energy storage materials

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Keywords:

1. Introduction

(1675 A -1) (2600 -1), (L, K) [1]. [2–4]

(1.67 10^5 $^{-1}$) 27 . ( ) ff fi 29 . ( ) L$_2$.

H , IF) C$_4$ (CC@C$_4$ - C A). CC@C$_4$ - C A , (3D) - , C$_4$ L L$_2$. A - /CC@C$_4$ - C A 1121 A^{-1} 100 0.5 C, (1356 746 A^{-1} / 0.2 C 5 C,), 0.035% 500 5 C C ffi ≈100%.

2. Experimental

2.1. Preparation of CC@ZIF-67

C (CC 2 2) H$_3$ (69%) 90 C 6 , , , (100 L) C ($_3$)$_2$ 6H$_2$ (0.72) 2-(2-M I , 1.64) . A 4 ( ), CC@ IF-67 60 C .

2.2. Preparation of CC@Co_3O_4-PCNA and CC@Co_4N-PCNA

, CC@ IF-67 600 C 2 C^{-1} 2 330 C 2 . fi CC@C$_3$ $_4$-C A. - CC@C$_3$ $_4$- C A , 350 C 5 C^{-1} 600 C 2 C^{-1}, fi 3 fl H$_3$ (50). - C$_4$ CC@C$_4$ - C A.

2.3. Preparation of CC@PCNA, CC@Co_4N NWs, ZIF-67 and Co_4N-PC

CC@ IF-67 , 600 C 2 C^{-1} 2 $_2$- . (1 M) 24 C CC@ C A.

CC@C$_3$ $_4$ (CC@C$_3$ $_4$) fi 24 . CC@C$_3$ $_4$. I , C ($_3$)$_2$ 6H$_2$ (0.41), H$_4$F (0.13) (0.42) (50 L) 10 , H$_3$- CC 10 . CC 100 L fl - - 120 C 5 . A , , 60 C 12 . 330 C 2 . fi CC@C$_3$ $_4$. CC@C$_4$ CC@C$_3$ $_4$ CC@C$_4$ - C A.

I , C ($_3$)$_2$ 6H$_2$ (0.72g) 2-M I (1.64g) (50 L). A , 4 . , , , 3 70 C C$_4$ - C IF-67 CC@C$_4$ - C A.

2.4. Preparation of the sulfur composites

/CC@C$_4$ - C A, /CC@C$_3$ $_4$- C A, /CC@C$_4$, /CC@ C A, /CC 50 . CC@C$_4$ - C A, (0.15) C$_2$ (10 L). D CC@C$_4$ - C A C$_2$ 20 , 50 C 6 . CC@C$_4$ - C A A 155 C 12 (F . 1). /CC@C$_3$ $_4$- C A, /CC@C$_4$, /CC@ C A. /CC 1.01–6.20 $^{-2}$, .

2.5. Preparation of the Li_2S_6 solution

L$_2$ 1:5 (HF) ,

2.6. Material characterization

, FE- EM (A 55), EM (JEM-2000E), H - EM (G2 20), (E CALAB 250, A -Kα), D (D/MA -2400, C Kα -), (D), IC (E I 300D), E (EL III), GA (D G-60AH) (A L200B) ff .

2.7. Electrochemical measurement

F , 2025 - . - (0.1). F L - , , , 1.0 M L F I D L/DME (1:1 ; F I = (fl) ; D L = 1,3- , DME =) 2.0 % L$_3$. 45 µL. / L C 2001A 1.7 2.8 . (C) E I (EI) - (M -300) 1.7 2.8 0.1 $^{-1}$.

2.8. Density functional theory calculations

(DF) (A) 51,52 . (A) - 53 , 91 - 54 . A ff 500 - . F 0.05 / . B M - 5 5 1 - 55 . A fi - .

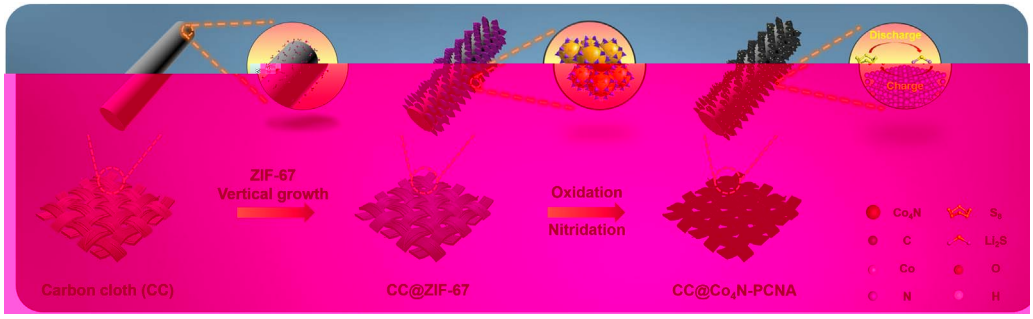

Fig. 1. w CC@C 4 - C A.

w fi

(E) w L 2 C 4
w w :

$$E_b = E_{Li2Sn} + E_{Co4N} - E_{Li2Sn+Co4N} \quad (1)$$

E_{Li2Sn} - E_{Co4N} L 2
C 4 , $E_{Li2Sn+Co4N}$ L 2 -C 4
.

3. Results and discussion

CC@C 4 - C A -
F . 1 F . 1. F , H 3 w
H 3 .
CC w w - -
(- H, -C H) IF
, w IF
. , 2D IF-67 w w
C (3)2 6H2 2-
(2-M I)
4 (CC@ IF-67). w ff (D)
- CC@ IF-67 w w IF-67
(F . 2). w IF-67
fi
(F . 1). , CC@ IF-67 w fi
CC@C 4 - C A w
2, H3 .

- w
fi (FE-
EM). F . 2 w IF-67 w
. , - . H w ,
CC, IF-67
w CC (F . 2 F . 2). FE- EM
CC@ IF-67
(F . 2). M w , CC@ IF-67
w w (F 3). A
CC@ IF-67 2 ,
C 3 4 - (
CC@C 3 4- C A) w (F . 2). H3
ff w fi
24 . A w F . 2 -,
fl w H3 600 C.
H3 .
. L
(. . 50)
CC@C 3 4- C A (. . 65). C 4 - C A w 2D
CC
, w . F
, CC@ IF-67 600 C 2
w w
(.
CC@ C A, F . 4) C 4
(C 4 - C) w w IF-67 CC
w (F . 2).

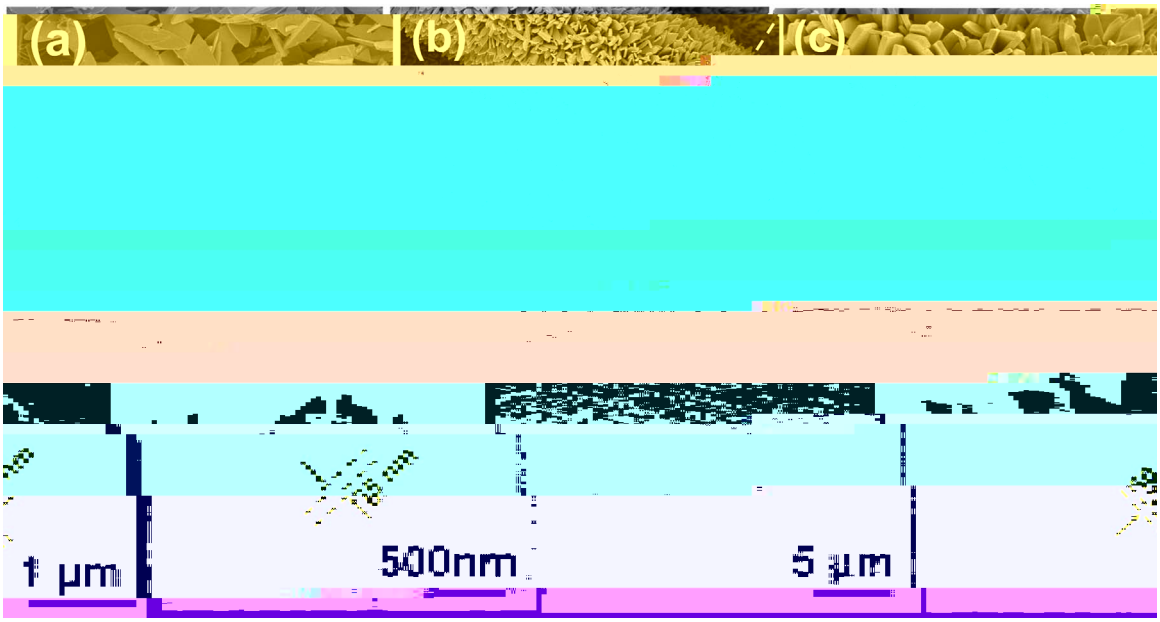

Fig. 2. FE- EM ( ) IF-67. (,) CC@ IF-67. ( ) CC@C 3 4- C A. (,) CC@C 4 - C A.

CC@ IF-67 CC@C 4 - C A (EM). (
CC@ IF-67 1.5 μ
(F . 3). A
(F . 3 -). F fi EM F . 3 ,
. 40
. H - EM (H - EM)
F . 3 F . 5 , 0.207 0.243 (111) C 4
(311) C 3 4, , 21 .
C 3 4 (*Fd3m* (227))
C 4 (*Pm3m* (221)). F . 5 F . 3 ,
. C 4
C -C
30 .
D CC, CC@C 4 - C A CC@C 3 4- C A
F . 4 . ff 25.6
(002) . D
C 3 4 (DF#42-1467) . - fi
0.243 , (311)
C 3 4, (F . 5). CC@C 4 - C A,
600 C 3 H3 fl 50
,
D (F . 6) C -
ff .
C 3 4 C 4 31 :

$$24Co_3O_4+64NH_3 = 18Co_4N + 23N_2+96H_2O \quad (2)$$

A F . 4 , , C 4
(DF#41-0943) (111), (200) (220) ,
C 3 4 C 4 . I
D , F . 3 (111) -
C 4 0.207 (F . 3). A
/CC@C 4 - C A ff
22.9, 25.7 27.6 (F . 7). EM
(F . 7), C 4 - C A,
L B . (IC).

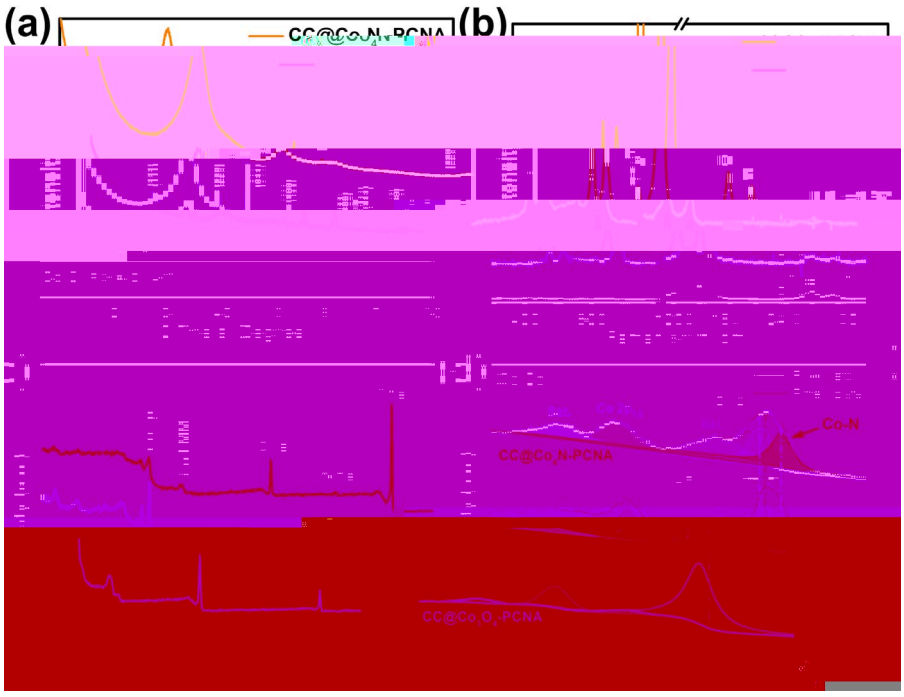

Fig. 4. ( ) D CC, CC@C 3 4- C A. CC@C 4 - C A. ( ) CC, CC@C 4 CC@C 4 - C A. ( ) . ( ) C 2 CC@C 3 4- C A, CC@C 4 CC@C 4 - C A.

L L 2. 2/L 2. 20 . M w , A1 /CC@C 4 - C A w , w L 2. 8. L . w A1. C1 0.36 0.42 /CC@C 3 4- C A /CC, , w 0.32 /CC@C 4 - C A, w C 4 w - , w 22,34 . , /CC@C 4 - C A fl C 4 , w L - L B 16,35,36 . /CC@C 4 - C A w 1.7 2.8 0.5 C 0.2 5 C w F . 9. , w w C . /CC@C 4 - C A. fl w w 170 0.5 C, w /CC /CC@C 3 4- C A, 264 190 , , (F . 5). C 4 L L - , w L B 37 . F . 5 w fi /CC@C 4 - C A. 0.5 C w ff w w 1.7–2.8 . /CC@C 4 - C A 1455 A -1 1121 A -1 100 . I 6.20 -2, /CC@C 4 - C A w w 543 A -1 0.5 C 200 (F . 10). 45 L. / (E/) L – fi 38 . L w E/ (L:): 9:1 . 0.2, 0.5, 1, 2, 3, 4 5 C, 1356, 1252, 1076, 936, 859, 802 746 A -1 , . A 1201 A -1 (88.56%) w 0.2 C, w , /CC@ C A, /CC@C 3 4- C A /CC@C 4 /CC (F . 5). I , - /CC@C 4 - C A (F . 11 3). A , fi . H , w /CC@C 4 - C A - (4) 39,40 . (EI) w . , w , ff EI fi , C E - . , / CC@C 4 - C A w w ( ) (F . 12). M , w 41 . A w F . 13, 120 11 , w 42 . F (F . 14) w CC@C 4 - C A (2.59 10 3 -1) CC@C 3 4- C A (1.85 10 3 -1) H 3- CC (1.53 10 3 -1). L , ff . A w F . 5 , - /CC@C 4 - C A w 5 C. A 0.1 C, /CC@C 4 - C A 727 A -1 766 A -1 100 . A 500 , /CC@ C 4 - C A 598 A -1. 0.035% C ffi

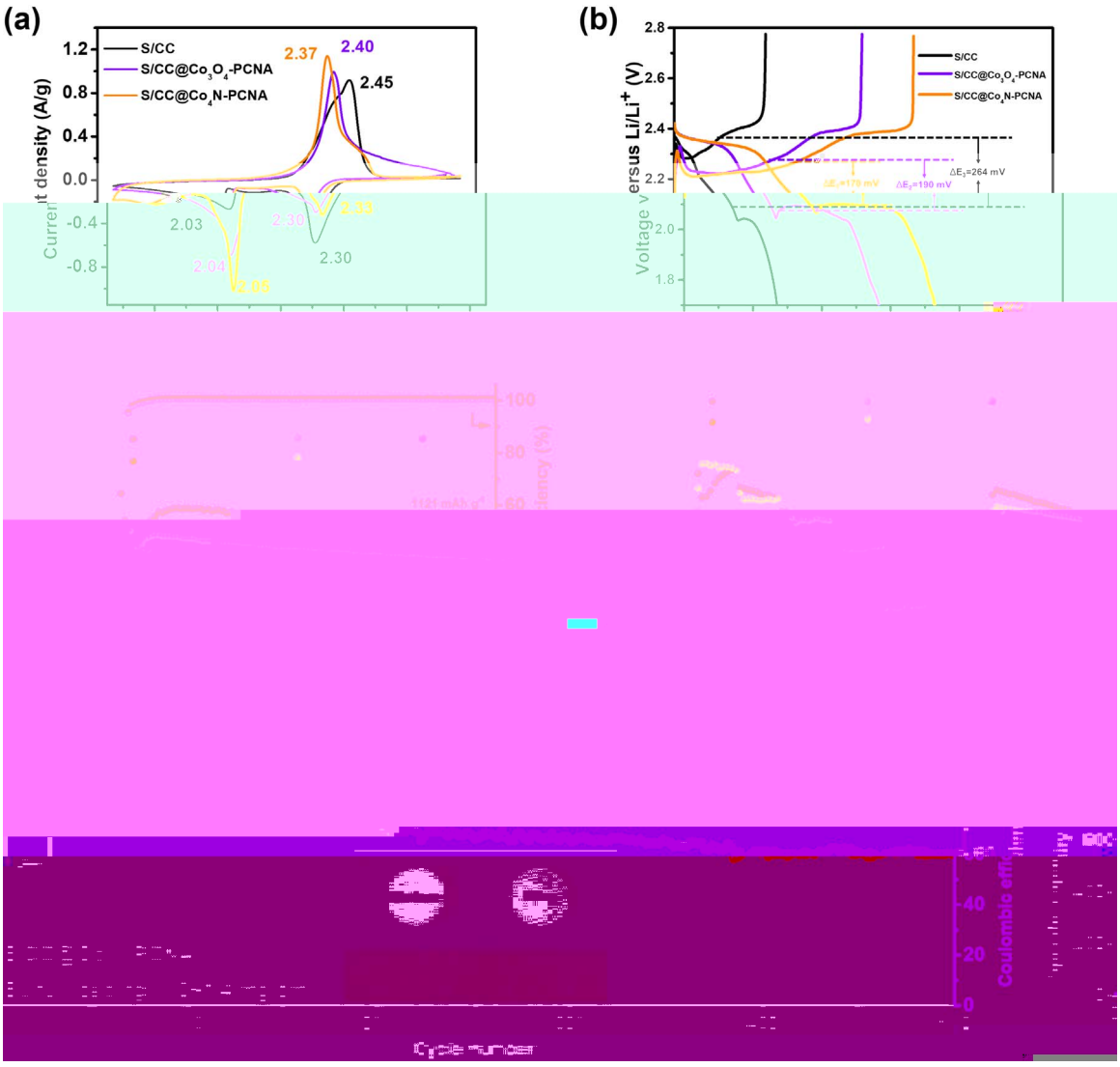

Fig. 5. ( ) C , ( ) G /CC, /CC@C 3 4- C A. /CC@C 4 - C A. 0.5 C. ( ) 0.5 C, ( ) (0.2 C 5 C) /CC, /CC@C 3 4- C A, /CC@C 4 , /CC@ C A. /CC@C 4 - C A. ( ) L - /CC@ C 4 - C A 5 C. ( ) /CC@C 4 - C A . 10 .

100% - . 3D w w , FE- EM , D (F . 5 F . 15), w / CC@C 4 - C A.

/CC@C 4 - C A ff L , (DF) w w C 4 (F . 6 , F . 16-17). (111) C 4 w . w C 4 8, L 2. 8, L 2. 6, L 2. 4, L 2. 2, L 2. -5.33, -7.22, -4.21, -4.18, -6.01 -4.66 , . w fi C 4 w C 3 4- L [43,44], 22,45–47 . DF /CC@C 4 - C A C 4 w L . fi ff w , w F . 18. , L 2. 6 - ff w CC@ C 4 - C A w , . CC@C 4 - C A L 2. 6 - w - w L . L 2. 6, L 1 CC@C 4 -L 2. 6 w 55.6 (F . 19), w 0.7 w w w L - L 2. 6 (56.3) 56 , L - 56.4 L L w C 4 57 . M w , C 2 CC@C 4 - C A. w F . 19 , w w 796.7 781.3 C 2 1/2- C 2 3/2 - C 4 . w L 2. 6 , 1.0 1.1 w w C - 778.5 29 . B , C 4 ffi w L DF .

/CC@C 4 - C A w C 4 L , / . C w ff .

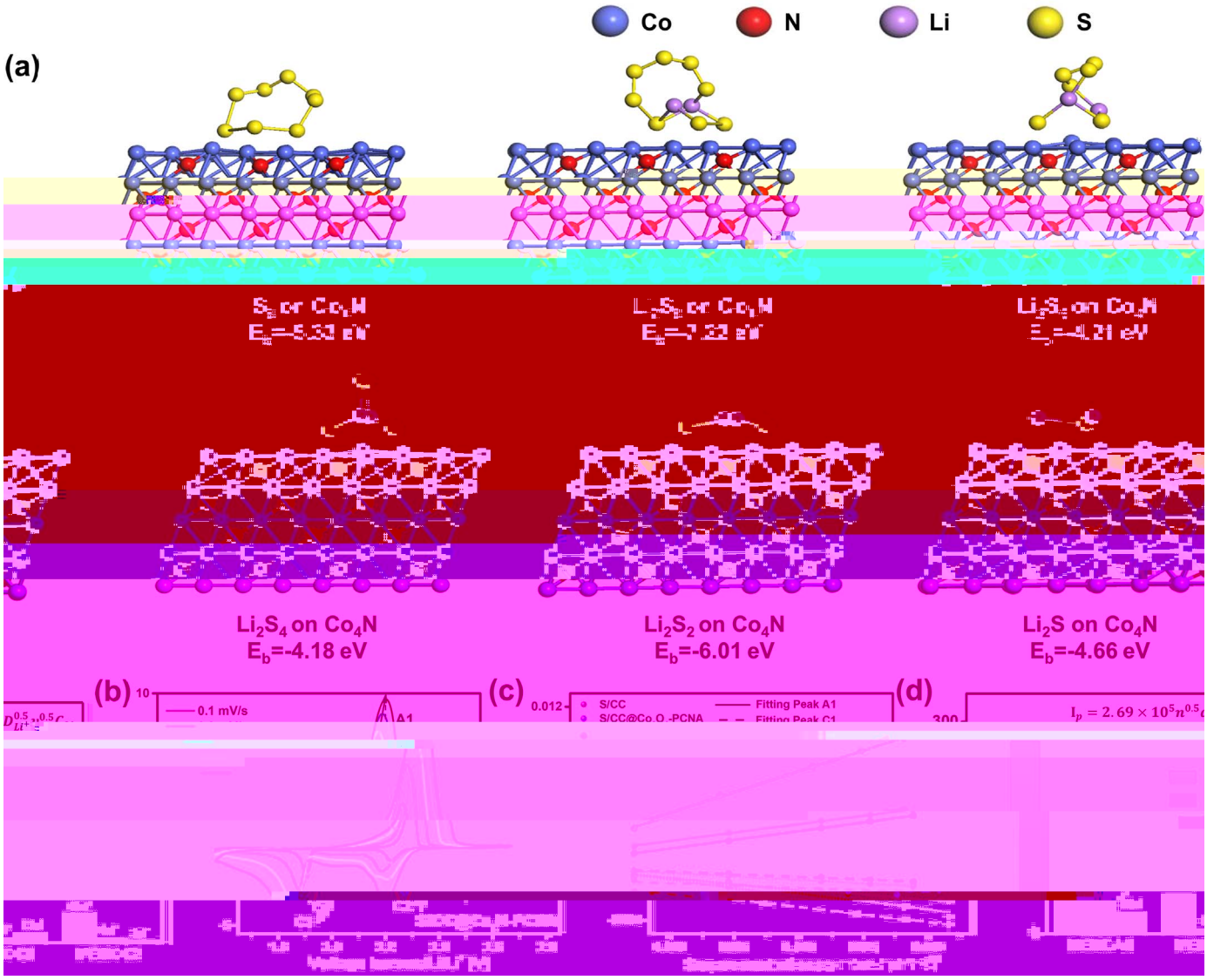

Fig. 6. ( ) C (E) L$_{2}$ (=1, 2, 4, 6 8) 8 (111) C$_{4}$. ( ) /CC@C$_{4}$ - C A ff . ( ) /CC, /CC@C$_{3}$ $_{4}$- C A. /CC@C$_{4}$ - C A ff ffi /CC, /CC@C$_{3}$ $_{4}$- C A. /CC@C$_{4}$ - C A .

0.1 1.0 $^{-1}$ / - ff (F . 6. , F . 20 -), /CC, / CC@C$_{3}$ $_{4}$- C A /CC@C$_{4}$ - C A 1.7–2.8 L /L^{+}. L (Δ) - . L fi 23,48 , / CC@C$_{4}$ - C A, Δ /CC@ C$_{3}$ $_{4}$- C A. /CC, , /CC@C$_{4}$ - C A (F . 20). A F . 6 , ff 49 :

$$I_p = 2.69 \times 10^5 n^{0.5} a D_{Li^+}^{0.5} \upsilon^{0.5} C_{Li} \quad (3)$$

I , , D$_{L}$$^{+}$ L^{+} ff ffi , υ C$_{L}$$^{+}$ L^{+} . L^{+} ff . F υ$^{1/2}$ I , L^{+} ff ffi F . 6. F /CC@C$_{4}$ - C A , $D_{Li^+}^{A1} = 2.7 \times 10^{-13}$, $D_{Li^+}^{C1} = 5.5 \times 10^{-14}$, $D_{Li^+}^{C2} = 4.1 \times 10^{-14}$ ^{2} $^{-1}$, 4 /CC@C$_{3}$ $_{4}$- C A /CC - /CC@C$_{4}$ - C A (F . 13), L - ff L$_{2}$ $_{2}$/L$_{2}$ 15,41 .

A F . 7 - , . F , C$_{4}$ - 3D fl , fi , C$_{4}$ L ff ff -

fi , “ ff ” L
, C 4 (w
L 2. 2/L 2. ,
ff fi . I ,
(w /CC@C 4 - C A (w
285 -1 660 -1, (
, 5), (w F . 21,
L B - - ,
.

4. Conclusions

I , (w C 4 -
fl
L B .
(w C 4 ff L ff
fi . B fi
ff L CC@
C 4 - C A, /CC@C 4 - C A (w
1121 A -1 0.5 C 100 ,
746 A -1 5 C (w
0.035% 500 5 C. (w (w
fl .

Acknowledgment

(w F
C (G . 51672033, 1610105, 1610255), F
K L I E A
M , M E , C (KLI EAM 201601),
F L E , D
, C (2016-54).

Appendix A. Supporting information

(w
:10.1016/ . .2018.12.005

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