engineering proceedings

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Abstract

Diamond: A Chemical Sensor's Best Friend †

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† Presented at the 9th International Symposium on Sensor Science, Warsaw, Poland, 20–22 June 2022.

Keywords: diamond; chemical sensor

For a few decades, diamonds have been grown in some laboratories using either the High Pressure High Temperature (HPHT) process or Plasma-Enhanced Chemical Vapor Deposition (MP-CVD). Single-crystal diamonds exhibit outstanding properties including high optical transparency over a broad electromagnetic spectrum, high thermal conductivity approx. five times higher than copper, and acoustic wave velocity close to 19,000 $m \cdot s^{-1}$. They also display remarkable mechanical properties with, e.g., a Young's modulus exceeding 1000 GPa along with high resistance to fracture, to name a few. Some of these properties also remain remarkable in their polycrystalline forms when compared to most other materials. Furthermore, diamonds can be doped, e.g., with nitrogen or boron during growth, offering electrical properties from semiconducting to quasi-metallic regimes. When heavily doped with boron ($\sim 2 \times 10^{21}$ cm^{-3}), so-called Boron Doped Diamond (BDD) electrodes become attractive electrodes featuring a high potential window >3 V in water and low double-layer capacitance. Moreover, diamonds are extremely resilient to corrosion and more generally to chemical attacks. They are also biocompatible, which makes them very attractive for in vivo sensing applications. Finally, the carbon nature of diamonds presents wide opportunities for the surface grafting of chemical or biochemical functional groups through highly stable covalent carbon–carbon bonding. One can take advantage of these properties to enhance the analytical performances and stability of chemical/biochemical sensors, and this has motivated our research over the last 15 years.

Our work mainly focuses on polycrystalline diamond thin films that can be grown typically on 4-inch silicon substrates, thus offering access to some clean-room processes and potentially large-scale production. As examples, diamond-based Microelectromechanical systems (MEMS) devices (microcantilevers and SAW sensors) take advantage of both the mechanical properties of diamonds along with steady carbon interfaces for convenient bio-functionalization. Our work here focused mainly on the detection of odorant molecules, using biomolecular receptors involved in olfaction in nature as sensitive layers, including Odorant Binding Proteins (OBPs), Major Urinary Proteins (MUPs) and Olfactory Receptors (OR). Multisensor array instrumentations were developed around this concept for applications ranging from breath analysis to security applications. In addition, heavily doped diamond electrodes were developed successfully both as macro- and micro-electrodes for biomedical, pharmaceutical or foodstuff analysis applications. These applications benefit both from the high analytical performances of diamond electrodes, in particular due to their low background signals and high reactivity, and high stability and reliability. BDD electrodes also offer significant advantages in electrochemiluminescence (ECL) techniques, which are being investigated for various applications ranging from foodstuff analysis to narcotics detection. A key benefit of BDD electrodes for all of the above applications is that they can certainly be electrochemically reactivated following fouling, sometimes directly in the analytical medium, to maintain high reactivity, thus paving the way for reusable sensors and online monitoring.

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Citation: Scorsone, E. Diamond: A Chemical Sensor's Best Friend. *Eng. Proc.* **2022**, *21*, 29. https://doi.org/10.3390/engproc2022021029

Academic Editors: Piotr Lesiak, Tomasz Woliński and Leszek Jaroszewicz

Published: 26 August 2022

Funding: Parts of this research was funded by European Union's Seventh Framework Programme under grant agreement No 285203 ("SNIFFER project") and from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653323 ("CBORD project") And The APC was funded by CEA, LIST.

Conflicts of Interest: The author declares no conflict of interest.