INVITED

SENSITIVITY AND DISCRIMINATION OF A BIOLOGICAL OLFACTORY SYSTEM

Anna Menini
Scuola Internazionale Superiore di Studi Avanzati, SISSA, Via Beirut 2, 34100 Trieste, Italy

Abstract

The mammalian olfactory system is a chemical detector that excels in both discrimination and detection. It reliably discriminates more than 3000 structurally diverse odorant molecules and has an amazingly high sensitivity that allows the detection of very low amounts of specific odorant molecules: for example the threshold for human detection of ethyl mercaptan (ethanethiol), commonly added to natural gas as an odorant, is as low as one part in 2.5 billion parts of air. In addition, the olfactory system has the capability to adapt to ambient odorants, allowing the recognition of newly introduced odorants.

In spite of the fact that our knowledge of the molecular mechanisms underlying olfaction has greatly improved in the past 20 years, leading to the 2004 Nobel prize in Physiology to Buck and Axel for their discoveries on odorant receptors, the questions of how the olfactory system finely discriminates among similar molecules and how it reaches a very high sensitivity are still far from being answered. In this lecture I will review the present knowledge about the molecular mechanisms of olfactory transduction (1-4).

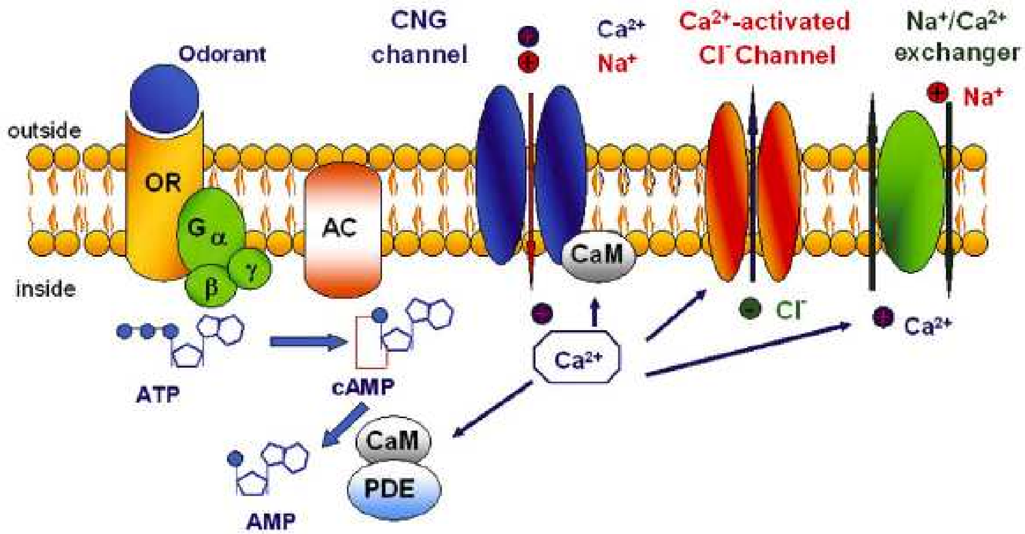

Fig. 1. Olfactory transduction in the cilia of olfactory sensory neurons. Odorant molecules bind to odorant receptors (OR) in the ciliary membrane activating a G-protein (G) that, in turn, stimulates an adenylate cyclase (AC). cAMP directly gates CNG channels causing an odorant-induced inward current carried by Na^+ and Ca^{2+} ions. The increased Ca^{2+} concentration in the cilia causes the opening of Ca^{2+}-activated Cl^- channels and the subsequent Cl^- efflux which further depolarizes the cell. Intracellular Ca^{2+} also binds to calmodulin (CaM) lowering the ligand sensitivity of the cAMP-gated channels. Ca^{2+}–calmodulin also stimulates the activity of a phosphodiesterase (PDE). Ca^{2+} is extruded by a Na^+/Ca^{2+} exchanger. Figure from Ref. (5).

For discrimination among different odorants the olfactory system utilizes an enormous superfamily of receptors, numbering >1000 in rodents and 450 in humans (these require between 2 and 5% of the genome to encode). For detection a canonical second messenger system is a key component. It provides two critical attributes: amplification or gain and increased signal to noise characteristics. This gives the system its remarkable detector capabilities: recognizing some compounds at parts per billion and doing so within a noisy background of wind currents, and multiple compounds.

How is the binding of an odorant molecule to receptors converted into an electrical signal? The olfactory sensory neurons are bipolar neurons with a single dendrite that terminates in a knob from which 10-20 fine cilia originate. These cilia are immersed in the nasal mucus and are the sites where the entire transduction mechanism occurs. The binding of odorants to odorant receptors in the cilia triggers a second messenger cascade as illustrated in Fig. 1, culminating in the depolarization of the olfactory neuron. The depolarization spreads passively to the dendrite and soma of the olfactory neuron, triggering action potentials that are conducted along the axon to the olfactory bulb.

The molecular mechanisms of the olfactory transduction cascade (Fig. 1) have several important physiological consequences. One is that the amplification of the transduction cascade allows the production of an electrical quantal event even by the binding of a single odorant molecule (6). The calcium-activated chloride channel, which produces a low noise signal amplification, is likely to be responsible for the high sensitivity. The channel is believed to possess a small conductance meaning that a large number must be opened more or less coincidentally for a meaningful depolarization to occur. This adds to the signal noise characteristics in that a large number of small events is less noisy than a small number of large events.

The other important consequence of the molecular mechanisms of olfactory transduction is that it is already at the level of the transduction process that the physiological process of adaptation to odorants occurs. Indeed, the initial response of an olfactory sensory neuron to an odorant stimulus is followed by a period of reduced responsiveness. It has been shown that, in combination with calmodulin, Ca^{2+} mediates odorant adaptation through a negative feedback, by desensitizing cAMP-gated channels (7). The complex calcium-calmodulin exerts a feedback action on the ion channel by decreasing its open probability and activating a phosphodiesterase that will reduce the concentration of cAMP, thus restoring the initial conditions (Fig. 1).

The understanding of the molecular mechanisms employed by these biological olfactory sensors to achieve their extraordinary properties of sensitivity and discrimination is of interest both for basic research and for the development of an artificial nose that operates on the same principles used by living organisms.

REFERENCES

1. Menini A (Editor), The Neurobiology of Olfaction. Frontiers in Neuroscience Series, CRC Press, Taylor and Francis Group. (2009) Boca Raton, FL, USA
2. Tirindelli R, Dibattista M, Pifferi S, Menini A. (2009) Physiological Reviews 89:921-956
3. Menini A, Lagostena L, Boccaccio A. (2004) News in Physiological Sciences. 19:101-104
4. Menini A. (1999) Current Opinion in Neurobiology. 9:419-426
5. Pifferi S, Boccaccio A., Menini A. (2006) FEBS Letters 580:2853-2859.
6. Menini A, Picco C, Firestein S. (1995) Nature 373: 435-437
7. Kurahashi T and Menini A. (1997) Nature 385: 725-729

LA SENSORISTICA:UN PONTE FRA I SETTORI DELLA CHIMICA E FRA LA CHIMICA E LE ALTRE SCIENZE

L. Campanella
Dipartimento di Chimica, Università Roma "La Sapienza", Roma

Abstract

La sensoristica, nata intorno agli anni ´60 oggi è connotata come una delle "nuove frontiere scientifiche" che si occupa di monitoraggio ambientale e clinico, ma che trova anche applicazioni non tradizionali in Archeometria,in Scienze dello Spazio,in Scienza dei Materiali,in Agronomia.

Le nuove tendenze scientifiche portano all´acquisizione ed elaborazioni delle risposte di sensori e biosensori mediante computer e con la collaborazione fra competenze diverse in un approccio necessariamente multidisciplinare (chimica, fisica, scienze della vita e della terra, informatica e statistica).

Da questa cooperazione stanno nascendo "nasi e lingue" elettronici in grado di rilevare non più un singolo segnale, ma un´impronta di segnali per elaborare dati molto complessi e utili nei diversi campi di ricerca.

Attualmente tramite biosensori (ad enzima, tessuto, cellula) e sensori (a stato solido e membrana) si può: monitorare l´inquinamento elettromagnetico causato dai cellulari; sostenere i rilevamenti delle missioni spaziali; certificare la qualità delle merci; misurare il potere nutritivo ed antiossidante degli alimenti; datare reperti archeologici cellulosici; eseguire analisi in situ ed in vivo (organi artificiali).

Da tutto ciò emerge un significativo ruolo culturale della sensoristica: mentre colpevolmente si tende a disarticolare la cultura,quasi per appropriarsi di parte di essa, la sensoristica è il terreno fertile per una ricomposizione, capace di dare alla cultura quel carattere di integralità di cui non può e non deve fare a meno.

NONAQUEOUS SOL-GEL ROUTES TO METAL OXIDES: VERSATILE PREPARATION METHODS OF NANOPOWDERS AND FILMS FOR SENSING APPLICATIONS

Nicola Pinna1,2*
[1] *Department of Chemistry, CICECO, University of Aveiro, 3810-193 Aveiro, Portugal.*
[2] *School of Chemical and Biological Engineering, College of Engineering, Seoul National University (SNU), Seoul, 151-744, Korea..*

Abstract

Nonaqueous sol-gel routes are elegant approaches for the synthesis of nanomaterials [1]. Indeed, high quality pure inorganic nanocrystals [1], ordered hybrid organic-inorganic materials [2] or thin films by atomic layer deposition (ALD) [3] can be obtained. Especially, the chemical mechanisms taking place during the metal oxide formation greatly influence the morphology, assembly and the final properties.

In this communication, after an introduction to nonaqueous sol-gel routes to inorganic nanocrystals and ordered hybrid organic-inorganic materials synthesized in surfactant-free system, we will concentrate on the ALD using nonaqueous conditions. The similarities and differences of the chemical processes taking place in solution and in ALD will be discussed.

ALD of metal oxides involves the reaction of a metal precursor with an oxygen source. Water is the most commonly used oxygen source and it is generally admitted that water hydrolyzes the surface molecular species forming hydroxyl groups. The resulting OH groups will further react with the metal precursors supplied by a new pulse forming the M-O-M bond.

Here, we will describe recent advances on metal oxide thin films deposition using nonaqueous sol-gel chemistry [3] and we will present a novel approach, based on the reaction of metal alkoxides with carboxylic acids, leading to the formation of high quality metal oxide thin films [4]. This process enables the growth of metal oxides at temperatures as low as 50 °C on various supports including monocrystalline substrates, carbon nanotubes, organic fibers, etc. Especially, this new approach permits the homogeneously coating of the inner and outer surface of carbon nanotubes with a highly conformal film of controllable thickness and hence, the production of high surface area multifunctional materials at a so far unprecedented quality [5,6].

The characteristics of these materials will be presented together with their formation mechanism. Finally, the gas sensing characteristics of devices made of metal oxide nanocrystals and carbon nanotubes homogeneously coated with thin layers of metal oxides will be discussed.

REFERENCES

1. Pinna, N. & Niederberger, M. Surfactant-free nonaqueous synthesis of metal oxide nanostructures, Angew. Chem. Int. Ed., 2008, 47, 5292-5304
2. Pinna, N. The "benzyl alcohol route": An elegant approach towards organic-norganic hybrid nanomaterials, J. Mater. Chem., 2007, 17, 2769-2774
3. Clavel, G.; Rauwel, E.; Willinger, M.-G. & Pinna, N. Nonaqueous sol-gel routes applied to atomic layer deposition of oxides, J. Mater. Chem, 2009, 19, 454-462
4. Rauwel, E.; Clavel, G.; Willinger, M.-G.; Rauwel, P. & Pinna, N. Non-aqueous routes to metal oxide thin films by atomic layer deposition, Angew. Chem., Int. Ed., 2008, 47, 3592-3595
5. Willinger, M.; Neri, G.; Rauwel, E.; Bonavita, A.; Micali, G. & Pinna, N. Vanadium oxide sensing layer grown on carbon nanotubes by a new atomic layer deposition process, Nano Lett., 2008, 8, 4201-4204
6. Willinger, M.; Neri, G.; Bonavita, A.; Micali, G.; Rauwel, E.; Herntrich, T. & Pinna, N. The controlled deposition of metal oxides onto carbon nanotubes by atomic layer deposition: Examples and a case study on the application of V_2O_4 coated nanotubes in gas sensing, Phys. Chem. Chem. Phys., 2009, 11, 3615-3622