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SUPPORTING IMFORMATION

Uniform GeO_2 dispersed in nitrogen-doped porous carbon core-shell architecture: Anode material for Lithium Ion Batteries

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Table S1. Chemical composition of GeO_2/N-C.

Sample	Weight Content (wt%)				
	N	C	H	Sulfur	GeO_2
GeO_2/N-C	1.22	15.86	0.22	0	82.7

*The weight contents of nitrogen, carbon, hydrogen, and oxygen were determined by elemental analysis (CHNS). The remaining content was GeO_2. This value is in good agreement with the TG data.

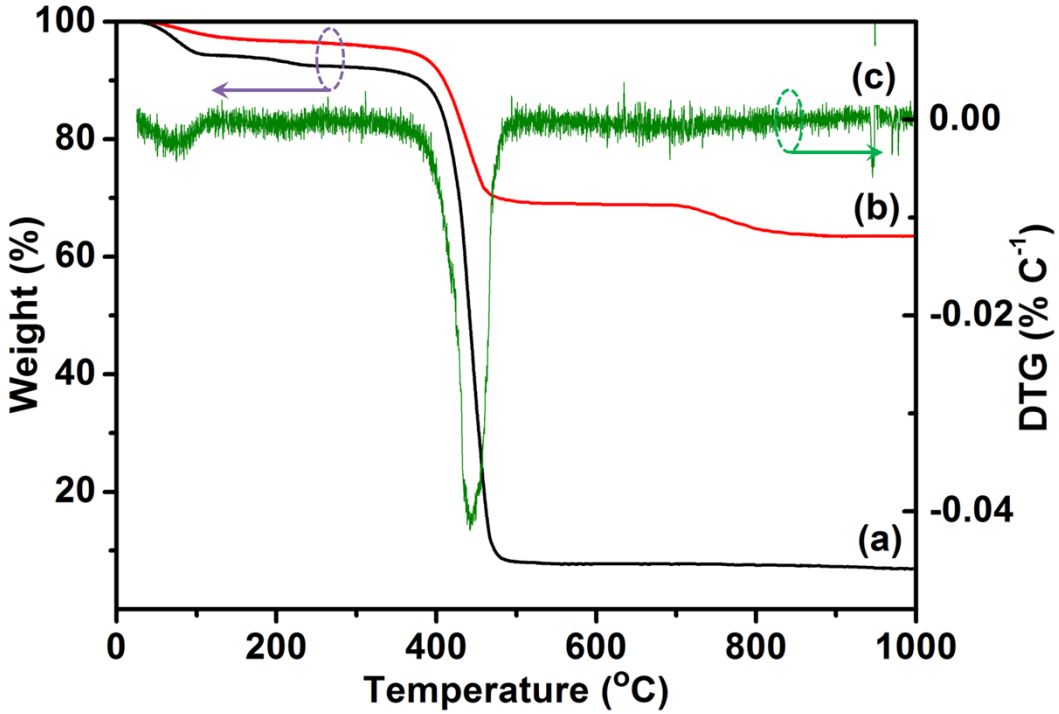

Fig. S1 Thermo-gravimetric (TG) analysis of (a) PVP and (b) mixture of GeO_2-PVP with a weight ratio of 2:1. (c) Derivative Thermogravimetric (DTG) analysis of PVP.

Thermo-gravimetric (TG) analysis of the samples was performed to study the thermal decomposition behavior of PVP and GeO_2/PVP. **Fig. S1** shows the TG curves of PVP and GeO_2/PVP obtained at a heating rate of 10 °C min^{-1} under argon flux of 50 ml min^{-1}. For the PVP (**Fig. S1**a), the weight loss observed below 100 °C was attributed to the moisture removal. The subsequent weight loss corresponded to the decomposition of PVP. The weight loss started at around 298 °C and continued up to 482 °C with 91.9% weight loss, leaving only residual carbon. The dramatic weight loss observed in the TG curve is attributed to the result of the break-down of the side groups of PVP.[1] According to Imre et al.,[2] the main gases evolved during the decomposition of PVP were CO_2, H_2O, NO, and NO_2. This phenomenon was also confirmed by a very sharp endothermic peak observed at 442 °C in the DTG curve (**Fig. S1**c). Herein, the

TG behavior of GeO_2/PVP (**Fig. S1**b) was similar to that of PVP. According to the observed thermal behavior of GeO_2/PVP, the annealing temperature for the decomposition of GeO_2 in the PVP matrix to prepare GeO_2/N-C was fixed to 500 °C. At a higher temperature, the particle size of GeO_2 could become larger due to the agglomeration of GeO_2 at an elevated temperature.

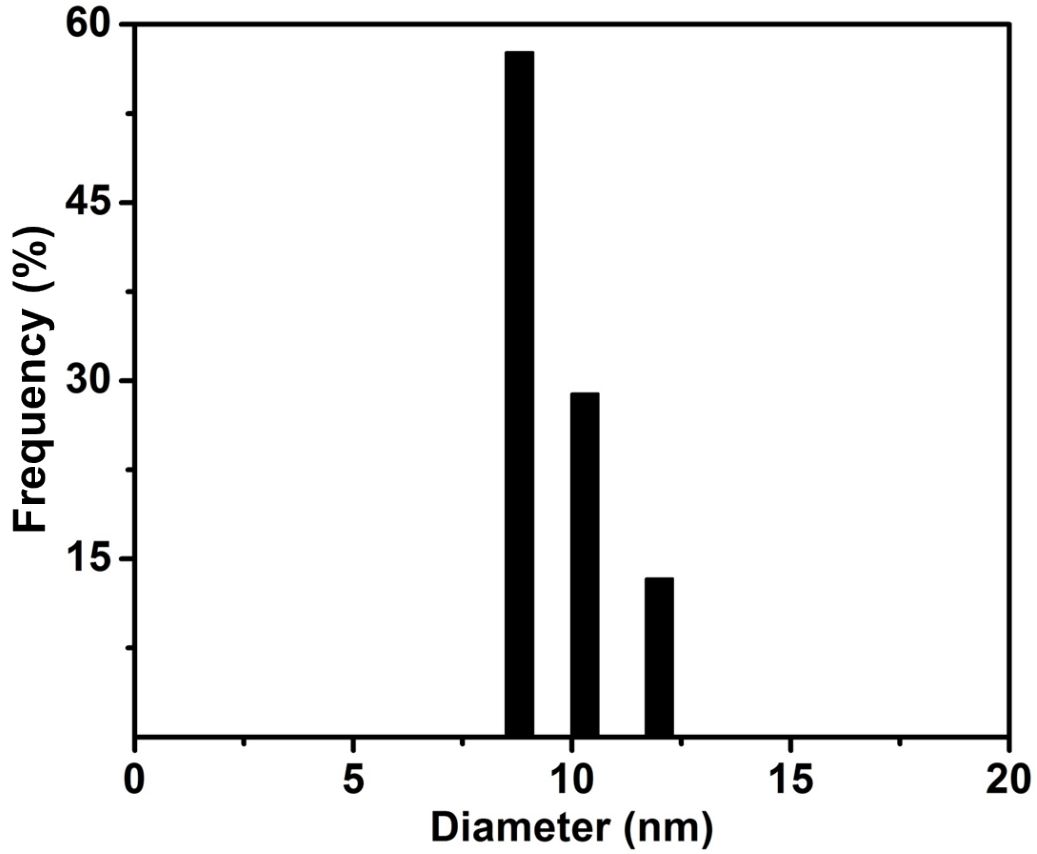

Fig. S2 Particle size distribution of GeO_2, prepared by sol-gel method, obtained from the DLS measurement.

The dynamic light scattering (DLS) measurement of the transparent colloidal dispersion exhibited a narrow size distribution of GeO_2 synthesized using the sol-gel method. As observed in **Fig. S2**, the particle size of GeO_2 was uniform with a diameter ranging from 8 to 12 nm, and the average diameter obtained from the DLS method was 10 ± 2 nm.

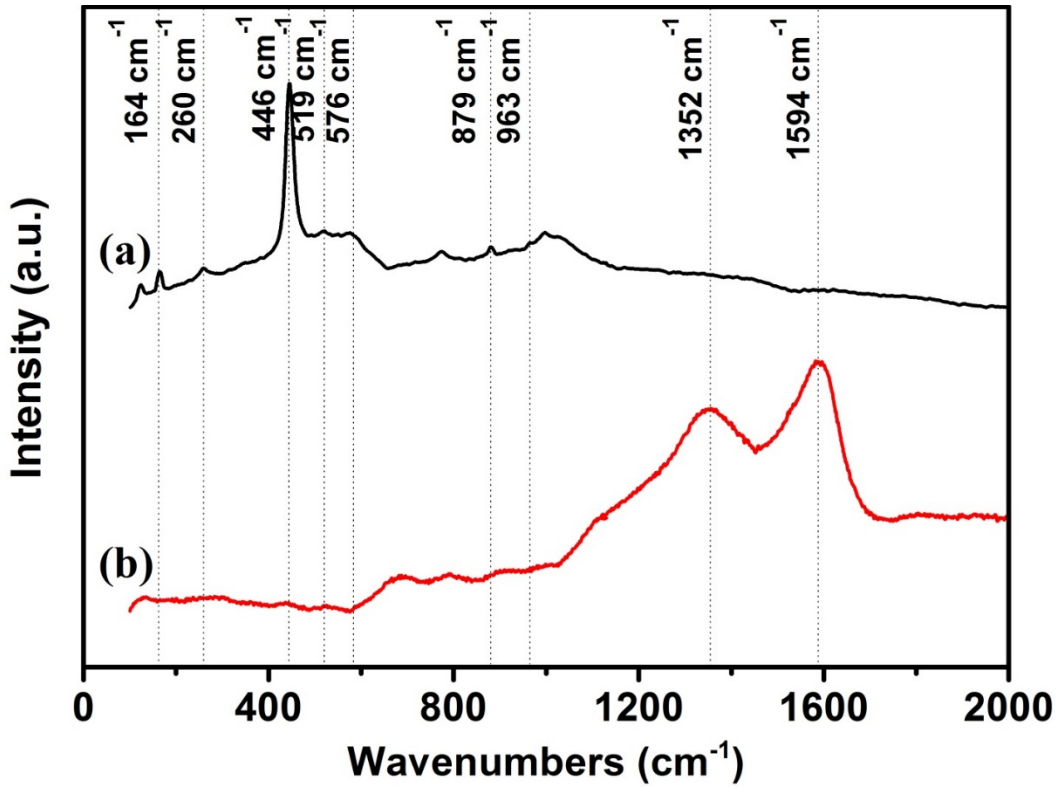

Fig. S3 Raman spectra of (a) GeO_2 and (b) GeO_2/N-C.

As shown in **Fig. S3**a (Raman shift of GeO_2), all peaks matched well with the vibration of GeO_2. The bands observed at 879 and 963 cm^{-1} corresponded to the Ge-O stretching, while the peaks observed at 519 and 576 cm^{-1} were attributed to the stretching of Ge-Ge. The band observed at 446 cm^{-1} corresponded to the symmetric Ge-O-Ge stretching, and the two bands observed at 164 and 260 cm^{-1} were related to the rotation of the GeO_4 tetrahedra.[3]

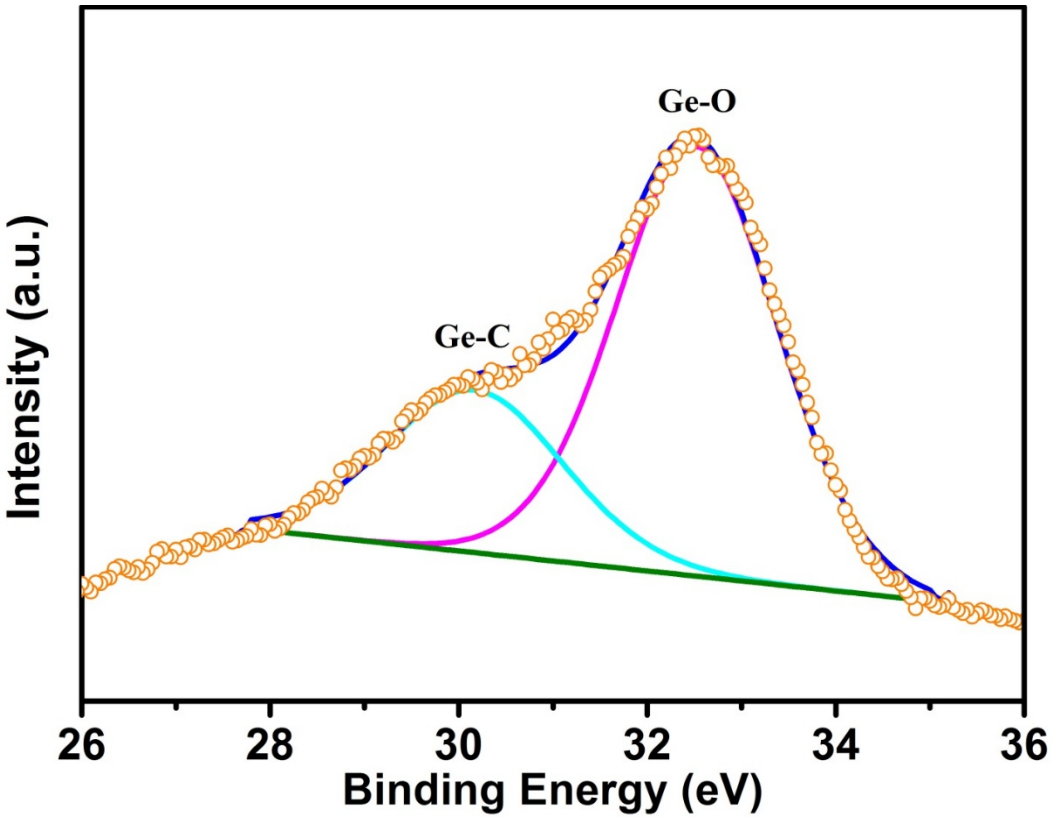

Fig. S4 High-resolution XPS core spectrum of Ge for the 3d level of GeO_2/N-C.

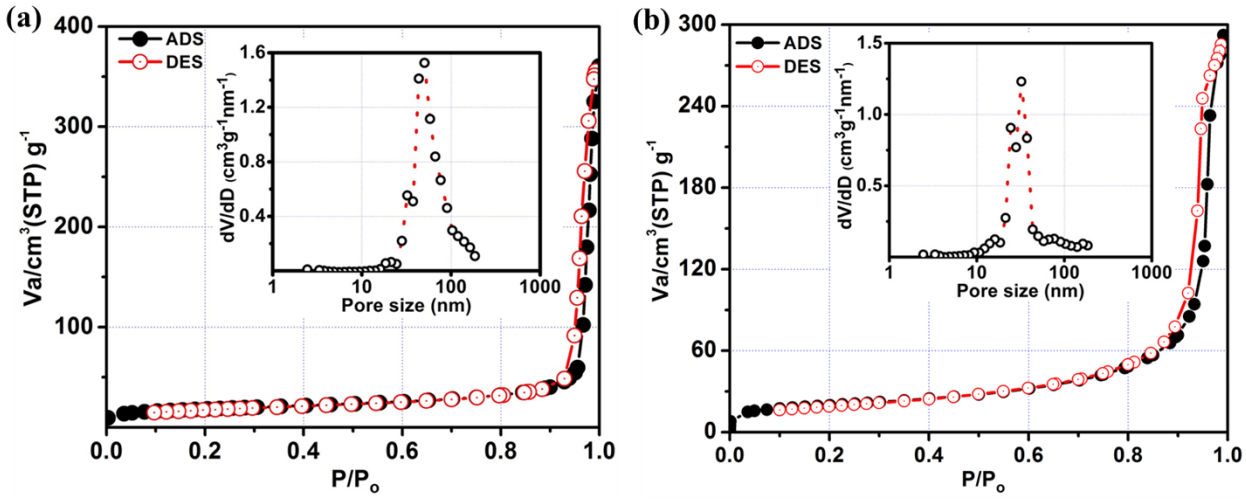

Fig. S5 N_2 adsorption/desorption isotherms of the samples (a) GeO_2 and (b) GeO_2/N-C. The inset fig.s show pore size distribution calculated using the Barrett-Joyner-Halenda (BJH) formula.

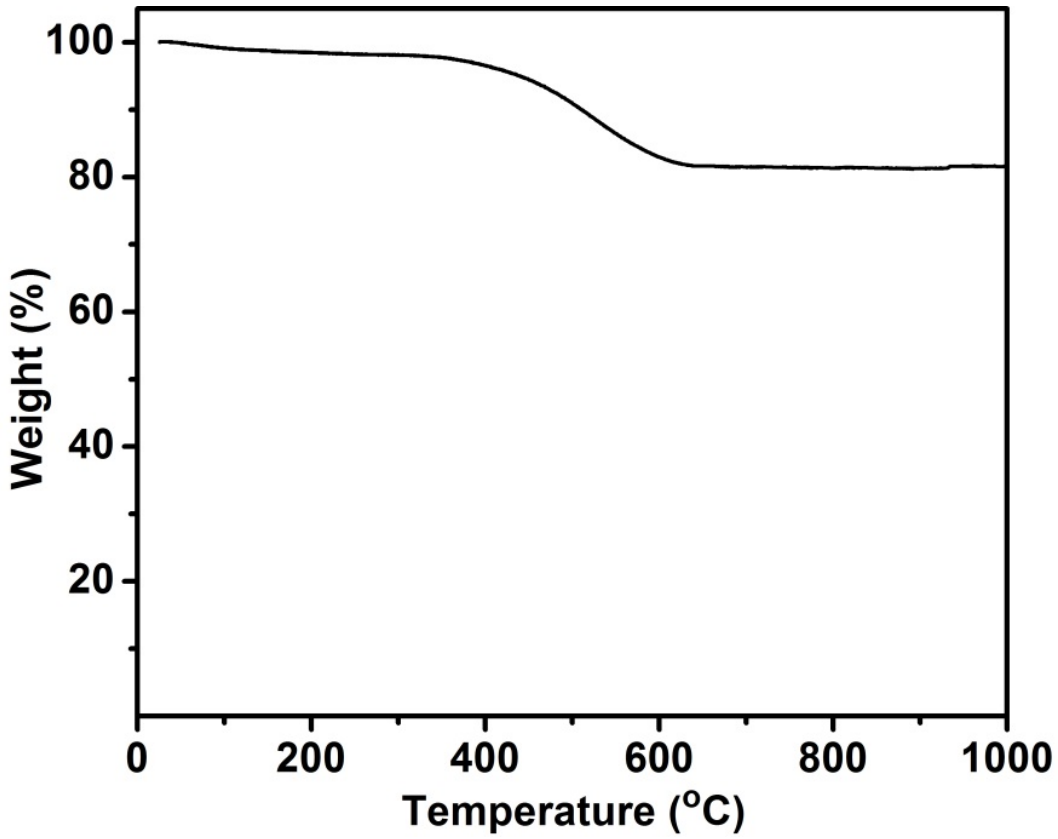

Fig. S6 Thermo-gravimetric analysis of GeO_2/N-C in air at a heating rate of 10 °C min^{-1}.

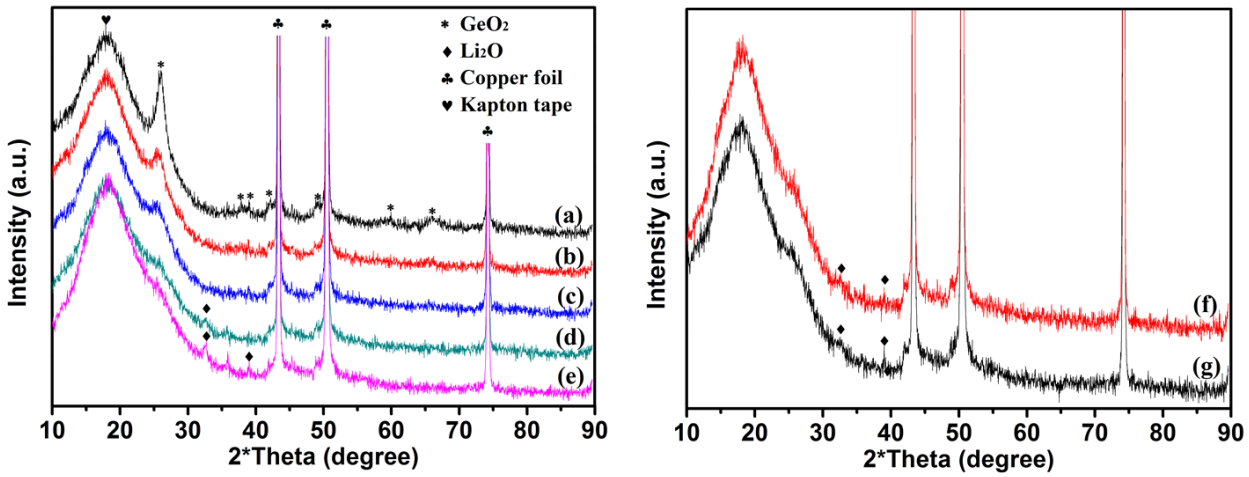

Fig. S7 XRD patterns of GeO_2 electrodes measured at the different states of discharge in the first cycle; (a) as-prepared, (b) discharged to 0.75 V, (c) discharged to 0.50 V, (c) discharged to 0.25 V, and (d) discharged to 0.01V. XRD patters of GeO_2/N-C electrodes tested after 50 cycles; (f) fully discharged and (g) fully charged.

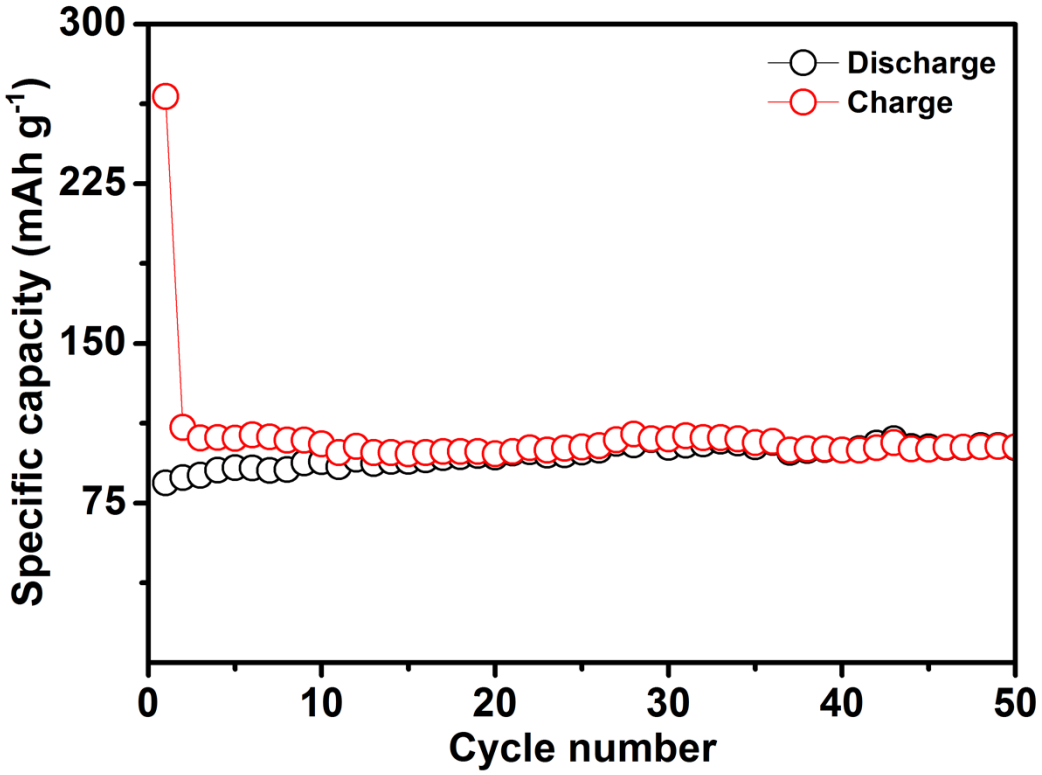

Fig. S8 Cyclability of pyrolysis carbon.

Herein, to investigate the contribution of pure N-carbon derived from PVP (pyrolysis carbon), we prepared pyrolysis carbon through carbonization of PVP at 500 °C for 1 h in argon atmosphere. As shown in **Fig. S8**, the specific capacity of pyrolysis carbon (~ 90 mAh g^{-1}) was much smaller than that of GeO_2 based electrodes.

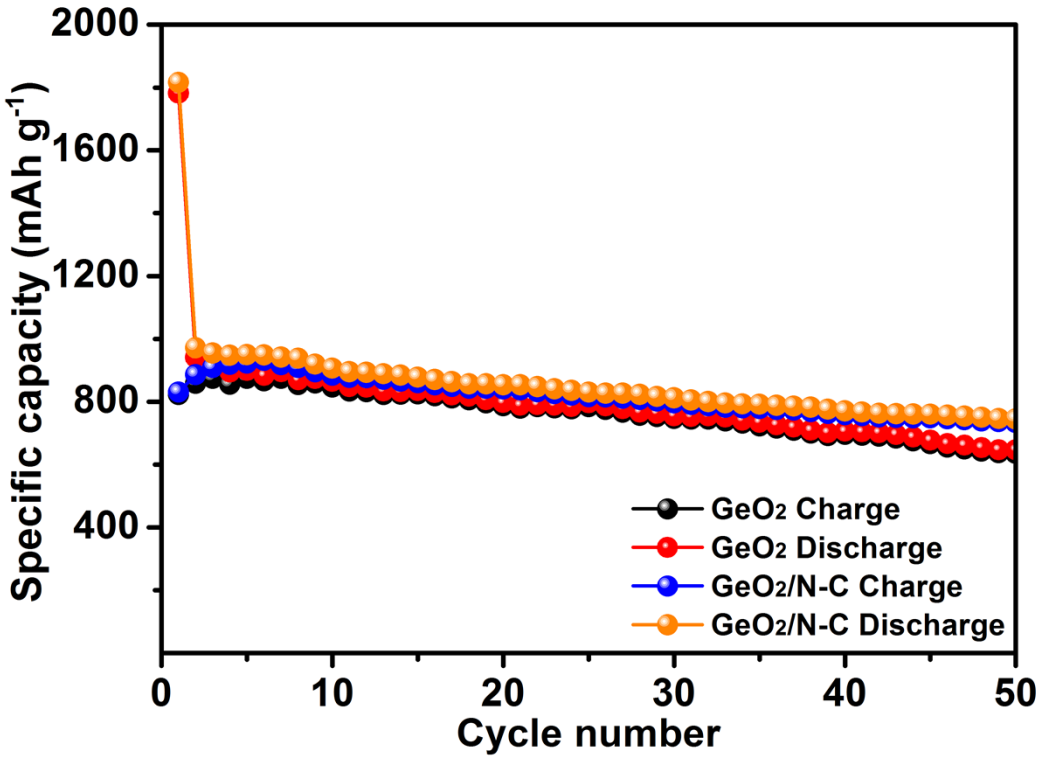

Fig. S9 Cyclability of GeO_2 and GeO_2/N-C electrodes with the high loading mass of 2 mg cm^{-2}, measured at the rate of C/2.

References

1. M. F. Silva, C. A. da Silva, F. C. Fogo, E. A. G. Pineda and A. A. W. Hechenleitner, *J. Therm. Anal. Calorim.*, 2005, **79**, 367-370.
2. I. Szilágyi, E. Santala, M. Heikkilä, M. Kemell, T. Nikitin, L. Khriachtchev, M. Räsänen, M. Ritala and M. Leskelä, *J. Therm. Anal. Calorim.*, 2011, **105**, 73-81.
3. V. V. Atuchin, T. A. Gavrilova, S. A. Gromilov, V. G. Kostrovsky, L. D. Pokrovsky, I. B. Troitskaia, R. S. Vemuri, G. Carbajal-Franco and C. V. Ramana, *Cryst. Growth Des.*, 2009, **9**, 1829-1832.