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Electronic Supporting Information

Effect of MXene on Co_3O_4-$LaVO_4$ Nanocomposites for Synergistic Charge Transport Enhancement and High-Performance VARTM Assisted Solid-State Supercapacitor Device using Woven Carbon Fibre

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Material Methods

Chemical used

The chemicals used in this study, including Lanthanum (III) nitrate hydrate, Ammonium metavanadate, Sodium hydroxide, Cobalt(ll) nitrate hexa-hydrate, Titanium aluminum carbide, Hydrofluoric acid (HF, 40 %), Hydrochloric acid (HCl 35 %–38 % AR grade) and Ethanol, Potassium hydroxide solution, and PVA (polyvinyl alcohol) were all purchased from Sigma-Aldrich and used as received without any further purification.

Detailed description of VARTM process

Woven carbon fibers (WCF) hydrothermally coated with the Co-LaVO-Mx3 nanocomposite were placed in the VARTM chamber, where polyester resin was used as the matrix, and PVA-Na_2SO_4 gel electrolyte served as the separator. A vacuum pump was used to reduce chamber pressure, facilitating uniform resin infusion. Vacuum levels were maintained between -80 to -95 kPa to ensure proper resin flow, eliminate voids, and achieve homogeneous resin distribution through the fiber preform. The polyester resin matrix, after adding the curing agent MEKP, was injected into the VARTM chamber at a controlled rate under vacuum conditions to achieve thorough saturation of the preform. The viscosity of the resin was maintained between 400 and 600 cP, ensuring optimal flow speed while preventing void formation. The PVA- Na_2SO_4 gel electrolyte, acting as the separator, was integrated within the composite structure, enhancing ionic transport while maintaining mechanical integrity. During the pre-filling phase, vacuum cycles were used to compact the fiber preform, increasing the fiber volume fraction. Multiple cycles were recommended to optimize compaction before resin infusion. The resin was injected into the mold at atmospheric pressure, while vacuum-assisted infusion ensured even distribution throughout the mold cavity. Careful monitoring of resin flow was essential to prevent race tracking, which could lead to incomplete preform saturation. A resin flow medium was used to guide the resin evenly, particularly for large structures. The chamber was sealed and maintained at room temperature for 72 hours, allowing for complete resin infusion and curing. This process ensures a well-integrated solid-state supercapacitor structure, where the polyester resin provides mechanical stability, while the PVA-Na_2SO_4 gel electrolyte enhances ion transport for electrochemical performance. Specific values for vacuum pressure, resin flow rate, and temperature control were carefully monitored to ensure reproducibility and reliability of the fabrication process.

Preparation of the gel electrolyte

The synthesis of the PVA-Na_2SO_4 gel electrolyte follows a simple procedure. First, 4 grams of PVA powder (molecular weight 89,000–98,000, obtained from Sigma Aldrich) are slowly mixed into 40 mL of deionized water in a beaker. The mixture is heated to 90 °C with continuous stirring until the PVA is completely dissolved, resulting in a clear, viscous solution. The solution is then allowed to cool to room temperature. Next, 6 g of Na_2SO_4 are measured and gradually added to the cooled PVA solution, while stirring vigorously to ensure thorough mixing. This process takes approximately 30 minutes to form a homogeneous gel. After achieving a homogeneous gel-like consistency, the PVA-Na_2SO_4 gel electrolyte was transferred into a mold and allowed to rest for dry under ambient conditions, to achieve the desired consistency and ensure proper adhesion to the substrate. Once prepared, the gel electrolyte is sandwiched between two electrodes to fabricate the device. The resulting PVA-Na_2SO_4 gel electrolyte exhibited excellent ionic conductivity and mechanical stability, making it suitable for use as an electrolyte and separator in supercapacitor devices. The gel was stored in an airtight container at room temperature to prevent contamination or evaporation.

S 1.2 Electrochemical Characterization

The complete preparation of working electrode is given as follows. LaVO, Co-LaVO, and Co-LaVO/Mx nanocomposites as catalytic component and Nafion solution as a binder and isopropanol as a solvent were mixed together. Subsequently, the obtained mixture was sonicated for 1 h. After then, with the help of drop cast method the slurry were coated on woven carbon fiber (WCF) (1 cm x 2 cm). The electrochemical studies were carried out using a CS350 corrtest electrochemical workstation. A three-electrode setup was used with LaVO, Co-LaVO, Co-LaVO/Mx1, Co-LaVO/Mx3, and Co-LaVO/Mx5 nanocomposites on WCF (1 cm x 2 cm) serve as the working electrode, Ag/AgCl acting as the reference electrode, and platinum wire serve as the counter electrode and 1M Na_2SO_4 as an electrolyte. All the electrochemical test were performed at room temperature [1] [2] [3]. Using data from cyclic voltammetry (CV) and galvanostatic charge/discharge curves, the following Equation S1 and S2 were used to determine the specific capacitance and Equation S3 and S4 for energy and power density of the electrode material [4] [5].

$$C_{sp} = \frac{\int I\, dv}{mv\Delta V} \qquad \text{(S1)}$$

$$C_{sp} = \frac{I\Delta t}{Ex\, m} \qquad \text{(S2)}$$

$$E = \frac{C_{sp} \times (\Delta V)^2 \times 1000}{2 \times 3600} \qquad \text{(S3)}$$

$$P = \frac{E \times 3600}{(\Delta t)} \qquad \text{(S4)}$$

Where C_{sp} signifies the specific capacitance, ΔV (voltage) is the restricted voltage window, I (A) represents the current acquired from the CV curve, Δt is the time duration of one complete cycle, ν is the time-rate of change of voltage or scan rate, and m is the mass of the sample deposited on the surface of electrode. E (Wh/kg) and P (W/kg) were the mass-based energy density, and the average power density respectively.

S 1.4 Characterization

The surface morphologies of samples were investigated by use of a Field emission scanning electron microscope (FE-SEM S-4800 Hitachi Ltd., Tokyo, Japan) with an accelerating voltage of 10 kV. XRD analysis of the NCs was carried out using a PAN alytical diffractometer with Ni-filtered CuKα radiation (λ = 1.5406 Å) at a scan rate of 10° min^{-1} and beam current and voltage of 30 mA and 50 kV, respectively. The high-resolution TEM (HRTEM) images were obtained using a microscope FEI Titan 80-300 TEM combined with energy dispersive spectrometry (EDS) and selected-area electron diffraction (SAED). All samples were sonicated using a C_2H_5OH solution and suspended on a copper grid (400-mesh, diameter: 3.5 mm). X-ray photoelectron spectra (XPS) was performed with a Thermo Scientific instrument with Mg Kα X-ray source at 1253.6 eV. Thermogravimetric analysis (TGA) was carried out on a Manufacturer (Model) TA Instruments (SDT Q600) with a heating rate of 10 °C/min and flowing N_2.

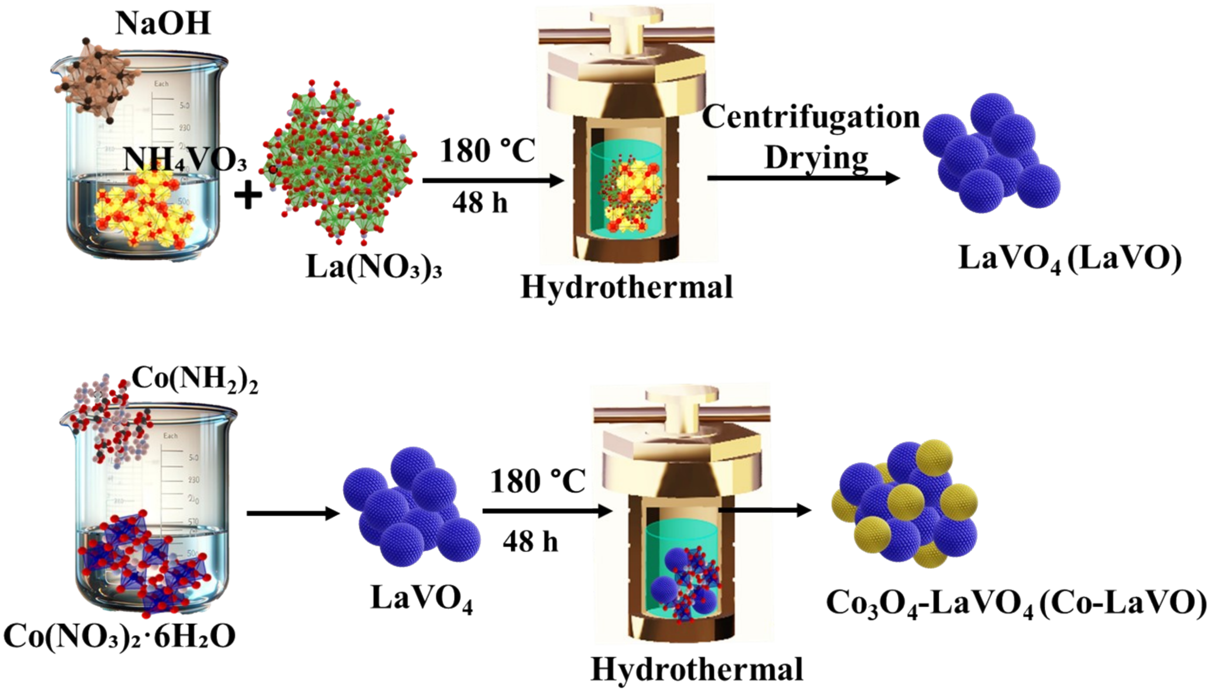

Figure S1. The schematic diagram for the synthesis of LaVO and Co-LaVO composite

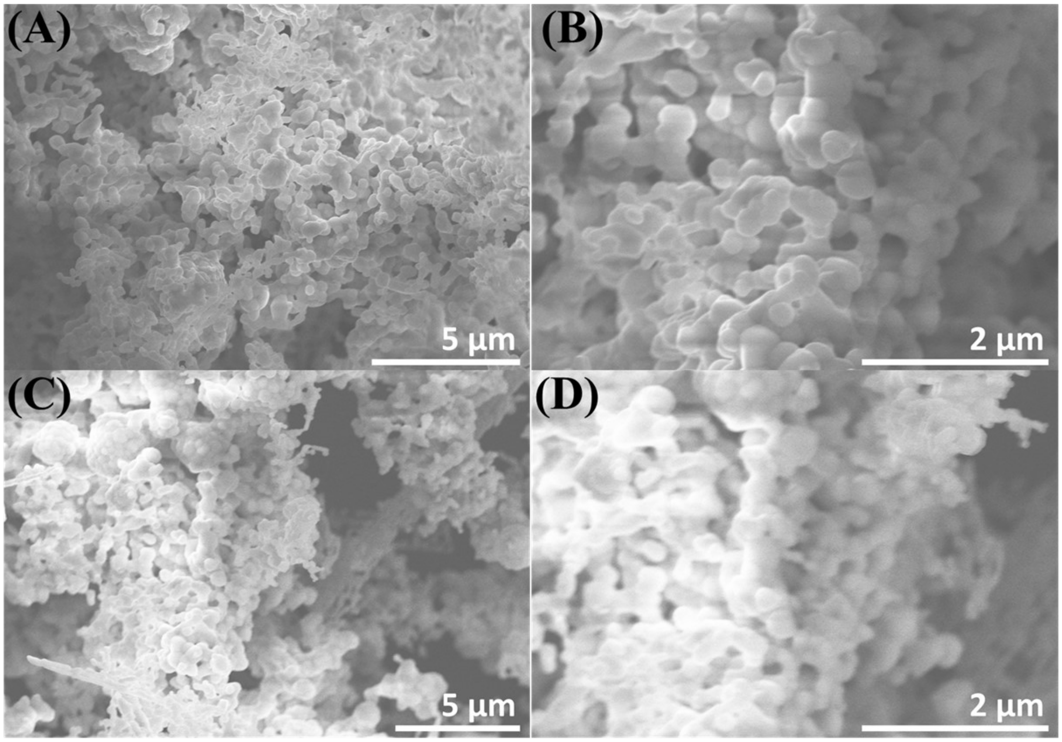

Figure S2. SEM of Co-LaVO (A) 5 µm, (B) 2 µm; SEM of Co-LaVO/Mx3 (C) 5 µm, (D) 2 µm.

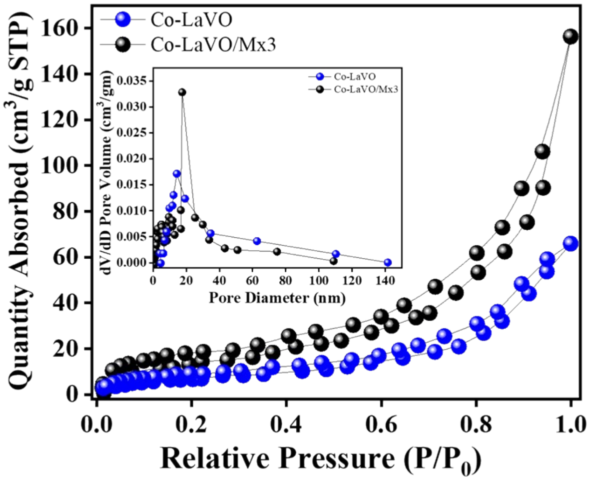

Figure S3. BET of Co-LaVO and Co-LaVO/Mx3

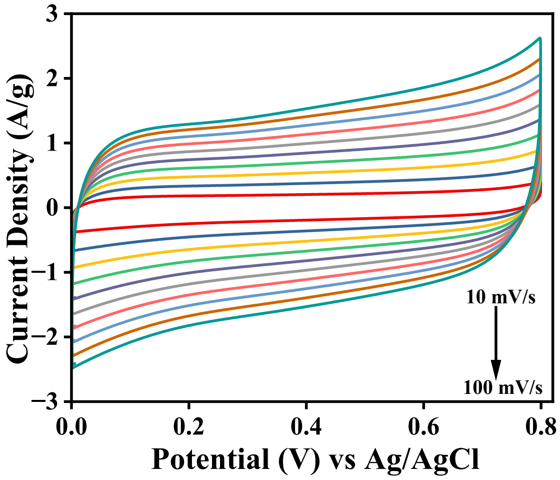

Figure S4. CV of WCFs at different scanning speeds (10 to 100 mV s^{-1}).

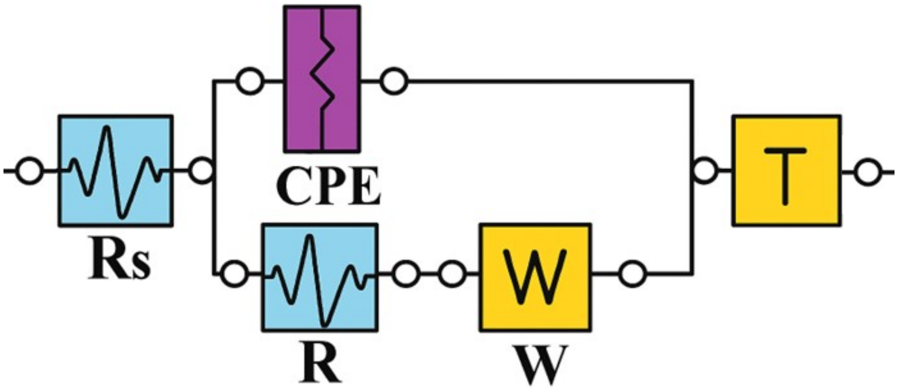

Figure S5. EIS fitted circuit for Co-LaVO/Mx3

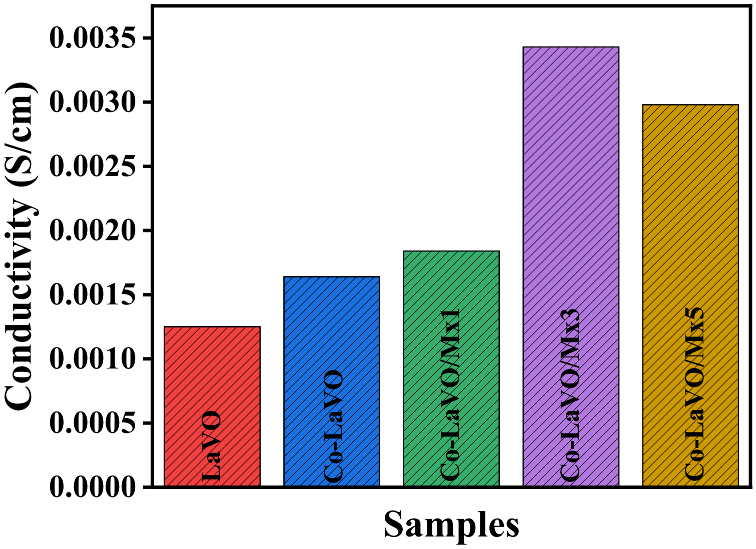

Figure S6. Electrical Conductivity of LaVO, Co-LaVO, Co-LaVO/Mx1, Co-LaVO/Mx3 and Co-LaVO/Mx5.

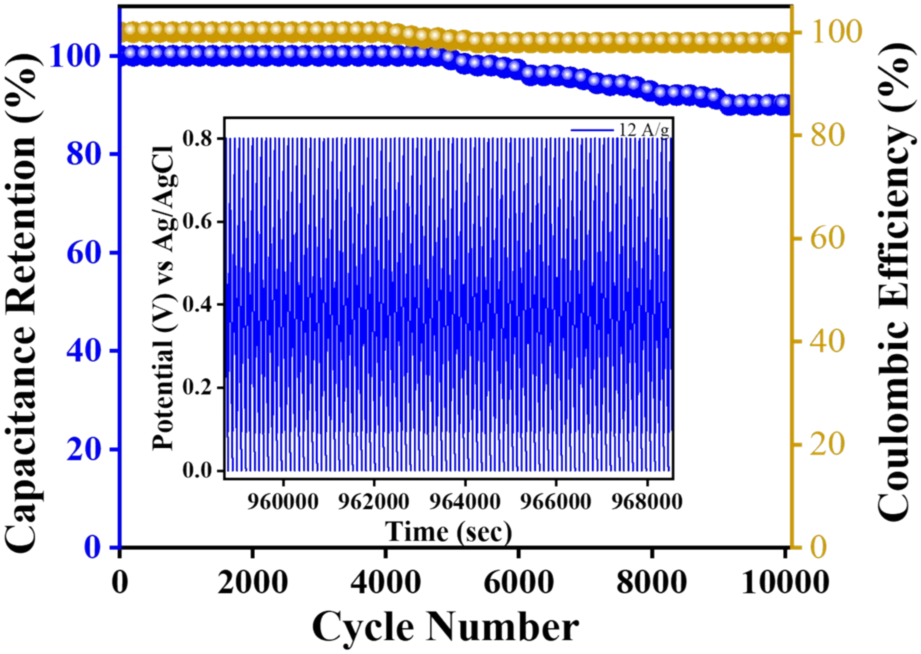

Figure S7. (A) Capacitive retention values and coulombic efficiency of Co-LaVO/Mx3 at 12 A/g for 10,000 cycles (inset shows the corresponding CD curves).

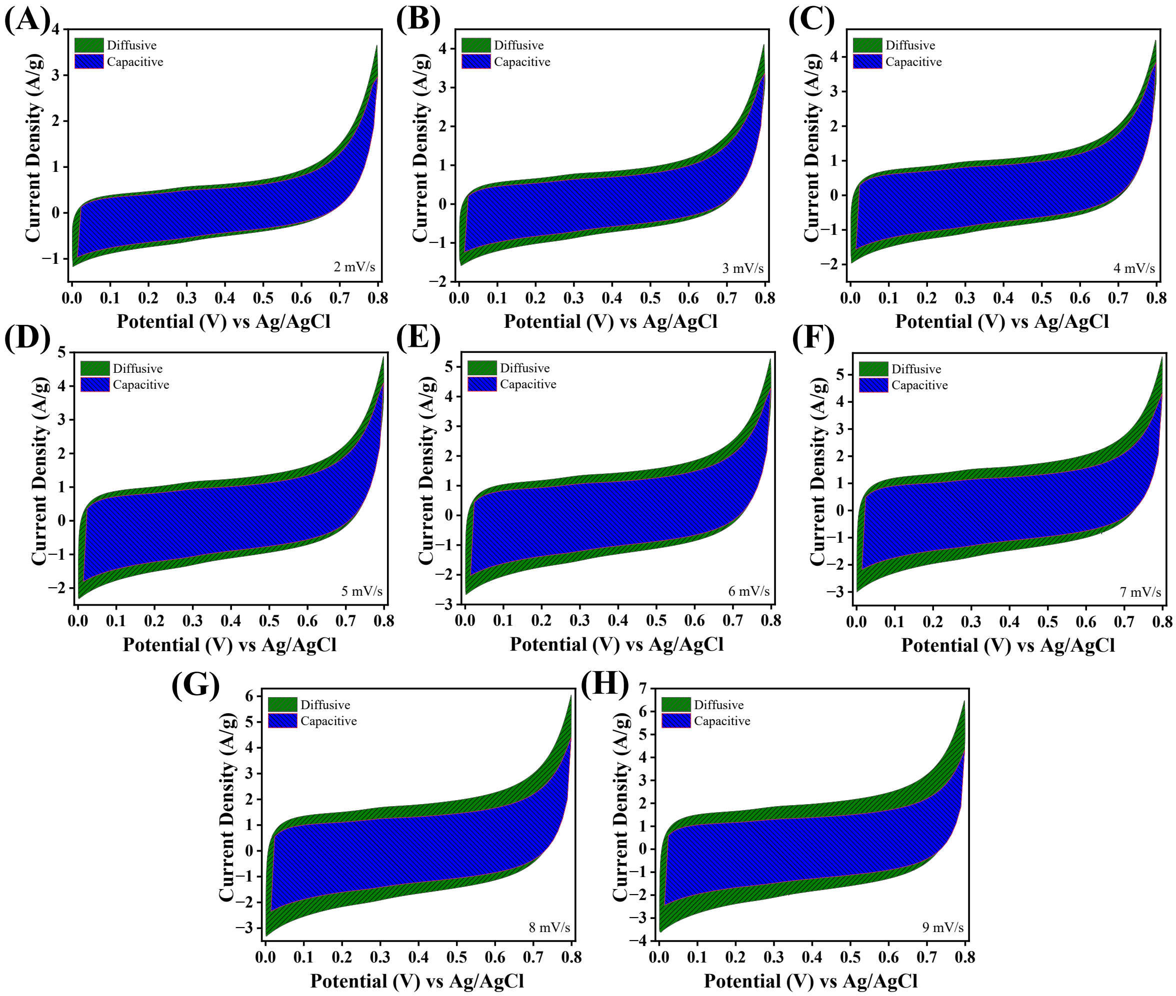

Figure S8. The separation of the capacitive as well as diffusion capacitance in the scan rate of 2 to 9 mV/sec

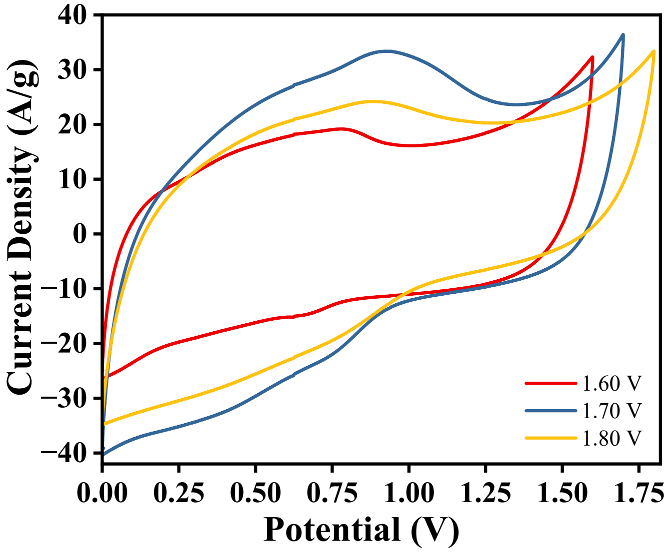

Figure S9. CV curves recorded at a scan rate of 100 mV s^{-1} over different potential windows ranging from 1.6 V to 1.8 V.

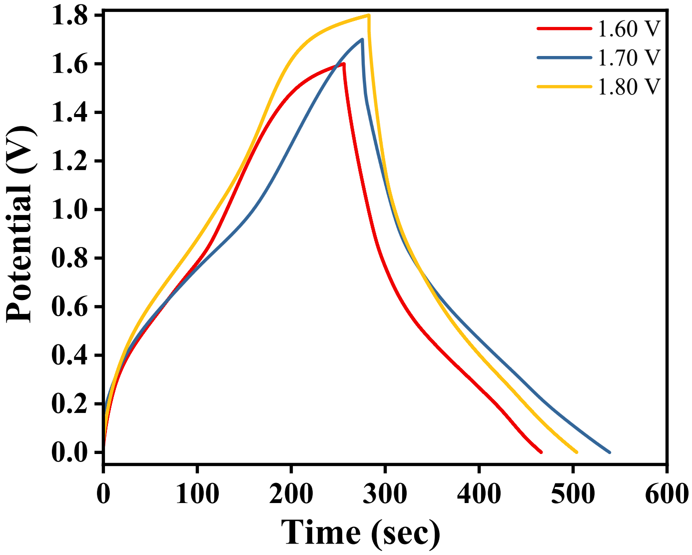

Figure S10. GCD profiles measured at a current density of 1 A g^{-1} across the voltage windows of 1.6 V to 1.8 V.

References

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