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Multipurpose fluorescent carbon dots from papaya seed waste as sensing materials for Cu^{2+} detection and diethyl ether vapor sensor via electronic nose system

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Abstract

Herein, carbon dots (CDs) as biocompatible, fluorescent carbon-based nanomaterials were synthesized from papaya seed waste as renewable carbon sources for the first time via a facile acid pyrolysis method. The papaya seed-derived CDs showed blue fluorescence emission under UV light (365 nm) with a quantum yield of 2.74%, and contained oxygen-, and nitrogen- containing functional groups. Due to their surface functionality, the CDs have a great potential for using as fluorescence sensing probe in metal ion sensing application. The CD solution exhibited the most selective detection to Cu^{2+} as presented the highest fluorescence quenching with the limit of detection (LOD) of 5.16 µM. The CD-paper-based fluorescent sensor was also developed for practical application, and the RGB value was used to compare the sensitivity of CDs toward metal ions. The CD sensing film was also prepared for diethyl ether vapor sensing via optical electronic nose system. The principal component analysis (PCA) score plots revealed the total variance of 99.3%, indicating that the CDs can be used to discriminate different concentrations of diethyl ether/ethanol vapor mixtures. This work demonstrated that the papaya seed-derived CDs have a great attention to be alternative materials for developing sensing materials in both solution and film forms.

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1. Calculation of surface coverage from fluorescent results

Diameter of CD $\approx$20 nm $\therefore$ Radius of CD $\approx$10 nm

$$\therefore \text{Area} = 4\pi R^2 = 4\pi(10^2) = 1256.64 \text{ nm}^2/\text{particle}$$

From the Cu^{2+} sensing experiment : 1.5 mL Cu^{2+}+3.5 mL NCD

$$\text{no. of } Cu^{2+} = \left(200 \times 10^{-6}\,\tfrac{\text{mol}}{\text{L}}\right)\left(1.5 \times 10^{-3}\text{ L}\right)\left(6.02 \times 10^{23}\,\tfrac{\text{ions}}{\text{mol}}\right) = 1.81 \times 10^{17} \text{ ions}$$

$$\text{mg of CDs} = \left(0.05\,\tfrac{\text{mg}}{\text{mL}}\right)(3.5\text{ mL}) = 0.175\text{ mg}$$

Density of CDs ≈ Density of graphite $= 2.26 \frac{g}{cm^3}$

$$2.26 \frac{g}{cm^3} = \frac{0.175 \times 10^{-3} g}{(\text{no. of CD particles}) \times \frac{4}{3}\pi \left(10 \times 10^{-7}\ cm\right)^3}$$

no. of CD particles $= 1.85 \times 10^{13}$ particles

$$\therefore \text{ Surface coverage } \left(\frac{ion}{nm^2}\right) = \frac{1.81 \times 10^{17}\ ions}{(1.85 \times 10^{13}\ particles)(1256.64\ nm^2/particle)} = 7.78\ ions/nm^2$$

2. Calculation of adsorption capacity

From surface coverage = 7.78 ions/nm^2

1 nm^2 of CD can adsorb 7.78 ions of Cu^{2+}

$$4\pi(10\ nm)^2 \text{ can adsorb } 4\pi(10\ nm)^2 \times 7.78 = 9776.64 \text{ ions} = \frac{9776.64\ ions}{6.02 \times 10^{23}\ ions/mol}$$

$$= 1.624 \times 10^{-20}\ mol$$

$\therefore$ 1.624×10^{-20} mol of Cu^{2+} = 1.624×10^{-20} mol × 63.546 g·mol^{-1} = 1.032×10^{-18} g = 1.032×10^{-15} mg

From mg of CDs = 0.175×10^{-3}g and no. of CD particles in solution = 1.85×10^{13} particles

$$\therefore \text{ g of 1 CD particle } = \frac{0.175 \times 10^{-3} g}{1.85 \times 10^{13}} = 9.46 \times 10^{-18} g$$

$$\therefore \text{ Adsorption capacity} = \frac{\text{mg of } Cu^{2+} \text{ adsorbed}}{\text{g of CD}} = \frac{1.032 \times 10^{-15}\ mg}{9.46 \times 10^{-18} g} = 109.1\ mg \cdot g^{-1}$$