Organosilicon PECVD-processed membranes for the selective detection of BTEX

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The quality of indoor air is one of the main environmental concerns. Any enclosed space can be easily polluted by harmful chemicals, such as volatile organic compounds, more specifically BTEX, standing for Benzene, Toluene, Ethylbenzene and Xylene, which are the focus of this study. BTEX can have devastating effects on humans' health, even at trace level. In this context, European legislation requires a strict monitoring of BTEX quantification in indoor air, which calls for the development of BTEX sensors, especially miniaturized ones.
Obviously, such sensors should display high affinity towards BTEX, and also demonstrate high selectivity over airborne co-contaminants. Quartz Cristal Microbalance (QCM) technology shows very promising performances in term of sensibility, small footprint, long-term stability and also low cost but it suffers from poor selectivity. To overcome this drawback, it is thus paramount to deposit an active layer at the QCM surface able to selectively adsorb the targeted molecular contaminants [1].
In this context, this study deals with the preparation of active layers based on organosilicon hybrid materials, processed by Plasma-Enhanced chemical vapor deposition (PECVD). Such kind of materials has already shown great results in terms of affinity and selectivity towards toluene in a previous research by our group [2]. The goal of this project was to optimize PECVD-prepared organosilicon active layers for tuning their textural, structural, chemical and mechanical features. This was achieved by changing the deposition parameters in the PECVD process, with the aim of displaying the best set of the operating conditions to maximize the active layers' sorption properties for BTEX, in terms of affinity, selectivity over co-contaminants (other VOCs, humidity…), and reversibility.
Organosilicon hybrid thin layers were successfully deposited on QCM transducers, using a capacitively-coupled radio-frequency PECVD reactor, starting from hexamethyldisiloxane as a precursor. Both the input power and the precursor flux were varying in wide ranges in order to largely tune the morphological, structural and so the adsorption features of the deposited thin films. XPS analysis of the materials confirmed their hybrid nature. The atomic composition was demonstrated close to that of polydimethylsiloxane (PDMS), while the silicon surrounding was more diverse than that observed for PDMS. Indeed, the materials structure results from a mixture of $SiOC_3$ and SiO_2C_2, present in the precursor, and also SiC_4, SiO_3C and SiO_4 environments, issued from the precursor fragmentation followed by complex radical recombination in the PECVD chamber. Interestingly, the chemical composition and the typical local environment of Si atoms strongly impact the textural and mechanical properties of the organosilicon-based membrane, and consequently their sorption properties towards toluene. Finally, we collected the sensor performances of the organosilicon@QCMs exposed to toluene vapor and further established the correlations between the sensor features, i.e. sensibility, selectivity, response time, detection range of the toluene concentration, limit of detection…, and the structural/textural/mechanical features of the organosilicon-based membranes.

[1] Gulcay-Ozcan, E., P. Iacomi, G. Rioland, G. Maurin and S. Devautour-Vinot, "Airborne Toluene Detection Using Metal-Organic Frameworks", ACS Appl. Mater. Interfaces, 14(48), 53777-53787 (2022).
[2] Dakroub, G., T. Duguet, J. Esvan, C. Lacaze-Dufaure, S. Roualdes and V. Rouessac, "Comparative study of bulk and surface compositions of plasma polymerized organosilicon thin films", Surf. and Interfaces, 25, 101256 (2021).