

Abstract

This doctoral dissertation is devoted to the design, synthesis, and characterization of the optical properties of carbon dots (CDs) for applications in molecular sensing and heterogeneous photocatalysis. The main aim of this thesis was to explain the correlation between surface chemistry and luminescence mechanisms, which is an important factor in tuning the functionality of carbon dots, and to apply this knowledge to the design of photocatalytic hybrid materials.

The research was conducted in four distinct stages. In the first stage, detailed studies were carried out on the influence of acidic, alkaline and aprotic chemical modifiers on the spectroscopic parameters of CDs. It was demonstrated that the selection of the synthesis environment allows for precise control over emission mechanisms, ranging from the stabilization of surface trap states (STS) in an acidic environment, which extends fluorescence lifetimes, to charge transfer (CT) processes in an alkaline and aprotic environment, enabling high quantum yield (QY) of up to 80%.

The second stage of the work examined the effect of environmental conditions on the optical properties of CDs. The resulting nanostructures exhibited a linear spectral response over a broad pH range (1-14) and a high sensitivity to the presence of hydroxyl groups in organic solvents. Using advanced spectroscopic diagnostics- including Fourier-Transform Infrared Spectroscopy (FTIR), alongside excitation and emission profiling - it was demonstrated that the sensing mechanism relies on dynamic surface interactions and structural transformations at the material-analyte interface.

The third part of the dissertation examined the potential of CDs as components of hybrid photocatalytic systems. By integrating fluorescent and phosphorescent CDs with mesoporous TiO_2 , materials with enhanced activity for the photodegradation of carbamazepine (CBZ) were obtained with the possibility of using visible light in this process. The results confirmed that CDs play a triple role in these systems: extending the absorption range of the matrix, acting as electron acceptors that suppress charge carrier recombination, and serving as active centers that increase the efficiency of electron-hole pair separation.

The fourth part examined how interfacial engineering strategies and the structural reorganization of the interface between CDs and ZnO allow for the precise modulation of the hybrid's catalytic properties. By developing and systematically analyzing five distinct modification paths it was demonstrated that the architecture of the heterojunction determines whether oxidative or reductive photocatalytic pathways are selectively promoted under UV-Vis light. The results revealed that while the presence of the organic phase can introduce competitive consumption of reactive oxygen species (ROS) due to autophotodegradation, specific approaches to hybrid materials preparation such as hydrothermal processing enhance charge transfer and result in exhaustive degradation of reaction intermediates like naproxen (NPX).

In summary, the results presented in this thesis demonstrate that CDs are materials with properties that can be precisely tuned through surface chemistry modification. The research conducted expands knowledge of photophysical processes in carbon nanostructures and indicates new possibilities for their application in modern environmental remediation technologies and advanced chemical analytics.