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Review Article

An Overview of the Microwave Assisted Synthesis of Carbon Nanodots (CNDs): A Fascinating Innovation in Nanotechnology

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Abstract

Carbon nanodots (CNDs) a novel class of carbonaceous nanomaterials, have sparked much attention due to their intriguing properties. These recently developed nanodots, with their low toxicity and other beneficial properties, have surpassed conventional semiconductor quantum dots. Research on CNDs has increasingly focused on synthesis techniques and applications in biology. The potential of microwave-assisted techniques, which can provide intense and efficient energy to reduce reaction time, has been a key area of interest. In this study, we present a microwave-assisted method for creating luminous and water-soluble CNDs from different sources. This method is not only efficient but also environmentally friendly, as it is 'green,' quick, and waste-reusable, providing reassurance about its sustainability. Additionally, Thus, a review and discussion of research publications pertaining to the environmentally friendly synthesis and uses of carbon nanomaterials with microwave assistance are conducted.

INTRODUCTION

CNDs With amazing diameters of less than 10 nm [1], carbon nanomaterials—primarily carbon nanotubes, fullerenes, graphene, and carbon nanofilms—are potential scaffolds that have been playing important roles in a variety of domains, including biochemistry, biomedicine, and biological markers [2–3]. Fluorescent carbon dots, or CNDs, have recently shown a significant influence on the development of a number of fields, including electronics, photonics, energy, catalysis, and medicine [4]. Their biocompatibility [5], photostability [6,-9], and ease of preparation [10,11], have also drawn growing attention. As a result, CNDs have been viewed as a viable option for imaging [12-16], biosensing, and catalysis. For instance, Ehrlich ascites carcinoma cells were conventionally bioimaged using CNDs [17].

Due to their advanced properties, a number of CNDs preparation techniques have been demonstrated in recent decades. These techniques include combustion/thermal, hydrothermal cutting strategies, arc discharge, electrochemical oxidation processes [18,19], and chemical oxidation methods [1,22,23]. However, several of the above-mentioned suggested ways need expensive, time-consuming, or specialized equipment; thus, creating quick and easy methods for CNDs synthesis is still important.

The homogeneity, microstructure, and synthesis methods of these nanomaterials all have a significant impact on their characteristics. Microwave (MW) heating, being volumetric, produces a homogeneous and distinctive microstructure while lowering synthesis time and energy [24-26]. In the solid phase, MW-assisted synthesis of carbon nanomaterials and nanocomposites is more common than in the liquid phase, offering a practical and feasible approach [27-28]. The solid precursors are directly irradiated at a greater power with an increased yield and are appropriate for mega-scale manufacturing since the electromagnetic field density is low in a solid phase system [29-30]. CNDs were applied to human breast cancer Bcap-37 cells for biological imaging [31], which showed that CNDs had strong transmembrane ability, minimal cytotoxicity, and outstanding biocompatibility. Furthermore, in biological imaging, CNDs may be a viable alternative to semiconductor quantum dots (SQDs) or organic dyes [32].

Microwave Irradiation

The most efficient and least time-consuming method for creating CNDs is microwave synthesis, which can also improve the quality and QY of the CNDs through short-duration heating. Table 1 lists the microwave irradiation methods used to create green CNDs. Wang

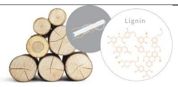
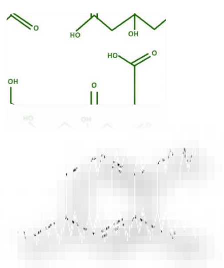
Serial. No.	Source	Fluorescence Colour	QY %	References
1.	Egg Shell Membrane 	Blue	13.45%	33
2.	Rose Petals 	Blue	14%	34
3.	Egg White (Albumin) 	Blue	54%	35
4.	 Lotus Root	Blue/Green	19%	38
5.	 Lignin	Purple	Not applicable	37
6.	 Casein	Blue	18.7 %	36
7.	Gelatin 	Blue	36 %	39
8.	Citric Acid (CA) and 4 -bromo-1,2-diaminobenzene 	White	87.5%	40

Table 1: Synthesis of Green CNDs by Microwave Irradiation

et al., [33], prepared CNDs from eggshell membranes using a microwave-assisted method, and the resulting CNDs had a remarkably high QY of 13.45% and excellent water solubility. Feng et al., [34], synthesized CNDs from rose petals as the carbon precursor using a microwave irradiation method, and the QY was an impressive 14%. The acquired CNDs demonstrated potential applications as a biosensor for tetracycline in human urine. In order to create CNDs in an aqueous solution, Hu et al., [35], started with albumin or egg white. With an average diameter of 3.2 ± 1.1 nm, the resulting CNDs might be used in place of organic dyes and semiconductor CNDs. By heating casein, a milk protein, in a microwave oven for 30 minutes, Bajpai et al., [36], created nitrogen-doped CNDs (N-CNDs). The produced CNDs, which were employed for the bioimaging of spinach leaf cells, had a high QY of 18.7% and were about 7 nm in size, making CNDs with lignin [37], lotus root [38], and gelatin [39], as the first ingredients using a microwave method.

Using formamide as the reaction solvent, using citric acid (CA) and 4-bromo-1,2-diaminobenzene., Qiang Fu et al., [40], synthesized white fluorescent carbon dots (CDs20) with a quantum yield of 87.5% using a microwave method. Formamide's numerous reactive sites and minimal steric hindrance led to significant surface defects on the CDs20. Additionally, we found that the choice of solvent is essential for controlling synthesis and aggregation, affecting the fluorescence colors, which can shift to orange, green, or yellow.

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