Supporting Information

Silver Citrate Engineered $NiCo_2S_4$/MOF-Derived Oxide@Carbon Frameworks for High-Energy Hybrid Supercapacitors

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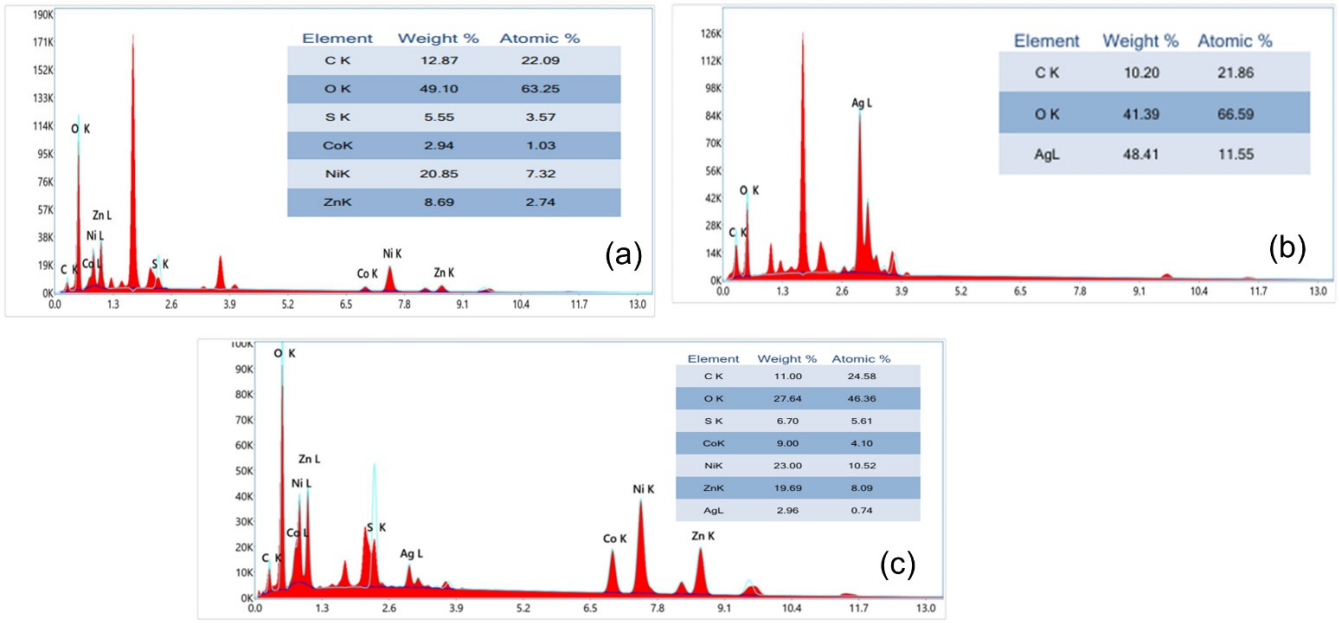

Figure S1: EDX spectra of sample (a) A1 (b) A2 and (c) A5 confirming the presence of constituent elements.

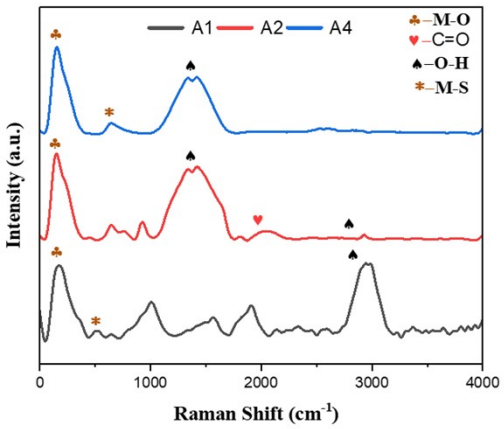

Figure S2: Raman spectra of A1 (calcined MOF–derived mixed metal oxides coupled with $NiCo_2S_4$), A2 (silver-citrate), and A3 (A1-A2 composite), highlighting metal-oxygen/metal-sulfur bonds vibrations in the low-wavenumber region and organic functional group bands at higher Raman shifts, confirming successful composite formation.

Raman spectroscopy using Model: BWS415-532S with Cu Ka radiation 1.54 Å was employed to investigate the bonding nature and structural evolution of the samples. Figure 1 shows the A1 (pristine NiCoZn oxide/$NiCo_2S_4$) sample exhibits strong Raman bands in the 400-700 cm^{-1} region, corresponding to metal-oxygen (Ni-O, Co-O, and Zn-O) vibrations, along with additional features attributed to metal-sulfur bonds, confirming the formation of mixed metal oxides integrated with $NiCo_2S_4$. In contrast, A2 (silver-citrate) shows dominant Raman bands associated with C=O, O-H, and C-H vibrations, characteristic of citrate ligands. The A4 (60 wt.% $NiCo_2S_4$@calcined-MOFs / 40 wt.% Ag-citrate) sample displays combined Raman features of both A1 and A2, indicating successful integration of the oxide-sulfide framework with Ag citrate. This synergistic integration is expected to enhance charge transfer and electrochemical performance.