Electronic Supplementary Material (ESI) for New Journal of Chemistry.

Supporting Information

Carbon coated nickel-cobalt bimetallic sulfides hollow dodecahedrons for supercapacitor with enhanced electrochemical performance

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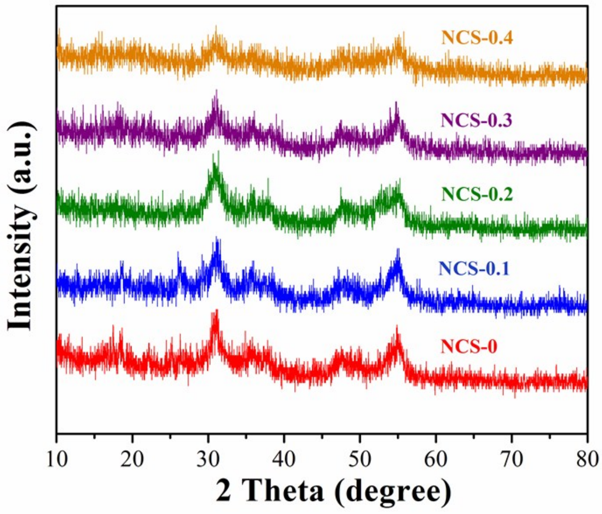

Fig. S1 XRD patterns of NCS-x (x = 0, 0.1, 0.2, 0.3, 0.4).

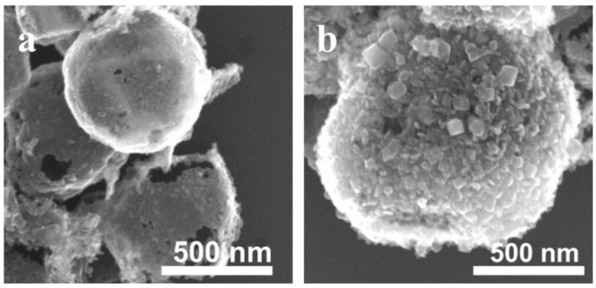

Fig. S2 SEM images of NCSC-0.2 coated by different mass ratios between NCS-0.2 and glucose: (a) 1:1, (b) 1:3.

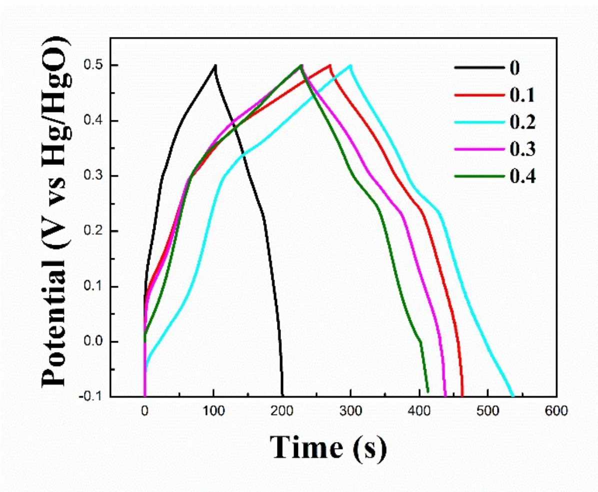

Fig. S3 GCD curves of NCS-x at the current density of 1 A g^{-1}.

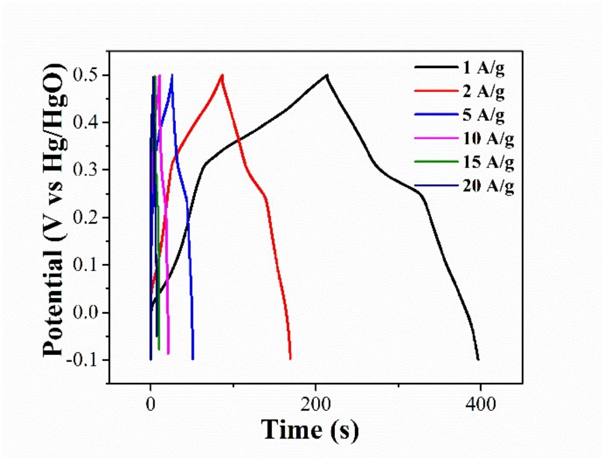

Fig. S4 Galvanostatic charge/discharge curves of the NCS-0.2 at different current densities.

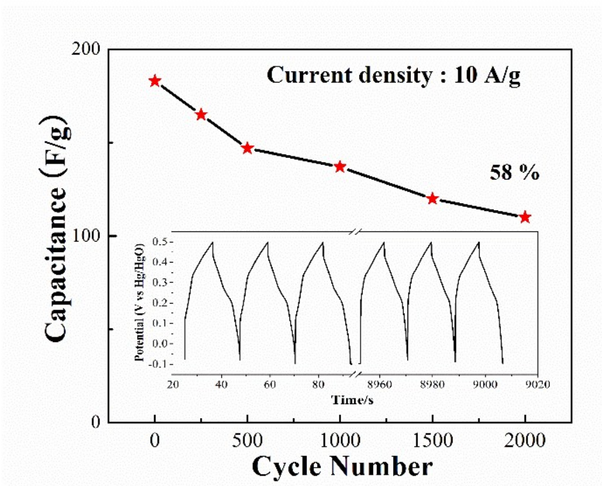

Fig. S5 Cycling performance of NCS-0.2.

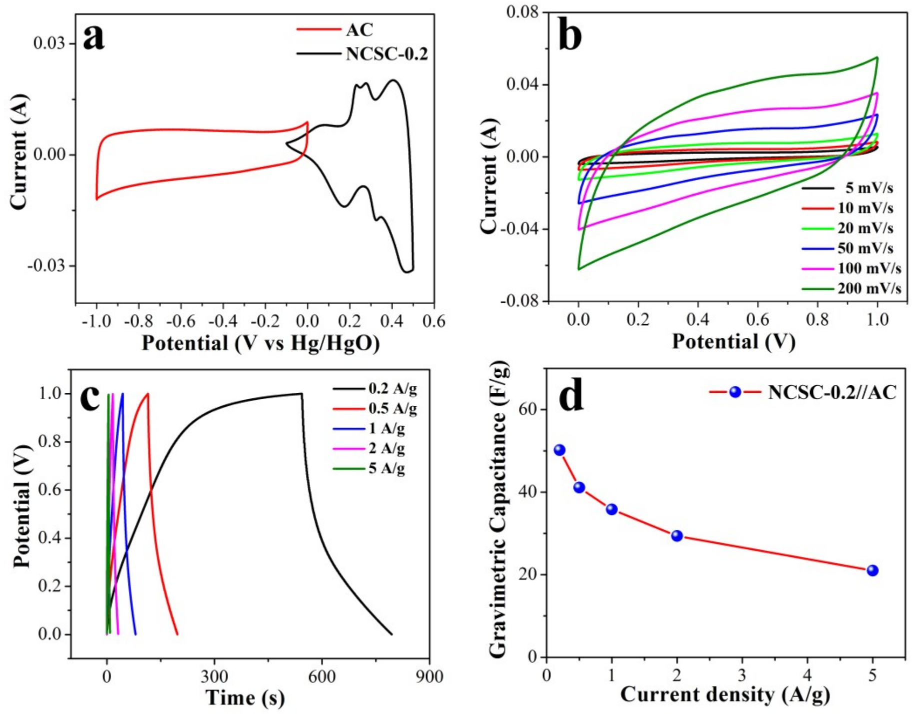

Fig. S6 (a) CV curves of the NCSC-0.2 and AC electrodes tested at a scan rate of 5 mV/s in a three-electrode system. (b) CV curves and (c) galvanostatic charge–discharge curves of NCSC-0.2//AC device. (d) Specific capacitance at various current densities of the assembled NCSC-0.2//AC asymmetric supercapacitor.

TEXT S1:

Additional Experimental Section:

The asymmetric supercapacitor was fabricated by using as-synthesized NCSC-0.2 and AC (activated carbon) as the positive electrode and the negative electrode materials, respectively. The total active materials mass for the two electrodes was 10.8 mg. Each electrode was composed of a mixture containing active material (80 wt%), aqueous emulsion of polytetrafluoroethylene (10 wt%) and carbon black (10 wt%). Then these two electrodes were separated by a filter paper. The fabricated cell was encapsulated after the electrodes and the filter paper rinsed through injecting KOH solution (6 M, 200 μL) into the cell. The measurements were conducted on a CHI660E electrochemical workstation (Chenhua, Shanghai). The specific capacitance was calculated from galvanostatic charge-discharge (GCD) curves based on the following equations:[S1]

$$C_s = \frac{\mathrm{It}}{m\Delta V} \tag{1}$$

The C_s, I, m, t and ΔV refer to the specific capacitance (F g^{-1}), current (A), mass of active materials (g), discharge time (s) and operating potential range (V), respectively. Energy density and power density are two crucial indexes to assess an asymmetric supercapacitor for practical application, which can be calculated by the following two equations:[S2,S3]

$$E = \frac{1}{7.2} C_s(\Delta V)^2 \tag{2}$$

$$P = 3600\frac{E}{t} \tag{3}$$

Where E (Wh·kg^{-1}) is the energy density, P (W·kg^{-1}) is the power density of the asymmetric supercapacitor.

Additional Discussion:

The CV curve for AC is close to rectangular shape without any redox peak in the potential window of -1.0-0 V, revealing a typical electric double-layer capacitance characteristic (Fig. S6a). Electrochemical performance of as-fabricated asymmetric supercapacitor has been evaluated by two electrode system. Fig. S6b showed CV curves of asymmetric NCSC-0.2//AC supercapacitor at various scan rates in the potential window of 0-1 V. The current increased with the increase of scan rate from 5 to 200 mV/s. The electrochemical performance of the asymmetric supercapacitor was further evaluated by galvanostatic charge/discharge measurement (Fig. S6c). The detailed specific capacitance of the asymmetric supercapacitor was calculated on the basis of the above GCD curves and shown in Fig. S6d. The capacitance of the asymmetric supercapacitor reached 50.2 F·g^{-1} at the current density of 0.2 A·g^{-1}. And the specific capacitances were 41.1 F·g^{-1}, 35.8 F·g^{-1}, 29.4 F·g^{-1} and 21.0 F·g^{-1} at the current density of 0.5 A·g^{-1}, 1 A·g^{-1}, 2 A·g^{-1} and 5 A·g^{-1}, respectively. After calculation according to the equations (2) and (3), the NCSC-0.2//AC asymmetric supercapacitor delivers the energy density of 7.0 Wh·kg^{-1} at a power density of 100.4 W·kg^{-1}, and still retains an energy density of 4.8 Wh·kg^{-1} at a power density of 490.0 W·kg^{-1}.

Table S1 Electrochemical performance of NCSC-0.2 hollow dodecahedrons electrode compared with reported sulfides electrodes.

Electrode structure	Specific capacitance	Capacitance degradation	Capacitance retention	Reference
NCSC-0.2 hollow dodecahedrons	620 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	27% after 2000 cycles at 10 A g^{-1}	81.6% from 1 to 10 A g^{-1}	this work
CoS_2-C@TCL hollow nanocage	873 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	12% after 2000 cycles at 5 A g^{-1}	73.4% from 1 to 10 A g^{-1}	S4
Ni_2CoS_4 nanoparticles	702.3 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	51% after 2000 cycles at 4 A g^{-1}	60.1% from 1 to 5 A g^{-1}	S5
Co_3O_4@CoS core-shell nanosheets arrays on carbon cloth	764.2 $F \cdot g^{-1}$ at 1 $A \cdot g^{-1}$	21.9% after 5000 cycles at 5 A g^{-1}	72.2% from 1 to 10 A g^{-1}	S6
Ni_7S_6/Co_3S_4 nanoboxes	631 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	-	64.3% from 4 to 10 A g^{-1}	S7
Co_3O_4@Co_3S_4 nanoarrays	425.1 $F \cdot g^{-1}$ at 10 $mV \cdot s^{-1}$	6.9% after 5000 cycles at 4 A g^{-1}	32.7% from 5 to 50 $mV \cdot s^{-1}$	S8
Co_9S_8@S,N-doped carbon	396 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	2% after 2000 cycles at 5 A g^{-1}	85.8% from 1 to 10 A g^{-1}	S9
Sheet-like Co_3S_4	787 $F \cdot g^{-1}$ at 4 $A \cdot g^{-1}$	5.7% after 3000 cycles at 1 A g^{-1}	63.8% from 1 to 8 A g^{-1}	S10
NiS_2–CoS_2 composites	751.8 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	0.01% after 1000 cycles at 5 A g^{-1}	60.6% from 1 to 10 A g^{-1}	S11

Table S2 Electrochemical performance of NCSC-0.2 hollow dodecahedrons electrode compared with some reported carbon materials based electrodes.

Electrode structure	Specific capacitance	Capacitance degradation	Capacitance retention	Reference
NCSC-0.2 hollow dodecahedrons	620 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	27% after 2000 cycles at 10 A g^{-1}	81.6% from 1 to 10 A g^{-1}	this work
PANI/rGO composites	514.9 $F \cdot g^{-1}$ at 5 $A \cdot g^{-1}$	31.9% after 1000 cycles at 10 $A \cdot g^{-1}$	68.1% from 0.5 to 10 $A \cdot g^{-1}$	S12
Graphene@Polyaniline@Graphene sandwich hollow spheres	about 550 $F \cdot g^{-1}$ at 1 $A \cdot g^{-1}$	12.4% after 10000 cycles at 50 $mV \cdot s^{-1}$	46.8% from 0.5 to 10 A g^{-1}	S13
Mulberry-like carbon fiber web	298.6 $F \cdot g^{-1}$ at 1 $A \cdot g^{-1}$	2.7% after 5000 cycles at 1 A g^{-1}	about 73.7% from 1 to 10 A g^{-1}	S14

[S1] Y. Li, L. Cao, L. Qiao, M. Zhou, Y. Yang, P. Xiao and Y. Zhang, *J. Mater. Chem. A*, 2014, **2**, 6540-6548.
[S2] X. Li, W. Sun, L. Wang, Y. Qi, T. Guo, X. Zhao and X. Yan, *RSC Adv.*, 2015, **5**, 7976-7985.
[S3] J. Yang, C. Yu, X. Fan, S. Liang, S. Li, H. Huang, Z. Ling, C. Hao and J. Qiu, *Energy Environ. Sci.*, 2016, **9**, 1299-1307.
[S4] M. Jin, S.-Y. Lu, L. Ma, M.-Y. Gan, Y. Lei, X.-L. Zhang, G. Fu, P.-S. Yang and M.-F. Yan, *J. Power Sources*, 2017, **341**, 294-301.
[S5] W. Du, Z. Zhu, Y. Wang, J. Liu, W. Yang, X. Qian and H. Pang, *RSC Adv.*, 2014, **4**, 6998-7002.
[S6] J. Ning, T. Zhang, Y. He, C. Jia, P. Saha and Q. Cheng, *Materials*, 2017, **10,** 608.
[S7] H. Hua, S. Liu, Z. Chen, R. Bao, Y. Shi, L. Hou, G. Pang, K. N. Hui, X. Zhang and C. Yuan, *Sci. Rep.*, 2016, **6**, 20973.
[S8] B. Liu, D. Kong, J. Zhang, Y. Wang, T. Chen, C. Cheng and H. Y. Yang, *J. Mater. Chem. A*, 2016, **4**, 3287-3296.
[S9] S. Liu, M. Tong, G. Liu, X. Zhang, Z. Wang, G. Wang, W. Cai, H. Zhang and H. Zhao, *Inorg. Chem. Front.*, 2017, **4**, 491-498.
[S10] B. Xu, L. Pan and Q. Zhu, *J. Mater. Eng. Perform.*, 2016, **25**, 1117-1121.
[S11] H. Zhang, B. Guan, J. Gu, Y. Li, C. Ma, J. Zhao, T. Wang and C. Cheng, *RSC Adv.*, 2016, **6**, 58916-58924.
[S12] Y. Tao, Z. Liu, X.-Z. Song, M. Bao and Z. Tan, *Nano*, 2017, **12**, 1750088.
[S13] X. Liu, N. Wen, X. Wang and Y. Zheng, *ACS Sustainable Chem. Eng.*, 2015, **3**, 475-482.
[S14] C. Liu, J. Liu, J. Wang, J. Li, R. Luo, J. Shen, X. Sun, W. Han and L. Wang, *J. Colloid Interface Sci.*, 2018, **512**, 713-721.