www.journalworlds.com
AGRI JOURNAL WORLD
VOLUME 3 ISSUE 1 JANUARY, 2023

CARBON DOTS: NEW CARBON-BASED NANOMATERIALS

Rajni Godara*, Parshant Kaushik, Neethu Narayanan, Kailashpati Tripathi and Riya Kundu
Division of Agricultural Chemicals ICAR-Indian Agricultural Research Institute, New Delhi 110012
*Corresponding author email- rajniiari1@gmail.com

ABSTRACT

Nanomaterials are materials with dimensions between 1 and 100 nm, tiny in size, with at least one dimension ≤ 100 nm. A new category of fluorescent carbon nanomaterials replaces the traditional semi-quantum dots. Carbon dots (CDs) have been explored in the last few years for their simple synthetic accession, good bio-consonance and several revelation applications. The properties, such as distinct photoelectronic and fluorescent properties, chemical inertness, etc., make CDs well-positioned to achieve unprecedented performance. The characteristics features like high photostability, biocompatibility, straightforward synthetic methods, flexible designability, etc., makes CDs the next generation of fluorescent probes.

INTRODUCTION

Since the beginning of the twenty-first century, nanotechnology has emerged as one of the most significant topics in various fields such as ecological preservation, electronics manufacture, astronomy, drug synthesis and delivery. Nanoparticles are currently used to produce countless everyday objects, including tyres, cosmetics, sunscreen, stain-resistant clothing and electrical equipment. Nanomaterials are microscopic particles with a minimum of one external dimension measuring 100 nanometers (one-millionth of a millimetre) or less (Nayak *et al.*, 2021). In comparison, human hair has a diameter of roughly 70,000 nanometers. The nanomaterials with one dimension, such as thin films and surface coatings, are known as "nanolayer".

Furthermore, the nanotubes and nanowires have two dimensions in the nanoscale. Nanoparticles are those which have all three dimensions in the nanoscale. Also, we can divide nanomaterials into carbon-based materials, metal-based materials, dendrimers, and composites. In the family of carbon-based nanomaterials, the carbon dots (CDs) defined by a feature size of <10 nm are a rising star with discrete quasi-spherical nanoparticles. Xu and coworkers accidentally discovered these carbon dots in 2004 for the first time (Xu *et al.*, 2004). These CDs have significant applications in a variety of fields, such as biomedicine, catalysis, optoelectronic devices, and anticounterfeiting, all thanks to their excellent and controllable photoluminescence (PL), high quantum yield (QY), low toxicity, small size, appreciable biocompatibility, and widely available low-cost sources (Liu *et al.*, 2020).

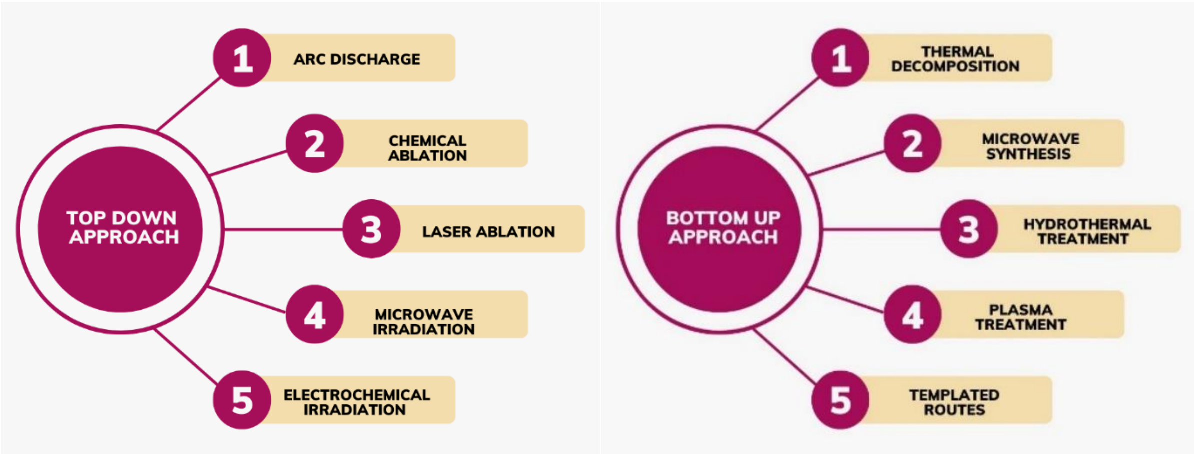

Fig.1 Different methods for synthesis of carbon dots

These carbon dots have recently found profound applications in the efficient detection of trace-level pesticides present in different parts of the environment. Broadly these CDs can be prepared by two approaches: "top-down" and "bottom-up". Ultimately, surface passivation and surface functionalization are used as surface modifications to enhance the surface characteristics of CDs (Fig. 2).

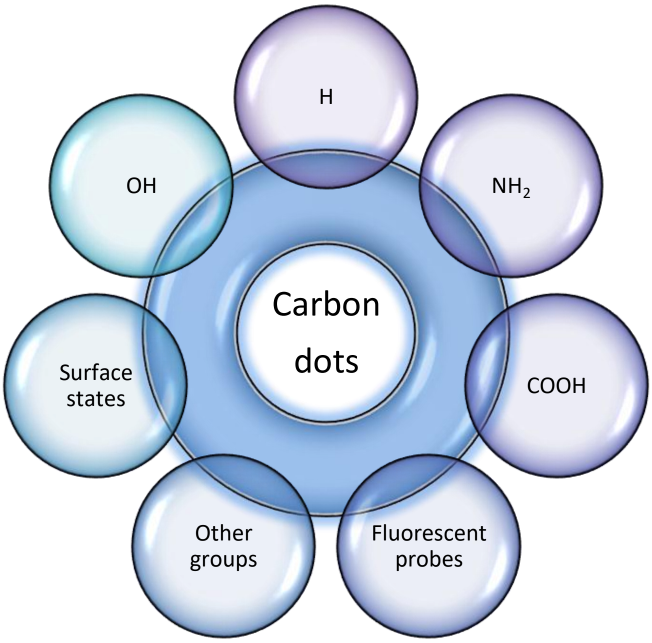

Fig. 2 Carbon dots with different surface functionalization

PHYSICOCHEMICAL PROPERTIES OF CARBON DOTS

1. *Absorption:* CDs show excellent optical absorption in the ultraviolet (UV) region (mainly 280-360 nm). The absorption may increase up to near-infrared region through surface modification.

2. *Fluorescence:* CDs show a type of photoluminescence because of their zero-dimensional structure. CDs exhibit strong fluorescence effects and are being developed as fluorescent molecules due to their excellent biocompatibility, low photobleaching, and protein surfaces, which are highly desirable for molecules to be used in biomedicine and biosensing.
3. *Phosphorescence:* When water-soluble CDs were employed as a phosphorescent material, the phosphorescence characteristics of CDs were brought to light.
4. *Chemiluminescence:* CDs have excellent chemiluminescence properties that have been exploited to determine different radioactive substances. C-dots concentration within a specific absorption range is the only factor influencing chemiluminescent intensity.
5. *Quantum yield (QY):* It is defined as the ratio of the number of emitted photons to the number of absorbed photons. It tells us about the fluorescent efficiency of the carbon dots prepared. Synthetic route and sometimes surface chemistry govern the quantum yield of CDs.

PREPARATIONS OF CARBON DOTS

GREEN SYNTHESIS OF CARBON DOTS

Recently studies have examined the green synthesis of CDs and discovered high salience. As we all know, carbon is found abundantly in nature and hence can be extracted by green synthesis. One such report mentioned the green synthesis of CDs' from orange peels using hydrothermal treatment (Prasannan and Imae, 2013) because it is a low-cost, sustainable way to make chemical compounds from environmentally favourable raw materials. Another study demonstrated a different technique for producing hydrothermal CDs from sugarcane bagasse, which has high carbon content and is thus regarded as a renewable resource since CDs can be made relatively easily (Liu *et al*., 2013). Utilizing greener techniques, CD synthesis recently improved. Using green chemistry instead of physical techniques simplifies the procedure and provides an environmentally friendly synthesis.

SYNTHETIC ROUTES FOR PREPARATIONS OF CARBON DOTS

The two main approaches for the synthesis of CDs are as follow (Fig 3.):

1. *Top-down:* Cutting carbon materials into carbon nanoparticles is known as top-down nano-cutting. This process often entails cutting various carbon resources, including graphite oxide or powder, carbon rod or nanotube, etc. Arc discharge, chemical ablation, laser ablation, microwave irradiation and electrochemical irradiation are examples of top-down nano-cutting techniques.
2. *Bottom-up:* This route includes dehydration and carbonaceous aggregation from small molecules. Sugar, bread, grass, glycerol, grains, potato, citric acid etc are used as carbon source. Bottom-up include thermal decomposition, microwave synthesis, hydrothermal treatment, plasma treatment etc.

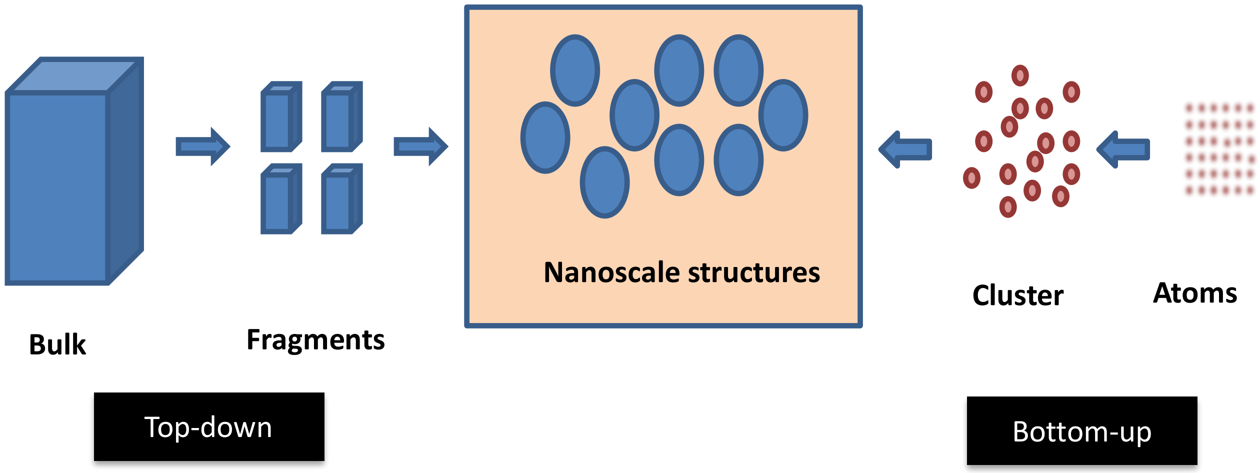

Fig. 3 Synthetic routes for the preparation of carbon dots

SURFACE MODIFICATIONS TO IMPROVE THE SURFACE PROPERTIES OF CDs

1. *Surface passivation:* CD surfaces have a high sensitivity to pollutants in their surroundings, making it possible for even very small amounts of contaminants to impact their qualities. Surface passivation of CDs is carried out to lessen the negative impact of surface contaminants on their optical characteristics. A thin insulating layer is often developed by attaching polymeric materials, such as oligomeric PEG, and PEG1500, to an acid-treated CDs surface (Fig 4). Effective surface passivation has been demonstrated to be a crucial step in producing CDs with high fluorescence intensities.
2. *Surface functionalization:* The functionalization of CDs is crucial because the addition of functional groups, such as amines and carboxyls, can produce various surface defects in CDs. Fluorescence emissions vary to a great extent as a result of these imperfections, which act as excitation energy traps. These cause an increase in the quantum yields (QYs) of CDs and alter the PL emission and the solubility in different solvents.

CHARACTERIZATION OF CARBON DOTS

Mostly for the characterization of CDs, we use High-Resolution Transmission Electron Microscopy (HRTEM), Raman spectroscopy, Fourier transform infrared (FTIR), X-Ray Diffraction (XRD), X-ray Photoelectron Spectroscopy (XPS), Nuclear Magnetic Resonance (NMR), Matrix-Assisted Laser Desorption Ionization Time-of-flight (MALDI-TOF).

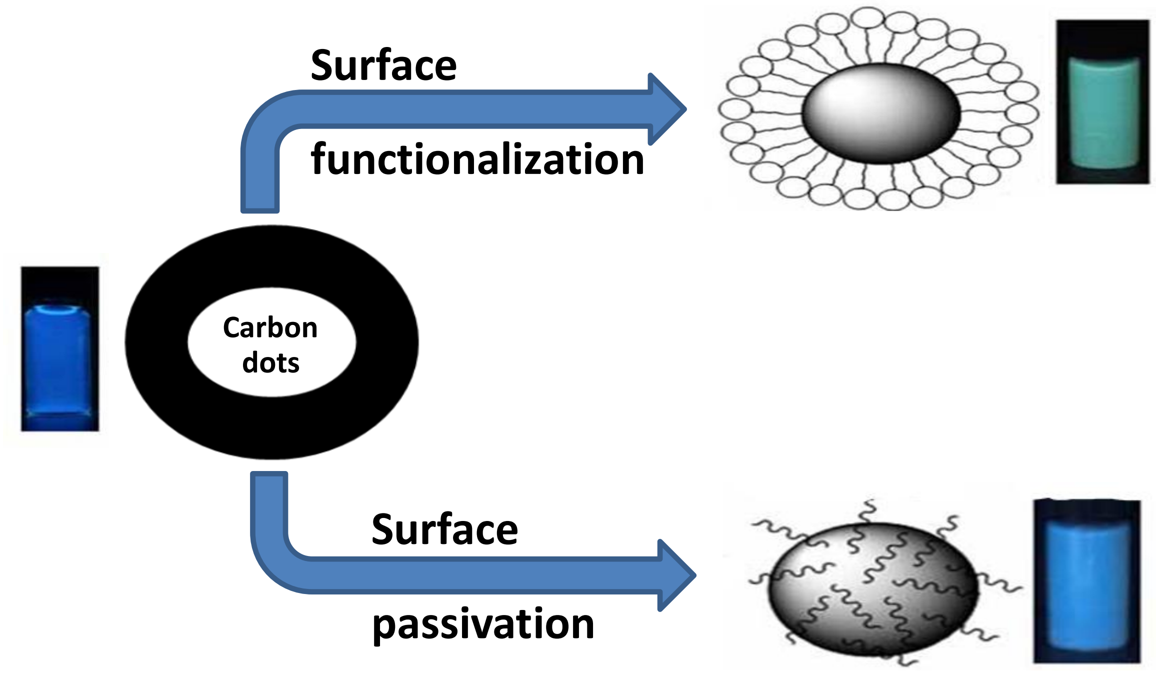

Fig. 4 Surface modifications in carbon dots

APPLICATIONS OF CARBON DOTS

1. **Biological applications:** CDs, a class of recently developed fluorescent nanomaterials, have demonstrated tremendous potential as adaptable nanomaterials for a variety of applications, including biosensing, bioimaging, drug delivery, photodynamic therapy, in vitro cell imaging, in vivo bioimaging, drug delivery, cancer therapy, enzyme activity modulation, cell membrane permeability, gene expression and antimicrobial application (Su *et al.*, 2021). Low toxicity and good biocompatibility of CDs are their most significant advantages for successful biological applications.
2. **Agricultural applications**: Due to high surface-to-volume ratios that give high sensitivity, sensors based on CDs are the most critical applications in pesticide detection. Based on CDs' fluorescence characteristics and surface functional groups, several biological and chemical sensors have been created. It is capable of detecting pesticides at levels that are far lower than some regulatory thresholds or standards. Furthermore, since they are so tiny and have a lot of surface functional groups and a high specific surface area, CDs are highly reactive and responsive to their surroundings. Therefore, the photoluminescence characteristics are mostly employed as superior detection probes.

ADVANTAGES OF USING CARBON DOTS

- Robust chemical inertness
- Chemical durability

- Easy accessibility
- Outstanding biocompatibility
- Low cost
- High resistance to photobleaching
- Good selectivity
- Simplicity
- Environmental compatibility
- Low or no toxicity

LIMITATION OF USING CARBON DOTS

- Lack of specificity
- Low quantum yield
- Unavailability of portable and miniaturized devices

CONCLUSION

Carbon dots (CDs), a new class of carbon-based nanomaterials, has gained growing interest in various scientific areas. The distinct photoelectronic and fluorescent properties, chemical inertness, an abundance of naturally occurring raw materials, ample supply of surface functional groups, facile functionalization, ease of synthesis, low or non-toxicity and environmental compatibility makes CDs well-positioned to achieve unprecedented performance. However, a detailed understanding of CDs' physical and chemical characteristics is still a major challenge owing to the complexity of CDs. Many crucial aspects, including structure, synthesis and optical qualities, are ambiguous, leaving open disputes and a non-uniform definition of their basics. The high photostability, great biocompatibility, straightforward synthetic methods, flexible designability, multicolour emission, deep red/NIR emission, and two-/multiphoton photoluminescence makes CDs the next generation of fluorescent probes.

REFERENCES

Liu, J., Li, R., & Yang, B. (2020). Carbon dots: A new type of carbon-based nanomaterial with wide applications. ACS Central Science, 6(12), 2179-2195.

Liu, X. J., Guo, M. L., Huang, J., & Yin, X. Y. (2013). Improved fluorescence of carbon dots prepared from bagasse under alkaline hydrothermal conditions. BioResources, *8*(2), 2537-2546.

Nayak, V., Munawar, S. M., Sabjan, K. B., Singh, S., & Singh, K. R. (2021). Nanomaterials' Properties, Classification, Synthesis, and Characterization. In Nanomaterials in Bionanotechnology 37-68.

Prasannan, A., & Imae, T. (2013). One-pot synthesis of fluorescent carbon dots from orange waste peels. Industrial & Engineering Chemistry Research, 52(44), 15673-15678.

Su, D., Li, H., Yan, X., Lin, Y., & Lu, G. (2021). Biosensors based on fluorescence carbon nanomaterials for detection of pesticides. TrAC Trends in Analytical Chemistry, 134, 116126.

Xu, X., Ray, R., Gu, Y., Ploehn, H. J., Gearheart, L., Raker, K., & Scrivens, W. A. (2004). Electrophoretic analysis and purification of fluorescent single-walled carbon nanotube fragments. Journal of the American Chemical Society, 126(40), 12736-12737.

****