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Microwave Sintering of W/Cu Functionally Graded Materials

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Research project

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Focused on

1) The fabrication of W/Cu functionally graded materials (FGM)

2) The evaluation on physical properties (i.e. relative density, thermal conductivity etc.)

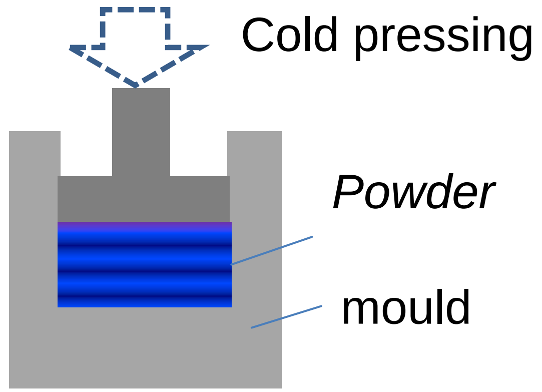
Fabrication of W/Cu FGM

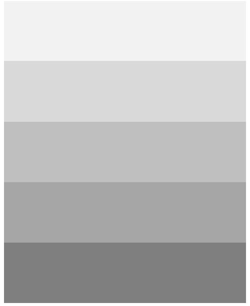
1) *W-Cu powders → hand mixed*

W: average particle size 3 μm, purity >99.9

Cu: average particle size 8 μm, purity >99.7%

2) *Green compact: ~500 MPa*





Five layers

3) *Sintering*

Microwave sintering (MWS) (30min.)

Spark plasma sintering (SPS)

Why W/Cu FGM?

Features of W and Cu

1) W: ideal candidate as plasma facing material and spallation material due to its high radiation resistance, high sputtering resistance;
2) Cu: heat sink material due to high thermal conductivity

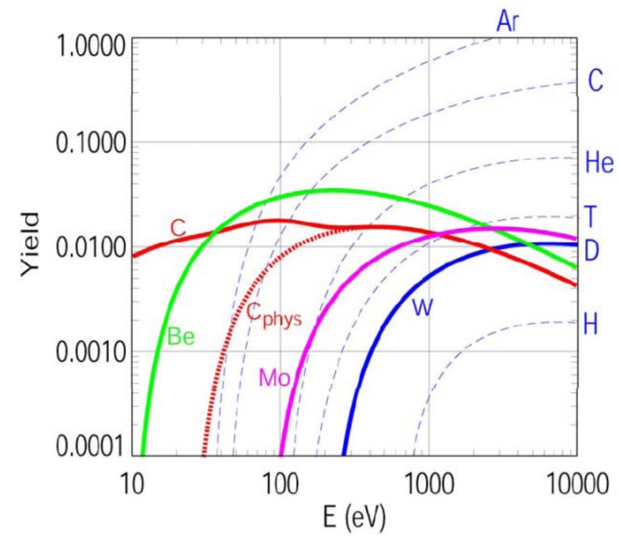
Joining of W and Cu

Challenges

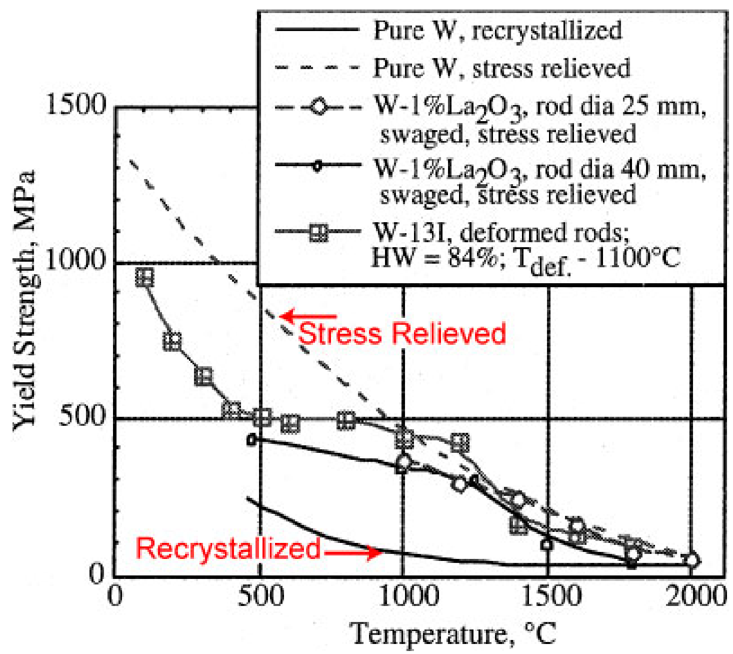
1) W: 500ºC(DBTT)~1300ºC (Recry. Temp.)
2) Mutual insolubility of W and Cu
3) Difference in coefficient of thermal expansion between W and Cu ($\alpha_{Cu} \approx 4 \alpha_W$)

→ formation of thermal-induced stresses at the interface

The design concept of functionally graded material between W and Cu



G. Mattews, presented at 15th PSI (2002)



J.W.Daviset al.,J. Nucl. Mater. 258-263 (1998) 308.

Why *Microwave sintering(MWS)?*

Points of MWS:

rapid heating rate and short sintering time

→ the crystal growth can be inhibited

→ fine grain size is beneficial to improve radiation resistance of materials because a lot of grain boundaries can trap the defects that were produced by irradiation.

Motivation: to fabricate the W/Cu FGM with good properties, such as high radiation resistance and thermal conductivity etc.

Overview of W/Cu FGM

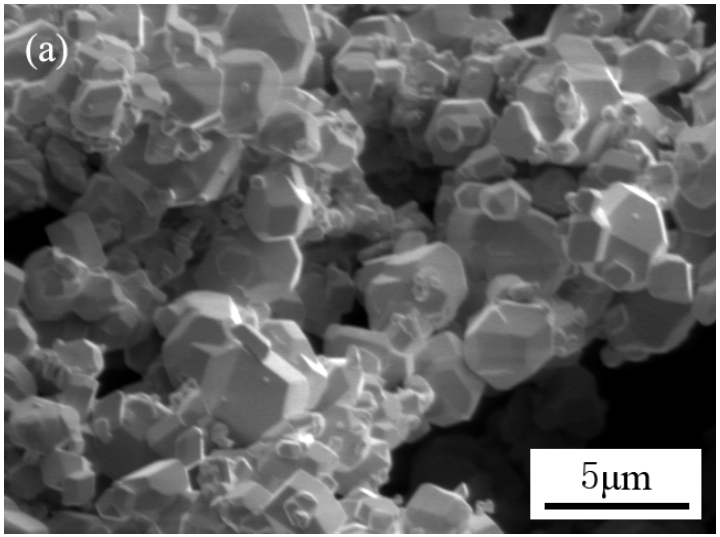
FGM structure (vol.%)	fabrication method	relative density	thermal conductivity (W/mK)	Ref.
W-25%Cu (and W-60%Cu)	plasma spraying	95% for W-25%Cu (SEM)	97 (at 100°C)	*Pintsuk et al., Fusion Eng. Des.66-68 (2003) 237*
W-Cu mixing powder/ W-25%Cu	plasma-spraying	92%-97% (SEM)	124-137 (at room temp.)	*Döring et al., Fusion Eng. Des. 66-68 (2003) 259*
W/ W-Cu20%/ W-Cu40%/ W-Cu60%/ W-Cu80%/ Cu	sintering under ultra-high pressure	-	113 (at room temp.)	*Zhou et al., J. Nuclear Mater. 363-365 (2007) 1309*
W/W-Cu25%/ W-Cu50%/ W-Cu75%/ Cu	one-step resistance sintering method	97%	-	*Zhou et al., J. Alloys. Comp. 428 (2007) 146*

Starting powders-before MWS

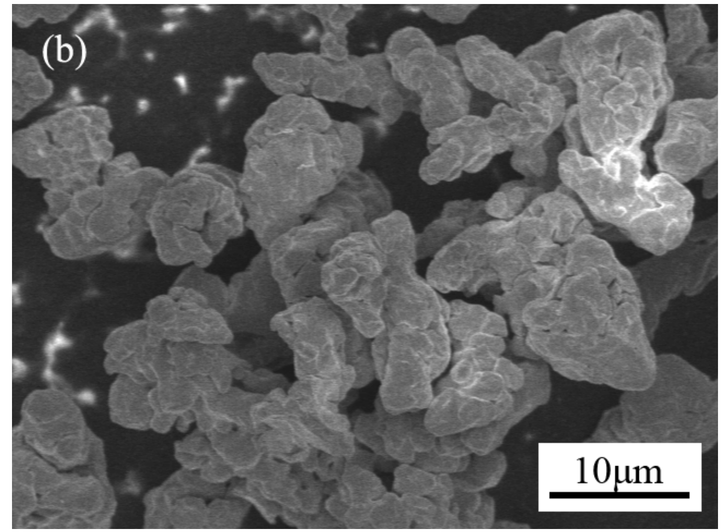
tungsten powders

copper powders

SEM

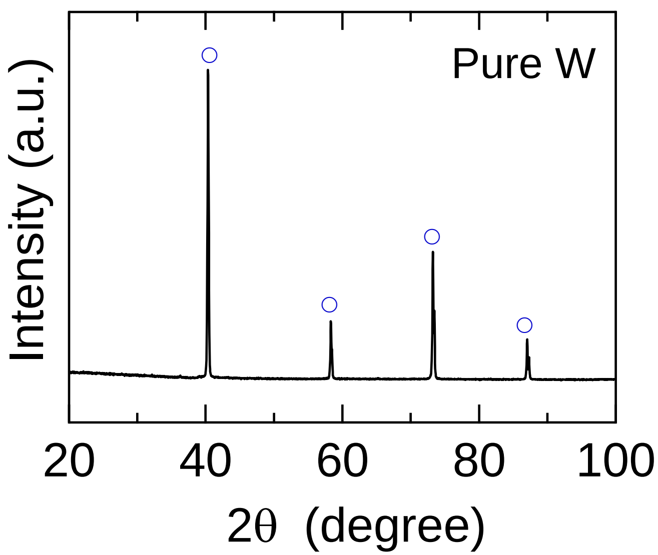


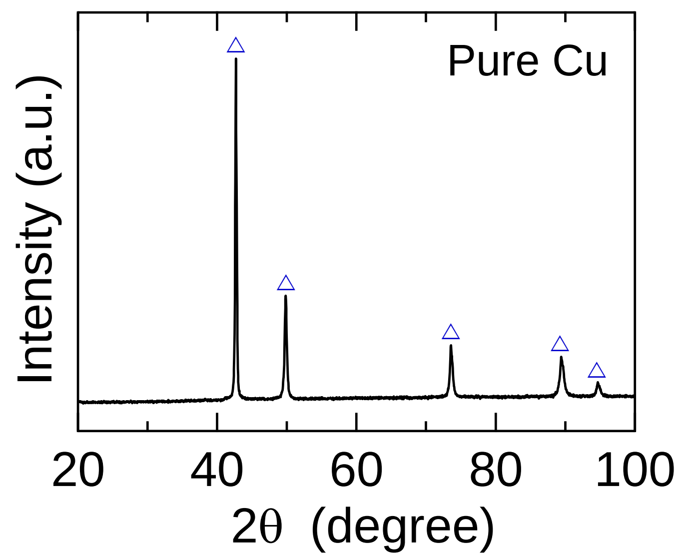
(W~3 μm)



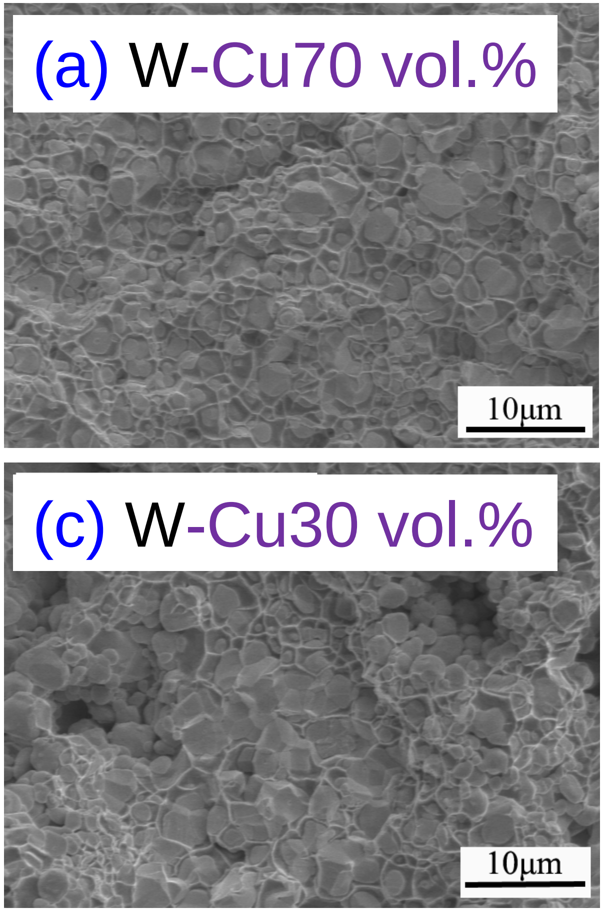
(Cu~8 μm)

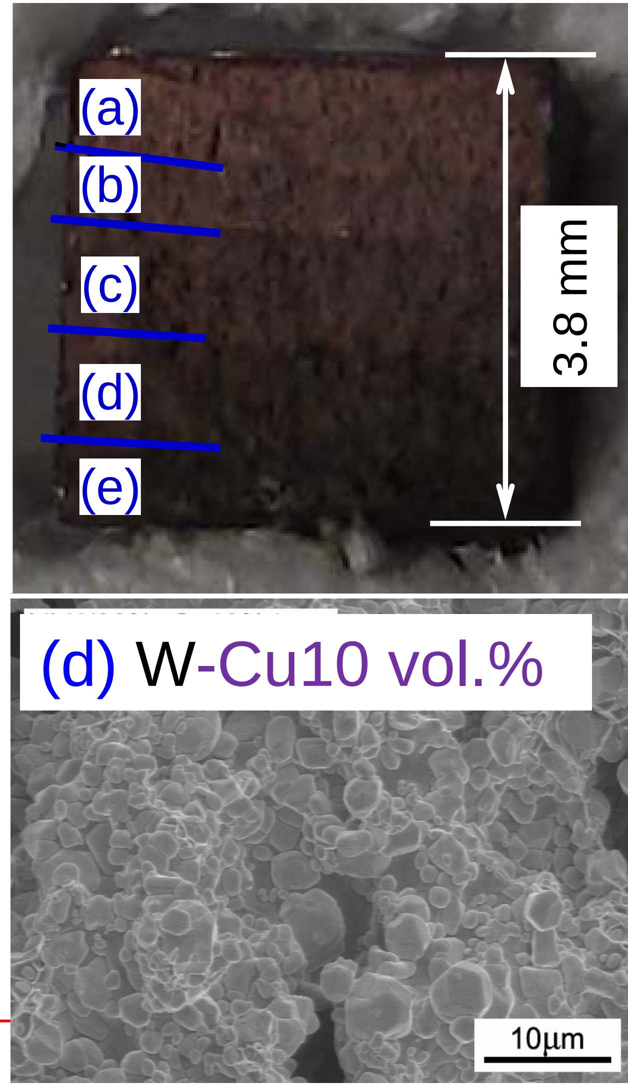
XRD

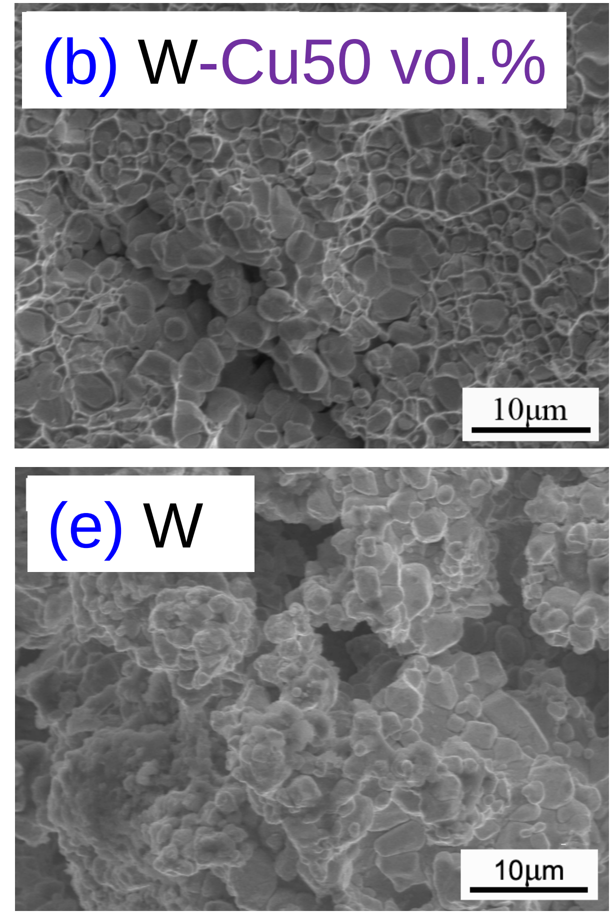




Cross-sectioned structure of W/Cu FGM-after MWS @ 1350ºC



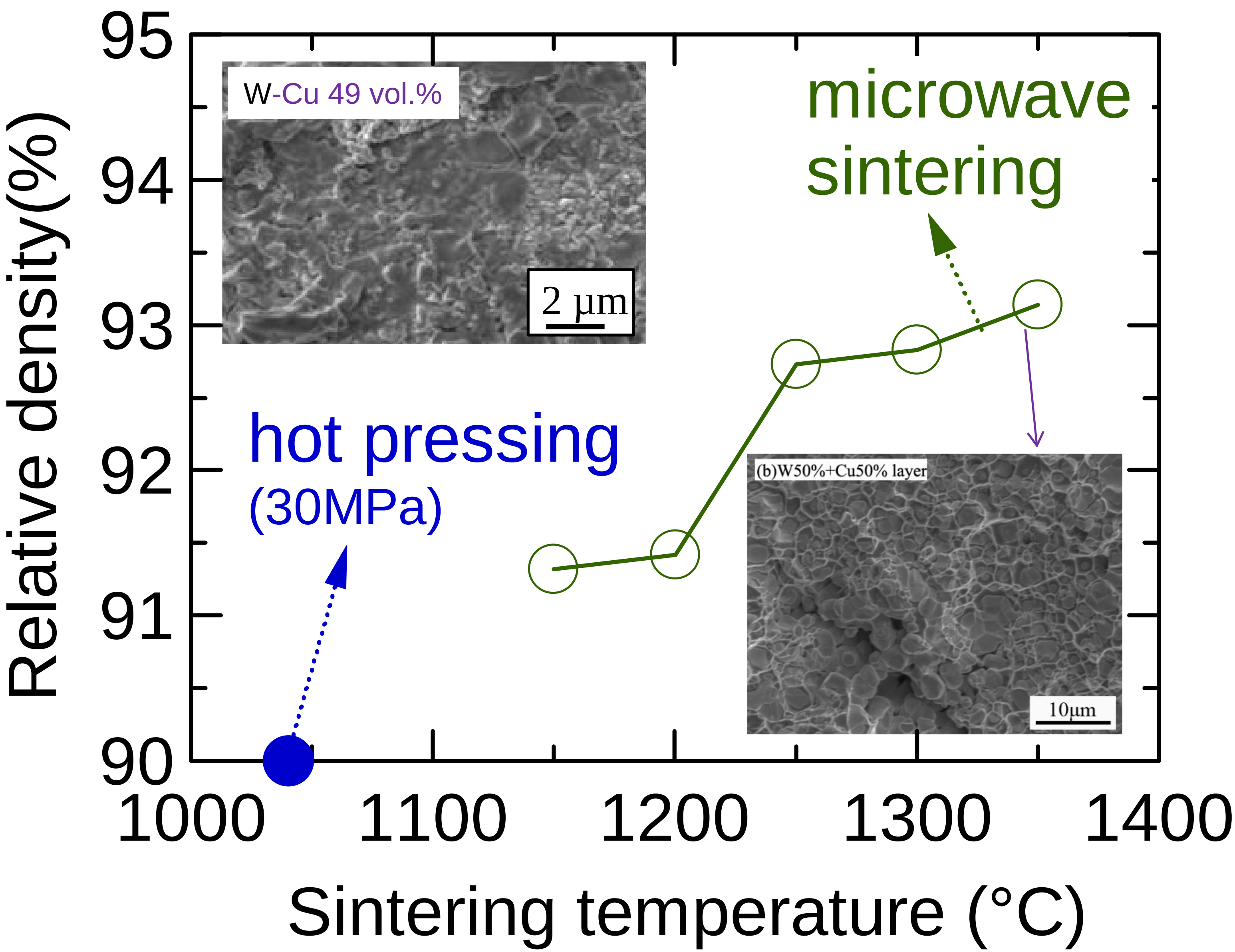




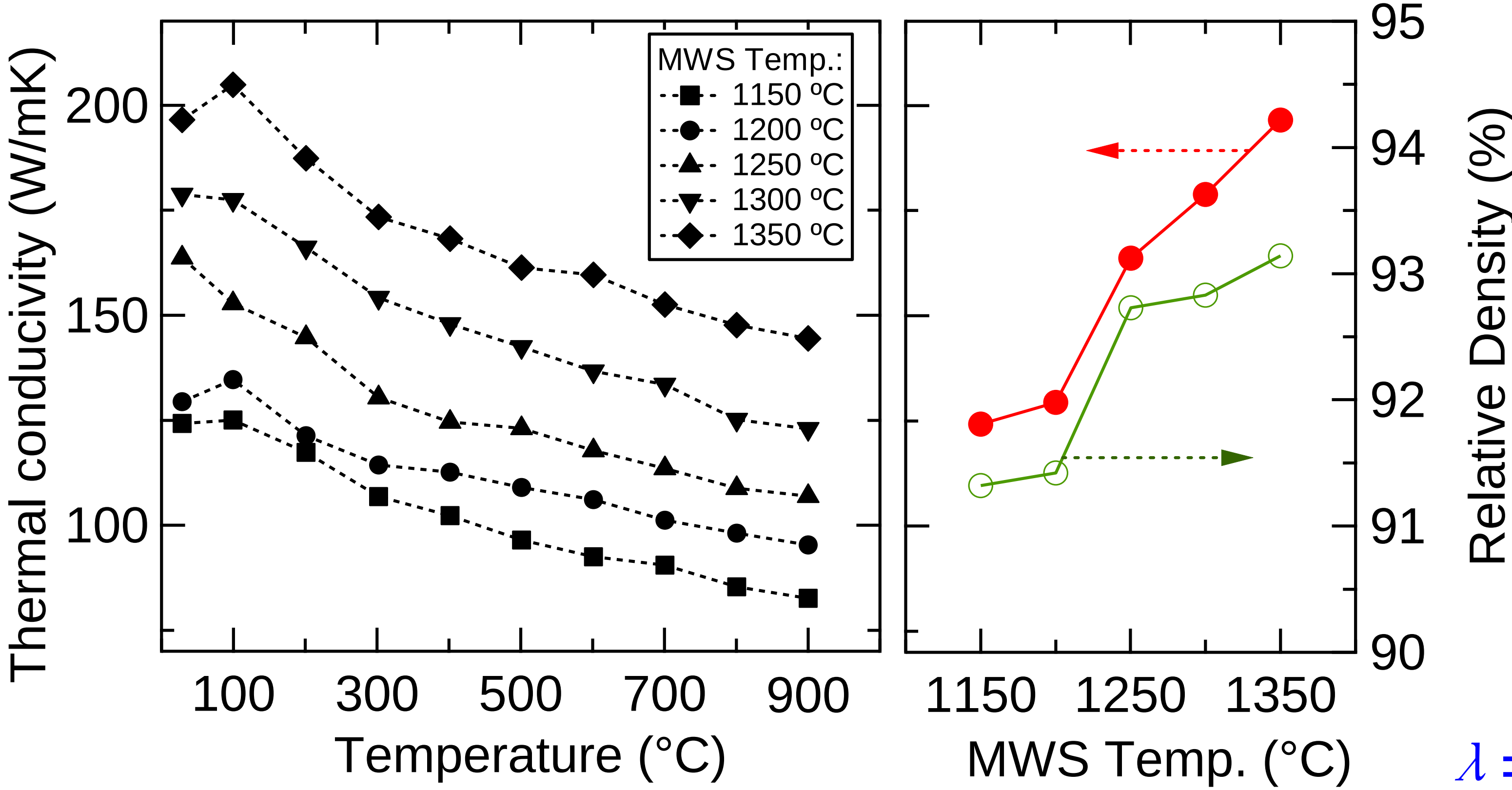
Point:

1) with the decrease of Cu, many pores are observed in layers；
2) the W particle sizes almost remain unchanged in all layers (W~3 μm)

Relative density of the W/Cu FGM



Thermal conductivity of W/Cu FGM



$\lambda = \alpha C_p \rho$

1) λ *of about 200 W/mK (room temp.) is* obtained in the W/Cu FGM, which is much higher than that in pure W(147 W/mK).

2) *Both* λ *and relative density have same tendency with MWS temperature, so* λ *may be dependent on the relative density.*

In comparison with Ref.

structure (vol.%)	fabrication method	relative density	thermal conductivity (W/mK)	Ref.
W-25%Cu (and W-60%Cu)	plasma spraying	95% for W-25vol.%Cu (SEM)	97 (at 100ºC)	Pintsuk et al., Fusion Eng. Des.66-68 (2003) 237
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W/W-Cu25%/ W-Cu50%/ W-Cu75%/ Cu	one-step resistance sintering method	97%	-	Zhou et al., J. Alloys. Comp. 428 (2007) 146
W/W-Cu10%/ W-Cu30%/ W-Cu50%/W-70%Cu	Microwave sintering	93%	200 (at room temp.)	present study

Summary

1) W/Cu FGM with five-layered structure W-Cu70% / W-Cu50% / W-Cu30% / W-Cu10% / W100% (vol.%) have been successfully fabricated by microwave sintering.
2) Microwave sintering is effective in densifying (93% MWS at1350ºC) the W/Cu FGM with high thermal conductivity of about 200 W/mK (room temp.).
3) The thermal conductivity of the W/Cu FGM was improved with increasing microwave sintering temperature.
4) Microwave sintering is a promising way for preparing W/Cu FGM.