Understanding the dynamics of Carbon Nanoparticles

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Introduction

Ever since the discovery of buckminster fullerene was reported in the seminal paper by Kroto et. al. [1], immense research efforts has been put to understand the fascinating properties of nanocarbon, further fuelled by the discovery of Carbon naotubes by Iijima [2]. Broadly speaking nanocarbon is carbonaceous material which can be differently bonded at molecular level to impart unique properties to Carbon. Carbon dots (C-dots) are the newest addition to the family of nanocarbons and have been discovered accidentally, only about eight years ago by Scriven and coworkers [3]. They are discrete, quasispherical nanoparticles with sizes below 10 nm [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. In this regard it is worth mentioning that C-dots, in their own way have formed a separate class of themselves as their known properties are widely different from the properties of already existing fluorophores. These unusual traits include excitation dependent emission spectra [13, 14], biocompatibility [6, 12, 13, 17], low cytotoxicity [12] and strong upconversion luminescence [6]. The ease of preparation is also an important factor [18]. The photoluminescence and environmentally benign characteristic of carbon-dots endows them with the promise to emerge as better alternatives for conventional quantum dots in cellular imaging [6]. Efforts have already begun in this direction. In order to achieve these goals to the maximum possible extent, it is essential to understand the mechanism of luminescence of these carbonaceous nanoparticles. It has been proposed that the luminescence of carbon dots arise from surface phenomena [19]. However, a clear picture of the mechanism of luminescence is yet to emerge. This is the motivation of the present project, the aim of which is to perform a systematic study of the excited dynamics involved in the luminescence of C-dots.

Methods and Synthesis

After the synthesis of C-dots by Sun and coworkers by laser ablation technique [14], extensive research efforts worldwide have resulted in a plethora of synthetic routes, involving top down (arc discharge [3], laser ablation [6, 13, 14], electrochemical synthesis [20, 21, 22]) as well as bottom up approaches (combustion, pyrolysis [5, 9, 12, 15] etc). Bottom up approaches are comparatively more attractive, not only because of they are easy to bring about, but also because the need of an additional functionalization step, which is essential in top down approaches, can be eliminated in bottom up approaches, by the use of appropriate precursors. Synthesis of carbon dots using templates have also been reported [11]. Microwave synthesis of carbon dots is gaining poularity, as the molecular precursors used themselves act as the source for the carbon core of the C-dots as well as the passivating agents. A simple example of MW synthesis is charring of the 3:1 (v/v) mixture of Poly(ethyleneglycol)200 (PEG200) and water. The methodology of synthesis plays a very important role in photophysical properties of the C-dots and this is the reason why efforts have been made to improve the quantum yield of the C-dots by doping the carbon core with foreign elements like N [23].
Applications

Bio imaging using carbon-dots

The large two photon absorption cross section, coupled with a very low cytotoxicity makes the C-dots attractive prospect as better alternatives for quantum dots in bio imaging [6, 14, 16, 17]. Several studies have been performed in this direction, in recent times. C-dots passivated with PPEI-EI have been used for two-photon luminescence microscopy of human breast cancer MCF-7 cells [6]. After incubation of the cells with C-dots for 2 h at 37ºC followed by washing to remove any extracellular C-dots, a bright luminescence is observed in the cell membrane as well as cytoplasm, upon excitation by pulsed laser at 800 nm. The cellular uptake C-dots has been reported to be temperature dependent, with no C-dots internalized at 48ºC. Notably, although the C-dots are likely to get internalized into the cell through endocytosis, the cell nucleus is not infiltrated significantly [6].

C-dots as fluorescent sensors

Recently efforts have been made in exploring the suitability of C-dots purpose of sensing and encouraging results have been obtained for copper [24] where the interaction of the Polyamine functionalized C-dots resulted in strong fluorescence quenching of the C-dots for which a inner filter mechanism is supposed to be responsible. The detection limit for the Cu$^{2+}$ in this experiment was observed to be 6nM. C-dots have been reported to be excellent sensors for mercury where a detection limit of 23 nM has been achieved [25]. This application was based on the fluorescence quenching of C-dots induced by Hg$^{2+}$. C-dots have also been reported to show peroxidase mimetic behavior taking organic dyes as model systems [26]. The degradation of methyl red using H$_2$O$_2$ was studied in presence as well as absence of C-dots [26]. In the absence of C-dot there was no significant change in the absorption spectra of the C-dots. Further experiments with another dye methyl orange also resulted in similar results [26]. C-dots based dual emission nanohybrid have been reported to be a ratiometric fluorescent sensor for in vivo imaging of copper ion [27]. Though bio sensing is less studied till now but the prospects seem to be bright.

Conclusion

To conclude this section, it may be said that till date, the synthesis of C-dots by different procedures has been an active area of research, but careful, in-depth studies of the spectral features of these systems is a less explored field. There is ample scope of work in this area, which is likely to provide a better understanding of the luminescence properties, thereby making it possible to fine tune the applications of the C-dots. Still the origin of the PL spectrum is not very clear. Once a deeper understanding of the fundamental properties of C-dots is achieved they can be massively used in optical sensors, cell imaging and other biologically motivated work [19].
References