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Efficient Interface Enabled by Nano-Hydroxyapatite@Porous Carbon for Lithium-Sulfur Batteries

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Efficient Interface Enabled by Nano-Hydroxyapatite@Porous Carbon for Lithium-Sulfur Batteries

Authors

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(b) Qi-Fan Peng¹, Yue-Peng Guan^{2*}, We 9008 (1 of 13)

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Ifur Batteries**

1. Yue-Peng Guan^{2*}, Wei-Kun Wang³,

^{1*}, Ya-Qin Huang^{1*}

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 Lithium-Sulfur Batteries

g¹, Qi-Fan Peng¹, Yue-Peng Guan^{2*}, Wei-Kun Wang³ $\begin{array}{ll} & \text{\#} & \mathbb{R} & \text{\#} \\ \text{L} & \text{Electrochem. 2022, 28(11), 2219008 (1 of 13)} \\ & \text{DOE 10,13208j-electrochem. 2219008} & \text{Htp://electrochem. xmu.edu.n} \\ \text{\textbf{Efficient Interface} \textbf{Enabledy N} \textbf{Non-Nydroxyapatite@Porous} \\ & \text{Carbon for Lithium-Sulfur Batteries} \\ & \text{Jia-Yu Wang} & \text{Xue-Feng Tong} \text{, Qi-Fan Peng} \text{Yue-Peng Guan}^2, \text{Wei-Kun Wang}^3$ $\begin{tabular}{ll} & \textbf{b} & \textbf{c} & \textbf{d} \\ & \textbf{d} & \textbf{d} & \textbf{d} \\ & \textbf{d} & \textbf{d} & \textbf{d} \\ & \textbf{d} & \textbf{d} & \textbf{d} & \textbf{d} \\ \end{tabular} \begin{minipage}{0.99\textwidth} \begin{tabular}{ll} \textbf{B} & \textbf{B} & \textbf{B} & \textbf{B} \\ \end{tabular} \end{minipage} \begin{minipage}{0.99\textwidth} \begin{tabular}{ll} \textbf{B} & \textbf{B} & \textbf{B} \\ \end{$ Chemical Technology, Beijing 100029, P.R. China; 2. Beijing Key Laboratory of Clothing Materials R&D and $\begin{array}{ll} & \psi & \mathcal{R} \quad \Leftrightarrow \\ \hline \end{array}$
 $\begin{array}{ll} \mathcal{R} \quad \text{A} \quad \mathcal{R} \quad \text{A} \quad \mathcal{R} \quad \mathcal$ **Example 18**
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 Example 1001: 10.13208 \hat{q} decision-**Hydroxyapatite @ Porous**
 Carbon for Lithium-Sulfur Batteries

Jia-Yu Wang¹, Xue-Feng Tong¹, Qi-Fan Peng¹, Yue-Pe *I. Electrochem.* 2022, 28(11), 2219008 (1 of 13)

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 Carbon for Lithium-Sulfur Batteries

Jia-Yu Wang¹, Xuc-Feng Tong¹, Qi-Fan Peng¹, Yuc-Peng Guanr $[Article] \begin{tabular}{c} {\footnotesize \begin{tabular}{l} \hline & $\#\$ \end{tabular} \end{tabular} \begin{tabular}{l} \hline & $\#\$ \end{tabular} \end{tabular} \begin{tabular}{c} \hline & $DCl: 10.13208/j.electrochem.2219008 (1 of 13) \end{tabular} \end{tabular} \begin{tabular}{c} \hline \hline & \hline \multicolumn{1}{c}{\text{Rtricle}} \end{tabular} \end{tabular} \begin{tabular}{c} \hline & \multicolumn{1}{c}{\text{Rtricley}} \end{tabular} \begin{tabular}{c} \hline & \$ 电 化 学

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 Enabled by Nano-Hydroxyapatite@Porous

Sichuza University of Science & Engineering, Zigong 643000, P.R. China)

Sistract: The dissolution and "shuttle effect" of lithium polysulfides (LPSs) hinder the application of lithium-sulfar (LeS) but-

In solve those pr **Abstract:** The dissolution and "shuttle effect" of lithium polysulfides (LiPSs) hinder the application of lithium-sulfur (Li-S) bate-
teriss. To solve those problems, inspired by natural materials, a nano-hydroxyapatite@ **Abstract:** The dissolution and "shuttle effect" of lithium polysulfides (LiPs) hinder the upplicution of lithium-sulfur (Li-S) bu-
teries. To solve those problems, inspired by natural materials, a nano-hydroxyapatitic@pr **Abstract:** The dissolution and "shuttle effect" of lithium polysulfides (LiPSs) hinder the application of fithium-sulfur (Li-S) batteries, To salve those problems, mapired by mutual materials, a manc-hydroxyquatitie/poro teries. To solve those problems, inspired by natural materials, a nano-hydroxyapatite@porous carbon derived from chicken cartilage

(nano-HA@CCPC) was fabriented by emplying a simple pre-cathonization and carbonization med (nano-HA@CCPC) was fabricated by employing a simple pre-carbonization and carbonization method, and applied in Li-S batter-
i.e. The tann-HA@CCFC' would provide a reactric interactric that allows efficient LiFSs costs con ies. The nato-HA@CCPC would provide a reactive interface that allows efficient LiPSs reduction. With a strong affinity for LiPSs respective that an excellent electronic condation and excellent charge interference for the and an excellent electronic conductive path for converting LiPSs, the shuttle effect of LiPSs was confined and the redox kinetics of

LiPSs was substantially chalmend. LiS butterine employing amen-HA(α CCPC-modified sep Everace of *Staticals Science and Engineering,*

School of *Materials Science and Engineering,*

rering, Zigong 643000, P.R. China)

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mization and carbonization method, and applied in Li-S fides (LiPSs) hinder the application of lithium-sulfur (Li-S) bat-
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mization and carbonization method, and applied in Li-S batter-
lows efficient LiPSs reduction. *Electrochem.* 2022, 28(11), 2219008 (1 of 13)

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 Carbon for Lithium-Sulfur Batteries
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1 Wang¹, Xuc-Feng Tong¹, Qi-Fan Peng¹, Yuc-Peng Guan **Efficient Interface Enabled by Nano-Hydroxyapatite@Porous**
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Jia-Yu Wang¹, Xuc-Feng Tong¹, Qi-Fan Peng¹, Yuc-Peng Guan², Wei-Kun Wang¹,

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(*I. Beijing Key Laboratory of Elec* **Carbon for Lithium-Sulfur Batteries**

Jia-Yu Wang¹, Xue-Feng Tong¹, Qi-Fan Peng¹, Vue-Peng Guan², Wei-Kun Wang²,

(1. Beijing Key Laboratory of Electrochemical Process and Technology for Materials, Key Laborato Jia-Yu Wang¹, Xuc-Feng Tong¹, Qi-Fan Peng¹, Yuc-Peng Guan²², Wei-Kun Wang³,

An -Pang Wang², Na²-Conner (*L. Beijing Key Laboratory of Electrochemical Process and Technology for Materials, Key Laboratory of
* Jia-Yu Wang¹, Xue-Feng Tong¹, Qi-Fan Peng¹, Yue-Peng Guan^{2*}, Wei-Kun Wang¹,

(*I. Beijing Key Laboratory of Electrochemical Process and Technology for Materials, Key Laboratory of

<i>Ehemical Mechnology, Beijing* JIA-Yu Wang, Xue-Feng Iong', Q1-Fan Peng, Yue-Peng Guan", We-Kun Wang',

(1. Beijing Key Laboratory of Electrochemical Process and Technology for Materials, Key Laboratory of

Eliminal Materials of Natural Macromolecules, proved rate capability. At 0.5 C after 325 cycles, a specific capacity of 815 mAh \cdot g⁻¹ and a low capacity fading rate of 0.051% were Peng Guan², Wei-Kun Wang²,

plin Huang^{1*}

gy for Materials, Key Laboratory of

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hina; 3. Research Institute of (1. Beijing Key Laboratory of Electrochemical Process and Technology for Macriclas, Key Laboratory of Biomedical Materials of Natural Macromolecules, Ministry of Education, Beijing University of Chemical Technology, Beiji (1. Beijing Key Laboratory of Electrochemical Process and Technology for Materials, Key Laboratory
 *Eleminedical Materials of Notaral Macromolecules, Ministry of Education, Beijing University of

Chemical Technology, Bei* Key words: conductive carbon framework; Amistry of Education, Beijing University of

Chemical Technology, Beijing 100029, P.R. China; 2. Beijing Engils Rey Loboratory of Colohings Materials R&D and

Assessment, Beijing Eng Chemical Technology, Beijing 100029, P.R. China; 2. Beijing Key Laboratory of Clothing Manus Assessment, Beijing Engineering Research Center of Textile Nano Fiber, Beijing In

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1 Introduction LIBs^[1-3]. Therefore, to satisfy this demand, new-genfides (LiPSs) hinder the application of lithium-sulfur (Li-S) bat-
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s shuttle effect of LiPSs was confined and the redox kineties of
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of 815 mAh ·g⁻¹ and e shuttle effect of LiPSs was confined and the redox kinetics of $QCCPC$ -modified separators exhibited long cycle life and im-
of 815 mAh · g^{-1} and a low capacity fading rate of 0.051% were
le preparation process make na **Key words:** conductive carbon framework; nano-hydroxyapatite; reactive interface; modified separator, redox reaction kineteries: $\frac{1}{2}$. Therefore, to satisfy this domand, new-gement-
 1 Introduction

Since a contin proved rute capability. At 0.5 C nfter 325 cycles, a specific capacity of 815 mAh- g⁺ and a low expecity fading rute of 0.051% were
bothinive muterial for supporting properties, sustainable raw materials, and facile perp The superior properties, sustimable raw meterials, and facile preparation process make nano-HA@CCTC a promising ad-
erial for practical Li-S batteries.
 The superior properties conduction
 The superior properties carbo

 $# \&L \# (J. \t{Electrochem.}) 2022, 28(11), 2219008 (2 of 13)$ challenge^[10, 11]

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Recently, extensive researches have focused on

ties of interfaces. Note that it is

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Recently, extensive researches have focused on

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Enallenge^[10,11]**. Strengthy extensive researches have focused on the interfaces. Note that it is critical the formation of high-order LiPSs in ports, there and (3) exergential appopenent of the physicochemical proper-
Recently, extensive researches have focused on the sof interfaces. Note that it is critical to developing
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Recently, extensive researches have focused on the sof interfaces. Note that it is critical to developing

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Recently, extensive researches have focused on thes of interfaces. Note tail is critical to developing

inhibiting the "shuttle effect" and increasing sulf $\text{4/2} \div \mathcal{L}$ *Electrochem*, 2022, 28(11), 2219008 (2 of 13)

challenge^{l/W.H}.
 Electrochemical proper-

Recently, extensive researches have focused on ties of interfaces. Note that it is critical to developing

in $TiO_2^{[19]}$, MgO^[20], Cr₂O₃^[21], MnO₂^[22] and heteroatom [19], MgO[20], Cr2O3 ± 1 *Electrochem.*) 2022, 28(11), 2219008 (2 of 13)

strongly dependent on the physicochemical p

researches have focused on ties of interfaces. Note that it is critical to deve

effect" and increasing sulfur a high-ef challenge^{na, 11}. **Example carbon and Constraines** and the proposition of the physicochemical proper-

Recently, extensive researches have focused on

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Recently, extensive researches have focused on these of interfaces. Note that it is critical to developing

inhibiting the "shuttle effect" and increasing sulfu Recently, extensive researches have focused on

intisting the "shuttle effect" and interesting sulfin- filin-filiciney reading the "shuttle effect" and interesting requirements: (1) a high affinity between

intilization¹ inhibiting the "shuttle effect" and increasing sulfor a high-efficiency reactive interface that satisfies the

utilization ⁽¹²⁵⁴M) Moreover, to effectivity blook lithium a following requirements: (1) a high affinity bet utilization^{(12,14}). Moreover, to effectively block lithium following requirements: (1) a high affinity between
polysufides (LiPSs), various carbon materials ^{18,141}^m the interface and LiPSs, which is essential to imm polysulfides (LiPSs), various carbon materials^{13.131} the interface and LiPSs, which is essential to immolated to heat common strategy. These bilize LiPSs and improve change transfer, (2) high ion have been applied to be have been applied to be a common strategy. These bilize LiPSs and improve charge transfer, (2) high ion
materials form a conductive network while limiting transport at the interface, and (3) exceptionally stable
the forma materials form a conductive network while limiting
transport at the interface, and (3) exceptionally stable
the formation of high-order LiPSs in pores, thereby
interfaces between phases.

the formation of high-order LiPSs the formation of high-order LiPSs in pores, thereby

interfaces between phases,

enching Li-S batteries to offer new orportunities for

enching the spectra of the new corportunities for

developing energy storage systems. enabling Li-S batteries to offer new opportunities for

developing energy storage, systems. However, nonpo-

duretive nano-hydroxyapatite (tano-HA) exhibits sig-

developing energy storage systems. However, nonpo-

LiPSs, lar materials offer weak physical adsorption to polar
inficent adsorption of LiPSs¹⁹¹, However, the performation
the shutle of LiPSs during is auch materials failing to restrain mane of sulfur cells with nano-1-1A as an LiPSs, resulting in such materials failing to restrain mance of sulfur cells with nano-HA as an additive is
the shutted of LiPSs during extended cycling. Thus, limited by its non-conductive nature. Conductive car-
polar m the shuttle of LiPSs during extended cycling. Thus, limited by its non-conductive nature. Conductive ear-
nolar materials with strong affinity to LiPSs, such as bon frameworks, which provides both high electronic
polar ma polar materials with strong affinity to LiPSs, such as

bon frameworks, which provides both high electronic

TOC⁷¹⁰, M₀O^T, Cr₅O₁³⁰, MoO_C¹²⁰, MoO_C¹²⁰ and heteroatom

conductivity and process tructure for TiO₂⁽¹⁹⁾, MgO^{[20}], MrQ)^{[20}], MnO₂⁽²¹⁾ and heteroatom conductivity and pore structure for ion transportation, (N, S, and O, ecc) doped carbon¹⁰⁹, have been applied are promising materials to construct efficie (N, S, and O, etc.) doped carbon^[23], have been applied

or inibility the shuttle of LiPSs and considerably in-

ecation interfaces with anal-BIA . Animal cartilages

or initial consideration of sulfide by forming chemi to inhibit the shuttle of LiPSs and considerably in-
reaction interfaces with anno-HA. Animal cartilages
or the utilization of sulfide by forming chemical could be encouraging necessors for constructing an
constant inclus erease the utilization of sulfide by forming chemical

could be encouraging precursors for constructing an

bonds with LiFSs. However, the poor conductivity of efficient reactive interface of nanof provis

metal oxides im bonds with LiPSs. However, the poor conductivity of

metal exiteris interface of nano-HA and porous

rental exited relability to continue the con-

certained refision and th). They are

version of adsorbed LiPSs. Therefor metal oxides impedes their ability to continue the con-
version of adsorbed LiFss. Therefore, metal suifades, natural organic/inorganic composite materials that
verifieds and phosphides (such as Cos,¹⁹⁴, MoS_i^{19, 28}), version of adsorbed LiPSs. Therefore, metal sulfides,
natural organic/inorganic composite materials that
nitrides and phosphides (such as Cos,¹⁹²⁶, MoS₁²⁶, ²⁶, ²⁶, ²⁶, ²⁶, ²⁶, ²⁶, ²⁶, ²⁶ (26 ²⁶)
be nitrides and phosphides (such as CoS,¹⁹⁰, MoS,¹⁹², primarily comprise structural collagen grid and a cer-
NiCop¹²⁷¹ and TNI⁵⁸¹) with high conductivity have tai amount of hydroxygnatite (HA). In general, duri-
Nico NiCoP¹²⁷¹ and TiN¹³⁸¹) with high conductivity have

became investigated, which could potentially reduce po-ing the carbonization process, HA serves as a the-situal

barrianion, and increase the capacity and operating
 been investigated, which could potentially reduce po-

ing the carbonization process, HA serves as an *in-situ*

hirredictron, and increase the equangity and operations are limitate to hibrican the protons frame-

hirfs o larization, and increase the capacity and operating self-sacrificial template to fabricate the porous frame-
infe of battericas. To better limit the dissolution of work in animal bones¹⁹³. The constrator f^FIA is a key life of batteries. To better limit the dissolution of work in animal bones^[33]. The polysulfides, considerable attention is being devoted indicator. Excessive HA corostructing an effective electrode interface with conne youlfides, considerable attention is being devoted
indicator. Excessive IIA content may lead to a dis-
constructing an effective clearode interfalce with connected archine convertex of the product. Among the
urbical requir

^{#1} (*J. Electrochem.*) 2022, 28(11), 2219008 (2 of 13)

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Recently, extensive researches have focused on

itis of interfaces. Note that it is critical t the \mathbb{R}^{2n} and \mathbb{R}^{2n} and \mathbb{R}^{2n} are building the \mathbb{R}^{2n} and \mathbb{R}^{2n} and \mathbb{R}^{2n} and \mathbb{R}^{2n} and \mathbb{R}^{2n} and \mathbb{R}^{2n} are focused on the physicochemical proper-
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Recently, extensive researches have focused on these of interface. Note that it is critical to developing

imhibiting the "shuttle effect" a 28(11), 2219008 (2 of 13)
strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1) a h $28(11)$, 2219008 (2 of 13)
strongly dependent on the physicochemical proper-
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a high-efficiency reactive interface that satisfies the
following requirements: (1 $28(11)$, 2219008 (2 of 13)
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strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
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strongly dependent on the physicochemical proper-
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its of interfaces. Note that it is critical to developing
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in high-efficiency reactiv trategy. These bilize LiPSs and improve charge transfer, (2) high ion
while limiting transport at the interface, and (3) exceptionally stable
pores, thereby interfaces between phases.
Dortunities for In our previous work, These bilize LiPSs and improve charge transfer, (2) high ion
transport at the interface, and (3) exceptionally stable
interfaces between phases.
So for the interface is two determined that noncon-
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ductive nano-hydrox developing energy storage systems. However, nonpo-

ductive name-hydroxyapatite (namo-HA) exhibits sig-

In matchs offer weak physical dasorption to polar

Infrastration of LIPSs⁷. However, the perfor-

ILPSs, see altiti $28(11)$, 2219008 (2 of 13)
strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1 $28(11)$, 2219008 (2 of 13)
strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1 $28(11)$, 2219008 (2 of 13)
strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1 $28(11)$, 2219008 (2 of 13)
strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1 $22(11), 2215000 (2.6115)$
strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1) a h strongly dependent on the physicochemical proper-
ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1) a high affinity between
the i ties of interfaces. Note that it is critical to developing
a high-efficiency reactive interface that satisfies the
following requirements: (1) a high affinity between
the interface and LiPSs, which is essential to immo-
bi a high-efficiency reactive interface that satisfies the following requirements: (1) a high affinity between the interface and LiPSs, which is essential to immo-
bilize LiPSs and improve charge transfer, (2) high ion trans following requirements: (1) a high affinity between
the interface and LiPSs, which is essential to immo-
bilize LiPSs and improve charge transfer, (2) high ion
transport at the interface, and (3) exceptionally stable
inte the interface and LiPSs, which is essential to immo-
bilize LiPSs and improve charge transfer, (2) high ion
transport at the interface, and (3) exceptionally stable
interfaces between phases.
In our previous work, we deter bilize LiPSs and improve charge transfer, (2) high ion
transport at the interface, and (3) exceptionally stable
interfaces between phases.
In our previous work, we determined that noncon-
ductive nano-hydroxyapatite (nano transport at the interface, and (3) exceptionally stable
interfaces between phases.
In our previous work, we determined that noncon-
ductive nano-hydroxyapatite (nano-HA) exhibits sig-
inficant adsorption of LiPSs¹³². Ho interfaces between phases.

In our previous work, we determined that noncon-

ductive nano-hydroxyapatite (nano-HA) exhibits sig-

nificant adsorption of LiPSs^[32]. However, the perfor-

mance of sulfur cells with nano-H In our previous work, we determined that nonconductive nano-hydroxyapatite (nano-HA) exhibits significant adsorption of LiPSs^[32]. However, the performance of sulfur cells with nano-HA as an additive is limited by its n ductive nano-hydroxyapatite (nano-HA) exhibits significant adsorption of LiPSs^[32]. However, the performance of sulfur cells with nano-HA as an additive is limited by its non-conductive nature. Conductive carbon framewor mificant adsorption of LiPSs¹³². However, the perfor-
mance of sulfur cells with nano-HA as an additive is
limited by its non-conductive nature. Conductive car-
bon frameworks, which provides both high electronic
conduc mance of sulfur cells with nano-HA as an additive is
limited by its non-conductive nature. Conductive car-
bon frameworks, which provides both high electronic
conductivity and pore structure for ion transportation,
are pro limited by its non-conductive nature. Conductive car-
bon frameworks, which provides both high electronic
conductivity and pore structure for ion transportation,
are promising materials to construct efficient sulfur
reacti bon frameworks, which provides both high electronic
conductivity and pore structure for ion transportation,
are promising materials to construct efficient sulfur
reaction interfaces with nano-HA. Animal cartilages
could be nductivity and pore structure for ion transportation,
promising materials to construct efficient sulfur
ction interfaces with nano-HA. Animal cartilages
ald be encouraging precursors for constructing an
icient reactive int are promising materials to construct efficient sulfur
reaction interfaces with nano-HA. Animal cartilages
could be encouraging precursors for constructing an
efficient reactive interface of nano-HA and porous
carbon for L reaction interfaces with nano-HA. Animal cartilages
could be encouraging precursors for constructing an
efficient reactive interface of nano-HA and porous
carbon for Li-S batteries (Figure 1a and 1b). They are
natural org could be encouraging precursors for constructing an
efficient reactive interface of nano-HA and porous
carbon for Li-S batteries (Figure 1a and 1b). They are
natural organic/inorganic composite materials that
primarily co efficient reactive interface of nano-HA and porous
carbon for Li-S batteries (Figure 1a and 1b). They are
natural organic/inorganic composite materials that
primarily comprise structural collagen grid and a cer-
tain amoun carbon for Li-S batteries (Figure 1a and 1b). They are
natural organic/inorganic composite materials that
primarily comprise structural collagen grid and a cer-
tain amount of hydroxyapatite (HA). In general, dur-
ing the natural organic/inorganic composite materials that
primarily comprise structural collagen grid and a cer-
tain amount of hydroxyapatite (HA). In general, dur-
ing the carbonization process, HA serves as an in-situ
self-sa primarily comprise structural collagen grid and a cer-
tain amount of hydroxyapatite (HA). In general, dur-
ing the carbonization process, HA serves as an *in-situ*
self-sacrificial template to fabricate the porous frame-

tain amount of hydroxyapatite (HA). In general, during the carbonization process, HA serves as an *in-situ* self-sacrificial template to fabricate the porous framework in animal bones^[33]. The content of HA is a key ind g the carbonization process, HA serves as an *in-situ* f-sacrificial template to fabricate the porous frame-
rk in animal bones^[33]. The content of HA is a key
licator. Excessive HA content may lead to a dis-
nnected ca self-sacrificial template to fabricate the porous framework in animal bones^[33]. The content of HA is a key indicator. Excessive HA content may lead to a disconnected carbon network of the product. Among the animal carti work in animal bones^[33]. The content of HA is a key
indicator. Excessive HA content may lead to a dis-
connected carbon network of the product. Among the
animal cartilages, chicken cartilage provides suitable
HA content indicator. Excessive HA content may lead to a dis-
connected carbon network of the product. Among the
animal cartilages, chicken cartilage provides suitable
HA content.
The lower HA content in chicken cartilage than
that i

 $\frac{\text{d}E}{\text{d}E}$ (*L Electrochem.*) 2022, 28(11), 2219008 (3 of 13)
content, a uniform interface was constructed which then dried in a vacuum oven at 60 °C for 24 h before
allows efficient sulfur reduction. During the $\frac{d}{dt}\mathcal{L}\neq (J. Electrochem.)$ 2022, 28(11), 2219008 (3 of 13)

content, a uniform interface was constructed which

allows efficient sulfur reduction. During the car-

being cut into circular disks (19 mm diameter). The

bonizat $\oplus \{\& \nexists (L) \& Electrochem.)\ 2022, 28(11), 2219008 (3 of 13)$

content, a uniform interface was constructed which then dried in a vacuum oven at 60 °C for 24 h before

allows efficient sulfur reduction. During the car-

being cut in then the more than the model of the the mand capability and thus, Li-S battering the mathematic properties with the material of the material of the material of the material and in-situ embedded and in-situ embedded in the **in the porous carbon**-coated which
 in the poronus carbon $\mathbb{E}[E\mathcal{F}(J, Electrochem) \cdot 2022, 28(11), 2219008 (3 of 13)$

content, a uniform interface was constructed which then dried in a vacuum oven at 60 °C for 24 h before

a **EART CONTINUME ACCONSTAND ACT CONTINUME STATE (THE NANOTEST AND SET CONDINE THE STATE INTERFER (I.1) THE NANOTEST AND THE SHOW INTO THE SHOW INTERFERENT (I.1) THE DESCRIPTION INTERFERENT ACT CONTINUME THE DOMINATION pro** \pm *CE (L Electrochem.*) 2022, 28(11), 2219008 (3 of 13)
content, a uniform interface was constructed which then dried in a vacuum oven at 60 °C for 24 h before
allows efficient sulfur reduction. During the car-
being c the $R\gg 1$ and the nano-HA@CCPC-modified separator
parameteries with the nano-HA diversion of 81 and the nano-HA diversion process, the orderly distributed HA main-
control an a vacuum oven at 60 °C for 24 h before
allow **Exhibited superior specific capacity, rate performance,** 2022 , $28(11)$, 2219008 (3 of 13)

content, a uniform interface was constructed which then dried in a vacuum oven at 60 °C for 24 h before

allows efficient su the molecular stability. The model of the model of the statement is a particular stability of \mathbb{R}^2 its assumption of the statement is a parametery. The flame and the model of the model and the model of the model of **Example 1.5** C, these batteries showed a specific properties at 1.3 C, these batteries showed a specific conduct a specific careform of \mathbb{C} C and \mathbb{C} **EVALUATION EXAMORE 120**
 EVALUATION CONTIG CONTIVE CONTIVE CONTIGATION
 EVALUATION CONTIFY
 EXAMORE CONTIFY
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 EVALUA EVALUATION THE SET ALTERT ALTERT SET ALTERT ALTERT SUPPOSE (SOFT ALTERT A Example 12
 Example 12 $\frac{\ln{4/2}x}{L}$, $\frac{\ln{4/2}x}{L}$, LiPSs. content, a uniform interface was constructed which

allows efficient sulftir reduction. During the car-

benization of the Dam diamet

interfeduction reduction of the exact in the correlations

tand dist amoscale properti abus efficient sulfar reduction. During the car-

being cut into circular disks (19 mm diameter). The

mization process, the orderly distributed HA main-

enoted is manoscale properties and in-situ embedded arators) were bonization process, the orderly distributed HA main-
control samples (nano-HA- and CCPC-modified sep-
time it is nanoscale properties and in-situ embedded areables. The properties of the chicken carbonical particular
stru tained its nanoscale properties and in-situ embedded

arators) were prepared by using the same method.

in the porous carbon to from exthon commention and anal-HA and 2.3 Preparation of the LiA_S Solution

structures. in the porous carbon to form carbon-coated nano-HA

structures. The nano-HA@CCPC showed high ab-

sorption and catalytic capability, and thus, Li-S bat-

teries with the nano-HA@CCPC showed high ab-

teries with the nano-

2 Experimental

2 Experimental
 2 Experimental
 2.1 Preparation of Nano-HA@CCPC monified electrodes, 45-w% anno-HA@CCPC pow-

Raw chicken cartilage was dried and ground to a

der, 45-w% AB, and 10w% LA132 occur converse in

provede **2.1 Preparation of Nano-HA@CCPC** modified electrodes, 45wt% nano-HA@CCPC pow-

Raw chicken cartilage was dried and ground to a

der, 45wt% AB, and (0wt% LA132 vere mixed into

powder before carbonization, and then the ch Raw chicken cartilage was dried and ground to a

or der, 45xe% AB, and 10xe% LA132 were mixed into

powder before carbonization and then the chicken

anano-Hamilton and homen-means share, and directly coated on alu-

cart powder before carbonization, and then the chicken

actriting was proceed on a du-

carting was proceed on the action of C with a heating

mum foil. As a control sample, the nano-HA and

rate of 5 °C - min⁻¹ in a tube fur cartilage was pre-carbonized at 400 °C with a heating

cartilage was pre-carbonized at 400 °C with a heating

CCPC electrode was prepared with

tant chicken carbon precursor and KOH were mixed at AB with LA132 (mass ratio rate of 5 °C·min⁻¹ in a tube furnace (CNT Furnace CCPC electrode was prepared with the same pr

ZSK1200) under a N₂ atmosphere for 2 h. The resultant chicken carbo revenues and KOH vere mixed and with AH 22 (mas ratio 1200) under a N₂ atmosphere for 2 h. The resultion the AB electrode was prehision carbon precursor and KOH were mixed

AB with LA132 (mass ratio 9:1). The resultion of the Separator of the Separator of the condition

in d chicken carbon precursor and KOH were mixed AB with LA132 (mass ratio 9:1). The electrodes were
sera ratio 1:1) and heated to 800 °C at 5 °C cmin⁻¹ obtained after the coated foils were cut into 12.0 mm
der a N₂ atmo (mass ratio 1:1) and heated to 800 °C at 5 °C -min⁻⁴ obtained after the coated foils were cut into 12.0 mm

under a N₃ atmosphere. After cooling, the obtained aftests. The batteries were then assembled into

under a M under a N₃ atmosphere. After cooling, the obtained disks. The batteries were then assembled into

carbon material was washed multiple times with dis-

cCR2025 coincils with two identical electrodys, Cel-

tiled water unt carbon material was washed multiple times with dis-

citled water until the residual NOH was removed. It gard 2325 separator and 40 μ L Li₅S₆ clectrolyte, The

slums then direct direct direct as a control sample,
 rilled water until the residual KOH was removed. It

was then dried at 60 °C for 24 h to obtain the Li-S₆ electrolyto (ToS mol-L⁻) was prepared by a
dual mano-HA@CCPC composite. As a control sample, img sulfur and Li-

28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)

then dried in a vacuum oven at 60 °C for 24 h before

being cut into circular disks (19 mm diameter). The

control samples (nano-HA- and CCPC-modified sep-

arators) were prepared by using the s 电化学(*J. Electrochem.*) 2022, 28(11), 2219008 (3 of 13)
vas constructed which then dried in a vacuum oven at 60 °C for 24 h before
ion. During the car-
distributed HA main-
control samples (nano-HA- and CCPC-modified sep-

(11), 2219008 (3 of 13)

en dried in a vacuum oven at 60 °C for 24 h before

ing cut into circular disks (19 mm diameter). The

introl samples (nano-HA- and CCPC-modified sep-

introls were prepared by using the same meth 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same 28(11), 2219008 (3 of 13)

then dried in a vacuum oven at 60 °C for 24 h before

being cut into circular disks (19 mm diameter). The

control samples (nano-HA- and CCPC-modified sep-

arators) were prepared by using the s 28(11), 2219008 (3 of 13)

then dried in a vacuum oven at 60 °C for 24 h before

being cut into circular disks (19 mm diameter). The

control samples (nano-HA- and CCPC-modified sep-

arators) were prepared by using the s 11), 2219008 (3 of 13)

11), 2219008 (3 of 13)

In dried in a vacuum oven at 60 °C for 24 h before

ing cut into circular disks (19 mm diameter). The

the strol samples (nano-HA- and CCPC-modified sep-
 3 Preparation of 28(11), 2219008 (3 of 13)
then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same **Example 12**

then dried in a vacuum oven at 60 °C for 24 h before

being cut into circular disks (19 mm diameter). The

control samples (nano-HA- and CCPC-modified sep-

arators) were prepared by using the same method.

n to form carbon-coated nano-HA
 2.3 Preparation of the Li,S₆ Solution

Ling CCPC showed high ab-

Ling, solution was used to investigate the adsorp-

Ling capacity, rad thus, Li-S bat-

ion of LiPSs according to a p structures. The nano-HA@CCPC showed high ab-

soprion on catalytic appability, and thus, 1.1-5 bat-

teries with the nano-HA@CCPC modified separator

teries with the nano-HA@CCPC modified separator

method^{1:94}, In parti sorption and catalytic capability, and thus, Li-S bat-

terics with the nano-HA(@CCPC-modified separator method.¹³¹⁹. In particular, sublimed sulfir and Li-S

exhibited superior specific capacity, rate performance, were teries with the nano-HA@CCPC-modified separator method¹⁵⁴. In particular, sublimed sulfur and Li₅S
exhibited superior specific capacity, rate performance, were mixed (molar ratio 5:1) with 13,-sloosolanc (DOL)
end sep exhibited superior specific capacity, rate performance, were mixed (molar ratio 5:1) with 1,3-dioxolane (DOL)

and especifily long-term cycling stability. After 325 and 1,2-dimethoxyteliane (DML) (volues ratio 1:1)

anycl and especially long-term cycling stability. After 325 and 1,2-dimethoxychlane (DME) (volume ratio 1:1)

eycles at 0.5 c, these batteries showed a specific ease under an argo at mosphere and the resultant solution

pacity eyeles at 0.5 C, these batteries showed a specific ca-

equal and a magon atmosphere and the resultant solution

paciely of 815 mAh erg¹ was the less of equasity pare was placed to stand for 2 days to form Li₅ s₆.
 pacity of 815 mAh - g⁻¹ and the loss of capacity per

was placed to stand for 2 days to form 1.i.s₆,

eycke was as loos as 60 os as 60 oc for 2.4 **A secenber of Eq. 34 maginal of radiation**

is a promissing material f eyele was as low as 0.051%. The nano-HA@CCPC 2.4 Assembly of Li_sS₆ Symmetric Battery

is a promising material for advancing the adoption of The LisS₅ symmetric batterts were assembled by

LiFSs.

2. **Experimental**
 is a promising material for advancing the adoption of

The Li_sS_s symmetric hatteries were assembled by

using identical electrodes as the cathode and anode
 21 Experimental
 21 Experimental electrodes and anode sim LiPSs.
 2. Experimental
 2. then dried in a vacuum oven at 60 °C for 24 h before
being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same method.
2.3 Preparation o being cut into circular disks (19 mm diameter). The
control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same method.
2.3 **Preparation of the Li₂S₆ Solution**
Li₂S₆ solution was used control samples (nano-HA- and CCPC-modified sep-
arators) were prepared by using the same method.
 2.3 Preparation of the Li_S₆ Solution

Li₂S₆ solution was used to investigate the adsorp-

tion of LiPSs accordin arators) were prepared by using the same method.
 2.3 Preparation of the Li₂S₆ Solution

Li₂S₆ solution was used to investigate the adsorption of LiPSs according to a previously reported

method^[34]. In partic 2.3 **Preparation of the Li₂S₆ Solution**
Li₂S₆ solution was used to investigate the adsorption of LiPSs according to a previously reported
method^[34]. In particular, sublimed sulfur and Li₂S
were mixed (molar r Li₂S₆ solution was used to investigate the adsorption of LiPSs according to a previously reported method^[34]. In particular, sublimed sulfur and Li₂S were mixed (molar ratio 5:1) with 1,3-dioxolane (DOL) and 1,2-d tion of LiPSs according to a previously reported
method^[34]. In particular, sublimed sulfur and Li₂S
were mixed (molar ratio 5:1) with 1,3-dioxolane (DOL)
and 1,2-dimethoxyethane (DME) (volume ratio 1:1)
under an argo method^[34]. In particular, sublimed sulfur and Li₂S
were mixed (molar ratio 5:1) with 1,3-dioxolane (DOL)
and 1,2-dimethoxyethane (DME) (volume ratio 1:1)
under an argon atmosphere and the resultant solution
was place were mixed (molar ratio 5:1) with 1,3-dioxolane (DOL)
and 1,2-dimethoxyethane (DME) (volume ratio 1:1)
under an argon atmosphere and the resultant solution
was placed to stand for 2 days to form Li_2S_6 .
2.4 Assembly of and 1,2-dimethoxyethane (DME) (volume ratio 1:1)
under an argon atmosphere and the resultant solution
was placed to stand for 2 days to form Li₂S_e.
2.4 Assembly of Li₂S_e Symmetric Battery
The Li₂S_e Symmetric under an argon atmosphere and the resultant solution
was placed to stand for 2 days to form Li₂S₆.
2.4 Assembly of Li₂S₆ Symmetric Battery
The Li₂S₆ symmetric batteries were assembled by
using identical elec was placed to stand for 2 days to form Li<sub>2S₆.
 2.4 Assembly of Li₂S₆ Symmetric Battery

The Li_{2S6} symmetric batteries were assembled by

using identical electrodes as the cathode and anode

simultaneously. To p</sub> Li_2S_6 electrolyte (0.05 mol \cdot L⁻¹) was prepared by addto form Li₂S₆.
 ymmetric Battery

ries were assembled by

the cathode and anode

the nano-HA@CCPC-

nano-HA@CCPC pow-

A132 were mixed into

lirectly coated on alu-

nple, the nano-HA and

if with the same proce-

v **2.4 Assembly of Li₂S₆ Symmetric Battery**
The Li₂S₆ Symmetric batteries were assembled by
using identical electrodes as the cathode and anode
simultaneously. To prepare the nano-HA@CCPC-
modified electrodes, 45wt% The Li₅S₆ symmetric batteries were assembled by
using identical electrodes as the cathode and anode
simultaneously. To prepare the nano-HA@CCPC-
modified electrodes, 45wt% nano-HA@CCPC pow-
der, 45wt% AB, and 10wt% LA -1 using identical electrodes as the cathode and anode
simultaneously. To prepare the nano-HA@CCPC-
modified electrodes, 45wt% nano-HA@CCPC pow-
der, 45wt% AB, and 10wt% LA132 were mixed into
a homogeneous slurry, and direct simultaneously. To prepare the nano-HA@CCPC-
modified electrodes, 45wt% nano-HA@CCPC pow-
der, 45wt% AB, and 10wt% LA132 were mixed into
a homogeneous slurry, and directly coated on alu-
minum foil. As a control sample, t y. To prepare the nano-HA@CCPC-
trodes, 45wt% nano-HA@CCPC pow-
B, and 10wt% LA132 were mixed into
us slurry, and directly coated on alu-
As a control sample, the nano-HA and
de was prepared with the same proce-
AB electr ring. der, 45wt% AB, and 10wt% LA132 were mixed into
a homogeneous slurry, and directly coated on alu-
minum foil. As a control sample, the nano-HA and
CCPC electrode was prepared with the same proce-
dure. And the AB electrode num foil. As a control sample, the nano-HA and
PPC electrode was prepared with the same proce-
re. And the AB electrode was prepared by mixing
3 with LA132 (mass ratio 9:1). The electrodes were
tained after the coated foi CCPC electrode was prepared with the same proce-
dure. And the AB electrode was prepared by mixing
AB with LA132 (mass ratio 9:1). The electrodes were
obtained after the coated foils were cut into 12.0 mm
disks. The batte dure. And the AB electrode was prepared by mixing
AB with LA132 (mass ratio 9:1). The electrodes were
obtained after the coated foils were cut into 12.0 mm
disks. The batteries were then assembled into
CR2025 coin cells w AB with LA132 (mass ratio 9:1). The electrodes were
obtained after the coated foils were cut into 12.0 mm
disks. The batteries were then assembled into
CR2025 coin cells with two identical electrodes, Cel-
gard 2325 separ obtained after the coated foils were cut into 12.0 mm
disks. The batteries were then assembled into
CR2025 coin cells with two identical electrodes, Cel-
gard 2325 separator and 40 μL Li₂S₆ electrolyte. The
Li₂S₆ r the coated foils were cut into 12.0 mm
batteries were then assembled into
cells with two identical electrodes, Cel-
parator and 40 μ L Li₂S₆ electrolyte. The
yte (0.05 mol·L⁻¹) was prepared by add-
d Li₂S (mol disks. The batteries were then assembled into
CR2025 coin cells with two identical electrodes, Cel-
gard 2325 separator and 40 µL Li₂S₆ electrolyte. The
Li₂S₆ electrolyte (0.05 mol·L⁻¹) was prepared by add-
ing 25 coin cells with two identical electrodes, Cel-
325 separator and 40 μ L Li₂S₆ electrolyte. The
lectrolyte (0.05 mol·L⁻¹) was prepared by add-
fiur and Li₂S (molar ratio 5:1) in a mixture of
nd DME (volume rat entical electrodes, Cel-

Li₂S₆ electrolyte. The

was prepared by add-

o 5:1) in a mixture of

1) containing 1 mol·L⁻¹

Ifonyl) imide (LITFSI)

ntinuous magnetic stir-
 nd Material Char-

ned sulfur, 30wt% AB,

d

acterization

mol \cdot L⁻¹ LITFSI and 0.4 mol \cdot L⁻¹ LiNO₃ in a combinagard 2325 separator and 40 μ L Li₂S₆ electrolyte. The
Li₂S₆ electrolyte (0.05 mol·L⁻¹) was prepared by add-
ing sulfur and Li₂S (molar ratio 5:1) in a mixture of
DOL and DME (volume ratio 1:1) containing 1 m $\#E\#(J. Electronchem.)$ 2022, 28(11), 2219008 (4 of 13)

HA-, CCPC-, and nano-HA@CC PC-modified sepa-

rators were adopted as the separators with the coated

structure. However, the diffraction peaks of HA crys-

side facing the ca $#E\#(J. Electron.)$
 $\oplus E\#(J. Electron.)$ 2022, 28(11), 2219008 (4 of 13)

HA-, CCPC-, and nano-HA@CCPC-modified sepa-

rators were adopted as the separators with the coated

side facing the cathode in the coin cells. The CR2025

coin c

EVALUATION EXECT (FRECTION ACCONT CONTECT (BET)
 EVALUATION CONTECT (FRECT) (THE NEW TO THE SEN improvements of the nano-HA@CCPC are not side facing the cathode in the coin cells. The CR2025 composite facing the catho HA-, CCPC-, and nano-HA@CCPC-modified sepa-

graphite, respectively¹⁵⁸), indicating the amorphous

strators were adopted as the separators with the coated

stratuter. However, the diffraction peaks of HA crys-

side fac rators were adopted as the separators with the coated

structure. However, the diffraction peaks of HA erys-

side facing the catalogical condital in an argon-filled

solid be attributed to the coverage of amorphosis which side facing the cathode in the coin cells. The CR2025

in the nano-HA@CCPC are not obvious which

equbits are

equbits are then assembled in an argon-filled could be attivuted to the coverage of amorphoson

electroscope (E coin cells were then assembled in an argon-filled could be attributed to the coverage of amorphous car-

Energy dispersive spectroscope (EDS, Quanta 650, content the formation of HA, we cal-

Energy dispersive spectroscope bon. Hence, to confirm the formation of HA, we cal-
Energy dispersive spectroscope (EDS, Quanta 650,

Energy dispersive spectroscope (SEM, JSMbon and the sample is denoted as nano-HA. The

7500F, JEOL) were used to char Fraergy dispersive spectroscope (FDS, Quanta 650, cined the nano-HA@CCPC in an air to remove carr-
FEI) and scanning clettom interscope (SEM, ISM-

bon and the sample is denoted as nano-11A. The
T300F, JFoIL) were used to FEI) and scanning electron microscope (SEM, JSM-

for and the sample is den

7500F, JEOL) were used to characterize the surface

2.8 XRD pattern of nano-HA exh

morphology of and elemental distribution in the

tino peaks, mg electron microscope (SEM, JSM-

bon and the sample is denoted as nano-HA. The

over used to characterize the surface

XRD pattern of nano-HA exhibits typical HA diffrac-

and elemental distribution in the tion peaks, co 7500F, JFOL) were used to characterize the surface XRD pattern of nano-HA exhibits typical HA diffrac-
morphology of and elemental distribution in the tion peaks, confirming the good crystalization of
mano-HA@CCPC. The el morphology of and clemental distribution in the tion peaks, confirming the good crystallization of

nano-HA@CCPC. The clemental composition of the nano-HA particles^{tes,50}^m, In addition, to illuminate the

nano-HA@CCPC nano-HA@CCPC. The elemental eomposition of the
nano-HA particles!^{ES-80}. In addition, to illuminate the
nano-HA@CCPC and the chemicial adsoption char-
materialis of the mano-HA @CCPC/Liss_n composite CCPC, CCPC was prep nano-HA@CCPC and the chemical adsoption char-
niteraction at the interface between nano-HA and
networks of the nano-HA@CCPC.
As composite CCPC, CCPC was premated by removing mano-HA
move investigated with X-ray photoelect acteristics of the nano-HA@CCPC/Li,S₆, composite

corpc), CCPC, CCPC was prepared by removing nano-HA

were investigated with X-ray photoelectron spec-

in CCPC. CCPC shows similar XRD patterns to

data were calculated were investigated with X-ray photoelectron spec-

und TG curve confirms the complete removal of HA

trossopy (XPS). The Brunauc-E-ment-Tcller (BET) in CCPC. CCPC shows similar XRD patterns to

data were calculated from AS troscopy (XPS). The Brunauer-Emmett-Teller (BET) in CCPC. CCPC shows
data were calculated from ASAP 2020 V4.01. The nano-HA@CCPC.
compositions of the raw chicken cartilage and nano-
 $HA@CCPC$ were characterized by thermograv S). The Brunauer-Emmett-Teller (BET) in CCPC. CCPC shows similar

leulated from ASAP 2020 V4.01. The nano-HA@CCPC.

of the raw chicken cartilage and nano-

The SEM image of nano-HA@CCPC

of the raw chicken cartilage and n data were calculated from ASAP 2020 V4.01. The nano-HA@CCPC.

compositions of the raw chicken cartilage and nano-

The SEM image of nano-HA@CCPC

EM-@CCPC were characterized by thermogravime-the EDS mapping is shown in Fi

 $#E# (J. Electrochem.) 2022, 28(11), 2219008 (4 of 13)$

HA-, CCPC-, and nano-HA@CCPC-modified sepa-

rators were adopted as the separators with the coated

structure. However, the diffraction peaks of HA crys-

side facing the cathode $\text{H} \&L^{\#}(J. \text{Electrochem.})$ 2022, 28(11), 2219008 (4 of 13)

HA-, CCPC-, and nano-HA@CCPC-modified sepa-

rators were adopted as the separators with the coated

structure. However, the diffraction peaks of HA crys-

side fac $\frac{dE}{dt}(L\text{ }Electrochem.)$
 $\frac{dE}{dt}(L\text{ }Electrochem.)$ 2022, 28(11), 2219008 (4 of 13)

HA-, CCPC-, and nano-HA@CCPC-modified separators with the coated

structure. However, the diffraction peaks of HA crys-

side facing the cathode $\frac{dE}{dt}E_{t}^{22}(L \t{Electrockem}) 2022, 28(11), 2219008 (4 of 13)$

A-, CCPC-, and nano-HA@CCPC-modified separations with the coated as the separations with the coated as the spectroscope (spectroscope tal in the nano-HA@CCPC are $\text{H/}\mathcal{H}(L\text{~Electrockem.})$ 2022, 28(11), 2219008 (4 of 13)

HA-, CCPC, and nano-HA@CCPC-modified sepa-

rathers, espectively¹⁸⁵¹, indicating the amorphous

rathers were adopted as the separators with the coated

structur **EACTER CONTING THE CONTING CONTING CONTING CONTING ACTES (COPC AND ARENDTIFICATION AND ARENDTIFICATION OF THE SURFACTED AND ARENDMENT CONTING THE SURFACTED AND AREND AREND THE SURFACTED AND SCIENCIPE THE SURFACTED AND SC** $\text{H}A$, CCPC, and nano-HA(\ddot{a})CPC and the controlled sepactively¹⁸¹, indicating the amorphous
mators were adopted as the separators with the coated structure. However, the diffraction peaks of HA crys-
side facin **HEW (***LEtertochem.*) 2022, 28(11), 2219008 (4 of 13)

HA-, CCPC-, and nano-HA@CCPC-modified sepa-

graphite, respectively¹⁸¹, indicating the amorphous

stators were adopted as the separators with the coated

structure **EVALUATION EXAMORE 1**
 EVALUATION CONTROV (4 of 13)

HA-, CCPC-, and nano-HA@CCPC-modified separations with the conted

strations were adopted as the separations with the conted

strations were adopted as the separatio **EVALUATION EXAMORE THE CONSTRANT (EXAMORE THE CONSTRANT)**

HA-, CCPC-, and nano-HA@CCPC-modified sepa-

ratios were adopted as the separators with the coated are strated with the coated spec-

side licing the canded in t $\text{#}(E\cong CL \text{Etermoken.}) 2022.28(11), 2219008 (4 of 13)$

HA-, CCPC-, and nano-HA@CCPC-modified sepa-

graphite, respectively¹⁸¹, indicating the amorphous

state disting the cantors were adopted as the separators with the coa $\frac{d}{dt}\mathcal{L}^{\infty}(L)$ *Electrobema*, 2022, 28(11), 2219008 (4 of 13)

HA-, CCPC-, and nano-HA@CCPC-modified separators with the coated structure. However, the diffraction peaks of HA crys-

side facing the cathode in the HA-, CCPC-, and nano-HA@CCPC-modifical separations of the raw chicken cartilage and structure interest and the carticle and struc 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a $28(11)$, 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a $28(11)$, 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a $28(11)$, 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a $28(11)$, 2219008 (4 of 13)
graphite, respectively^[33], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage 28(11), 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of a $28(11)$, 2219008 (4 of 13)
graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage nano-HA@CCPC. The SEM intertance of the morphous
phite, respectively^[35], indicating the amorphous
in the nano-HA@CCPC are not obvious which
ald be attributed to the coverage of amorphous car-
n. Hence, to confirm the formation of HA graphite, respectively^[35], indicating the amorphous
structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of amorphous car-
bon. Hence, structure. However, the diffraction peaks of HA crys-
tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of amorphous car-
bon. Hence, to confirm the formation of HA, we cal-
cined the nano-H tal in the nano-HA@CCPC are not obvious which
could be attributed to the coverage of amorphous car-
bon. Hence, to confirm the formation of HA, we cal-
cined the nano-HA@CCPC in an air to remove car-
bon and the sample is could be attributed to the coverage of amorphous car-
bon. Hence, to confirm the formation of HA, we cal-
cined the nano-HA@CCPC in an air to remove car-
bon and the sample is denoted as nano-HA. The
XRD pattern of nano-HA bon. Hence, to confirm the formation of HA, we cal-
cined the nano-HA@CCPC in an air to remove car-
bon and the sample is denoted as nano-HA. The
XRD pattern of nano-HA exhibits typical HA diffrac-
tion peaks, confirming t 电化学(*J. Electrochem.*) 2022, 28(11), 2219008 (4 of 13)

CC PC-modified sepa-

graphite, respectively^[35], indicating the amorphous

rators with the coated

structure. However, the diffraction peaks of HA crys-

oin cel

mpositions of the raw chicken cartilage and nano-

The SEM image of nano-HA@CCPC ware in the space of weatherence characterized by thermogravimel-

in EDS mapplers is above in Figure 1d. The

analyzer (TGA, Hengiu, China) HA@CCPC were characterized by thermogravimet-

the EDS mapping is shown in Figure 1d. The

rein amalyzer (TGA, Hengit, China). X-ray diffractione and HA@CCPC demonstrates a hierarchical poros

(XRD) patterns were obtained ric analyzer (TGA, Hengiju, China). X-ray diffraction

carbonized barear as therachical porous

(XRD) patterns were obstained by a D/max 2500 V structure with uniformly distributed N and Ca ele-

X-ray diffractometer, and (XRD) patterns were obtained by a D/max 2500 V
structure with uniformly distributed N and Ca-
eX-ray diffract
omentous can the adsorption of EL'88 ments. This indicates the even distribution of HA on
some (TU-1810). In th X-ray diffractometer, and the adsorption of LiPSs ments. This indicates the even distribution of HA on

sono (TU-1810). In the voltage window from 1.7 to $\frac{1}{2}$ mage of re-calcined anno 11A particles (Figure

2.8 V vs. onto the samples was studied using UV-vis spectro-

conto framework. And according to the SEM

scope (TU-18)0. In the voltage window from 1.7 to image of re-caliend mano HA particles (Figure

2.8 V vs. Li/Li, a LAND-CT200 scope (TU-1810). In the voltage window from 1.7 to image of re-calcined nano HA particles (Figure 2.8 V vs. LitAl', a LAND-CT2001A instrument was $$\text{S3.4b}$, the average particle is are of HA is less than used to measur 2.8 V vs. Li/Li, a LAND-CT2001A instrument was

83a-b), the average particle size of HA is less than

used to measure the eveloper

from and removing celectroschem-

in the reason for the distribution distriction of

ical used to measure the cycle performance. Electrochem-

ical impedance spottcoscopy (EIS) and cyclic voltain-

HA between the two metricals could be attributed to

inetry (CV) were then employed to perform mea-

the *in-situ* ical impedance spectroscopy (EiS) and cyclic voltam-
netw materials could be attributed to
netw (CV) were then employed to perform mean-
the *the skine-covered* eards to perform the summer to the summer (CV) were then emp metry (CV) were then employed to perform mea-
survenchas by using an Antolah PGSTA7204 in the of HA, which limits the aggeomerator of HA particles.
The peaks are the surface of HA particles and real that in the specifical surements by using an Autolab PGSTAT204 in the of HA, which limits the agglomeration of HA parti-
frequency range from 100 mHz to 100 kHz and in the clear and results in small HA particles. Table S2 shows
voltage window f cined the nano-HA@CCPC in an air to remove car-
bon and the sample is denoted as nano-HA. The
XRD pattern of nano-HA exhibits typical HA diffrac-
tion peaks, confirming the good crystallization of
nano-HA particles^{[36,38} bon and the sample is denoted as nano-HA. The
XRD pattern of nano-HA exhibits typical HA diffrac-
tion peaks, confirming the good crystallization of
nano-HA particles^{[36,38}]. In addition, to illuminate the
interaction a XRD pattern of nano-HA exhibits typical HA diffraction peaks, confirming the good crystallization of nano-HA particles^[36,38]. In addition, to illuminate the interaction at the interface between nano-HA and CCPC, CCPC w tion peaks, confirming the good crystallization of
nano-HA particles^{[36,38}]. In addition, to illuminate the
interaction at the interface between nano-HA and
CCPC, CCPC was prepared by removing nano-HA
and TG curve confi nano-HA particles^[36,38]. In addition, to illuminate the
interaction at the interface between nano-HA and
CCPC, CCPC was prepared by removing nano-HA
and TG curve confirms the complete removal of HA
in CCPC. CCPC shows interaction at the interface between nano-HA and CCPC, CCPC was prepared by removing nano-HA
and TG curve confirms the complete removal of HA
in CCPC. CCPC shows similar XRD patterns to
nano-HA@CCPC.
The SEM image of nano CCPC, CCPC was prepared by removing nano-HA
and TG curve confirms the complete removal of HA
in CCPC. CCPC shows similar XRD patterns to
nano-HA@CCPC.
The SEM image of nano-HA@CCPC along with
the EDS mapping is shown in F and TG curve confirms the complete removal of HA
in CCPC. CCPC shows similar XRD patterns to
nano-HA@CCPC.
The SEM image of nano-HA@CCPC along with
the EDS mapping is shown in Figure 1d. The
nano-HA@CCPC demonstrates a hi in CCPC. CCPC shows similar XRD patterns to
nano-HA@CCPC.
The SEM image of nano-HA@CCPC along with
the EDS mapping is shown in Figure 1d. The
nano-HA@CCPC demonstrates a hierarchical porous
structure with uniformly distri nano-HA@CCPC.
The SEM image of nano-HA@CCPC along with
the EDS mapping is shown in Figure 1d. The
nano-HA@CCPC demonstrates a hierarchical porous
structure with uniformly distributed N and Ca ele-
ments. This indicates th The SEM image of nano-HA@CCPC along with
the EDS mapping is shown in Figure 1d. The
nano-HA@CCPC demonstrates a hierarchical porous
structure with uniformly distributed N and Ca ele-
ments. This indicates the even distrib the EDS mapping is shown in Figure 1d. The
nano-HA@CCPC demonstrates a hierarchical porous
structure with uniformly distributed N and Ca ele-
ments. This indicates the even distribution of HA on
the carbon framework. And nano-HA@CCPC demonstrates a hierarchical porous
structure with uniformly distributed N and Ca ele-
ments. This indicates the even distribution of HA on
the carbon framework. And according to the SEM
image of re-calcined n structure with uniformly distributed N and Ca elements. This indicates the even distribution of HA on the carbon framework. And according to the SEM image of re-calcined nano HA particles (Figure S3a-b), the average parti ments. This indicates the even distribution of HA on
the carbon framework. And according to the SEM
image of re-calcined nano HA particles (Figure
S3a-b), the average particle size of HA is less than
100 nm. The reason fo the carbon framework. And according to the SEM
image of re-calcined nano HA particles (Figure
S3a-b), the average particle size of HA is less than
100 nm. The reason for the distribution distinction of
HA between the two image of re-calcined nano HA particles (Figure S3a-b), the average particle size of HA is less than 100 nm. The reason for the distribution distinction of HA between the two materials could be attributed to the *in-situ-c* a-b), the average particle size of HA is less than
0 nm. The reason for the distribution distinction of
between the two materials could be attributed to
 $in-situ$ -covered carbon framework on the surface
HA, which limits the a 100 nm. The reason for the distribution distinction of HA between the two materials could be attributed to the *in-situ-covered carbon framework* on the surface of HA, which limits the agglomeration of HA parti-cles and r HA between the two materials could be attributed to
the *in-situ-covered carbon* framework on the surface
of HA, which limits the agglomeration of HA parti-
cles and results in small HA particles. Table S2 shows
the atomi the *in-situ-covered carbon framework on the surface*
of HA, which limits the agglomeration of HA parti-
cles and results in small HA particles. Table S2 shows
the atomic percentages. The Ca/P atomic ratio in the
nano-HA@ of HA, which limits the agglomeration of HA parti-
cles and results in small HA particles. Table S2 shows
the atomic percentages. The Ca/P atomic ratio in the
nano-HA@CCPC was 1.52, which is lesser than the
theoretical va

 $\text{E/}\mathcal{L}\#(\mathcal{L} \text{ *Electrochem*}) 2022, 28(11), 2219008 (5 of 13)\n\text{series of reactions occurred between the KOH and nano-HA were highly coincident and the N₁ adsor-
carbon (i.e., KOH \rightarrow H₂O + H₂O, C + H₂O \rightarrow H₂ + \text{ } to an amount approached zero. Only certain adsorp
CO, CO + H₂O + H₂ + CO₃, K₂O + CO₂$ adsorption was induced[41], indicating a well-develthe $\mathcal{C}(L \text{ Electrowe})$

operations occurred between the KOH and

one HA were highly coincident and the N₂ assorp-

carbon (i.e., KOH \rightarrow K₂O + H₂O, C + H₂O + H₂ \rightarrow H₂+ tion amount approached zero. Only certai However, the low- and mediator co, CO + H2O → H₂+ CO₃ K₂O + CO₂ → K₂

 $\#l\#(J. \text{Electrochem.}) 2022, 28(11), 2219008 (5 of 13)$
series of reactions occurred between the KOH and
nano-HA were highly coincident and the N₂ adsorp-
carbon (i.e., KOH → K₂O + H₂O, C + H₂O → H₂ +
CO, CO + H₂O → H $\# \# \#$ *L Electrochem.*) 2022, 28(11), 2219008 (5 of 13)

series of reactions occurred between the KOH and

carbon (i.e., KOH → K₂O + H₂O, C + H₂O → H₂ + tion amount approached zero. Only certain adsorp

CO, C E(*E*²/*Electrochem.*) 2022, 28(11), 2219008 (5 of 13)

series of reactions occurred between the KOH and

nano-HA were highly coincident and the N₂ adsorp-

carbon (i.e., KOH → K₂O + H₂O, C + H₂O → H₂+ tion a $\# \{\&\cong (J. \nElectrochem.)\ 2022, 28(11), 2219008 (5 of 13)\}\n\text{series of reactions occurred between the KOH and nano-HA were highly coincident and the N₂ adsor-
\ncarbon (i.e., KOH $\rightarrow K_2O + H_2O, C + H_2O \rightarrow K_2O$),
\ntion amount approached zero. Only certain adsorp
\nCO, CO + H₂O $\rightarrow H_2 + CO_2, K_2O + CO_2 \rightarrow K_2CO_2$,
\ntion occurred in the high-pressure zone, suggesting
\nK₂O + H₂ $\rightarrow$$ **EART ACCONSTER 1999**
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series of reactions occurred between the KOH and nano-HA were highly coincident and the N₂ adsorp-

carbon (i.e., KOH → K₂O + H₂O, C + H₂O → H₂ **h** $f(E^2)(I \cdot R(errochen))$ 2022, 28(11), 2219008 (5 of 13)

series of reactions occurred between the KOH and

nano-HA were highly coincident and the N₂ adsorp-

carbon (i.e., KOH \rightarrow K,O + H,O, C + H,O \rightarrow H, +

tion amount 28(11), 2219008 (5 of 13)
nano-HA were highly coincident and the N₂ adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA mater 28(11), 2219008 (5 of 13)
nano-HA were highly coincident and the N_2 adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA mate 28(11), 2219008 (5 of 13)
nano-HA were highly coincident and the N₂ adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA mater 28(11), 2219008 (5 of 13)
nano-HA were highly coincident and the N₂ adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA mater 28(11), 2219008 (5 of 13)

mano-HA were highly coincident and the N_2 adsorp-

tion amount approached zero. Only certain adsorp

tion occurred in the high-pressure zone, suggesting

the macroporous structure of nano-HA 28(11), 2219008 (5 of 13)
nano-HA were highly coincident and the N₂ adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA mater 28(11), 2219008 (5 of 13)
nano-HA were highly coincident and the N₂ adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA mater $28(11)$, 2219008 (5 of 13)
nano-HA were highly coincident and the N₂ adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA m $28(11)$, 2219008 (5 of 13)
nano-HA were highly coincident and the N_2 adsorp-
tion amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA 28(11), 2219008 (5 of 13)
nano-HA were highly coincident and the N₂ adsorption amount approached zero. Only certain adsorp
tion occurred in the high-pressure zone, suggesting
the macroporous structure of nano-HA materia 28(11), 2219008 (5 of 13)

nano-HA were highly coincident and the N₂ adsorption amount approached zero. Only certain adsorp

tion occurred in the high-pressure zone, suggesting

the macroporous structure of nano-HA mate 28(11), 2219008 (5 of 13)

nano-HA were highly coincident and the N₂ adsorption amount approached zero. Only certain adsorption occurred in the high-pressure zone, suggesting

the macroporous structure of nano-HA materi $\exists E(E\#(J. \text{Electrochem.}) 2022, 28(11), 2219008 (5 of 13)$

etween the KOH and nano-HA were highly coincident and the N₂ adsorp-

H₂O, C + H₂O → H₂ + tion amount approached zero. Only certain adsorp

K₂O + CO₂ → K₂CO

 $\text{\#E*}(J. \text{ Electronic}, 2022, 28(11), 2219008 (6 of 13) \text{ \#C}(\text{L}) = 222, 28(11), 2219008 (6 of 13) \text{ \#C}(\text{C}(\text{L})) = 222, 28(11), 2219008 (6 of 13) \text{ \#C}(\text{L}) = 222, 28(11), 2219008 (6 of 13) \text{ \#C}(\text{L}) = 222, 28(11), 2219008 (6 of 13) \text{ \#C}(\text{L})$ **ELE***(*J. Electrochem.*) 2022, 28(11), 2219008 (6 of 13)
 ELEX (*CCPC*, a total specific surface area (SSA) of 2060.6 (at 168.56 and 169.82 eV, corresponding to sul-

CCPC, a total specific surface area (SSA) of 2060. ^t $\frac{1}{2}$ ²/(*Litectrochem.*) 2022, 28(11), 2219008 (6 of 13)

manoHA@CCPC and nano-HA. For the nano-HA@ while at 168.56 and 169.82 eV, corresponding to sul-

CCPC, a total specific surface area (SSA) of 2060.6 fate s ⁴¹(*J. Electrochem.*) 2022, 28(11), 2219008 (6 of 13)
 annol HA@CCPC and nano-HA. For the nano-HA@ while at 168.56 and 169.82 eV, corresponding to sul-

CCPC, a total specific surface area (SSA) of 2060.6 fate species $\frac{\text{d}(E\#(J. Electrochem.) 2022, 28(11), 2219008 (6 of 13)}{\text{manoHA@CCPC and nano-HA. For the nano-HA@} \qquad while at 168.56 and 169.82 eV, corresponding to su-CCPC, a total specific surface area (SSA) of 2060.6\n \n The species formed by the oxidation of sulfur in an $m^2 \cdot g^{-1}$ with a micropore SSA of 498.0 $m^2 \cdot g^{-1}$ and an $m^2 \cdot g^{-1}$. After the nano-HA@CCPC adsorbed Li₂S₆, two average pore size of 2.0 nm$ H(*E²²*(*L Electrochem.*) 2022, 28(11), 2219008 (6 of 13)

manoHA@ CCPC and nano-HA. For the nano-HA@ while at 168.56 and 169.82 eV, corresponding to sul-

CCPC, a total specific surface are (SSA) of 2060.6

m³ · g the *R*^{(*g*} *CEC* and nano-HA. For the nano-HA*(g*) while at 168.56 and 169.82 eV, corresponding to sul-
CCPC, a total specific surface area (SSA) of 2060.6 fate species formed by the oxidation of sulfur in an² · the mand the species formed by the oxida th $\mathbb{R} \times \mathbb{C}$ and nano-HA. For the nano-HA@ while at 168.56 and 169.82 eV, corresponding to sulcting the state species formed by the oxidation of sulfur in an $m^2 \cdot g^{-1}$ with a micropore SSA of 498.0 m² e⁻¹ and \pm l/ \pm // \pm /*C Electrochem.*) 2022, 28(11), 2219008 (6 of 13)

nanoHA@CCPC and nano-HA. For the nano-HA@ while at 168.56 and 1

CCPC, a total specific surface area (SSA) of 2060.6 fate species formed b

m²·g⁻¹ of Li^+ ions^[43].

penetration, which is beneficial for the fast transport

che Ir cole of the reactive interface in accelerating the

The adsorption and eatalytic capability of nano-

ics sever investigated by using Li_Ss-electrolyte sym-LiPSs reduction reactions. The redox reactions kinet-
The adsorption and eatalytic capability of nano-

HA@CCPC were finther investigated. The UV-vis insertic batteries with CV scan rate of 50 mV s⁻¹ and
spectra of LiPS The adsorption and eatalytic eapability of nano-

its were investigated by using Li.S_pclectrolyte sym-

HA(\overline{B} CCC were further investigated. The UV-vis metric hatteres with CV scan rate of 50 mV·s⁺² and

HA($\overline{$ HA@CCPC were further investigated. The UV-vis metric batteries with CV scan rate of 50 mV ·s⁻¹ and
specina of LiPSs shors and after being mixed with whitege window from -0.7 to 0.7 U (Figure 2o). The po-
specina of Birs spectra of LiPSs before and after being mixed with
voltage window from -0.7 to 0.7 V (Figure 2e). The po-
variaty variaty of repared LiPSs shows high absorption
density of Li.S, and the minior capacitive enerer-
designal various adsorbents are shown in Figure 2a. UV-vis
signation profiles comprise the main redox current
signal below 500 nm¹⁶¹. The signal is obviously ressing of chies, and the minor capacitive current den-
signal below 5 spectrum of prepared LiPSs shows high absorption

signal below 500 mm¹⁶³. The signal is obvionly re- sity of free Li₅₆⁰³⁸, The symmetric battery with nano-

signal below 500 mm¹⁶⁴. The signal is obvionly re- sity signal below 500 nm^{(at]}. The signal is obviously re-
sity of free Li.S_n⁵⁹. The symmetric battery with anco-
to the large specific surface area and rich pore structed
that the CCPC, indicating that more than is respe duced after being mixed with CCPC. This is related

that difference are and right of the large specific surface torea and right of the large specific surface reas and right of the large specific surface are and right of t to the large specific surface area and rich pore struc-
that of CCPC, indicating that more than simply en-
ture of CCPC which lead to strong physical adsorption and the LiPSs atsorption, the introduction of
tion of LiPSs. ture of CCPC which lead to strong physical adsorp-
hanning the LiPSs alsorption, the introduction of
line is higher also prince HA@CCPC and mel-HA@CCPC as consinued the redox recation
an illapity higher alsorption capacit tion of LiPSs. The nano-HA@CCPC sample shows nano-HA@CCPC also enhanced the redox reaction
slightly higher absorption capacity of LiPSs com-
kinetics of LPSs. The ElS profiles shows in minimum
pared to that of CCPC which slightly higher absorption capacity of LiPSs com-

linetics of LiPSs. The EIS profile shows the minim

pared to that of CCPC which is attributed to the

chenge-transfer resistance of the nano-HA@CCC

canalysis was further pared to that of CCPC which is attributed to the charge-transfer resistance of the nano-HA@CCPC,
enhealing adsorption of LiPSs on nano-HA, XPS for the charge-transfer adstresses of LiPSs adsorption and the charge-efficies chemical adsorption of LiPSs on nano-HA. XPS further demonstrating that the high-efficiency reac-
enargyis was further conducted to understand the pro-
energy sas further conducted to understand the pro-
energy sase for L analysis was further conducted to understand the pro-

cess of LiPSs adsorption onto nano-HA@CCPC. The tion kineties of LiPSs (Figure 2p^{pm},

NPS Ca 2p spectrum shows two peaks at binding en—————————————————————————————— cess of LiPSs adsorption onto nano-HA@CCPC. The tion kinetics of LiPSs (Figure 2p³⁶⁾,

XPS Ca 2p spectrum shows two peaks at binding en-

The original combining of the high LiPSs adsorp-

Septence of 251.19 (2p₂₂) and XPS Ca 2p spectrum shows two peaks at binding en-

The original combining of the high LiPSs adsorp-

ergize of 331.19 (2p₀.s) and 347.69 eV (2p₀.s) (Figure tion CCPC and nano-HAA@CCPC and

2b), which are consistent wi ergies of 351.19 $(2p_{\nu 0})$ and 347.69 eV $(2p_{\nu 0})$ (Figure ion CCPC and nano-IIA catalyst makes nano-IIA@
2b), which are consistent with those of $C_6^{3.160}$. After CCC a promising eardied at for Li-S batteries. The

chem.) 2022, 28(11), 2219008 (6 of 13)

HA@ while at 168.56 and 169.82 eV, corresponding to sul-

2060.6 fate species formed by the oxidation of sulfur in an

and an air^{51.53}. After the nano-HA@CCPC adsorbed Li₂S₆ 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air^[51-53]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectr 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air^[51-53]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectr 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air^[51-53]. After the nano-HA@CCPC adsorbed Li₂S₆ two
new peaks of the S 2p spectru 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air^[51-53]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectr 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air^[51,53]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S-2p spectr (11), 2219008 (6 of 13)

iile at 168.56 and 169.82 eV, corresponding to sul-

e species formed by the oxidation of sulfur in an

g^[51,53]. After the nano-HA@CCPC adsorbed Li₂S₆, two

w peaks of the S 2p spectrum occ $\frac{\text{H} \& \frac{\text{L}}{\text{L}}(J. \text{Electrochem.}) 2022, 28(11), 2219008 (6 of 13)}{\text{L}}$

The nano-HA@ while at 168.56 and 169.82 eV, corresponding to sularea (SSA) of 2060.6 fate species formed by the oxidation of sulfur in an of 498.0 m

The adsorption and catalytic capability of nano-

The advantage of the advantage of the advantage of the advantage of the section of sulfurian and an ano-HA. For the anno-HA@ while at 168.56 and 169.82 eV, corresponding $\#4\mathcal{E}(\mathcal{L}Eermchem,)2022, 28(11), 2219008 (6 of 13)$

manoHA@CCPC and nano-HA. For the nano-HA@ while at 168.56 and 169.82 eV, corresponding to sul-

ncCPC, a total specific surface area (SSA) of 2060.6 fate species formed $\frac{d}{dx}\mathcal{L}Z(LEecrocheom.) 2022, 28(11), 2219008 (6 of 13)
\n**panOHA@CCPC and nano-HA.** For the nano-HA@ which is a 168.56 and 169.82 eV, corresponding to sul-
\nCCPC, a total specific surface area (SSA)/ of 2060.6 the species formed by the oxidation of sulfur in an
\n $m^2 \cdot g^{-1}$ with a microprocess of 498.0 m²·g⁻¹ and an air²⁰·g⁻⁶. After the nano-HA@CCPC adsorbed Li₂₅two
\nav$ $\mathbf{u}_{2}(\mathcal{E}(\mathcal{E}(\mathbf{C}(\mathbf{P}(\mathbf{C}(\mathbf{C}(\mathbf{P}(\mathbf{C}(\mathbf{C}(\mathbf{P}(\mathbf{C}(\mathbf{C}(\mathbf{P}(\mathbf{C}(\mathbf{C}(\mathbf{P}(\mathbf{C}(\mathbf{C}(\mathbf{P}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\mathbf{C}(\$ **EVACTE (Example 10.5** and 4π and 6π content and the present and and the prepared absorption of sulfuring the subsetted absorption, the prepared absorption of sulfuring the subsetted CCPC, a total specific surface **EXECTS**
 EXECTS and nanofHA(\hat{g} CCPC and nanofHA \hat{f} and \hat{f} an nanoHA@CCPC and nano-HA. For the nano-HA@ while at 168.56 and 169.82 cV, corresponding to sul-
CCPC, a total specific surface area (SSA) of 2060.6 fine species formed by the oxidation of sulthr in an
m²·g⁻¹ with a mic CCPC, a total specific surface area (SSA) of 2060.6 fate species formed by the oxidation of sulfar in an m⁻₂⁻¹ with a micropore SSA of 498.0 m⁻¹₂ area and micropore specific adsorbed Lis_{ek} two average pore siz m² g⁻¹ with a microporc SSA of 498.0 m² g⁻¹ and an air²⁰²³. After the nano-HA@CCPC adsorbed LisS₆ two converge pore size of 2.0 m was obtained. The highly new peaks of the S z pepertum occurred at 165.73 dev average pore size of 2.0 nm was obtained. The highly

are weaks of the S 2p spectrum occurred at 163.73

developed miroriorisoprotous situation of the nano-

HA@CCPC might offer an interface with a larger and 164.89 cV, wh developed micro/mesoporous structure of the nano-

and 164.89 eV, which can be attributed to S-P^{54.59}.

H/ $\alpha/2$ CCCP cmiglt offer an interface with a larger

and starface area, thereby increasing the contact area be

go HA@ CCPC might offer an interface with a larger bue to the strong P-S bond, the nano-HA exhibits
usurface area, thereby increasing the contact area be-
specially conditation. Both
meteoral different phases and facilitatin surface area, thereby increasing the contact area be-

eyood catalytic capability for LiPSs reduction. Both

epenetration, which is beneficial for the fast transport

the role of the reactive interface in accelerating the
 tween different phases and facilitating electrolyte CV and EIS tests were carried out to gain insight into
portation, which is beneficial for the fast transport the role of the reactive interface in accelerating the
of Li 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air^{51-53]}. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectru 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air⁵¹⁻⁵³! After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectrum 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air⁵¹⁻⁵³! After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectrum 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
in^[5133]. After the nano-HA@CCPC adsorbed Li₂S₆ two
new peaks of the S 2p spectrum 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
 $\text{air}^{[5153]}$. After the nano-HA@CCPC adsorbed Li₂S₆ two
new peaks of the S 2p spect 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air.^[9143]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectr and 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
 $air^{[31,53]}$. After the nano-HA@CCPC adsorbed Li₂S₆ two
new peaks of the S 2p spectrum 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air.^[9143]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectr 28(11), 2219008 (6 of 13)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air.^[51-33]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spect $25(11), 221>000$ (6 of 1.5)
while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
air.^[51-33]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spe and 169.82 eV, corresponding to sul-
med by the oxidation of sulfur in an
nano-HA@CCPC adsorbed Li₂S₆, two
e S 2p spectrum occurred at 163.73
which can be attributed to S-Pi^{54.55}.
rong P-S bond, the nano-HA exhibits while at 168.56 and 169.82 eV, corresponding to sul-
fate species formed by the oxidation of sulfur in an
 $air^{51:53}$. After the nano-HA@CCPC adsorbed Li₂S₆ two
new peaks of the S 2p spectrum occurred at 163.73
and 164 fate species formed by the oxidation of sulfur in an $\text{air}^{[51,53]}$. After the nano-HA@CCPC adsorbed Li₂S₆ two new peaks of the S 2p spectrum occurred at 163.73 and 164.89 eV, which can be attributed to S-P^[54.53]. air^[91,33]. After the nano-HA@CCPC adsorbed Li₂S₆, two
new peaks of the S 2p spectrum occurred at 163.73
and 164.89 eV, which can be attributed to S-P^{[94.59}].
Due to the strong P-S bond, the nano-HA exhibits
good new peaks of the S 2p spectrum occurred at 163.73
and 164.89 eV, which can be attributed to S-P^{[84.59}].
Due to the strong P-S bond, the nano-HA exhibits
good catalytic capability for LiPSs reduction. Both
CV and EIS tes and 164.89 eV, which can be attributed to S-P^{[54.53}].
Due to the strong P-S bond, the nano-HA exhibits
good catalytic capability for LiPSs reduction. Both
CV and EIS tests were carried out to gain insight into
the role Due to the strong P-S bond, the nano-HA exhibits
good catalytic capability for LiPSs reduction. Both
CV and EIS tests were carried out to gain insight into
the role of the reactive interface in accelerating the
LiPSs redu good catalytic capability for LiPSs reduction. Both
CV and EIS tests were carried out to gain insight into
the role of the reactive interface in accelerating the
LiPSs reduction reactions. The redox reactions kinet-
ics w CV and EIS tests were carried out to gain insight into
the role of the reactive interface in accelerating the
LiPSs reduction reactions. The redox reactions kinet-
ics were investigated by using Li₂S_e-electrolyte symthe role of the reactive interface in accelerating the LiPSs reduction reactions. The redox reactions kinet-
ics were investigated by using Li₂S_e-electrolyte sym-
metric batteries with CV scan rate of 50 mV ·s⁻¹ and PSs reduction reactions. The redox reactions kinet-
were investigated by using Li_2S_e -electrolyte sym-
tric batteries with CV scan rate of 50 mV ·s⁻¹ and
ltage window from -0.7 to 0.7 V (Figure 2e). The po-
ization pro ics were investigated by using Li₂S_o-electrolyte sym-
metric batteries with CV scan rate of 50 mV·s⁻¹ and
voltage window from -0.7 to 0.7 V (Figure 2e). The po-
larization profiles comprise the main redox current
de metric batteries with CV scan rate of 50 mV \cdot s⁻¹ and
voltage window from -0.7 to 0.7 V (Figure 2e). The po-
larization profiles comprise the main redox current
density of Li_{-S}₆ and the minor capacitive current d voltage window from -0.7 to 0.7 V (Figure 2e). The po-
larization profiles comprise the main redox current density of Li₂S₆ and the minor capacitive current density of free Li₂S₆⁵⁵¹. The symmetric battery with n larization profiles comprise the main redox current
density of Li₂S₆ and the minor capacitive current den-
sity of free Li₂S₆⁵⁵⁸. The symmetric battery with nano-
HA@CCPC exhibits twice current density as high a density of Li₂S₆ and the minor capacitive current density of free Li₂S₆⁵⁵¹. The symmetric battery with nano-HA@CCPC exhibits twice current density as high as that of CCPC, indicating that more than simply enhanc sity of free Li₅S₀¹⁵³. The symmetric battery with nano-
HA@CCPC exhibits twice current density as high as
that of CCPC, indicating that more than simply en-
hancing the LiPSs adsorption, the introduction of
nano-HA@ HA@CCPC exhibits twice current density as high as
that of CCPC, indicating that more than simply en-
hancing the LiPSs adsorption, the introduction of
nano-HA@CCPC also enhanced the redox reaction
kinetics of LiPSs. The E

y of LiPSs com-

kineties of LiPSs. The EIS profile shows the minimum

attributed to the

charge-transfer resistance of the nano-HA@CCPC,

n nano-HA. XPS

further demonstrating that the high-efficiency reac-

ederstand th that of CCPC, indicating that more than simply en-
hancing the LiPSs adsorption, the introduction of
nano-HA@CCPC also enhanced the redox reaction
kinetics of LiPSs. The EIS profile shows the minimum
charge-transfer resist ncing the LiPSs adsorption, the introduction of
no-HA@CCPC also enhanced the redox reaction
netics of LiPSs. The EIS profile shows the minimum
arge-transfer resistance of the nano-HA@CCPC,
ther demonstrating that the highnano-HA@CCPC also enhanced the redox reaction
kinetics of LiPSs. The EIS profile shows the minimum
charge-transfer resistance of the nano-HA@CCPC,
further demonstrating that the high-efficiency reac-
tive interface of nan kinetics of LiPSs. The EIS profile shows the minimum
charge-transfer resistance of the nano-HA@CCPC,
further demonstrating that the high-efficiency reac-
tive interface of nano-HA@CCPC enhances the reac-
tion kinetics of charge-transfer resistance of the nano-HA@CCPC,
further demonstrating that the high-efficiency reac-
tive interface of nano-HA@CCPC enhances the reac-
tion kinetics of LiPSs (Figure 2f)^[56]. The original combining of th further demonstrating that the high-efficiency reac-
tive interface of nano-HA@CCPC enhances the reac-
tion kinetics of LiPSs (Figure 2f)^[58].
The original combining of the high LiPSs adsorp-
tion CCPC and nano-HA catal

tive interface of nano-HA@CCPC enhances the reaction kinetics of LiPSs (Figure 2f)^[56].
The original combining of the high LiPSs adsorption CCPC and nano-HA catalyst makes nano-HA@CCPC a promising candidate for Li-S bat tion kinetics of LiPSs (Figure 2 $f^{[S6]}$.
The original combining of the high LiPSs adsorption CCPC and nano-HA catalyst makes nano-HA@
CCPC a promising candidate for Li-S batteries. The
strong adsorption capacity construc ince 2f)^[56].

of the high LiPSs adsorp-

atalyst makes nano-HA@

ate for Li-S batteries. The

constructs a micro-envi-

sconcentration around the

1, which is more beneficial

PSs by HA catalysis. These

ive interface The original combining of the high LiPSs adsorption CCPC and nano-HA catalyst makes nano-HA@
CCPC a promising candidate for Li-S batteries. The
strong adsorption capacity constructs a micro-environment with higher LiPSs co tion CCPC and nano-HA catalyst makes nano-HA@
CCPC a promising candidate for Li-S batteries. The
strong adsorption capacity constructs a micro-envi-
ronment with higher LiPSs concentration around the
nano-HA coated by CCPC

Example 1.1 The large of the large contact angle of PP separa-

Example of Li-S batteries with the large contact angle of PP separa-

Example of Li-S batteries with the large contact angle of Li-S batterian and the large

SO

SO

TOO 1150 2000

SO

T/(ohm)

SO

T/(ohm)

The nano-HA CCPC, and nano-HA (QCCPC powders. (b-d) XPS

and nano-HA (QCCPC/L₁S_n, together with their respective fitted

etween soluble LiPSs. (f) EIS spectra of AB, CC SO

Moreover, and nano-HA@CCPC powders. (b-d) XPS

Z/(ohm)

ano-HA@CCPC/Li_{5&} together with their respective fitted

een soluble LiPSs. (f) EIS spectra of AB, CCPC, and nano-

the spectra of AB, CCPC, and nano-

the elect Formance of Li-S batteries with CCPC-, and nano-
formance of Li-S batteries with their respective fitted
when a man-HA@CCPC powders. (b-d) XPS
and nano-HA@CCPC Li, S_o, together with their respective fitted
extern solubl

separator. The surface (a) and cross-section (b) SEM images of

the man-HA@CCPC-modified separator. The contuct ungles

conversion of 815 mAh \cdot g⁺ the conservation of SHS and the COPC-modified separator. The conversio the annot $\text{Hg}_0(\text{CCPC} \cdot \text{modified} \text{ separator})$. The contect angles

for (solution $\text{Hg}_0(\text{CCPC} \cdot \text{modified})$ separation: The contect angles

for (solution interval (d) $\text{Pg}_0(\text{max})$ context and (d) $\text{Pg}_0(\text{max})$ context and \text for (c) nano-HA@CCPC-modified separator and (d) PP separa-

united stable at -99%. However, after 200 cycles,

the batteries with the CCPC-modified separator sis-

HA@CCPC-modified separators (Figure 4). CV was

played re or (color on line)

mained stable at -99%. However, after 200 cycles,
 $\text{H}\text{A}\& \text{CCCPC-model-model}$ at $\text{H}\text{A}\& \text{CCCPC-model-model}$ and $\text{H}\text{A}\& \text{CCCPC-model-model}$ are at $\text{H}\text{A}\& \text{CCCPC-model-model}$ and the batterics with the CCPC-modi HA@CCPC-modified separators (Figure 4). CV was

ib abuteries with the CCPC-modified separator dis-

conducted to illustrate the improved redox reactions

is worth noting that after 20 cylets, the nano-11A@

of the Li-S ba IIA@CCPC-modified separators (Figure 4). CV was

elayed relatively low eapacity of 700 mAh - g⁻¹. It

conducted to illustrate the improved redox reactions

of the Li-8 batteries with the nano-HA@CCPC-modified separator conducted to illustrate the improved redox reactions

is worth noting that after 20 cycles, the nano-HA@

of the Li-S batteries with the nano-HA@CCPC-modi-
 $CCPC$ -modified separator fillus mano-

Hog strational a uniform-
 of the Li-S batteries with the nano-HA@CCPC-modi-

GCPC-modified separator still maintained a uniform-

Irelator (Figure 4a). The battery with the nano-

HA@CCCPC-modified separator exhibits a harp cases of the batteris s fied separator (Figure 4a). The battery with the nano-

HA@CCPC-modified separator exhibits sharp carried controllated surface morphology without obvious

HA@CCPC-modified separator, indicating a finite factors of the hat HA@CCPC-modified separator exhibits sharp careads (Figure S6). According to Equation 3-1, the thodie and anotic peaks. It shows a small polarization

and the charge current density compared with those of the content densi thodic and anodic peaks. It shows a small polarization shuttle factors of the batteries with the nano-HA@ and a large current designator at this cCPC-condified separator at 0.5 C were conversion of Li2S2/Li2S to the conve and a large current density compared with those of

the CCPC-modified separator, indicating a faster re-

the CCPC-modified separator, indicating a faster re-

to 0007 and 0029, respectively, where $\ell_{c=1}$ is Coulombic and a mge current cursay computed with unose of the batteries with CCPC-modified separator, indicating a faster re-
 $\frac{2f+ln(1+f)}{f}$ intervals suggest that the nano-
 $\frac{1}{2}F - \frac{1}{2}f - \frac{1}{2}f - \frac{1}{2}f - \frac{1}{2}f - \frac{1}{2}$ action kinetics. These results suggest that the nano-

HAGCCPC-modified separator constructs a conduc-

HAGCCPC-modified separator constructs a conduc-

teristic carbo framework, offering a high-efficiency in-

Equation 3 HA@CCPC-modified separator constructs a conduc-

Equation 3-1: $C_{\text{eff}} = \frac{2f + \ln(1 + f)}{2f - \ln(f)}$

tive canbon framework, offering a high-efficiency in-

Ecritices to accederate the conversion of Lipsopellics of

Earlies and

Figure 3 Characterization of the nano-HAQCCPC-modified sparator. The context quality of 815 mAh -g⁻¹; the capacity factor (color on line)

The nano-HAQCCPC-modified sparator overlap well compared with the nano-HAQCCPC-m **EVALUATION CONTITURE (A)** COPC-mandent-RA-modified separators (Figure SS),

which could be attribute to the promoted LiPSs re-

ducino. As the cycle number increased, the voltage

curves of the battery with the nano-HA(**the nano-HA** (CPC-modified separator. The separator of the properties with the nano-HA (CCPC-modified separator. These results indicate that the behand of the contact angles of the burgher increased, the contact angles o **for (***c***)**
 for (*c***)**
 for (*c***)**
 for (*c***) and the control in the control of the properties of the stripute of the batteries with mann-HA(** α **CCPC-mod** which could be attrout to the promote LHS community of Total CCPC-modified separator conclusion. As the cycle number increased, the voltage curves of the battery with the nano-HA α @CCPC-modified separators. These result duction. As the eyele was of the batterig with the mono-HA($QCCPC$ -modified spanned redox reactions into the set of the batteric svih mano-HA- and CCPC-modified set of the state reactions. These results indicate that the ba For the batteries with the nano-HA@CCPC-
 $\frac{1}{25}$ and $\frac{1}{35}$ iftel separator overlap with the nano-HA@CCPC-
 $\frac{1}{35}$ the batteries with ano-HA and CCPC-modified
 $\frac{1}{35}$ based overlap at the nano-HA@CCPC-modi Figure 3. Channel MigitCEPC and the batteries with another of the batteries with another and CCPC-modified separator contains the batteries with a meth-the mano-HA/@CCPC-modified separator. The sums also developed cycling (c)

3s (d)

3s the hatters with nano-HA-a CCPC-modified separator

118°

118°

118°

118°

118°

118°

118°

128°

129°

129°

129°

129°

129°

129°

129°

129 parators. These results indicate that the battery with

the nano-HA(\hat{q} (CCPC-modified separator exhibites)
 Example 3
 Exam 118° the nano-HA(@CCPC-modified separator exhibited
good cycling sability. The systems endines the same structurization of the nano-HA(@CCPC-modified separator in
the results. As shown in Figure
separator. The surface (**Example 19.** and 14.60CCP and the non-HA/@CCPC-modified separator (i.e., i.e., i.e ther confirms the above results. As shown in Figure
 Figure 3 Characterization of the nano-HA@CCPC-modified 40.05 C. A ther 325 cycles, the batteries with the nano-

separator. The surface (a) and cross-section (b) SHM **Example 10**
 Example 20
 Example 20
 Example 20
 Example 20
 Example 20
 Example 20 Figure 3 Characterization of the nano-HA@CCPC-modified 0.05 C. After 325 cycles, the batteries with the nano-
separator. The surface (i) and cross-section (b) SEM images of HA@CCPC-modificial separator realined a high-e 28(11), 2219008 (8 of 13)
CCPC- and nano-HA-modified separators (Figure S8),
which could be attribute to the promoted LiPSs re-
duction. As the cycle number increased, the voltage
curves of the battery with the nano-HA@CCP $28(11)$, 2219008 (8 of 13)
CCPC- and nano-HA-modified separators (Figure S8),
which could be attribute to the promoted LiPSs re-
duction. As the cycle number increased, the voltage
curves of the battery with the nano-H $28(11)$, 2219008 (8 of 13)
CCPC- and nano-HA-modified separators (Figure S8),
which could be attribute to the promoted LiPSs re-
duction. As the cycle number increased, the voltage
curves of the battery with the nano-H 28(11), 2219008 (8 of 13)

CCPC- and nano-HA-modified separators (Figure S8),

which could be attribute to the promoted LiPSs re-

duction. As the cycle number increased, the voltage

curves of the battery with the nano-H 28(11), 2219008 (8 of 13)

CCPC- and nano-HA-modified separators (Figure S8),

which could be attribute to the promoted LiPSs re-

duction. As the cycle number increased, the voltage

curves of the battery with the nano-H $28(11)$, 2219008 (8 of 13)

CCPC- and nano-HA-modified separators (Figure S8),

which could be attribute to the promoted LiPSs re-

duction. As the cycle number increased, the voltage

curves of the battery with the na $28(11)$, 2219008 (8 of 13)

CCPC- and nano-HA-modified separators (Figure S8),

which could be attribute to the promoted LiPSs re-

duction. As the cycle number increased, the voltage

curves of the battery with the na $28(11)$, 2219008 (8 of 13)

CCPC- and nano-HA-modified separators (Figure S8),

which could be attribute to the promoted LiPSs re-

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CCPC- and nano-HA-modified separators (Figure S8),

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CCPC- and nano-HA-modified separators (Figure S8),
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CCPC- and nano-HA-modified separators (Figure S8),
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CCPC- and nano-HA-modified separators (Figure S8),
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parators. These results indicate that the battery with
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ther confirms the parators. These results indicate that the battery with
the nano-HA@CCPC-modified separator exhibited
good cycling stability. The cycling performance fur-
ther confirms the above results. As shown in Figure
4d, all batteri the nano-HA@CCPC-modified separator exhibited
good cycling stability. The cycling performance fur-
ther confirms the above results. As shown in Figure
4d, all batteries were pre-activated for two cycles at
0.05 C. After 3 good cycling stability. The cycling performance fur-
ther confirms the above results. As shown in Figure
4d, all batteries were pre-activated for two cycles at
0.05 C. After 325 cycles, the batteries with the nano-
HA@CCP ther confirms the above results. As shown in Figure 4d, all batteries were pre-activated for two cycles at 0.05 C. After 325 cycles, the batteries with the nano-
HA@CCPC-modified separator retained a high ca-
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A@CCPC-modified separator retained a high ca-

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is worth notin mained stable at ~99%. However, after 200 cycles,
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CCPC-modified the batteries with the CCPC-modified separator dis-
played relatively low capacity of 700 mAh · g^{-1} . It
is worth noting that after 20 cycles, the nano-HA@
CCPC-modified separator still maintained a uniform-
ly distribu 电化学(*J. Electrochem.*) 2022, 28(11), 2219008 (8 of 13)

CCPC- and nano-HA-modified separators (Figure S8),

which could be attribute to the promoted LiPSs re-

duction. As the cycle number increased, the voltage

curves

Equation 3-1: $C_{\text{eff}} = \frac{2f + \ln(1 + f)}{2f - \ln(1 - f)}$

played relatively low capacity of 700 mAh \cdot g⁻¹. It
is worth noting that after 20 cycles, the nano-HA@
CCPC-modified separator still maintained a uniform-
ly distributed surface morphology without obvious
cracks (Fig is worth noting that after 20 cycles, the nano-HA@
CCPC-modified separator still maintained a uniform-
ly distributed surface morphology without obvious
cracks (Figure S6). According to Equation 3-1, the
shuttle factors o at after 20 cycles, the nano-HA@
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. According to Equation 3-1, the
he batteries with the nano-HA@
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cracks (Figure S6). According to Equation 3-1, the
shuttle factors of the batteries with the nano-HA@
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0.007 and 0.029, res cracks (Figure S6). According to Equation 3-1, the
shuttle factors of the batteries with the nano-HA@
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CCPC- and CCPC-modified separators at 0.5 C were
0.007 and 0.029, respectively, where C_{eff} is Coulombic ef-
ficiency and f is the shuttle factor. Figure S7b)^[59].
 CCPC- and CCPC-modified separators at 0.5 C were
0.007 and 0.029, respectively, where C_{eff} is Coulombic ef-
ficiency and f is the shuttle factor. Figure S7b)^[59].
Equation 3-1: $C_{\text{eff}} = \frac{2f + \ln(1 + f)}{2f - \ln(1 - f)}$
Co 0.007 and 0.029, respectively, where C_{eff} is Coulombic efficiency and f is the shuttle factor. Figure S7b)^[59].
Equation 3-1: $C_{\text{eff}} = \frac{2f + \ln(1 + f)}{2f - \ln(1 - f)}$ Consequently, the nano-HA@CCPC-modified separator eff ficiency and f is the shuttle factor. Figure S7b)^[69].
Equation 3-1: $C_{\text{eff}} = \frac{2f + \ln(1 + f)}{2f - \ln(1 - f)}$ Consequently, the nano-HA@CCPC-modified separator effectively hinders the shuttle effect. The rate performance of b Equation 3-1: $C_{\text{eff}} = \frac{2f + \ln(1 + f)}{2f - \ln(1 - f)}$
Consequently, the nano-HA@CCPC-modified separator effectively hinders the shuttle effect. The rate performance of batteries was investigated by cycling at rates of 0.2, 0.5

Example 19
 Example 19 Simple the second control of the second capacitor excited second capacitor of the second control of the second control of the second capacitor of the Li-S reduction reactions, the onset potential of the second step of the ⁸⁰
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finther demonstrate the kinetics of LiPSs reduction

fu **EVALUAT CONSTRANT (2018)**

40 50 60 70

The secondary conduct of different cycles at 0.5 C for batteries

the long-term cycling performance of batteries at 0.5 C for batteries

the long-term cycling performance of batter uid-liquid reaction can proceed with the minimum

the *C* Electrochem.) 2022, 28(11), 2219008 (10 of 13)

required driving force and that the nano-HA@CCPC 1167-1176.

has a certain catalytic effect⁽⁶⁰. Therefore, the redox re-

action kinetics of battery with the nano $#E# \langle J. \text{ \textit{Electrochem.}}) 2022, 28(11), 2219008 (10 of 13)$

Frequired driving force and that the nano-HA@CCPC

has a certain catalytic effect^[60]. Therefore, the redox re-

able lithium-sulfur batteries[J]. Chem. Rev., 2014, $\begin{array}{lllllllll} \text{#L}\#^c(J. \textit{Electrochem.}) & 2022, 28(11), 2219008 (10 of 13) \\\\ \text{required driving force and that the nano-HA@CCPC} & 1167-1176. \\\\ \text{has a certain catalytic effect} & \text{Therefore, the redox re-} & 12 & \text{Manthiram-A, Fu Y, Chung S H, Zu C, Su Y S. Recharge-} \\ \text{action kinetics of battery with the nano-HA@CCPC-} & \text{able lithium-sulfu battery battery in the condusion, we constructed an efficient reactive function.} & 11751-11787. \\\\ \text{4 & Conclusions} & \text{nonnumer$ modified separator are strongly enhanced.

4 Conclusions

 $\frac{d}{dt}\mathcal{L}^{\#}(I, \text{Electrochem.}) 2022, 28(11), 2219008 (10 of 13)$

1911 puired driving force and that the nano-HA@CCPC

1913 Manhimm A, Fu Y, Chung S H, Zu C, Su Y S. Recharge-

221 Manhimm A, Fu Y, Chung S H, Zu C, Su Y S. Rech **interface** by using nano-HA@CCPC and the regulate the rano-HA@CCPC 1167-1176.
 interface and that the nano-HA@CCPC 1167-1176.

has a certain catalytic effect^{ion}. Therefore, the redox re-

additional A, Fu V, Chung S $\begin{array}{l|l|l} \hline \textbf{q} & \textbf{if}(k\#cL \textit{Lberrochem.}) & 2022, 28(11), 2219008 \ (10 of 13) \\ \hline \textbf{required driving force and that the nano-HA@CCPC} & 1167-1176. \\ \hline \textbf{has a certain catalytic effect} \#7. \textbf{Rerefore, the redox red-} & 21 \text{ Manthinum A, Fu V, Chung S H, Zu C, Su V S. Recharge-} \\ \hline \textbf{a} & \textbf{is a certain catalytic effect} \#8. \textbf{H} & \textbf{is a certain catalytic effect} \#9. \$ terface area and excellent electronic conductive path effectively accelerated the LiPSs conversion. In par- $\begin{tabular}{l|c|c|c} $t\hline & \mbox{\bf (t t-th}} & \mbox{\bf (t t-th}} \\ \hline \hline \end{tabular} \begin{tabular}{l|c|c|c} $t\hline & \mbox{\bf (t t-th}} & \mbox{\bf (t t-th}} \\ \hline \end{tabular} \begin{tabular}{l|c|c|c} $t\hline & \mbox{\bf (t t-th}} \\ \hline \end{tabular} \begin{tabular}{l|c|c|c} $t\hline & \mbox{\bf (t $t t-th}} \\ \hline \end{tabular} \begin{tabular}{l|c|c|c} $$ $#1/2⁴⁶ (L. Klectnoshem,) 2022, 28(11), 2219008 (10 of 13)
\nhas a certain catalytic effect⁶⁶ (L. Rectnoshem,) 2022, 28(11), 2219008 (10 of 13)
\nhas a certain catalytic effect⁶⁶ (L. Rectn)
\nhas a certain catalytic effect⁶⁶ (L. Rectn)
\nand the same-HA@CCPCC
\n= 1157-11787.
\n4 **Conclusions of** battery with the nano-HA@CCPCC
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traguited diving force and that the nano-HA@CCPC 1167-1176.

has a certain catalytic effect^{ion}, Therefore, the redox re^c [2] Manthiam Λ, Fu Y, Clung S H, Zu C, required driving force and that the nano-HA@CCPC

has a certain eatalytic effect¹⁶⁸. Therefore, the redox re-

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has a certain eatalytic effect¹⁶⁸. Therefore, the redox re-

21) Manthiman A, Fu Y, Chung S H, required driving force and that the nano-HA@CCPC [21 M67-1176.

has a certain catalytic effective (IP (Therefore, the redox research in the same action kinetics of battery with the nano-HA@CCPC and be lithium-sulfur batte has a certain catalytic effect⁶⁹. Therefore, the redox re-

action kineking Stellar Particular Softkattry with the name-HA(gCCPC-

action kineking softkattry with the name-HA(gCCPC-

and in Stellar Softkattry with the m action kinetics of battery with the nano-HA@CCPC-

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 44 Conclusions
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13 San Y.M, Eab N.A, Cui Y. Promises and challenges of

13 San Y.M, Eab N.A, Cui Y. Promises and challenges for

interface by using nano-HA@CCPC to regulate the

14 Maro In conclusion, we constructed an efficient reactive

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ele electrochemical redox reaction of LiPSs. The rich in-

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erfictively accelerated the LiPSs conversion. In par-

erfictively accelerated the LiPSs conversion. In par terface area and excellent electronic conductive path

(Figure in the good dispersion and embeddent of Michalkumar G, Michalkumar G, Michalkumar G, Michalkumar G, Michalakumar G, Michalakumar G, Michalakumar G, Michalakum ticular, the good dispersion and embedment of

Micke W. Lithium-air battery: promis

nano-HA into the porous carbon enhanced the affini-

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conductive framework played an excellent coo nano-HA into the porous carbon enhanced the affini-
 $\frac{1}{10}$ (6) Rosemann A, Markevish is, Sailmar 4, Author).

The interferee for LiFSS, Fortdermore, the CCPC

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sconductive framework played an excellent coopera-

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good rate performance, long cycle life, and good stands and high-energy lichium-sulfur

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bility. When cycled at 0.5 C for 325 cycles, the batter-

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is W. Recharged the Still displayed a specific cap bility. When cycled at 0.5 C for 325 cycles, the batter-

is N. Rechargeshle linkingwidth at hard HI, Kim III, Kim III, Kim III, Kim III, Kim III, Nim III, Ni ies still displayed a specific capacity of 815 mAh \cdot is with deterbytion are more there wind such a specific and understand-
per cycle. Because of sufficient sources, facile prepare and pay \times 2007, 52082.

per cycle with an average capacity fading rate of only 0.051%

maximum accomospace exertoyes and exertoyes and exerto the charge of sufficient sources, facile prepa-

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mechanism

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摘要: 由于正极活性物质硫具有能量密度高、成本低廉和储量丰富等优点,锂硫(Li-S)电池受到了人们的极大关 注。然而,锂硫电池充放电过程中产生的多硫化锂的"穿梭效应"严重阻碍了其实用化进程。为了解决这个问题, 本研究借助动物软骨的组成和结构特点,制备了纳米羟基磷灰石 @多孔碳(nano-HA@CCPC)复合材料,并以此 设计了面向正极的锂硫电池隔膜涂层。研究表明,纳米羟基磷灰石不仅对多硫化物具有吸附固定作用,并且对多 硫化锂的转化具有催化作用,加快了多硫化锂的氧化还原动力学,有效地提升了活性物质硫的利用率。另外,软骨 基碳复合材料的多孔结构形成了很好的导电网络,为电化学反应提供了优良的电子传导路径;也有利于电解液的 浸润,加快了离子传输;碳的氮原子掺杂进一步限制了多硫化物的穿梭效应。因此,采用 nano-HA@CCPC 隔膜涂 **生在移行,在全学各生,参考、关越、购买标记和技术活动。**
法在检验与全学各生,多着繁生,关越 鹏学,工作冲³
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北京化工大学, 地方10029, 2. 北 -' 的放电比容量,并且每次的容量衰减率仅为 0.051%。nano-HA@CCPC 的设计制备将为锂硫电 池的发展提供新材料。

关键词: 导电碳框架; 纳米羟基磷灰石; 反应界面; 改性隔膜; 氧化还原反应动力学; 锂硫电池