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Non-Thermal Plasma Engineered Mn-Ferrite Quantum Dots Embedded Polydopamine for Biosensing Applications

Micro discharge plasma (MDP) is a non-thermal, non-equilibrium technique that offers precise control over nanomaterial synthesis. By adjusting MDP operating parameters, enables effective control of particle size, structure, and morphology through plasma driven chemical reactions that control the properties of nanomaterials. In this work, manganese ferrite quantum dots (MFQDs) were synthesized and were embedded in situ within the polydopamine (PDA) matrix to form hybrid nanostructures using MDP with oxygen as the plasma gas. The role of PDA in particle size, phase formation, and morphology was systematically investigated. Optical emission spectroscopy was employed to monitor the reactive plasma species during the synthesis which confirms the presence of hydroxyl radical (OH•) and atomic oxygen (O). XRD showed that PDA added system produced phase pure spinel $MnFe_2O_4$, while FTIR identified characteristic PDA functional groups (C-N, C=C, N=H) along with metal oxygen bonds. XPS revealed the coexistence of mixed Mn^{2+}/Mn^{3+} and Fe^{2+}/Fe^{3+} oxidation states as well as carbon related bonds (C-O, C-C, C-N, C=C, C-H), indicating strong MFQD–PDA interaction. HRTEM showed MFQDs of 6 to 9 nm, embedded within PDA spheres and layered structures, with reduced aggregation and the formation of hybrid structure. The peroxidase-like activity of MFQDs–PDA hybrid nanostructures was evaluated using a TMB–H_2O_2 colorimetric assay, showing distinct blue colour development with significantly higher absorbance at 652 nm. The corresponding kinetic parameters ($V_(max)$ & K_m) were evaluated which was found to be superior to that of pristine $MnFe_2O_4$, indicating enhanced catalytic activity after PDA incorporation. These results demonstrate that PDA significantly improves peroxidase-like catalytic performance, making the MFQDs–PDA hybrid nanostructure a promising platform for enzyme free biosensing.

Keywords: Micro discharge plasma, $MnFe_2O_4$, Polydopamine, hybrid nanostructure, peroxidase mimetic.
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