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Synthesis and Applications of Carbon Dots

Carbon atoms can bond together in different molecular configurations leading to different carbon allotropes including diamond, fullerene, carbon nanotubes, graphene, and graphdiyne. Carbon dots (CDs), which are generally surface-passivated carbon nanoparticles less than 10 nm in size, are other new members of carbon allotropes. CDs were serendipitously discovered in 2004 during the electrophoresis purification of single-walled carbon nanotubes. Similar to their popular older cousins, fullerenes, carbon nanotubes, and graphene, CDs have drawn much attention in the past decade and have gradually become a rising star because of the advantages of chemical inertness, high abundance, good biocompatibility, and low toxicity. Interestingly, CDs typically display excitation-energy- and size-dependent fluorescent behavior. Depending on their structures, the fluorescence from CDs is either attributed to the quantum-confinement effect and conjugated π-domains of the carbogenic core (intrinsic states), or determined by the hybridization of the carbon skeleton and the connected chemical groups (surface states). Compared with the traditional semiconductors, quantum dots, and their organic dye counterparts, fluorescent CDs possess not only excellent optical properties and small-size effect, but also the advantages of low-cost synthesis, good photo-bleaching resistance, tunable band gaps, and surface functionalities. For these reasons, CDs holds promise as emergent nanolights for bio-imaging, sensing, and optoelectronic devices. Additionally, CDs feature abundant structural defects at their surface and edges, excellent light-harvesting capability, and photo-induced electron-transfer ability, thus facilitating their applications in photocatalysis and energy storage and conversions. To date, remarkable progress has been achieved in terms of synthetic approaches, properties, and applications of CDs. This review aims to classify the different types of CDs, based on the structures of their carbogenic cores, and to describe their structural characteristics in terms of synthesis approaches. Two well-established strategies for synthesizing CDs, the top-down and bottom-up routes, will be highlighted. The diverse potential applications, in the bio-imaging and diagnosis, sensing, catalysis, optoelectronics, and energy-storage fields, of CDs with different structures and physicochemical properties, are summarized, covering the issues of surface modification, heteroatom doping, and hybrids made by combining CDs with other species such as metals, metal oxides, and biological molecules. The challenges and opportunities for the future development of CDs are also briefly outlined.