Composites Part A 135 (2020) 105904

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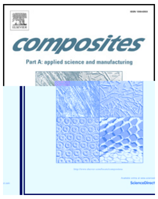

In-situ [illegible]

K[illegible] C[illegible], W[illegible], [illegible] Li[illegible]*, Li[illegible] H[illegible], C[illegible], [illegible] Li[illegible], [illegible] Li[illegible], [illegible] W[illegible], K[illegible] E[illegible], Li[illegible] L[illegible], X[illegible] G[illegible], T[illegible] P[illegible]

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Keywords:
[illegible]

ABSTRACT

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

1. Introduction

G[illegible] *sp*^{2} [illegible] (2630 [illegible]^2 [illegible]$^{-1}$) [1] [illegible] (2 [illegible] 10^5 [illegible]^2 V^{-1} [illegible]$^{-1}$) [illegible] (5000 W [illegible]$^{-1}$ K^{-1}) [2]. H[illegible] π-π [illegible] (2D) [illegible] [3]. A[illegible] (3DG) [illegible] (99.7%) [illegible] (0.6 [illegible]$^{-2}$) [4] [illegible]

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

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* C[illegible]: G[illegible], C[illegible] U[illegible] G[illegible], W[illegible] 430074, PR C[illegible].
E-mail address: [illegible]

[illegible]/10.1016/j.[illegible].2020.105904
R[illegible] 31 J[illegible] 2020; R[illegible] 1 A[illegible] 2020; A[illegible] 13 A[illegible] 2020

. .] s . T x ı s ı s (ı ., s ı ı ı -
s ı ı), ı ı ıfl ı ı fi ı] ı s ı ı
(ı .,] ı ı ı ss, f s) f ı ı 3DG. B s s, ı-
ı 3DG w]] ı ı ı ı ı s f ı]]
(ı ., ı s , ı s , s f]). H w], s f ı s
]] s ı ı ı ı ı] s ıffi]
ı s] ı] ı ı s , f ı s ı , ı] N f
ı ı]] ı s ı s ı] ı ı]] f ı ı
ı ı , s s ı] ı 3DG s w ı ı ı] f ı -
s ı ı ı s ı f ı s f ı s ıfi f ı ı ı] s ı [17,18] .
H ı , ı s f ı ss]]] s, w ı
ı s] ı] f ı ı ı s s ı 3DG w
ı] s ı ı s ı s] f ı ı s [19] .

S] ı] s ı] ı (SLM), s ı ı ı ı ı ı -
f ı (AM) ı] , s ı]] s ı f ı f ı ı ı
f s s ı / ı ı s x ı - ı ı s ı] (3D)]] s
w x ı s f] ı ı s ı , ffi ı ı ı ı ı
ı fl ı ı f *in-situ* f ı ı . T , ı ı s
ı s ı s ı ı SLM ı s s ı ı s f T]] s [20] ,
s ı] ss]] s [21] , ı N]] s [22] . C s s w] s f ı/
s s ı f ı] ı ı ı ı s s ı s - f - ı ı -
s ı ı ı s ı] ı s . C ı w N ı ı s s ı ,
ı s ı ı s s ı] s s ı f ı ı ı w ,
ı CVD] w ı ı s ı ı]] (< 0.001 . %) ı
ı w ı ss s f]-] ı ı f ı , w ı ı ı -
.] s ı]] ı ı w] ı ı ı s [23] . W ı N s
ı ı ı ı s] ı (> 0.1 . %) [17] , ı ı ı fi] s ı
f ı s f ss ı ı ı ı ı ı [24] . H w ı, ı -
s ı ı SLM f ı ı s s]] ı ı s ı f ı s f ı s ffi ı ı
ı f ı w s] ı ı f ı s ı ı s ı ı]
ı ı ı ı ı fl ı ı w ı s ı] s ı w] ı
(1000–1100 ı). F ı ı f ı s ı ı s ı s ff] s
ı SLM s s]] f ı ı]] ı s [25] .

T ı] ı ı ı s, w ı f ı fi s ı ı s
f s ı] - ı ı 3DG/ ı (3DG/C) s ı -
ı s ı SLM s] ı s] ı ı ı ı w ı CVD ı w f
ı ı . A w]]- s ı ı ı - ı s ı] w s
ı ı ı]] ı s ı ı SLM f ı ı ı s ı ı]] ı -

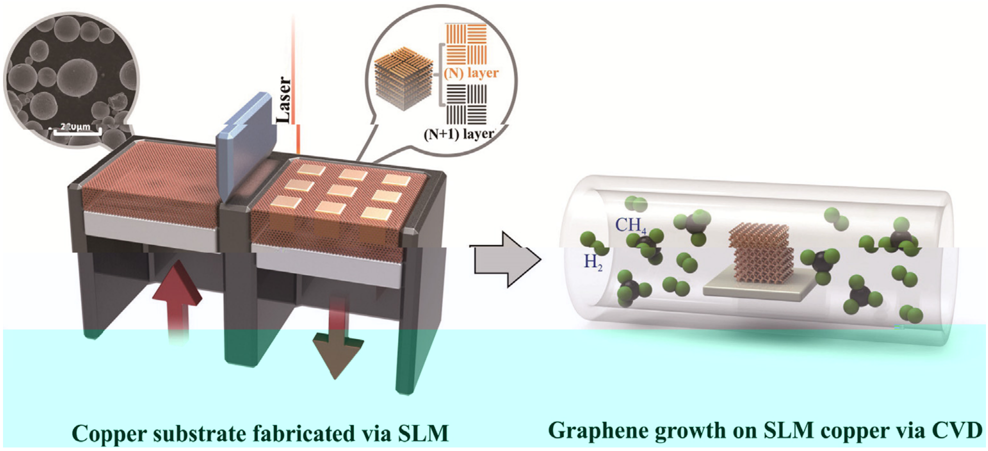

Fig. 1. Ill ... 3DG/C ... ss: ... ff ... SLM (...) ... *in-situ* ... ff ... CVD (...). (F ... fi ... , ...)

ASTMB193-2002 ... 2 ... 2 ... 20 mm^3 ... . T ... iff ... (2 ... 10 ... 10 mm^3) ... (5 ... 10 ... 10 mm^3) ... ASTME1461-2013 ... LFA (L ... fl ... , N ... LFA457, G ...). R ... (SENTERRA, B ... x, G ...) ... 3DG/C ... ff ... 514 nm. T ... *S* ... (*S11* ... *S21*) ... (VNA, A ... PNA-N5244A, US) ... 2–18 GHz. 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 ... (...) ... . Diff ... s f s ... (Fig. 2) ... , ... 30% ... (A), 26.7% ... (B), 16.7% ... (C) ... 26.7% ... (D). Diff ... , LED (J/m) [27] (E . 6, ... SI). T ... fl ... . T ... ss ... iffi ... . In ... A, ... iffi ... ffi ... . In ... B, ... fi ... . T ... fl ... ffi ... , ... LED ... 400 J/m (... C). W ... LED (> 800 J/m) ... , ... 130 μm ... (... D), ... [28].

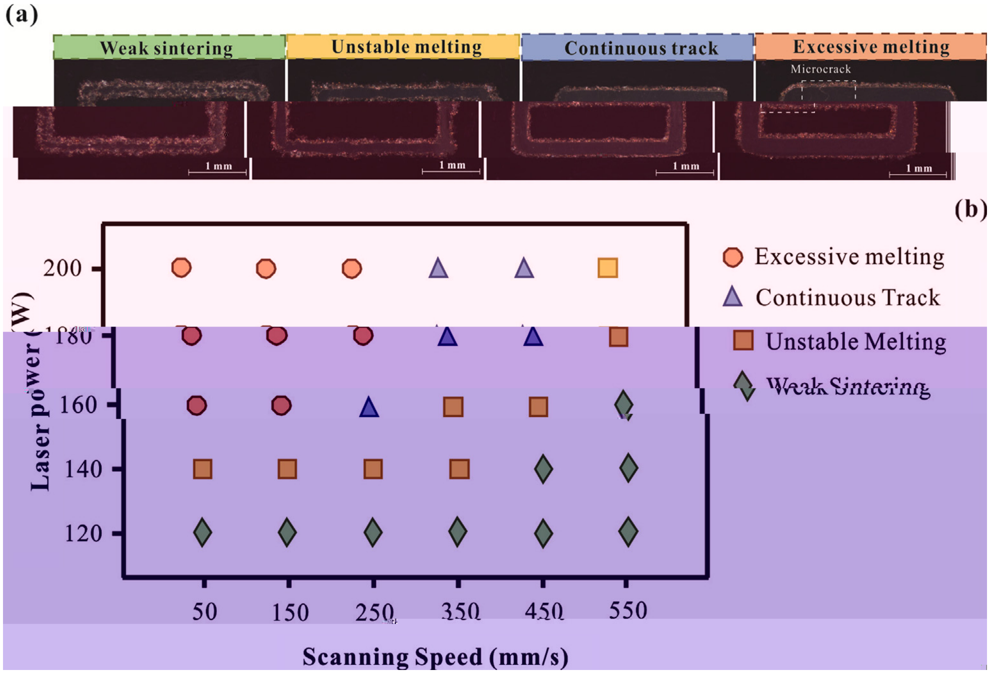

Fig. 2. ( ) T ... , ... , ... ; ( ) ... . (F ... fi ... , ...)

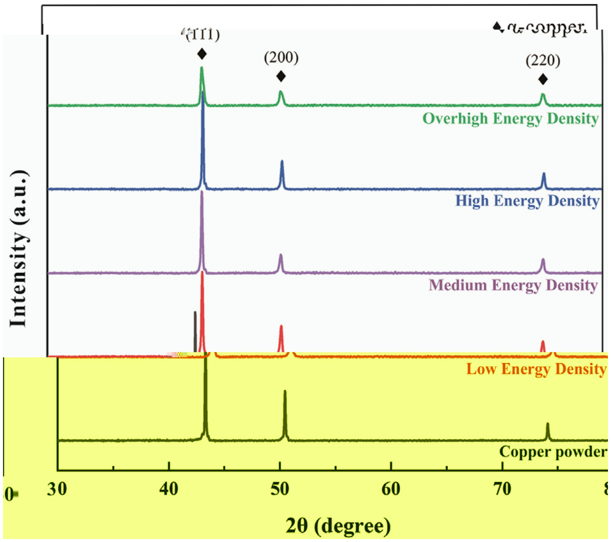

Fig. 3. XRD [illegible] (F[illegible] [illegible].)

3.1.2. Formation of anisotropic microstructure under different volumetric energy density

T[illegible] α- [illegible] XRD [illegible] (1 1 1) [illegible] (2 0 0) [illegible] 2θ = 43.32 [illegible] 2θ = 50.45 , [illegible] (Fig. 3), [illegible] (1 1 1) [illegible]. T[illegible] XRD [illegible] SLM [illegible]. I[illegible] SLM [illegible] [29].

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

T[illegible] SLM [illegible] (Fig. 5). T[illegible]. T[illegible] [32]. T[illegible]. S[illegible] W[illegible] [33], [illegible]

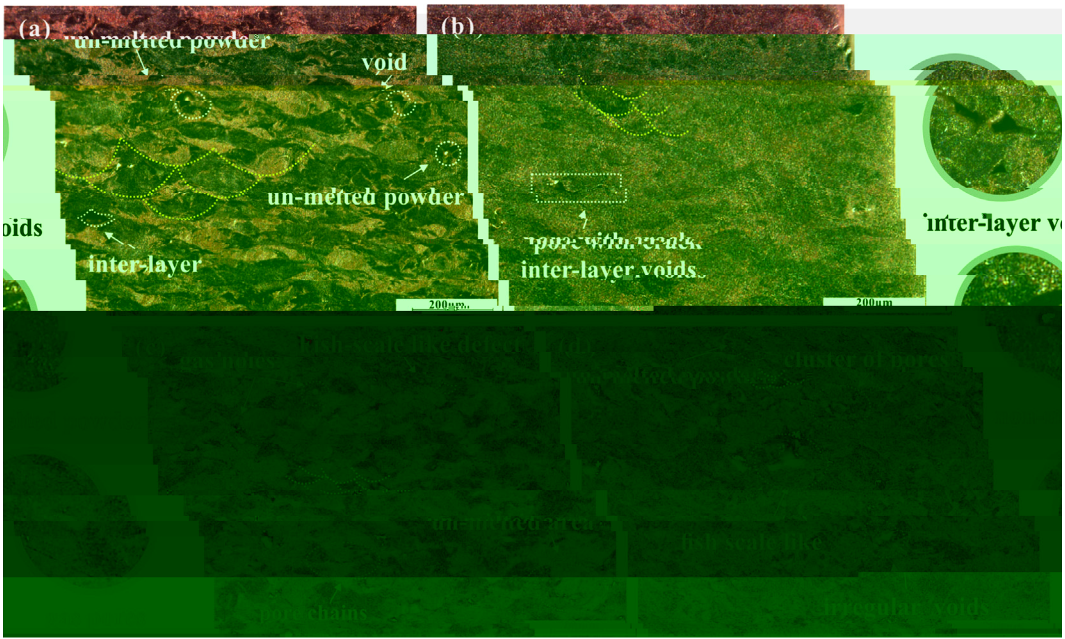

Fig. 4. O[illegible] (3000 J/mm³), ( ) [illegible] (857 J/mm³), ( ) [illegible] (285 J/mm³), ( ) [illegible] (128 J/mm³), [illegible]. (F[illegible].)

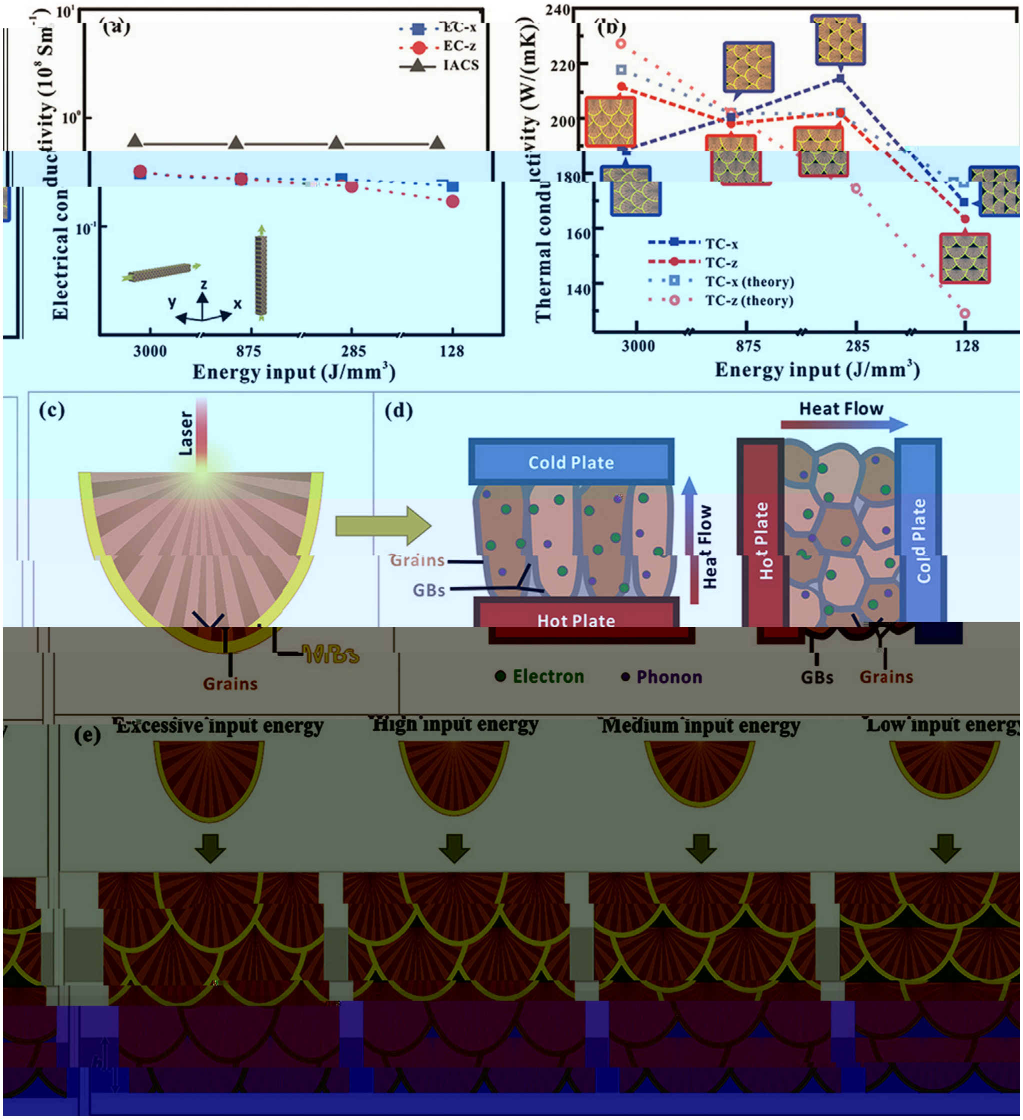

Fig. 7. ( ) El[illegible] ( ) [illegible] ; ( ) [illegible] ; ( ) [illegible] ; ( ) [illegible] . (E[illegible]). (F[illegible] fi[illegible] .)

[illegible].

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

F[illegible] *in-situ* [illegible] CVD [illegible]. A[illegible] [illegible] fil[illegible] 39 . A [illegible] 33 V [illegible] (25 V [illegible]) 39 . U[illegible] C [illegible] Ni, Li [illegible]. 40 [illegible] H [illegible] 23 , [illegible] 41) [illegible] CVD- [illegible] fl[illegible]

[illegible]. A [illegible] SEM, [illegible]. T SEM [illegible] 3DG/C [illegible] 450 μm (Fig. 8a). A [illegible] (Fig. 8b), [illegible] fl[illegible]. T [illegible], EDS [illegible] (Fig. 8c-d), [illegible]. A [illegible] fl[illegible] (Fig. 8e-g). T [illegible] 3DG/C [illegible] (Fig. 8h).

R[illegible] 3DG/C [illegible]. T [illegible] G- [illegible] (~1590 cm^{-1}) [illegible] 2D- [illegible] (2699 cm^{-1}) [illegible] 42 (Fig. 8i). S[illegible] D- [illegible] (~1350 cm^{-1}) [illegible] fl[illegible] 43 , [illegible] D [illegible] G [illegible] (I_D/I_G) [illegible]

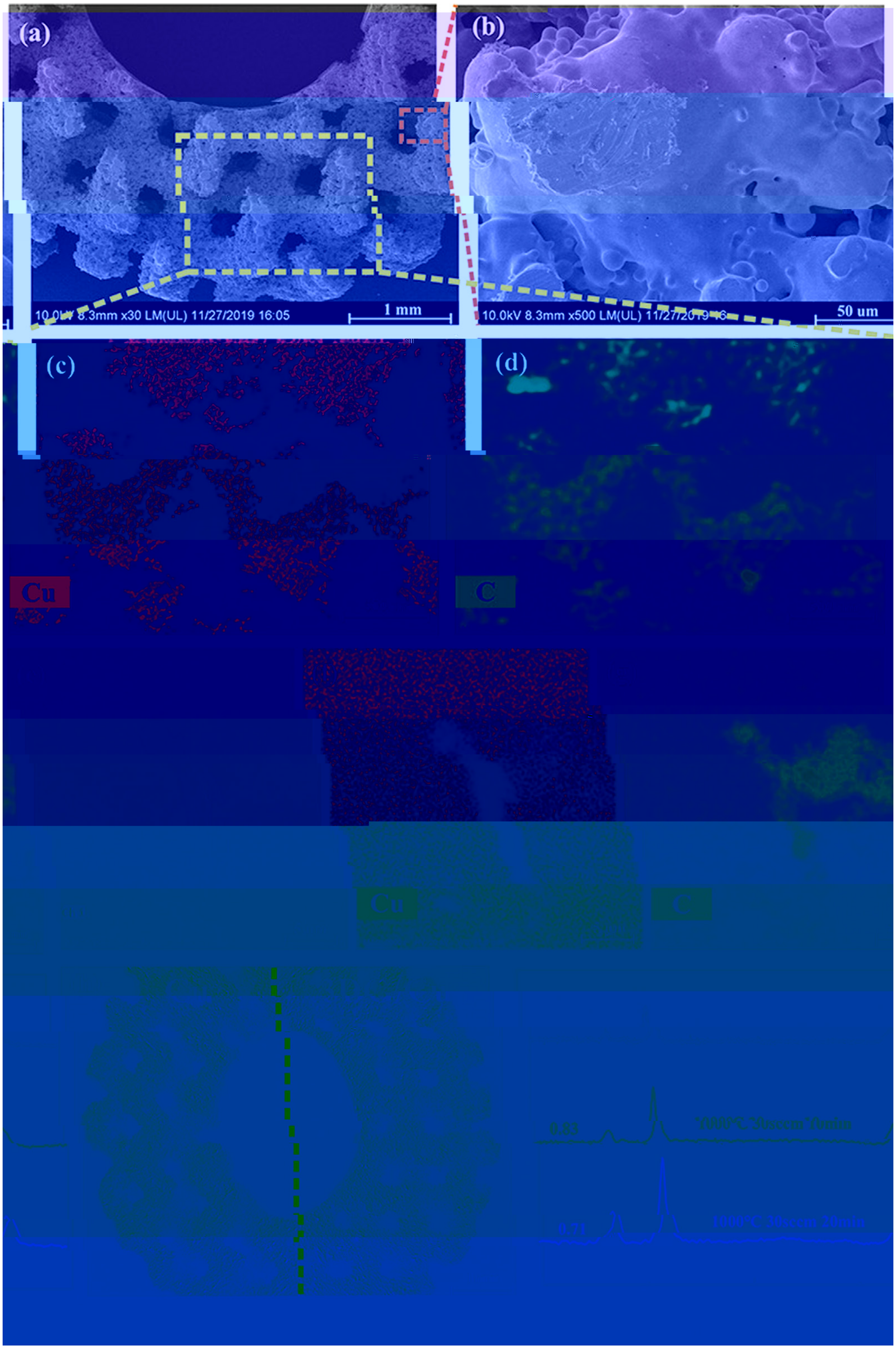

Fig. 8. (-) SEM [illegible] 3DG/C[illegible] ff[illegible] iff[illegible] [illegible]; EDS [illegible] ( ) C [illegible] ( ) C; ( ) [illegible] SEM [illegible], [illegible] EDS [illegible] ( ) C [illegible] ( ) C; ( ) [illegible] OM; (i) R [illegible] ff[illegible] iff[illegible]. (F[illegible].)

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

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

T[illegible] iff[illegible] C[illegible] ff[illegible], [illegible] 26.8% [illegible] 14.8% [illegible]

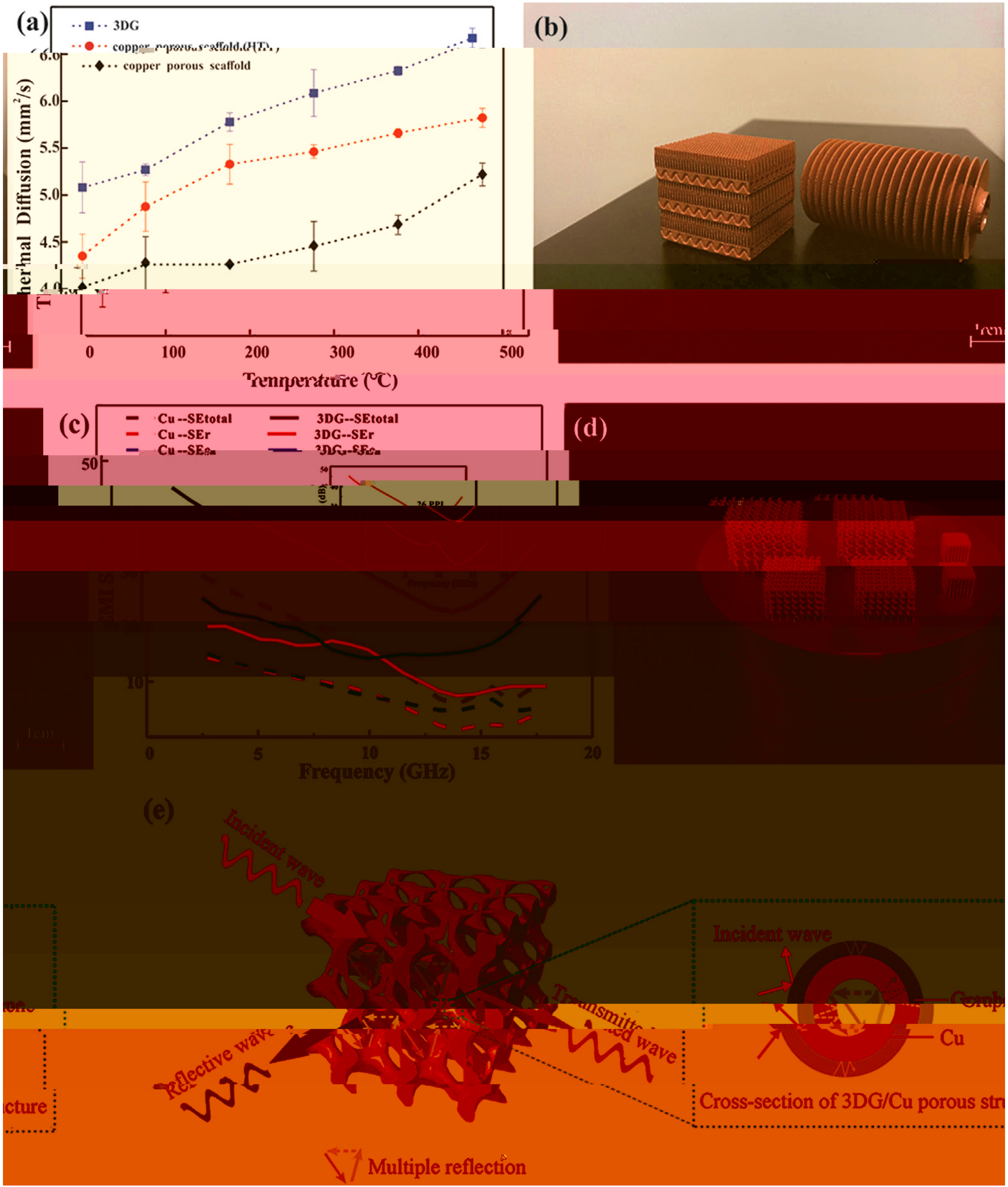

Fig. 9. P[illegible] 3DG/C[illegible]: ( ) [illegible]; ( ) SLM [illegible]; ( ) EMI SE; ( ) C[illegible]; ( ) S[illegible] 3DG/C[illegible] EMI. (F[illegible].)

Table 1

C[illegible] EMI [illegible].

Coating materials	Substrate	Method	Maximum shielding efficiency (dB)	Improvement of thermal property (%)	Ref
[illegible]	[illegible]	[illegible]	37	–	50
[illegible]	PS	[illegible]	29.3	–	56
[illegible]	PMMA	[illegible]	19	–	57
[illegible]	[illegible]	[illegible]	–	8.5	58
[illegible]	[illegible]	[illegible] + CVD	–	554	59
[illegible]	[illegible]	[illegible]	20	–	60
[illegible]	[illegible]	[illegible] + CVD	–	2.4	61
[illegible]	[illegible]	[illegible]	47	6.3	62
[illegible]	[illegible]	CVD + SLM	47.8	27	[illegible]

Note: [illegible])-PPMA, [illegible]-PS.

HT [illegible] *in-situ* [illegible] (Fig. 9a). [illegible] 3DG/C [illegible] HT [illegible] 1–2 [illegible] SLM [illegible] 500 μm) [illegible] (Fig. 9b), [illegible] (Table 1). [illegible] Ni [illegible]

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

[illegible] EMI [illegible] (SE_r), [illegible] (SE_a) [illegible] (EM) [illegible] [47], [illegible] [48]. [illegible] [49] [illegible] [50]. [illegible] EMI [illegible] [51]. [illegible] [52] [illegible] SiO_2 [53]. [illegible] 3DG/C [illegible] SE_r [illegible] SE_a, [illegible] Fig. 9e. [illegible] 3DG/C [illegible] 3DG/C [illegible] EM [illegible] EM [illegible] SE_r. [illegible] EM [illegible] EM [illegible] [54]. [illegible] EM [illegible] EM [illegible] [44]. [illegible] 3D [illegible] EM [illegible] CVD [illegible] Section 3.3 [illegible] [55]. [illegible] EM [illegible] 3DG/C [illegible]

4. Conclusions

A [illegible] 3DG/C [illegible] *in-situ* [illegible] CVD [illegible] 3DG/C [illegible] EMI *SE* [illegible] 15.9 ([illegible]) [illegible] 32.3 dB, [illegible] 47.8 dB (88.2% [illegible]), [illegible] 26.8% [illegible] 3DG/C [illegible] EMI [illegible] 3DG/C [illegible] EMI [illegible]

Credit authorship contribution statement

Kaka Cheng: [illegible] **Wei Xiong:** [illegible] **Yan Li:** [illegible] **Liang Hao:** [illegible] **Chunze Yan:** [illegible] **Zhaoqing Li:** [illegible] **Zhufeng Liu:** [illegible] **Yushen Wang:** [illegible] **Khamis Essa:** [illegible] **Li Lee:** [illegible] **Xin Gong:** [illegible] **Ton Peijs:** [illegible]

Declaration of Competing Interest

T … i … fli … f …

Acknowledgement

T … f … 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 … f … s:// … /10.1016/j. … .2020.105904.

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