

Comparative Study on Carbon Dots and Carboxyl-Carbon Dots - LSPR for Creatinine Detection

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Keywords

Carbon dots
Carboxyl carbon dots
SPR
Creatinine
Optical sensor

Article History

Received: 4 May 2025

Accepted: 5 June 2025

Published: 30 October 2025

Abstract

The detection of creatinine, a crucial biomarker for kidney function, has attracted significant attention due to the need for rapid and sensitive detection. In this study, we report a comparative analysis of Carbon Dots (CDs) and Carboxyl-Carbon Dots (CDsCOO) for developing a fluorescent-based creatinine sensor. Both carbon dots were synthesized via a hydrothermal approach, with surface modification introduced to generate carboxyl functional groups in CDsCOO. Creatinine sensing performance was evaluated based on the fluorescence quenching response, calibration curve linearity, sensitivity, and limit of detection (LOD). The effectiveness of this material was evaluated at concentrations ranging from 0 to 0.6 mg/dL. The CDsCOO demonstrated superior performance with enhanced sensitivity and a lower LOD than unmodified CDs, achieving a LOD of approximately (0.05 mg/dL & 0.28 mg/dL) and a sensitivity of 20.123 nm/mg/dL & 3.696 nm/mg/dL. This work highlights the potential of CDsCOO as a promising platform for efficient and selective creatinine detection.

1. Introduction

Localized Surface Plasmon Resonance (LSPR) is an optical phenomenon increasingly appreciated for its high sensitivity in biomolecule detection. LSPR sensors can detect environmental changes through the interaction of light and metal nanoparticles, thus presenting a viable solution for numerous sensing applications [1]. One such field is Chronic Kidney Disease (CKD), where exact and sensitive detection is significant. CKD is a global health problem, intimately connected with rising blood creatinine levels. Therefore, it is a key indicator for evaluating kidney function. Conventional techniques for measuring creatinine, including the Jaffe method and high-performance liquid chromatography (HPLC), have drawbacks, including low sensitivity and sample contamination by other chemicals, which complicate early diagnosis [2]. CDs have great potential to improve LSPR sensor performance due to their unique optical properties, biocompatibility, and stability, which can be further modified to boost sensitivity and selectivity. CDs modified with carboxyl groups are especially effective in creating hydrogen bonds with creatinine, which improves the sensor's capacity to identify at low concentrations. This work intends to investigate the combination of LSPR sensors with CDsCOO to offer a more sensitive, selective, and consistent technique for creatinine detection, increasing the possibility for early CKD diagnosis.

2. Materials and Methodology

CDs and CDsCOO were synthesized through a hydrothermal process. At the same time, silver nanotriangles, AgNT were prepared via a reduction method. Glass slides were first cleaned using piranha solution and then functionalized with APTES [2], [3]. The sensing materials were prepared with AgNT in a 1:4 ratio and fabricated onto the functionalized glass slides. The LSPR experimental setup, as shown in Figure 1, included a light source (DH-2000-BAL, Ocean Optics, Orlando, Florida, USA) with a spot size of 1-2 mm², coupled with an HR4000CG-UV-NIR spectrometer (Ocean Optics) to record spectra in the range of 350-850 nm after exposure to the analytes.

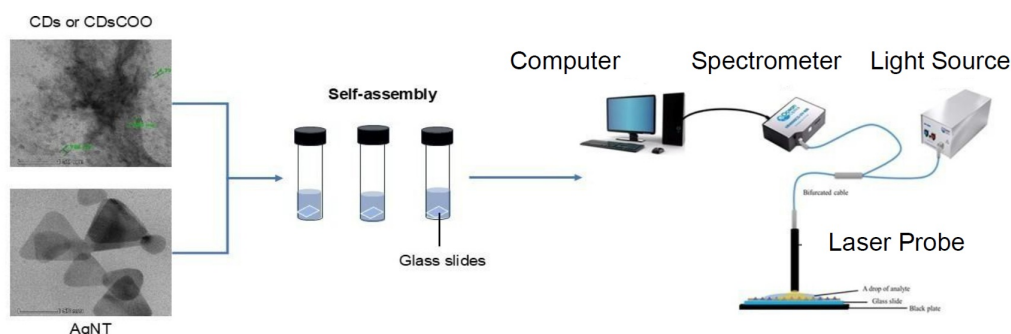


Figure 1. Schematic representation of the creatinine detection process using AgNT/CDs and AgNT/CDsCOO through LSPR.

3. Results and Discussion

Figure 2a and 2b show the LSPR spectra and calibration plot (Figure 2c) for AgNT/CDs and AgNT/CDsCOO in creatinine detection. AgNT/CDsCOO had a sensitivity of 20.123 nm/mg/dL at lower concentrations (0-0.04 mg/dL), and 3.696 nm/mg/dL from 0.04 to 0.6 mg/dL. Its detection limit was 0.06 mg/dL. AgNT/CDs had a higher sensitivity of 33.45 nm/mg/dL for concentrations between 0 and 0.1 mg/dL, but less sensitivity at higher levels, with 2.787 nm/mg/dL from 0.1 to 0.6 mg/dL. The detection limit for AgNT/CDs was 0.25 mg/dL.

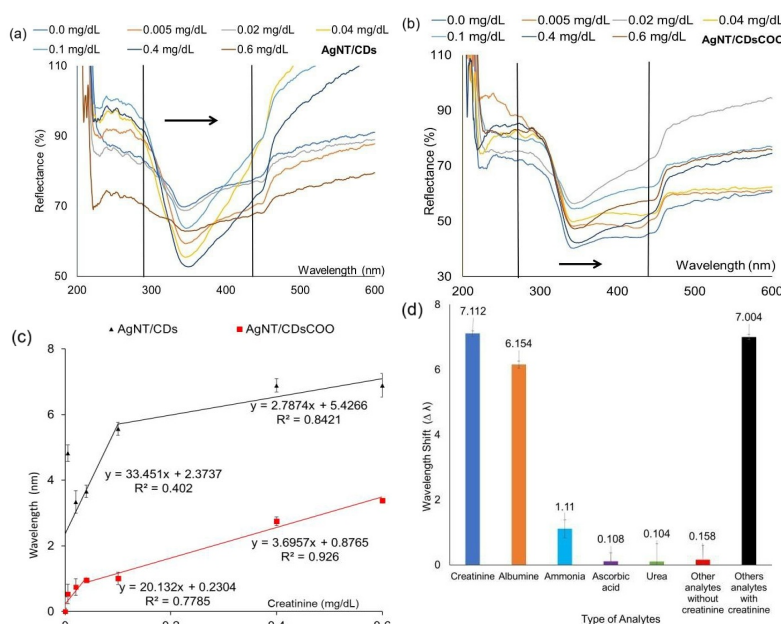


Figure 2. The LSPR spectra: A) AgNT/CDs, B) AgNT/CDsCOO, C) Calibration curve, D) Selectivity graph of AgNT/CDsCOO.

The linearity (R^2) for AgNT/CDsCOO was higher (0.779 and 0.926) than AgNT/CDs (0.402 and 0.842). While AgNT/CDsCOO showed less sensitivity at lower concentrations, it could still detect creatinine up to 0.6 mg/dL.



The sensor selectivity was tested with several analytes in Figure 2d. The sensor was most sensitive to creatinine due to the oxygen of CDsCOO that attracts hydrogen in creatinine to form a hydrogen bond. Due to hydrogen bonding between the amine groups of albumins and CDsCOO, it showed similar selectivity. However, its larger size and complex structure limited its interaction with the sensor surface. Ammonia, ascorbic acid, and urea showed lower reactivity, with the bar graph indicating that creatinine caused the most significant wavelength change.

4. Conclusion

This study demonstrated that AgNT/CDsCOO exhibited better performance in detecting the presence of creatinine. It showed a lower detection limit (0.06 mg/dL) and greater selectivity than AgNT/CDs. AgNT/CDsCOO was more sensitive at higher concentrations and exhibited improved linearity ($R^2 = 0.926$). The results indicate that AgNT/CDsCOO could serve as a promising and user-friendly sensing material, particularly useful in biomedical settings for early detection and ongoing monitoring of renal health based on creatinine levels.

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