Synthesis of Low Dimensional Carbon Nanostructures for Sensing, Bio-imaging and Optoelectronic Devices

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By

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8 Conclusion and future scope

The goal of this study was to find novel uses for carbon nanostructures and to take use of their promising applications. Carbon nanomaterials are a form of nanomaterial consisting completely of carbon and including at least one dimension of nanoscale structural units. The exceptional qualities of these materials are demonstrated in their high aspect ratio, high stability, strong conductivity, low toxicity, and eco-friendliness. This thesis utilizes applications of carbon nanotubes and carbon quantum dots the most frequently. Several methods exist for synthesizing these carbon nanomaterials, which can be generally categorized as top-down and bottom-up. Specifically, this thesis outlines the most significant aspects of CQDs, as well as the methodologies used to synthesize them and their practical applications. In recent years, carbon quantum dots (CQDs), a new family of fluorescent carbon nanomaterials, have attracted a great deal of interest due to their outstanding photoluminescence capabilities, photo-stability, low toxicity, and affordable price. Due to their adjustable synthesis methods and carbon source alternatives, these CQDs are more usable. The majority of investigations have applied them to bio-imaging and sensing applications, notably in various tissue types. In addition, we describe how to fabricate optoelectronic devices such as OLEDs and OLETs using SWNTs and CQDs as the dopant and electron transport layer, respectively. The purpose of this report was to advance this research further.

In the third chapter, we analyzed the optical and electrical properties of octadecylamine-functionalized SWNT doped in green light emitting polymer PSBF for usage in organic light emitting light emitting diodes as well as the performance of organic light emitting transistors. A basic introduction to optoelectronic devices was provided. This study has concentrated mostly on the doping effect of SWNT in the fabrication of optoelectronic devices. The incorporation of a functional group, such as octadecylamine, into single-walled carbon nanotubes can facilitate the uniform dispersion of SWNT in organic polymer. As a result of the high electron mobility of CNTs, the electronic properties of optoelectronic devices can be easily modified and enhanced by doping with SWNT. The most significant contribution of this chapter is the fabrication of an OLED and VOLET structure with an exceptionally low threshold voltage and outstanding luminance. A VOLET can be fabricated by adding a capacitor to the top of an OLED. This extraordinary device has two functions: it generates light as an OLED and switches current as a transistor. However, only one colour (green) has been shown to achieve this level of efficiency. OLEDs of various colours, including white, with comparable efficiency have not yet been developed. In actuality, white OLEDs are more important for display and lighting applications. This thesis requires additional research to determine whether the same device design approach can be applied to white OLEDs.

In the fourth chapter, the use of CQDs in the field of optoelectronics is described as being of great interest and having enormous growth potential. CQDs have previously been implemented in OLED and solar cells, however their performance must be upgraded. We synthesized CQDs from banana leaves using a simple hydrothermal technique. These CQDs were used as an electron transport layer in the fabrication of OLEDs. According to our knowledge, this is the first report of employing CQD as an electron transport layer in OLED. On indium tin oxide (ITO)-coated glass substrates, multilayered device structures are fabricated. Current-Voltage (I-V) curves reveal that the turn-on voltages are reduced from 8V to 6V when compared to the original PFO device. Additionally electroluminescence of the device also enhance as compared to pristine device. The results indicate that CQD as an ETL has enhanced the performance and efficiency of OLEDs.

In fifth chapter, we have emphasized recent advances in CQDs in terms of their production, optical characteristics, and use in metal ion sensing. We examined the sensing mechanism and potential of CQDs for detecting heavy metals ions in drinking water. The CQDs obtained from banana leaves extract were found to be abundant in chlorophyll, oxygen, and nitrogen containing functional groups; their average size was 3.5 nm, and they fluoresced strongly in a pink colour with a quantum yield of 42% when excited at a wavelength of 410 nm. A wide range of CQDs with distinct optical characteristics is obtainable by tuning their temperature from 120 to 230 degrees Celsius. Here, we show that chlorophyll-rich CQDs (ChlCQDs) synthesized at 160°C can be used as a switchable ON/OFF sensor for the selective detection of As^{3+} ions and Hg^{+} ions, respectively. The detection thresholds were determined using PL spectroscopy to be 67 pM for mercury and 1.53 μM for arsenic ions, respectively. We show, by means of surface-sensitive X-ray photoelectron spectroscopy studies, that As^{3+} ions bind extremely strongly with the carbonyl group of the chlorophyll moiety, whereas Hg^{+} ions bind very weakly to the carbon atoms of the CQDs. Density Functional Theory (DFT) simulations were carried out to understand the atomic-level interactions between As^{3+} and Hg^{+} on the surface of ChlCQD. CQD fluorescence emissions are greatly influenced by π-π interactions, hydrogen bonds, hydrophobic and even electrostatic interactions between them. This variation is sensitive enough to be recorded, allowing for detection of mercury and arsenic ions from real water sample.

In sixth chapter, since their development, CQDs have demonstrated their applicability in numerous scientific domains, particularly biological applications, and constitute a viable alternative to conventional heavy metal-based quantum dots. We summarized contemporary applications of CQDs as new diagnostic and therapeutic tools. First we synthesized CQDs and its uses in cancer theranostics, including cell imaging and cancer medication development, are discussed and illuminated in this thesis. In the present work, we used a straightforward and eco-friendly hydrothermal technique to produce chlorophyll functionalized carbon quantum dots (Chl-CQDs) from banana leaves with high quantum yields. It has been determined that Chl-CQDs have a life time of 6.29 ns and that their emission spectra peak at 677 nm. Chl-CQDs were tested on normal HEK-293 cells and human cervical cancer SiHa cells to determine their cytotoxic, bioimaging, and apoptogenic capabilities, and their free radical activity was assessed using DPPH. The MTT assay results demonstrated that Chl-CQDs significantly affected SiHa cells with an IC_{50} of around 100 μg/ml after 24 hours, while having no effect on HEK-293 cells. Bioimaging and apoptogenic experiments verified the therapeutic potential of Chl-CQDs against SiHa cells but found no cytotoxicity against HEK-293 cells. The data as a whole pointed to the possibility that Chl-CQDs were non-cytotoxic against normal cells but cytotoxic toward cervical cancer cells. We have covered CQDs' unique characteristics, their synthesis and characterization processes, and their characterization and cancer-targeting applications. To develop more practical and adjustable CQDs by self-assembly, further research into structural design and molecular interactions between biomolecules is required. For future prospects, an in-vivo investigation of these environmentally friendly Chl-CQDs has needed.

In the seventh chapter, CQDs have garnered a great deal of interest due to the capabilities and applications they offer in a vast array of environmental and health-related sectors. For the detection of ammonia vapour and lead in drinking water, we present research on a novel, very sensitive zero-dimensional material as CQDs. Using a single-step hydrothermal process, CQD samples were synthesized at temperatures of 180^0 C. We employed *Lagerstroemia speciosa* plant leaves as a precursor in DI water. FTIR, XRD, TEM, PL, UV-Vis, and photoluminescence spectroscopy were used to determine the chemical composition, shape, and fluorescence of CQDs. A thin film of CQDs was placed on an ITO-covered glass substrate, and the response was monitored at room temperature in order to detect and quantify ammonia vapour (NH_3). By measuring the associated variation in conductance, the variation in film resistance is examined. A synergistic combination between the catalytic properties of an active functional group on the CQDs surface and the localized electronic surface states of CQDs may result in enhanced ammonia sensing properties. Compared to previously reported ammonia sensors, this one is more sensitive, has a faster response time. Eventually, these CQDs were also employed to detect lead selectively in drinking water. In CQDs, the successive addition of lead ion (Pb^{2+}) reduces UV- absorbance. In aqueous solution, the limit of detection (LOD) for Pb^{2+} ions is 191 nM. The study of the CQDs' sensing efficiency revealed that the material possesses high sensitivity, high accuracy, and good selectivity for Pb^{2+} ions. Due to their high surface-to-volume ratio, biocompatibility, photo-stability, and resistance to changes in ionic strength, these investigations demonstrate that CQDs can be employed for sensing. Possibilities for the future development of CQD-based sensing probes for environmental monitoring applications.

This thesis explored the three principal uses of carbon nanostructure: optoelectronic devices, bio-imaging and sensors. Specially we focus on the special aspects of CQDs such as biocompatibility, fluorescence behaviour, and sensitivity. CQDs are beyond intriguing materials that have a potential to transform the existing sectors of biomedical engineering, pharmaceutical, electronics, energy harvesting and even more areas that haven‘t employed them yet. In future, drawing cue from this study, many more characteristics, surface passivation technique, energy transfer and applications using CQDs will be carried on. Further investigations are needed to establish their fluorescence mechanism and optimise CQDs emission, especially in the red area of the visible light spectrum. By researching the mechanism, essential features of CQDs can be understood extensively. We anticipate that this work will provide vital knowledge regarding the properties of CQDs, and will allow researchers to move forward and explore the hidden potential of CQDs, improve the current research, and implement new applications of this unique class of nanomaterials.