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In-situ - ff

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

Gemmological Institute, China University of Geosciences, Wuhan 430074, PR China
Hubei Gem and Jewelry Engineering Technology Research Center, Wuhan 430074, PR China
School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
Mechanical Engineering, University of Birmingham, Birmingham B15 2TT, UK
School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
WMG, Materials Engineering Centre, University of Warwick, CV4 7AL Coventry, UK

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B

ABSTRACT

C , - (3DG) . H , - (SLM) - (3D) . G *in-situ* (CVD) C , 3DG . A CVD SLM ff ( ) - (,) , 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} (2630 ^{2} $^{-1}$) [1], (2 10^5 ^{2} V^{-1} $^{-1}$) (6 5000 W $^{-1}$ K^{-1}) [2]. H , (2D) ff , , - [3]. A . C (3DG) fi (6 0.6 $^{-2}$) [4] , -

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

* C : G I , C U G , W 430074, PR C .
E-mail address: @ . . (. L).

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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 -
, 3( ) 45.13, . 2()-37 /T1 441(250.7(288.5(

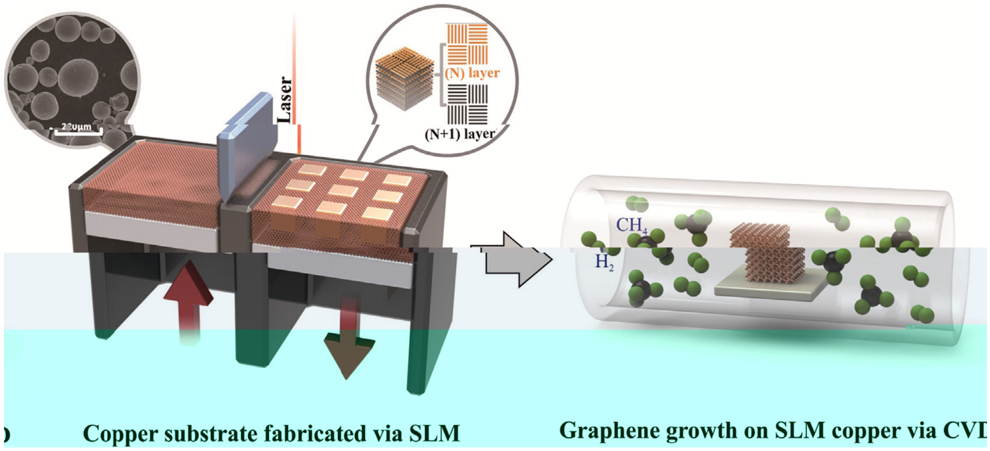

Fig. 1. 3DG/C : ff SLM ( ) *in-situ* ff CVD ( ). (F fi , .)

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

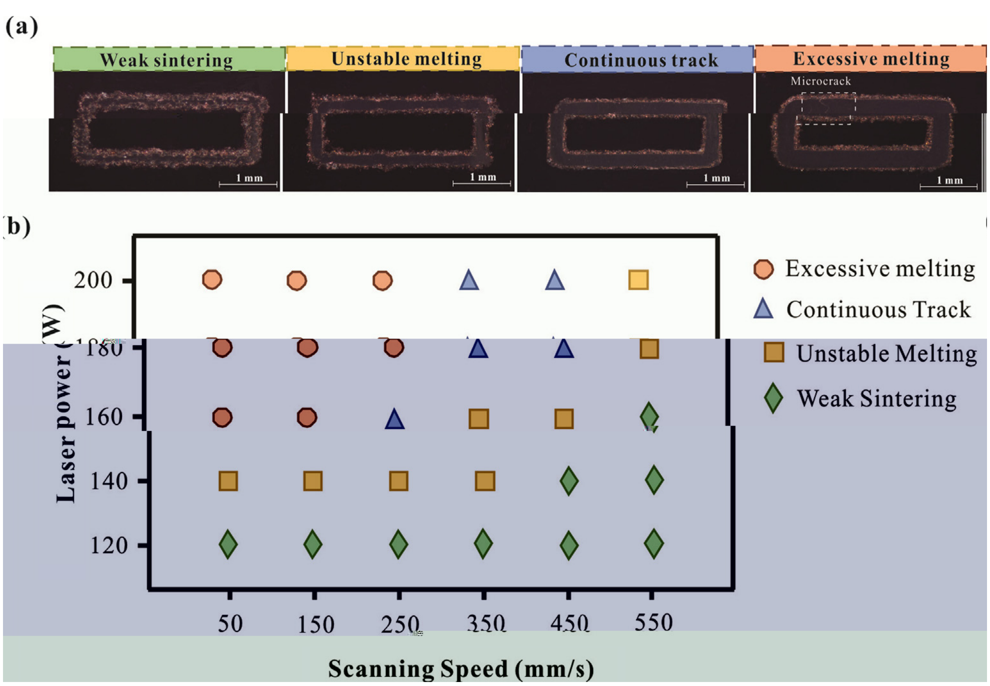

Fig. 2. ( ) T , , ; ( ) (F - fi , .)

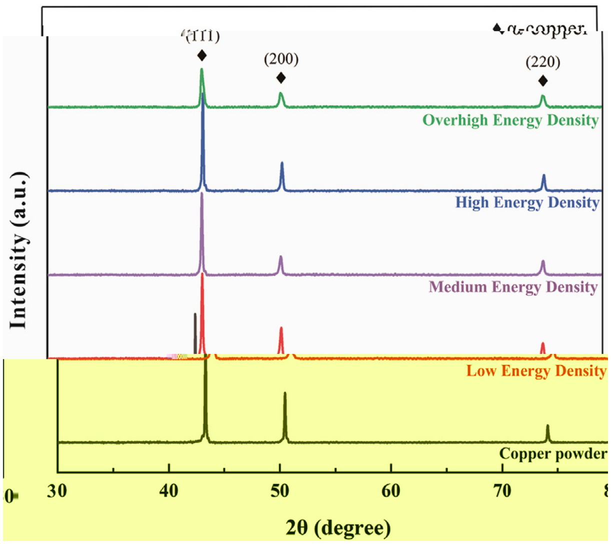

Fig. 3. RD - - . (F fi , .)

3.1.2. Formation of anisotropic microstructure under different volumetric energy density

T α- RD (1 1 1) (2 0 0) fl ff 2θ = 43.32 2θ = 50.45 , (F . 3), (1 1 1) . T - RD 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 , ,

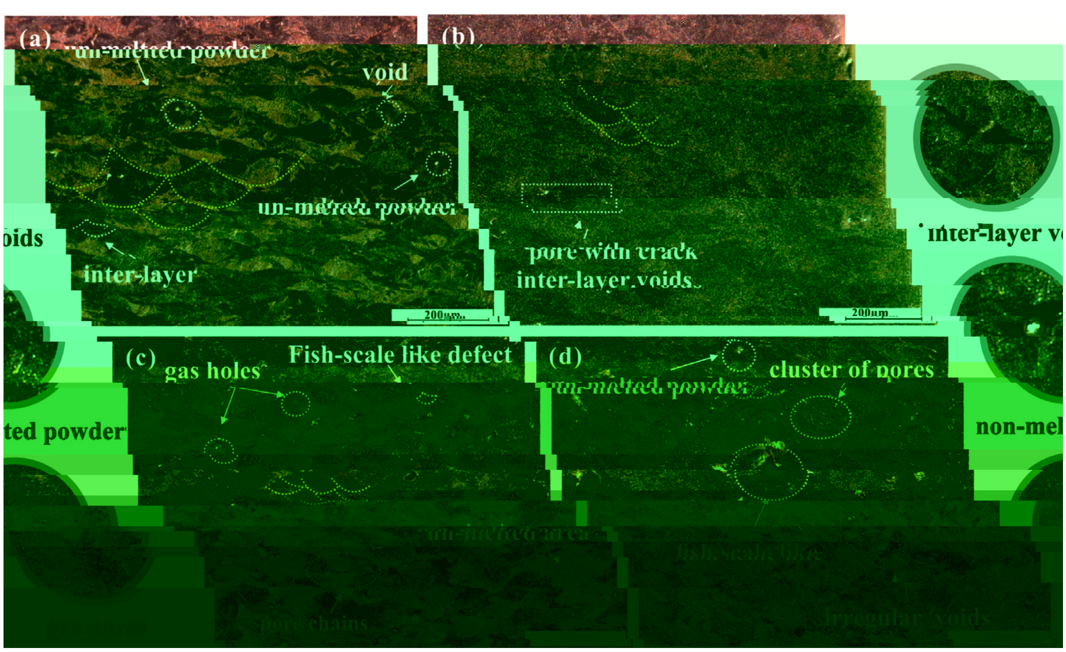

Fig. 4. O : ( ) (3000 J/ 3), ( ) (857 J/ 3), ( ) (285 J/ 3), ( ) (128 J/ 3), . (F fi , .)

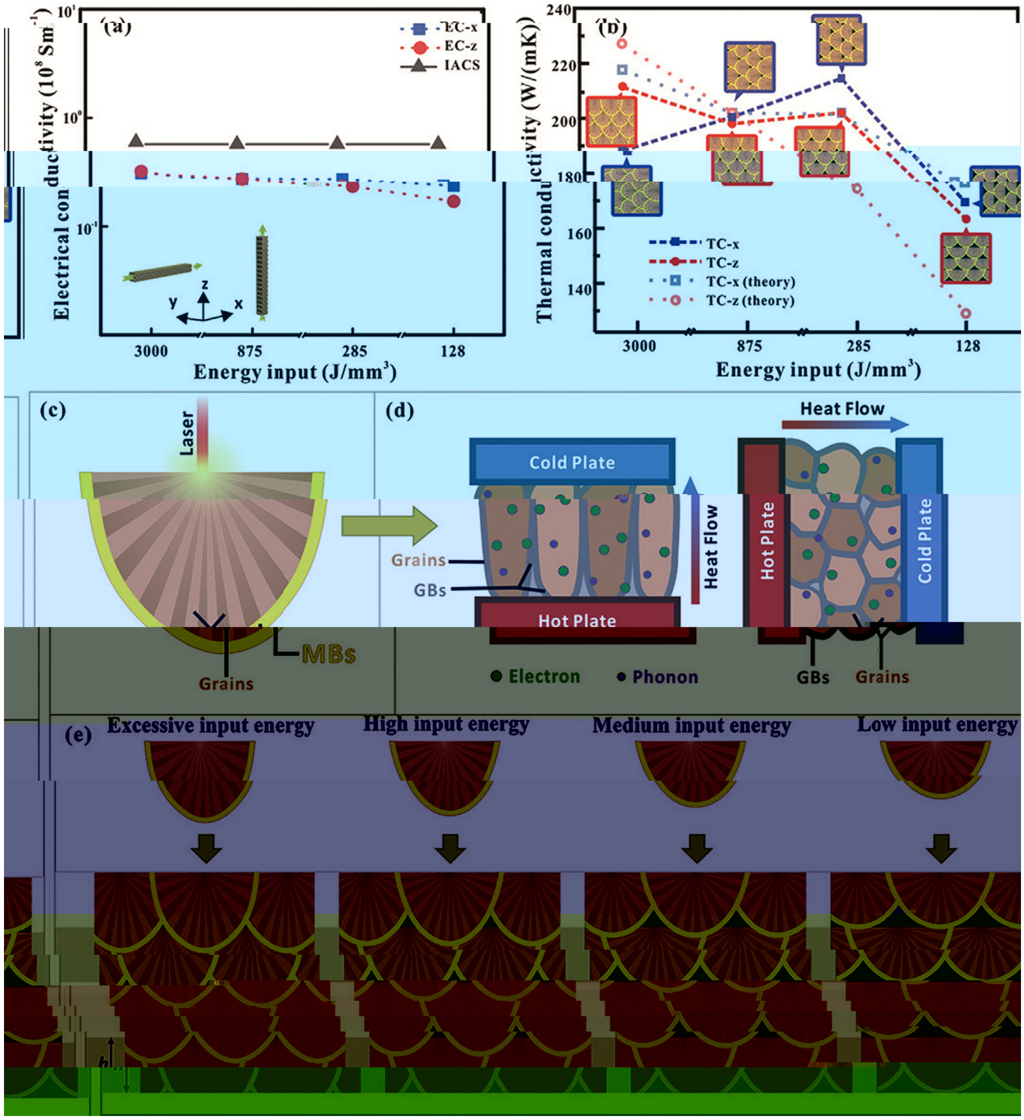

Fig. 7. ( ) E ( ) ; ( ) ; ( ) ;
( ) ff . (E). (F
fi , .)

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

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

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

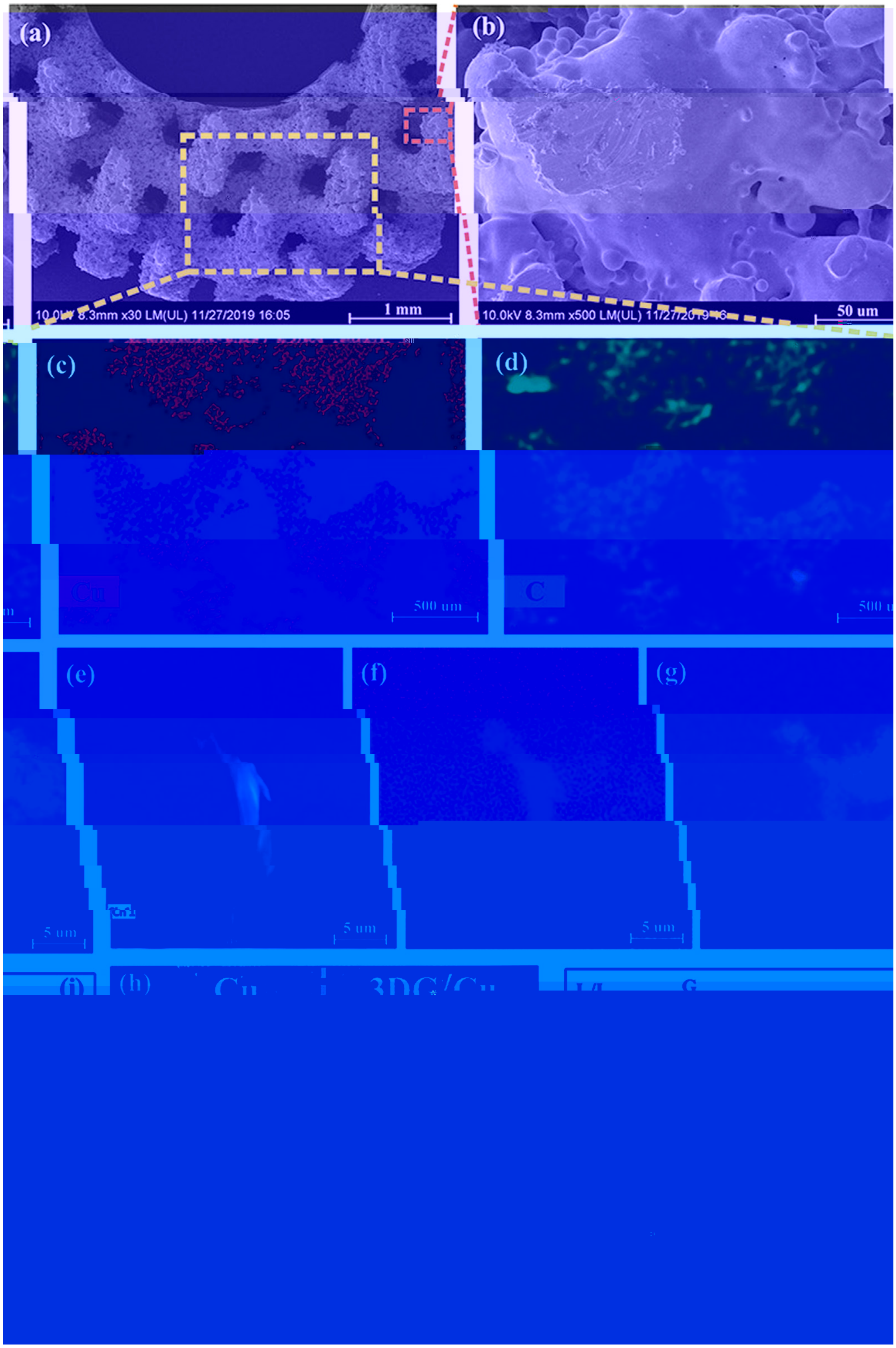

Fig. 8. (-) SEM 3DG/C ff ff fi ; EDS ( ) C ( ) C; ( ) fi SEM , EDS ( ) C ( ) C; ( ) OM; ( ) R ff ff . (F fi , .)

. 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%

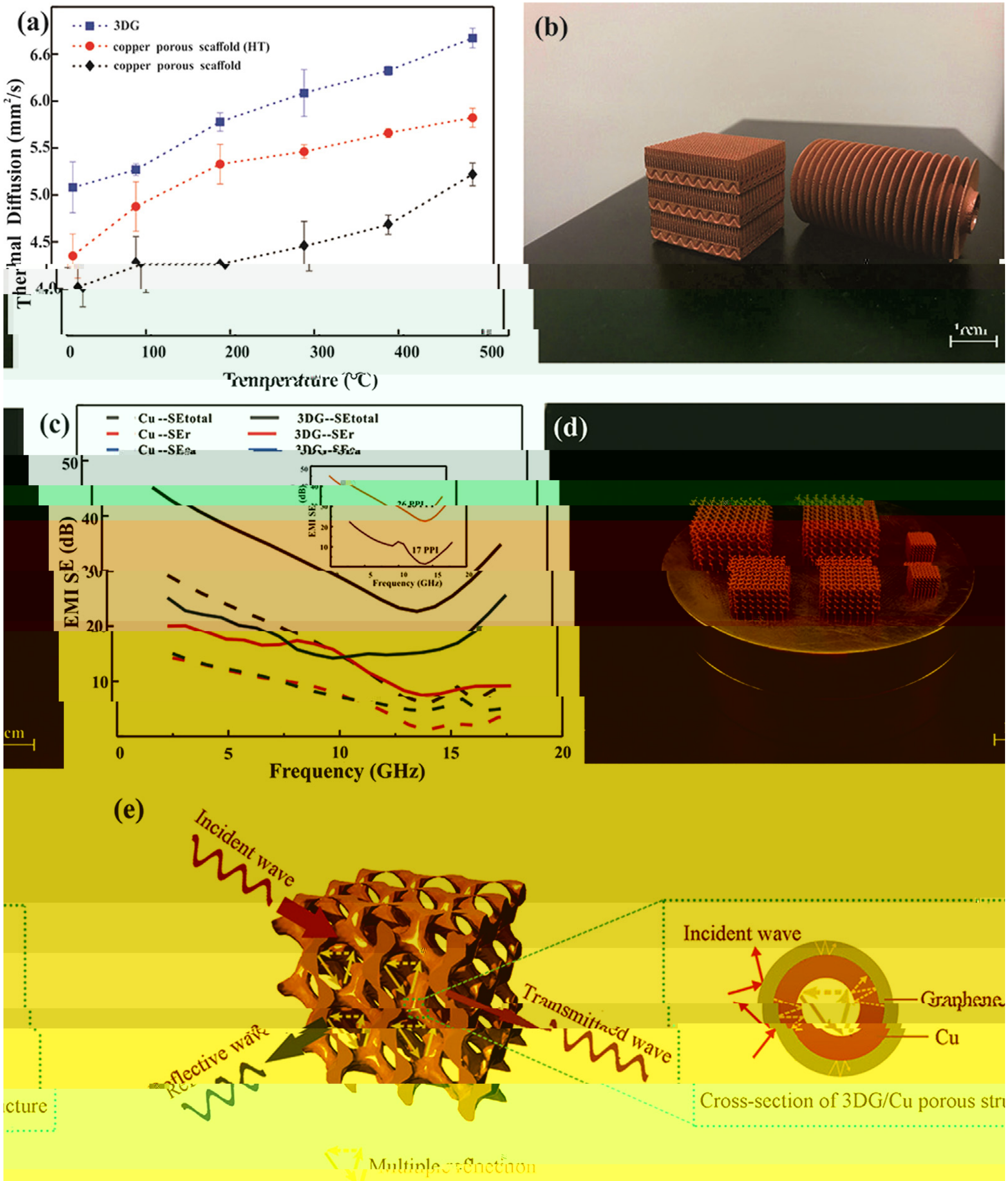

Fig. 9. P 3DG/C ff : ( ) ff ; ( ) SLM fl (- fl) - ; ( ) EMI SE; ( ) C ff ff ; ( ) S 3DG/C EMI. (F fi , .)

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 K 45 EMI . W 17 26 PPI (F . 9c insert) 105% EMI *SE*. I , EMI 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 , . T , ff 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 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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