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Carbon Dot – An Updated Review

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ABSTRACT

These days, carbon dots (CDs) are the rising stars of nanomaterials. Carbon dots (CDs) are small carbon nanoparticles with the same type of surface passivation (less than 10 nm in size). Researchers found C-dots by accident while purifying single-walled carbon nanotubes (SWCNTs) manufactured using the arc-discharge process. Toxic metal-based quantum dots are being replaced with carbon dots (QDs). Carbon dots are currently being prepared from a variety of natural resources in order to obtain self-passivated products at a reasonable cost. Because of their superior photo physical characteristics, biocompatibility, and low toxicity, carbon dots have prospective applications in bio sensing, bio imaging, and drug administration. Different synthetic processes, precursors, salient properties, and applications were reviewed in this review, as well as some future prospects, obstacles, and possible solutions for future development. Because of their tunable optical characteristics and better biocompatibility, luminous carbon-based nanomaterials have sparked a lot of scientific interest. Different light emission properties of carbon are discussed in this review. Distinct synthesis procedures have resulted in different carbon dots (CDs). Summarized here. The optical properties of CDs that haven't been synthesized yet surface doping and element doping can be used to further control it. CDs are being functionalized for an adjustable band gap. As a result of their luminescent with reduced cytotoxicity and tunable optical characteristics CDs have been thoroughly investigated in terms of their potential uses in biomedicine, such as analytical sensors, and instruments for bioimaging. Fluorescent carbon dots are a new type of nanomaterial from the carbon family. Green CDs, which have attracted a lot of attention from researchers because of their better water solubility, high biocompatibility, and eco-friendly nature when compared to chemically generated CDs, can be made from a variety of inexpensive and renewable resources. The presence of heteroatoms on the surface of green CDs in the form of amine, hydroxyl, carboxyl, or thiol functional groups, which can improve their physicochemical qualities, quantum yield, and likelihood of visible light absorption, eliminates the need for additional surface passivation.

Keywords: Carbon dots, Surface passivation, Quantum dots, Bio-sensing, Bio-imaging.

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INTRODUCTION

Fluorescent Carbon Dots (C-Dots) were accidently discovered[1] in 2004 during electrophoretic purification of single walled carbon nanotubes (SWCNTs) generated by the arc-discharge process. The production of fluorescent carbon material with a size less than 10 nm was announced in 2006,[2] and the term "carbon dots" was coined. Carbon dots are a relatively new type of nanomaterial. Carbon dots are notable for their outstanding photo physical features, including strong photoluminescence, biocompatibility, bioavailability, low toxicity, and excellent water solubility. Carbon dots offer a wide range of bio-applications that will be critical in the medical profession in the future, including biosensing, bioimaging, medication delivery, and real-time sample processing. There are numerous precursors for carbon dot production, including citric acid,[3-5] EDTA,[6-7] EDA, and ethylene glycol.[8] Benzene,[9] for example. Carbon dots can be made in a variety of ways, including hydrothermal,[10-14] solvothermal,[15-17] electrochemical,[18-20] arc discharge, laser ablation,[2,21] pyrolysis, and others.[22-25] However, to improve water solubility and fluorescence,[2] these synthetic approaches require multiple stages, including pricey precursors, post-preparative treatment, and a surface passivating agent. One-step self-passivated carbon dot preparations have recently piqued interest, however they are time-consuming, expensive, and need a high temperature, as well as a poor quantum yield (QY) and limited solubility. Green synthesis is emerging as a solution to these issues. Carbon dots made from green precursors are known as green carbon dots. Green precursors are compounds that are found in nature. These techniques are low-cost, eco-friendly, and have a high quantum yield (QY) and water solubility.[26]

GREEN CARBON DOT PREPARATIONS

Fruit Derivatives as Green Precursors

Fruits and derivatives have an important role as carbon sources[27] in the fabrication of highly green fluorescent carbon dots from Orange juice (Citrus nobilis deliciosa) in one step hydrothermal treatment at low temperature 120°C for less than 150 min as a precursor. They created the carbon dot by carbonizing several of the primary chemical elements of orange juice hydrothermally. The average size distribution of the CDs was in the range of 1.4–4.5 nm, with an OY of 26%. The use of banana juice as a green precursor for carbon dot was reported in the next experiment,[28] where a simple heating technique is used in an oven for 4 hr at 150°C to produce the carbon dot. Several methods were used to make the CDs, including hydrolysis, dehydration, and polymerization., aromatization, carbonization etc. the average particle size of the CDs were 3 nm with 58% synthesis yield and 8.95% QY.[29] Apple was also used (Malus domestica) to synthesize carbon dot by hydrothermal carbonization at 150°C having several surface functional groups like hydroxyl, amino, keto, carboxylic acid etc with QY of 4.27%.

Table 1: (Green Sources for Carbon Dots).

Fruit Sources	Vegetables	Animal Derivatives	Food and Beverages	Human Derivatives	Waste Materials
1.Orange	1.Cabbage	1.Silk Worm	1.Soy Milk	1.Hair Fiber	1.Onion Peel
2.Apple	2.Sweet Potato	2.Crab Shell	2.Milk	2.Human Hair	2.Food Waste
3.Banana	3.Garlic	3.Chicken Egg	3.Ground Coffee	3.Human Urine	3.Paper Waste

Vegetables

Vegetables have always been a good source of carbon.[30] A high-yield self-passivated C-Dots prepared by treating cabbage hydrothermally at 140°C for 5 hr. Both centrifugation and dialysis have been performed. The CDs had a QY of 16.5 percent and a synthesis yield of 7.07 percent.[31] A hydrothermal treatment has been also used to synthesize fluorescent CDs from sweet potatoes. CDs ranged in size from 2.2 to 5.5 nm, with a QY of 8.64 percent.[32] A self-passivated CDs from garlic as a green supply of carbon, nitrogen, and sulphur for N-S-co-doped carbon dots with 17.5% quantum yield has been prepared as well.

Animal And Derivatives

Animals and their derivatives have been utilized as carbon sources for a long time.[33] A microwave aided synthesis developed to create self-passivated C-Dots from silkworm chrysalis, which is high in protein and chitosan. The average size distribution ranged from 13 to 26 nm, with a QY of 46%.[34] Crab shell was utilized as a carbon source because it contains chitin, a linear polymer widely employed in the biomedical area. They used microwave aided pyrolysis for 10 min at 220°C to make CDs. To give magnetic characteristics, Gd^{+3}, Eu^{+3}, and Mn^{+2} were used as dopants. The QY was found to be highest in the case of Gd^{+3} doping (19.84%), Eu^{+3} (14.97%), and Mn^{+2} (14.97%). (12.86 percent).[4] The plasma-induced manufacture of CDs produced from egg yolks or egg whites, Plasma was turned into CD under ambient settings after a few minutes of treatment. CDs had a QY of 5.96 percent.

Food And Beverages

One of the most important categories of green sources is food and beverages.[35] Soy milk was utilized as a green source to make carbon dots using a hydrothermal technique at 180°C and a QY of 2.6 percent.[36] On the other hand, milk was employed as a green precursor because to its low cost and renewable nature. To make self-passivated N-doped C-Dots, milk was heated hydrothermally at 180°C for 8 hr. The particles had an average size of 5 nm and a QY of 12 percent. If the milk can be handled for 8 hr, the QY will be at its highest. If the C-Dots are doped with Nitrogen or Sulfur, the size can be reduced.[37] NESCAFE instant coffee powder was also utilized to extract natural C-Dots by simply combining coffee powder with hot water and centrifuging the mixture and filtration. QY was of 5.5%.

Human Derivatives

Hair fiber was the first human derivative used to make Sulfur-Nitrogen-co-doped-C-Dots.[38] With a high QY and a long emission wavelength, the particle size was smaller at high temperatures. The QY was 295 at 140°C, with a high Sulfur and Nitrogen content of 5.08 and 5.64 percent, respectively.[39] A solvent-free method was developed for producing carbon dots from human hair by thermal decomposition at 300°C in a nitrogen environment, resulting in highly luminous, polymer-compatible C-Dots with no surface passivation. Due to the presence of keratin as a precursor, the manufactured C-Dots were N-Doped. The percentage of QY was 17.3 percent.[40] Some researchers pioneered the use of thermal upcycling of human urine to create C-Dots as PEE-DOTS. Carbonization for 12 hr at 200°C was the reaction process.

Waste Material

Waste removal has been a major issue in recent years. However, they are an excellent supply of carbon for making carbon dots.[41] Some made use of onion waste. To make C-Dots, use a basic autoclave process. The CDs had an average size of 7.25 nm and a 28 percent QY.[42] Using basic synthetic procedures, 100 kg of food waste was converted into 120 g of green carbon dot. The average size was 4 nm, with an internal QY of 2.85 percent. Wei *et al.*[43] employed simple carbonization and hydrothermal procedures to create C-Dots from paper ash and waste paper,[44] respectively. When compared to paper ash, the waste paper technique provides a more controlled environment. The QY of both approaches was satisfactory, with 9.3% and 10.8%, respectively.

PROPERTIES OF GREEN CARBON

Absorption

Carbon dots have an absorbance peak in the UV-region, with a tail that extends into the visible range. The majority of carbon dots absorb between 250 and 380 nm. After surface passivation, the absorbance of carbon dots used to increase to longer wavelengths.[10,45-49] The -* transition of C=C is responsible for the absorbance in the 230-270 nm range, while the n-* transition of C=O[50-53] is responsible for the absorbance in the 300-330 nm range. [27]CDs, orange juice shows a broad UV-absorption at 288 nm, which is consistent with carbonized chitosan nanoparticles.[31] on the other hand, found a 266 nm absorption peak for a carbon dot from sweet potato.[4] egg-derived CDs were shown to have an absorption characteristic at 275 nm.

Fluorescence

Carbon dots have a unique excitation-dependent emission characteristic[54-55] the colour luminescence of CDs that had been passivated with polyethyleneimine (PEI). UV (330-385 nm), blue (460-495 nm), or green (530-550 nm) were used to activate the blue, green, or red fluorescence, respectively. Under longer wavelength excitation, the fluorescence intensity dropped. Because of their homogeneous surface state,[56-57,10] Some introduced an excitation independent emission of Nitrogen-Sulfur-co doped N,S-CDs. When stimulated at 325-445 nm,[58] CDs made from ginger juice produced fluorescence spectra when excited at 325-445 nm.

Structural Properties

Dynamic light scattering (DLS), Transmission electron microscopy (TEM), and scanning electron microscopy (SEM) can all be used to estimate the size of carbon dots (SEM). Milk-derived CDs,[36] a TEM picture that shows the CDs are well separated from one another and have a uniform size distribution between 2-4 nm. The particles were well disseminated and showed spherical morphology with an average dimension of 5 nm and a size distribution in the range of 7.25 nm in the instance of[41] Onion waste-derived CDs. Powder x-ray diffraction is commonly used to depict C-Dots' amorphous nature (PXRD). Carbon dots have a broad diffraction peak in the region of $2\theta = 20°–25°$ and an inner layer spacing (d) of 0.31-0.38 nm,[33,40,51,59] according to PXRD spectra. Lemon juice-derived C-Dots had a broad diffraction peak at 25°C, with d-spacing of 0.32 nm and an average size of 4.6 nm, according to Han Z, Bhamore JR[60,41] the XRD pattern of onion waste-derived CDs shows an intense peak at 2θ= 22.79° with d spacing of 0.39 nm, which is somewhat higher than graphite (0.34nm) due to the due to the increase in amorphous character, which can be related to the introduction of oxygen and other functional groups. XPS and FTIR can be used to determine the elemental composition of carbon dot. Without any further reagents, the XPS spectra of self-passivated Onion peels reveal the presence of Nitrogen, Phosphorus, and Sulfur.[59] The atomic ratio of C/O in CDs generated from orange juice is 6.2.[27] The presence of C=C, C-O, COOH bonds can suggest functional groups such as hydroxyl, epoxy, carbonyl, and carboxylic acid. There are several functional groups in[31] sweet potato derived CD, including –OH (3291 cm^{-1} stretching), C-H (2925 cm^{-1} stretching), C=O (1695 cm^{-1} stretching), C=C (1608 cm^{-1} stretching), C-H (1388 cm^{-1} bending), C-OH(1145 cm^{-1} stretching), C-O(1145 cm-1 stretching), C-O(1145 cm^{-1} stretching), C-O(1145 cm^{-1} stretching), C-O(1145 cm^{-1} stretching) (1022 cm^{-1} stretching).

Quantum Yield

Carbon dots can be used to increase brightness and photo stability. Photo bleaching is not a problem for carbon dots.[62] Because of these characteristics, researchers are concentrating their efforts on creating CDs with a high QY. For luminous nanomaterials, QY is a critical parameter. Initially, CDs were made using citric acid, candle soot, graphite graphene fiber, and had a low QY (less than 10%).[46,57,62-63] Surface passivation or alteration, as well as doping, can be used to improve QY. For the PEG1500N- CDs with high fluorescence[48,64] as per the report a QY of 60%. To prepare CDs with a high QY of 44.9 percent, amino acid was used as a precursor. Other ways are being researched to improve QY.[65] To attain high QY, developed CDs were doped with inorganic salt. The CDs doped with ZnS had a QY of 45 percent, while CDs doped with ZnO had a QY of more than 50 percent.

Up-Conversion Photoluminescence

Up-conversion fluorescence is an optical property of green carbon dots in which the emission wavelength is shorter than the excitation wavelength. Hair-derived S and N-co-doped C-Dots demonstrate up-conversion, with the emission wavelength shifting red with increasing excitation wavelength from 600 to 900 nm.[38] Up-conversion fluorescence can be caused by a multi-photon active process or anti-Stokes photo luminescence.[29,30,37,66-69]

APPLICATIONS

Bio-Imaging

Carbon dots' optical qualities are crucial to their practical application. They generate bright fluorescence and have little cytotoxicity, making them ideal for bio-imaging and bio-medical research.

In vitro Imaging

In vitro bio imaging is used to offer sufficient information on imaging capabilities, cytotoxicity, and probe distribution in cells. Carbon dots have been successfully employed in a variety of cell imaging applications, including HeLa,[70,71] Human neural stem cells,[72] 4T1,[73] and others. Endocytosis allowed the carbon dots to enter the cells and concentrate in the cytoplasm.[74] Solvothermal preparation of a low-cytotoxicity green carbon dot for use in cell imaging. Carbon dots containing folic acid and Doxorubicin (DOX) have been reported in different studies for cancer cell identification, drug transport, and imaging.[75]

In vitro Imaging

Zebra fish are widely used for medical science because of its well-defined development stages and amenability to optical imaging, so zebra fish has been chosen for fluorescence imaging model. Carbon dots accumulated in eye and yolk sac after maintaining it for 60 hrs. So for long term observation of the development stages of zebra fish growth phase C-Dots were ideal.[76-78]

Bio-Sensing

Despite their high biocompatibility, CDs can be used to detect ions, biological pH values, proteins, enzymes, vitamins, and nucleic acids, among other things.[69] Developed CDs from dopamine as a raw material that could be employed as a Fe^{+3} sensor with a detection limit of 0.32 m.[70] Developed branched polyethyleneimine modified C-Dots with a detection limit of 6 nm for Cu^{+2} detection in river samples. The physiological pH value in living cells and tissues can be determined using CDs. CDs have recently been made to detect nucleic acids.[71] Some designed CDs to detect DNA, which reduces the intensity of the CD's fluorescence.

Drug Delivery

Carbon dots can be employed in the administration of drugs and the transfer of genes. Folic acid-modified CDs, for example, were utilized to detect cancer cells via an amide condensation process, which could be a useful tool for developing cell screening and disease diagnostics.[55,72-73] PEG-modified C-Dots were developed and employed in the loading and delivery of Doxorubicin (DOX).[74]

CONCLUSION

Carbon dots are a relatively new type of nanoparticle. Quantum dots have a higher cytotoxicity than carbon dots. Because of their optical characteristics and ease of manufacture, carbon dots are preferable to quantum dots. Because of the cheap availability of raw materials, low toxic effects, low environmental hazards, low cost, and, most significantly, their high fluorescence and QY, the development of green carbon dots is a huge advantage these days. Carbon dots are tiny particles with a variety of functional groups on their surfaces. In the medical field, C-Dots can be used in a variety of ways. Due to their strong fluorescence, CDs can be employed in bio-imaging research such as cell imaging (HeLa, cancer cells). Organic, inorganic ions (Cu^{+2}, Hg^{+2}, Fe^{+3}, Zn^{+2}, etc.), protein, and pH can all be sensed or detected by CDs.

Carbon dots can potentially be utilized to deliver drugs and transfer genes.

Carbon dots are a type of nanoparticle that has a lot of potential uses and applications in the future.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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