Supporting Information

Nitrogen-Doped Carbon-Encapsulated Antimony Sulfide Nanowires Enable High Rate Capability and Cyclic Stability for Sodium Ion Batteries

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Figure S1 TGA curve of (a) Sb$_2$S$_3$@N-C and (b) Sb$_2$S$_3$@N-HC composites from room temperature to 700 °C at a heating rate of 10 °C min$^{-1}$ under air atmosphere.

Figure S2 Full survey of the XPS spectrum of Sb$_2$S$_3$@N-C composites. The XPS spectra of Sb$_2$S$_3$@N-C composites show that the binding between Sb$_2$S$_3$ nanowires and carbon mainly comes from the stable C-S bonds, possibly enhancing the electronic conductivity due to the synergistic bridging effect. It also improves performance by suppressing the dissolution of S during the cycling process, resulting in the long term stability for sodium ion batteries.

Figure S3 (a) and (b) SEM images of Sb$_2$S$_3$ nanowires with different magnifications.
The conductivity for the carbon materials was enhanced at the high annealing temperature. But Sb$_2$S$_3$ and carbon composites are not stable at the high temperature because of the dopamine layer annealed at 500 °C under Ar atmosphere was initially carbonized and then acted as the reduction agent to further convert Sb$_2$S$_3$ to metallic Sb.

Figure S4 CVs of Sb$_2$S$_3$@N-C composites at 0.1 mV s$^{-1}$ between 0.01 V and 2.5 V versus Na/Na$^+$ for the first three cycles.

The CVs of Sb$_2$S$_3$@N-C composites at 0.1 mV s$^{-1}$ between 0.01 V and 2.5 V versus Na/Na$^+$ for the first three cycles were obtained as shown in Figure S4.

Figure S5 (a) Rate capability of Sb$_2$S$_3$@N-HC composites at various current densities; (b) cyclic stability of Sb$_2$S$_3$ nanowires tested at a current density of 0.1 A g$^{-1}$ for the first 5 cycles and then tested at 1.0 A g$^{-1}$ for 1000 cycles.
Figure S6 (a) Rate capability of Sb$_2$S$_3$ nanowires at various current densities; (b) cyclic stability of Sb$_2$S$_3$ nanowires tested at a current density of 0.1 A g$^{-1}$ for the first 5 cycles and then tested at 1.0 A g$^{-1}$ for 300 cycles.

Figure S7 Cyclic stability of Sb$_2$S$_3$@N-C composites tested at a current density of 0.2 A g$^{-1}$ for the first 5 cycles and then tested at 2.0 A g$^{-1}$ for 2000 cycles.

Figure S8 Nyquist plots ($Z'$ vs. $-Z''$) of Sb$_2$S$_3$ nanowires and Sb$_2$S$_3$/N-C composites in the frequency range from 100 kHz to 5 mHz.
Figure S9 (a) and (b) SEM images of Sb$_2$S$_3$@N-C composites with different magnification after 1000 cycles tested at a current density of 1.0 A g$^{-1}$.

Table S1 Comparison of electrode performance of the Sb$_2$S$_3$@N-C composites with previous reported Sb$_2$S$_3$-based anode materials for SIBs.

| Sample                                      | Voltage range (V) | Current density (mA g$^{-1}$) | Capacity (mAh g$^{-1}$) (Cycle number) |
|---------------------------------------------|-------------------|--------------------------------|----------------------------------------|
| rGO/Sb$_2$S$_3$ 17                         | 0-2               | 50                             | 670 (50)                               |
| Sb$_2$S$_3$@C rods 38                      | 0-2.5             | 200                            | 640.8 (100)                            |
| Sb$_2$S$_3$-graphite 20                     | 0-3               | 100                            | 656 (100)                              |
| Flower like Sb$_2$S$_3$ 49                  | 0-2               | 200                            | 641.7 (50)                             |
| Sb$_2$S$_3$/SGS composite 26                | 0-2.5             | 2000                           | 524.4 (900)                            |
| rGO/Sb$_2$S$_3$ 23                         | 0.005-1           | 100                            | 306 (60)                               |
| carbon-coated 1D Sb$_2$S$_3$ nanorod 47     | 0-2               | 100                            | 570 (100)                              |
| Sb$_2$S$_3$ in P/C composite 22             | 0-2               | 50                             | 611 (100)                              |
| MWNTs@Sb$_2$S$_3$@PPy 21                   | 0-2               | 100                            | 492 (85)                               |
| Sb$_2$S$_3$/RGO 28                         | 0.005-3           | 50                             | 581 (50)                               |
| Sb$_2$S$_3$/MWCNTs 16                      | 0.005-3           | 50                             | 412.3 (50)                             |
| This work: Sb$_2$S$_3$/N-C                 | 0.01-3            | 1000                           | 625 (1000)                             |