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In-situ - ff

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A R T I C L E I N F O

Keywords:
T -
C ff
S
C
B

A B S T R A C T

C , - (3DG) , . H - - (SLM) - (3D) . G *in-situ* (CVD) C , 3DG . A CVD SLM ff 3DG - (, ,) - (,) ff . T 3DG/ ff 88% 27% (EMI) ff , . P , EMI ffi- (*SE*) 47.8 B 2.7 GH *SE* 32.3 B 2–18 GH . T SLM .

1. Introduction

G , *sp*^{2} , (2DG), 5 , 6,7 , (2630 ^{2} $^{-1}$) 1 , V (EMI) 8 . (2 10^5 ^{2} V^{-1} $^{-1}$) 4 , 3DG (6-5000 W $^{-1}$ K^{-1}) 2 . H , (2D) 9 , 10 , ff , , , - 3 . A - 11 , 12 . H , - π-π . F , ff - 13 . S - ( ) . C 14 . D - (3DG) 15 . M fi ff - - CVD , fi (6-0.6 $^{-2}$) 4 (6-99.7%), fi - - 16 . B , , , - ,

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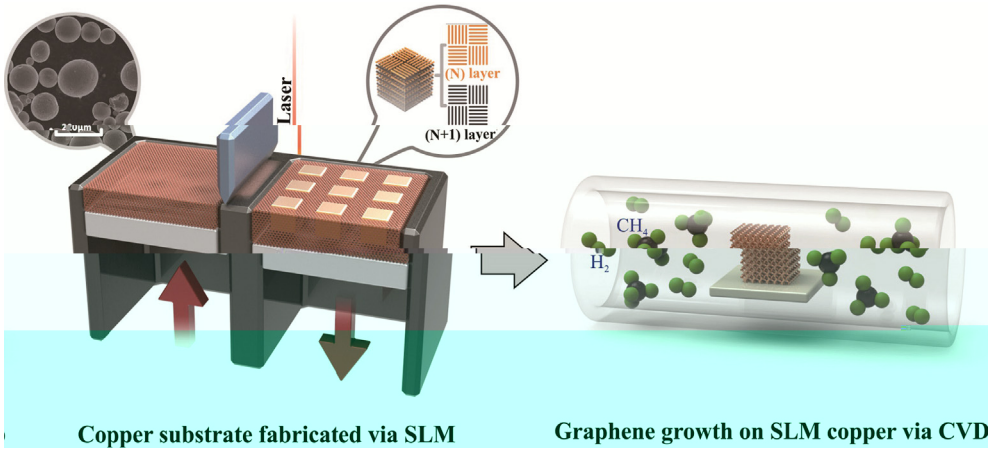

Fig. 1. I 3DG/C : ff SLM ( ) *in-situ* ff CVD ( ). (F fi , .)

ASTMB193-2002 2 2 20 ^{3} . T ff (2 10 10 ^{3}) (5 10 10 ^{3}) ASTME1461-2013 LFA (L fl , N LFA457, G). R (SENTERRA, B , G) 3DG/C ff - 514 . T *S* (*S11* *S21*) fl (VNA, A PNA-N5244A, US) 2–18 GH . T *SE* , *SE* , *SE* fl E . 2–5 S I .

3. Results and discussion

3.1. Formation of SLM copper

3.1.1. SLM manufacturing of copper under different line energy densities

T ff ( ) . D ff (F . 2) , 30% (A), 26.7% (B), 16.7% (C) 26.7% (D). D ff , LED (J/) 27 (E . 6, SI). T . T ffi . I A, ffi . I B, fi . T fl ffi , LED 400 J/ (C). W LED (> 800 J/) , 130 μ - (D), - 28 .

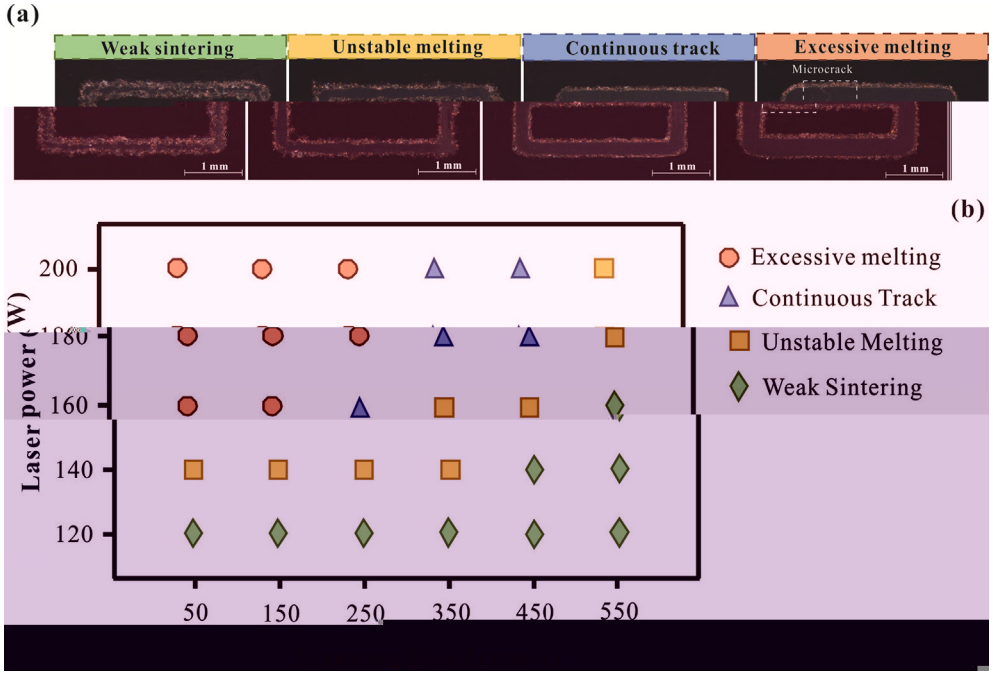

Fig. 2. ( ) T , , ; ( ) , (F - fi , .)

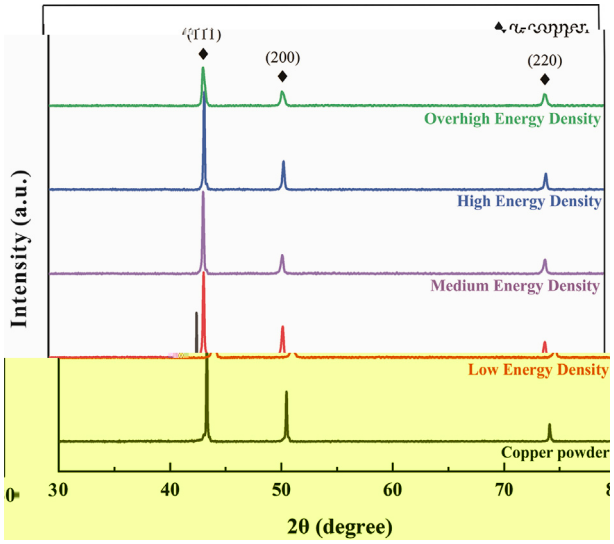

Fig. 3. XRD - . (F fi , .)

3.1.2. Formation of anisotropic microstructure under different volumetric energy density

T α- XRD (1 1 1) (2 0 0) fl ff 2θ = 43.32 2θ = 50.45 , (F . 3), (1 1 1) . T - XRD ff fi SLM . I , ff SLM ff , - 29 . T - SLM . T

: ( ) , ( ) - , ( ) . A 3000 J/ 3 (F . 4**a**), 180 μ , (F . 4**d**). T M 30 fl . T fi . W 857 J/ 3, (F . 4**b**). U , fi- 96.2% . H , , - . T (398 W −1 K−1), ffi (F . 4**c**). G , M - . B , SLM 31 . I , 128 J/ 3, - - fi , 88.6% - (F . 4**d**). T SLM (F . 5). T - - , . T , - 32 . T fi fl - . S W . 33 , ,

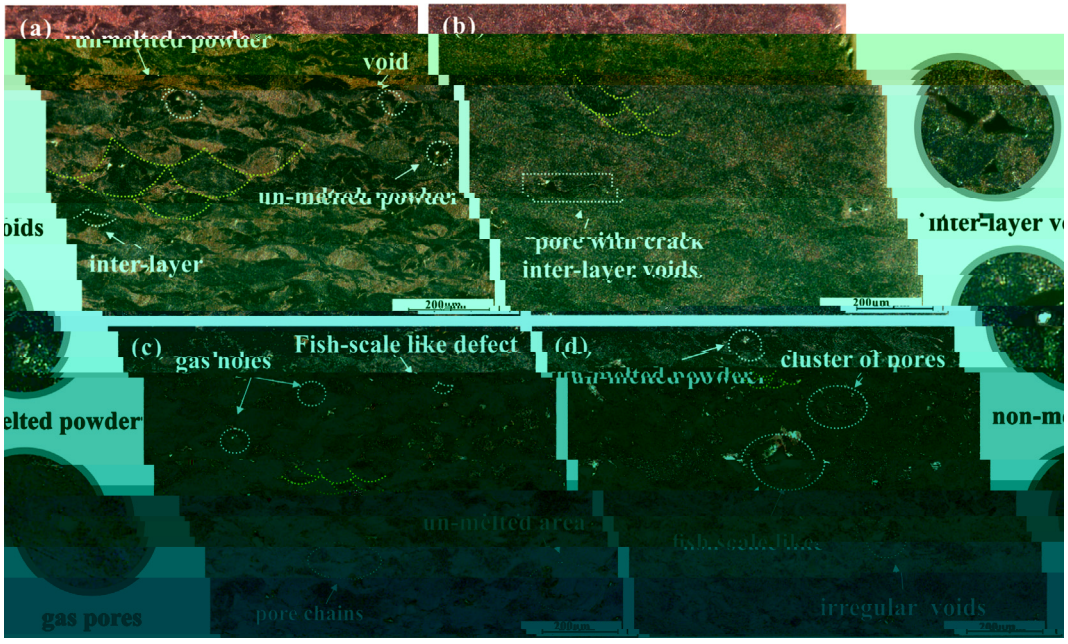

Fig. 4. O : ( ) (3000 J/ 3), ( ) (857 J/ 3), ( ) (285 J/ 3), ( ) (128 J/ 3), . (F fi , .)

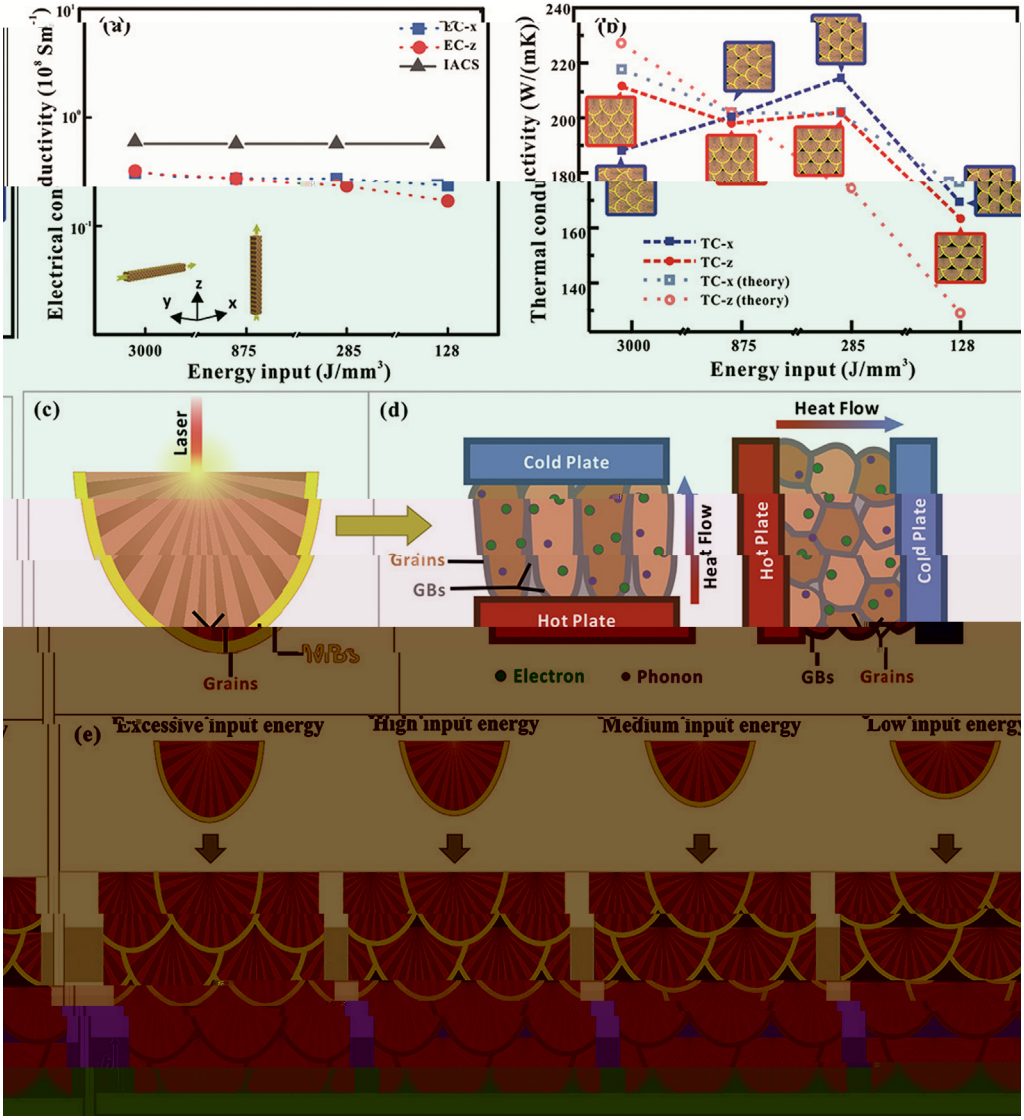

Fig. 7. ( ) H ( ) ; ( ) ; ( ) ; ( ) ff . (E). (F fi , .)

. . A , SEM, - - . T SEM - 3DG/C ff - 450 μ (F . 8**a**). A fi (F . 8**b**), fl ff , . T - ff , EDS (F . 8**c-d**), fi V - . A fl fi (F . 8**e-g**). T 3DG/C ff - (F . 8**h**). R 3DG/C - . T G- (~ 1590 $^{-1}$) 2D- (6·2699 $^{-1}$) 42 (F . 8). S D- (~1350 $^{-1}$) fl - 43 , D G (I_D/I_G)

3.3. Morphology and structure of CVD 3DG/Cu porous scaffolds

F ff ff ff . G *in-situ* CVD . A ff , fi ’ 39 . A , - 33 V , - (25 V) 39 . U C N , L . 40 - . H , (. . 23 , - 41) CVD- , - fl

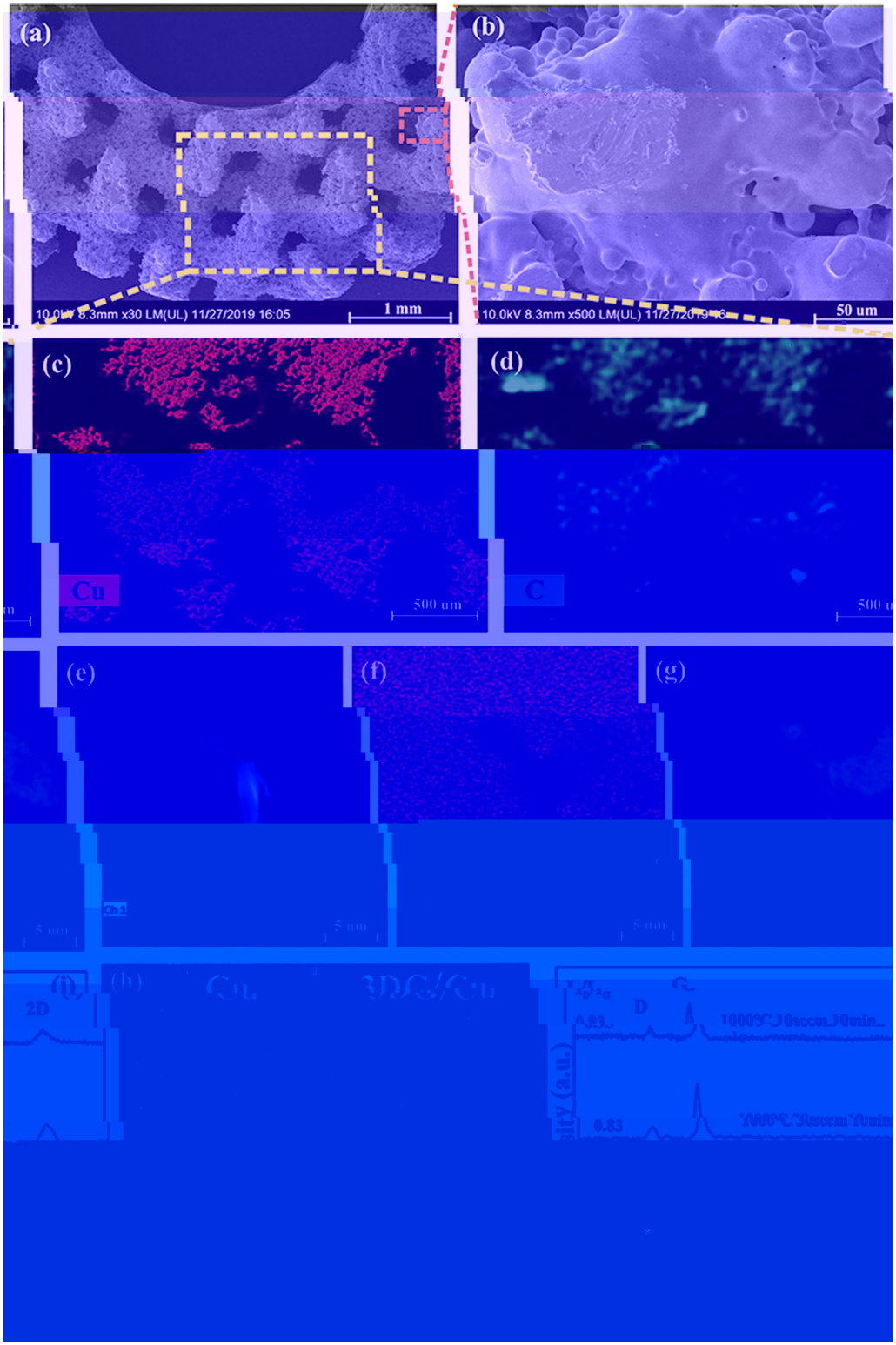

Fig. 8. (-) SEM 3DG/C ff ff fi ; EDS ( ) C ( ) C; ( ) fi SEM , EDS ( ) C ( ) C; ( ) OM; ( ) R ff ff . (F fi , .)

. W fl , I_D/I_G 0.71 0.93, - . A , (T ff 1000 C, fl CH_4 30 , C ff , 26.8% 20) 3DG/C . 14.8%

3.4. Thermal property and EMI shielding effectiveness of 3DG/Cu porous scaffolds

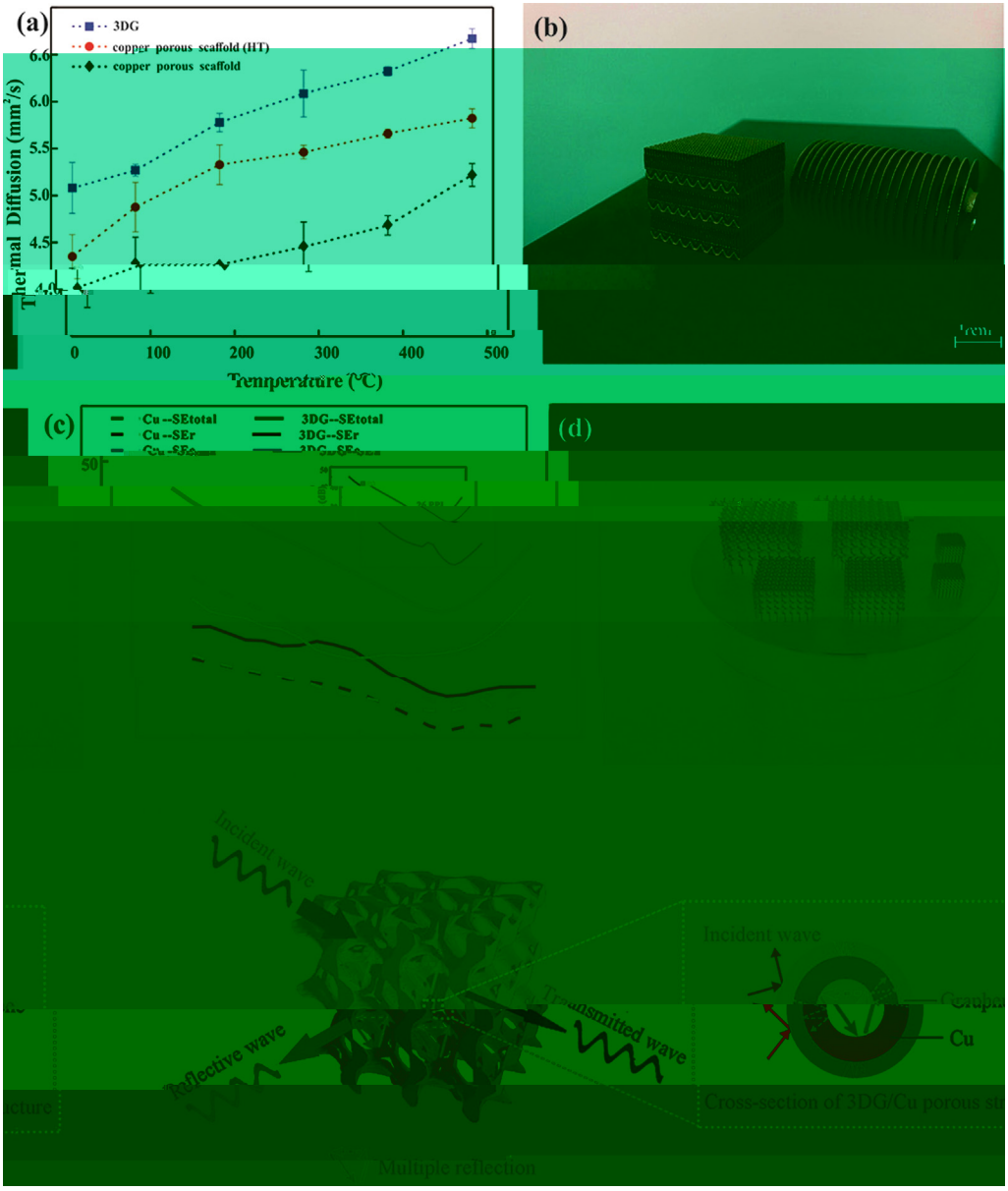

Fig. 9. P 3DG/C ff : ( ) ff ; ( ) SLM fl (- fl) - ; ( ) EMI SE; ( ) C ff ff ; ( ) S 3DG/C EMI. (F fi , .)

Table 1
C - EMI -
.

Coating materials	Substrate	Method	Maximum shielding efficiency (dB)	Improvement of thermal property (%)	Ref
G	G	I + + +	37	–	50
G	PS	H - +	29.3	–	56
G	PMMA	S + +	19	–	57
C /G /C	A	S fi +	–	8.5	58
G	N	F + CVD	–	554	59
G	C -N	+	20	–	60
G	C	P + CVD	–	2.4	61
G	C	F - +	47	6.3	62
G	C	CVD + SLM	47.8	27	T

Note: ( )-PPMA, -PS.

HT *in-situ* (F . 9**a**). S - - - 3DG/C ff . I HT 1–2 . I , . W , SLM fl (fl 500 μ) (F . 9**b**), - . G , , , - (T 1). I . O - , N . T 3DG/C ff EMI, EMI *SE,* (EM) , 2–18 GH (F . 9**c**), . W *in-situ* ff , *SE* 15.9 32.3 B, 47.8 B (88.2%), 6 20 B. T 3DG/C fi . J K . 44 EMI . T EMI *SE* 133% (. .,) 20 110 PPI ( ). R V K 45 EMI . W 17 26 PPI (F . 9**c insert**) 105% EMI *SE*. I , EMI V ff SLM. T 3DG/C 26 PPI EMI *SE* 32.3 B, 99.9% EMI . T 60 (30 ff) 46 . T EMI 3DG/C - - T 1. I EMI *SE* 3DG/C 3D - , . T EMI fl (SE_r), (SE_a) fl (EM) 47 , , , , 48 . R 49 , fl , . T EM fi 50 . R EMI . T - - - ff , C 51 . F - , - 52 S O_2 53 . W 3DG/C ff fi SE_r SE_a, F . 9**e**. W 3DG/C ff , fl , - ff . S - , 3DG/C - fl . T EM fi EM , SE_r. O , ff fi EM ff , , EM - . T ff J 54 . I fi fl ff . M , , fl , EM EM . T 44 . T 3D EM . I , CVD R - S 3.3 , 55 . I EM , . O , 3DG/C fl , fi . T ff .

4. Conclusions

A 3DG/C ff *in-situ* CVD . T ff . W , 3DG/C EMI *SE* 15.9 ( ) 32.3 B, 47.8 B (88.2%), 26.8% ff . T 3DG/C ff fl , fl - . T V EMI 3DG/C ff EMI .

Credit authorship contribution statement

Kaka Cheng: C , M , F , W - . **Wei Xiong:** V , I , W - . **Yan Li:** W - & , F , R , S . **Liang Hao:** F . **Chunze Yan:** R , F . **Zhaoqing Li:** V . **Zhufeng Liu:** F . **Yushen Wang:** I , S . **Khamis Essa:** W - & . **Li Lee:** D . **Xin Gong:** S . **Ton Peijs:** W - & , S .

Declaration of Competing Interest

T fl .

Acknowledgement

T fi N N S F C (N . 51671091, N . 51902295, N . 51675496). T J F R F C U , C U G (W) (N . (N . CUG170677) H P N S F (N . 2019 CFB264).

Appendix A. Supplementary data

S :// . /10.1016/J .2020.105904.

References

1 B RG, N N, M K, M S. G : . P M S 2018;91:24–69.

2 B AA, G S, B W, C I, T D, M F, . S . N L 2008;8(3):902–7.

3 L , H, C M, P H, P O, S G, . I : ffi . ACS A M I 2016;8(36):24112–22.

4 K M, K J, J B, C , K JH, A JH. G - . ACS N 2017;11(8):7950–7.

5 P , C M, H M, T M, , L D. P - . A C , B 2020;262:118266–76.

6 L XJ, W, C LL, J SH, W G, L, . H C-G . C P A 2017;101:50–8.

7 HQ, L SW, C LH, J SH, H HQ. S - - - . J M C A 2018;6(42):21216–24.

8 D TM, S P, D P, K J, K M, A T, . 3D - - fl H . P C . P 2017;1(4):467–70.

9 Q L, L L. T - . RSC A 2014;4(72):38273–80.

10 D X, H L SP, N, W JG. 3D - M S_2 : P - . C P A 2016;90:424–32.

11 L XL, XW, S CQ, H MK, X HL, D W , . S - – - 3D fi EM - . A F M 2018. :// . /10.1002/ . 201803938.

12 L J, P , X C, R G, , N D, . G S O_2 . ACS N 2013;7(7):6001–6.

13 J SH, A S, G A. L - . A C I E 2017;56:15520–38.

14 I , T , S K, K M, T T, T K, . T - . PCCP 2018;20(9):6024–33.

15 S K, D N, M C, V V N, E J. T . J B S 2002;149(8):370–7.

16 C XH, S M, S WH, L G, H X, Q , P 3D . S 2011;7(22):3163–8.

17 K H, G M, J I, H J, W C, C M. U - - . M 2019;1(4):1077–87.

18 S Q, F, X, L W, L H, L , . C - - - . A M 2017;29(31):1701583–90.

19 X X, G C, X L, T H, D, W , . T - . ACS N 2019. :// . /10.1021/ .9 08191.

20 C C, H , B X, N J, C S, L F, . 3D T 6A 4V : ff ; . M D 2019;175:107824–33.

21 S š ć J, B ž ć D. T ff N B - 316L SLM. S C T 2016;307:407–17.

22 R DC, HB, L J, L SJ, J W, R, . M T –N . M S E A-S 2020;771:138586–95.

23 L X, C W, A J, K S, N J, D, . L - - fi . S 2009;324(5932):1312–4.

24 C P, R WC, G LB, L BL, P SF, C HM. T - fl - . N M 2011;10:424–8.

25 J SD, D S, G L, K JP, H JV, V K. I fl . J M P T 2019;270:47–58.

26 X W, H L, L , T D, C Q, F , . Eff , fi - , . M D 2019;170:107697–708.

27 G DD, M W, W K, P R. L : , . I M R 2013;57(3):133–64.

28 L E, T S, C L, F A. Eff (SLM) 316L . J M P T 2017;249:255–63.

29 X , S, W , L J, W P, C , . F T 6A 4V. A P A: M S P 2018;124:685–98.

30 L , , M, S, D W, S C. I A S 316L . M D 2015;87:797–806.

31 L CLA, M S, T M, A RC, W PJ, L PD. T ff . A M 2019;166:294–305.

32 T X, K , T WQ, T J, D M, M D, . R - α/β - - T -6A -4V. S R 2016;6:26039–48.

33 K H, T XP, L NH, T SB, C CK. G - T –6A –4V . V P P 2016;11(3):183–91.

34 R fi HK, K NV, G H, S TL, S BE, M 6 4 . J M E P 2013;22(12):3872–83.

35 T X, K , T J, V G, P QX, G, . A T –6A –4V. J A C 2015;646:303–9.

36 R DA, M LE, M H , . N - . A M 2011;59(10):4088–99.

37 , X, , W H. Eff - C -2.4N -0.7S . J A C 2018;743:258–61.

38 K S. W . S E 2003;23:309–48.

39 L G , G J ff R, G N P. E C (111). N L 2010;10(9):3512–6.

40 L XS, C WW, C L , R ff R S. E N C . N L 2009;9(12):4268–72.

41 XW, X C, X, W H, SQ, L. A - . C 2020;161:479–85.

42 F AC, M JC, S V, C C, L M, M F, . R . P R L 2006;97(18):187401–4.

43 S , G , J SH, F PC, H HQ. H - fi . M L 2017;200:97–100.

44 J K, H, J, C J, D . F - C –N CNT . A S S 2014;311:351–6.

45 R V K, M DP, A C, M S, S VK. E EMI , . C P A 2018;12:475–84.

46 S B, L , W, W. C - V (EMI) . ACS A M I 2016;8(12):8050–7.

47 H S, 07.5S , , F, 5.9(L)- X, G T 0TT 1L S L J5.3(D)-310 1 537TD T ((

M 2019;34(5):489–98.
53 W B, C M, L M. R : - - ffi . A M 2014;26:3484–9.
54 C H, W S, J , J, X, C J, . S ff F $_3O_4$ fl (fl) fl . C P A 2019;121:139–48.
55 W L, J, Q. T ff MWCNT - –MWCNT . J M S : M B 2015;26(3):1895–9.
56 D X , P GR, H P, Q F, M B , ML. Effi / . J. M C 2012;22:18772–4.
57 HB, Q, WG, H X, T - . ACS A M I 2011;3:918–24.
58 S A, U N, T V. T - . M R 2016. :// . /10.1051/ /2016021.
59 P MT, J H, R ff RS, S L. T - - . N L 2012;12:2959–64.
60 J K, H, H , D . P - C –N - . M L 2017;122:244–7.
61 R H, L S, B S, K TW, L DS, L HJ, . T - - - . S R 2015. :// . /10.1038/ 12710.
62 XT, F SG, L , G Q, L G, R KP, . S - 3D / . M S E A-S 2020. :// . /10.1016/J .2019.105670.
63 R DA, M LE, M E, H DH, M JL, M BI, . N - . A M 2011;59(10):4088–99.
64 E SF, L KC, S VK, M IC. T . J T E 1973;1(1):10–38.