Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Supporting information

Germanium nanoparticles/molybdenum disulphide (MoS_2) nanocomposite as a high-capacity, high-rate anode material for lithium-ion batteries

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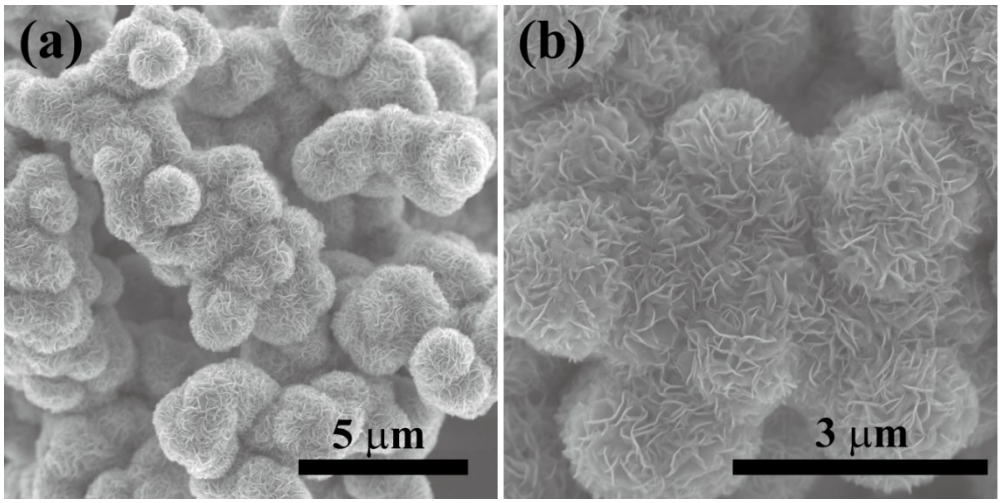

Figure S1. (a, b) SEM images of the MoS_2.

By X-ray diffraction (XRD), XRD pattern of the MoS_2 corresponds to the database of the MoS_2 (JCPDS #371492) and indicates that the MoS_2 is a hexagonal structure in **Figure S2a**. The peaks of the XRD pattern of the MoS_2 around 14.4, 32.7, 39.5, 49.8 and 58.3 ^{o} with the high intensity shows the good crystallization and purity of MoS_2 and is consistent with the (002), (100), (103), (105) and (110) plane, respectively. The microstructure of the MoS_2 was observed by transmission electron microscope (TEM), high-resolution transmission electron microscope (HRTEM) and selected-area electron diffraction (SAED). The low-magnification and high-magnification TEM images of the MoS_2 are showed in **Figure S2 (b, c)**, respectively. By observing the HRTEM images of the MoS_2, the obvious interplanar spacing of the MoS_2 was measured about 0.63 nm, corresponding to the (002) crystalline plane of the MoS_2 in **Figure S2d**. The SAED pattern of the MoS_2 (**Figure S2e**) demonstrates the five diffraction rings that can be indexed the (002), (100), (103), (105) and (110) crystalline plane of the MoS_2, respectively.

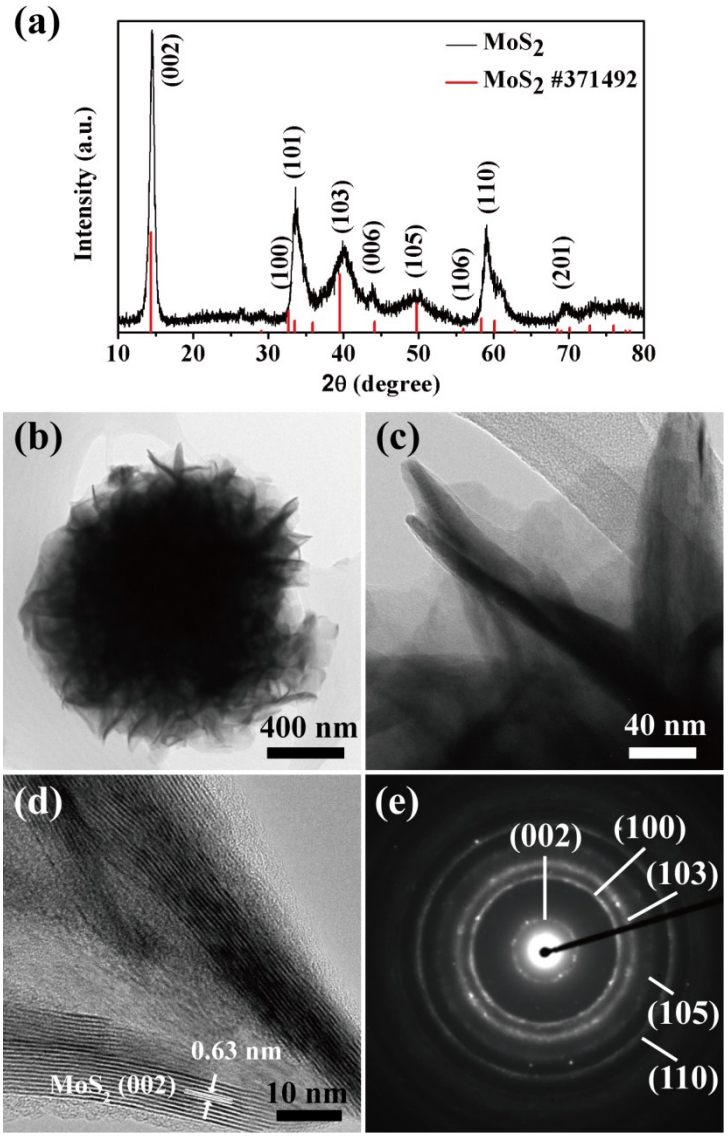

Figure S2. (a) XRD pattern, (b, c) TEM images, (d) HRTEM image and (e) SAED pattern of the MoS_2.

The XRD pattern of Ge nanoparticles is indexed to the cubic phase (JCPDS #895011) in **Figure S3** and the five apparent diffraction peaks are shown at 27.3, 45.3, 53.7, 66.0 and 72.8 °, respectively. The TEM image of Ge nanoparticles is shown in **Figure S4a** and the SAED pattern, which corresponds to the (111), (220) and (311) crystalline plane of Ge, is exhibited in **Figure S4b**.

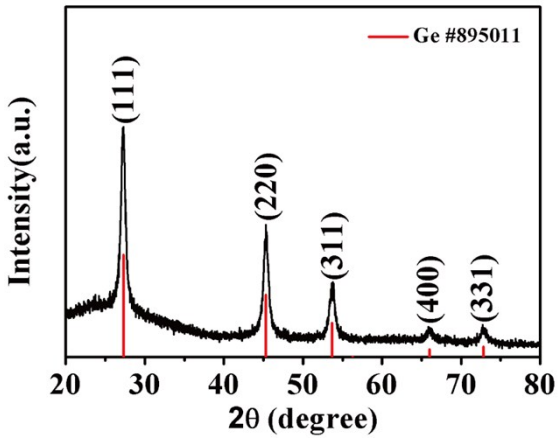

Figure S3. XRD pattern of the Ge nanoparticles.

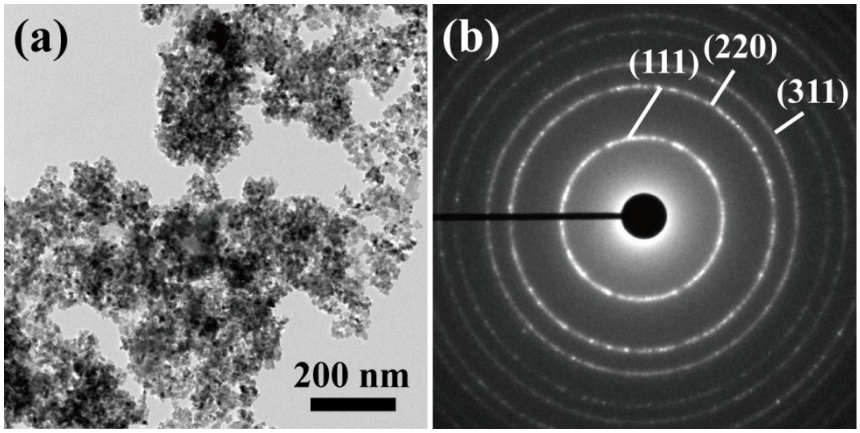

Figure S4. (a) TEM image and (b) SAED pattern of the Ge nanoparticles.

To explore the effect of annealing at 350 °C for 2 h, electrochemical impedance spectroscopy (EIS) measurements were used. **Figure S5 (a, b)** show the EIS results of the Ge/MoS_2 composites before and after annealing, which were cycled at 0.1 A/g for 10 cycles. Inset of **Figure S5 (a, b)** is the equivalent circuit model and R_e represents the resistance of the system of half cell such as electrolyte and separator. R_f and R_{ct} can be attributed to the resistance of the SEI and charge transfer, respectively. CPE1 and CPE2 are the constant phase element and related double layer capacitor, respectively. Finally, Z_w is the Warburg impedance, which is related to diffusion process of Li-ions. Obviously, the Ge/MoS_2 composites after annealing exhibit the lower resistance of charge transfer than the Ge/MoS_2 composites before annealing. The result also indicates that the electrical conductivity of the Ge/MoS_2 composites after annealing is higher than the Ge/MoS_2 composites before annealing. Then, the electrodes after 10 cycles show the better result than the electrodes before cycles. The better interface, which can be formed after discharge and charge process, between electrolyte and electrode results in a decreasing resistance of charge transfer.

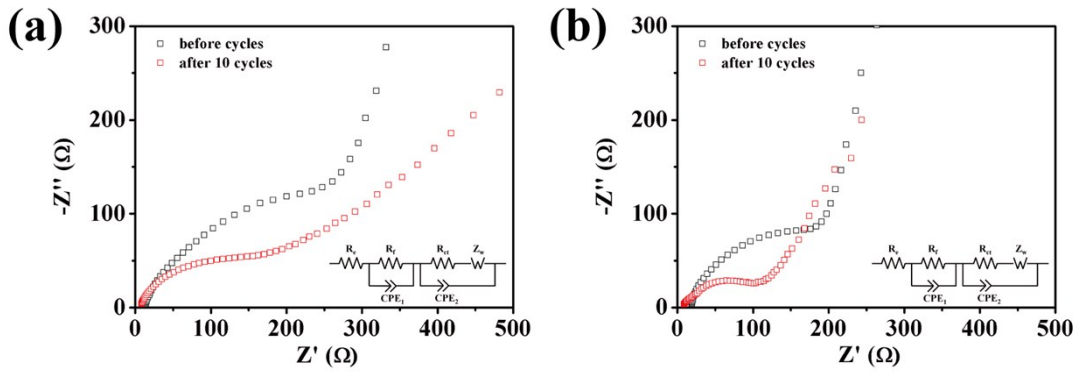

Figure S5. Nyquist plots of the Ge/MoS_2 composites (a) before and (b) after annealing with the current density at 0.1 A/g. The equivalent circuit is shown in the inset of (a) and (b).

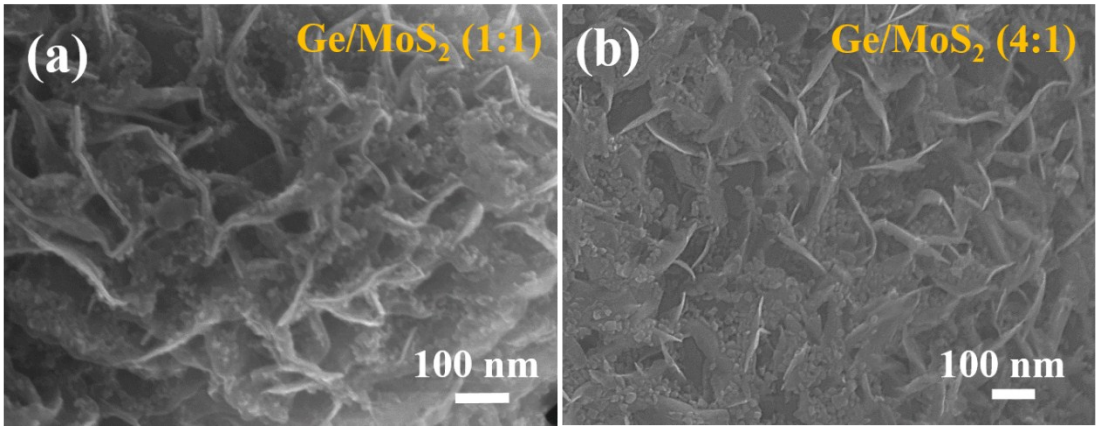

Figure S6. SEM images of Ge/MoS2 nanocomposites with different mixed weight ratios. (a)1:1 (b)4:1

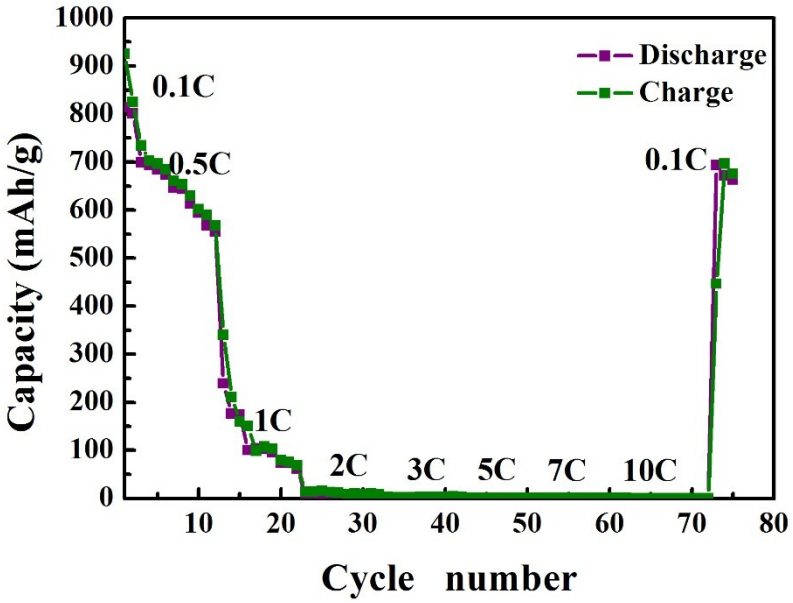

Figure S7. Rate capability of pure MoS_2 nanosheet at various current densities of 0.1C, 0.5C, 1C, 2C, 3C, 5C, 7C, 10C, and finally returned to 0.1 C (1C=1A/g). The results show bare MoS_2 exhibited unstable capacity retention and poor high rate performance due to low conductivity of electrode.

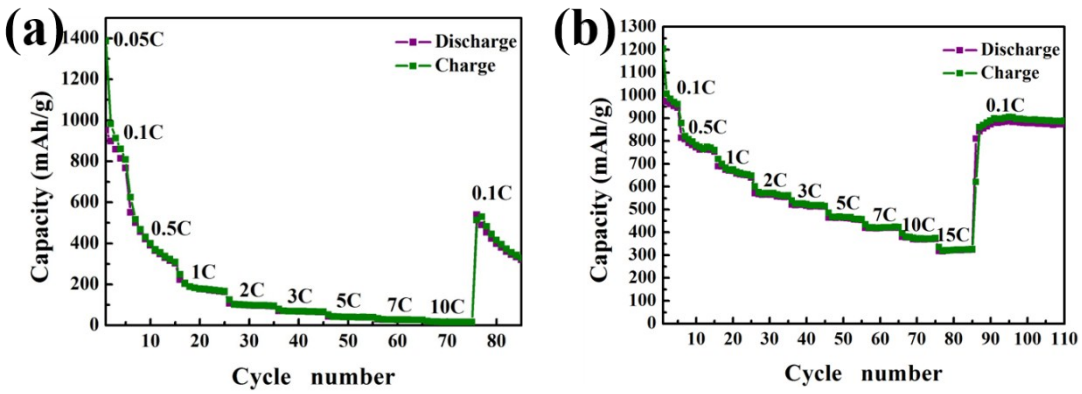

Figure S8. Rate capability of Ge/MoS2 nanocomposites at various weight ratios to evaluate the appropriate parameter at the current densities from 0.1C to 10C, and finally returned to 0.1 C (1C=1A/g). (a) Ge/MoS_2 (1:1) (b) Ge/MoS_2 (4:1)

(a)

Element	Weight %	Atomic %
Mo	21	16.7
S	31	33
Ge	48	50.3

(b)

Element	Weight %	Atomic %
Mo	9.6	7.6
S	14.4	15.2
Ge	76	77.2

Table S1. Quantitative characterization of the composition of Ge/MoS_2 composites with different weight ratios by EDS analysis (a) Ge/MoS2 (1:1) (b) Ge/MoS2 (4:1)