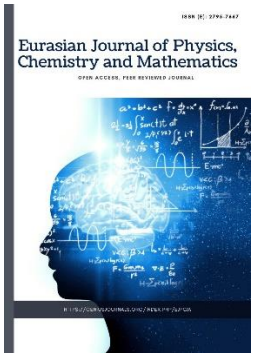

Synthesis And Photocatalytic Properties Of Carbon Dots

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ABSTRACT

Carbon dots (CDs) are a class of Carbon-based nanomaterials, typically smaller than 10 nm, known for their excellent optical properties, biocompatibility, and environmental friendliness. Their synthesis involves a variety of methods, including top-down approaches like arc-discharge and laser ablation, as well as bottom-up techniques such as hydrothermal and pyrolysis processes. The choice of precursor materials, which can range from organic molecules to waste biomass, and the synthesis method significantly influence the size, surface functionality, and quantum yield of the resulting carbon dots.

Keywords: Quantum dots, colloid synthesis, cadmium selenide, zinc sulfide, “core/shell”, nanoparticles, luminescence, precursor.

INTRODUCTION

One of the remarkable features of CDs is their tunable photoluminescence, making them highly desirable for applications in bioimaging, sensing, and photocatalysis. The photocatalytic properties of carbon dots arise primarily from their ability to absorb light and generate reactive oxygen species (ROS), such as hydroxyl radicals and superoxide ions, under irradiation. These properties are particularly useful in environmental remediation, where CDs are employed to degrade organic pollutants, dyes, and even for water splitting processes [1-3].

The mechanism behind the photocatalytic activity of CDs is closely related to their surface functional groups and the effective separation of photo-generated charge carriers. Doping CDs with heteroatoms such as nitrogen, sulfur, or phosphorus can further enhance their

photocatalytic performance by improving light absorption and facilitating electron transfer [4]. In summary, the synthesis of carbon dots and their photocatalytic properties offer a promising avenue for sustainable environmental technologies and energy conversion systems. Their versatility in synthesis and functionalization allows for tailoring CDs to specific photocatalytic applications, ranging from pollutant degradation to renewable energy generation [5].

The mechanism behind the photocatalytic activity of CDs is closely related to their surface functional groups and the effective separation of photo-generated charge carriers. Doping CDs with heteroatoms such as nitrogen, sulfur, or phosphorus can further enhance their photocatalytic performance by improving light absorption and facilitating electron transfer. [6]. The synthesis of quantum dots with a core/shell structure is formed by the growth of monolayers by adding precursors to the reaction medium. The thickness of the shell is one of the important parameters determining the properties of the crystal, which allows one to determine the yield, stability, and other properties of quantum dots. The nature and composition of a semiconductor as an nucleus play an important role in the synthesis of quantum dots. By changing the composition of the semiconductor, effective luminescence can be achieved in the desired range. Among the most studied nanoparticles among QDs are CdSe nanocrystals with good luminescence properties [7-9].

Material and methods

1. **Carbon Precursors:** Citric acid, glucose, or biomass-derived materials (e.g., orange peels, waste coffee grounds) were selected as carbon sources for carbon dot (CD) synthesis.
2. **Nitrogen Source (for doping):** Urea or ethylenediamine were used for nitrogen-doped carbon dots (N-CDs).
3. **Reagents for Photocatalytic Tests:** Methylene blue (MB), Rhodamine B (RhB), or organic pollutants were selected as model pollutants to assess photocatalytic degradation. Hydrogen peroxide (H_2O_2) was used to enhance ROS generation in photocatalytic tests.
4. **Solvents and Buffers:** Deionized (DI) water, ethanol, and phosphate-buffered saline (PBS) were used throughout the synthesis and testing process.

Synthesis of Carbon Dots: Hydrothermal Synthesis: Citric acid (1 g) and urea (0.5 g) were dissolved in 20 mL of DI water to form a clear solution. The solution was transferred to a Teflon-lined autoclave and heated at 180°C for 6 hours in an oven. After cooling to room temperature, the solution was filtered using a 0.22 μm filter to remove large particles. The filtrate containing carbon dots was collected and dialyzed (1,000 Da cutoff) for 24 hours to remove residual impurities. The carbon dot solution was then dried under vacuum, yielding a dry powder of CDs. **Doping (for enhanced photocatalysis):** Nitrogen doping was performed by adding urea to the carbon source before hydrothermal treatment. For sulfur or phosphorus doping, thiourea or phosphoric acid was used in place of urea.

After synthesis, the resulting N-doped CDs (N-CDs) were similarly filtered and purified through dialysis.

Characterization of Carbon Dots:

1. **Particle Size and Morphology:**

Transmission electron microscopy (TEM) was used to determine the size and morphology of the synthesized CDs.

Dynamic light scattering (DLS) was performed to measure the size distribution and zeta potential.

2. **Optical Properties:**

UV-Vis absorption spectroscopy was used to assess the optical absorption profile of the CDs.

Fluorescence spectroscopy was performed to evaluate photoluminescence emission under different excitation wavelengths.

RESULTS AND DISCUSSION

The obtained nanoparticles have a spectral range of 500-600 nm in the luminescence spectrum. The spectrum shows that the luminescence range is narrow and symmetrical.

This suggests that nanocrystals have very few surface defects and are characteristic of colloidal synthesis. The selected synthesis method made it possible to obtain monodispersed quantum dots. The maximum photoluminescence intensity of quantum dots is 555 nm (Figure 2a). The quantum yield of the synthesized hybrid CdSe/ZnS quantum dots was determined by the coumarin method, based on a solution of rhodamine 6G (96%) in ethanol [9]. The quantum yield of hybrid CdSe/ZnS nanocrystals was 19%.

The photoluminescence and absorbance spectra of the QDs was recorded in n-hexane (Fig. 2). The maximum luminescence intensity was at 513 nm at wavelength excitation 350 nm.

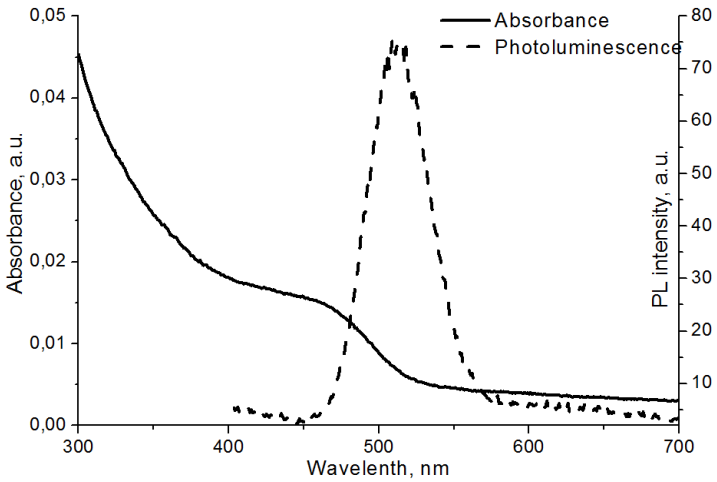

Figure 1. Absorbance and photoluminescence (λ_{ex} = 350 nm) spectra of CdSe QDs.

Fourier transform infrared spectroscopy (FTIR) spectra were recorded on samples embedded in KBr pellets on a Nicolet Nexus spectrometer. It determines the chemical bonds in the molecule by forming an infrared absorption spectrum (Fig. 2).

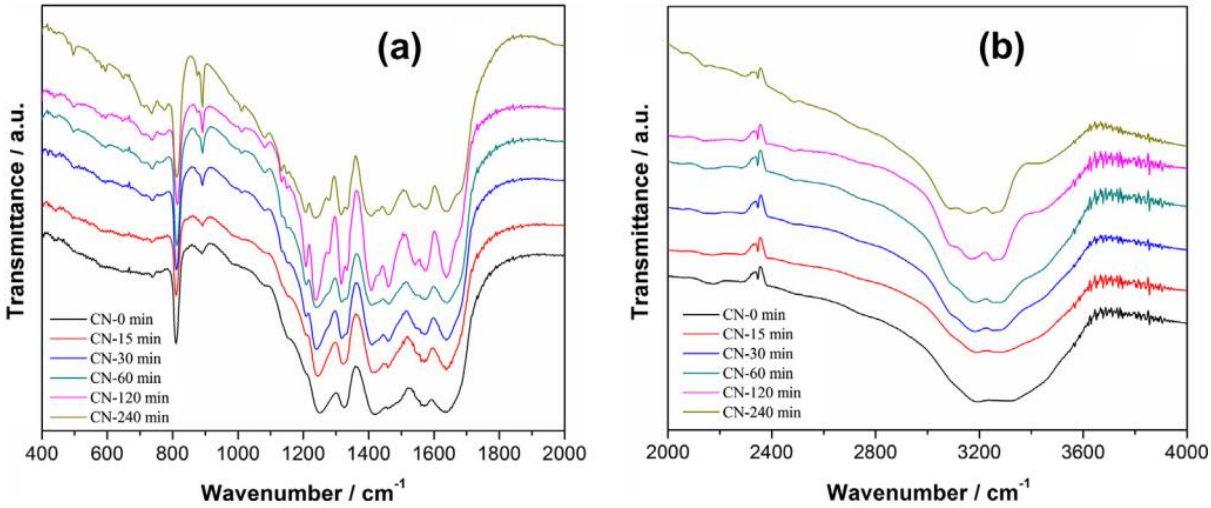

Figure 2. FT-IR spectra of γ-C3N4 samples treated for different times between 400-2000 cm-1 and 2000-4000 cm-1 (b)

The synthesis of CdSe QDs was performed with partial modifications based on the method described by the authors [10].

The method recommended by the authors [11-13] was used to grow the ZnS shell around the CdSe nucleus.

To prepare a solution of zinc oleate (0.1M), a solution prepared from a mixture of 1.41 ml of oleic acid (OA) of 0.0405 g ZnO and 3.6 ml of octadecene was prepared by heating at 260°C. A precursor of a sulfur (0.1M) solution was obtained by dissolving 0.016 g of sulfur in 5 ml of octadecene at 200°C.

A 20 ml solution was prepared by adding 5 ml of octadecene to a solution of CdSe ($6.6 \cdot 10^{-6}$ mol/l) QD in toluene and heated to 200°C until the toluene in the mixture evaporated. Then, 2.2 ml of oleilamine and 4.7 ml of zinc oleate solution were added and mixed for 15 min. A total of 4.7 ml of sulfur precursor solution was added to the reaction mixture every 15 minutes. The mixture is stirred in a magnetic stirrer for 30 min at 200°C so that the components in the

mixture are fully reactive. The purification process is performed in the same order as for CdSe quantum dots.

Synthesis was performed on the surface of CdSe nanocrystals based on changes in the addition time of sulfur precursors (for 3, 7, 10, 15 minutes) during ZnS shell growth.

Oleic acid was used as a stabilizer in the synthesis of CdSe QDs and was synthesized at high temperatures in an octadecene medium.

Synthesis of hybrid CdSe/ZnS quantum dots stabilized with oleic acid was performed. The luminescence spectra of CdSe/ZnS QDs were studied. The absorption and luminescence spectra of the hybrid CdSe/ZnS quantum point moved to the short region of the wavelength peak. An increase in luminescence quantum yield was observed to be 1.5–19%.

CONCLUSIONS

In summary, the synthesis of carbon dots and their photocatalytic properties offer a promising avenue for sustainable environmental technologies and energy conversion systems. Their versatility in synthesis and functionalization allows for tailoring CDs to specific photocatalytic applications, ranging from pollutant degradation to renewable energy generation..

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