

Heteroatom-doped biochar-derived carbon nanomaterials as metal-free electrocatalyst for efficient water splitting reaction

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Introduction

- Electrochemical water splitting is limited by expensive noble-metal catalysts.
- Biomass-derived heteroatom-doped porous carbon offers a sustainable alternative.
- N, S, and P doping enhances defects, conductivity, and catalytic activity.
- Developed biochar-derived metal-free electrocatalysts for efficient HER and OER.

Synthesis

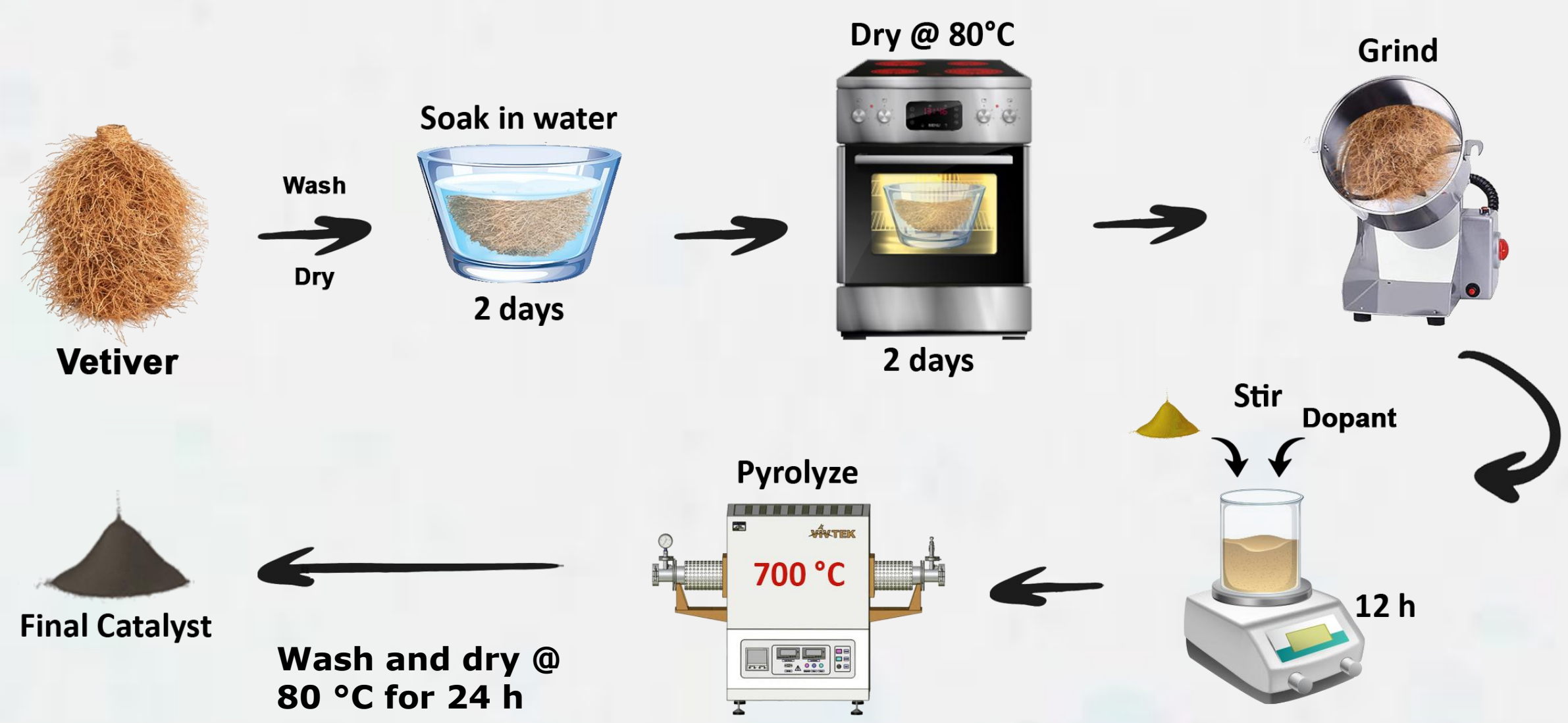


Figure 1. Schematic illustration of the catalyst synthesis strategy.

Structural & Morphological Studies

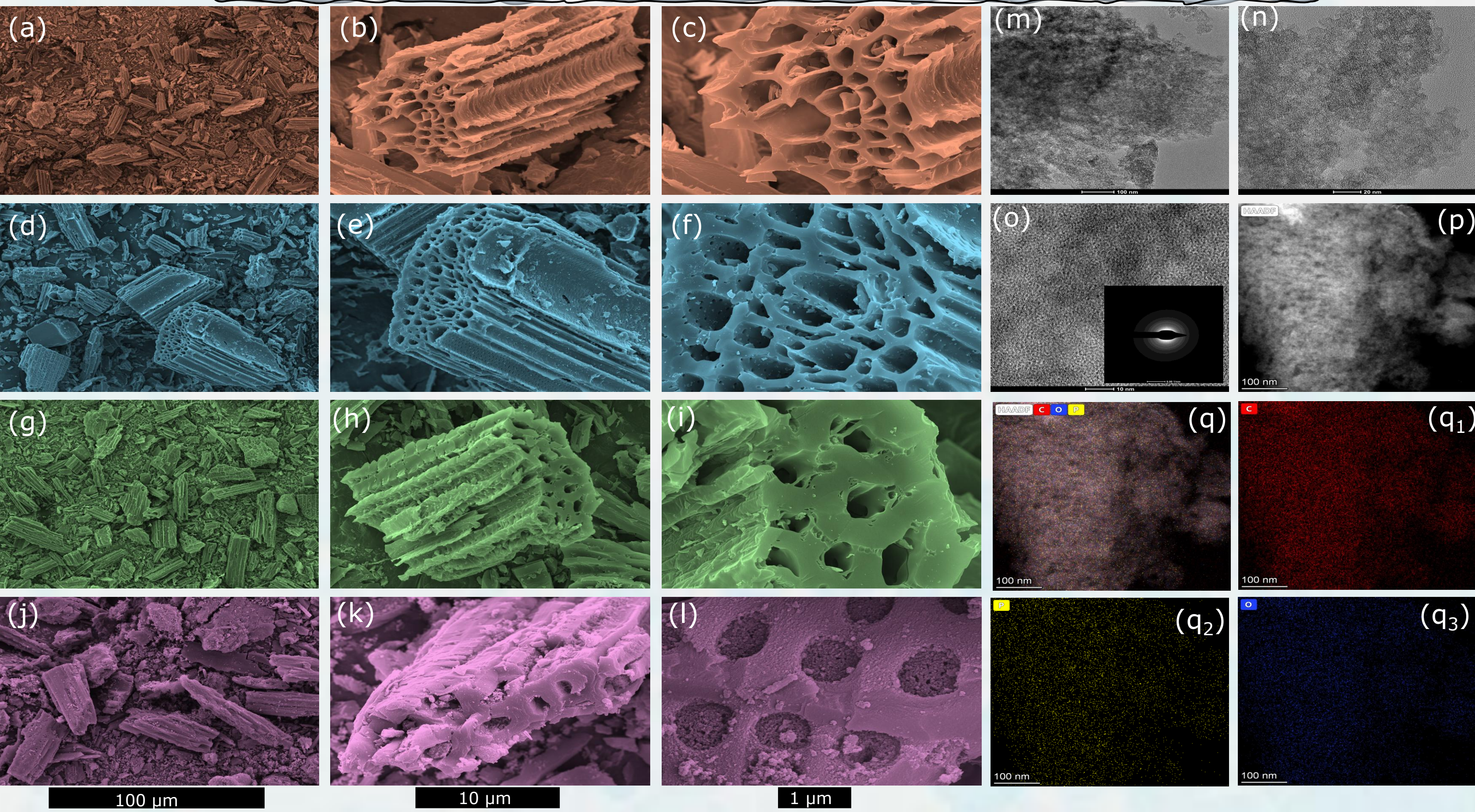


Figure 2. Morphological and structural characterization of BC, N-BC, S-BC, and P-BC: SEM images of (a-c) BC, (d-f) N-BC, (g-i) S-BC, and (j-l) P-BC at different magnifications; (m-o) TEM/HRTEM images and SAED pattern of P-BC; (p) HAADF-STEM image; and elemental mapping of (q) C, (q₁) C, (q₂) P, and (q₃) O for P-BC.

Physical Characterization

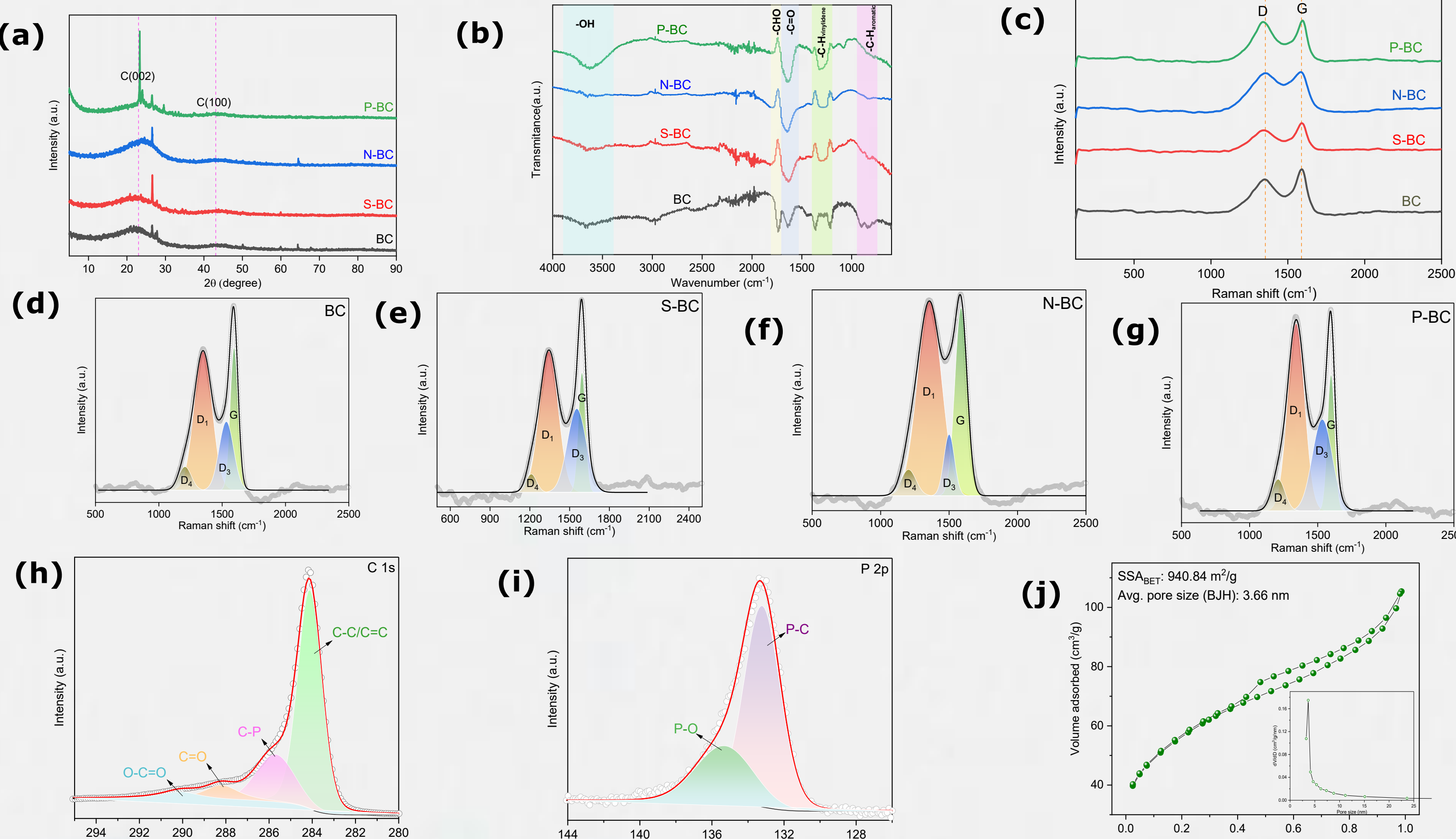


Figure 3. Structural and surface characterization of BC, S-BC, N-BC, and P-BC: (a) XRD patterns, (b) FTIR spectra, (c-g) Raman and deconvoluted Raman spectra, (h-i) XPS spectra, and (j) BET N₂ adsorption-desorption isotherm with pore size distribution of P-BC.

Oxygen Evolution Reaction

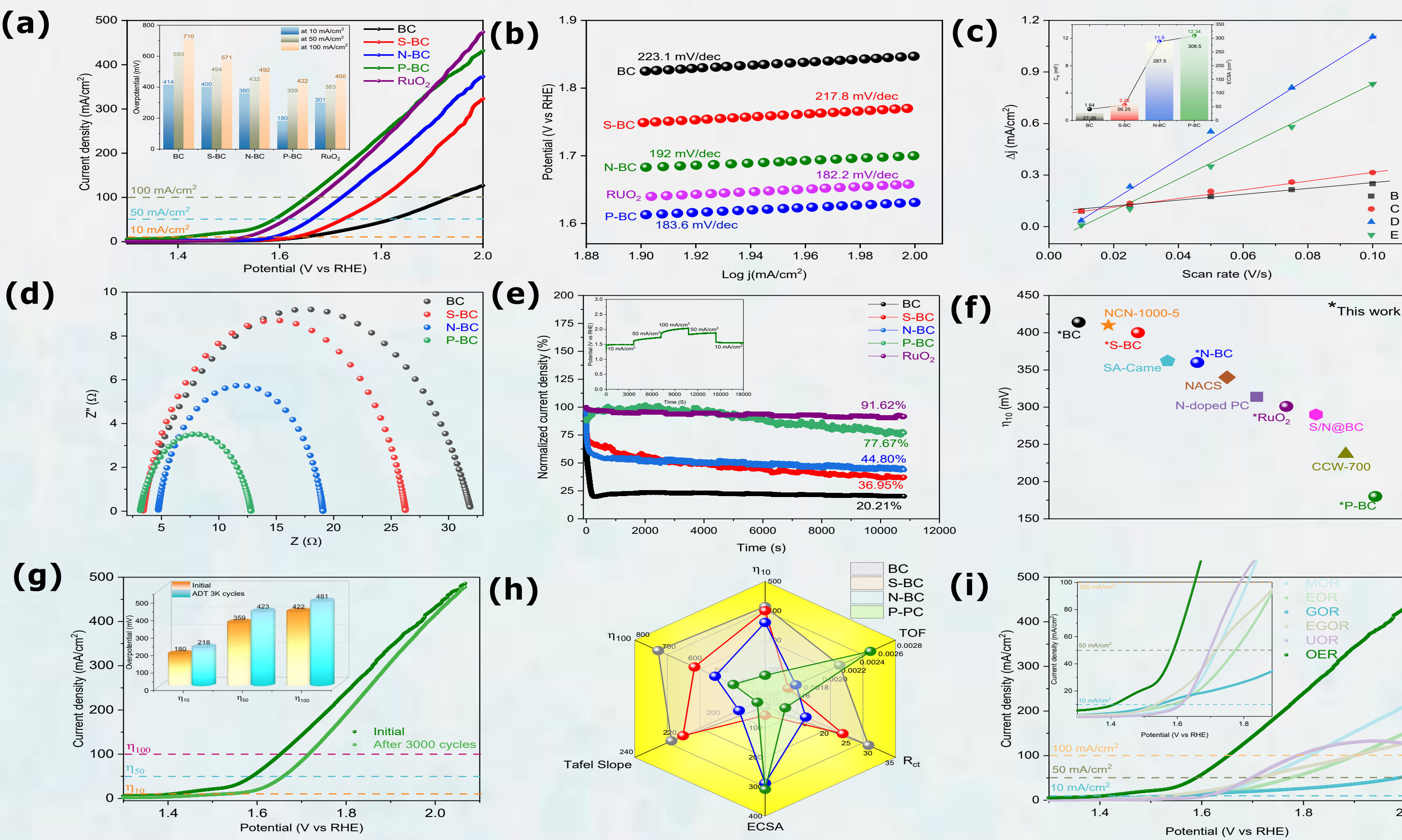


Figure 4. OER electrocatalytic performance of BC, S-BC, N-BC, P-BC, and RuO₂: (a) LSV curves, (b) Tafel plots, (c) ECSA analysis, (d) EIS spectra, (e) chronoamperometric stability, (f) literature comparison, (g) cycling stability, (h) radar plot comparison, and (i) alternative oxidation reactions.

Hydrogen Evolution Reaction

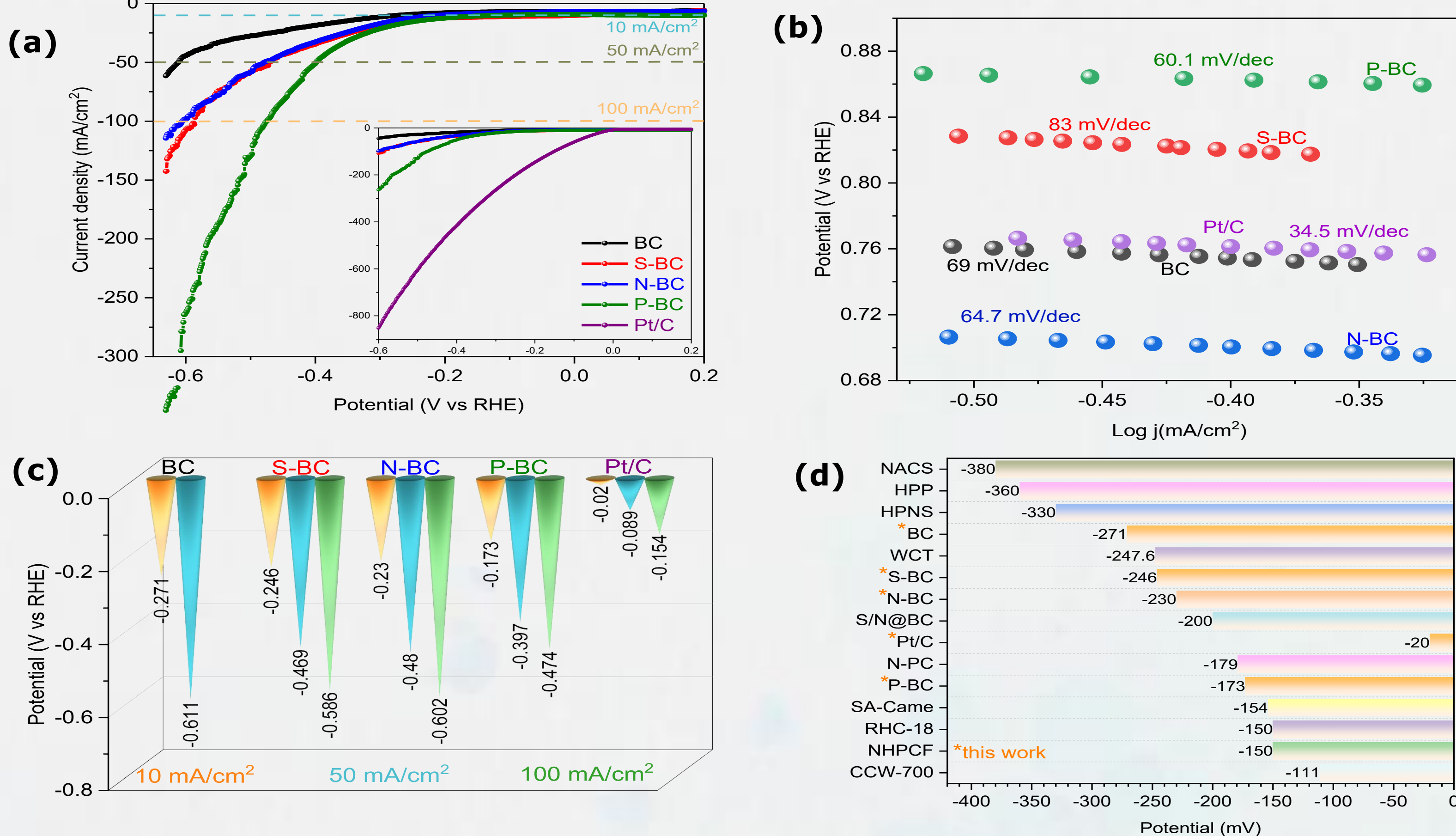


Figure 5. HER electrocatalytic performance of S-BC, N-BC, P-BC, and Pt/C: (a) LSV curves, (b) Tafel plots, (c) overpotential comparison at different current densities, and (d) comparison with reported catalysts.

Conclusion

- Heteroatom doping (N, S, P) improved porosity, defect density, and conductivity of biochar.
- Structural analyses confirmed the formation of a defect-rich partially graphitized carbon framework.
- P-BC showed the best HER performance due to synergistic effects of defects, heteroatom doping, and efficient electron transport.
- Doped catalysts exhibited enhanced electrochemical activity, faster charge transfer, and improved reaction kinetics.

Acknowledgement

This work was supported by SRM University-AP under grants, SRMAP/URG/SEED/2024-2025/022, SRMAP/URG/SEED/2025-26/072 and SRMAP/UG-PG/SEED/2025-26/006.

References

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