Fluorescent Carbon Dots via a Green Synthesis Approach

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ABSTRACT

Carbon Dots (CDs) are best alternative to heavy metal-based quantum dots and fluorescent dyes. The horizon of green carbon dots is developing swiftly, but it faces several challenges like ensuring the durability of their properties. Herein, we discuss the green synthesis of carbon dots from papaya extract using hydrothermal method. The physical, chemical and optical properties of the synthesised CDs is critically analysed using several methods like UV spectroscopy, photoluminescence, high resolution transmission electron microscopy and Fourier transform infrared spectroscopy. The development of cost effective stable and sustainable green CDs with tuneable properties has a wide range of applications include physics, chemistry, biology, nanotechnology, energy and other interdisciplinary areas.

Keywords: Carbon Dots; Green Synthesis; Biomedical.

1 Introduction

Scientific community is its extensive search to enhance the efficiency of environmentally friendly and renewable raw materials to address energy crisis and the challenges faced by the world due to its dependence on non-renewable energy. Carbon Dots attracts the attention of the researchers due to their unique properties and potential applications in various fields, including biomedicine, optoelectronics, and energy storage [1]-[7]. CDs have the potential to contribute to a more sustainable future in several ways. CDs can be produced from sustainable sources such as biomass, which can reduce reliance on fossil fuels and decrease carbon emissions associated with traditional carbon-based materials production. CDs are zero dimensional optically active carbon-based nanomaterials with a size of less than ten nanometres and which are biocompatible, have small size with relatively large surface area, high quantum yield, strong absorption, photoluminescence, excellent water solubility, good conductivity, photo chemical stability, low toxicity and environmental friendliness [6], [8]. CDs have shown promise in a variety of applications, including energy storage and conversion, which can contribute to the development of more sustainable energy sources [9]. Since CDs are biocompatible and biodegradable, they may offer a more sustainable alternative to traditional carbon-based materials in biomedical applications. In this work, we introduce the synthesis and characterization of CDs prepared from Papaya via cost effective hydrothermal method.

2 Materials and Methods

2.1 Materials and Characterization

Steady state absorption spectra were recorded using a Shimadzu-3600 UV–VIS-NIR spectrophotometer. Fluorescence spectra were carried out with Horiba fluorolog fluorescence spectrometer (450-W xenon arc lamp as excitation source). High resolution TEM (HRTEM) images of

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the QDs were taken using a 200 kV JEOL-JEM 2100. The FTIR spectrum was recorded using Perkin Elmer spectrum 400 spectrometer.

2.2 Synthesis of CDs

A fresh Carica Papaya is plucked and thoroughly washed in a running water. After that, its skin was pealed and about and 100gm of fruit was carefully cut into small pieces, which is then mixed with distilled water and crushed well mechanically. The prepared papaya extract was first filtered by filtration with the help of a cotton and then using a filter paper. A simple one-pot hydrothermal carbonization process was used for the preparation of CDs from the papaya extract. The solution was kept in a hot air oven for 5 hours in 160 ^{0}C. After the sufficient cooling the solution was taken out from the hot air oven. Then, the solution was centrifuged and filtered using a syringe filter with 0.2 micro meter pore size. The resultant light brown solution of CDs was collected and carefully stored in a cool place at 5 ^{0}C for further studies.

3 Results and Discussion

$\alpha = \beta/(h\nu)(h\nu - Eg)^n$Steady state absorption was used as the primary characterization for analysing the structures synthesized. Figure (1) shows the absorption spectrum of the CDs obtained from synthesis. The absorption covers the UV region and extended to the visible spectrum. The obtained CDs show broad absorption where the λ_{max} falls at 299 nm. The band gap energy (E_g) of CDs were determined from the extrapolated plot of $(ahv)^2$ vs. hv by Tauc plot (Fig. 2) using the relation , where a is the linear absorption coefficient and β is the band gap tailoring parameter constant [10]-[12]. The band gap energy (E_g) was found to be 2.605 eV.

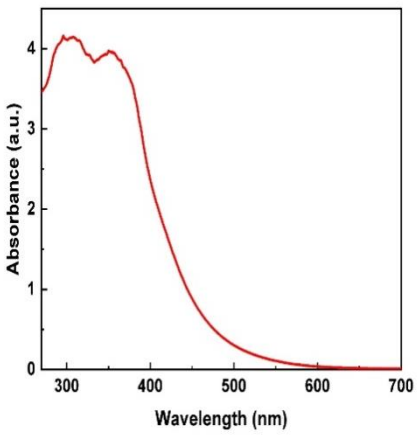

Fig.1*: UV- Vis Spectrum of carbon dots*

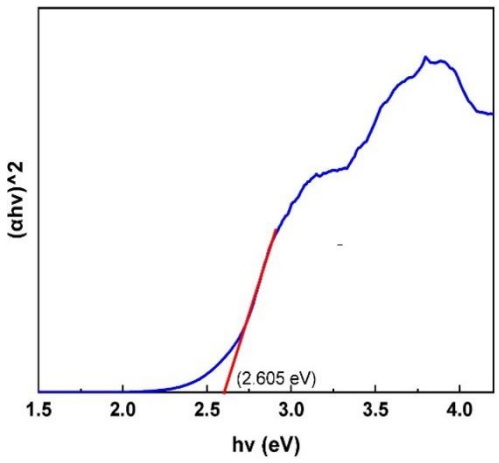

Fig.2*: Extrapolated plot of $(ahv)^2$ vs. hv obtained from the absorption spectra*

The intensity versus wavelength graph of photoluminescence analysis of CD is drawn using the data (Fig. 3). It is observed that maximum intensity is observed at approximately 430 nm. In carbon dots fluorescence is observed rather than photoluminescence as there occurs emission of light within no time after absorption of radiation. When the carbon dots in the solution is subjected to a radiation of wavelength in the range 350-400 nm, there will not occur any fluorescence or photoluminescence as at those wavelengths, the electrons will not achieve the threshold energy for the transition from valence band to conduction band

and also no non-radiative transitions and consequently no transition to ground state occurs-which implies there will not occur any photoluminescence. From the plot, it is clear that photoluminescence is observed at the radiation's wavelength range approximately between 400 nm-600 nm. The intensity of emitted radiations at a given temperature increases with decrease in wavelength and maximum intensity of emission is at 430 nm. The maximum intensity implies that maximum number of photons are emitted. Thus, large number of emitted photons is due to the large number of photon absorption at a particular excitation wavelength.

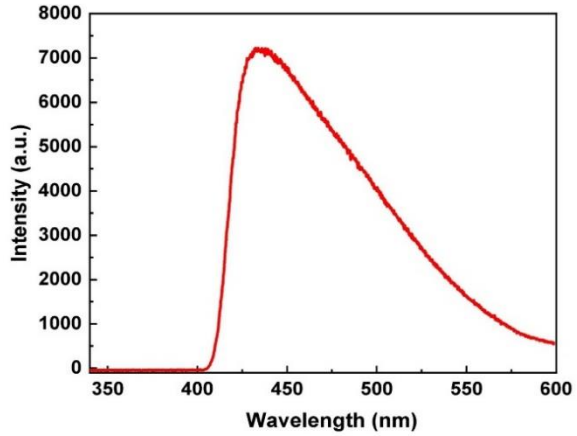

Fig.3: *Emission spectra of CDs*

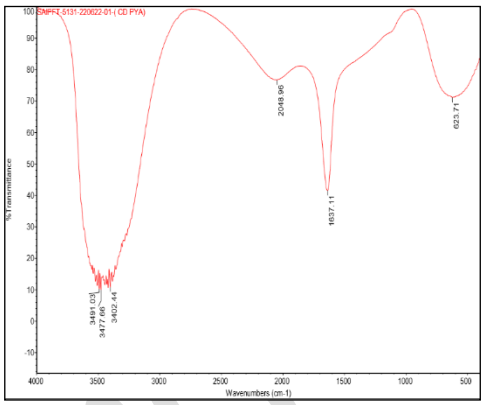

Fig. 4: *FTIR spectrum of CDs*

TIR spectra of carbon dots are shown in figure 4. It shows bands centred at 623.71 cm^{-1}, 1637.11 cm^{-1}, 2048.96 cm^{-1}, 3402.44 cm^{-1}, 3477.66 cm^{-1}, 3491.03 cm^{-1}. These bands represent different functional groups present in the carbon dot solution. The band centred at 623.71cm^{-1} represents the vibration of C-Cl bond, while band at 1637.11 cm^{-1} is assigned to specify the presence of stretching vibrations of C-O-C bond. The band at 2048.96 cm^{-1} corresponds to C C. The bands at 3402.44 cm^{-1}, 3477.66 cm^{-1} and 3491.03 cm^{-1} correspond to stretching vibration of OH bond. Therefore, the presence of such bonds is responsible for imparting hydrophilicity and consequent water dispersibility of the CDs. TEM micrographs at different magnifications of 5 nm and100 nm respectively are shown in the fig 5. HRTEM is used to observe the morphological characteristics of the synthesized carbon dots. The formation of carbon dots with an average size of 4 nm was confirmed from TEM micrographs. It reveals that carbon dots are spherical in shape, monodisperse and narrow in size. Carbon dots had well-ordered lattice fringes.

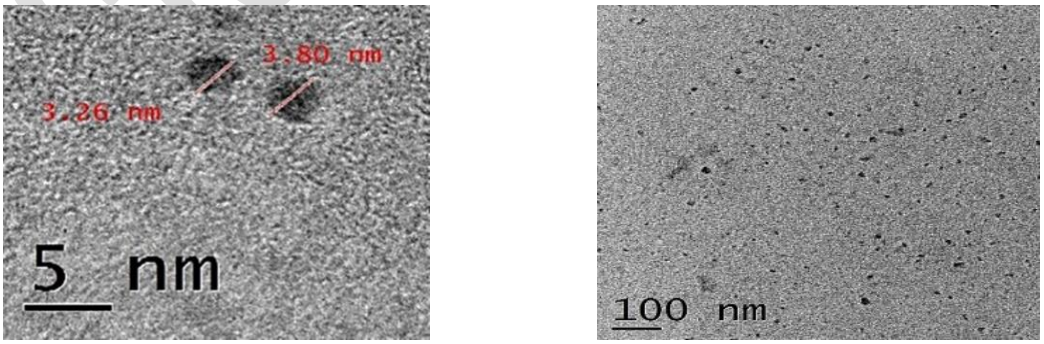

Fig. 5: *High resolution TEM image of Carbon Dots at 5 nm and 100 nm magnifications respectively*

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4 Conclusions

Highly fluorescent CDs were synthesized from papaya extract through hydrothermal method. The samples were characterized using optical absorption, emission, HRTEM and FTIR studies. The band gap energy (E_g) of the CDs were found to be 2.605 eV. The emission spectrum of CDs were found to be broad and extended to the higher wavelength range of visible region. The HRTEM image exhibits the monodispersity and crystallinity of the samples grown. EDAX spectrum confirms the elemental composition. The presence of such bonds is responsible for imparting hydrophilicity and consequent water dispersibility of the CDs.

5 Declarations

5.1 Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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