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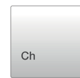
In-situ - ff



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ABSTRACT

C , - (3DG) w , w . H w - - (SLM) - (3D) . G w *in-situ* w (CVD) C , 3DG . A w CVD w 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] , w w , (2630 m^2 g^{-1}) [1], (2 10^5 cm^2 V^{-1} s^{-1}) (5000 W m^{-1} K^{-1}) [2]. H w , π-π w w (2D) - ff , , w , - [3]. A fi ff w - . C w , - - (3DG) w (99.7%), w fi (0.6 mg cm^{-2}) [4] w fi w , w -

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

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

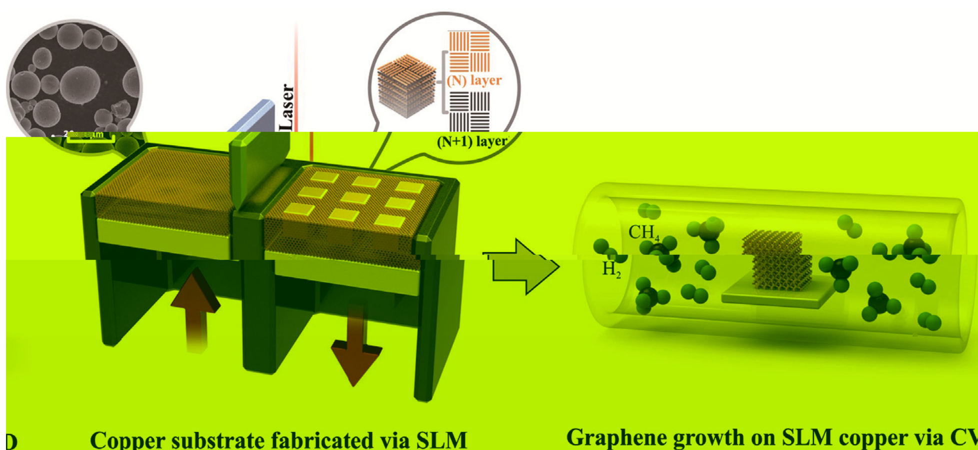

Fig. 1. I 3DG/C : ff SLM ( ) *in-situ* w ff CVD ( ). (F fi , w .)

ASTMB193-2002 w 2 2 20 ^{3} . T ff (2 10 10 ^{3}) (5 10 10 ^{3}) w ASTME1461-2013 w LFA (L fl , N LFA457, G). R (SENTERRA, B , G) w 3DG/C ff w - w 514 . T *S* (*S11* *S21*) w w w (VNA, A PNA-N5244A, US) 2–18 GH . T *SE* , *SE* , *SE* fl w 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 (w) w . D ff w w (F . 2) , 30% w (A), 26.7% (B), 16.7% (C) 26.7% (D). D ff LED (J/) 27 (E . 6, SI). T fl . T ffi w ffi . I A, w ffi . I B, w w w w fi . T fl w w ffi , w w LED 400 J/ (C). W LED (> 800 J/) , 130 µ w (D), w w w w w w 28 .

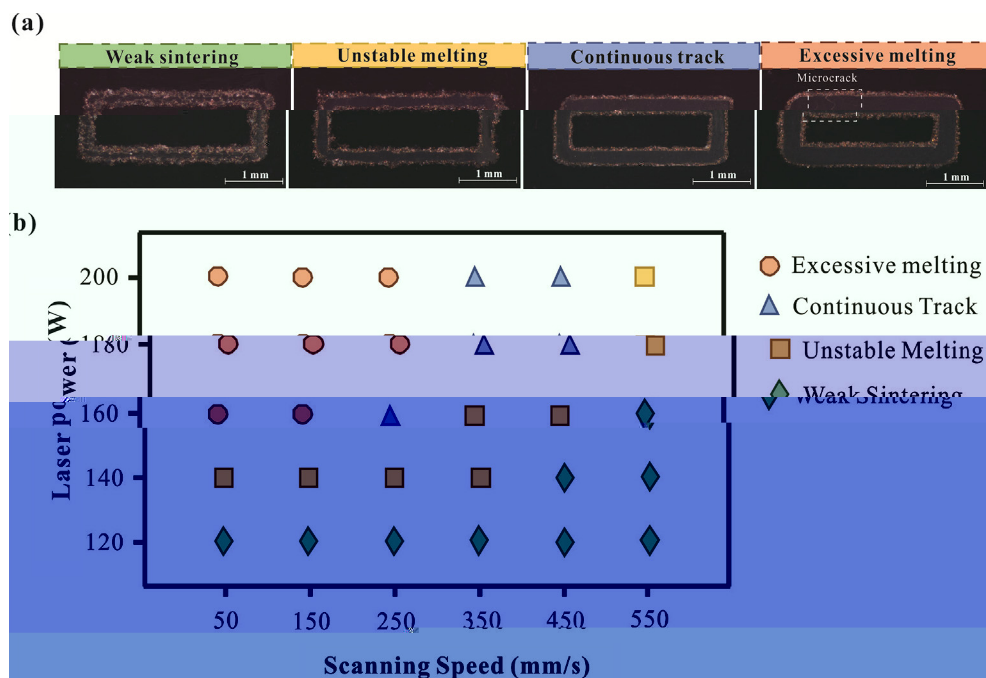

Fig. 2. ( ) T w , , - , ; ( ) w w w . (F - fi , w .)

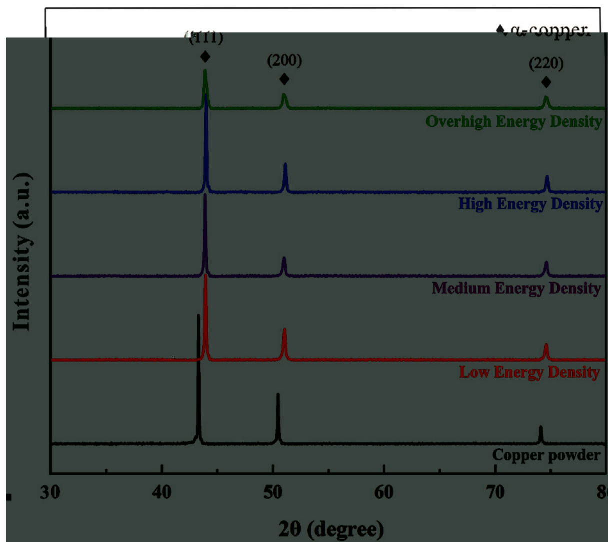

Fig. 3. RD ... w ... fi ... w ...)

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 , ... (Fig. 3), ... (1 1 1) ... w ... T ... RD ... w ... ff ... w ... fi ... SLM ... I ... ff ... SLM ... ff ... [29].

T ... w ... SLM ... w ... T ... w

... : ( ) ... , ( ) ... w , ... ( ) ... A ... 3000 J/mm³ (Fig. 4a), ... w ... w ... 180 μm, ... w ... w ... (Fig. 4d). T ... M ... [30] ... fl ... T ... w ... w ... fi ... W ... 857 J/mm³, ... w ... w ... w ... w ... (Fig. 4b). U ... , ... fi- ... 96.2% w ... H w , w ... , ... w ... T ... (398 W m⁻¹ K⁻¹), ... ffi ... w ... w ... (Fig. 4c). G ... , w ... w ... M - ... B ... , ... w ... SLM ... [31]. I ... , w ... 128 J/mm³, ... w ... w ... w ... w- ... w fi ... , ... 88.6% ... (Fig. 4d).

T ... SLM ... w ... w ... (Fig. 5). T ... w ... , w ... w ... T ... w ... w w ... , w ... w ... [32]. T ... fi ... fl w ... S ... w ... W ... [33], ... ,

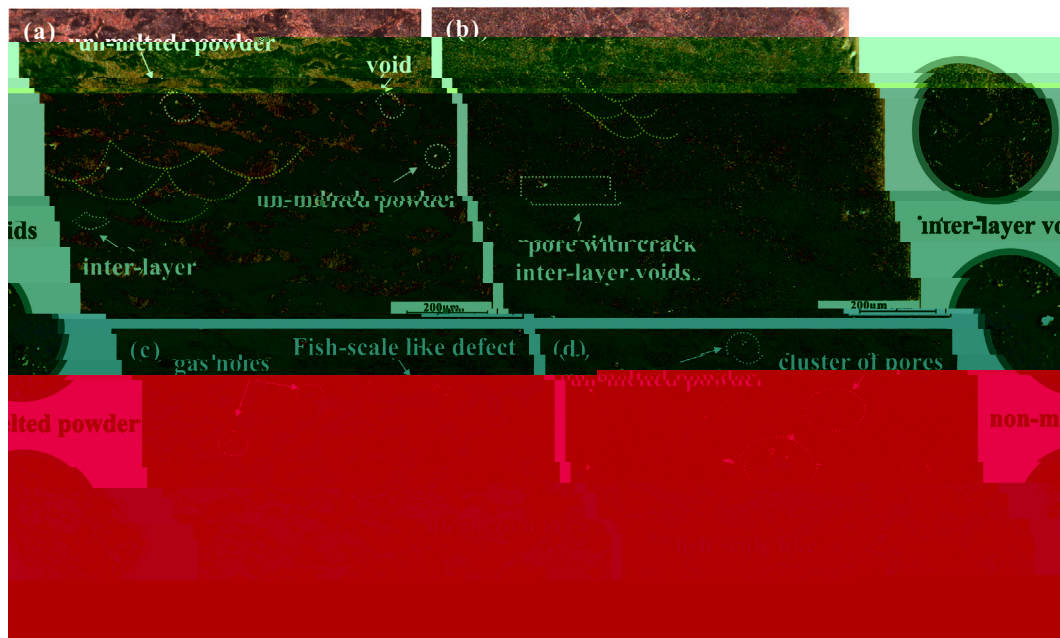

Fig. 4. O ... : ( ) ... (3000 J/mm³), ( ) ... (857 J/mm³), ( ) ... (285 J/mm³), ( ) w ... (128 J/mm³), ... (F ... fi ... , ... w ...)

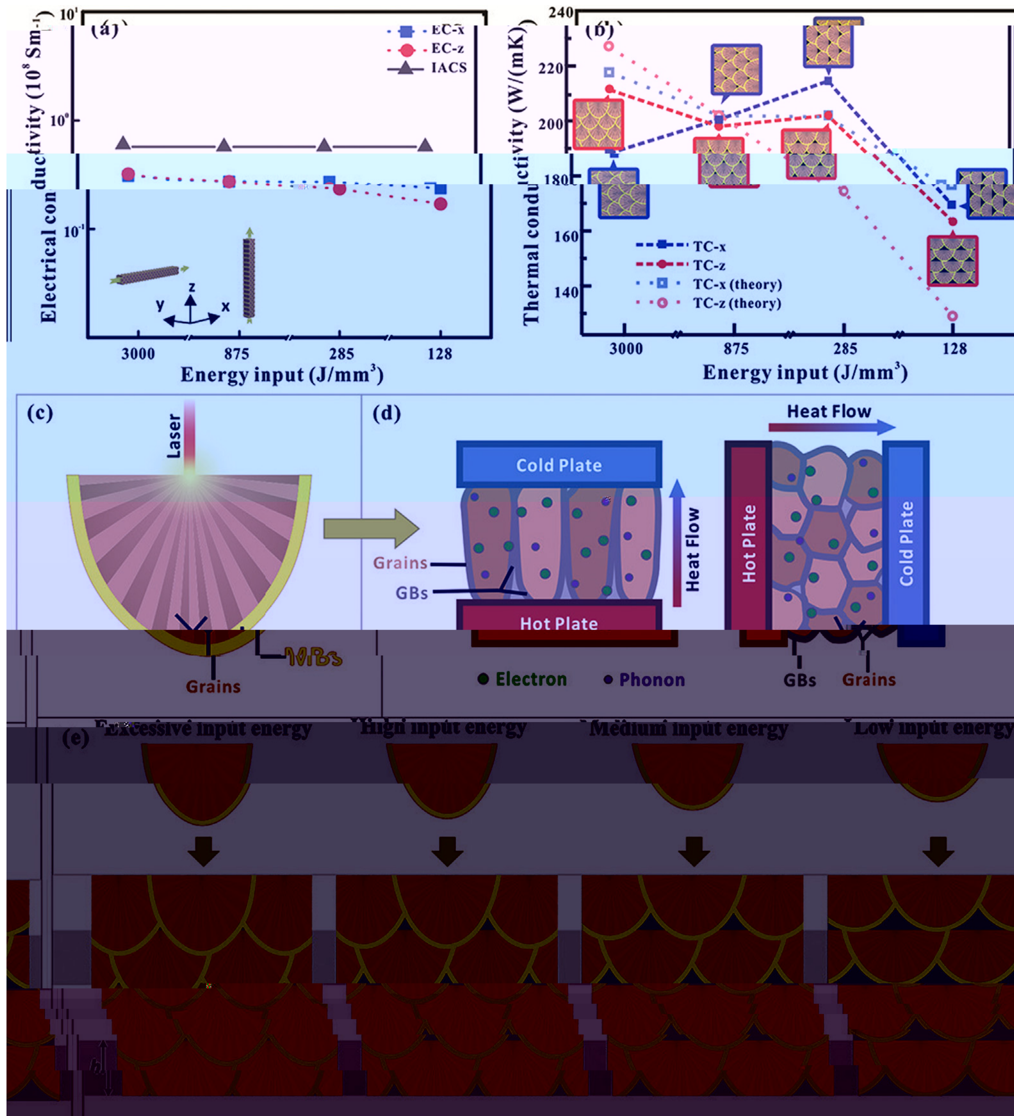

Fig. 7. ( ) E ( ) ; ( ) ; ( ) ; ( ) ff . (E). (F fi , w .)

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

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

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

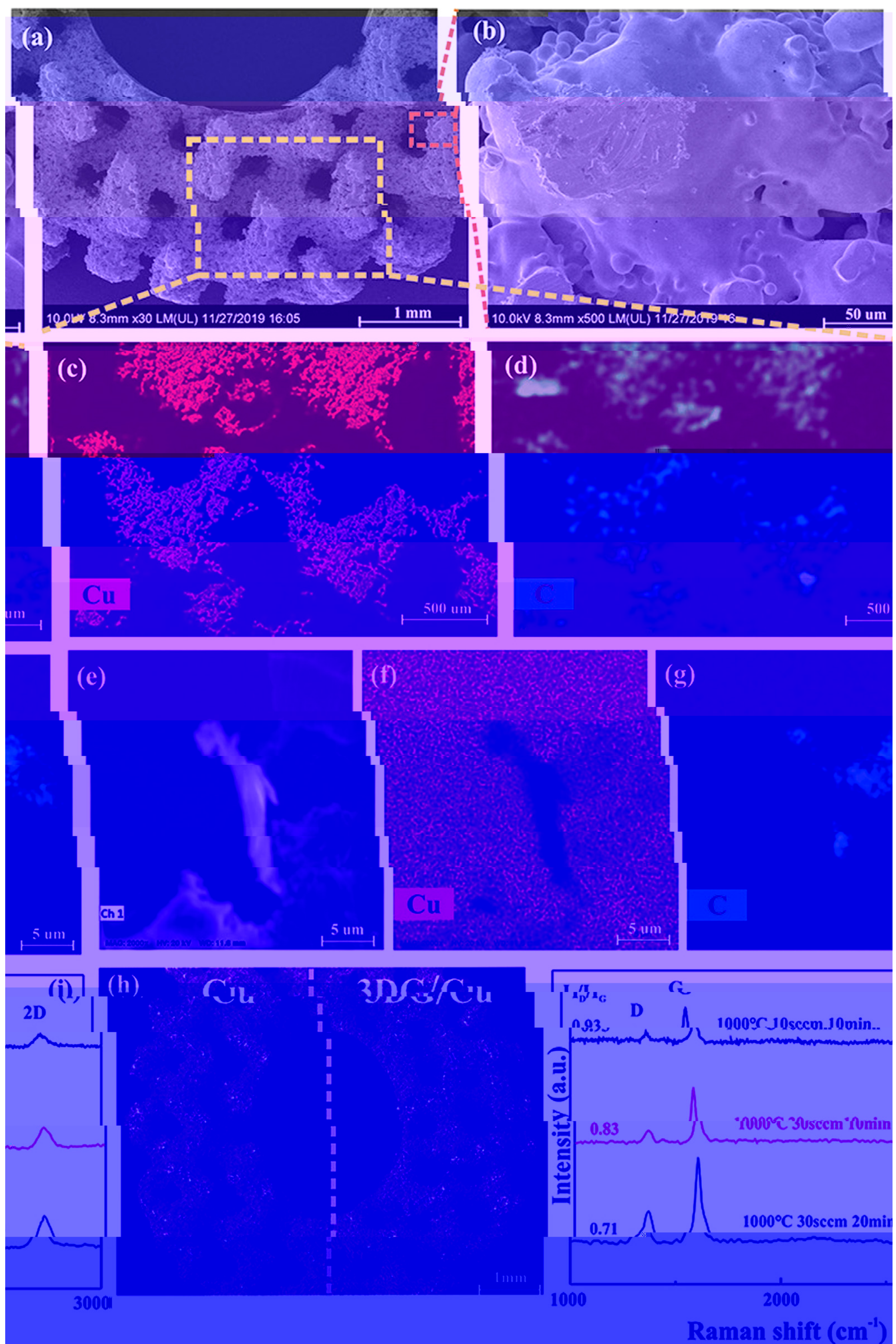

Fig. 8. (-) SEM 3DG/C ff ff fi ; EDS ( ) C ( ) C; ( ) fi SEM , EDS ( ) C ( ) C; ( ) w OM; ( ) R ff ff w . (F fi , w .)

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

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

T ff C ff , 26.8% 14.8%

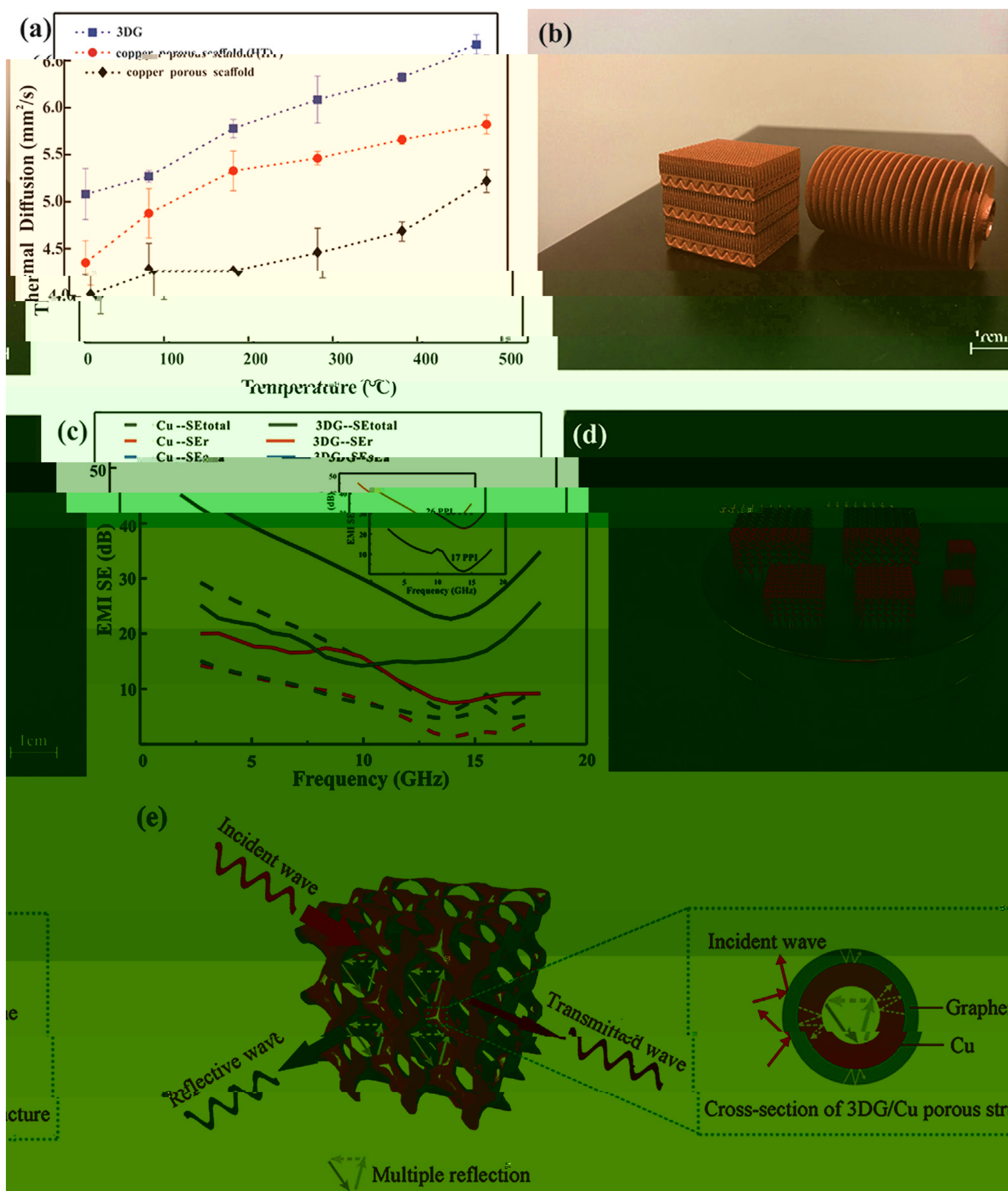

Fig. 9. P 3DG/C ff : ( ) ff ; ( ) SLM fl w (w fl) - ; ( ) EMI SE; ( ) C ff w ff ; ( ) S 3DG/C EMI. (F fi , w .)

Table 1
C - w 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	E +	20	–	60
G	C	P w + CVD	–	2.4	61
G	C	F - +	47	6.3	62
G	C	CVD + SLM	47.8	27	T w

Note: ( )-PPMA, -PS.

HT *in-situ* w (Fig. 9a). S 3DG/C ff I HT w 1–2 I w w SLM fl w 500 µ (Fig. 9b), w G w (Table 1). I w w O w N

T 3DG/C ff EMI, EMI *SE*, w (EM) w 2–18 GHz (Fig. 9c), W *in-situ* w ff *SE* 15.9 32.3 dB, w 47.8 dB (88.2%), 20 dB. T 3DG/C fi w EMI [44] w T EMI *SE* 133% w (20 110 PPI ( ). R K [45] w EMI W 17 26 PPI (Fig. 9c insert) 105% EMI *SE*. I w EMI ff w w SLM. T 3DG/C 26 PPI EMI *SE* 32.3 dB, 99.9% EMI w . T w 60 (30 ff) [46]. T EMI 3DG/C w Table 1. I EMI *SE* 3DG/C w 3D

T EMI fl (SE_r), (SE_a) fl (EM) w [47], w w [48]. R [49] w fl w w EM w T w fi [50]. R EMI T w w w fi C [51]. F w [52] SO_2 [53]. W 3DG/C ff w

w fi SE_r SE_a, w Fig. 9e. W w w 3DG/C ff w w fl , w S 3DG/C fl w w T EM w fi w EM w EM w SE_r. O w ff , w w fi EM w ff EM T ff w w J [54]. I w fi w fl ff M w w fl EM w EM w T w [44]. T w 3D EM w w I CVD R Section 3.3 [55]. I EM w w , w O w 3DG/C fl w fi T w ff

4. Conclusions

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

Credit authorship contribution statement

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

Declaration of Competing Interest

T fl

Acknowledgement

T w 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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