

# Enhancement of Energy Storage Performance of Polyaniline via Carbon Dots Incorporation

YanYe<sup>1</sup>, Huijun Li\*<sup>1</sup>

*1School of Materials Chemistry, University of Shanghai for Science and Technology, Shanghai 200093, China*

---

## **Abstract**

*In order to improve the energy storage performance of polyaniline (PANI), nitrogen-doped carbon dots (N-CDs) were incorporated into PANI matrix via chemical oxidative polymerization to prepare N-CDs/PANI composite. The structure of the composite was characterized by Fourier transform infrared spectroscopy (FTIR), transmission electron microscopy (TEM) and X-ray diffraction (XRD). The electrochemical energy storage performance was tested by cyclic voltammetry (CV), galvanostatic charge-discharge (GCD) and electrochemical impedance spectroscopy (EIS). The results showed that the introduction of N-CDs effectively improved the dispersibility of PANI and constructed a more efficient conductive network. When the doping amount of N-CDs was 10%, the specific capacitance of the composite reached 541.7 F/g, which was 62.3% higher than that of pure PANI. After 5000 charge-discharge cycles, the capacitance retention of the composite remained 86.9%, indicating excellent cyclic stability. This study provides a new strategy for the design of high-performance energy storage electrode materials. -.*

**Keywords:** Nitrogen-doped carbon dots; Polyaniline; Electrodeposition; Composites; Supercapacitor; Electrochemical performance

---

Date of Submission: 05-03-2026

Date of Acceptance: 15-03-2026

---

## **I. Introduction**

The escalating global energy demand and the urgent need to mitigate environmental pollution have spurred intensive research into advanced energy storage technologies<sup>1</sup>. Among various energy storage systems, supercapacitors have garnered significant attention due to their exceptional power density, rapid charge-discharge capability, and superior cycling stability<sup>2</sup>. These distinctive characteristics position supercapacitors as promising candidates for a wide range of applications<sup>3</sup>, including electric vehicles, portable electronics, and grid-scale energy storage systems<sup>4</sup>. However, the relatively low energy density of supercapacitors compared to batteries remains a critical challenge that limits their broader commercialization, driving extensive efforts to develop novel electrode materials with enhanced electrochemical performance<sup>4</sup>.

Conducting polymers have emerged as one of the most promising classes of pseudocapacitive electrode materials due to their reversible faradaic redox reactions, high theoretical specific capacitance, and good intrinsic conductivity<sup>5</sup>. Among these, polyaniline (PANI) stands out as a particularly attractive candidate owing to its facile synthesis, environmental stability, low cost, and multiple redox states that contribute to energy storage<sup>6</sup>. The theoretical specific capacitance of PANI can reach up to 2000 F/g, making it highly competitive among organic electrode materials. Despite these advantages, the practical application of pure PANI in supercapacitors is severely hindered by several inherent limitations. During repeated charge-discharge cycles, PANI undergoes substantial volume expansion and contraction, leading to mechanical degradation, structural pulverization, and eventual detachment from the current collector. This results in rapid capacity decay and poor cycling stability, with typical capacitance retention of only 50-60% after 1000 cycles. Furthermore, the rate capability of PANI is often unsatisfactory due to its limited electrical conductivity and sluggish ion transport kinetics, especially at high current densities<sup>7</sup>.

Carbon dots (CDs), a novel class of zero-dimensional carbon nanomaterials with sizes typically below 10 nm<sup>8</sup>, have recently emerged as promising functional modifiers for energy storage materials. CDs possess a unique combination of properties including high electrical conductivity, large specific surface area, abundant surface functional groups (such as amino, carboxyl, and hydroxyl groups), and excellent dispersibility in various solvents. These characteristics make CDs ideal candidates for constructing conductive networks and enhancing interfacial interactions within composite electrodes<sup>9</sup>. Nitrogen-doped carbon dots (N-CDs) represent an advanced variant with further improved electrochemical activity, as nitrogen doping introduces additional defect sites and alters the electronic structure, providing enhanced conductivity and pseudocapacitive contributions. The incorporation of N-CDs into polymer matrices has been demonstrated as an effective strategy to address the

limitations of pure conducting polymers. The strong interfacial interactions between N-CDs and polymer chains can inhibit volume changes during cycling, while the conductive carbon network facilitates rapid electron transport and ion diffusion.<sup>10</sup>

Electrodeposition has emerged as a particularly advantageous method for preparing PANI-based composite electrodes<sup>11</sup>. Compared to conventional chemical oxidative polymerization, electrodeposition offers several distinct benefits: it enables direct growth of active materials on the current collector surface, eliminates the need for binders and conductive additives, provides precise control over film thickness and morphology through deposition parameters, and ensures intimate contact between the active material and substrate. These features are essential for achieving low interfacial resistance and maximizing material utilization. Despite these advantages, the preparation of N-CDs/PANI composite electrodes via electrodeposition and their systematic investigation for supercapacitor applications remain relatively unexplored<sup>12</sup>.

In this study, we report a facile one-step electrodeposition method for the fabrication of N-CDs/PANI composite electrodes<sup>13</sup>. Nitrogen-doped carbon dots were first synthesized via a hydrothermal approach, and subsequently co-deposited with aniline monomers onto a stainless steel mesh substrate through cyclic voltammetry. The structure, morphology, and chemical composition of the resulting N-CDs/PANI composites were systematically characterized using transmission electron microscopy (TEM), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and X-ray photoelectron spectroscopy (XPS). The electrochemical performance of the composite electrodes was evaluated by cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS). The influence of N-CDs concentration on the microstructure and electrochemical properties was systematically investigated to identify the optimal composition. The underlying mechanism for the enhanced energy storage performance was elucidated based on experimental observations and theoretical considerations. This work demonstrates that electrodeposited N-CDs/PANI composites hold great promise as high-performance electrode materials for next-generation supercapacitors, and provides valuable insights into the design and development of advanced energy storage systems.

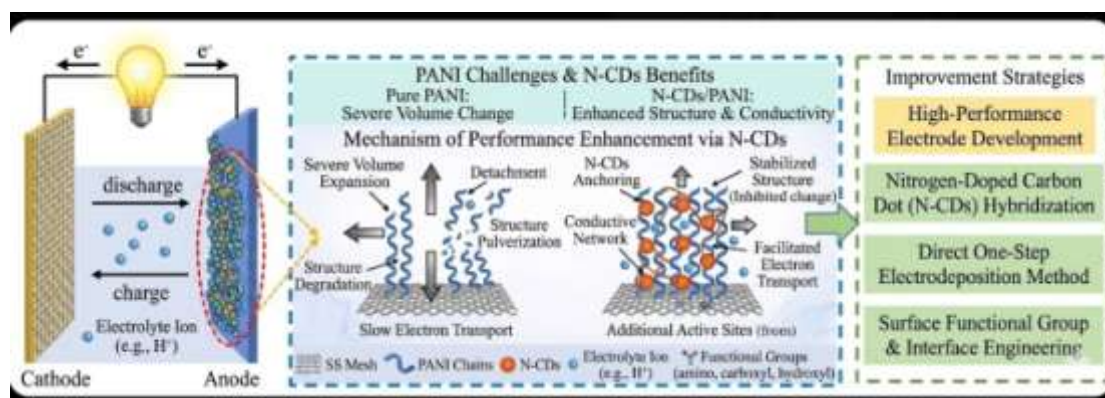


Fig. 1. Schematic illustration of the one-step electrodeposition synthesis of N-CDs/PANI composites

## II. Experimental Section

### 2.1 Materials and Reagents

Aniline (analytical grade), ammonium persulfate (APS, analytical grade), hydrochloric acid (HCl, analytical grade), urea (analytical grade), citric acid (analytical grade), and anhydrous ethanol (analytical grade) were purchased from Sinopharm Chemical Reagent Co., Ltd. Deionized water was used in all experimental processes.

### 2.2 Instruments

Fourier transform infrared spectrometer (FTIR, Nicolet iS50, Thermo Fisher Scientific, USA)

Transmission electron microscope (TEM, JEM-2100F, JEOL, Japan)

X-ray diffractometer (XRD, D8 ADVANCE, Bruker, Germany)

Electrochemical workstation (CHI660E, Chenhua Instruments, China)

Centrifuge (TDL-5-A, Anting Scientific Instrument Factory, China)

Vacuum drying oven (DZF-6050, Shanghai Jinghong Laboratory Instrument Co., Ltd., China)

### 2.3 Preparation of Nitrogen-Doped Carbon Dots (N-CDs)

N-CDs were prepared by a hydrothermal method. 1.0 g of citric acid and 1.5 g of urea were dissolved in 20 mL of deionized water, and the mixture was stirred until completely dissolved. The solution was then transferred to a 50 mL Teflon-lined autoclave and heated at 180°C for 6 h. After the reaction, the autoclave was

naturally cooled to room temperature. The product was dialyzed against deionized water for 24 h to remove unreacted reagents, and then freeze-dried to obtain N-CDs powder.<sup>14</sup>

#### **2.4 Electrodeposition of Nitrogen-Doped Carbon Dots (N-CDs)**

Carbon dots were deposited onto the ITO film using a two-electrode system. The electrolyte was an aqueous dispersion of carbon dots at a concentration of 10 mg mL<sup>-1</sup>. Electrodeposition was performed at room temperature under a constant voltage of 10 V for 600 s. After deposition, the obtained electrode was rinsed with deionized water and dried at 50 °C for 1 h.

#### **2.5 Electrodeposition of N-CDs/PANI Composites**

A three-electrode electrochemical cell was used for electrodeposition of PANI thin films on the N-CDs-deposited ITO film. The bath solution was composed of 0.25 mol L<sup>-1</sup> C<sub>6</sub>H<sub>5</sub>NH<sub>2</sub>, 0.5 mol L<sup>-1</sup> H<sub>2</sub>SO<sub>4</sub>, and ethanol as the solvent. The reference electrode was Ag/AgCl, and a platinum sheet served as the counter electrode. The PANI films were prepared by single cyclic voltammetric (CV) technique in the potential range of 0.2 V to 1.0 V under the speed of 0.05 V s<sup>-1</sup> for 10 cycles, respectively. All the as-deposited N-CDs/PANI thin films were then washed with anhydrous ethanol and dried on the 50 °C heating plate for 1 h.<sup>15</sup>

#### **2.6 Electrochemical Performance Tests**

Electrochemical tests were carried out using a three-electrode system. The working electrode was the N-CDs/PANI composite electrode, the counter electrode was a platinum sheet, and the reference electrode was Ag/AgCl. The electrolyte was 1.0 mol/L H<sub>2</sub>SO<sub>4</sub> solution.

CV Tests: Cyclic voltammetry tests were performed at scanning rates of 5-100 mV/s.

GCD Tests: Galvanostatic charge-discharge tests were carried out at current densities of 0.5-5 A/g.

EIS Tests: Electrochemical impedance spectroscopy tests were conducted in the frequency range of 0.01 Hz-100 kHz with an amplitude of 5 mV.

### **III. Results And Discussion**

#### **3.1 Structural Characterization**

Figures 2.a-j show multiple characterization results of pure PANI and N-CDs/PANI composites, which systematically reveal the regulatory effect of N-CDs introduction on the structure and morphology of polyaniline, providing a structural basis for the improvement of its energy storage performance.

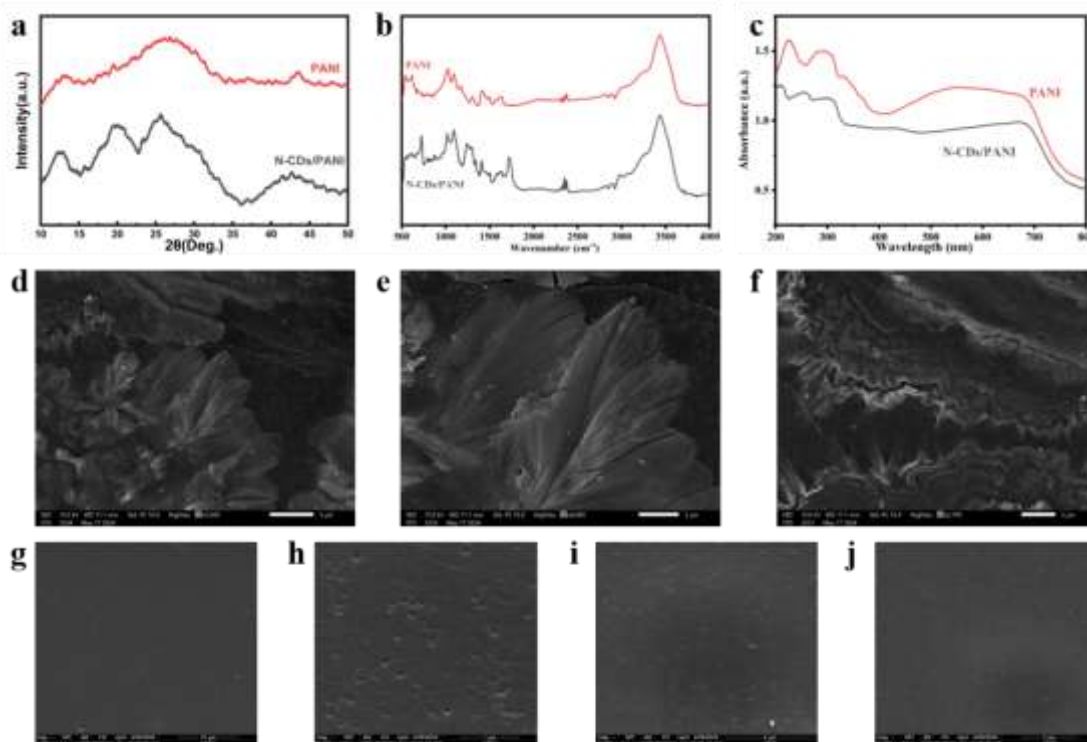
Figure 2.a is the XRD patterns of the two materials. Pure PANI shows two broad diffraction peaks at  $2\theta=20^\circ$  and  $25^\circ$ <sup>16</sup>, corresponding to the (011) and (200) crystal planes of PANI, reflecting its typical amorphous structure characteristics. After the introduction of N-CDs, the intensity of the diffraction peaks of PANI is significantly reduced, and a characteristic peak of the (002) crystal plane of N-CDs appears at  $2\theta=26^\circ$ , confirming that N-CDs are successfully embedded in the PANI matrix. The reduction in the intensity of the diffraction peaks indicates that the introduction of carbon dots inhibits the crystalline growth of PANI, making the structure of the composite more amorphous. This structure is more conducive to the diffusion and transport of electrolyte ions, providing a structural basis for the improvement of energy storage performance.

Figure 2.b is the FTIR spectra of the two materials. Pure PANI shows characteristic peaks at 3430 cm<sup>-1</sup> (N-H stretching), 1575 cm<sup>-1</sup> (benzene ring vibration), 1490 cm<sup>-1</sup> (quinone ring vibration), 1300 cm<sup>-1</sup> and 1140 cm<sup>-1</sup> (C-N stretching), and 820 cm<sup>-1</sup> (out-of-plane bending of benzene ring), which are consistent with the structural characteristics of PANI. For the N-CDs/PANI composite, the N-H stretching peak at 3430 cm<sup>-1</sup> is significantly enhanced, which is due to the hydrogen bonding interaction between the amino groups on the surface of N-CDs and the N-H groups of PANI; meanwhile, a C=O stretching vibration peak appears at 1630 cm<sup>-1</sup>, corresponding to the carboxyl functional groups on the surface of N-CDs, further confirming the successful compounding of N-CDs and PANI, and the existence of intermolecular interactions between them, which helps to improve the structural stability of the material.

Figure 2.c is the UV-Vis absorption spectra. Pure PANI has characteristic absorption peaks at about 330 nm and 600 nm, corresponding to the  $\pi$ - $\pi$  transition of the benzene ring and the n- $\pi$  transition of the quinoid structure, respectively. The absorption peaks of the N-CDs/PANI composite have a red shift, and the absorption intensity changes, which indicates that the introduction of N-CDs changes the electronic structure of PANI, and there is electronic interaction between them. This regulation of the electronic structure is beneficial to improving the conductivity of the material, thereby improving the charge transport in the electrochemical energy storage process.

Figures 2.d-f are SEM images of pure PANI. Under different magnifications, it can be seen that pure PANI presents a morphology of nanofiber agglomeration<sup>16</sup>, with fibers closely stacked and obvious agglomeration areas. This agglomerated structure will hinder the diffusion of electrolyte ions and limit the utilization rate of active sites. Figures 2.g-j are SEM images of the N-CDs/PANI composite. It can be seen that

after the introduction of N-CDs, the dispersion of PANI nanofibers is significantly improved, the agglomeration is significantly suppressed, and N-CDs are uniformly dispersed on the surface of PANI nanofibers, forming a more uniform and dense morphology. This morphology constructs a more continuous conductive network and provides more channels for ion diffusion, which can effectively improve the electrochemical active area and charge transfer efficiency of the electrode material, which echoes the results of the increase in specific capacitance and optimization of cycle stability of the composite in subsequent electrochemical tests.



**Fig.2** (a) XRD patterns of PANI and N-CDs/PANI. (b) FTIR spectra of PANI and N-CDs/PANI. (c) UV-vis absorption spectra of PANI and N-CDs/PANI. (d–f) SEM images of pure PANI at different magnifications: (d) 5  $\mu\text{m}$ , (e) 2  $\mu\text{m}$ , (f) 5  $\mu\text{m}$ . (g–j) SEM images of N-CDs/PANI composite at different magnifications: (g) 10  $\mu\text{m}$ , (h) 1  $\mu\text{m}$ , (i) 4  $\mu\text{m}$ , (j) 5  $\mu\text{m}$ .

#### IV. Electrochemical Performance

Based on the electrochemical characterization of pure PANI and N-CDs/PANI composites with varying concentrations of nitrogen-doped carbon dots (N-CDs), the following analysis can be derived from the cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS) data presented in Figures a, b, and c, respectively.

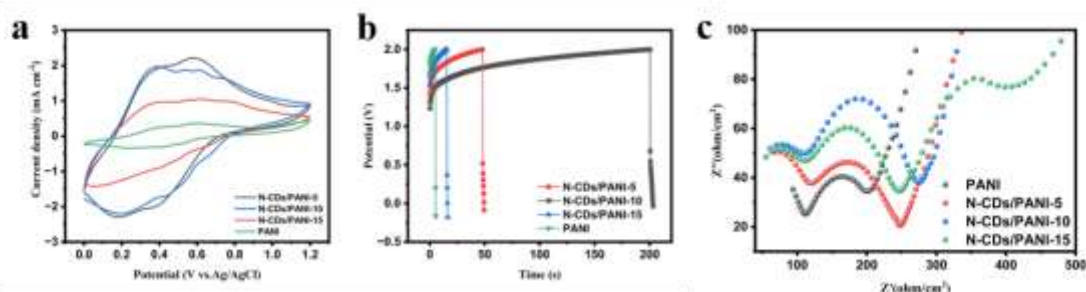
The cyclic voltammetry (CV) curves presented in Figure 3.a provide insight into the redox behavior and electrochemical reversibility of the fabricated electrodes<sup>17</sup>. Pure PANI exhibits characteristic redox peaks corresponding to its transition between different oxidation states (leucoemeraldine to emeraldine and emeraldine to pernigraniline). Upon the incorporation of N-CDs<sup>18</sup>, specifically for the N-CDs/PANI-5, N-CDs/PANI-10, and N-CDs/PANI-15 composites, a noticeable enhancement in the current response under the CV curve is observed. This increase in integrated area indicates a higher specific capacitance for the composite electrodes compared to pristine PANI. The improved performance can be attributed to the synergistic effect between the highly conductive N-CDs and the PANI matrix. The N-CDs facilitate more efficient charge transport and provide additional active sites for electrochemical reactions. Furthermore, the shapes of the CV curves for the composites retain the characteristic redox features of PANI, suggesting that the incorporation of N-CDs does not alter the fundamental Faradaic processes but rather enhances the overall electrochemical kinetics.

The galvanostatic charge-discharge (GCD) measurements, depicted in Figure 3.b, were employed to evaluate the rate capability and specific capacitance of the electrodes. The GCD profiles for all samples exhibit nonlinearity, confirming the pseudocapacitive nature dominated by Faradaic reactions, which aligns with the CV results. Notably, the N-CDs/PANI composites display prolonged discharge times compared to pure PANI at the same current density, directly correlating to an increase in specific capacitance. Among the composites, the N-CDs/PANI-10 electrode demonstrates the longest discharge duration, suggesting an optimal loading level of N-CDs. Beyond this threshold (e.g., N-CDs/PANI-15), a slight decrement in discharge time is observed, which may be due to the agglomeration of N-CDs at higher concentrations, potentially blocking some active sites or

hindering ion diffusion pathways. The symmetry of the charge-discharge curves also indicates good electrochemical reversibility and coulombic efficiency for the composite electrodes<sup>19</sup>.

Electrochemical impedance spectroscopy (EIS) analysis, as shown in Figure 3.c, was conducted to probe the internal resistance and charge transfer kinetics at the electrode/electrolyte interface<sup>20</sup>. The Nyquist plots typically consist of a semicircle in the high-frequency region, representing the charge transfer resistance (Rct), and a linear portion in the low-frequency region, indicative of the Warburg impedance related to ion diffusion. Pure PANI exhibits a relatively large semicircle diameter, signifying higher charge transfer resistance. In contrast, all N-CDs/PANI composites show a significant reduction in the semicircle diameter, with the N-CDs/PANI-10 sample exhibiting the smallest Rct value. This confirms that the introduction of N-CDs substantially enhances the electrical conductivity and accelerates the Faradaic reactions at the interface. Additionally, the steeper slope of the linear part in the low-frequency region for the composites, particularly N-CDs/PANI-10, indicates lower ion diffusion resistance and more ideal capacitive behavior. This improved conductivity and ion transport are crucial for achieving high-performance supercapacitor electrodes.

In summary, the electrochemical data collectively demonstrate that the integration of N-CDs into the PANI matrix significantly enhances the capacitive performance. The N-CDs act as conductive bridges, improving charge transfer and providing a larger electroactive surface area. The N-CDs/PANI-10 composite, in particular, emerges as the optimal formulation, striking a balance between enhanced conductivity and available pseudocapacitive sites, thereby delivering superior electrochemical properties compared to pure PANI and other composite ratios.



**Fig. 3** (a) Cyclic voltammetry (CV) curves of pure PANI, N-CDs/PANI-5, N-CDs/PANI-10, and N-CDs/PANI-15 electrodes at a scan rate of 50 mV/s. (b) Galvanostatic charge-discharge (GCD) profiles of the same electrodes at a current density of 1 A/g. (c) Nyquist plots of electrochemical impedance spectroscopy (EIS) for the pure PANI and N-CDs/PANI composite electrodes measured in the frequency range of 100 kHz to 0.01 Hz.

## V. Conclusion

In this study, a series of nitrogen-doped carbon dots/polyaniline (N-CDs/PANI) composites with varying N-CD loadings were successfully synthesized via an in situ chemical oxidative polymerization method, using ammonium persulfate (APS) as an oxidant in an acidic medium. The incorporation of N-CDs into the PANI matrix was designed to leverage the exceptional electrical conductivity and abundant surface functional groups of the carbon dots to enhance the pseudocapacitive performance of the conducting polymer.

The structural and morphological characteristics of the as-prepared composites were systematically investigated using a range of analytical techniques, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD). The characterization results revealed that the introduction of N-CDs significantly influenced the polymerization and growth of PANI. Specifically, the N-CDs acted as nucleation sites, promoting the formation of a more uniform and porous PANI structure. This improved morphology effectively mitigated the common issue of PANI agglomeration, thereby increasing the electrochemically active surface area available for charge storage. Furthermore, the strong  $\pi$ - $\pi$  interactions between the conjugated backbone of PANI and the graphitic structure of the N-CDs facilitated the construction of an efficient three-dimensional conductive network. This interconnected network provided express pathways for electron transport and significantly shortened the ion diffusion distance within the electrode material, leading to enhanced electrochemical kinetics.

The electrochemical performance of the pure PANI and N-CDs/PANI composite electrodes was rigorously evaluated through cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS). The results demonstrated a marked improvement in capacitive behavior upon N-CD incorporation, which was highly dependent on the doping amount. Notably, the N-CDs/PANI composite with a 10 wt% doping level (N-CDs/PANI-10) exhibited the most outstanding electrochemical properties. It achieved a maximum specific capacitance of 541.7 F/g at a current density of 1 A/g, representing a substantial 62.3% increase compared to that of pure PANI (approximately 333.8 F/g). This

enhancement is attributed to the synergistic effect where the N-CDs not only improved the conductivity but also contributed additional pseudocapacitance through their surface nitrogen functionalities.

In addition to high specific capacitance, the composite electrode demonstrated excellent rate capability and long-term cycling stability. Even after 5000 consecutive charge-discharge cycles at a high current density, the N-CDs/PANI-10 electrode retained 86.9% of its initial capacitance. This superior cyclic stability is primarily due to the structural reinforcement provided by the N-CDs, which buffer the mechanical stresses caused by volumetric swelling and shrinkage of PANI during repeated ion insertion/de-insertion processes, thereby preventing structural degradation and capacity fading.

In summary, this study not only confirms the successful fabrication of high-performance N-CDs/PANI composites but also elucidates the critical role of N-CDs in modulating the microstructure and enhancing the charge storage mechanisms of PANI. The findings provide a new and effective strategy for the rational design and development of advanced electrode materials for high-performance energy storage systems. The outstanding electrochemical performance suggests that N-CDs/PANI composites hold broad application prospects in the field of supercapacitors. Furthermore, this work offers a valuable reference for the modification of other conductive polymers—such as PEDOT, PPy, and their derivatives—aiming to overcome their inherent limitations and unlock their full potential for next-generation energy storage applications.

### References

- [1]. Sun, J.; Chen, Z.; Zhang, R.; Yin, M.; Zhu, Y.; Hu, J.; Zhou, Q.; Shao, P.; Huang, Q.; Ma, D.; Wen, R.-T.; Wang, J. Electrochromic Smart Windows with Co-Intercalation of Cations and Anions for Multi-Band Regulations. *Nat. Commun.*2025, 16 (1), 6993.
- [2]. Wang, H.; Lin, J.; Shen, Z. X. Polyaniline (PANI) Based Electrode Materials for Energy Storage and Conversion. *J. Sci.: Adv. Mater. Devices*2016, 1 (3), 225-255.
- [3]. Kazemi, F.; Naghib, S. M.; Zare, Y.; Rhee, K. Y. Biosensing Applications of Polyaniline (PANI)-Based Nanocomposites: A Review. *Polym. Rev.*2021, 61 (3), 553-597.
- [4]. Yao, Q.; Wang, Q.; Wang, L.; Chen, L. Abnormally Enhanced Thermoelectric Transport Properties of SWNT/PANI Hybrid Films by the Strengthened PANI Molecular Ordering. *Energy Environ. Sci.*2014, 7 (11), 3801-3807.
- [5]. Mota, M. L.; Carrillo, A.; Verdugo, A. J.; Olivas, A.; Guerrero, J. M.; De la Cruz, E. C.; Noriega Ramírez, N. Synthesis and Novel Purification Process of PANI and PANI/AgNPs Composite. *Molecules*2019, 24 (8), 1621.
- [6]. Bedre, M. D.; Basavaraja, S.; Salwe, B. D.; Shivakumar, V.; Arunkumar, L.; Venkataraman, A. Preparation and Characterization of Pani and Pani-Ag Nanocomposites via Interfacial Polymerization. *Polym. Compos.*2009, 30 (11), 1668-1677.
- [7]. Zhang, L.; Liu, P.; Su, Z. Preparation of PANI-TiO<sub>2</sub> Nanocomposites and Their Solid-Phase Photocatalytic Degradation. *Polym. Degrad. Stab.*2006, 91 (9), 2213-2219.
- [8]. Jose, J.; Salam, J. A.; Jayakrishnan, R.; Thomas, V. Polyaniline/cellulose nanocrystals/carbon dot composite for supercapacitor application. *J. Polym. Sci.*202563(8), 1796-1807.
- [9]. Bai, J.; Collin-Dufresne, P. The CDS-bond Basis. *Financ. Manage.*2019, 48 (2), 417-439.
- [10]. Berndt, A.; Obreja, I. Decomposing European CDS Returns. *Rev. Financ.*2010, 14 (2), 189-233.
- [11]. Liu, H.; Zhong, X.; Pan, Q.; Zhang, Y.; Deng, W.; Zou, G.; Hou, H.; Ji, X.. A review of carbon dots in synthesis strategy. *Coord. Chem. Rev.*2024, 498, 215468.
- [12]. Liu, J.; Bi, H.; Cesar Morais, P.; Zhang, X.; Zhang, F.; Hu, L. Room-Temperature Magnetism in Carbon Dots and Enhanced Ferromagnetism in Carbon Dots-Polyaniline Nanocomposite. *Sci. Rep.*2017, 7 (1), 2165.
- [13]. Lakshmi, K.; John, H.; Mathew, K. T.; Joseph, R.; George, K. E. Microwave Absorption, Reflection and EMI Shielding of PU-PANI Composite. *Acta Mater.*2009, 57 (2), 371-375.
- [14]. Ghosh, T.; Ghosh, R.; Basak, U.; Majumdar, S.; Ball, R.; Mandal, D.; Nandi, A. K.; Chatterjee, D. P. Candle Soot Derived Carbon Nanodot/Polyaniline Hybrid Materials through Controlled Grafting of Polyaniline Chains for Supercapacitors. *J. Mater. Chem. A Mater.*2018, 6 (15), 6476-6492.
- [15]. Qin, T.; Deng, L.; Zhang, N.; Zhang, P.; Liu, Y.; Qin, L.; Huang, S.; Qiu, L.; Peng, S. Flexible Polyaniline/Carbon Quantum Dots Films for Enhanced Electrochromic Performance. *Ceram. Int.*2024, 50 (24), 53254-53263.
- [16]. Qin, T.; Gao, X.; Zhang, P.; Qin, L.; Li, C.; Xie, H.; Huang, S.; Liao, C.; Deng, L. Implementation of High-Performance Flexible Electrochromic Device Based on Polyaniline/ Carbon Quantum Dots. *Org. Electron.*2023, 113.
- [17]. Zhao, Z.; Xie, Y. Enhanced Electrochemical Performance of Carbon Quantum Dots-Polyaniline Hybrid. *J. Power Sources*2017, 337, 54-64.
- [18]. Ru, Y.; Waterhouse, G. I. N.; Lu, S. Aggregation in Carbon Dots: Special Issue: Emerging Investigators. *Aggregate.*2022, 3(6), e296.
- [19]. Liu, J.; Rehman, S. ur; Wang, J.; Fang, Z.; Zhang, X.; Bi, H. Magnetic-Field Assisted Synthesis of Carbon Dots-Doped Polyaniline Nanotubes with a High-Performance Supercapacitance. *Synth. Met.*2018, 246, 23-30.
- [20]. Coğalrı, F. T.; Demirelli, K.; Barım, E.; Ük, N.; Ünlü, C.; Şenkal, B. F.; Dere, A.; Tuncer, H.; Yakuphanođlu, F. Preparation of Carbon Dot/Polyaniline Composites as Voltage Based Dielectric Material for Capacitor Applications. *Surf. Interfaces*2024, 55.