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Review article

Artful and multifaceted applications of carbon dot in biomedicine

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ABSTRACT

Carbon dots (C-dots) are luminescent carbon nanomaterial having good biocompatibility and low toxicity. The characteristic fluorescence emission property of C-dots establishes their role in optical imaging. C-dots which are superior to fluorescent dyes and semiconductor quantum dots act as a safer in vivo imaging probe. Apart from their bioimaging application, other applications in biomedicine such as drug delivery, cancer therapy, and gene delivery were studied. In this review, we present multifaceted applications of C-dots along with their synthesis, surface passivation, doping, and toxicity profile.

1. Introduction

Carbon is one of the abundant elements in the universe with an interesting number of allotropes. Carbon family nanomaterial (CFN) consists of carbon nanofibres, nanotubes, nanodiamonds, graphene, fullerene and carbon dots (C-dots). Among these, C-dots are the recently discovered member with superior properties and are presently a well-established functional nanomaterial.

C-dots, coming under the class of quantum dots, consist of nano-sized particle derived from carbon sources, having peculiar fluorescent properties. Being a nanoparticle, it exhibits additional features arising from their dimension over other fluorescent probes. The photo-luminescence property of C-dots and their size distribution in the nano range (usually having a size < 10 nm) made them a research point in various fields. In addition to this, biocompatibility and safety profile of C-dots are also favorable [1]. Metallic quantum dots are highly efficient bioimaging agent, but the toxic heavy metal present in them limits their application in living tissues [2,3]. Several studies have been conducted for evaluating the safety profile of quantum dots. Surface modified quantum dots such as carbonyl and amine quantum dots can induce coagulation and cause vascular thrombosis [3]. The heavy metals present in them are a contrary to in vivo application even at low concentration. The cytotoxicity of quantum dots gets reduced by the inclusion of a core material in the bioimaging probe. Incorporation of C-dots to the probe also enhances the bioimaging property [2].

In search of a biocompatible, non-toxic, fluorescent sensor, an accidental discovery made in 2004 by Xu et al. opened the new world of fluorescent carbon quantum dot, more commonly known as C-dots, with a wide range of applications [4]. Its tunable emission property and surface passivation possibility aroused much attention in research.

C-dots are synthesized mainly by two different methods; top down and bottom up approach and are usually composed of elements like carbon, hydrogen, and oxygen. Other atoms such as nitrogen, boron, sulfur etc. can be included via suitable doping method that further alters their properties.

The characteristic fluorescence property of C-dots opened the era for their bioimaging application. They are superior to other fluorescent carbon nanoparticles owing to their quantum yield, aqueous solubility, and facile synthesis. In addition, they have excellent physicochemical and photochemical stability [5]. The carboxyl group present on the surface attributes to its aqueous solubility, while other chemical groups facilitate surface functionalization and passivation. On the other hand, surface functionalization and passivation results in changes in fluorescence behavior and also physical properties [6,7]. The functionalization and surface passivation ability further expanded their utilization from bioimaging to other areas of biomedicine such as drug delivery, gene delivery, biosensing, catalysis etc.

2. Fluorescence property

The characteristic fluorescence property of C-dots arises due to the surface defects and quantum size effect [7–9]. The presence of numerous surface defects bring about the energy centers which contributes to multiple emissions [7]. The quantum confinement effect

Abbreviations: RNase A, ribonuclease A; PEI, polyethyleneimine; bPEI, branched polyethyleneimine; APTS, (3-aminopropyl) triethoxysilane; PPEI-EI, poly-(propionylethylenimine-*co*-ethylenimine); PEG, poly ethylene glycol; DETA, diethylenetriamine; TTDA, 4,7,10-trioxa-1,13-tridecanediamine; EDA, 2,2′-(ethylenedioxy)bis(ethylamine); BSA, bovine serum albumin; SWNT, single-walled carbon nanotubes; MWCNT, multi-walled carbon nanotubes; TTDDA, 4,7,10-trioxa-1,13-tridecanediamine; TPP, porphyrin; DOX, doxorubicin; PAC-diol, phenylpropan-1,2-diol; PAMAM, poly(amidoamine); P2P, phenylpropan-2-one; PNIPAM, poly(N-isopropylacrylamide)

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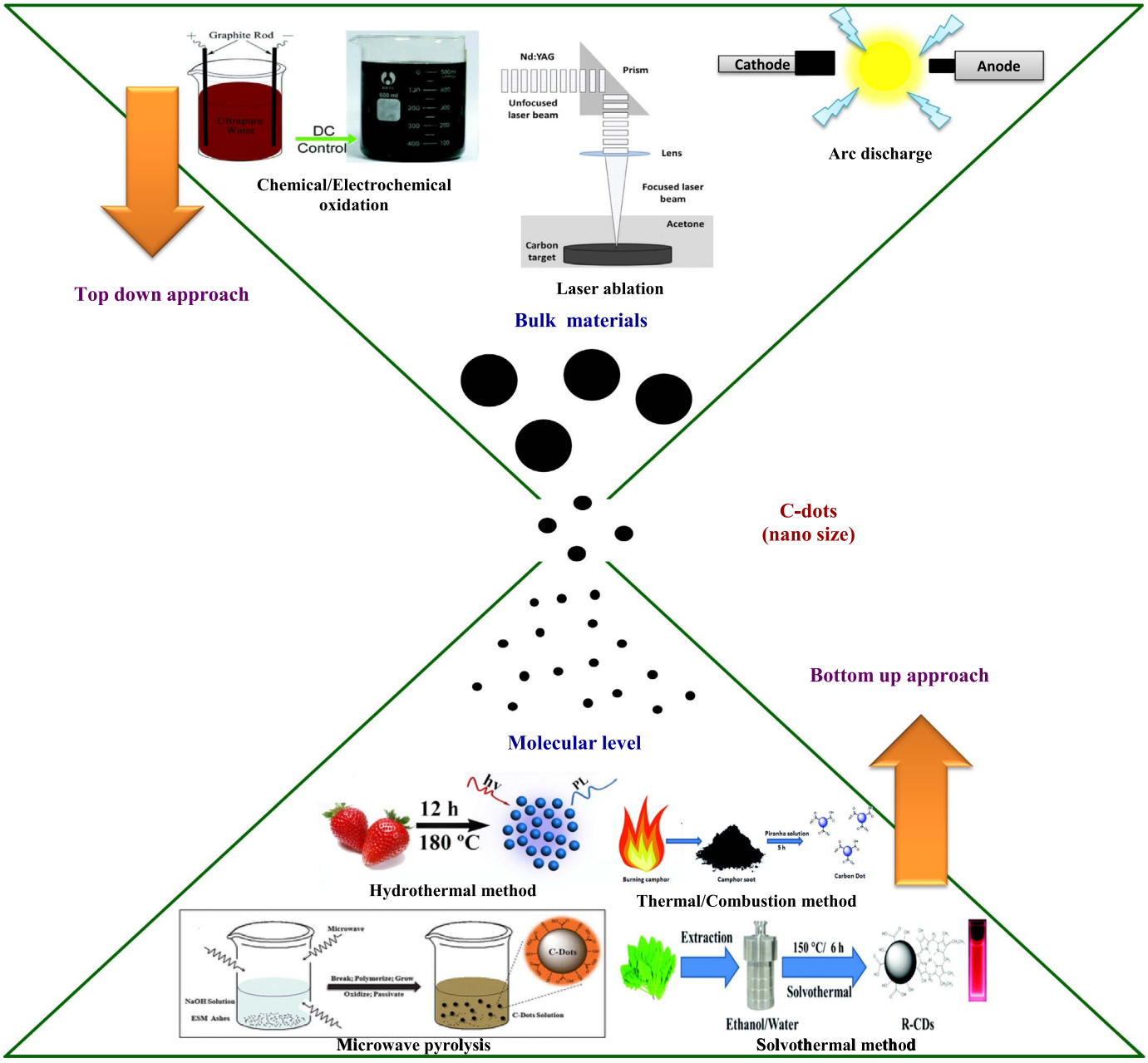

Fig. 1. Two main approaches involved in the synthesis of C-dots. Top down approach: Chemical/Electrochemical oxidation, Reprinted with permission from [21]. © (2012) Royal society of chemistry, Laser ablation.
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