Supporting Information

Sb_2O_3/MXene($Ti_3C_2T_x$) hybrid anode materials with enhanced performance for sodium-ion batteries

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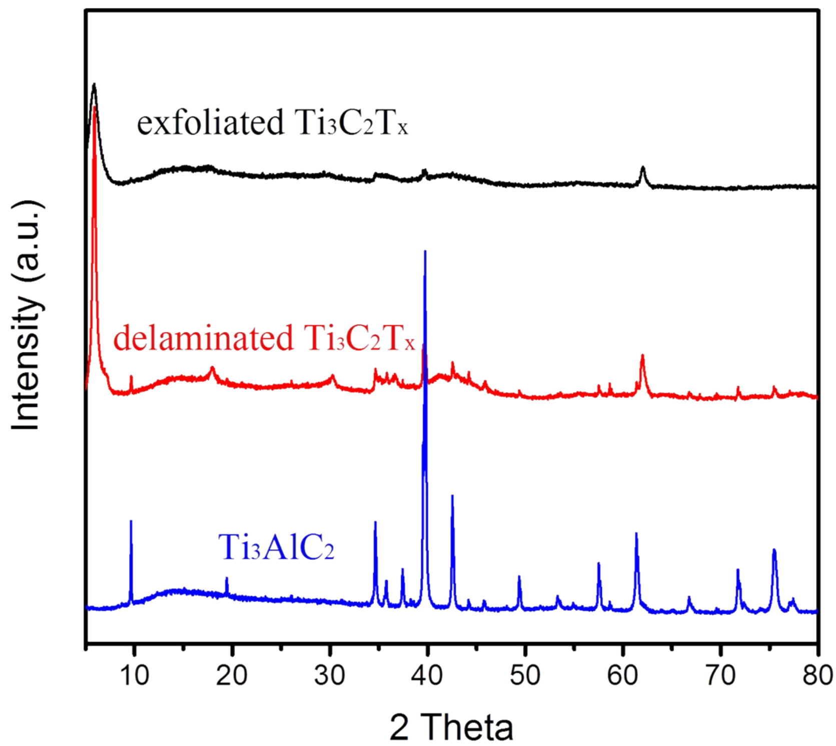

Figure S1 XRD patterns of Ti_3AlC_2, delaminated $Ti_3C_2T_x$ and exfoliated MXene $Ti_3C_2T_x$.

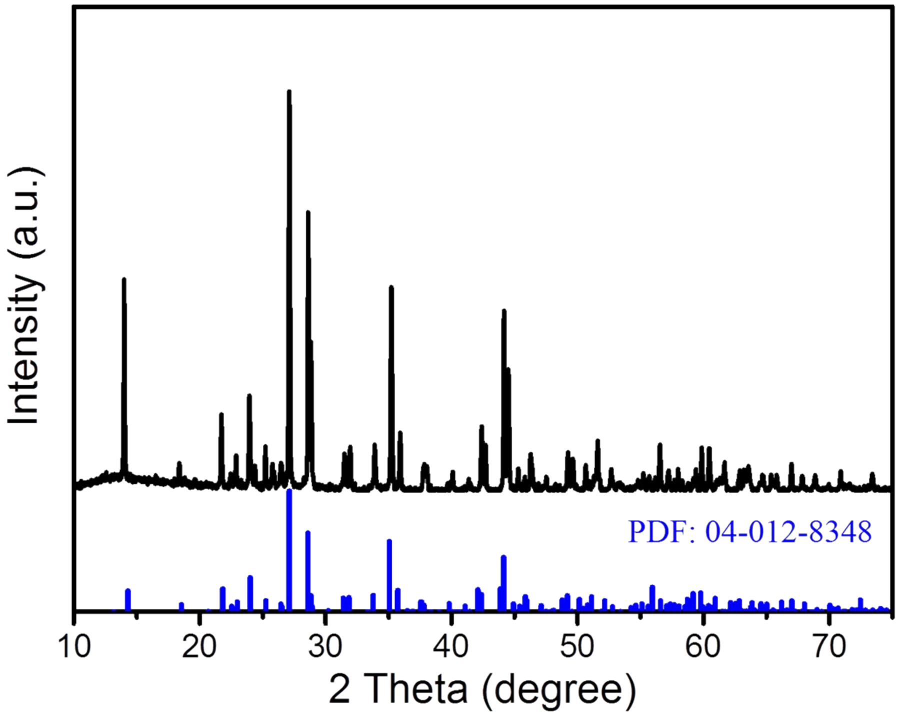

Figure S2 XRD pattern of the intermediate product, which can be indexed as the $Sb_4O_5Cl_2$ phase according to PDF database.

Based on the XRD result, the reaction equation for the preparation of the $Sb_2O_3/Ti_3C_2T_x$ can be proposed as follows:

$$SbCl_3 + H_2O \rightarrow Sb(OH)Cl_2 + HCl$$

$$Sb(OH)Cl_2 + H_2O \rightarrow Sb(OH)_2Cl + HCl$$

$$Sb(OH)_2Cl \rightarrow SbOCl + H_2O$$

$$4SbOCl + H_2O \rightarrow Sb_2O_3 \cdot 2SbOCl\ (Sb_4O_5Cl_2) + 2HCl$$

$$Sb_2O_3 \cdot 2SbOCl + 2NaOH \rightarrow 2Sb_2O_3 + 2NaCl + H_2O$$

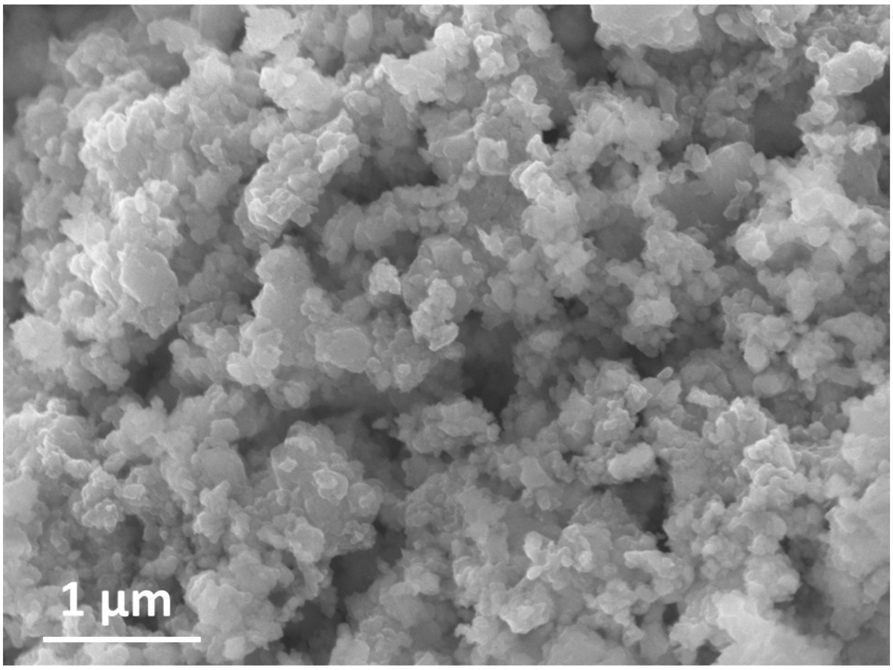

Figure S3 SEM image of Sb_2O_3 material.

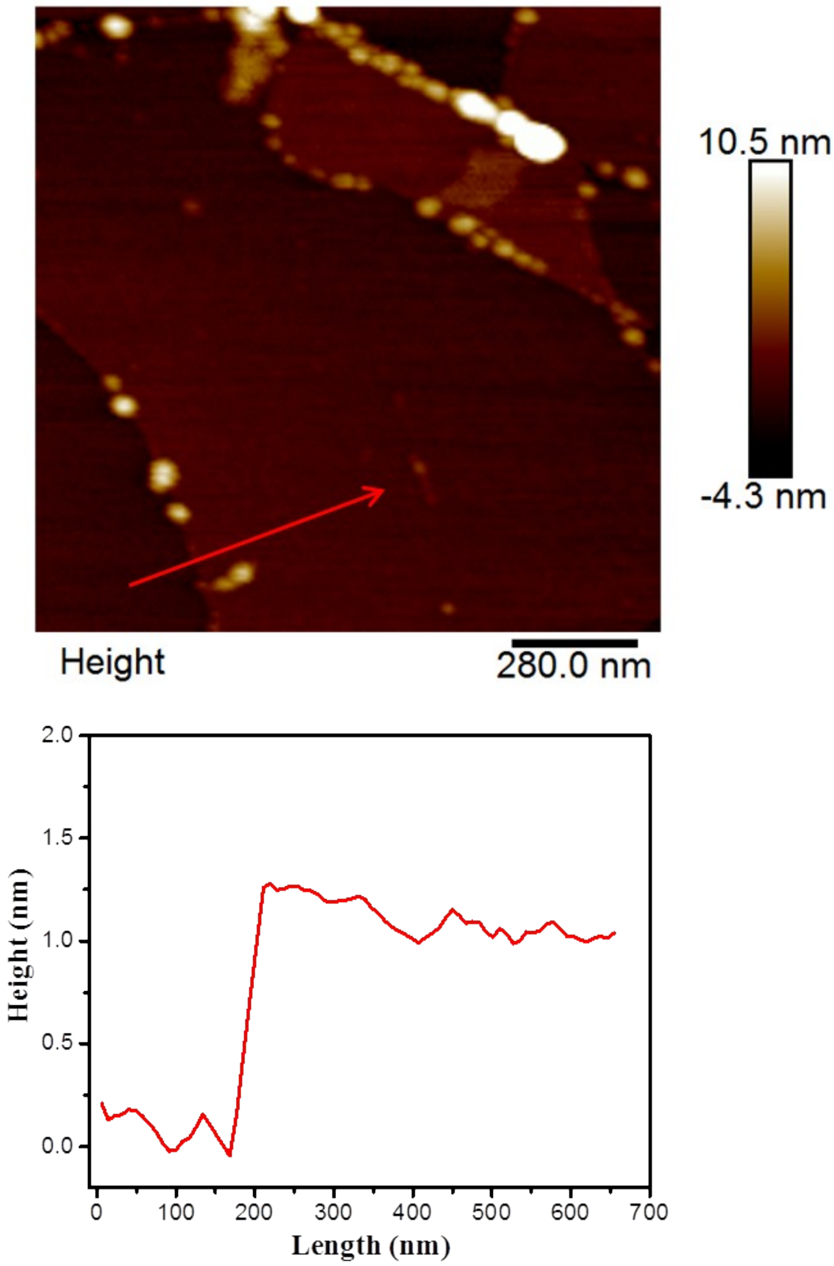

Figure S4 AFM image of the exfoliated MXene $Ti_3C_2T_x$ and corresponding height profile.

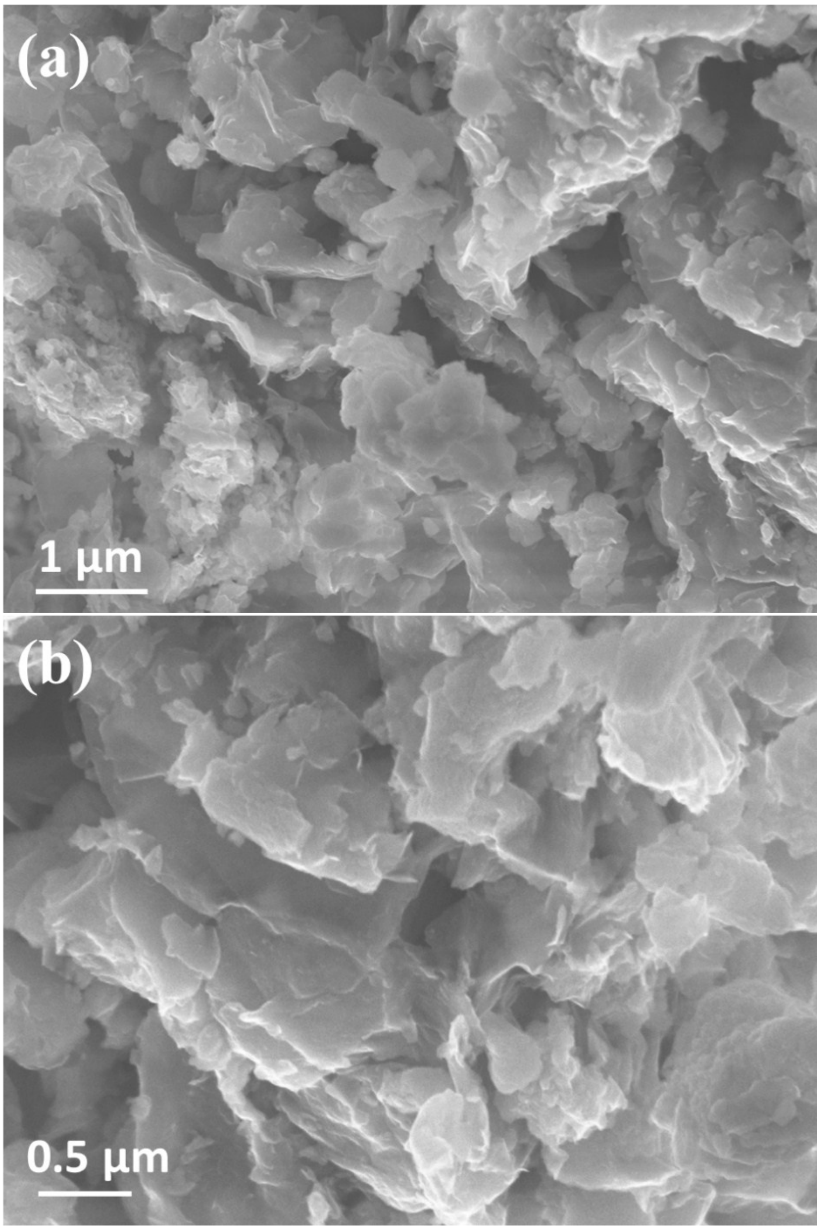

Figure S5 SEM images of the Raw-Sb_2O_3/$Ti_3C_2T_x$ composite fabricated under an immediate hydrolysis process without PVP. Typically, the same amount of NaOH solution was added into the $SbCl_3$ and $Ti_3C_2T_x$ mixture in one fell swoop instead of the dropwise addition.

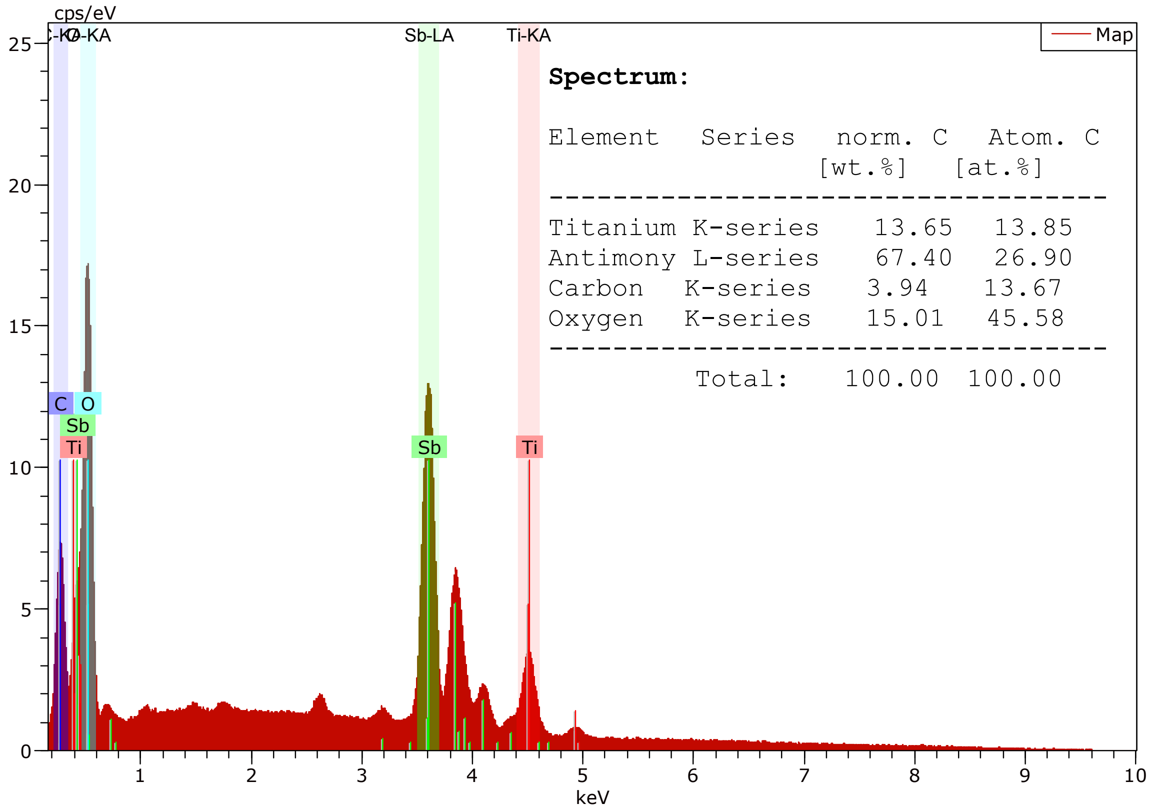

Figure S6 Energy dispersive spectroscopy (EDS) analysis of the $Sb_2O_3/Ti_3C_2T_x$ composite.

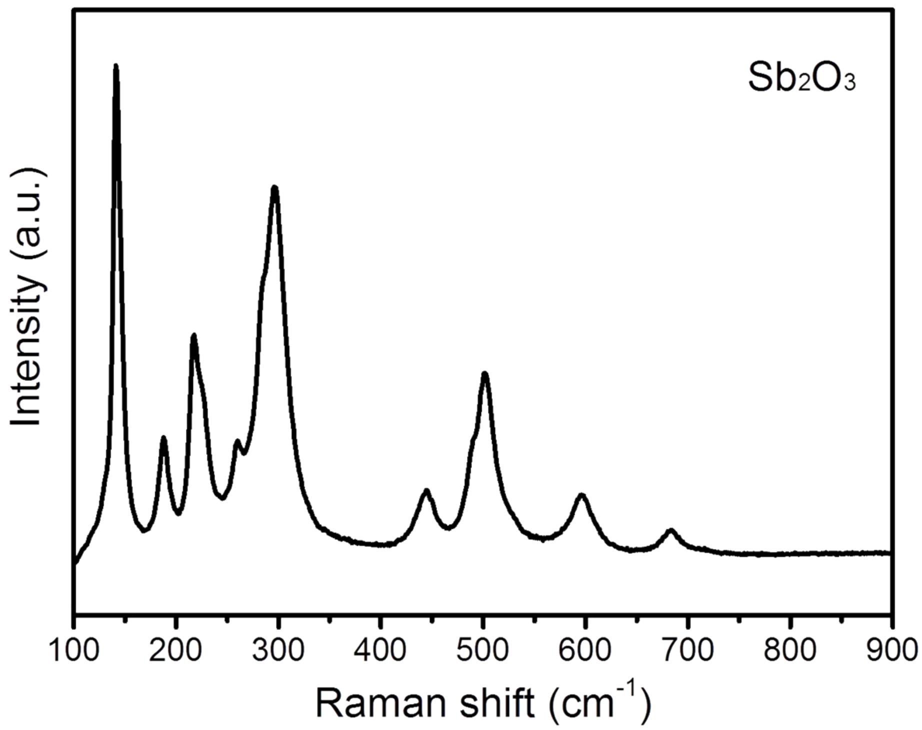

Figure S7 Raman spectrum of pure Sb_2O_3 material.

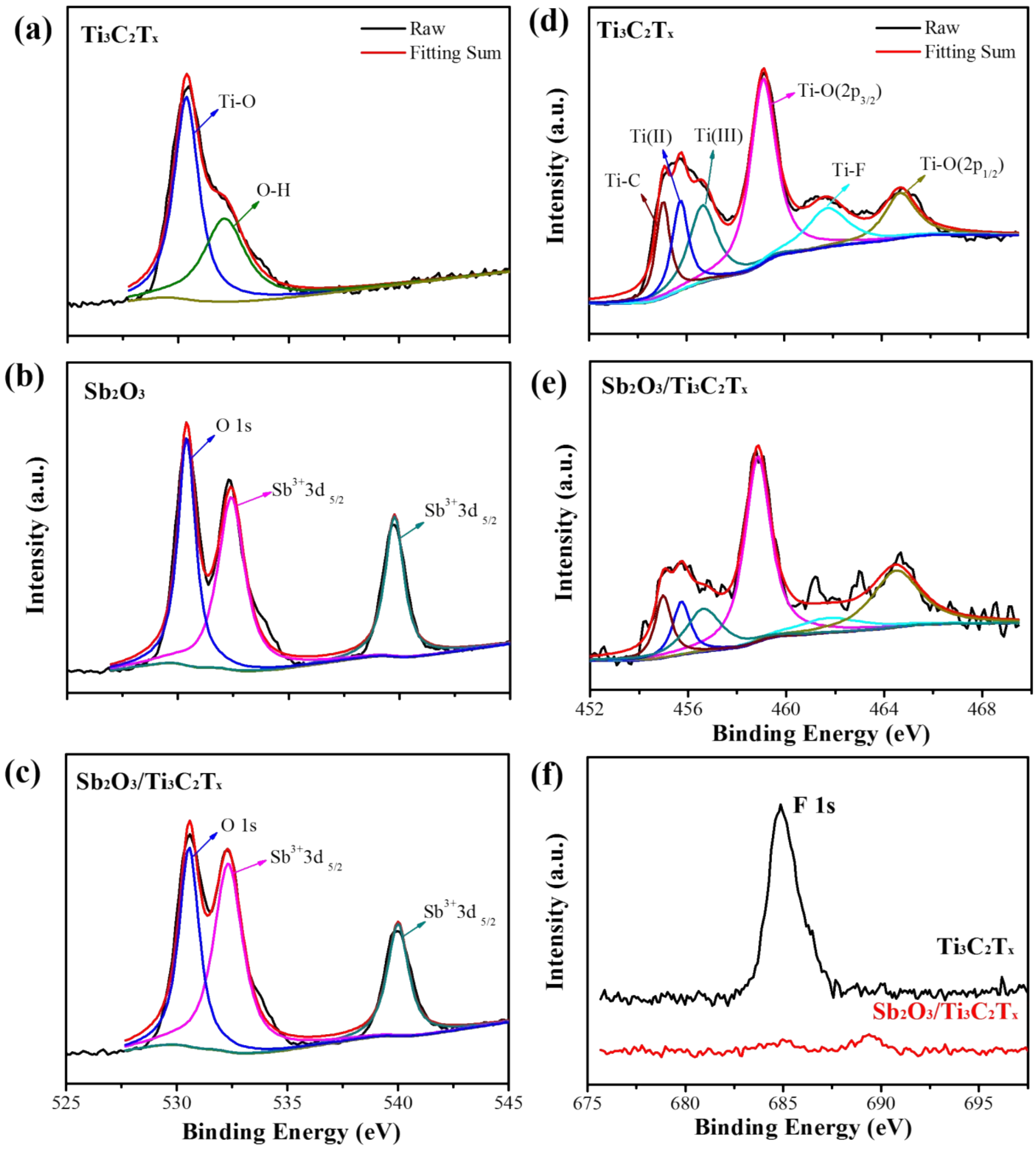

Figure S8 XPS spectra in the Sb 3d and O 1s region of (a) $Ti_3C_2T_x$, (b) Sb_2O_3 and (c) $Sb_2O_3/Ti_3C_2T_x$; Ti 2p spectra of (d) $Ti_3C_2T_x$ and (e) $Sb_2O_3/Ti_3C_2T_x$; (f) comparison of the spectra of $Ti_3C_2T_x$ and $Sb_2O_3/Ti_3C_2T_x$ in the F 1s region.

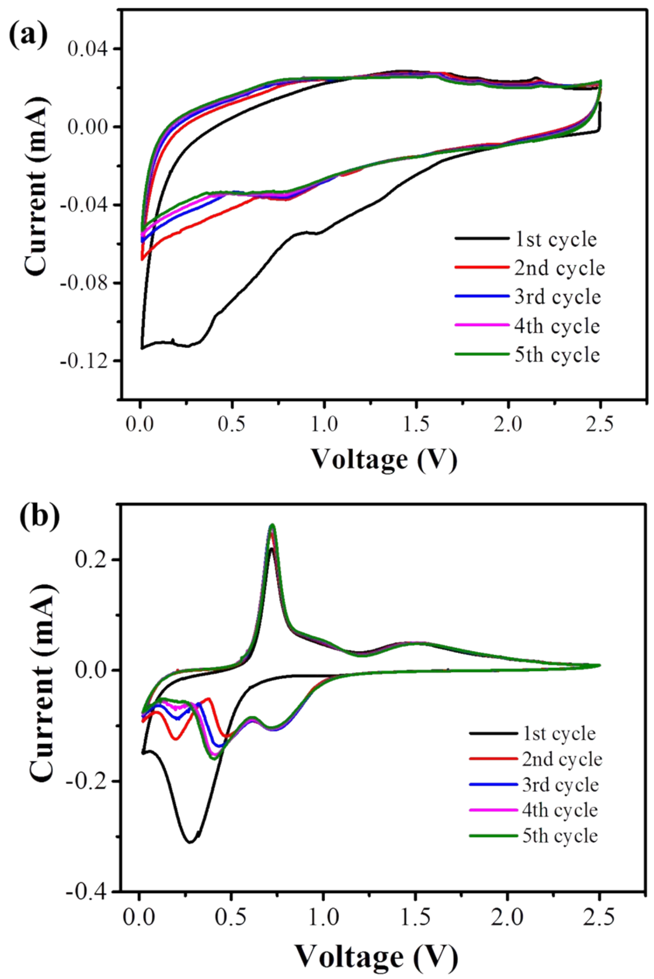

Figure S9 The first 5 cycles of cyclic voltammetry curves of the (a) $Ti_3C_2T_x$ and (b) Sb_2O_3 anode at a scan rate of 0.1 mV s^{-1}.

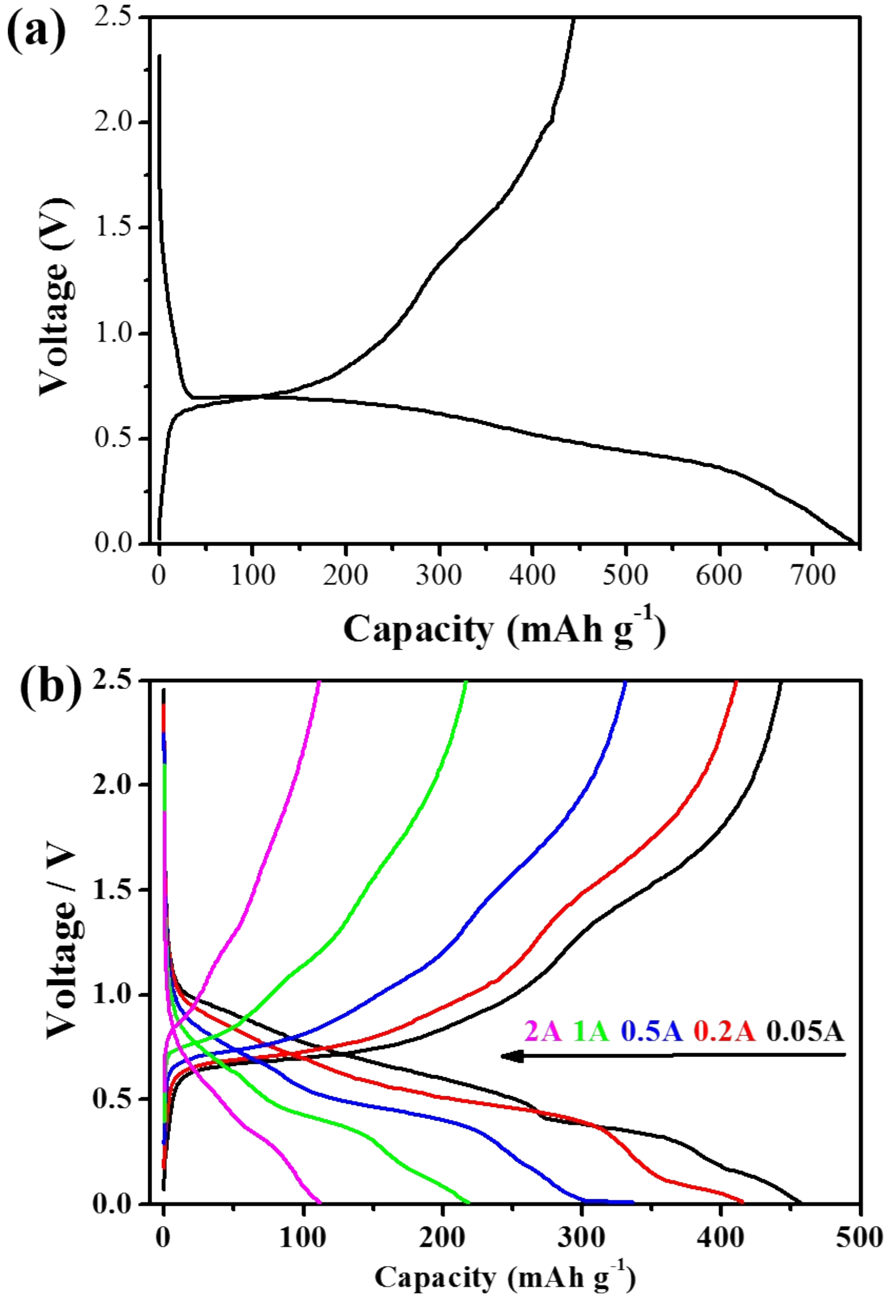

Figure S10 (a) First charge-discharge curves of the Sb_2O_3 electrode at a current density of 50 mA g^{-1}. (b) Charge-discharge curves of the Sb_2O_3 electrodes at different current densities.

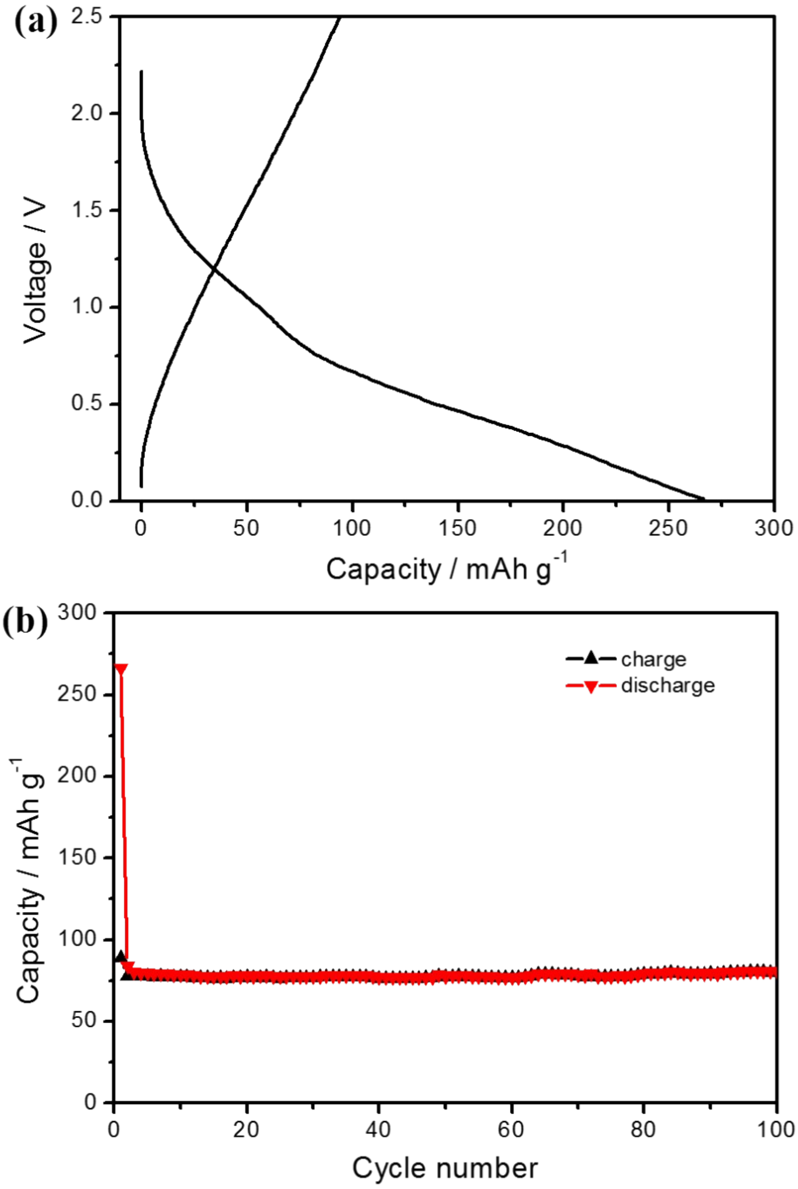

Figure S11 (a) First discharge-charge curves of Na-ion batteries with $Ti_3C_2T_x$ anode at a current density of 50 mA g^{-1}, and (b) cycling performance with $Ti_3C_2T_x$ anode at a current density of 50 mA g^{-1}.

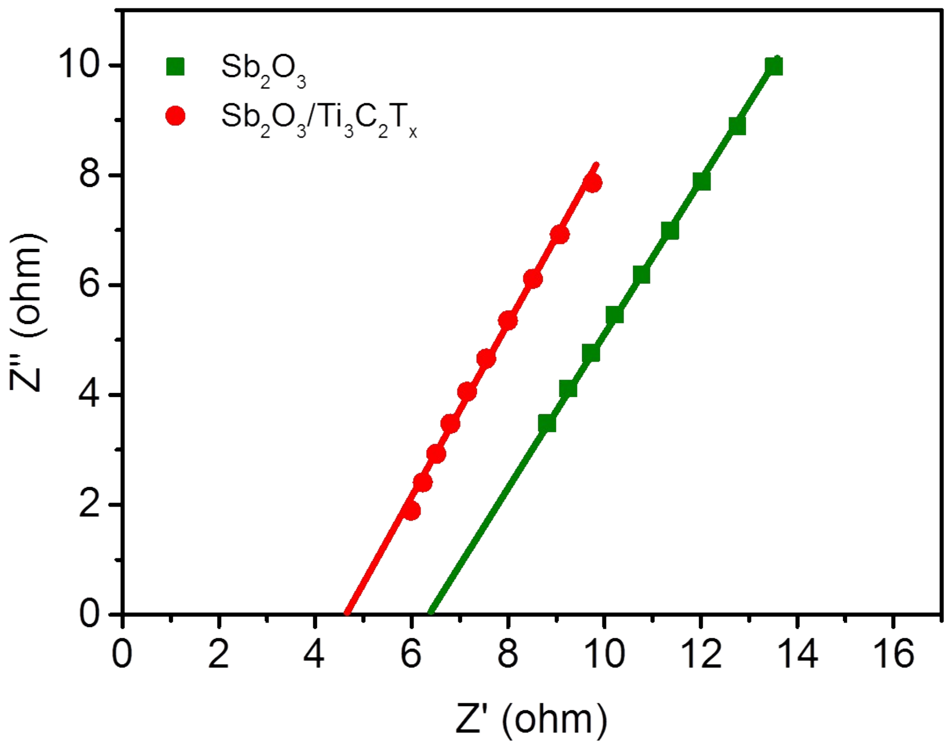

Figure S12 Nyquist plots of the $Sb_2O_3/Ti_3C_2T_x$ and Sb_2O_3 electrodes at room temperature in high frequency region.

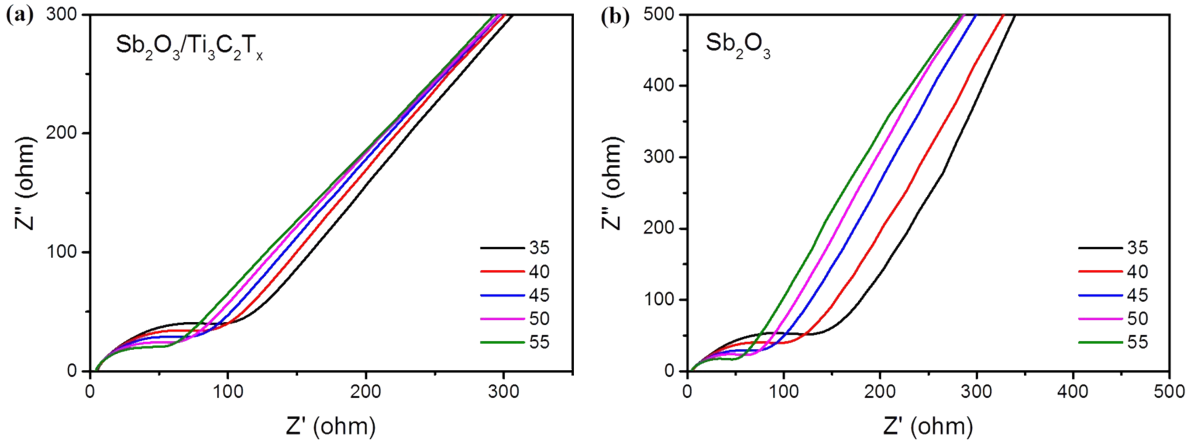

Figure S13 Electrochemical impedance spectra (EIS) for the batteries made of (a) the $Sb_2O_3/Ti_3C_2T_x$ and (b) Sb_2O_3 at different temperature range from 35 °C to 55 °C.

For sodium ions intercalation reaction, the apparent activation energy E_a, namely, the energy barrier between reactant and product, represents different value for different material. The E_a for the sodium intercalation and exchange current (i_0) can be calculated from the following equation.

$$i_0 = RT/(nFR_{ct}) = Aexp(-E_a/RT)$$

Where R is the gas constant, T is the absolute temperature, n is the number of transferred electrons, F is Faraday constant, and A is a temperature-independent coefficient. The EIS profiles tested at different temperatures are shown as Figure S10. The activation energies are 33.5 kJ mol^{-1} and 47.1 kJ mol^{-1} for the $Sb_2O_3/Ti_3C_2T_x$ and Sb_2O_3, respectively, as calculated from the Arrhenius plots.

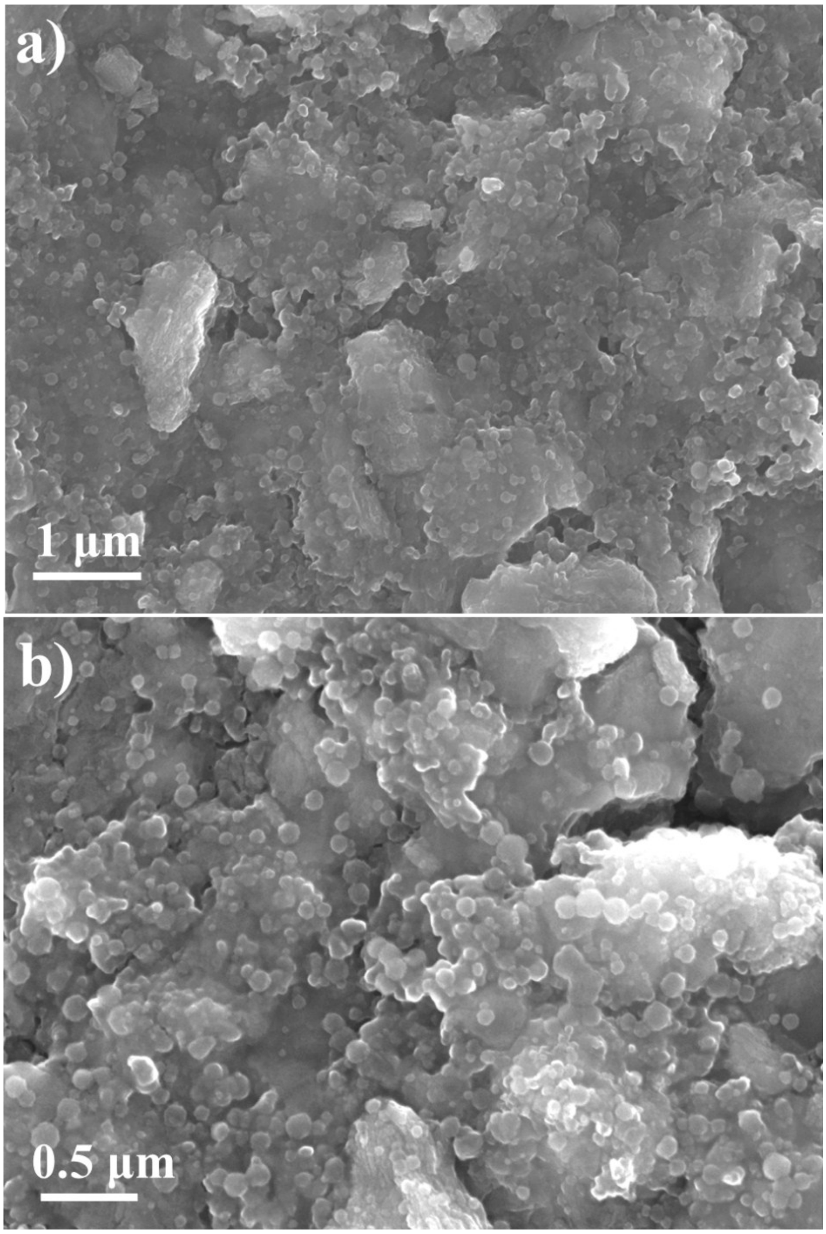

Figure S14 Ex-situ SEM images of the $Sb_2O_3/Ti_3C_2T_x$ electrodes after (a) 10 cycles and (b) 50 cycles.