Doctoral Dissertation
Doctoral Program in Metrology (32^{nd} cycle)

Development and characterization of sensors for human health

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Summary

This thesis focuses on the development of sensors for human health. Several different factors impacts people live and health. Among them surely pollution and health care are extremely important.

First part of the thesis deals with the pollution topic and, in particular with the atmospheric particulate matter. Atmospheric pollution due to the particulate is nowadays a serious issue and it turns out in severe effects on human health. Many studies demonstrated the correlation between high aerosol concentrations and the presence of several diseases in the exposed subjects. Transitory diseases of respiratory system, such as bronchitis, asthma and inflammations, are very common even though lung cancer and cardiovascular problems were registered as well. Atmospheric particulate is also correlated with different negative consequences on climate. Among them, the most worrying one is surely the direct climate forcing due to the high light absorption coefficient of the particulate and, consequently, the increasing of local atmospheric temperature. This has significant secondary effects on cloud formation and on wet precipitations as well.

The effects of atmospheric particulate matter are related to several properties of the particles, such as size, chemical composition and morphology. Such characteristics can largely change according to aerosol source and environment conditions. Therefore, a suitable monitoring of the concentration of particulate matter is mandatory both for assuring safe life conditions to people and to better understand the processes involved in formation, transformation and deposition of aerosols.

Unfortunately, available monitoring devices employs detection approaches which provide only a partial characterization of the aerosol. Furthermore, they are typically very expensive and not suitable to be employed in a capillary monitoring of the territory. This turns out in the necessity of developing small low-cost monitoring nodes to be employed in smart wireless sensor networks. With this aim, a new detection approach based on a small digital camera able to detect the single particles captured on a standard glass fibre filter was developed. Three different prototypes, employing such an approach but differing in filter management, were realized and characterized with several tests. In particular, preliminary tests were carried out to assess the feasibility of the proposed approach and the characteristics of the air pumping system employed to sample a specified volume of air and the effective resolution achieved by the camera optical system. Further characterizations were carried out to investigate the blocking

capability of the selected filters and the principal properties of the captured particles. Eventually, a comparison of the proposed system towards a commercial laser-scattering station was carried out. The results achieved are very promising even though a significant difference is still present between the two instruments.

Second part of the thesis, instead, deals with health care and the employment of breath analysis as alternative to conventional diagnostic methods. Breath analysis is based on the detection of specific gaseous species, called biomarkers, in exhaled breath. Such biomarkers, when present at abnormal concentrations, are indicative of specific diseases.

Breath analysis has several advantages such as non-invasiveness, quick response and virtually low-cost. Unfortunately, still nowadays, there are many limitations to an effective employment of such a technique. In particular, biomarkers are present in human breath at extremely low concentration. Furthermore, being the exhaled breath a complex mixture as several different gaseous species is very difficult to distinguish between them and accurately detect specific biomarkers. Therefore, high sensitivity and selectivity are required features of any device employed in breath analysis. This turns out in expensive equipment which partially deprives the advantages of such a method. A possible solution to such issues is the employment of cheap and small gas sensors able to achieve suitable sensitivity and selectivity.

In such a framework, several conductometric gas sensors based on thin film of niobium oxide were deposited on small alumina substrates by using reactive magnetron sputtering deposition in a RF capacitively-coupled parallel-plate plasma reactor. Several different combinations of deposition parameters were tested and many sensor prototypes were realized and fully characterized with the aim to develop effective sensors for acetone, a recognized biomarker of diabetes.

Preliminary characterization were performed in order to assess film structure and morphology by means of an electron scanning microscope. Subsequently, the chemical composition of deposited films was investigated employing the x-ray photo-electron spectroscopy which revealed a deposited film mainly composed by Nb_2O_5.

Sensing performance of prototypes were investigated and compared in order to find the optimal deposition parameters. Dedicated tests were carried out with an experimental measurement setup in order to assess sensitivity, selectivity, stability and response times of the realized prototypes. In particular, one of them revealed good sensitivity suitable for detecting acetone at concentrations lower than 1 ppm. Quick response times and an excellent selectivity were assessed as well.

Such sensing performance together with a low-cost and a low power consumption pave the way for the development of small breath analyzers able to non-invasively monitoring diabetes patients by means of an effortless sampling of exhaled breath.

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