Transforming Invasive Weeds into Energy Solutions: Water Hyacinth-Based Hybrid Electrodes for Green Supercapacitors

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The synthesis process is illustrated in Figure 1.

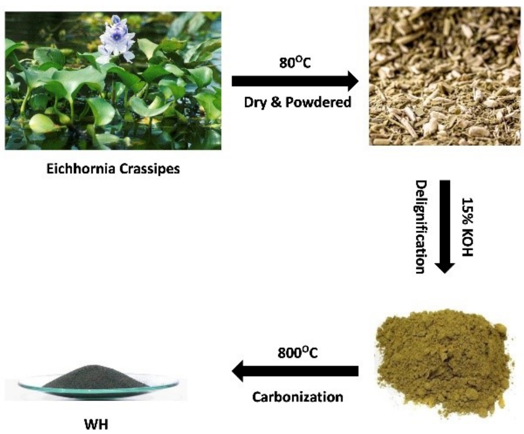

Figure 1. Schematic illustration of the preparation process of WH

Raman Analysis

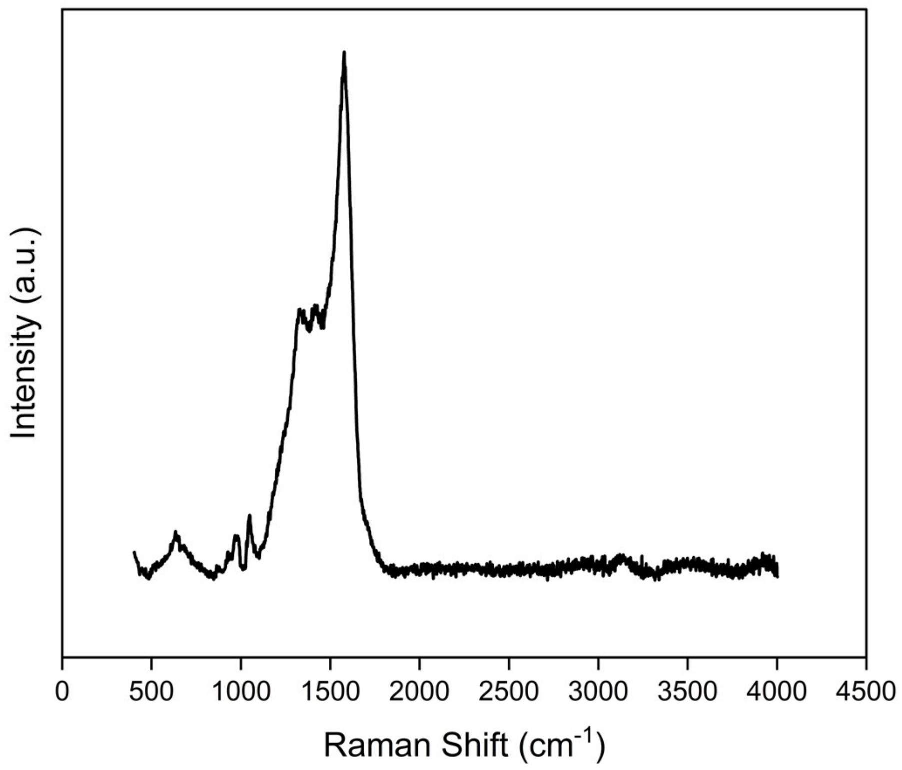

Figure 2. Raman Analysis

Raman spectroscopy was conducted to evaluate the structural characteristics and degree of graphitization of the carbon content in the WH-TiO_2/PPy composite. As shown in Figure 2, the spectrum displays two prominent peaks located at approximately 1350 cm^{-1} and 1580 cm^{-1}, corresponding to the D band and G band, respectively.The D band is associated with structural defects and disordered carbon, while the G band arises from the in-plane stretching vibration of sp^2-hybridized carbon atoms in graphitic domains. The presence of both bands confirms that the carbon structure consists of partially disordered graphitic carbon.

The intensity ratio of the D to G bands (I_D/I_G) provides insight into the degree of graphitization. In this case, the pronounced G band and the noticeable D band indicate a moderate degree of graphitization, suggesting the coexistence of both ordered and disordered carbon regions. This is consistent with the XPS analysis, where a peak at 284.23 eV in the C 1s spectrum further confirmed the presence of sp^2 graphitic carbon.

Overall, the Raman results validate the partial graphitic nature of the carbon derived from water hyacinth, which is beneficial for enhancing electrical conductivity and charge transport in the composite electrode.

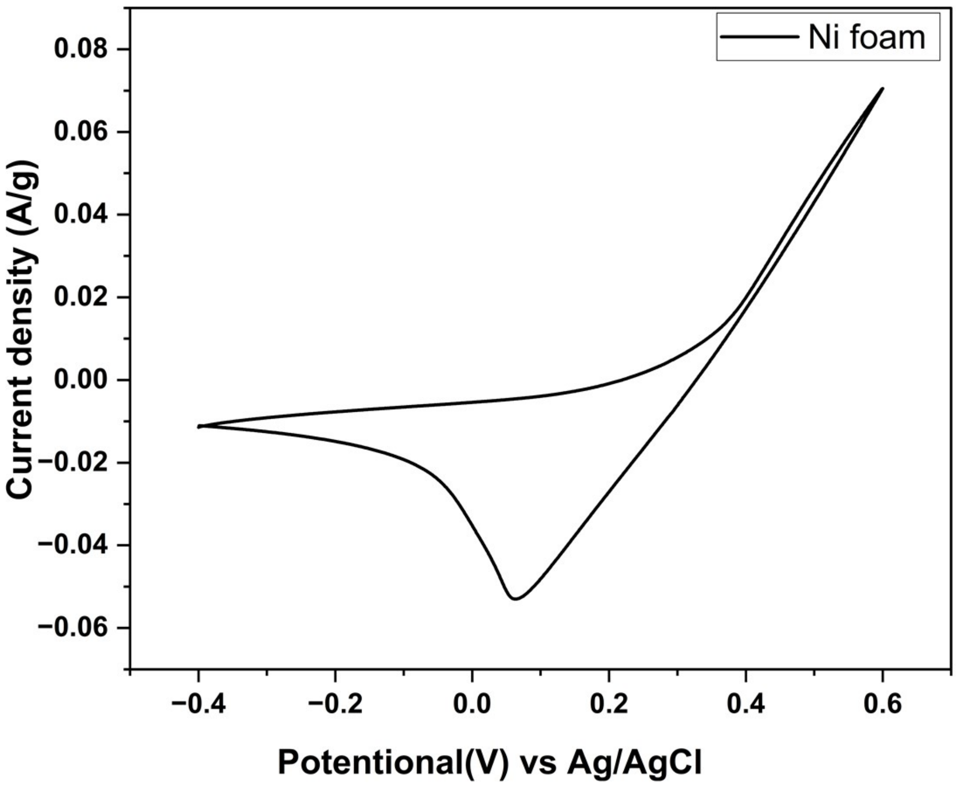

Figure 3 CV analysis was conducted on bare Ni foam

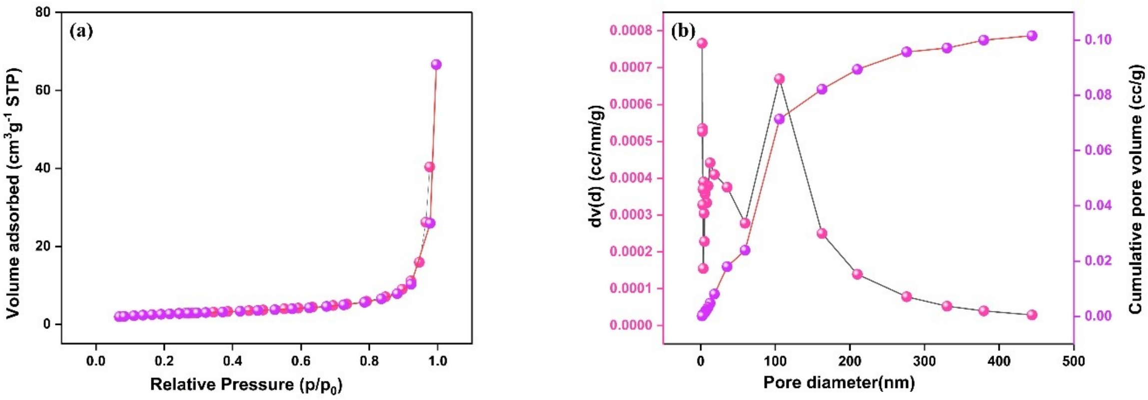

Figure 4 BET analysis was conducted on WH-TiO2/PPy

The isotherm of adsorption-desorption promotes (Figure 3a), such behavior is typical for a Type IV isotherm type, thus demonstrating the presence of mesopores in the material. The increase in adsorption with increasing relative pressure offers (P/P_0 values > 0.8) indicates capillary condensation, thus confirming the mesoporous nature. This phenomenon is usually seen in materials with highly porous architecture where larger pores are filled as higher relative pressure is attained.

Availability in this case is suggested by the pore size distribution plot (Figure 3b), which indicates that most of the pores are situated in the mesopore range (2–50 nm). The plot indicates a higher than average occurrence of pore size distribution in close proximity to 100 nm which is a meso-porous behavior. The summation of pore volume obtained is about 0.1 cm^3/g, it outlines quite a good volume of pore structures that helps in enhancing ion movement during electrochemical activities, hence can be used in supercapacitors.

By the means of the balance of mesopores and moderate micropores, the material provides both the high surface area for ions adsorbed and effectively ionic diffusion which in turns makes the material a potential one for energy sources. The uniform size of the pores also indicates that the material is tile stable since there will be no excessive agglomeration or blockage of pore structures that advance long-term cycling stability

Figure 5. The schematic representation of the symmetric supercapacitor device

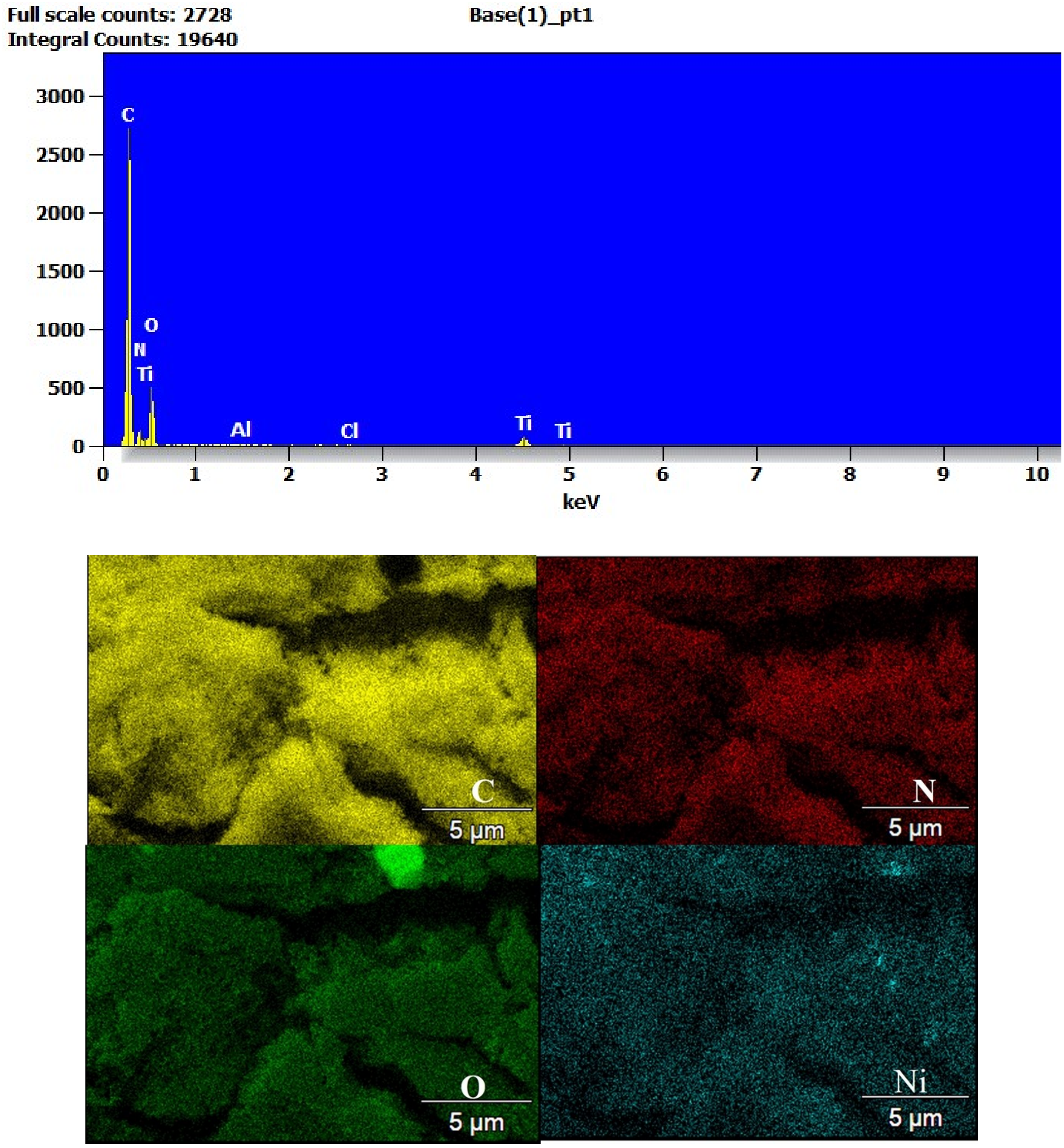

Figure 6. SEM-EDS of WPT

The elemental mapping images of the sample (C, N, O, Ni) display a uniform distribution of carbon, nitrogen, oxygen, and nickel across the surface, confirming the successful incorporation of these elements in the composite material. The presence of oxygen and nickel suggests that the sample contains oxides or nickel-based compounds, which are essential for electrochemical performance. Nitrogen indicates the possible incorporation of nitrogen-doped carbon, enhancing the conductivity and overall performance.

The EDS spectrum further confirms the elemental composition, showing significant peaks for carbon (C), oxygen (O), and nitrogen (N), with trace amounts of titanium (Ti), aluminum (Al), and chlorine (Cl). The strong carbon peak indicates the carbon-rich nature of the material, while the presence of nitrogen and oxygen corroborates the formation of functional groups that improve the electrochemical properties. The titanium peaks suggest the presence of TiO_2, which is commonly used for its beneficial role in supercapacitors and electrode materials.

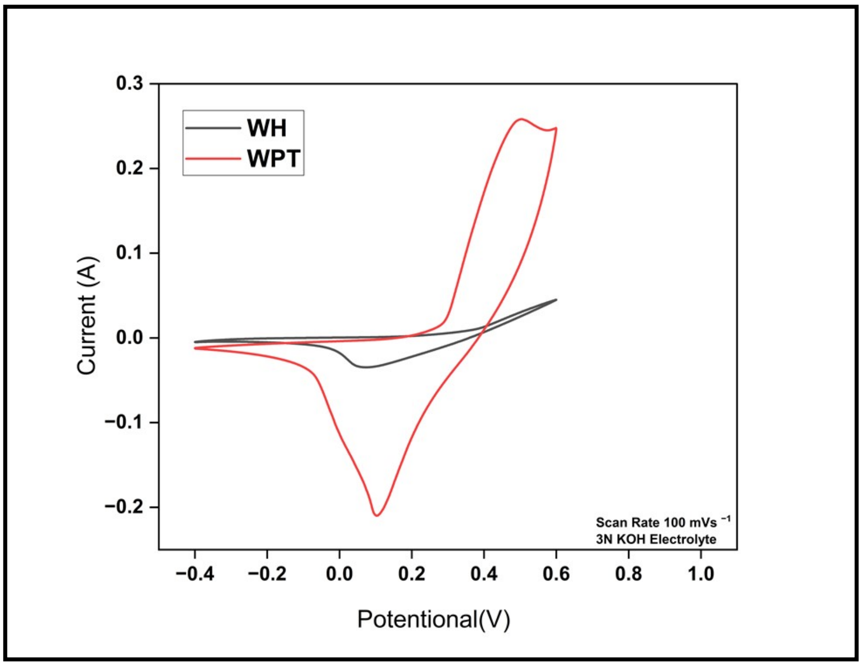

Figure 7 Comparison of Water hyacinth/Polypyrrole/TiO2 with Water hyacinth

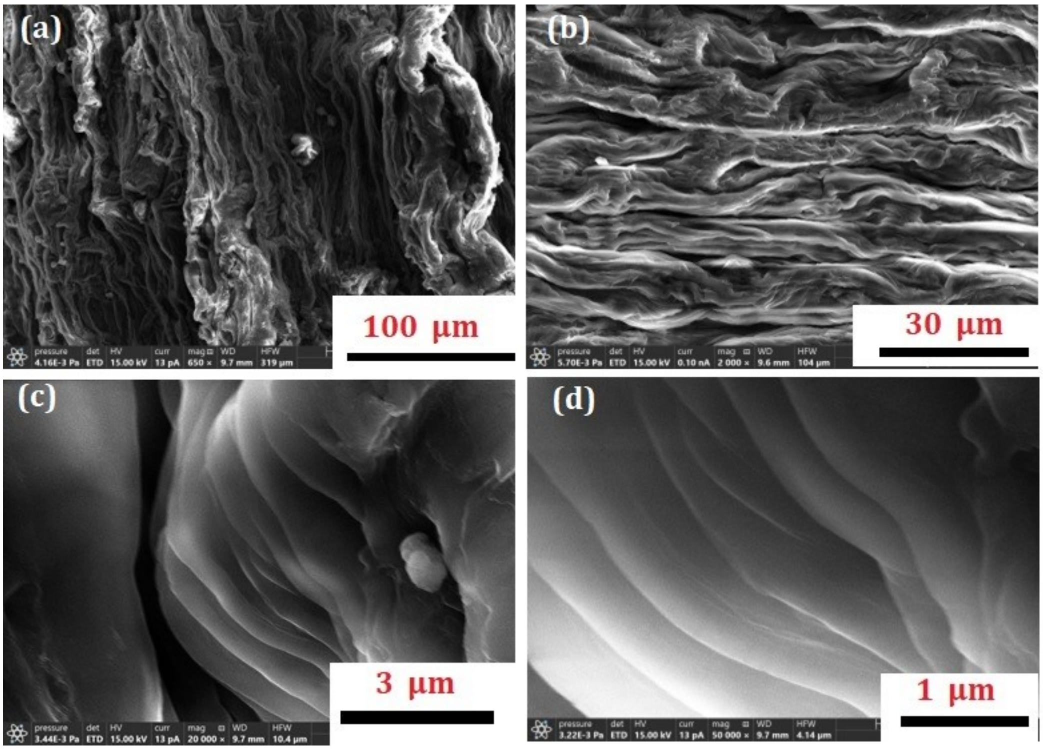

Figure 8 WH SEM images