Development of nanostructured electrochemical sensors for food packaging applications

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This PhD thesis research project aims to develop electrochemical sensors with low limit of detection and wide linear range for detecting and quantifying hazardous analytes that can migrate from the packaging materials to the food, thus representing a potential risk for the consumer' health. Our ultimate goal is to provide evidence for the feasible scale up of the outcomes arising from the project by manufacturing electrochemical sensor prototypes that can profitably be used by the food packaging companies.

Sviluppo di sensori elettrochimici nanostrutturati per applicazioni nel settore del food packaging

Il presente progetto di dottorato ha come obiettivo lo sviluppo di sensori elettrochimici caratterizzati da bassi limiti di rivelabilità e ampio intervallo lineare per l'individuazione e la quantificazione di analiti pericolosi che possono migrare dai materiali di imballaggio all'alimento confezionato, quindi rappresentando un potenziale rischio per la salute dei consumatori. L'obiettivo finale è quello di dimostrare la fattibilità dell'industrializzazione dei risultati ottenuti nell'ambito del progetto mediante la realizzazione di prototipi di sensori elettrochimici a vantaggio di un diretto uso da parte delle industrie di imballaggio alimentare.

1. State-of-the-Art

Worldwide foodborne illness prompts increasing consumers' demand for healthier and high quality foods. For this reason, quantification and control of food packaging materials and food constituents has become dramatically important in recent years for both consumers and companies. Most of the food safety-related legislative and regulatory implementations over the past decade aimed to provide increasingly safer food by protecting it from potential microbiological, chemical, and toxic hazards, which may occur either naturally or accidentally in the lengthy farm-to-table food supply chain. Different methods are currently available for the quality assessment of food. Among others, chromatographic, spectrophotometry, optical, and colorimetric methods are the most widely adopted. Because of some inherent disadvantages of these conventional methods (e.g. they are expensive, time-consuming, and complicated), they are not often used as quality control tools within companies, being rather used within specialized laboratories (Subramanian*et al*., 2009). Lately, electrochemical sensors were recognized as more selective, reliable and sensitive devices over other instrumental devices, with additional advantages such as lower cost, ease of use, and faster response time.
A sensor is a device or system that includes control and processing electronics, interconnection networks, and software. Such a sensor responds to a chemical or physical quantity to make an output that is quantifiable and is proportional to the measure. Most sensors include four major components: (1) the receptor, i.e. a sampling area where the surface chemistry occurs; (2) the transducer, i.e. the component able to 'sense' the quantity variation arising from the surface chemistry (e.g., pH change, electron transfer, thermal variation, etc.); (3) signal processing electronics, i.e. all the electronic elements enabling the shift of the raw quantity change into an electronic signal; and (4) a signal display unit, which shows a digital output readily available for the operator (Neethirajan*et al*., 2009). In recent years different kinds of sensors intended for food applications have been developed, such as electrochemical, fluorescent, and luminescence sensors, which are the most representative examples. Electrochemical sensors represent an important subclass of chemical sensors in which an electrode is the transduction element. Such devices hold a leading position among sensors presently available, have reached the commercial stage, and have found a vast range of important applications in the fields of food, clinical, industrial, environmental, and agricultural analyses (Wang, 2006).

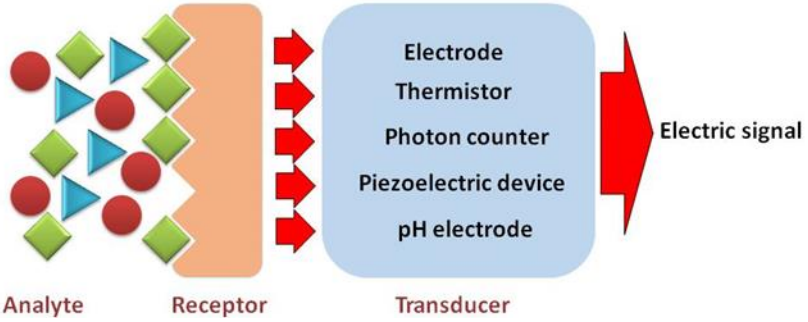

Figure 1 *Schematic representation of a sensor.*

More recently, nanotechnology principles opened the way to a novel subset of electrochemical sensors with enhanced sensitivity and limit of detection, raising renewed interest around the world. These kinds of sensor have a wide area of usage in different food technologies, such as dairy industry (Xiong *et al*., 2014), juice industry (Nasirizadeh*et al*., 2015), and meat industry (Saghatforoush *et al.* 2014). However, there is a lack of potential applications envisaged for the food packaging field, as demonstrated by the very few papers published on this topic until now. Indeed, there are several critical substances that can migrate from the package to the food, such as additives, process residues, contaminants, and even neo-formed products, which would certainly deserve much attention as far as the development of new analytical techniques for their determination is concerned. This PhD project aims to the design and development of electrochemical sensors for the detection of potentially hazardous substances that migrate from the packaging materials to the food matrix. The potential use of these sensors for practical issues will be also covered.

2. PhD Thesis Objectives and Milestones

Within the overall objective mentioned above, this PhD thesis project can be split into the following activities according to the Gantt diagram given in Table 1:

A1) **Experimental part,** which will include: i) finding the best modifiers and the optimum conditions for modifying the bare electrode; ii) studying the electrochemical behavior of the modified electrode in the presence and absence of the analyte; iii) investigating the effect of the analyte on the surface of the electrode; using different methods to calculate the linear range and the limit of detection; and assessing the sensor suitability for the detection of the selected analyte(s) in real food matrices.

A2) **Scaling up the developed technology.** Investigation of the efficiency and potential application of the proposed sensor for different real cases within companies.

A3) **Writing and editing** of the PhD thesis, scientific papers and oral and/or poster communications.

Table 1 *Gantt diagram for this PhD thesis project.*

Activity	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A1)	***Experimental***	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
	1) Finding proper modifiers	■	■	■	■																				
	2) Finding proper nanoparticles					■	■	■	■																
	3) Investigating electrochemical behavior of modified electrode									■	■	■	■												
	4) Investigating the effect of analyte on the surface of modified electrode													■	■	■	■								
	5) Determining analytes in real samples																	■	■	■	■				
A2)	***Scale up the sensor***																					■	■	■	■
	1)Investigating application of the sensor in different industries																					■	■	■	■
A3)	***Thesis and Paper Preparation***	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

3. Selected References

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