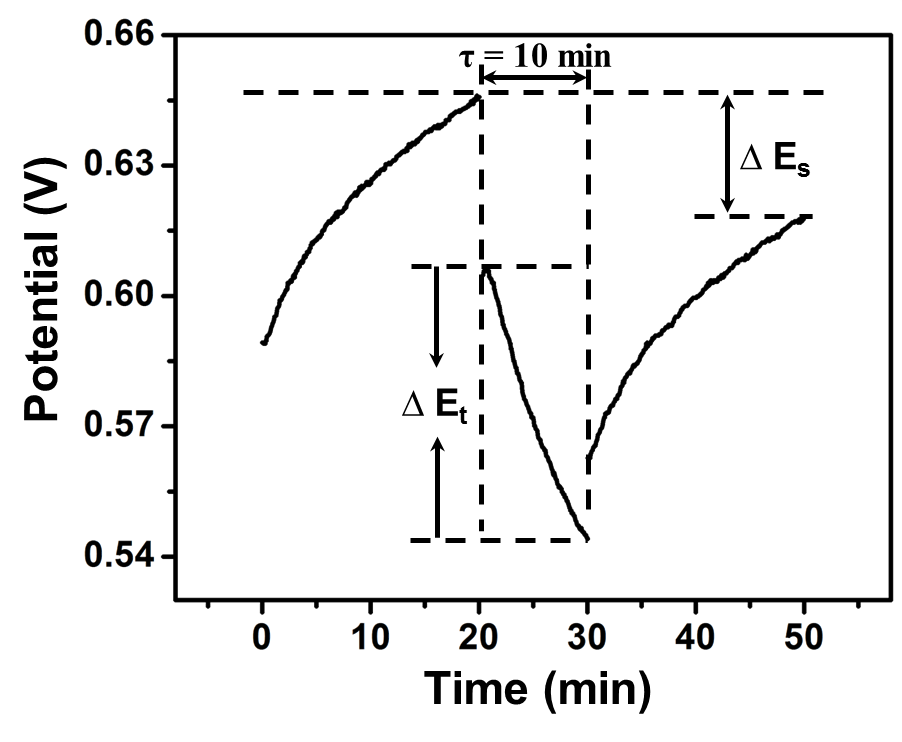
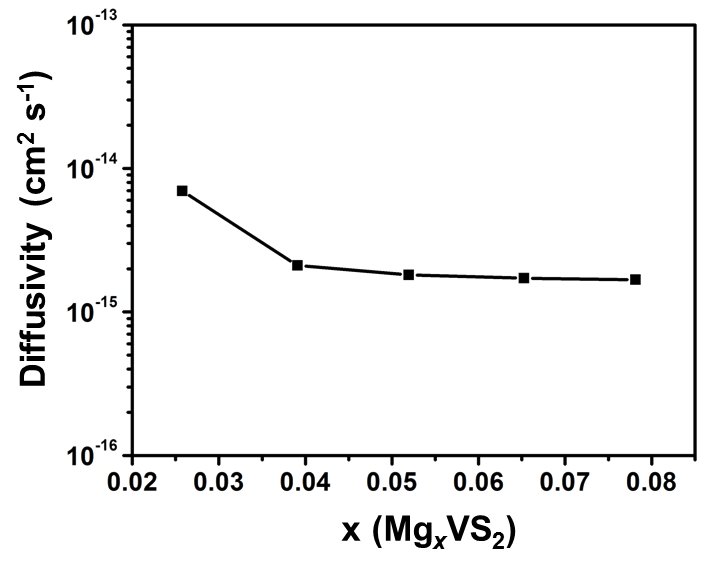
Supporting information

**High-rate and Long-life VS2 Cathodes for Hybrid Magnesium-Based Battery**

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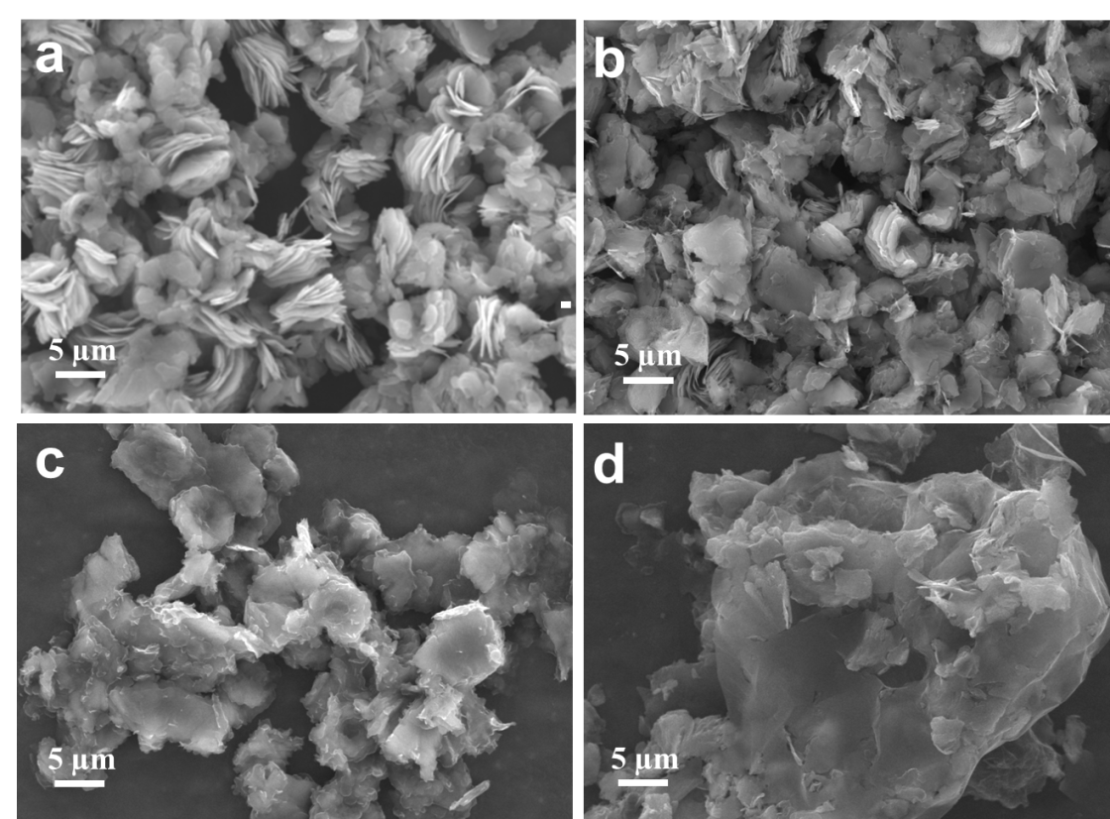
**Fig. S1.** GITT potential response curve with time. The experiment was carried out at constant current pulse of 20 mA g−1 for 10 min followed by a relaxation period of 20 min. △*ES*is voltage difference during a single-step experiment, and △*Eτ* is the total change of cell voltage during a constant current pulse.

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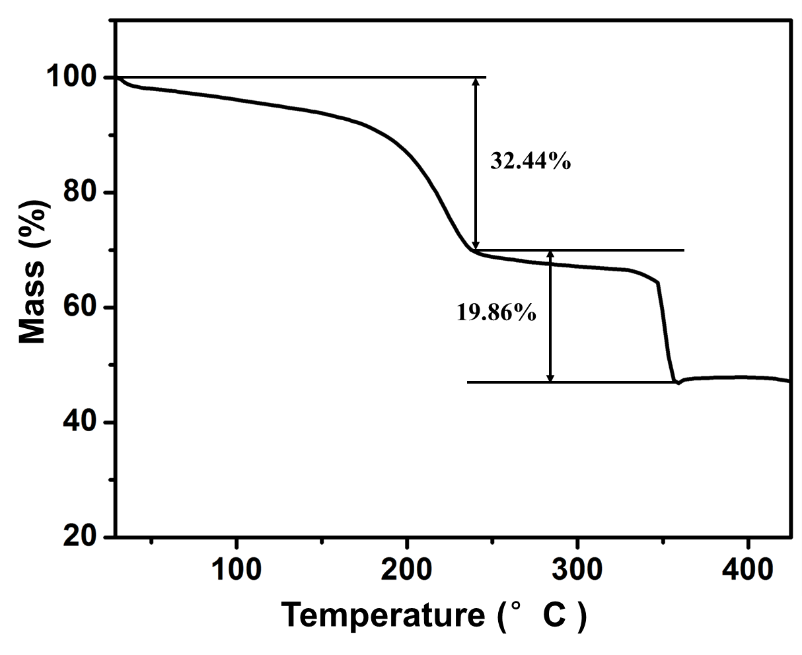
**Fig. S2.** Mg2+ diffusivity versus the state of discharge.

**Table S1.** The mass contents of V and S elements.

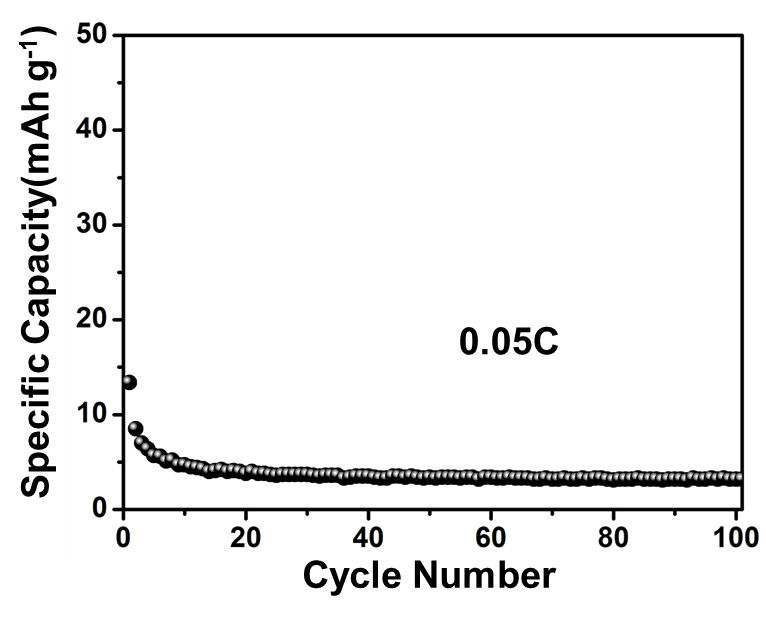
|  |  |  |  |
| --- | --- | --- | --- |
| Elements | Mass Contents (wt.%) | Atom ratio |  |
| V | 43.05 | 1 |  |
| S | 50.77 | 1.87 |  |

****

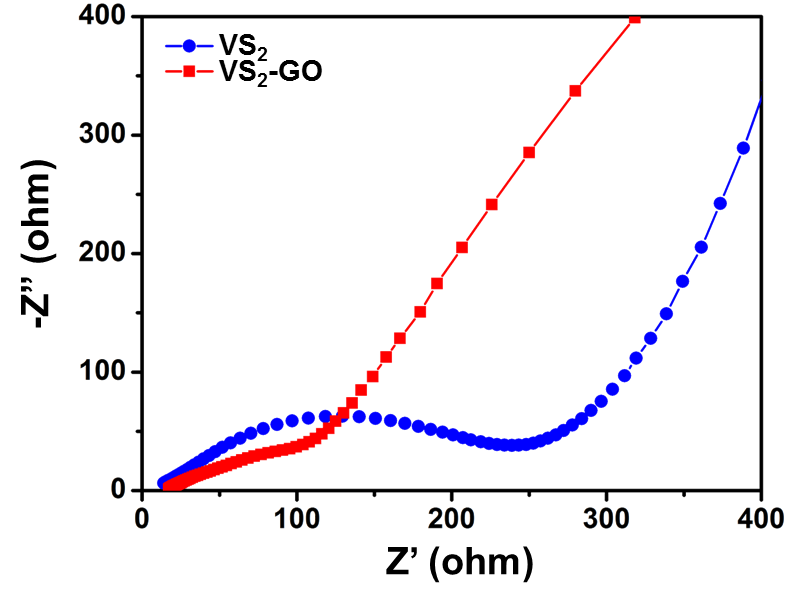
**Fig. S3.** SEM images of (a) VS2, (b) VS2-GO, (c) VS2-GO-1 and (d) VS2-GO-2.

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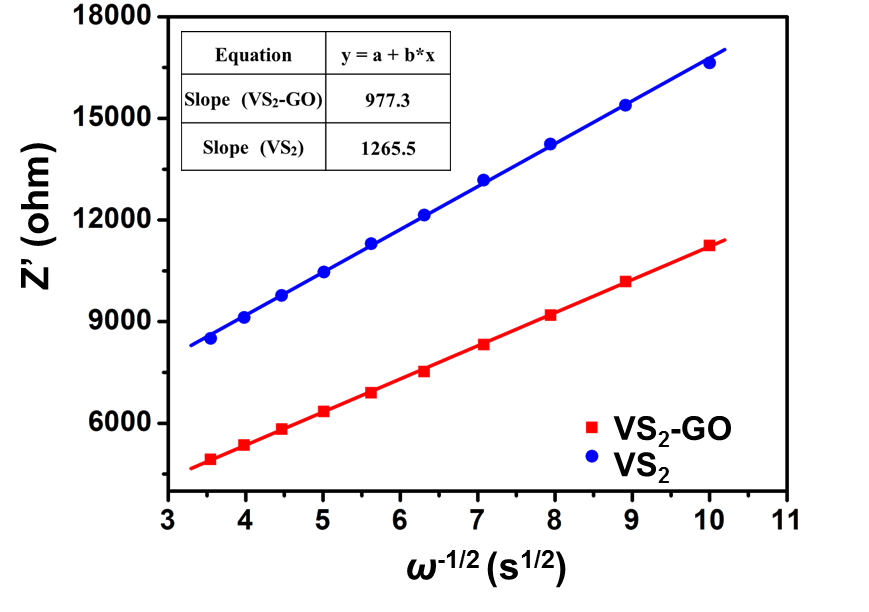
**Fig. S4.** TG curve of VS2-GO.

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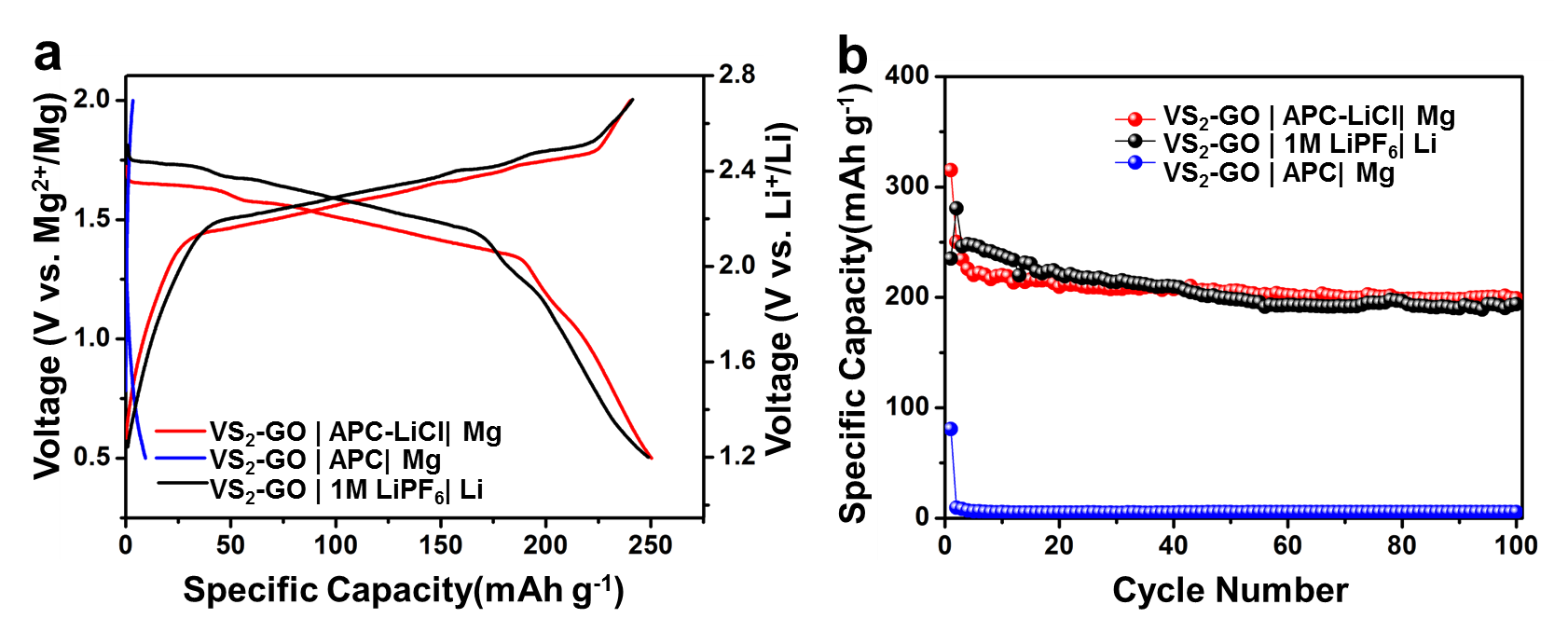
**Fig. S5.** Cycling performance of the pure GO electrode at 10 mA g-1.

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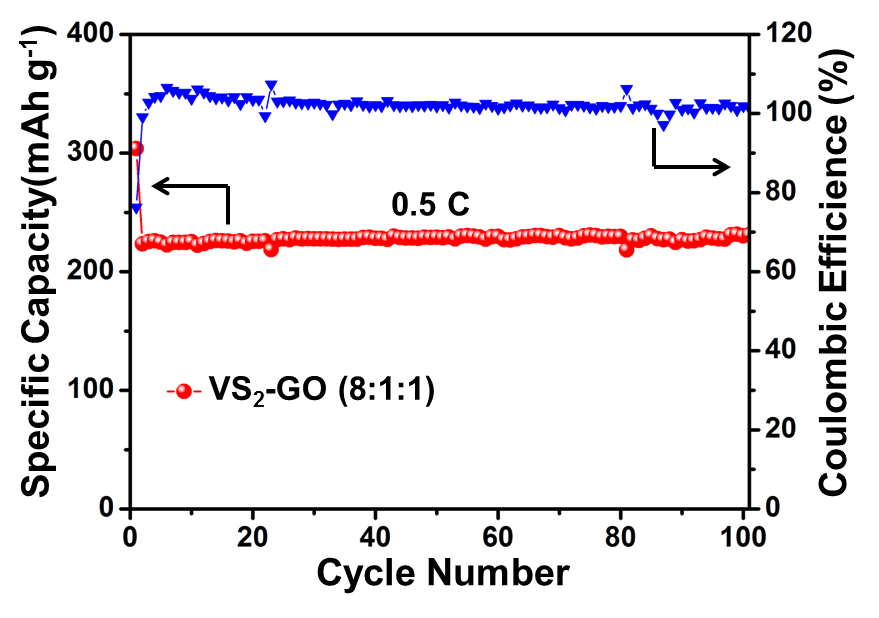
**Fig. S6.** Nyquist plots of VS2-GO and VS2 after 50 cycles.

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**Fig. S7.** The fitted lines and real part of the impedance versus *ω*−1/2 for VS2-GO and VS2.

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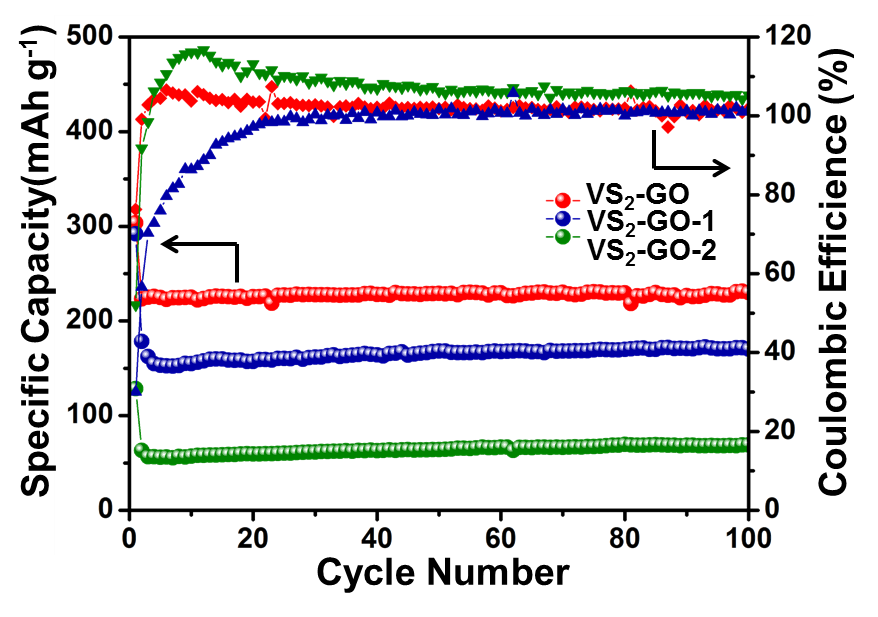
**Fig. S8.** (a) Discharge-charge curves of VS2-GO cathode in the VS2-GO|APC-LiCl|Mg hybrid battery (0.5-2 V), VS2-GO|1 M LiPF6/ EC+DMC+EMC (volume ratio of 1:1:1)|Li LIB (1.2-2.7 V) and VS2-GO|APC|Mg MIB (0.5-2 V) at the same current density of 0.5 C. (b) corresponding cycling performance.

****

**Fig. S9.** Cyclic performance of VS2-GO electrode prepared by mixing the active materials, acetylene black and PTFE in a weight ratio of 8:1:1.

**Table S2.** Carbon contents of the samples according to C-S analyzers.

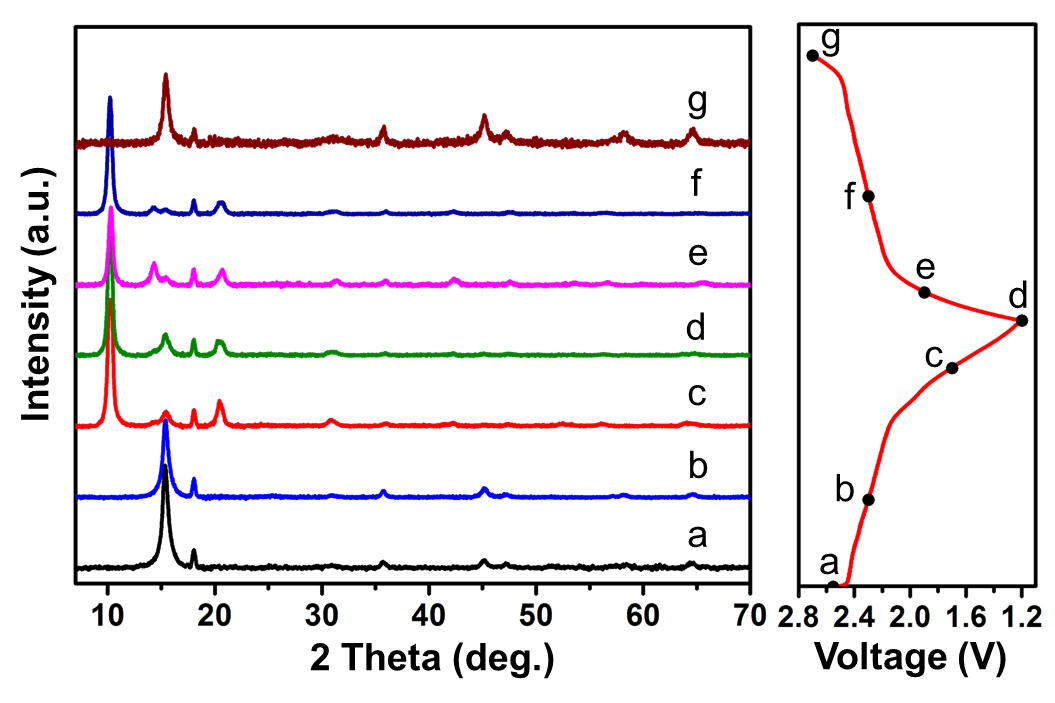
|  |  |
| --- | --- |
| Samples | Carbon Contents (%) |
| VS2-GO | 6.10 |
| VS2-GO-1 | 9.36 |
| VS2-GO-2 | 19.48 |

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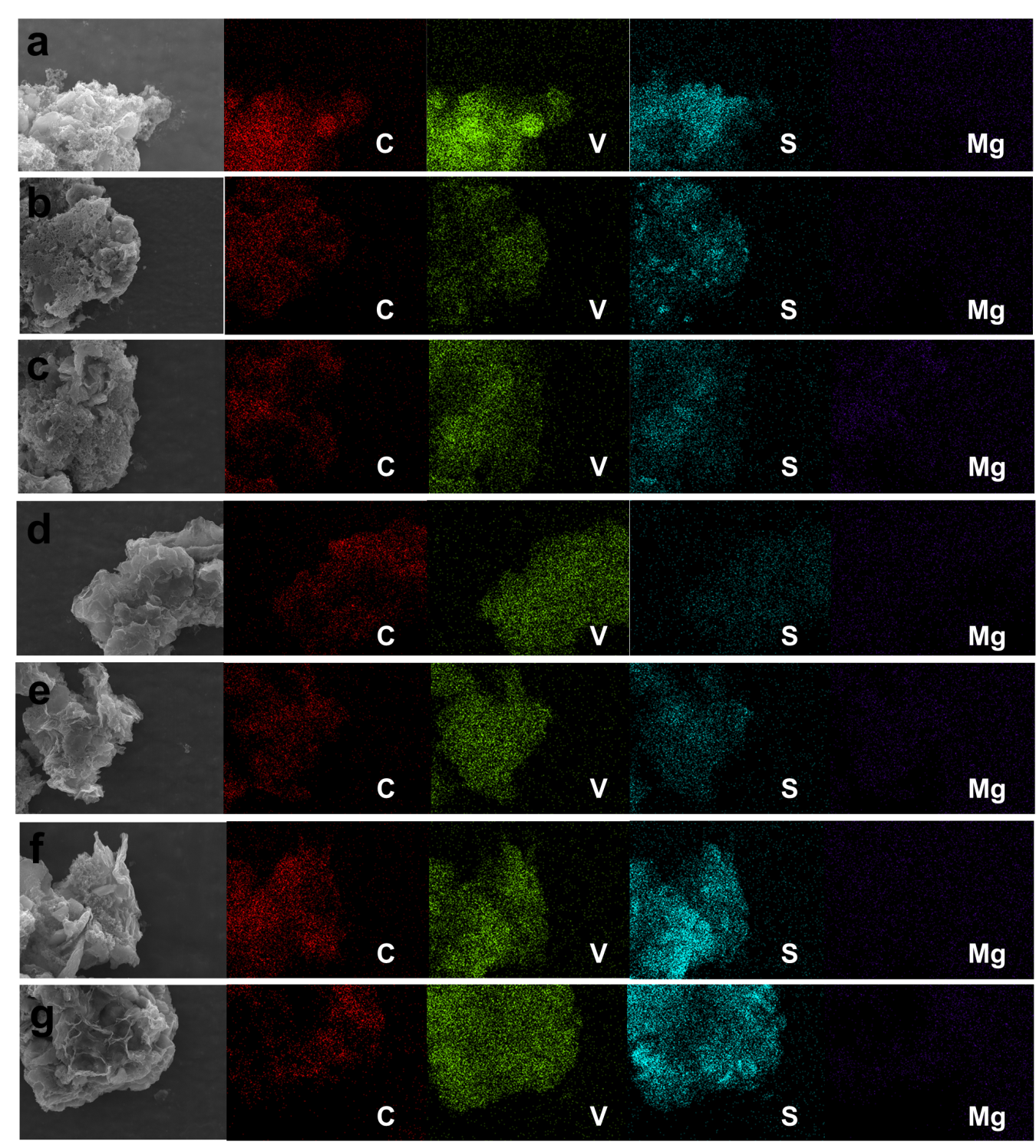
**Fig. S10.** Cycling performances of VS2-GO, VS2-GO-1 and VS2-GO-2 at the rate of 0.5 C prepared by mixing the active materials, acetylene black and PTFE in a weight ratio of 8:1:1.

**Table S3.** Comparison of the electrochemical performance of the state-of-the-art intercalation cathodes for various reported MLIBs with low voltage (< 2.0 V)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Cathode** | **Average voltage (V *vs.* Mg2+/Mg)** | **Capacity (mA h g−1)** | **Energy density (Wh Kg−1)** | **Rate capability** | **Reference** |
| Mo6S8 | 1.3 | 126 | 163.8 | 109 mA h g−1 at 1.03 A g−1 | Ref. 20 |
| TiS2 | 1.4 | 220 | 308 | 50 mA h g−1 at 4.82 A g−1 | Ref. 21 |
| TiO2 | 0.7 | 200 | 140 | 116 mA h g−1 at 0.67 A g−1 | Ref. 22 |
| Li4Ti5O12 | 0.7 | 175 | 122.5 | 120 mA h g−1 at 0.3 A g−1 | Ref. 23 |
| MoS2 | 1.0 | 225 | 225 | 150 mA h g−1 at 1.0 A g−1 | Ref. 41 |
| d-Ti3C2T*x* | 0.75 | 105 | 78.8 | 40 mA h g−1 at 1.0 A g−1 | Ref. 47 |
| MoO2 | 0.75 | 217 | 162.8 | 150 mA h g−1 at 0.1 A g−1 | Ref. 46 |
| VS2 | 1.5 | 250 | 375 | 129 mA h g−1 at 14.4 A g−1 | Our present work |

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**Fig. S11.** *Ex-situ* XRD patterns of VS2-GO during galvanostatic charge and discharge at 0.5 C.

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**Fig. S12.** *Ex-situ* EDS Mapping of VS2-GO during first discharged and charged states. discharged to (a) 1.2 V, (b) 0.8 V, (c) 0.5 V and charged to (d) 0.8 V, (e) 1.2 V, (f) 1.6 V, (g) 2.0 V.

**S1.** **Calculation of energy density for the Mg-Li hybrid battery:**

Positive electrode: VS2 + 2Li+ + 2e- = Li2VS2

Negative electrode: Mg + 2Cl- = MgCl2 + 2e-

Overall reaction: VS2 + Mg + LiCl= Li2VS2 + MgCl2

Specific capacity = 2\*26800/( Li2VS2 + MgCl2)

=2\*26800/(128.94+95.21)=239.14 mAh/g

Theoretical specific energy density for Mg-Li/VS2 = 1.5 V \* 239.14 mAh/g = 358.71 Wh/kg, where 1.5 V is the average discharge voltage.

Experimental demonstrated energy density: [1.966\*26800/(128.94+95.21)] \* 1.5 = 352.59 Wh/kg.

Where 1.966 Li+ is reversibly inserted/deinserted into VS2-GO framework instead of 2 Li+ in theoretical calculation.