more or less when challenged with a vapor. Novel materials include chiral compounds and calixarenes to gain specific and unique sensing behavior.

Electrochemical sensors (liquid electrolyte).—There are two major sensor classes that use liquid electrolytes: amperometric and potentiometric sensors. The earliest example of an amperometric gas sensor, the Clark oxygen sensor used for the measurement of oxygen in the blood is more than 40 years old. The amperometric sensor produces current signal, which is related to the concentration of the analyte by Faraday's law and the laws of mass transport. The schematic structure of an amperometric sensor is shown in Fig. 2d. It is operated in a region where mass transport is limiting and therefore has a linear response with concentration of analyte. This type of sensor has now been developed in many different geometries and for a broad range of analytes, such as CO, nitrogen oxides, H_2S, O_2, glucose, unique gases like hydrazine, and many other vapors.[19] The amperometric gas sensor has an advantage over many other kinds of sensors because it combines small size, low power, high sensitivity, as well as relatively low price, making it idea for portable toxic and explosive gas instrumentation. With microfabrication techniques, the entire sensor can be assembled on a chip or be part of a μ-TAS (microfabricated total analytical system).

Ion-selective electrodes.—Ion-selective electrodes (ISEs) belong to potentiometric chemical sensor group and are most often based on the measurement of the interfacial potential at an electrode surface caused by a selective ion exchange reaction. The well-known glass pH electrode is a typical ISE and an illustration is provided in Fig. 2c. This type of sensor has a long history[20] and was the topic of the earliest sensor related ECS symposium (see Table II, 1979). The design of ion selective membrane is the key to the development of this type of sensor. Much has been written concerning ionophore-based potentiometric sensors and other improvements[21] to these kinds of devices. As opposed to the amperometric sensor, potentiometric sensors use the voltage at zero current that is typically representative of an equilibrium electrochemical process. These voltages arise because an electrochemical reaction can occur at wires, or at membranes in solid, liquid, or condensed phases. Because the signal is taken for a process at equilibrium, the ultimate signal is less influenced by mass transport characteristics or sensor dimension and provides a reading reflecting the local equilibrium conditions. The generated signal is an electromotive force that is dependent on the activity of the analyte, and is described by Nernst's equation. Response time seems to depend mostly upon how fast equilibrium can be established at the sensor interface.

Solid electrolyte sensors.—Using a solid electrolyte to replace the liquid electrolyte in an electrochemical sensor, one can construct a solid electrolyte electrochemical sensor. Solid electrolyte sensors are typically designed to operate at high temperature and can operate in either a potentiometric or amperometric mode as shown in Fig. 2e and f. An example of a potentiometric sensor is the well-known yttria-stabilized zirconia (YSZ) based oxygen sensors that have been widely used for air/fuel ratio control in internal combustion engines. The sensor response is described by the Nernst equation at equilibrium.

Over the past ten years, two potentiometric designs have evolved: surface-modified solid electrolyte gas sensors[22-24] and mixed potential gas sensors.[25,26] In the former, the surface of a solid electrolyte is coated with an auxiliary phase which will react electrochemically and reversibly with the analyte and generate an interfacial potential. Sensitivity and selectivity to the analyte are provided by the auxiliary phase, *e.g.*, the Na_2CO_3/NASICON system can be used for CO_2 sensing because the carbonate can introduce the electrochemical reaction: $CO_3^{2-} = CO_2 + 1/2O_2 + 2e^-$. This approach allows the use of several conventional ceramic solid electrolytes, including YSZ, β-alumina, or NASICON to construct sensors for many gases[27-29] especially the environmental gaseous pollutants such as CO_2, CO, NO_x, SO_x, H_2, Cl_2, and NH_3, etc. An important advantage of this approach is the development of detection methods that survive harsh conditions where typical liquid electrochemical sensors would be inappropriate.

In a mixed potential sensor design[25,26] more than one electrochemical reaction takes place at the electrodes so that a mixed potential is established by competing reactions. The catalytic activity of the electrode material is particularly important, *e.g.*, the Pt/YSZ/Au sensor can measure CO and hydrocarbons due to the difference in catalytic activities between the Pt and Au electrodes.

Piezoelectric sensors and optical sensors.—The Sensor Division has held special symposium on Acoustic Wave-Based Sensors six times (Table II). The acoustic measurement is made by finding the resonant frequency of the piezoelectric solid, *i.e.*, looking for the point of maximum admittance between the two electrodes. The resonant frequency is a function of many variables, including the mass loading, temperature, density, viscosity, and pressure. The challenge is to keep all of these constant while measuring only the mass change that is proportional to the analyte concentration. Acoustic gas sensing typically requires the crystal to be coated with an active layer, often a polymer or other nonvolatile coating, which performs a function similar to the stationary phase in a gas chromatograph. The gases absorb into the layer and change the mass or viscoelastic

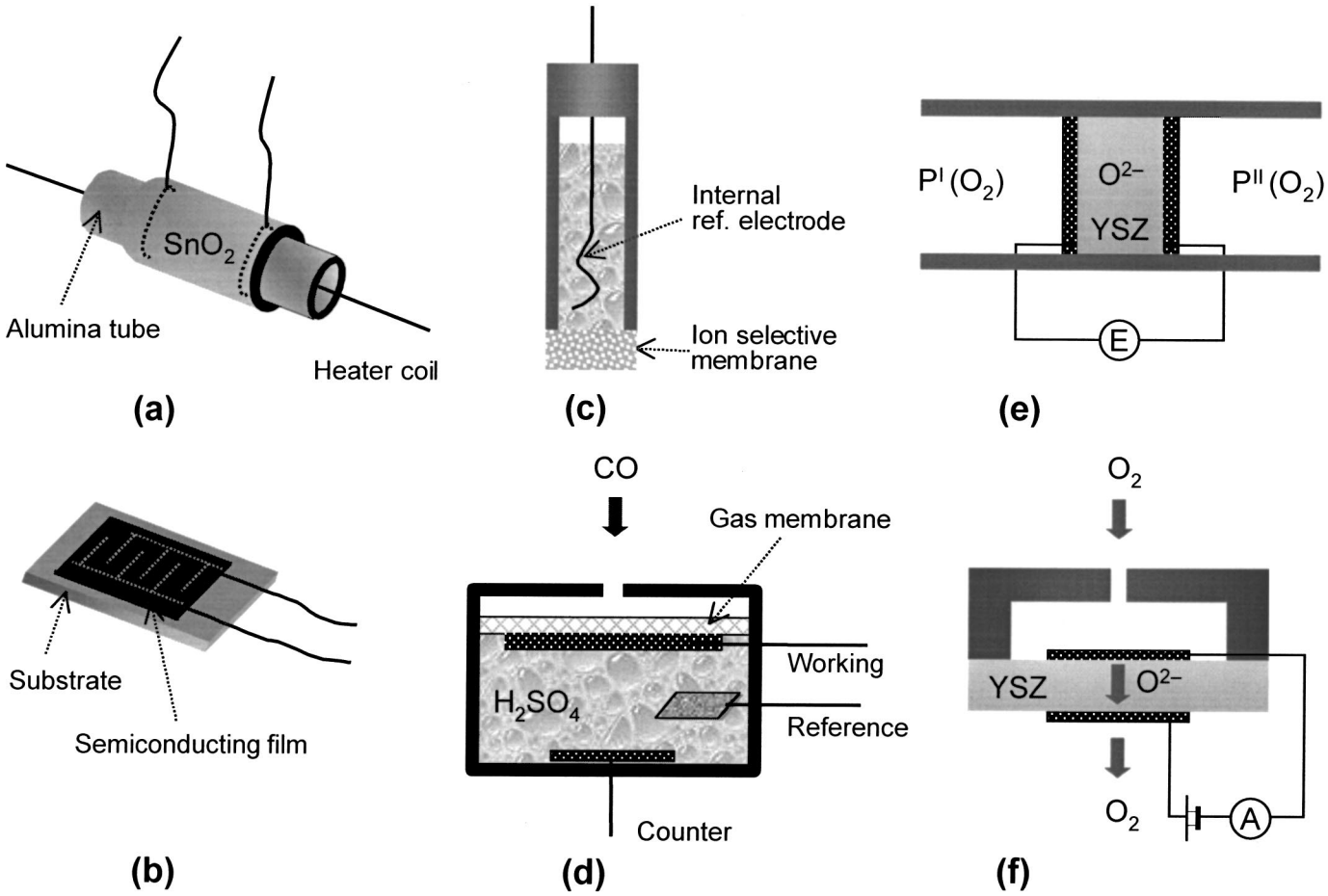

Figure 2. Typical chemical sensors: (a) tubular type SnO_2 gas sensor; (b) planar semiconductor sensor; (c) ion selective electrode (potentiometric); (d) amperometric gas sensor with liquid electrolyte; (e) potentiometric solid electrolyte O_2 sensor (concentration cell); (f) amperometric solid electrolyte O_2 sensor (current-limit type).

properties of the coating and cause a change in attenuation in the acoustic wave. A recent review[30] discusses many examples of this type of gas sensors.

The acoustic wave in many ways parallels the electromagnetic light wave. Attenuation of light waves can be used to construct some of the most effective chemical sensors and articles are published in ECS proceedings and journals on this topic. The sensor design frequently uses a waveguide or optical fiber for convenient construction. If the analyte is placed at the interface of the fiber and a coating, it will have the opportunity to interact with the light. If the conditions are appropriate for either absorption or emission, the intensity and wavelength of the characteristic light provide the opportunity to obtain an analytical signal for quantitative and/or qualitative analysis. Optical techniques may often depend upon a coating and therefore derive many analytical properties, such as sensitivity, selectivity, and stability, from the choice of coating. Optical platforms are frequent choices for biosensors because of the sensitivity that can accompany fluorescence measurements.

Sensor arrays and artificial senses.—Sensor arrays have also

Table IV. Examples of common chemical sensors.

Sensor type	Principle	materials	Analyte
Semiconducting oxide sensor	Conductivity impedance	SnO_2, TiO_2, ZnO_2, WO_3, polymers	O_2, H_2, CO, SO_x, NO_x, HC_s, alcohol, H_2S, NH_3,
Electrochemical sensor (liquid electrolyte)	Amperiometric	composite Pt, Au catalyst	H_2, O_2, O_3, CO, H_2S, SO_2, NO_x, NH_3, glucose, hydrazine,
Ion-selective electrode(ISE)	Potentiometric	glass, LaF_3, CaF_2,	pH, K^+, Na^+, Cl^-, Ca^{2+}, Mg^{2+}, F^-, Ag^+
Solid electrolyte sensor	Amperiometric	YSZ, H^+-conductor	O_2, H_2, CO, HC_s
	Potentiometric	YSZ, β-alumina, Nasicon, Nafion	O_2, H_2, CO_2, CO, NO_x, SO_x, H_2S, Cl_2, H_2O, HC_s
Piezoelectric sensor	Mechanical w/ polymer film	quartz	HC_s, VOCs
Catalytic combustion sensor	Calorimetric	Pt/Al_2O_3, Pt-wire,	H_2, CO, CH_s,
Pyroelectric sensor	Calorimetric	Pyroelectric + film	Vapors
Optical sensors	Colorimteric fluorescence	optical fiber/indicator dye	Acids, bases, HC_s, biologicals

been a part of the ECS sensor journey.[5] When combined with a sampling system and a means of pattern classification, sensor arrays are often called electronic noses or electronic tongues, because of their remarkable ability to mimic the mammalian senses.[31] Electronic noses offer the capability for analyte recognition rather than mere concentration measurement and can operate in very chemically complex matrices with nonspecific or unknown molecular endpoints, like the quality of wine. The Eighth International Symposium on Olfaction and the Electronic Nose (ISOEN 8) was held at the 2001 Spring ECS meeting and resulted in the proceedings volume *Artificial Chemical Sensing*.[5] Sensing with arrays is now being applied to the diagnosis of disease, the quality of meats and fruits, smart fire detection, homeland security, as well as wine, perfume, and coffee analysis. The continued use of sensors as parts of systems will insure that the field will grow and be active for many years to come.

Conclusions

Sensors are practical devices and, as such, activities are both fundamental and applied. Also, understanding sensor devices requires some knowledge of a variety of academic areas. This leads to a very interdisciplinary field populated by physicists, chemists, engineers, biologists and biochemists, materials scientists, electrochemists, and others. The interdisciplinary nature of sensor research, combined with the ability of the Society to transcend singular disciplines and bring scientists and engineers together to work on complex goals like sensor systems will insure a contining role for ECS in the development of physical and chemical/biochemical sensors. One finds sensor symposia at all ECS meetings these days, as well as the meetings of other groups including Pittcon, FACSS, ACS, AICHE, IEEE, and the MRS in Europe, Japan, and the USA. The impact of advances in electrochemical sensors on all three continents is substantial, and detection has been recognized as a key target for technology development in the new USA Homeland Security initiative.

Of course there are many other sensors that could be included in our brief discussion. Apologies are extended to any of our colleagues who may not see coverage for their favorite chemical or physical sensor. A consequence of the rapid expansion of the field has been the inability to cover all of it, even superficially, in a short article. Additional information on sensors can be found in books[32,33] and recent reviews.[34-36]

Finally, excitement in the world of sensors comes from their ability to provide immediate feedback on the world around us just like our own five senses of taste, sight, hearing, touch, and smell. Also, sensors include the most up to date science and technology and new sensors are emerging made from biomolecules, nanostructures, and nanodevices. Single molecule detection is at hand. Sensors are marching toward the day that they can smell out diseases, see danger, cook our food, spot terrorists, help catch fugitives, improve environmental pollution control, and enable clean and efficient climate controls for human safety and comfort in our cars, workplaces, and homes. All in all, the world should be a better place because of the advances in sensors and there is no better place to promote sensor science and technology than The Electrochemical Society and its Sensor Division.

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