Sustainable Carbon Nanomaterials in Theranostic, Environmental and Green Energy Applications

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Abstract

In recent years, carbon dots, a relatively new class of nanomaterials, have gained significant attention. These dots are composed of carbon, oxygen, nitrogen, and hydrogen, with carbon and oxygen typically making up about 80% of their elemental composition. They are usually water-dispersible and can be synthesized from a wide range of inexpensive precursors, including small molecules like citric acid, amino acids, and sugars. Despite their small size (typically ~10 nm), carbon dots can exhibit high quantum yields of emission, which are controlled through surface passivation. Their optical properties are particularly noteworthy, as they can be fine-tuned by selecting appropriate starting materials and synthesis methods, enabling fluorescence emission from the blue to the near-infrared regions of the spectrum. The versatility of their optical properties, including the development of dual-fluorescent systems, facilitates the design of ratiometric optical sensing probes. These probes are valuable for biological applications, such as monitoring temperature and pH changes in live biological systems. Additionally, the low cytotoxicity of carbon dots makes them suitable for studying cellular uptake mechanisms and localization in both healthy and diseased cell lines. Finally, we leverage their electroconductive properties to elicit neurite outgrowth supporting potential advancements in the treatment of neurodegenerative diseases.

Beyond biological applications, we also leverage their optical properties for environmental sensing, focusing on the detection of heavy metals and emerging contaminants. Our research extends to converting sustainable biomass into carbon-based adsorbents for the removal of pharmaceutical waste from water. This work adopts a comprehensive approach, integrating artificial intelligence, molecular modeling, and experimental design to investigate competitive adsorption and desorption processes.

Finally, in a departure from a focus on their optical properties, we focus on the development of these dots as novel, sustainable and metal-free heterogeneous catalysts. Here we show that these dots can trans/esterify the conversion of oils to biofuels with sustained catalytic efficiency over multiple reaction cycles. Our second and third-generation catalysts allow for a significant reduction of reaction temperature and operation at ambient pressures without a significant increase to the catalyst loading. Our work now tackles waste and inedible oils to reduce the overall cost of the process.

Biography

Rafik Naccache obtained his PhD (2012) in Chemistry at Concordia University in Quebec, Canada working on lanthanide-doped upconverting nanoparticles for imaging applications. There, he was the recipient of the Distinguished Doctoral Dissertation Prize and the Governor General Gold Medal in the area of Technology, Industry, and the Environment. He subsequently carried out his NSERC postdoctoral training in nanobiophotonics at l'Institut National de la Recherche Scientifique developing Terahertz sensing applications in nanobiophotonics. In December 2015, he accepted a tenure track faculty position as a strategic hire in the Department of Chemistry and Biochemistry at Concordia University. Shortly afterwards, he was named a University Research Fellow and a Petro-Canada Young Innovator. He is currently an Associate Professor, the Director of the Centre for NanoScience Research and a Concordia University Research Chair. His group's research focuses on the study of the fundamental properties of fluorescent carbon nanomaterials and hybrid nanosystems for the development of biosensing/imaging, drug delivery and catalysis applications. To date, he has published 85+ manuscripts garnering over 10,000 citations. He has also delivered over 90 conference presentations, including invited, keynote, and plenary lectures, and holds seven patents and disclosures of invention. In addition to his academic career, Dr. Naccache has 10 years of experience in pharmaceutical R&D, having worked at Merck & Co. (1998–2008) in materials characterization and drug development. He continues to consult pharmaceutical companies, leveraging his extensive expertise in the field.

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