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In-situ

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ABSTRACT

(3DG) ... (SLM) ... (3D) ... *in-situ* ... (CVD) ... 3DG ... CVD ... SLM ... 3DG ... 3DG/ ... 88% ... 27% ... (EMI) ... (*SE*) ... 47.8 ... 2.7 GH ... *SE* ... 32.3 ... 2–18 GH ... SLM

1. Introduction

... sp^2 ... (2630 ...) [1] ... $(2 \times 10^5$ ... V^{-1} ... $s^{-1})$ ... (5000 W ... K^{-1}) [2] ... π-π ... (2D) ... [3] ... (3DG) ... (99.7%) ... (0.6 ... $^{-2}$) [4] ...

(2DG) ... [5] ... [6,7] ... [4] ... (EMI) ... [8] ... 3DG ... [9] ... [10] ... [11] ... [12] ... [13] ... [14] ... [15] ... CVD ... [16] ...

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s . T x s s s (. ., s -
s), fl fi s
(. ., ss, f s) f 3DG. B s s, -
3DG s f
(. ., s , s , s f). H , s f s
s ffi
s , f s , N f
s s f
, s s 3DG s s f -
s s f s f s fi f s [17,18] .
H , s f ss s,
s f s s 3DG
s s s f s [19] .
S s (SLM), s -
f (AM) , s s f f
f s s / s x - s (3D) s
x s f s , ffi
fl f *in-situ* f . T , s
s s SLM s s s f T s [20] ,
s ss s [21] , N s [22] . C s s s f /
s s f - s s s - f- - -
s s s. C N s s ,
s s s s s f
CVD s (< 0.001 . %)
ss s f- f , -
s s [23] . W N s
s x (> 0.1 . %) [17] , fi s
f s f ss [24] . H , -
s SLM f s s s f s f s ffi
f s f s s
fl s s
(1000–1100). F f s s s ff s
SLM s s f s [25] .
T s, f fi s s
f s - 3DG/ (3DG/C) s -
s SLM s s CVD f
. A - s - s s
s SLM f s -
s f , s s s s3( ) 45.13, . 2()-37 /T1 (s441(250.7(s 288.5(

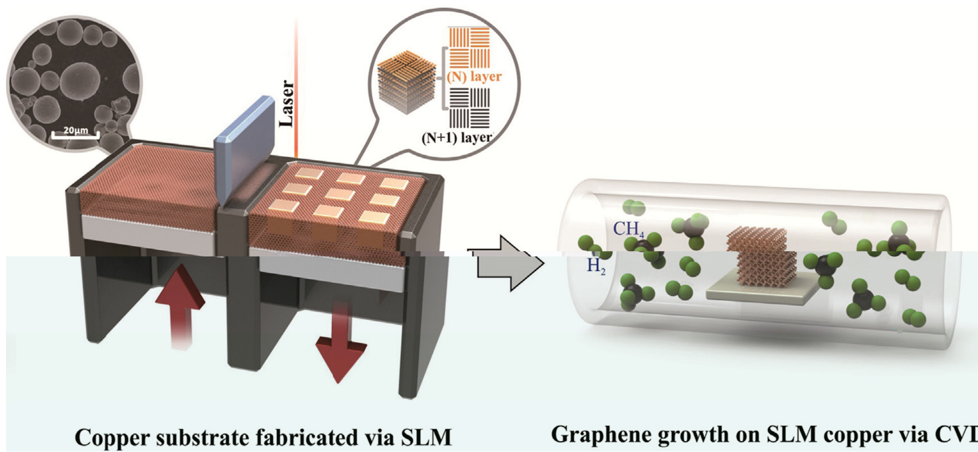

Fig. 1. Ill s f 3DG/C s s f ss: s ff l f SLM (l f) *in-situ* s ff l CVD ( ). (F f f s l s fi l , s f s f s l .)

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

3. Results and discussion

3.1. Formation of SLM copper

3.1.1. SLM manufacturing of copper under different line energy densities

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

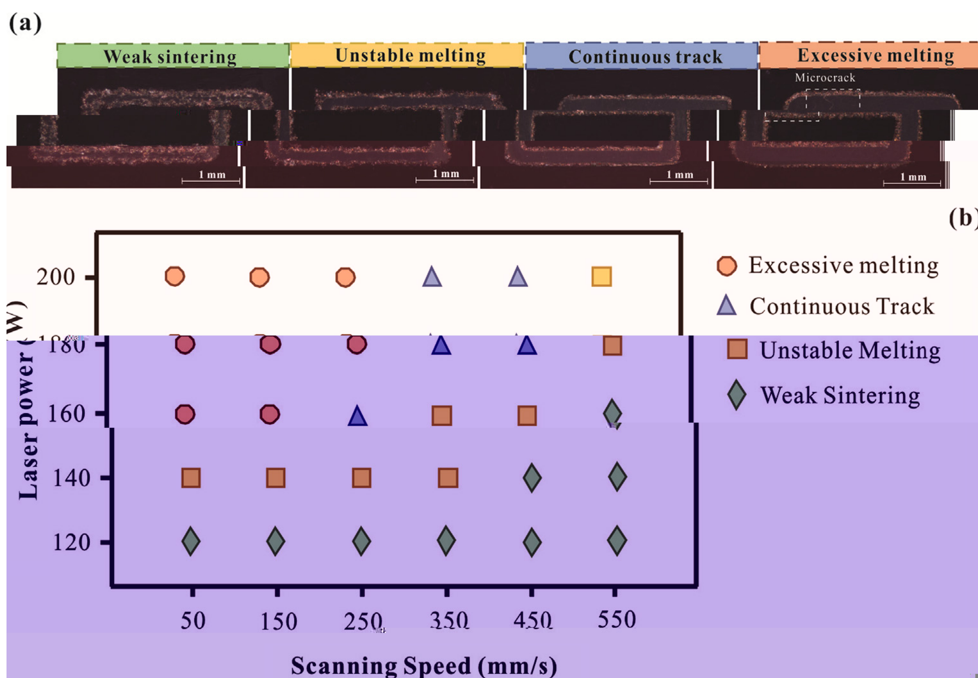

Fig. 2. ( ) T l s f s , s l x l , - s , ss l , s l ; ( ) ss f l s s s . (F - f f s l s fi l , s f s f s l .)

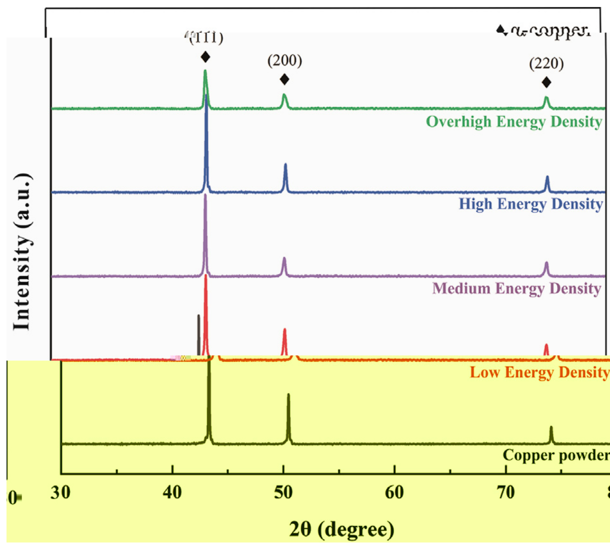

Fig. 3. RD ... s f ... s ... s- ... s. (F ... f ... f ... s ... s fi ... s f ... s f s .)

3.1.2. Formation of anisotropic microstructure under different volumetric energy density

T ... s α- ... RD ... s ... (1 1 1) ... (2 0 0) fl ... s ff ... 2θ = 43.32 ... 2θ = 50.45 , ... s ... (Fig. 3), ... (1 1 1) ... s ... . T ... s- ... s ... RD ... s ... ff ... fi ... SLM ... ss. I ... ff ... s f SLM s ... ff ... s, ... f ... s ss ... s- ... s ... [29]. T ... f ... s ... s ... f SLM ... f ... s s f s ... s ... . T ... s f f s

s ... : ( ) ... s, ( ) ... ( ) s ... s. A ... ss ... f 3000 J/ ... ^{3} (Fig. 4a), ... s s ... s 180 μ , s ... s ... f ... (Fig. 4d). T ... s ... s ... s ... M ... [30] s ... fl ... . T s s ... s ... ss ... fi ... s ... s ... . W ... f ... s ... 857 J/ ... ^{3}, s ... s ... f ... s ... s ... s ... s (Fig. 4b). U ... s ... s, ... s fi- ... 96.2% ... . H ... s ... s ... s- ... s s ... s. T ... s ... f s ... s ... f ... (398 W $^{-1}$ K^{-1}), s s ffi ... s ... s (Fig. 4c). G s ... s ... s f ... s s, f ... s f ... M- ... . B s s, ... s ... s ... s ... s ... s ... s s f ... f ... SLM ... ss [31]. I ... s , ... f 128 J/ ... ^{3}, ... s f- ... s ... ss ... s ... -s ... fis s ... s, ... f 88.6% f ... (Fig. 4d). T ... f ... s ... s SLM ss ... s ... s (Fig. 5). T ... s ... f ... s ... s ... f ... f ... . T ... s ... f s f ... f ... s ... s s , ... f ... s ... f ... s ... s [32]. T ... f ... s ... s fi s ... fl ... . S ... W ... [33], ... s ... , s ... f

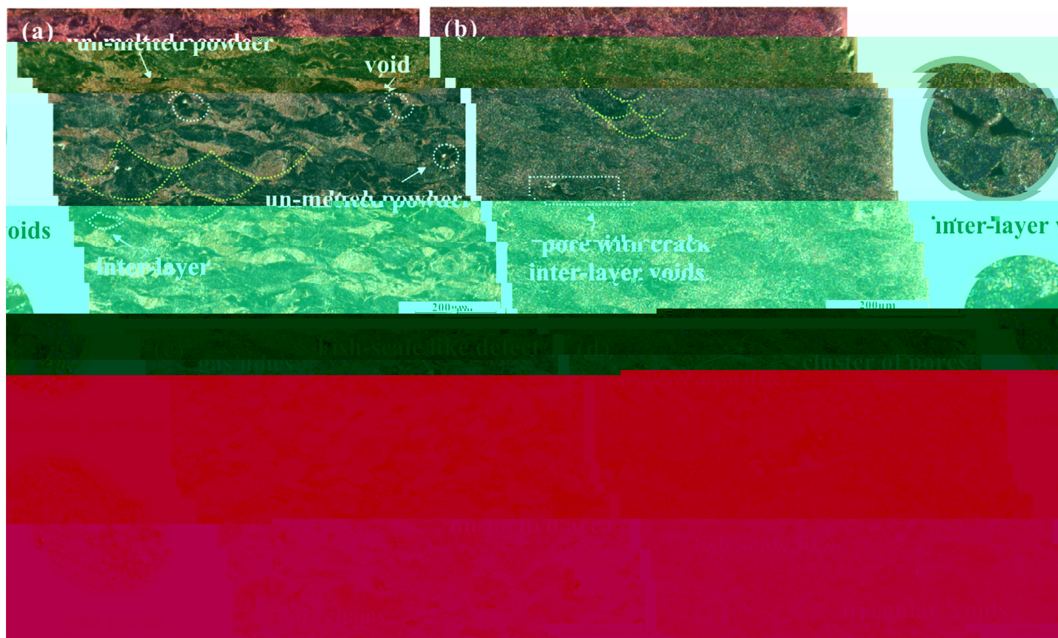

Fig. 4. O ... s f ... f s ... s f ... s ... : ( ) ... ss (3000 J/ ^{3}), ( ) (857 J/ ^{3}), ( ) (285 J/ ^{3}), ( ) (128 J/ ^{3}), s ... . (F ... f ... f ... s ... s fi ... , ... s f ... s f s .)

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

s f s s s .

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

F s s ff s ff s f s ss s s f f ff . G s *in-situ* CVD . As f s s s s f ff s f s, s f s s , s fi s f 39 . A s f , s s f 33 V , s f (25 V) 39 . Us s C N , L . 40 s f ss. H , s s sf s (. . sf 23 , -f sf s 41) CVD- f s s , fl s

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

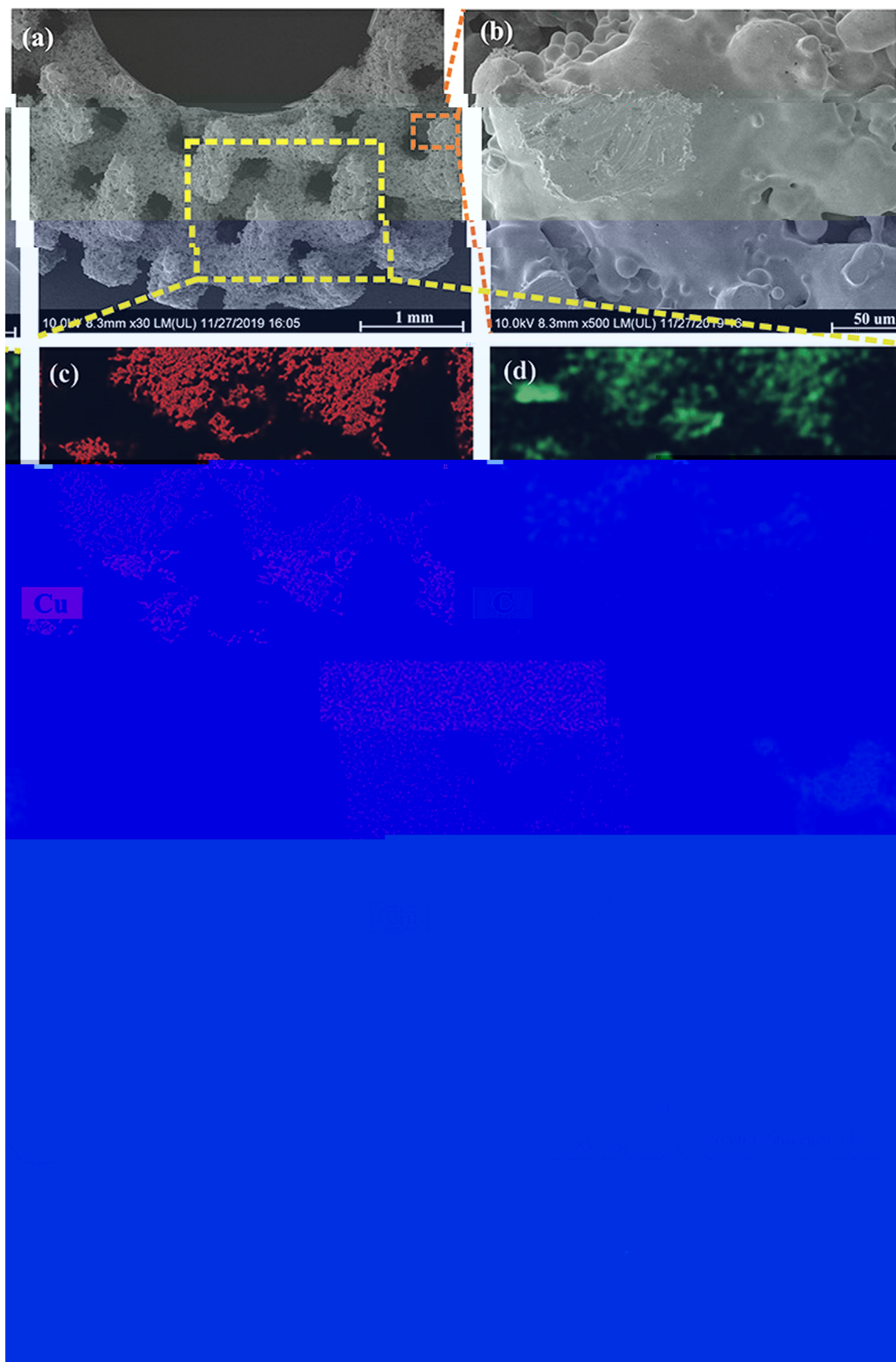

Fig. 8. (-) SEM s f 3DG/C s s ff fi s; EDS f ( ) C ( ) C; ( ) fi f SEM , s EDS f (f) C ( ) C; ( ) s f f f OM; ( ) R s f s ff ff s. (F f f s s fi , s f s f s .)

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

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

T ff s f s s s f C s s ff , 26.8% s f s 14.8% s

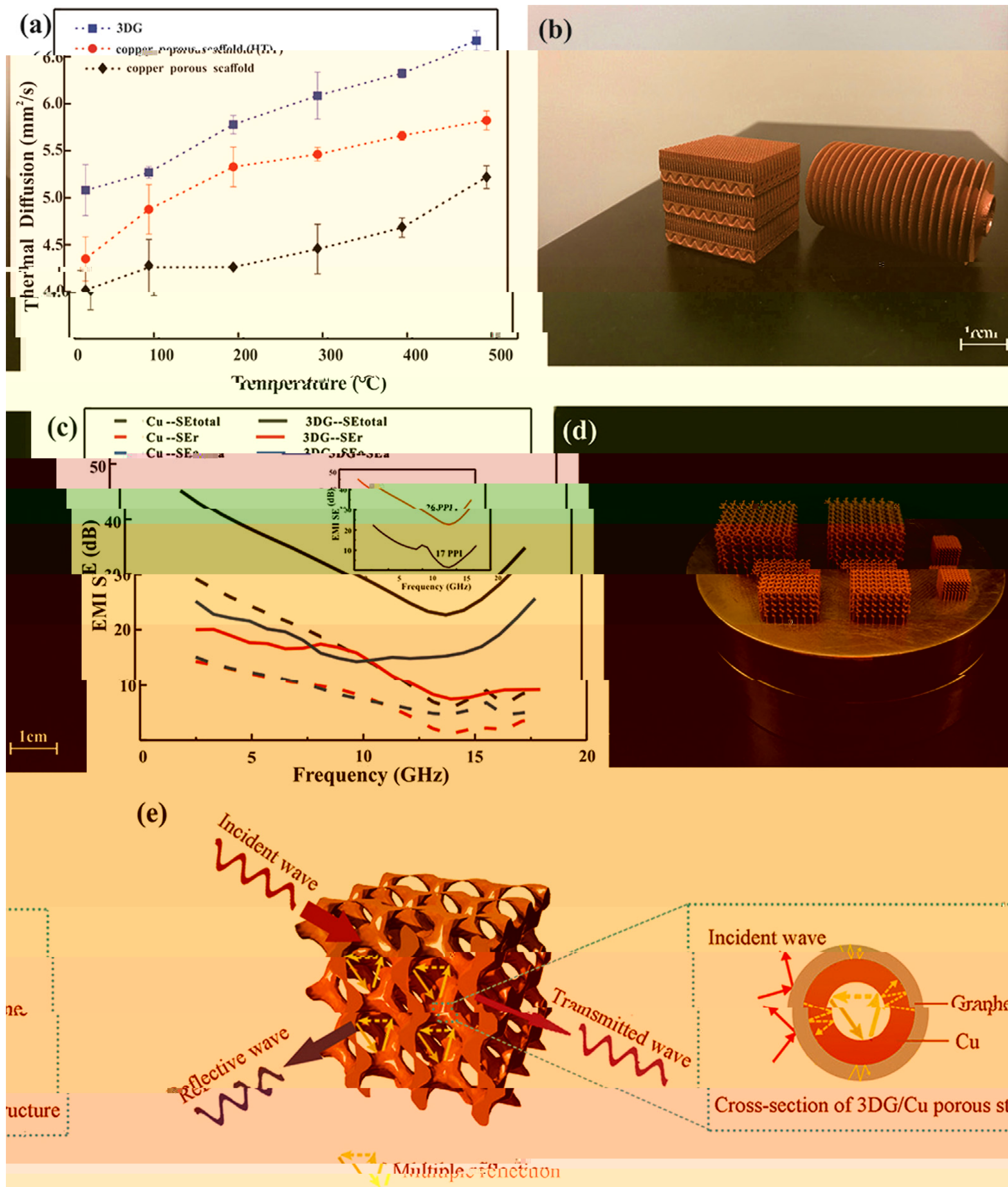

Fig. 9. P f f 3DG/C s s ff l : ( ) l ff s ; ( ) SLM -l ssfl x (-s l fl l) l - s f l ; ( ) EMI SE; ( ) C s ff l ff s ; ( ) S f 3DG/C EMI. (F f f s l s fi l , s f s f s l .)

Table 1
C s f f - s s ls s l s s EMI s l f l f - f l .

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

Note: l (l l)-PPMA, l s -PS.

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

s s s s s s fi s f
SE_r SE_a, s s s F . 9e. W s
s f f 3DG/C s s ff , s
s fl , -
s s s s ff . S -
s , s f 3DG/C s s -
s f f s f fl s s s f
s s s. T
EM s fi s
s EM s, s
f ss f SE_r. O
, s
s ff , s fi EM
s s ff , s s , EM -
s ss s s s s. T
f s ff s
J 54 . I s
fi s s
f f fl ff s. M ,
s f s f
s s , f s f s
s f s, f fl s s f
EM s s , s f ss f
EM s. T s f s
s f 44 . T s s ss s
s 3D s
s EM s s
s. I s , s f CVD f s s
R s s f f f s -
s s s S 3.3 s f s s s
ss s s ,
s f 55 . I s
EM s f s s, s
s s f ss. O ,
s s f 3DG/C s s
fl , s , s fi
s . T ss s s
s f s f s ff f s
sf .

4. Conclusions

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

Credit authorship contribution statement

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

Declaration of Competing Interest

T s l s fl f s
l f s .

Acknowledgement

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

Appendix A. Supplementary data

S l s l f l s://
. /10.1016/ s s .2020.105904.

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