Supplementary Information

High-performance all-solid-state electrolyte for sodium batteries enabled by the interaction between the anion in salt and Na$_3$SbS$_4$

Yong Lu*, Lin Li*, Qiu Zhang, Yichao Cai, Youxuan Ni, and Jun Chen*

Frontiers Science Center for New Organic Matter, Renewable Energy Conversion and Storage Center (RECAST), Haihe Laboratory of Sustainable Chemical Transformations, Key Laboratory of Advanced Energy Materials Chemistry (Ministry of Education), College of Chemistry, Nankai University, Tianjin 300071, China

*These authors contributed equally to this work.

*Correspondence: chenabc@nankai.edu.cn

Supplementary Information contains this PDF file and one Video file (“Supplementary Video S1.mp4”).
Table of Contents

Experimental Section ........................................................................................................... S3

Density Functional Theory (DFT) Calculation Details .......................................................... S6

Finite Element Method (FEM) Simulation Details ................................................................. S6

Figure S1. XRD patterns of the prepared Na₃SbS₄ at different states .................................... S7

Figure S2. SEM images of the prepared Na₃SbS₄ ................................................................. S7

Figure S3. Ionic conductivity of the prepared Na₃SbS₄ ......................................................... S8

Figure S4. Investigation on whether Na₃SbS₄ can be dissolved in PEO ................................. S9

Figure S5. Na⁺ transference number of PEO/NaTFSI electrolyte ........................................ S10

Figure S6. Elemental mapping of the obtained PEO/NaTFSI/Na₃SbS₄ electrolyte ................ S10

Figure S7. AFM characterization on the obtained PEO/NaTFSI electrolyte ......................... S11

Table S1. Comparison on surface roughness and Young’s modulus of different electrolytes ... S11

Figure S8. Thermal stability of the PEO/NaTFSI/Na₃SbS₄ electrolyte ............................... S12

Figure S9. Electrochemical stability window of the PEO/NaTFSI/Na₃SbS₄ electrolyte ............ S12

Table S2. Comparison on performance of different electrolytes ........................................... S13

Figure S10. Voltage profiles of symmetric cells with different electrolytes at 0.1 mA cm⁻² .... S14

Table S3. Comparison on performance of Na|Na symmetric cells with different electrolytes ... S14

Figure S11. XPS spectra of Na electrode after stripping/plating with different electrolytes ... S15

Figure S12. Geometry used in FEM simulation ................................................................. S16

Table S4. FEM simulation parameters setting for Na deposition ........................................... S16

Figure S13. High-resolution SEM images of the interfaces ................................................. S17

Figure S14. Rate performance of Na–PTCDA batteries with PEO/NaTFSI electrolyte ........... S17

Figure S15. Cycling performance of Na–PTCDA batteries with liquid electrolyte ............... S18

Table S5. Comparison on performance of Na batteries with different electrolytes ............... S19

References ............................................................................................................................. S20
Experimental Section

Synthesis of Na$_3$SbS$_4$

Na$_3$SbS$_4$ was synthesized according to the previous literature.[1] In a typical synthesis, 12 mmol (0.936 g) anhydrous Na$_2$S (Aladdin, Shanghai, China), 4 mmol (0.128 g) S (Aladdin, Shanghai, China), and 2 mmol (0.583 g) Sb$_2$O$_3$ (Aladdin, Shanghai, China) were added to 4 mL H$_2$O at 50 °C in turn. Then, the mixture was stirred at 60 °C for 30 mins, followed by filtration. The filtrate was put in ice bath for 1 h and then filtered to get precipitate. The precipitate was crystalized again to obtain pure Na$_3$SbS$_4$ sample. The sample was dried under vacuum at 80 °C for 12 h and then 150 °C for 6 h. Before preparing all-solid-state electrolytes, the sample was ball-milled (weight ratio of sample to bead is 1:20) at 500 rpm for 6 h under Ar atmosphere and stored in an Ar-filled glove box where O$_2$ and H$_2$O concentrations were kept less than 0.1 ppm. The reactions during synthesis can be described as:

\[
6 \text{Na}_2\text{S} + 2\text{S} + \text{Sb}_2\text{O}_3 + 21\text{H}_2\text{O} = 2\text{Na}_3\text{SbS}_4 \cdot 9\text{H}_2\text{O} + 6\text{NaOH}
\]  
\[
\text{Na}_3\text{SbS}_4 \cdot 9\text{H}_2\text{O} \rightleftharpoons \text{Na}_3\text{SbS}_4 + 9\text{H}_2\text{O}
\]

Preparation of all-solid-state electrolyte

The all-solid-state electrolyte was prepared via a simple solution casting method. For the preparation of PEO/NaTFSI electrolyte, PEO (1 g, molecular weight: 600000, Aladdin, Shanghai, China) and NaTFSI (0.689 g, molar ratio of EO to Na$^+$ is 10:1, DodoChem, Suzhou, China) were added to anhydrous acetonitrile (HEOWNS, Tianjin, China, treated with activated 3Å molecular sieve to remove trace H$_2$O before use and stored in an Ar-filled glove box where O$_2$ and H$_2$O concentrations were kept less than 0.1 ppm) and stirred intensely for 12 h at room temperature to form homogeneous solution. Then, the solution was poured into a polytetrafluoroethylene mold. The electrolyte film can be obtained after the mold was heated at 65 °C under vacuum for 24 h to remove residual acetonitrile. For the preparation of PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte with different contents of Na$_3$SbS$_4$, 0.1, 0.15, 0.2, 0.25, 0.3, or 0.4 g Na$_3$SbS$_4$ (weight ratio to PEO is 10,
15, 20, 25, 30, or 40 wt%, respectively) was added in the mixture of PEO and NaTFSI before stirring. Other preparation processes are the same as those for the preparation of PEO/NaTFSI electrolyte. To avoid any interference from H2O, all the electrolyte preparation procedures were conducted in an Ar-filled glove box where O2 and H2O concentrations were kept less than 0.1 ppm.

Materials characterizations

The crystal structure of Na3SbS4 and the crystallinity of PEO were characterized by X-ray powder diffraction (XRD, Rigaku MiniFlex600, CuKα radiation). The microstructures of Na3SbS4, PEO/NaTFSI/Na3SbS4 electrolyte, Na metal, and Na–PTCDA batteries were observed via field-emission scanning electron microscopy (SEM, JEOL JSM-7500F). AFM topography image and Young’s modulus mapping were obtained with Peak Force QNM mode (Multimode 8.0, Bruker). The surface elemental information and chemical composition of PEO/Na3SbS4, PEO/NaTFSI/Na3SbS4 electrolyte and Na electrode after cycles, as well as the solubility of Na3SbS4 in PEO were confirmed through X-ray photoelectron spectroscopy (XPS, PerkinElmer PHI 1600 ESCA or Thermo Scientific K-Alpha+). In addition, the solubility of Na3SbS4 in PEO was also studied by Fourier transform infrared spectroscopy (IR, Bruker Tensor II Sample Compartment RT-DLaTGS). The chemical bonds in PEO/Na3SbS4, PEO/NaTFSI electrolyte, and PEO/NaTFSI/Na3SbS4 electrolyte were detected by Raman (Thermo-Fisher Scientific, excitation wavelength, 532 nm). The thermal property/stability of PEO/NaTFSI electrolyte and PEO/NaTFSI/Na3SbS4 electrolyte were evaluated via differential scanning calorimeter (NETZSCH, DSC204) and thermogravimetric analyzer (NETZSCH, STA 449F3).

Electrochemical measurements

The 3,4,9,10-perylenetetracarboxylic dianhydride (PTCDA, HEOWNS, Tianjin, China) cathode was prepared by mixing active materials (PTCDA, 50 wt%), conductive carbon materials (Super P, 40 wt%), binder (PVDF, 10 wt%), and N-methyl-2-pyrrolidinone as dispersing agent to form a slurry. The slurry was smeared onto an Al foil current collector and dried at 80 °C for 12 h in a
vacuum furnace. The mass loading of PTCDA in each cathode is about 0.3–0.5 mg cm$^{-2}$. The anode of the batteries is Na foil. The all-solid-state Na–PTCDA batteries and Na|Na symmetric cells are CR2032 coin-type and fabricated using all-solid-state PEO/NaTFSI or PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte without a separator or additional liquid electrolyte in an Ar-filled glove box where O$_2$ and H$_2$O concentrations were kept less than 0.1 ppm. All the all-solid-state Na–PTCDA batteries and Na|Na symmetric cells were tested at 45 °C (The Na–PTCDA batteries with liquid 1M NaPF$_6$/diglyme electrolyte were tested at room temperature). To achieve favorable electrode/electrolyte interface, all the all-solid-state Na–PTCDA batteries were rested at 70 °C for 6 h before rested and tested at 45 °C. The galvanostatic charge/discharge tests at different rates and the potentiostatic charge tests were performed by Land CT2001A battery instrument. Linear sweep voltammetry in the voltage range of 1–6 V at 0.5 mV s$^{-1}$ and electrochemical impedance spectroscopy in the frequency range of 100k–1 Hz with an amplitude of 5 mV were tested by CHI 660E and CHI 760E electrochemical workstation (ChenHua, Shanghai). The formula to calculate Na$^+$ transference number ($t_+$) is shown as follows.

$$t_+ = \frac{i_{ss}(\Delta V - i_0 R_0)}{i_0(\Delta V - i_{ss} R_{ss})}$$  \hspace{1cm} (3)

where $t_+$, $i_{ss}$, and $i_0$ are the Na$^+$ transference number, steady-state current, and initial current, respectively. $R_{ss}$ and $R_0$ are the resistances at steady state and initial state, respectively. $\Delta V$ is the applied constant potential. The criterion for achieving steady state is that the current and resistance do not further change under the constant potential.
Density Functional Theory (DFT) Calculation Details

All the DFT calculations were carried out by using the Vienna Ab Initio Simulation Package (VASP) with the projector augmented wave (PAW) method.[2] The electronic exchange and correlation effects were described by the generalized gradient approximation (GGA) functional parameterized by Perdew-Burke-Ernzerhof (PBE).[3] The plane-wave cutoff energy was set to 450 eV. The convergence criteria of energy and force were set to $10^{-4}$ eV and 0.02 eV Å$^{-1}$, respectively. The Na$_3$SbS$_4$(111) surface was modelled by a 2 × 2 supercell. A vacuum layer of above 20 Å was adopted to avoid the interaction between the periodic slabs. The adsorption energies were obtained as follows:

$$E_{\text{ads}}(\text{Na}) = E(\text{NaTFSI}) - E(\text{TFSI}) - E(\text{Na})$$

$$E_{\text{ads}}(\text{Na})_{\text{sub}} = E(\text{sub + NaTFSI}) - E(\text{sub + TFSI}) - E(\text{Na})$$

$$E_{\text{ads}}(\text{NaTFSI})_{\text{sub}} = E(\text{sub + NaTFSI}) - E(\text{sub}) - E(\text{NaTFSI})$$

where $E(\text{Na})$, $E(\text{TFSI})$, and $E(\text{NaTFSI})$ are the energies of Na, TFSI, and NaTFSI, respectively. $E(\text{sub + NaTFSI})$ and $E(\text{sub})$ are the energies of the Na$_3$SbS$_4$ substrates with and without adsorbed NaTFSI, respectively. $E(\text{sub + TFSI})$ is the energy of the Na$_3$SbS$_4$ substrates with adsorbed TFSI.

Finite Element Method (FEM) Simulation Details

The pillared electrode was built to simulate the unavoidable microscopic swelling on practical electrode surface (Figure S12).[4] The simulation was performed using the mass transportation laws in concentrated solution which consider the interaction between cations and anions. The simulation temperature is set as 318 K according to the practical operating temperature of batteries in this work.
**Figure S1.** XRD patterns of the prepared Na$_3$SbS$_4$ at different states (pristine, exposed in air for 24 h, and reheated at 150 °C under vacuum for 10 h after exposed in air for 24 h).

When testing XRD, we used Kapton film (polyimide) to seal and protect the Na$_3$SbS$_4$ sample from contacting with air.

**Figure S2.** SEM images of the prepared Na$_3$SbS$_4$ at (a) low magnification and (b) high magnification.
Figure S3. Ionic conductivity of the prepared Na$_3$SbS$_4$. Electrochemical impedance spectroscopy (EIS) plot of the Na$_3$SbS$_4$ disc with two blocking electrodes (stainless steel) at room temperature. Inset: the enlarged area at the high frequency. The diameter and thickness of the Na$_3$SbS$_4$ disc are 16 mm and 1.04 mm, respectively.
Figure S4. Investigation on whether Na₃SbS₄ can be dissolved in PEO. (a) IR spectra of acetonitrile and the supernatant of acetonitrile/Na₃SbS₄ mixture. (b) IR spectra of the supernatant of acetonitrile/PEO mixture and acetonitrile/PEO/Na₃SbS₄ mixture. (c) XPS survey spectrum and (d) S 2p spectrum of the residual material after removing acetonitrile.

Note that Na₃SbS₄ cannot be dissolved in acetonitrile (Figure S4a) while PEO can be dissolved in acetonitrile (Figure S4b). Thus, we added Na₃SbS₄ into the solution composed of PEO and acetonitrile, and stirred the mixture intensely. Then the mixture was centrifugated, and the obtained supernatant was characterized by IR. As shown in Figure S4b, no signal for Na₃SbS₄ can be detected in the supernatant. We further removed acetonitrile in the supernatant by heating in oven and tested the residual material by XPS. The XPS survey spectrum in Figure S4c and S 2p spectrum in Figure S4d reveal that the S content is extremely low (0.28 at%) and the signal of S is very weak. Both IR and XPS spectra verify that Na₃SbS₄ can be hardly dissolved in PEO. The amounts of Na₃SbS₄, PEO, and acetonitrile in these experiments are 100 mg, 100 mg, and 5 mL, respectively.
Figure S5. Variation of current with time for the symmetric cell with PEO/NaTFSI electrolyte at an applied voltage of 12 mV. Inset: EIS plots before and after polarization.

Figure S6. Elemental mapping (C, N, O, F, Na, Sb, and S) of the obtained PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte. All the scale bars represent 25 μm.
Figure S7. (a) AFM topography image with a 3D view and (b) Young’s modulus of the obtained PEO/NaTFSI electrolyte.

Table S1. Comparison on surface roughness and Young’s modulus of the PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte in this work versus other reported polymer-based all-solid-state electrolytes for sodium batteries.

| Electrolyte                     | Surface roughness (nm) | Young’s modulus (MPa) | Ref.       |
|---------------------------------|------------------------|-----------------------|-----------|
| PEO-PVP/NaPF$_6$                | 130                    | –                     | [5]       |
| PMA/PEG/α-Al$_2$O$_3$/NaClO$_4$ | 6                      | 50.79                 | [6]       |
| PVDF-HFP/SN/NaClO$_4$           | –                      | 7.3                   | [7]       |
| PEO/NaTFSI/Na$_3$SbS$_4$        | 39.3                   | 47.8                  | This work |
Figure S8. Thermal stability of the PEO/NaTFSI/Na₃SbS₄ electrolyte. TG curve of the electrolyte in the temperature range of 25–775 °C at a heat rate of 5 °C min⁻¹ under Ar atmosphere. The weight loss of the electrolyte begins at about 345 °C.

Figure S9. Electrochemical stability window of the PEO/NaTFSI/Na₃SbS₄ electrolyte. Linear sweep voltammetry (LSV) of the electrolyte in the voltage range of 1–6 V at 0.5 mV s⁻¹ (45 °C). The anodic decomposition potential of the electrolyte is about 3.7 V (vs. Na⁺/Na).
Table S2. Comparison on performance of the PEO/NaTFSI/Na₃SbS₄ electrolyte in this work versus other reported polymer-based all-solid-state electrolytes for sodium batteries.

| Electrolyte                              | Ionic conductivity (S cm⁻¹) | Na⁺ transference number | Thermal stability (°C) | Ref.   |
|------------------------------------------|-----------------------------|-------------------------|------------------------|--------|
| PMA/PEG/α-Al₂O₃/NaClO₄                   | 1.46 × 10⁻⁴ (70 °C)         | –                       | 250                    | [6]    |
| PEO/NaFNFSI                              | 3.36 × 10⁻⁴ (80 °C)         | 0.24                    | 300                    | [8]    |
| PEO/CQDs/NaClO₄                          | 7.17 × 10⁻⁵ (RT)            | 0.42                    | –                      | [9]    |
| PEO/NaClO₄/Na₃Zr₂Si₂PO₁₂                 | 2.1 × 10⁻⁵ (30 °C)          | –                       | –                      | [10]   |
| CD-HSPE3                                 | 2.83 × 10⁻⁵ (30 °C)         | 1.31 × 10⁻⁴ (60 °C)     | 280                    | [11]   |
| POSS-4PEG2K                              | 4.5 × 10⁻⁶ (30 °C)          | 2.6 × 10⁻⁴ (80 °C)      | –                      | [12]   |
| PEO/E8 LC/NaIO₄                          | 1.05 × 10⁻⁷ (RT)            | 0.384                   | –                      | [13]   |
| PCL–PTMC:NaFSI                           | 1.64 × 10⁻⁵ (25 °C)         | 0.48                    | –                      | [14]   |
| PEO/NaCF₃SO₃/MIL-53(Al)                  | 6.87 × 10⁻⁵ (60 °C)         | 0.4                     | 175                    | [15]   |
| Polyether/NaTFSI/Na₃Zr₂Si₂PO₁₂            | 1.03 × 10⁻⁵ (25 °C)         | –                       | –                      | [16]   |
| PEO/NaTFSI/Na₃SbS₄                        | 2.47 × 10⁻⁵ (25 °C)         | 3.72 × 10⁻⁵ (30 °C)     | 345                    | This work |
|                                          |                             | 1.33 × 10⁻⁴ (45 °C)     |                        |        |
|                                          |                             | 3.08 × 10⁻⁴ (60 °C)     |                        |        |
|                                          |                             | 5.64 × 10⁻⁴ (70 °C)     |                        |        |
|                                          |                             | 0.49                    |                        |        |
Figure S10. Voltage profiles of symmetric cells with PEO/NaTFSI electrolyte and PEO/NaTFSI/Na₃SbS₄ electrolyte at 0.1 mA cm⁻² and 45 °C.

Table S3. Comparison on performance of the Na|Na symmetric cells in this work versus other reported Na|Na symmetric cells with polymer-based all-solid-state electrolytes.

| Electrolyte                        | Current density (mA cm⁻²) /overpotential (V) | Test temperature (°C) | Ref.  |
|------------------------------------|----------------------------------------------|------------------------|-------|
| PEO/NaFNFSI                        | 0.1/~0.09                                    | 80                     | [8]   |
| PEO/CQDs/NaClO₄                    | 0.05/~0.18, 0.1/~0.32                         | 60                     | [9]   |
| HMOP–PEO–NaTFSI                    | 0.3/~0.8                                     | 65                     | [17]  |
| PEGDMA–NaFSI–SPE                   | 0.1/~0.6                                     | 60                     | [18]  |
| PVDF/NaCF₃SO₃/SiO₂                 | 0.2/~0.6                                     | 60                     | [19]  |
| PEO/Na₂Zn₂TeO₆/NaTFSI              | 0.1/~0.4                                     | 80                     | [20]  |
| PEO/NaTFSI/Na₃SbS₄                 | 0.05/0.153, 0.1/0.504                         | 45                     | This work |
**Figure S11.** XPS survey and F 1s spectra of Na electrode after stripping/plating with different all-solid-state electrolytes. (a,b) PEO/NaTFSI electrolyte. (c,d) PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte. Insets in (a) and (c): the corresponding atomic fraction of different elements.

The total ratio of F element on Na anode in the PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte system (3.43 at%, Figure S11c) is lower than that in the PEO/NaTFSI electrolyte system (6.94 at%, Figure S11a). Moreover, the Na–F ratio among all the F-containing species in the former system (69.24%, Figure S11d) is lower than that in the latter system (78.85%, Figure S11b). Thus, we can conclude that the ratio of generated NaF among all the SEI species on Na electrode after stripping/plating with PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte is lower than that with PEO/NaTFSI electrolyte.
Figure S12. Geometry used in FEM simulation.

Table S4. FEM simulation parameters setting for Na deposition.

| Parameters                        | PEO/NaTFSI | PEO/NaTFSI/Na\textsubscript{3}SbS\textsubscript{4} |
|-----------------------------------|------------|-----------------------------------------------|
| Na\textsuperscript{+} concentration (mol L\textsuperscript{-1}) | 2.5        | 2.5                                           |
| Na\textsuperscript{+} transference number | 0.20       | 0.49                                          |
| Na\textsuperscript{+} diffusion coefficient (10\textsuperscript{-10} cm\textsuperscript{2} s\textsuperscript{-1}) | 5          | 5                                              |
| Exchange current density (mA cm\textsuperscript{-2}) | 0.5        | 0.5                                           |
| Ionic conductivity (10\textsuperscript{-5} S cm\textsuperscript{-1}) | 4.19       | 13.3                                          |
**Figure S13.** High-resolution SEM images of the interface between (a) PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte and PTCDA cathode, (b) PEO/NaTFSI/Na$_3$SbS$_4$ electrolyte and Na metal anode.

**Figure S14.** Discharge and charge profiles of the all-solid-state Na–PTCDA batteries with PEO/NaTFSI electrolyte at different rates (0.2, 0.5, 1, 2, 5, and 10 C) and 45 °C.
Figure S15. Cycling performance of Na–PTCDA batteries with 1M NaPF₆/diglyme electrolyte at 0.2 C and room temperature.
**Table S5.** Comparison on performance of the Na–PTCDA batteries in this work versus other reported Na batteries with polymer-based all-solid-state electrolytes (Here all the anodes are Na metals).

| Electrolyte               | Cathode                        | Rate performance a) | Cycling performance b) | Test temperature c) | Ref.  |
|---------------------------|--------------------------------|----------------------|-------------------------|---------------------|-------|
| PEO/NaFNFSI               | NaCu_{1/9}Ni_{2/9}Fe_{1/3}Mn_{1/3}O_{2} | 89.7/2 C            | ~75/70%/150             | 80                  | [8]   |
| PEO/CQDs/NaClO_{4}        | Na_3V_2(PO_4)_3                | 56/8 C               | 89.4/88%/100            | 60                  | [9]   |
| PEO/NaClO_{4}/Na_{3}Zr_{2}Si_{2}PO_{12} | Na_2MnFe(CN)_6              | 88/2 C               | 90.8/83%/300            | 60                  | [10]  |
| HMOP–PEO–NaTFSI           | NaTi_2(PO_4)_3                | –                    | 80/69.6%/~120           | 65                  | [17]  |
| PVDF/NaCF_3SO_3/SiO_2      | Na_3V_2(PO_4)_3               | 54/5 C               | ~88/86%/250             | 60                  | [19]  |
| PEO/beta-alumina/NaClO_{4} | Na_3V_2(PO_4)_3              | 61.5/2 C             | 77.8/83.6%/100          | 60                  | [21]  |
| PEO/TiO_2/NaClO_{4}        | Na_{2/3}Co_{2/3}Mn_{1/3}O_{2} | –                    | 45/~90%/25              | 60                  | [22]  |
| PEO/NaTFSI/Na_3SbS_4       | PTCDA                         | 92/10 C              | 101/84%/200             | 45                  | This work |

a) The values in this column represent capacity (mAh g⁻¹) and corresponding current rate, respectively.

b) The values in this column represent capacity (mAh g⁻¹) after cycles, capacity retention, and corresponding cycle number, respectively.

c) The unit of test temperature is °C.
References

[1] J. Wei, J. Wei, D. Lan, Z. He, H. Lu, Y. Cao and Z. Lu, CN 108163890 A, 2018.

[2] a) G. Kresse and J. Furthmüller, Phys. Rev. B, 1996, 54, 11169–11186. b) P. E. Blöchl, Phys. Rev. B, 1994, 50, 17953–17979.

[3] J. P. Perdew, K. Burke and M. Ernzerhof, Phys. Rev. Lett., 1996, 77, 3865–3868.

[4] X. Xu, Y. Liu, J.-Y. Hwang, O. O. Kapitanova, Z. Song, Y.-K. Sun, A. Matic and S. Xiong, Adv. Energy Mater., 2020, 10, 2002390.

[5] A. Arya and A. L. Sharma, J. Solid State Electrochem., 2018, 22, 2725–2745.

[6] X. Zhang, X. Wang, S. Liu, Z. Tao and J. Chen, Nano Res., 2018, 11, 6244–6251.

[7] Y. Lu, Y. Cai, Q. Zhang, L. Liu, Z. Niu and J. Chen, Chem. Sci., 2019, 10, 4306–4312.

[8] Q. Ma, J. Liu, X. Qi, X. Rong, Y. Shao, W. Feng, J. Nie, Y.-S. Hu, H. Li, X. Huang, L. Chen and Z. Zhou, J. Mater. Chem. A, 2017, 5, 7738–7743.

[9] C. Ma, K. Dai, H. Hou, X. Ji, L. Chen, D. G. Ivey and W. Wei, Adv. Sci., 2018, 5, 1700996.

[10] X. Yu, L. Xue, J. B. Goodenough and A. Manthiram, ACS Mater. Lett., 2019, 1, 132–138.

[11] S. Chen, F. Feng, Y. Yin, H. Che, X.-Z. Liao and Z.-F. Ma, J. Power Sources, 2018, 399, 363–371.

[12] Y. Zheng, Q. Pan, M. Clites, B. W. Byles, E. Pomerantseva and C. Y. Li, Adv. Energy Mater., 2018, 8, 1801885.

[13] H. K. Koduru, Y. G. Marinov, G. B. Hadjichristov and N. Scaramuzza, Solid State Ionics, 2019, 335, 86–96.

[14] C. Sångeland, R. Younesi, J. Mindemark and D. Brandell, Energy Storage Mater., 2019, 19, 31–38.

[15] Z. Ge, J. Li and J. Liu, Ionics, 2020, 26, 1787–1795.

[16] K. Hiraoka, M. Kato, T. Kobayashi and S. Seki, J. Phys. Chem. C, 2020, 124, 21948–21956.

[17] W. Zhou, H. Gao and J. B. Goodenough, Adv. Energy Mater., 2016, 6, 1501802.
[18] Y. Yao, Z. Wei, H. Wang, H. Huang, Y. Jiang, X. Wu, X. Yao, Z.-S. Wu and Y. Yu, *Adv. Energy Mater.*, 2020, **10**, 1903698.

[19] S. Bag, C. Zhou, S. Reid, S. Butler and V. Thangadurai, *J. Power Sources*, 2020, **454**, 227954.

[20] J.-F. Wu, Z.-Y. Yu, Q. Wang and X. Guo, *Energy Storage Mater.*, 2020, **24**, 467–471.

[21] Y. Yao, Z. Liu, X. Wang, J. Chen, X. Wang, D. Wang and Z. Mao, *J. Mater. Sci.*, 2021, **56**, 9951–9960.

[22] Y. L. Ni'mah, M.-Y. Cheng, J. H. Cheng, J. Rick and B.-J. Hwang, *J. Power Sources*, 2015, **278**, 375–381.