Composites Part A 135 (2020) 105904

C t ts lists il l t S i Di t

C sit s P t A

journal homepage: www.elsevier.com/locate/compositesa

In-situ sitie f t - i sie l s l ti l s lt s ffel s f i f li tie s

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A R T I C L E I N F O

Keywords:
T - i sie l
C s s ffel
S l ti l s lti
C i l sitie
El t ti i t f s i l i

A B S T R A C T

C tly, t - i sie l (3DG) f i tie s st i t y t li t ss, st i t i l tie s s ll s st t l y. H i ti ly s tte - st t y t t l - s t s l ti l s lti (SLM) t i t f t t - i sie l (3D) s t l t . G s t *in-situ* i i l sitie (CVD) t t i s C t l t , f i 3DG sit s. A i tie f tie l t i CVD t i it SLM f i t s ffel t l t s l t si l tie f 3DG f -st t (it ty , sity, t) t i -st t (t t , s f lity) t l t ly i l t s s ffel . T 3DG/ s ffel l i 88% 27% t i l t ti i t f (EMI) s i l i t l iff sie , s ti ly. P ti l ly, t i st EMI s i l i ffi- i y (*SE*) t 47.8 B t 2.7 GH i it *SE* f 32.3 B t t f 2–18 GH . T sy isti s i l i is s t f t i t i f t s f y i sit t i ls is it t f t SLM s st t .

1. Introduction

G , sisti f *sp*^{2} y i i t s, s i i l ity i t its t s f , s s i s f (2630 ^{2} $^{-1}$) [1], ll t i t i si i ility (2 10^5 ^{2} V^{-1} s^{-1}) s i t l ti ity (~5000 W $^{-1}$ K^{-1}) [2]. H , t st π-π i t tie t t i sie l (2D) si l -l y s t is t - tie , s s ff s f s i st ility s it t s t ll, s ll, i l , f l - l ss it is st i t s li s f [3]. Af tie f t s l t si ifi tly ff ti ti s t t ti l is s ti l - li tie s. C f ti it t s l s, t - i sie l - (3DG) s s tt is i i sity (~99.7%), l s ifi ity (~0.6 $^{-2}$) [4] i it i s ifi s f s s ll s l i ity, f st l t i tie ss t sf s i t t t f t - i sie l (2DG), t i li tie s i t lysis [5], y st [6,7], s s s [4], l t ti i t f (EMI) s i l i [8] s . V i s ty s f t s i 3DG tie l , i l i f yi [9], y t l tie [10], s lf- ss ly [11], - lly [12] s . H , t f - tie t s still f i s ll s. F l , f yi y t l tie s ff f t l l i s tie s f l y s [13]. S lf- ss ly t i s l ss ti (s l ys) i t i lysis ly ili tie [14]. D - lly t s s li it tie t lli t ty s titi s f s t t s l ti iss l tie f sitie [15]. M st s tie ly t st t si l st t t s tisfy t i t f f tie l si , il t l t - i t CVD t s s t is s ity, s ll s t t s f l - i - lity [16]. By t is t , t t is li , is s l l t f t t l s st t i ts s tie

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tt s:// i. /10.1016/j. sit s .2020.105904
R i 31 J y 2020; R i i is f 1 A il 2020; A t 13 A il 2020

t lyst. T i os o i t isti s (i. ., o ositio i o- st t), t t i i fl o t fi l i ost t (i. ., l y t i ss, f ts) of t 3DG. B si s, t - t 3DG ill i it t o o ti s f o t t l t l t (i. ., o osity, o si , s f lity). Ho , ost of t o o s t l t l t s y o tio l t o s iffi lty io sly l ti o osity, fo i st , t o i l Ni fo lly s t o osity y o ly o t oll fo i t o t t, t s s tly o t i 3DG s o s oo o t ol of o- s o i i os o i f t s fo s ifi f tio l si 17,18]. H , it is of ssity to lo t l t l t s, i is ly i l t f o o to i o s ts to i 3DG it t l st t s st l fo s 19].

S l ti l s lti (SLM), s i o ti iti - f t i (AM) t olo y, is ti l ly si fo t f i tio of so isti t /o is t - i sio l (3D) t l t l t s it t t s of o l ity i si , ffi i y i o tio fl i ility of *in-situ* f t i ility. To t , o s s s o t SLM o o s st t s of Ti lloys 20], st i l ss lloys 21], Ni lloys 22]. C is t ost i ly s foil/ s st t fo l - sy t si i st t -of-t - t - s i st i l s. Co it Ni o ot s st t , o is s o si l s st t fo o t i CVD to t lo o s t tio l l (< 0.001 t. %) o t o ss s lf-li iti of o , i t to t i - lity si l l y it l s 23]. W il Ni s i o sol ility (> 0.1 t. %) 17], t i fil s t to fo s of ssi o i it tio 24]. Ho , - s i SLM of o is still i its i f y s of i s ffi i t ti fo o s lti i f o its i t i si i t l o ti ity fl ti ity to s o o l s l t (1000–1100). F i tio of is o s o s ffol s i SLM is still f i y ll s 25].

To o o o li it tio s, fo t fi st ti o os f si l otto - o to o 3DG/ o (3DG/C) st - t s i SLM si lt o sly i o i tio it CVD o t of . A ll- si y oi -ty o o s o t l t s i iti lly i sti t i SLM f o i ost t l ol tio to - os o i fo , s i lly it s t to isot o y -1.3 45.13,o . lt 2()-37 o i ity /T1 (l s441(250.7(s it 288.5(ti)-290

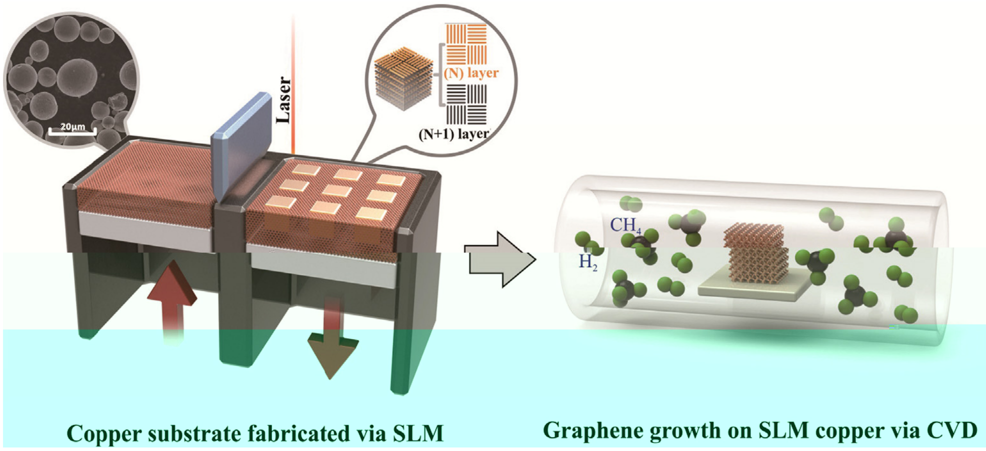

Fig. 1. Ill st ti f t 3DG/C s st t f i ti ss: s ff l f i t i SLM (l ft) *in-situ* t t s ff l i CVD (i t). (F i t t ti f t f s t l i t is fi l , t is f t t si f t is ti l .)

ASTMB193-2002 i ts it s l si f 2 2 20 ^{3} f t i t l ti l i t ti s. T t l iff si ity s t t i (2 10 10 ^{3}) s st t (5 10 10 ^{3}) f ll ASTME1461-2013 it s l si f t f ti t i t ti s si t LFA (L s fl s t , N t s LFA457, G y). R s t s y (SENTERRA, B , G y) s s t t i t 3DG/C s ff l it - it ti l t f 514 . T *S* t s (*S11* *S21*) s it t t ly (VNA, A il t PNA-N5244A, US) si t i l t i 2–18 GH . T l s f SE_{tot} l, *SE* s ti , *SE* fl ti t i s E . 2–5 i t S ti I f ti .

3. Results and discussion

3.1. Formation of SLM copper

3.1.1. SLM manufacturing of copper under different line energy densities

T st ff ti t s (l s s i s) li i ily i sti t i si l t i . Diff t ty s f si l t s s t ssi i l i i i t f isti is i s (Fi . 2) s t lti t s lity, i l i 30% si t i (A), 26.7% st l lti (B), 16.7% ti s t (C) 26.7% ssi lti (D). Diff t s s t i s li y sity, LED (J/) 27] (E . 6, l s f t SI). T s l t l s i ssi ti i ti t t ll s f i fl ti ity t l ti ity f . T l ss ti s t ls i i t t f i iffi lty it li it ss t s. I A, s i t s iffi lt f s t li y sity s i s ffi i t. I B, t l t f st l i t t s it l ts f lt sti i t t s f i t y fi i y. T lt fl f t lt l s st l it s ffi i t t f t ti i t t f l y s s lt, l ti ly s t t s t i it i i i t LED f 400 J/ (C). W ssi LED (> 800 J/) is li , ly 130 μ i t i - s ls (D), i s y i - si l st ss s s lti f t ss t l ti ss i t it t i s ll s l s i s 28].

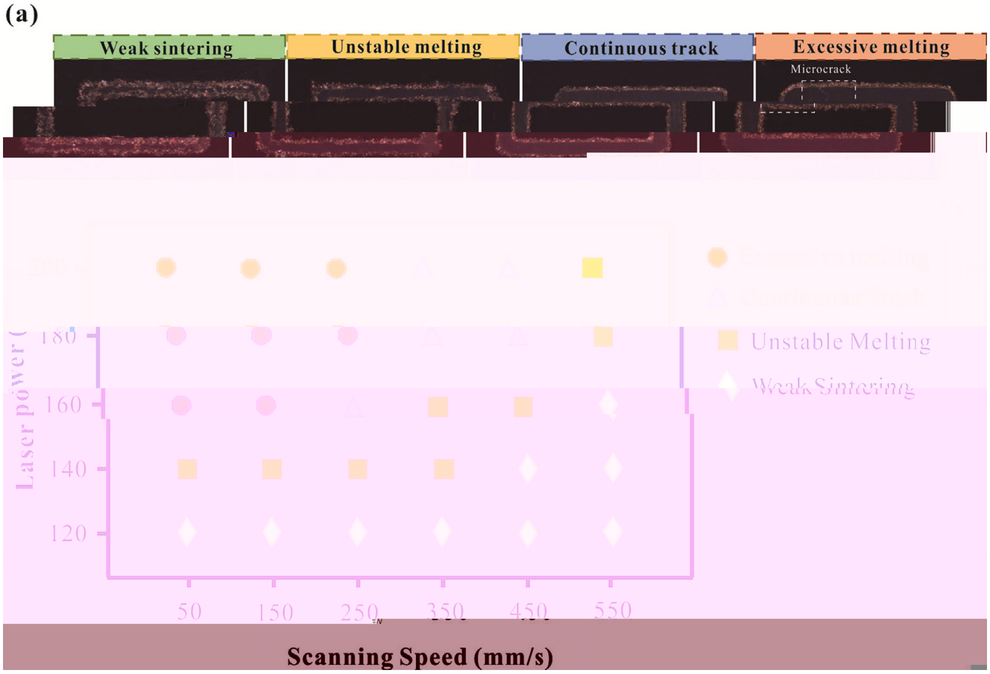

Fig. 2. ( ) Ty i l t ty s f si t i , st l lti , ti s t , ssi lti , s ti ly; ( ) ssi i f l s s i s . (F i t t ti f t f s t l i t is fi l , t is f t t si f t is ti l .)

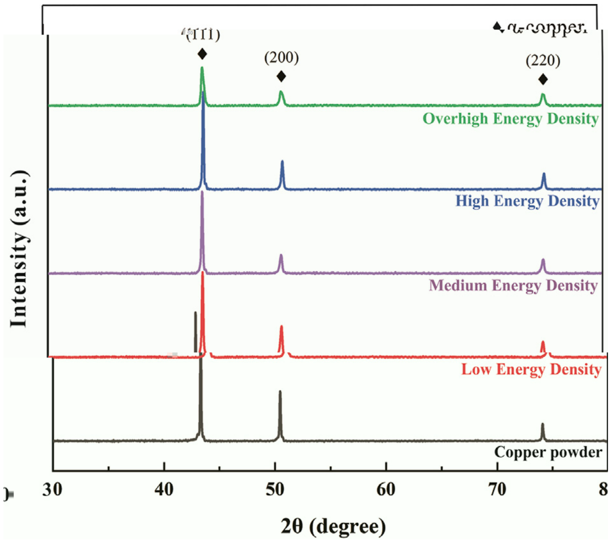

Fig. 3. RD tt s f t st ti s- ilt s i- s. (F i t t ti f t f s t l i t is fi l , t is f t t si f t is ti l .)

3.1.2. Formation of anisotropic microstructure under different volumetric energy density

T i s α- l l ly t i i ll RD tt s y t (1 1 1) (2 0 0) fl ti s iff t t 2θ = 43.32° 2θ = 50.45°, s ti ly (Fi . 3), t (1 1 1) i ti s ili . T s- ilt s i s s t si il RD tt s t t st ti t isti is i iff s i t f s i i li i fi t i t SLM ss. I iti , t iff ti s f SLM s l s s ift t i iff ti l s, i i ti t f si l st ss i t s- ilt s l s t t i li t 29].

T l y f t lt l s t i t - ti l s ti f t SLM t t ly f t is s f s l s it yi y i t. T i ty s f f ts s : (i) i t -l y i s, (ii) - lt , (iii) s s. At ssi i t y f 3000 J/ ³ (Fi . 4a), t lt l s s i s 180 μ , si ti s i t f t l y (Fi . 4d). T l t s tt s l s t t M i ti 30] si ti fl t ti ti i t lt l. T s s tt s l t i t -l y i l si s i i t s i ssi fi lly l i t i s i si t t. Wit t i t y f t si s ttli t 857 J/ ³, s ts it f i s s t i t lt l si i i is s i i t y t y ll s (Fi . 4b). U t s iti s, t t i i ly sifi- ti t 96.2% it t ll i l i . H , it si i t y y i t t ist , i l s - lt is s i t i i l y s. T t i t lt l t s itt f st t t s i t t i t l ti ity f (398 W ⁻¹ K⁻¹), t s i s ffi i t i t y s l t lt t t i ls t ly (Fi . 4c). G s l s l ls f i t is s , i f il t s f t lt l t y t M - i ti . B si s, t t t s s t t i t t i ls y ls l t s l s t i s y t s l ti sit s f f ti i t SLM ss 31]. I t st, t l i t y f 128 J/ ³, ts f - lt i l i s ss t l s l it -s ll fis s l -li i s, ti f 88.6% f t - l ti sity (Fi . 4d).

T l ti f i st t si t SLM ss s t st t l t s (Fi . 5). T ty i l it i l - l i s ll l t il i i ti f t - ti l s ti , i i ly tti t t t is t y f t i f t t t i t. T t t i t t t sli –li i i t f is f t t f t lt l t t tt i t t ti lly s t ti t t t s st t , i f ilit t s t t f l i - st t s 32]. T t ly i t l ti ity f i sli st t i t sifi s t t fl l t il i i- ti . Si il t t y W t l. 33], t ll t i t st t i t i t l l , s lti f

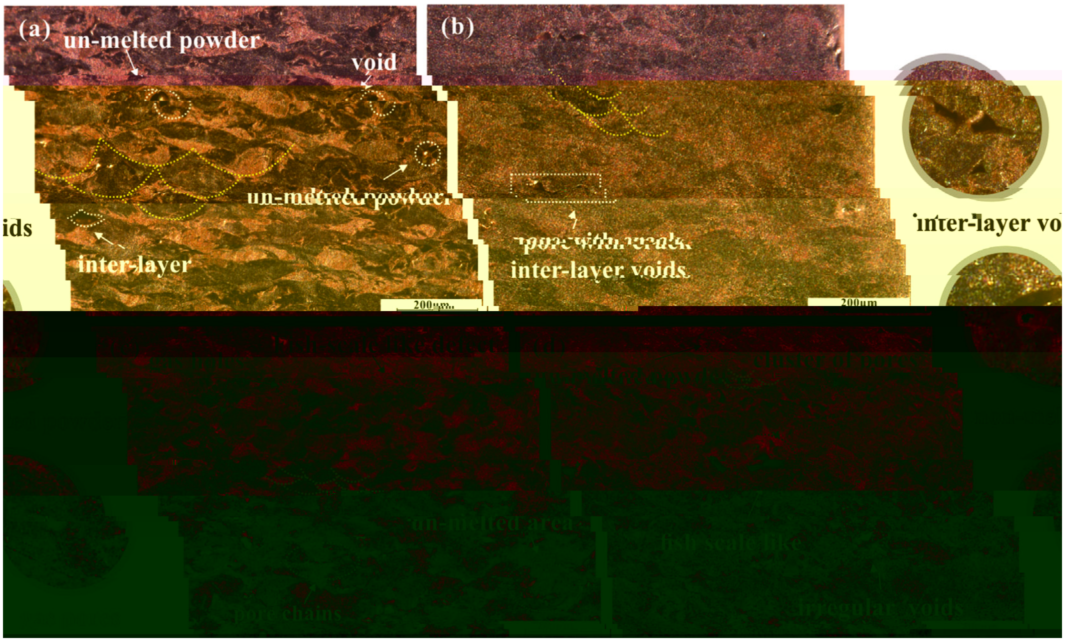

Fig. 4. O ti l i s f ty i l l y f s l s f i t y i s i t y i ti l i ti : ( ) ssi (3000 J/ ³), ( ) i (857 J/ ³), ( ) i (285 J/ ³), ( ) l y (128 J/ ³), s ti ly. (F i t t ti f t f s t l i t is fi l , t is f t t si f t is ti l .)

t i ti t t s i i t.

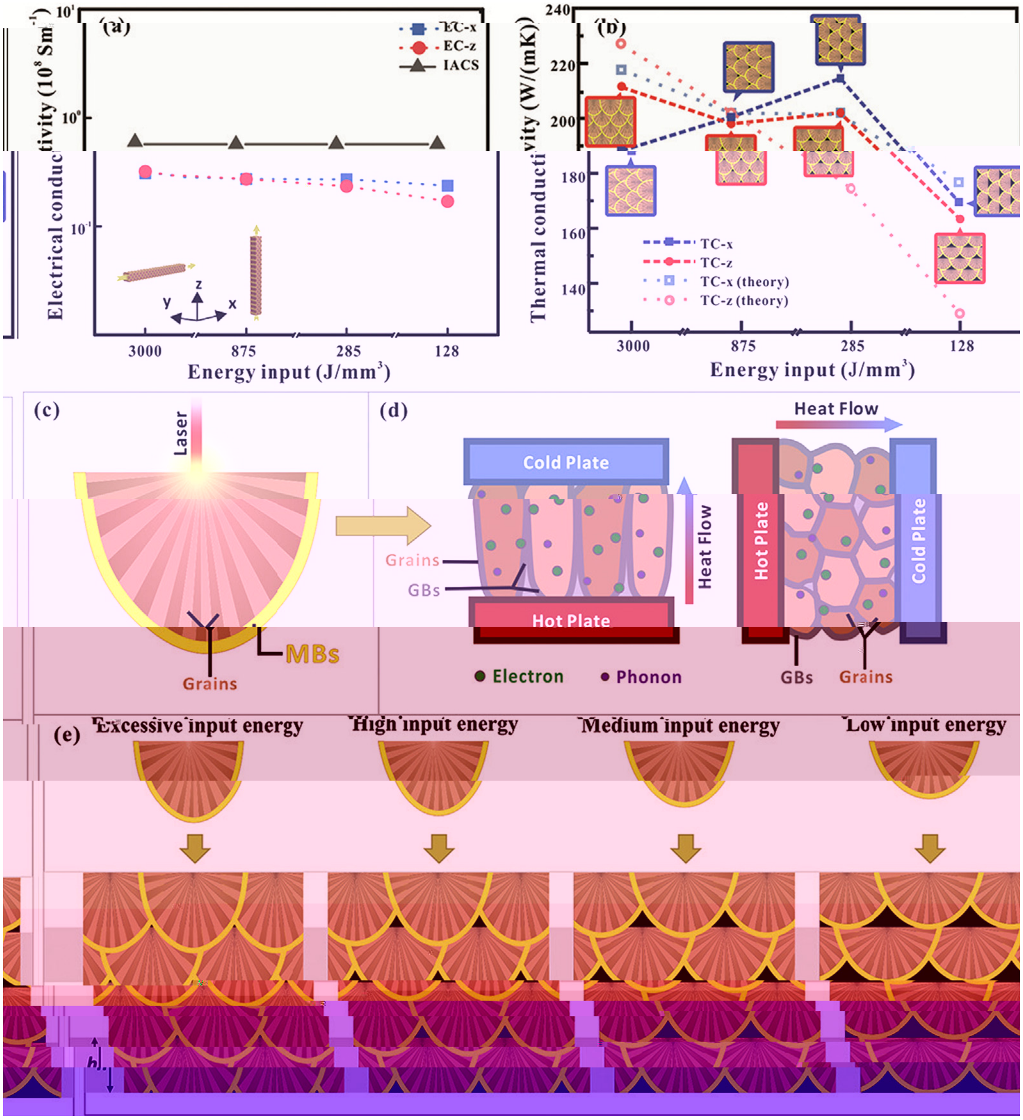

Fig. 7. ( ) El t i l ( ) t l ti ity f f ty s f i t y; ( ) s ti f lt l; ( ) s ti f t l ti ity s t; ( ) s ti f lt l f ti iff t i t y. (E s itt f tt i). (F i t t ti f t f s t l i t is fi l , t is f t t si f t is ti l .)

is y i f s l si i st t .

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

Fi s s ffl s it iff t sity f t si ti l ssi t s t l t is t y i f ti f ff ti ly. G s t *in-situ* t t l t i CVD t . As t t f t s st t i ly i l s s f iff si l ti f t s, yi s f s ti is , t i t ti t t lyst fil is l ti ly f l 39]. A i t sity f ti l t y, - s i it s st t t l i i y f 33 V t , si il t t i t l i i f - it (25 V t) 39]. Usi ist l li i t C Ni, Li t l. 40] st t t t t l- i f i t i ss. H , si l s i i l t sf t s (. . i t t sf t 23], ly -f t sf t s 41]) l t t CVD- f t s st t , - fl ti t t t s i t ti t t

t l. A t lly, t i t i sti t t i t f f t l s st t si SEM, i t ss-s ti - l y t t t l f i t ti f . T SEM i - st t f t 3DG/C s s ffl l - t ll i l i f it st t i t f i t ly 450 μ (Fi . 8a). A i t i ifi ti i s f t l y (Fi . 8b), fl s i s t f i f t s ffl , s i lly i t f t i . T - st t t ist i ti f t s ffl s st t , EDS i i i t t s ssf l t f t ll l t l t it ly if ist i ti (Fi . 8c-d), i fi t t ti l f t j st t i s st t f i - ti . A fl s ti l ly t t t i ifi ti (Fi . 8e-g). T t i 3DG/C s y i s ffl s - l ti ly l st it t iti l t t (Fi . 8h).

R s t s y s f t f t 3DG/C t - t i iti l st t l i f ti . T ty i l G- (~ 1590 $^{-1}$) s ll s t 2D- (~2699 $^{-1}$) s st t i ss ist i ti t f l y s 42] (Fi . 8i). Si t D- (~1350 $^{-1}$) fl ts t is l l i - 43], t i t sity ti f D t G s (I_D/I_G) s i t

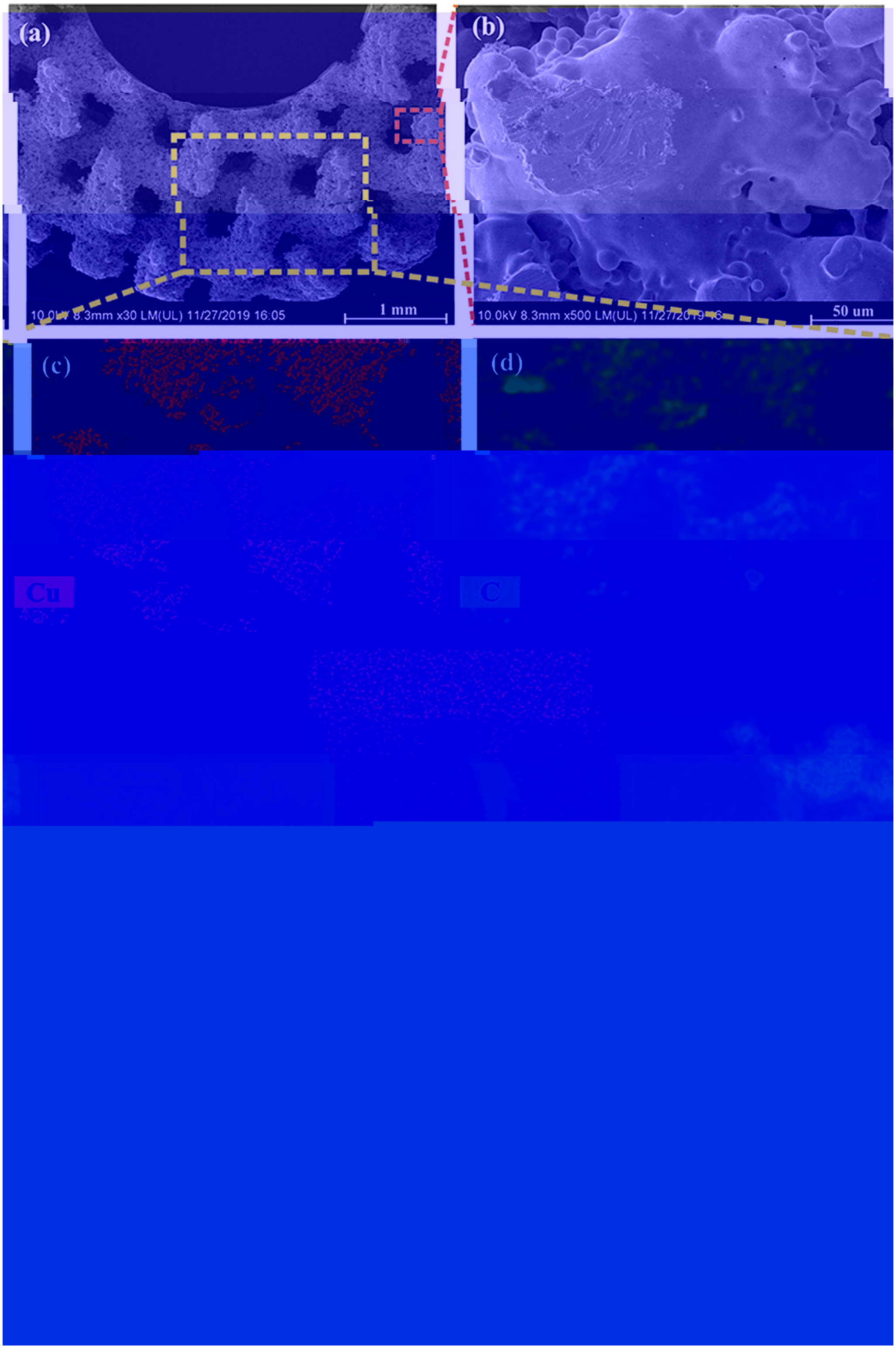

Fig. 8. (-) SEM i s of 3DG/C o o s s ffol iff t ifi tio s; EDS i i of ( ) C ( ) C; ( ) lo l ifi tio of SEM i , o s o i EDS i i of (f) C ( ) C; ( ) o iso fo ft o t of OM; (i) R s t of o o s ffol iff t o t o itio s. (Fo i t t tio of t f s to olo i t is fi l , t is f to t sio of t is ti l .)

l t sity of f ts. Wit s o t o t ti s o lo flo t s, t l of I_D/I_G i s fo 0.71 to 0.93, i i t i- s of f ts i ly tt i t to tot lly iso i f t st t s. As o s , o ti l o t o itio (o t t t of 1000 °C, flo t of CH_4 i 30 s , o t ti of 20 i) s s fo t 3DG/C o o s st t .

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

T l iff sio fo s st ti lly i s o t itio of o t C o o s s ffol , to 26.8% i s o to t i iti l o f s l 14.8% i s

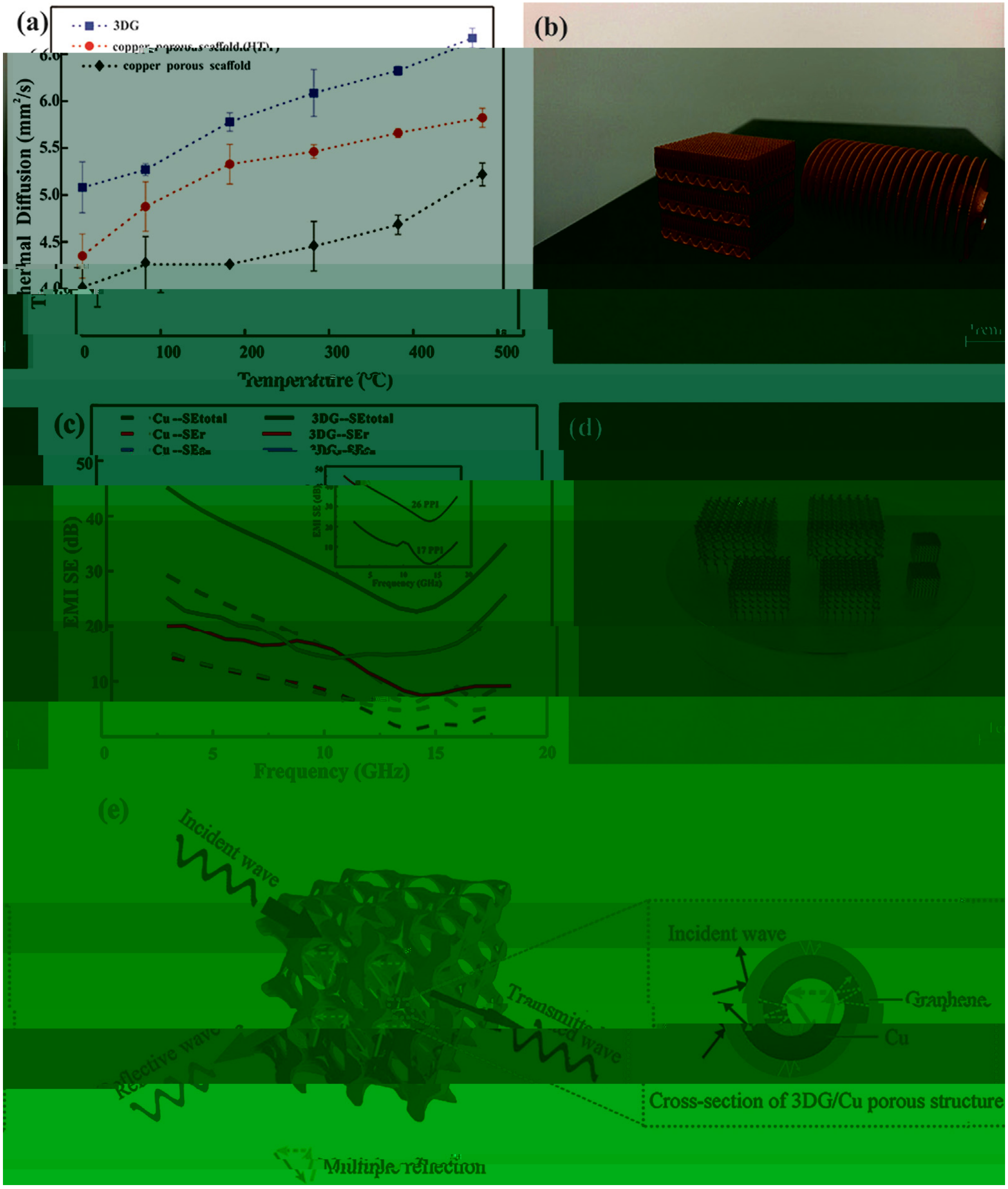

Fig. 9. P fo of 3DG/C o o s s ffol : ( ) t l iff sio ; ( ) SLM o i -li i ossflo t (it i o -s l i i ofl i l) l t -t st t fo t l t; ( ) EMI SE; ( ) Co s ffol it iff t o osity; ( ) S ti of 3DG/C o EMI. (Fo i t t tio of t f s to olo i t is fi l , t is f to t sio of t is ti l .)

Table 1
Co iso of t t of - s o o s t i ls it si il o ositio o st t o EMI s i l i fo t l fo i - o t fo lit t .

Coating materials	Substrate	Method	Maximum shielding efficiency (dB)	Improvement of thermal property (%)	Ref
G o ls	G it t t	I sio + f i + l + i l t o s	37	–	50]
G	PS	Hi - ss o ssio ol i + s lt-l i	29.3	–	56]
G	PMMA	Sol tio l i + lt o o i + t fo i	19	–	57]
C /G /C	Al	S f o ifi tio + l t o i l l ti	–	8.5	58]
G	Ni	Fo i + CVD	–	554	59]
G	C -Ni	El t ol ss l ti + l t o o ti ositio	20	–	60]
G	C	Po si t i + CVD	–	2.4	61]
G o ls	C	F - yi + t l li	47	6.3	62]
G	C	CVD + SLM	47.8	27	T is o

Note: oly (t yl t yl t)-PPMA, olysty -PS.

to t HT o s l s t s t t st *in-situ* o t (Fi . 9a). Si t s i l o - to -t i l st - t of t i s fo o o t s o t, t i - t tio of t 3DG/C o o s s ffol oss ss s o - t . It is lso o t oti t t t HT o s l lso o t i is i t l fo to i si o t y 1–2 o s of it i t t t t. I t is s , i s i si s i o y s tt i i st i ts t f t y of t i , t s i o i t t t sf . Wit s t to t oo t l fo , so isti t SLM o i –li i ossflo t (it i i ofl i l i t l ss t 500 µ) l t -t st t s s ssf lly f i t (Fi . 9b), f t o st ti its ot ti l fo li tio i o l t s it t s of i i i li tio ost ti -s i . Gi t t l o ty is los to t t - i ls o ositio s, t st t of s l , f t i o ss, t fo o o iso o t t l o ty i - o t fo ft o ti o t t l s st t (T l 1). It o l o l t t t is o s t f l s lt o it si il s s. Ot t ly i - t i ly s lt f o t lt lo t l o ti ity s , li Ni o ly .

To o st t t ot ti l of t 3DG/C o o s s ffol fo EMI, t EMI *SE*, i t i s t ility to tt t t l t o ti (EM) i tio , s i sti t o t f y of 2–18 GH (Fi . 9c), i iti sli t f y o t f y . Wit *in-situ* o o o o o s s ffol , t *SE* i s f o 15.9 to 32.3 B, it l of 47.8 B (88.2% i s), f s ssi t o - i lly i l l fo li tio of ~20 B. T l t i l t l o ti s of 3DG/C o fi oo i t f t t s st t . Ji K t l. 44] o t t EMI of t o osit s i s it i si o sity. T EMI *SE* i o t 133% i o t it i s o osity sity (i. ., s ll t s) f o 20 to 110 PPI (o s i). R j K s o 45] lso it t is oi t y i os to t o osity of o fo i o to o ti i t EMI fo . W fo si il s lt y i si o osity sity f o 17 to 26 PPI (Fi . 9c insert) o t i 105% EMI *SE*. I ot o s, t EMI s i l i o ti s j st y s ffol o osity it t i of li t i t si f o SLM. T 3DG/C o o s st t i 26 PPI i it EMI *SE* of 32.3 B, o s o i to 99.9% lo i of t EMI s. T s l l of s i l i i fo s i si 60 t i fo (30 ti s t i t o t s ffol) 46]. T EMI s i l i fo s of 3DG/C it si il - s t - i ls lso list i T l s 1. It o l o l t t t EMI *SE* of t 3DG/C i o o is o l o i t t os of ot 3D - s o osit s, o i i l ti ly o isi li tio ot ti l.

T i is s of EMI o sist of fl tio (SE_r), so tio (SE_a) lti l fl tio s of l t o ti (EM) s 47], i i ly o it o il i s, l t i o ti i ol s, i t f s of s i l i t i ls, s ti ly 48]. R s s 49] fo t t t l li o it i l t i l o ti ity, i ly l ys ol i fl ti l t o ti s, i is tt i t to t i t tio it f l t o s o ol s. T is t to s o so tio o i t EM loss s lt f o t i t tio of t l t o ti fi l l t i i ol s 50]. R t s s o EMI o ti lly i s . T ost o o ly s t o is to fo t -i- sio l o ti t o it i o o - o ti t i y i it t l fill s, s s C 51]. Fo i t of tt so tio - o i t s i l i fo , s - lly i o o t i to o y 52] o SiO_2 53]. W fo t t t is 3DG/C o o s s ffol s o o tst i fo to t sy isti s i l i is s it si ifi t i s fo ot SE_r SE_a, s s ti lly s o i Fi . 9e. W t i o s i i t o t s f of t 3DG/C o o s s ffol , so s i i t ly fl t i to t i o t, il t - i i s t t i si t o o s s ffol . Si lt - o sly, t il y st t of t 3DG/C o osit s o i i - s of i t f s fo fl tio s so tio s of i o s o i to t i is t t l y s. T i i i EM s fi stly o t t l y it t i st i o ility i t tio it t EM s, s lti i t of t o i loss o ti fo t SE_r. O t ot , t iti ll i t t is t i t i o s ffol , i s tly fi i l to t EM so tio i to t s ffol , s s lt, tt t EM - i s y y issi tio o y o s i s o s s. T fo tio i t si t l iff sio i l to o t i o y i to Jo l ti 54]. It is o t to ot t t t fil o tly l s t i o s to t t t t lli l y lo it i lly fo f t fl tio ff ts. Mo o , t l s f o osity of t i t o t to o t y oi ll l s st t , o of t i l io i i i ls f s it s f s, f ilit t lti l fl tio s s tt i of EM s i si t i l, t s f t o oti t issi tio of EM s. T s tt i of t i i t s i lly it o t s f 44]. T is s ssi s tt i io i ll i tio s it i t 3D i t o t s l to i ly t i tio i t sity ti l ost EM s so y t t i ls. I t sti ly, t isti of CVD f ts s l y R s t os o y t fo tio of i f t s - st t s s l i S tio 3.3 lso f tio s s tt i t s o t i ti to t loss s s y i l t i l tio , t y li i i s i l i fo 55]. It is li t t t EM s ill t y t f t st t s, i t s s tt i t s to f ilit t ol i tio loss. O t ol , t o o s st t of t 3DG/C o osit s tt t t i tio y fl tio , s tt i , so tio t t fil o s l to . T lti l issi tio is s t t s of t i o s f o t s ffol fo i so t sfo i to t o ot y.

4. Conclusions

A t l 3DG/C o o s s ffol s s ssf lly f i t it o o o sly *in-situ* ositio of l y i CVD t o . T iso t o i i ost t t o s o ositio o ti i fo t o o o s s ffol f i tio . Wit t t si l tio f o o ositio to st t , t 3DG/C st t s lt i l t i EMI *SE* f o 15.9 (fo f s l) to 32.3 B, i iti l of 47.8 B (88.2% i s), s ll s 26.8% i s i t t l iff sio . T y i 3DG/C o st t t o i ily sy ti ff ts i fl tio , so tio lti l fl tio s i l i - is s. T s jo i o ts i EMI t l o ti ity t t 3DG/C o o s s ffol s o isi lt ti fo li tio s i EMI s i l i t l t.

Credit authorship contribution statement

Kaka Cheng: Co t li tio , M t o olo y, Fo l lysis, W iti - o i i l ft. **Wei Xiong:** V li tio , I sti tio , W iti - o i i l ft. **Yan Li:** W iti - i & iti , F i isitio , R so s, S isio . **Liang Hao:** F i isitio . **Chunze Yan:** R so s, F i isitio . **Zhaoqing Li:** V li tio . **Zhufeng Liu:** Fo l lysis. **Yushen Wang:** I sti tio , Soft . **Khamis Essa:** W iti - i & iti . **Li Lee:** D t tio . **Xin Gong:** Soft . **Ton Peijs:** W iti - i & iti , S isio .

Declaration of Competing Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgement

The authors gratefully acknowledge the financial supports from the National Natural Science Foundation of China (No. 51671091, No. 51902295, No. 51675496). The project is also financially supported by the Fundamental Research Funds for the Central Universities, China University of Geosciences (Wuhan) (No. (No. CUG170677) and Hubei Provincial Natural Science Foundation Project (No. 2019 CFB264).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compositesa.2020.105904.

References

[1] Bai RG, Ninan N, Muthoosamy K, Manickam S. Graphene: A versatile platform for nanotheranostics and tissue engineering. Prog Mater Sci 2018;91:24–69.
[2] Balandin AA, Ghosh S, Bao W, Calizo I, Teweldebrhan D, Miao F, et al. Superior thermal conductivity of single-layer graphene. Nano Lett 2008;8(3):902–7.
[3] Li , H, C s o M, Po l H, Pi ot O, S t i li G, et al. I sit - foli tio of i o y si s: f il st t y to ffi i t l s l o o osit s. ACS Appl Mater Interfaces 2016;8(36):24112–22.
[4] Kang M, Kim J, Jang B, Chae Y, Kim JH, Ahn JH. Graphene-based three-dimensional capacitive touch sensor for wearable electronics. ACS Nano 2017;11(8):7950–7.
[5] P , C M, H M, Ti M, , Lo D. P o i t oo -t t o i ti s lf i tio ti ity of t - i sio l l li o l. Appl Catal, B 2020;262:118266–76.
[6] Li o J, W, C LL, Ji SH, W G, L, et al. Fl i l C-G i fo oly i o osit s it i i l t i itti ity. Compos Part A 2017;101:50–8.
[7] HQ, Li SW, C o LH, Ji SH, Ho HQ. S lit i tio of o - o ti oly i to i - fo lit i -io tt i s. J Mater Chem A 2018;6(42):21216–24.
[8] D i ls TM, S it i P, Dits y t P, K t J, K M, A iso T, et al. 3D - - o ot s- oly i t yl silo fl i l l t o s fo si lt o s l t o i l t tio s of H . P C . Proceedings 2017;1(4):467–70.
[9] Qi L, L L. T i sio l o o s - itos o osit s fo o i - i ss ly fo i t l t o t sf l t o t lysis of l os o i s. RSC Adv 2014;4(72):38273–80.
[10] Di , H Li SP, N, W JG. 3D it t o i - MoS_2 o osit : P tio ll t l t o ti so tio - fo . Compos Part A 2016;90:424–32.
[11] Li L, i W, So CQ, H MK, HL, D W, et al. S lf- ss ly o –s ll - i olle s s s 3D fo it lt i s ifi EM - so tio fo . Adv Funct Mater 2018. https://doi.org/10.1002/adfm.201803938.
[12] Li J, P , i C, R G, , N t lso D, et al. G o i o ost t S O_2 o o osit o s fo lit i io tt i s. ACS Nano 2013;7(7):6001–6.
[13] Jiang SH, Agarwal S, Greiner A. Low-density open cellular sponges as functional materials. Angew Chem Int Ed 2017;56:15520–38.
[14] Ito , T , S K, Kos i o M, T s i T, T i i K, et al. T - i sio l o o s t o s - s l t o i i li tio s. PCCP 2018;20(9):6024–33.
[15] Sieradzki K, Dimitrov N, McCall C, Vasiljevic N, Erlebacher J. The dealloying critical potential. J Electrochem Soc 2002;149(8):370–7.
[16] C o H, S i M, S i WH, L G, H , Q , et al. P tio of o l 3D t o s fo s ito li tio s. Small 2011;7(22):3163–8.
[17] K s i H, Gi o M, Jo so I, H J, W C, C M. U t l t o- ti i t f s i l i fo t - i sio l i- o ti o s o o o s . Matter 2019;1(4):1077–87.
[18] So Q, F, i , Li W, Li H, Li , et al. C o ot - ltil y l o -s ll y i fo s fo lt i - fo l t o ti -i - t f s i l i . Adv Mater 2017;29(31):1701583–90.
[19] , G C, L, T H, D, W , et al. T i sio lly f - fo l fo it si st t s fo y io t l li tio s. ACS Nano 2019. https://doi.org/10.1021/acsnano.9b08191.
[20] C C, H o , B i , Ni J, C S, Li F, et al. 3D i t o o s Ti6Al4V : ff ts of iti l o s f o ti s io o ti ility; o i o t i l ti i o l. Mater Des 2019;175:107824–33.
[21] Stašić J, Božić D. The effect of NiB additions on surface morphology and microstructure of 316L stainless steel single tracks and layers obtained by SLM. Surf Coat Technol 2016;307:407–17.
[22] R DC, HB, Li J, Li SJ, Ji W, R, et al. Mi ost t o ti s of i to i Ti–Ni lloy f i t y s l ti l s lti . Mater Sci Eng A-Struct 2020;771:138586–95.
[23] Li X, Cai W, An J, Kim S, Nah J, Yang D, et al. Large-area synthesis of high-quality and uniform graphene films on copper foils. Science 2009;324(5932):1312–4.
[24] Chen ZP, Ren WC, Gao LB, Liu BL, Pei SF, Cheng HM. Three-dimensional flexible and conductive interconnected graphene networks grown by chemical vapour deposition. Nat Mater 2011;10:424–8.
[25] Jadhav SD, Dadbakhsh S, Goossens L, Kruth JP, Humbeeck JV, Vanmeensel K. Influence of selective laser melting process parameters on texture evolution in pure copper. J Mater Process Technol 2019;270:47–58.
[26] io W, H o L, Li , T D, C i Q, F , et al. Effect of s l ti l s lti t s o o olo y, i ost t , sifi tio i l o ti s of s st t sil lloy. Mater Des 2019;170:107697–708.
[27] Gu DD, Meiners W, Wissenbach K, Poprawe R. Laser additive manufacturing of metallic components: materials, processes and mechanisms. Int Mater Rev 2013;57(3):133–64.
[28] Liverani E, Toschi S, Ceschini L, Fortunato A. Effect of selective laser melting (SLM) process parameters on microstructure and mechanical properties of 316L austenitic stainless steel. J Mater Process Technol 2017;249:255–63.
[29] i , S, W i , Li J, W i P, C , et al. Fo i f t lysis fo si l t s i i s l ti l s lti of Ti6Al4V. Appl Phys A: Mater Sci Process 2018;124:685–98.
[30] Li , , M i S, Di W, So C. I sti tio i to s tt io i s l ti l s lti of AlSi316L st i l ss st l o . Mater Des 2015;87:797–806.
[31] Leung CLA, Marussi S, Towrie M, Atwood RC, Withers PJ, Lee PD. The effect of powder oxidation on defect formation in laser additive manufacturing. Acta Mater 2019;166:294–305.
[32] T , Ko , To WQ, T J, D s oi s M, M li D, et al. R li - t siti t sfo tio α/β i t f o l tio i l t o lti t - i sio l- i t Ti-6Al-4V. Sci Rep 2016;6:26039–48.
[33] Ko H, T P, Lo NH, To SB, C CK. G o t y of i ost t i o ss fo s l ti l t o - lt Ti–6Al–4V ts. Virtual Phys Prototy 2016;11(3):183–91.
[34] Rafi HK, Karthik NV, Gong H, Starr TL, Stucker BE. Microstructures and mechanical properties of Ti6Al4V parts fabricated by selective laser melting and electron beam melting. J Mater Eng Perform 2013;22(12):3872–83.
[35] T , Ko , T J, Vastola G, Pei Q , G, et al. An experimental and simulation study on build thickness dependent microstructure for electron beam melted Ti–6Al–4V. J Alloys Compd 2015;646:303–9.
[36] R i DA, M LE, M ti H , et al. No l i it t - i ost t l it t lo i t f i tio of s oli o o o ts y iti f t i si l t o lti . Acta Mater 2011;59(10):4088–99.
[37] o , , , W H. Effect of yst llo i t t s o t l - isot o y of s l ti l s lt C -2.4Ni-0.7Si lloy. J Alloys Compd 2018;743:258–61.
[38] Kou S. Welding metallurgy. Second Edition 2003;23:309–48.
[39] Li Gao, Guest Jeffrey R, Guisinger Nathan P. Epitaxial graphene on Cu(111). Nano Lett 2010;10(9):3512–6.
[40] Li Xuesong, Cai WW, Colombo Luigi, Ruoff Rodney S. Evolution of graphene growth on Ni and Cu by carbon isotope labeling. Nano Lett 2009;9(12):4268–72.
[41] W, C, o , W H, i SQ, L. A s l l oly -f t o fo t sf i o to it y s f s. Carbon 2020;161:479–85.
[42] Ferrari AC, Meyer JC, Scardaci V, Casiraghi C, Lazzeri M, Mauri F, et al. Raman spectrum of graphene and graphene layers. Phys Rev Lett 2006;97(18):187401–4.
[43] o S , o G , Ji SH, F PC, Ho HQ. Fl i l f to y t t l i - o l t os ofi s it i o l s l t i o ti ity. Mater Lett 2017;200:97–100.
[44] Ji K, o H, J, C J, D i . F i tio l t o ti i t f s i l i fo of o - ll fo of C –Ni lloy i t t it CNTs. Appl Surf Sci 2014;311:351–6.
[45] R j K, Mo l DP, A is C, M S, S oj K. E ll t EMI s i l i fo t l i s l ti o ti s i li t i t, ltif tio l o - os o osit fo s. Compos Part A 2018;12:475–84.
[46] Shen B, Li Y, Zhai W, Zheng W. Compressible graphene-coated polymer foams with ultralow density for adjustable electromagnetic interference (EMI) shielding. ACS Appl Mater Interfaces 2016;8(12):8050–7.
[47]

M t 2019;34(5):489–98.

53] W B, Co M, L M. R oi s: li t- i t i - ffi i y l to ti i t f s i l i t l t t t s. A M t 2014;26:3484–9.

54] C H, W i S, Ji , i J, , C J, t l. Sy ti ff t of F $_3$O$_4$ o ti l s o o fl i l oly (i yli fl o i) s fil s it i t issi tio to i o l to ti s i l i . Co os P t A 2019;121:139–48.

55] W L, J, Q. T ff t of MWCNTs o t i o l to- ti o ti s of f it –MWCNTs o osit s. J M t S i: M t El to 2015;26(3):1895–9.

56] Di , P GR, H P, Qi F, Mi B , o ML. Effi i t l to ti i t f s i l i of li t i t / olysty o osit . J. M t C 2012;22:18772–4.

57] HB, Q, WG, H , . To - oly i o ll l fo s fo l to ti i t f s i l i . ACS A l M t I t f s 2011;3:918–24.

58] Si o i i A, U i llo N, T li f i V. T l i l i o t of l i o - lls fo s t o l to ositio of o . M f t R 2016. tt s:// oi.o /10.1051/ f i /2016021.

59] P tt s MT, Ji H, R off RS, S i L. T l t s o t i t - i sio l fo - it t s of f -l y lt t i it . N o L t 2012;12:2959–64.

60] Ji K, o H, H , D i . P fo of o - ll fo of C –Ni lloy i - t t it s s i l i st l to ti i t f . M t L tt 2017;122:244–7.

61] R o H, L S, B S, Ki TW, L DS, L HJ, t l. T - i sio l o o s o - t ost t s it ility i t issi tio - fo . S i R 2015. tt s:// oi.o /10.1038/s 12710.

62] T, F SG, Li , G o Q, Li G, R KP, t l. Sy o o sly i o l to ti i t f s i l i t l o ti ity fo o y o- o osit s y o st ti 3D o o i s/t lly l o l f o . M t S i E A-St t 2020. tt s:// oi.o /10.1016/j. o osit s .2019.105670.

63] R i DA, M LE, M ti E, H DH, M ti JL, M o BI, t l. No l i it t - i ost t l it t lo i t f i tio of soli o o o ts y iti f t i si l to lti . A t M t 2011;59(10):4088–99.

64] Et is SF, Li KC, Sis VK, Moo IC. T l ility t sti of o . J T st E l 1973;1(1):10–38.