Supplementary Material (ESI) for Chemical Communications

Development of High-Performance Supercapacitor Electrodes Using Novel Ordered Mesoporous Tungsten Oxide Materials with High Electrical Conductivity

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Synthesis of m-WO_{3-X}, m-WO_3 and b-WO_3: Mesoporous silica KIT-6 was used as a hard template and synthesized following the reported procedure.[1] KIT-6 was impregnated with phosphotungstic acid in two steps. In first impregnation stage, 1.2 g of phosphotungstic acid was incorporated into the pores of 0.45 g KIT-6 by impregnation method and calcined at 350 ºC under air. In the second impregnation step, 0.6 g of phosphotungstic acid was incorporated into the pores of prepared composite, and calcined at 550 ºC under air to obtain WO_3/KIT-6. HF etching of WO_3/KIT-6 generated m-WO_3. To obtain m-WO_{3-X}, WO_3/KIT-6 composite was heat-treated at 600 ºC under Ar/H_2 (4 wt%) atmospehre for 4 hours and further stirred with 5 wt% HF solution for the removal of silica.[2] b-WO_{3-X} (bulk WO_{3-X}) was prepared following the same procedure for m-WO_{3-X} except KIT-6 was not used.

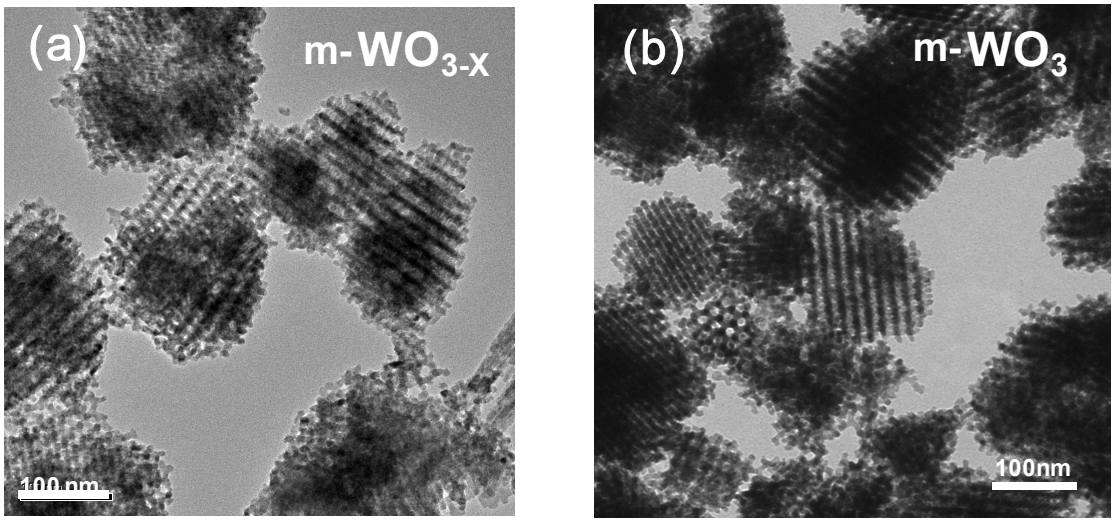

Figure S1. TEM images of (a) m-WO_{3-X} and (b) m-WO_3. Both materials were synthesized using KIT-6 hard template and have the same ordered pore structure.

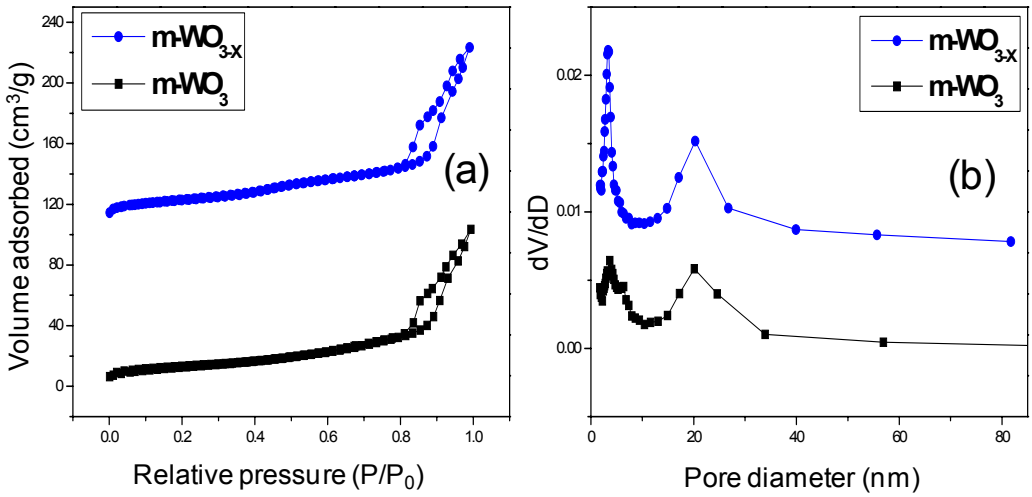

Figure S2. (a) Nitrogen adsorption-desorption isotherms of m-WO_{3-X} and m-WO_3 (b) Pore size distributions of m-WO_{3-X} and m-WO_3 estimated from adsorption branch using BJH (Barett-Joyner-Halenda). The pore structure of m-WO_3 judged by N_2 isotherm and pore size distributions is nearly identical to that of m-WO_{3-X}. An N_2 adsorption shows

two distinct jumps at ~0.5 P/P_0 and ~0.9 P/P_0, corresponding to uniform 3.5 nm pores and ~20 nm pores observed in pore size distributions, respectively. ~20 nm sized pores might be produced by filling phosphotungstic acid in either one of two chiral channels and removal of KIT-6 template.[2]

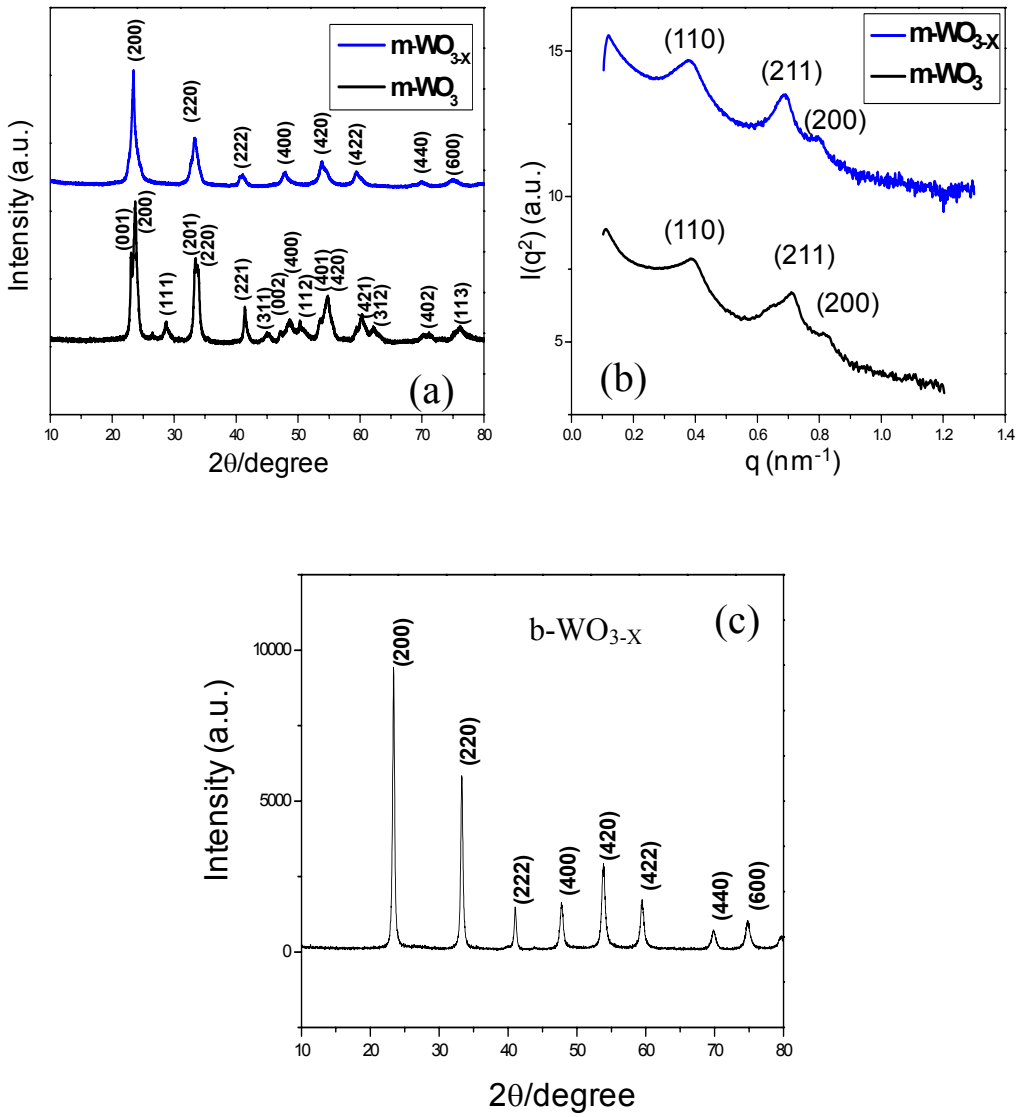

Figure S3. (a) XRD patterns of m-WO_{3-X} and m-WO_3. Diffraction peaks in m-WO_{3-X}

can be indexed to the cubic WO_{3-X} phase (JCDPS:46-1096). The XRD pattern of m-WO_3 is well-matched with tetragonal phase (JCDPS:89-1287) (b) Small angle X-ray scattering (SAXS) patterns of m-WO_{3-X} and m-WO_3. (c) XRD pattern of b-WO_{3-X}. Diffraction peaks in b-WO_{3-X} can be indexed to the cubic WO_{3-X} phase (JCDPS:46-1096)

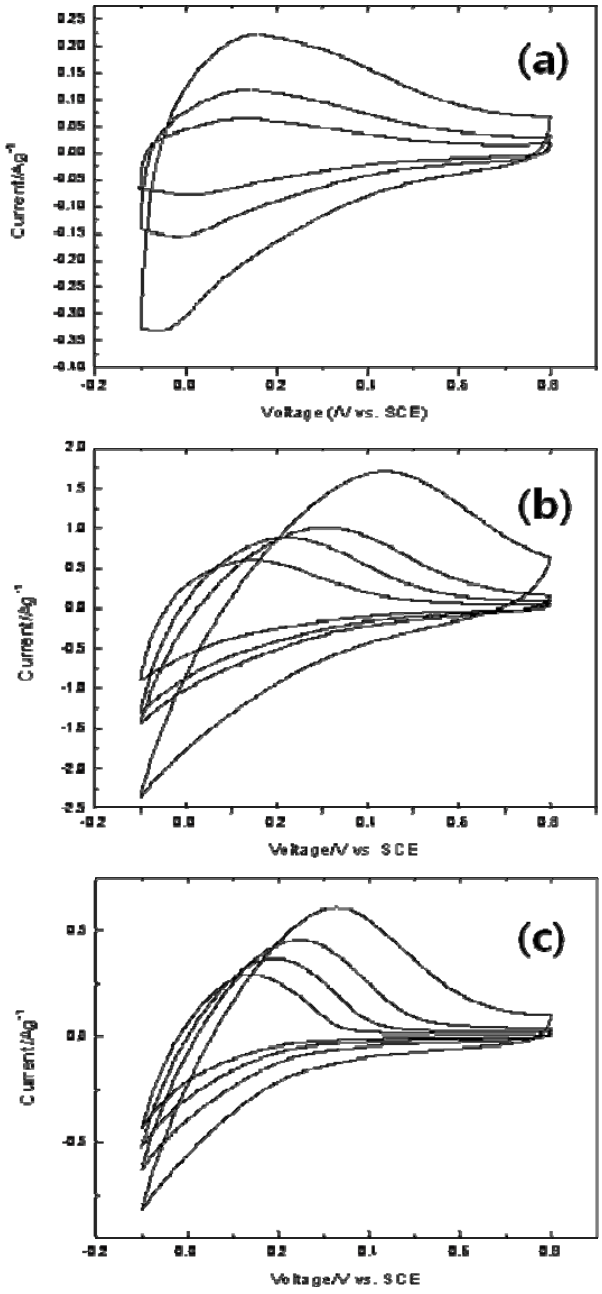

Figure S4. Cyclic voltamograms with change of scan rate from 5 to 50 mV/s for b-WO_{3-X} (a), m-WO_{3-X} (b) and m-WO_3 (c)

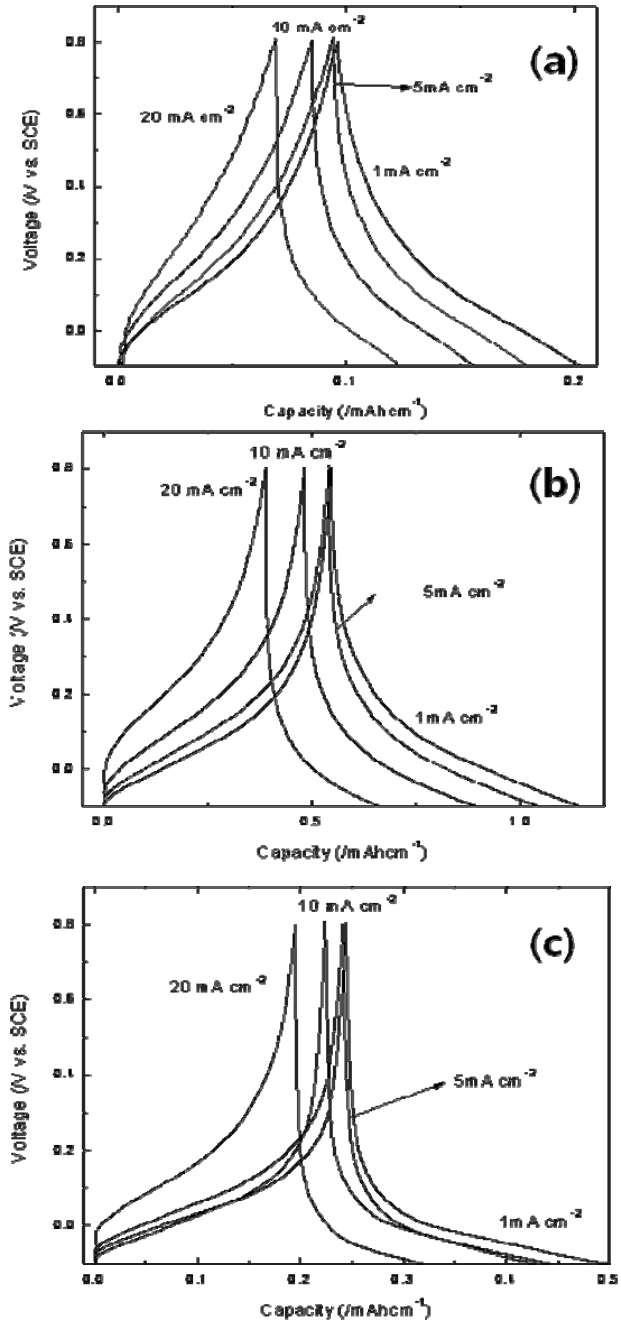

Figure S5. Galvanostatic charge-discharge patterns with change of applied current from 1 to 20 mA/cm^2 for b-WO_{3-X} (a), m-WO_{3-X} (b) and m-WO_3 (c)

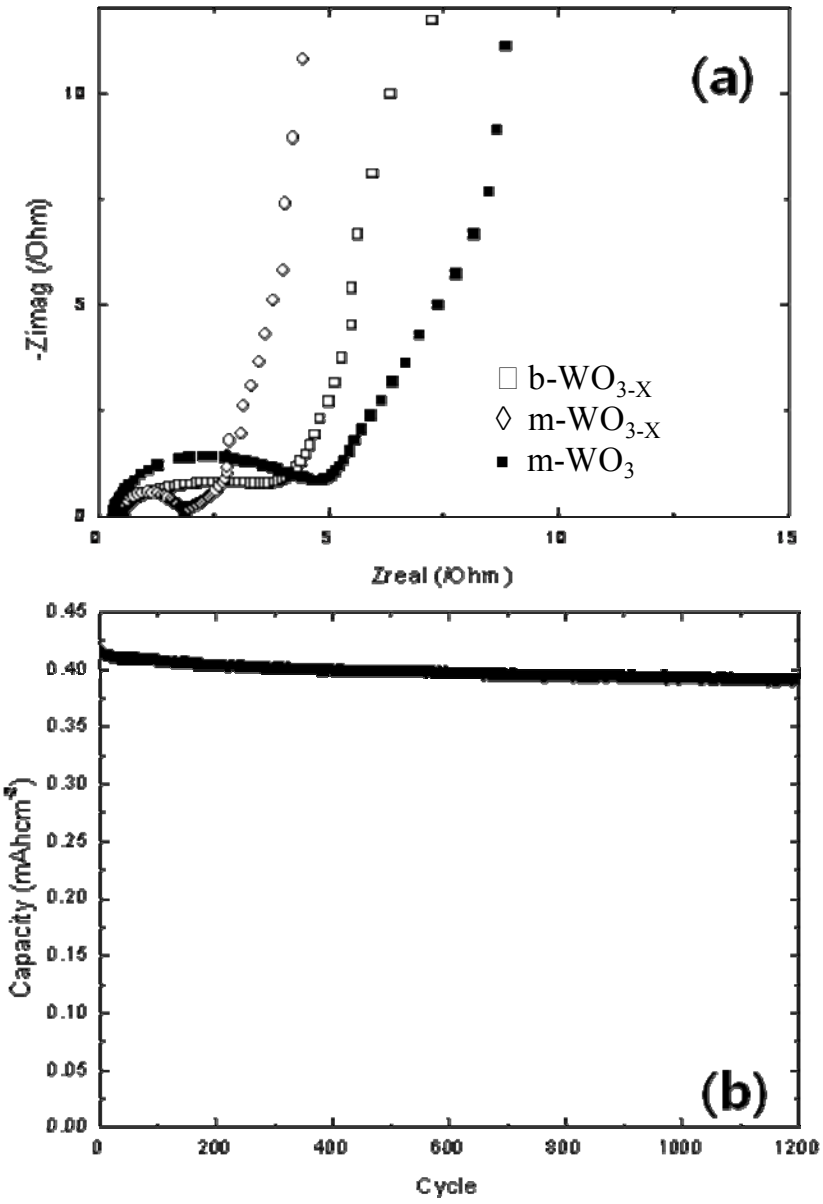

Figure S6. (a) Electrochemical impedance spectra for three tungsten oxide electrodes when 5 mV voltage magnitude from 5 mHz to 10^5 Hz at open circuit voltage (OCV). (b) Change of capacity with cycles of m-WO_{3-X} electrodes.

References

1. F. Kleitz, S. H. Choi, R. Ryoo, *Chem. Commun.* 2003, 2136.

2. (a) Shi, Y.; Guo, B.; Corr, S. A.; Shi, Q.; Hu, Y. –S.; Heier, K. R.; Chen, L.; Seshadri, R.; Stucky, G. D. *Nano Lett.* 2009, **9**, 4215. (b) Kang, E.; An, S.; Yoon, S.; Kim, J. K.; Lee, J. *J. Mater. Chem.* 2010, **20**, 7416.