Carbon Dots as Functional Components in Photochemical Systems for 3D Printing

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Carbon dots (CDs) are a versatile class of chemically stable nanomaterials whose tunable optical and electronic properties position them as promising components in advanced functional systems at the intersection of materials science and biotechnology. Their structural diversity, arising from controllable surface chemistry and heteroatom incorporation, enables precise modulation of photophysical behavior, making them particularly attractive for applications involving light-driven processes, including photopolymerization and photocatalysis [1]. In this context, the development of sustainable and scalable synthetic strategies is of growing importance. Here, we report a simple, one-step, solvent-free synthesis of CDs derived from citric acid, designed in accordance with green chemistry principles to minimize environmental impact while maintaining synthetic efficiency and reproducibility. The resulting nanomaterials were subjected to thorough purification procedures to eliminate residual low-molecular-weight fluorophores and other by-products, ensuring that the observed optical and catalytic properties originate from the carbon nanostructures themselves [2,3].

Beyond the synthetic approach, this study focuses on elucidating the behavior of CDs as components of complex photochemical systems, with particular emphasis on the role of surface chemistry and heteroatom doping. A systematic investigation was carried out to understand how these structural features influence key photophysical processes, especially the balance between energy transfer and electron transfer mechanisms. These pathways are central to the generation of reactive oxygen species (ROS), which play a critical role in both photocatalysis and photoinitiated polymerization. Photocatalytic activity was experimentally evaluated through the detection of singlet oxygen via endoperoxide formation, as well as hydroxyl radicals through peroxide-assisted hydroxylation of terephthalic acid. The results indicate that distinct types of CDs preferentially promote either energy transfer or electron transfer processes, depending on their surface functionalization and doping configuration [4].

To bridge the gap between fundamental understanding and practical application, the performance of CDs was also evaluated in the context of photopolymerization processes. Kinetic studies were conducted to assess their influence on reaction rates and polymer network formation under light irradiation. The incorporation of CDs into photoinitiating systems enabled efficient initiation of both cationic and free-radical polymerization pathways, demonstrating their multifunctional character. Importantly, these systems were successfully applied in additive manufacturing, where three-dimensional structures were fabricated using digital light processing (DLP) 3D printing technology. The resulting materials exhibited good structural fidelity and mechanical integrity, confirming the suitability of CDs for advanced manufacturing applications.

Overall, this work provides a comprehensive, multiscale perspective on the design, characterization, and application of carbon dots in complex photochemical systems. By integrating experimental studies with mechanistic insights into energy and electron transfer processes, it contributes to a deeper understanding of how nanoscale features translate into macroscopic performance. The findings underscore the potential of citric acid-derived, heteroatom-doped CDs as efficient, sustainable components in photoinitiating systems and beyond. More broadly, the study highlights how interdisciplinary approaches combining green synthesis, advanced spectroscopy, and application-driven testing can lead to innovative solutions for real-world challenges in materials science and related fields.

This research was funded by the National Science Centre (NCN, Poland), OPUS, ("Emerging strategy approaches for the design and functionalization of carbon dots as multifunctional, dynamic, green systems photoinitiators and photocatalysts involved in photopolymerisation processes") Grant No. UMO-2021/41/B/ST5/04533 and by the Ignacy Łukasiewicz ORLEN Foundation under the "TURBOgrant" grant, project no. DKN/00057/2025.

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