CREATIVE WRITING

High-voltage Anode-free Sodium–sulfur Batteries

Published: 12 January 2026

Authors

Bikash Pradhan

Bikash Pradhan

Title

High-voltage Anode-free Sodium–sulfur Batteries

Subtitle

High-voltage anode-free sodium–sulfur batteries

Abstract

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

Introduction

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

Concept & Approach

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

Creative Output

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

Analysis/Reflection

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

Figure 1

Write figure description Here

Conclusion

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

Acknowledgment

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

References

1. Liu, R. et al. Establishing reaction networks in the 16-electron sulfur reduction reaction. Nature 626, 98–104 (2024). 2. Pan, H. et al. Non-encapsulation approach for high-performance Li–S batteries through controlled nucleation and growth. Nat. Energy 2, 813–820 (2017).

Acknowledgement

Room-temperature sodium–sulfur (Na–S) batteries offer a sustainable energy storage solution to conventional lithium (Li)-based systems1,2,3, owing to the high element abundances and theoretical electrochemical performance4,5. However, their practical applications have been severely hindered by the low discharge voltages and the need for largely excessive Na metal anode6,7,8. Here we report a 3.6 V class Na–S battery featuring a high-valence sulfur/sulfur tetrachloride (S/SCl4) cathode chemistry and anode-free configuration. We show that sodium dicyanamide (NaDCA) can simultaneously unlock reversible S/SCl4 conversion and Na plating/stripping in a non-flammable chloroaluminate electrolyte. This design enables the maximum energy and power densities of 1,198 Wh kg?1 and 23,773 W kg?1, respectively, calculated on the basis of the total electrode mass including both the cathode and the anode. Also, we demonstrate facilitated S/SCl4 conversion by incorporating a bismuth-coordinated covalent organic framework (Bi-COF) catalyst (8 wt% loading) into the S cathode, which realizes an impressive discharge capacity of 1,206 mAh g(sulfur+catalyst)?1, contributing to a maximum energy density of 2,021 Wh kg?1 calculated on the basis of the total electrode mass. With an estimated cost of US$5.03 per kWh and excellent scalability, our anode-free Na–S battery shows promise in grid energy storage and wearable electronics.

References

1. Liu, R. et al. Establishing reaction networks in the 16-electron sulfur reduction reaction. Nature 626, 98–104 (2024).

2. Pan, H. et al. Non-encapsulation approach for high-performance Li–S batteries through controlled nucleation and growth. Nat. Energy 2, 813–820 (2017).

Keywords

electrochemical · tetrachloride · chloroaluminate · dicyanamide · electrode