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C S D

C P A

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In-situ -
ff

K C , W X , L *, L H , C , L , L ,
W , K E , L L , X G , T P J

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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 - (,) - (,) 88% 27% ff . T 3DG/ ff (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 (2630 ^{2} $^{-1}$) [1], (2 10^5 ^{2} V^{-1} $^{-1}$) (6 5000 W $^{-1}$ K^{-1}) [2]. H , π-π (2D) ff , , - [3]. A fi ff - . C (3DG) fi (6 0.6 $^{-2}$) [4] , -

(2DG), [5], [6,7], [4], (EMI) [8]. 3DG V , [9], [10], - [11], - [12]. H , - . F , ff [13]. S - ( ) [14]. D - [15]. M - (6 99.7%), , - CVD , fi - - [16]. B , , ,

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. T (. ., -
), fl fi
(. ., ,) 3DG. B , -
3DG
(. ., , ,). H ,
ffi
, , N
, 3DG -
fi [17,18] .
H ,
3DG
[19] .
S (SLM), -
(AM) ,
/ - (3D)
, ffi
fl *in-situ* . T
SLM T [20] ,
[21] , N [22] . C /
- - - - -
. C N ,
CVD (< 0.001 . %)
, -
[23] . W N
(> 0.1 . %) [17] , fi
[24] . H , -
SLM ffi
fl
(1000–1100). F ff
SLM [25] .
T , fi
- 3DG/ (3DG/C) -
SLM CVD
. A - -
SLM -

-579684 -574TD(3D7(574((> 32(5748(103JT9207740 5159-11.0 1228302(50T (7)00.4.70TD 770320 7703218(8(097.6787T (S

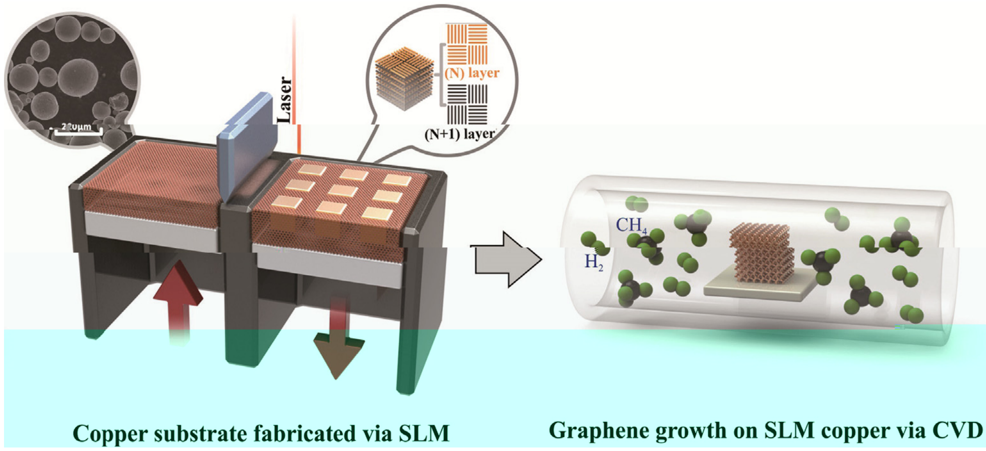

Fig. 1. 3DG/C : ff SLM ( ) *in-situ* ff CVD ( ). (F fi , .)

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*) (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 fl . T ffi . I A, ffi . I B, fi . T fl ffi , LED 400 J/ (C). W LED (> 800 J/) , 130 µ - (D), - 28 .

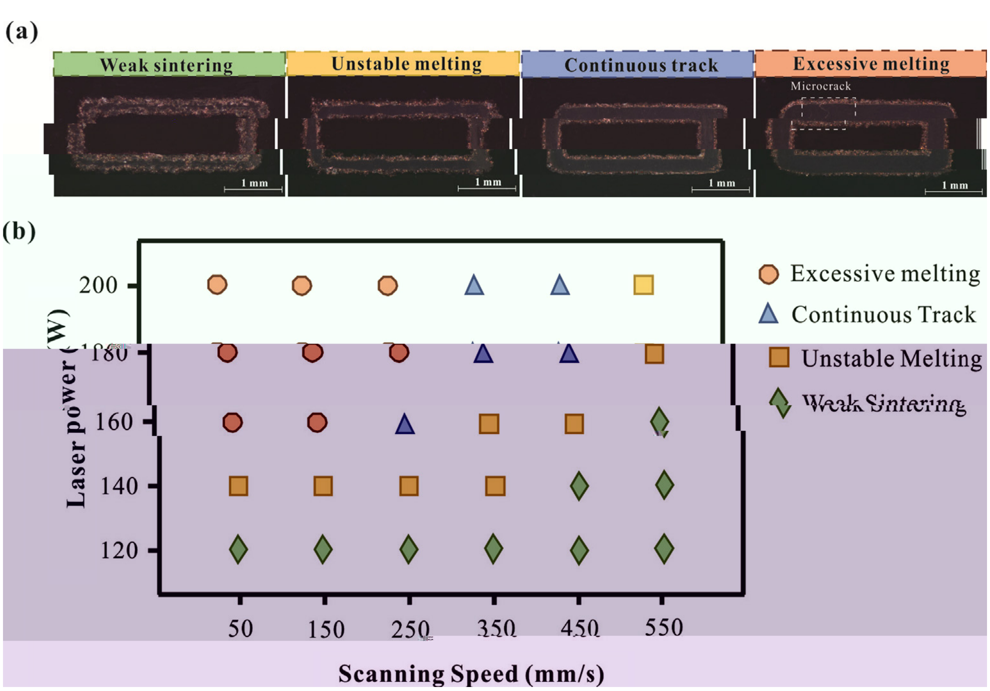

Fig. 2. ( ) T , ; ( ) , (F - fi , .)

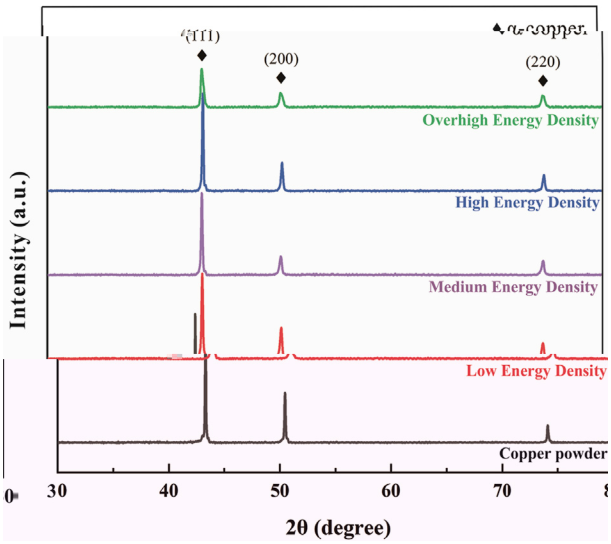

Fig. 3. XRD - - . (F fi , .)

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

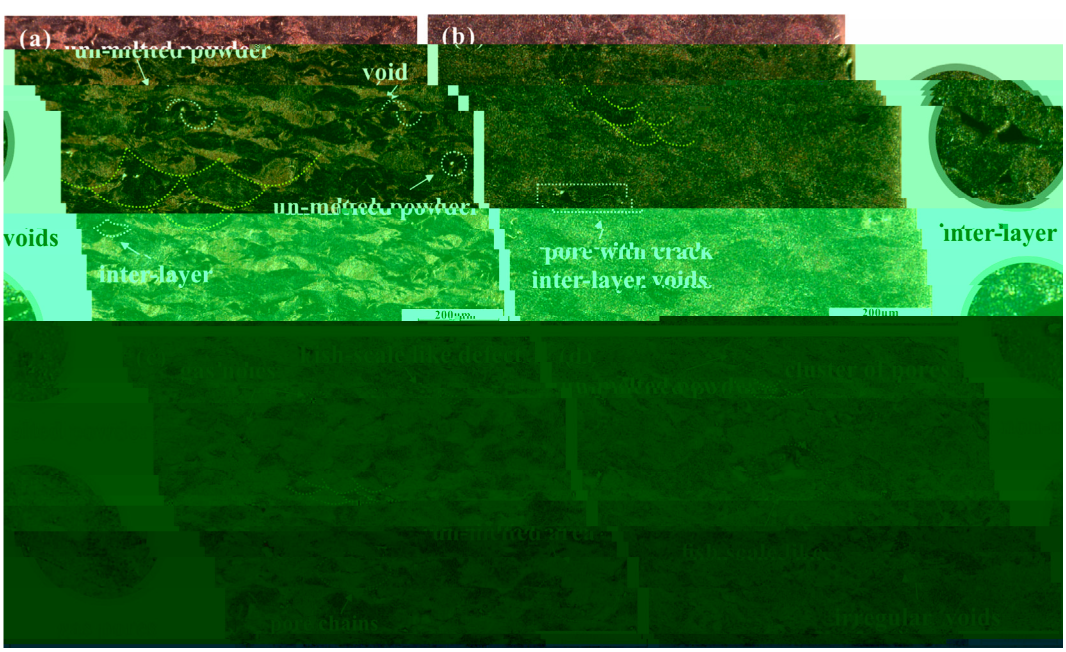

Fig. 4. O : ( ) (3000 J/ ^{3}), ( ) (857 J/ ^{3}), ( ) (285 J/ ^{3}), ( ) (128 J/ ^{3}), . (F fi , .)

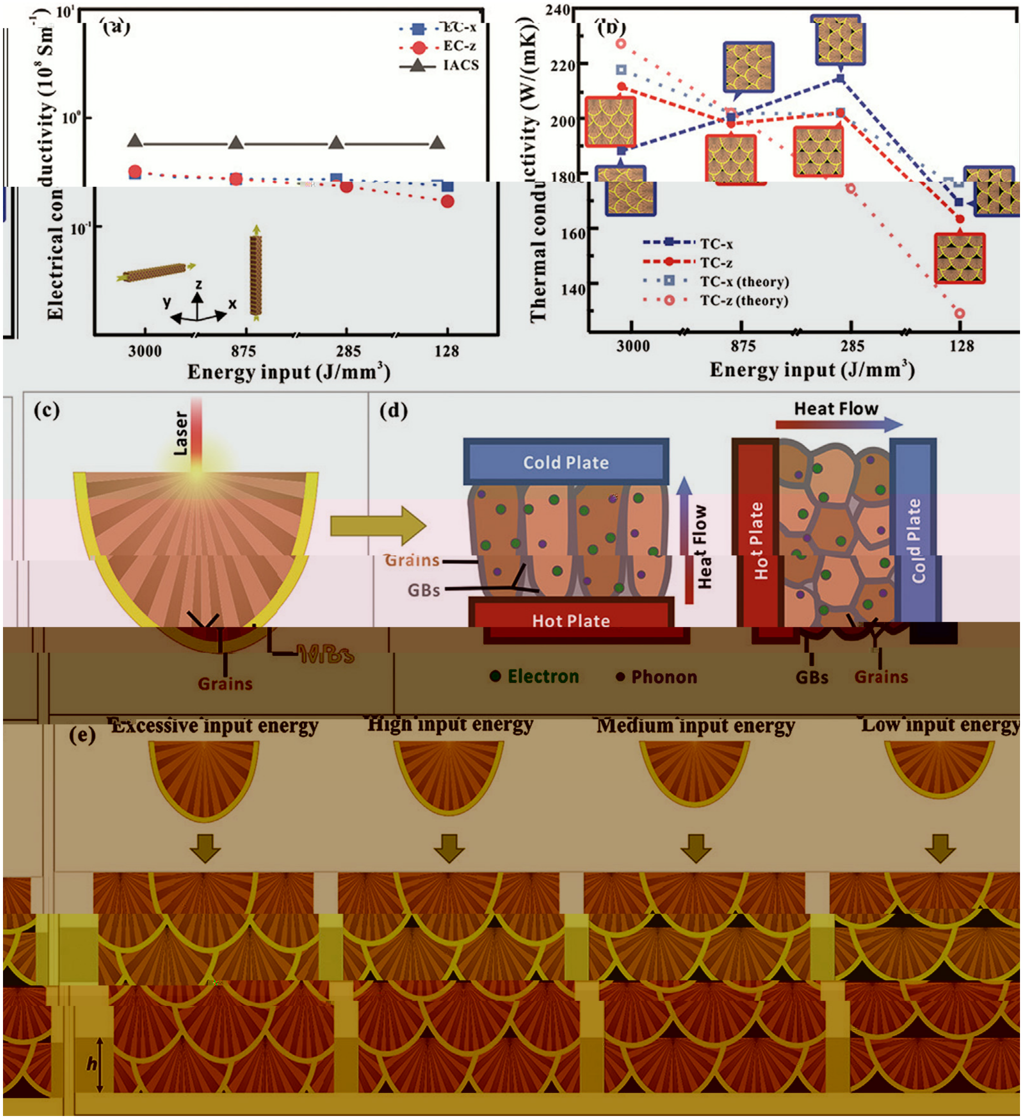

Fig. 7. ( ) E ( ) ; ( ) ; ( ) ; ( ) ff . (E). (F fi , .)

. A ,

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

F 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

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

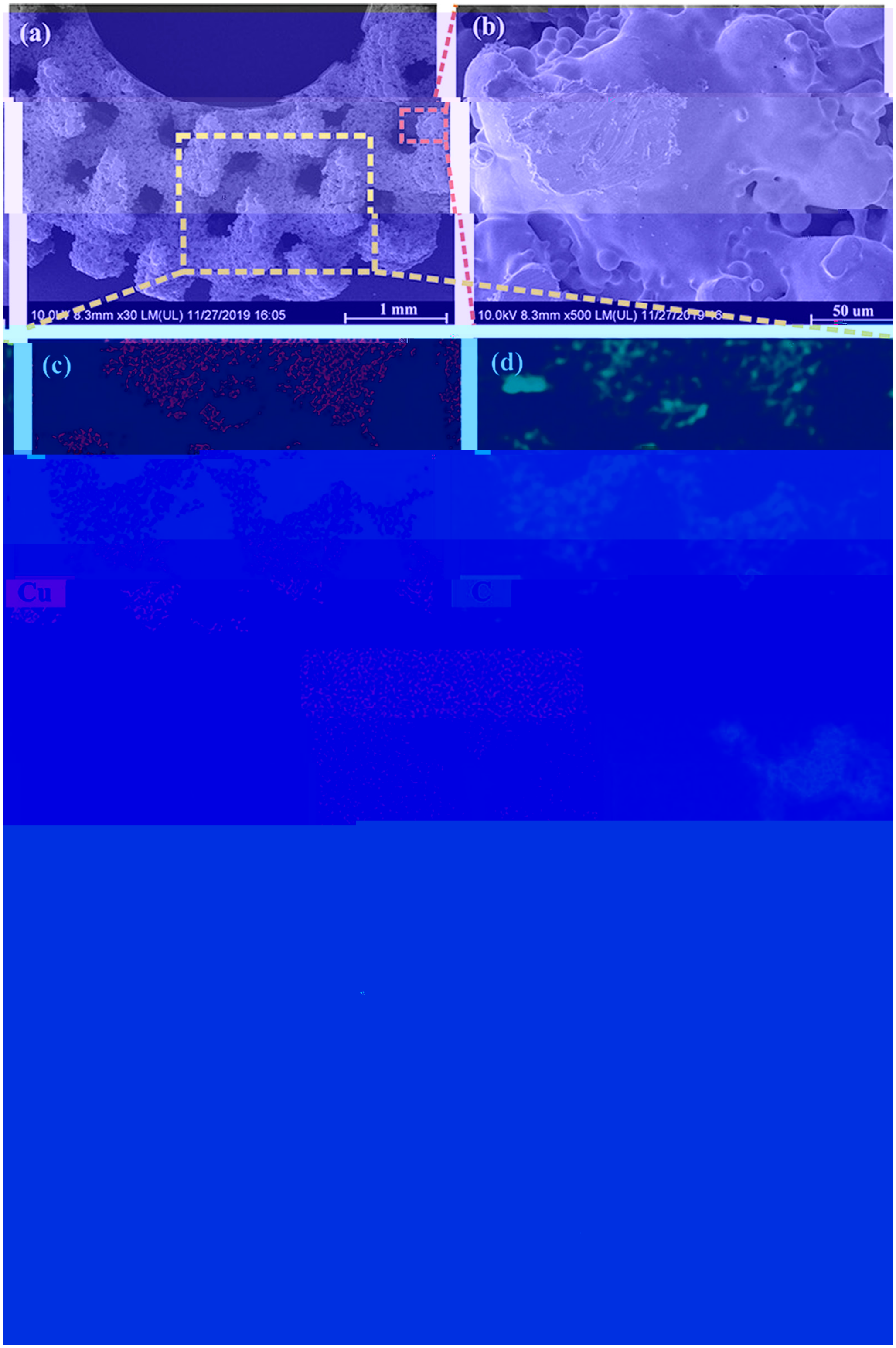

Fig. 8. (-) SEM 3DG/C ff ff fi ; EDS ( ) C ( ) C; ( ) fi SEM , EDS ( ) C ( ) C; ( ) OM; ( ) R ff ff . (F fi , .)

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

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

T ff C ff , 26.8% 14.8%

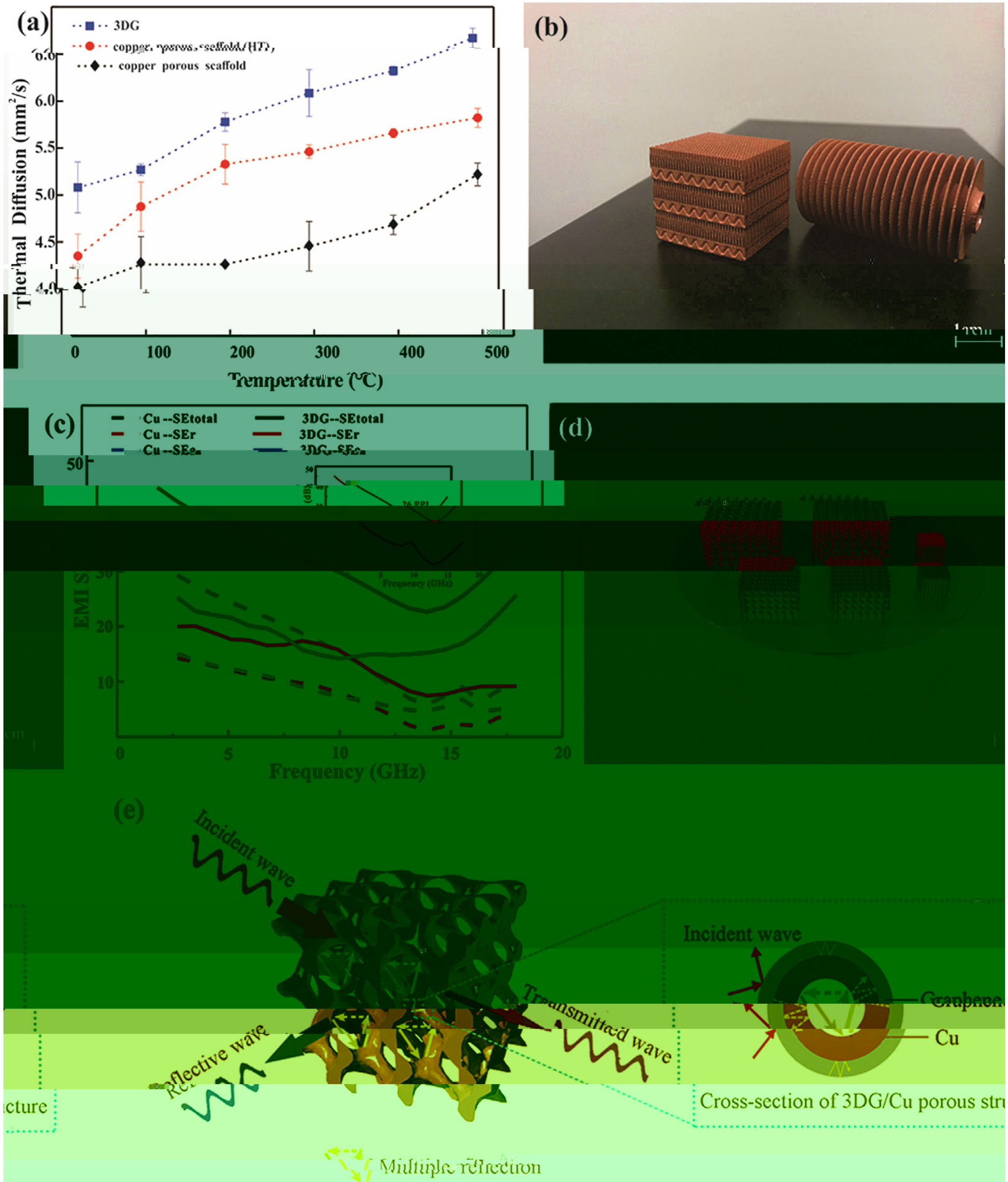

Fig. 9. P 3DG/C ff : ( ) ff ; ( ) SLM fl (- fl) - ; ( ) EMI SE; ( ) C ff ff ; ( ) S 3DG/C EMI. (F fi , .)

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	B +	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 . 9a). S - - -
, -
3DG/C ff -
. I HT
1–2 . I ,
, . W
, SLM
fl (fl
500 μ) -
(F . 9b),
- . G -
, , ,
-
(T 1). I
. O -
, N .
T 3DG/C ff
EMI, EMI *SE*,
(EM) ,
2–18 GH (F . 9c),
. 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 J K 45
EMI
. W
17 26 PPI (F . 9c insert) 105%
EMI *SE*. I , EMI J
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 . 9e. 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 J 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
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/ .2020.105904.

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