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# Microstructure, thermal physical property and surface morphology of W-Cu composite fabricated via selective laser melting

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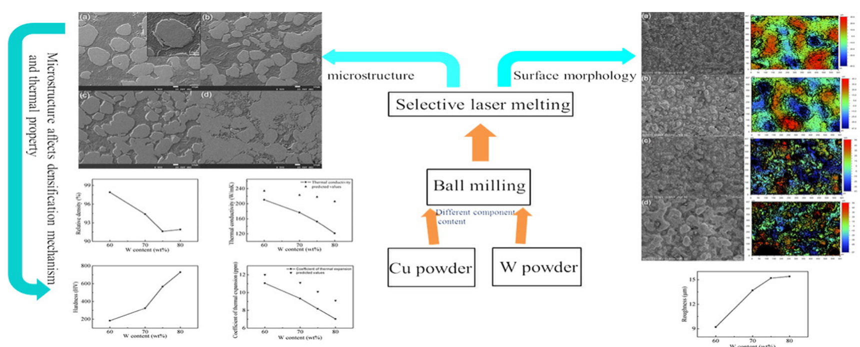
## HIGHLIGHTS

- Selective laser melting was adopted to fabricate W-(Ni)-Cu composites.
- The densification mechanism transformation of W-(Ni)-Cu composite with different composition content was revealed.
- The heat transfer model of W-(Ni)-Cu composite was depicted.
- Thermal properties and surface morphology was influenced by microstructure of W-Cu and the intrinsic property of W/Cu.

## GRAPHICAL ABSTRACT

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## ABSTRACT

In this work, the W-(Ni)-Cu composites were fabricated by Selective Laser Melting with the different W content up to 80 wt.%. The effects of relative density, microstructure on thermal conductivity, thermal expansion coefficient, roughness and hardness of W-(Ni)-Cu composites were evaluated. The results indicate that during SLM W-(Ni)-Cu composites, there are two kinds of densification mechanism reflected on the microstructure characteristic. Rearrangement densification favors to achieve higher relative density, dense compact Cu matrix and a homogeneous distribution of W solids, the thermal conductivity closer to theoretical value. Solid-state sintering densification obtains porous Cu matrix with W-W contiguity and the phenomenon is severer with the increase of W content, the thermal conduction structure is in good agreement with Randall's model. Ni additive is beneficial to densify the Cu matrix. The obtained coefficient of thermal expansion (CTE) through two kinds of densification mechanism are both lower than the theoretical value. The results show that the thermal conductivity and CTE increase with the Cu content, while the relative density trends on the contrary. The surface morphology presents easy to balling due to the instinct property of W and Cu. The roughness and hardness also increase with the increase of W content.



## 1. Introduction

As the demand of thermal management material which has high thermal conductivity and matching thermal expansion coefficient with semiconductors increased continuously, the choice of material

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with appropriate thermal properties and mechanical properties is critical for the applications in microelectronic and optoelectronic package. So far, high-performance composites have a tendency to substitute the pure metal in thermal management material. W-Cu composite is a typical high-performance thermal management material among them.

W-Cu composite is combined with the natural properties of W, for example the high melting temperature and low coefficient of thermal expansion, with those unique properties of Cu, such as high thermal conductivity and electrical conductivity [1–4]. Conventionally, W-Cu alloys are produced by liquid sintering, activated sintering [5] and infiltration [6]. However, traditional process methods are limited by some factors. For instance, in liquid infiltration, normally green density no more than 60% of the theoretical density can be obtained and extra densification is necessary, which results in high production costs [7]. In addition, it is difficult to fabricate complex-shaped components by using methods aforesaid because the expensive and special equipments are necessary, thermal management components always have delicate structures such as micro-channels and fins. Therefore, developing an advanced processing method for manufacturing complex-shaped W-Cu parts has huge demand.

Selective laser melting (SLM) is a laser-based additive and layer-by-layer manufacturing technology. The main advantage of SLM is to build object with complex geometries from powders in one step controlled by computer. Many previous works have been issued on the scope of SLM, including stainless steel [8–13], nickel-base super-alloys [14–17], cobalt-chromium alloys [18–22], titanium alloys [23–26] and even refractory metal [27,28], which suggest that all metals have potential for the SLM process. Some researchers studied the feasibility of adopting SLM to manufacture W-Cu composite. Zhang et al. [29] established the process parameter window of SLM W90-Ni2.5-Cu7.5 alloy. Kumar [30] studied the mechanical properties of tungsten carbide-cobalt composite fabricated by SLM. Gu et al. [31] fabricated W-Cu components by DMLS using $CO_2$ laser and studied the relationship between process parameter and the microstructure. Meanwhile, there are also some reports about the thermal and mechanical properties of W-Cu composite manufactured by conventional process. Chen et al. [32] studied the thermal and electrical properties of W-Cu composite produced by activated sintering, meanwhile introduced Zn additives to enhance the densification. Lee et al. [33] approximated a microstructure in which spherical W particle homogeneous distributed in Cu matrix, the thermal transfer preferentially occurs through the Cu phase. Zhang et al. [34] studied the mechanical properties of the W-Cu composite fabricated by three methods: SPS, CIP before SPS and CIP before liquid infiltration, Zn addition was used to promote the densification.

Although the thermal and mechanical properties of W-Cu composites fabricated by conventional process have been widely studied, no reports provided a comprehensive analysis of the thermal property and surface morphology of W-Cu composite fabricated via SLM. SLM owns unique sintering mechanism and heat, mass, momentum transfers modes [35]. As a high energy density-short interaction time process, SLMed components own finer grains while it's unable to eliminate pores completely [36]. Due to its versatility in terms of both materials and shapes as well as quick response ability, making a rounded analysis of applying SLM to fabricate W-Cu composite has important significance.

For W-Cu composite used in thermal management application, the most concerned property is thermal physical property including thermal conductivity (TC) and coefficient of thermal expansion (CTE). In addition, considering some inner-channels and fins in thermal management component, the roughness and hardness of forming surface should also be regarded. According to the reported results and references, it was difficult obtain full-density W-Cu composite. However, the most harmful factor for thermal conductivity was pore [37]. Previous literatures have reported that adding some additive element such as Zn, Ni, Co is beneficial to densification in condition of low sintering temperature [38,39], especially for the high W content. The purpose of adding Ni in the composite is to significantly lower the temperature to achieve high-density of W-Cu composite. Meanwhile, the addition of Ni could strengthen the combination of W-W, W-Cu interfaces and enhance the corrosion resistance of inner-channels.

In the present work, W-Cu40 wt.%, W-Cu30 wt.%, W-Cu25 wt.% and W-Ni5 wt.%-Cu15 wt.% composite powder was prepared by mechanically milling, respectively. Then the SLM method was originally developed for fabricating W-(Ni)-Cu alloy components. The relative density, microstructure, surface morphology, thermal properties, roughness and hardness of the composite were investigated and measured, and the reasons for the different thermal properties and surface features of the alloys were discussed.

## 2. Experimental procedures

W powders (purity, 99%), gas atomization Cu powders (purity, 99%), and gas atomization Ni powders (purity, 99%) were used in this experiment. The mean particle size of three raw powders was 20 μm, 20 μm, and 30 μm, respectively. The chemical composition of composite powder was W-Cu40 wt.%, W-Cu30 wt.%, W-Cu25 wt.% and W-Ni5 wt.%-Cu15 wt.%, respectively. The mixed powders were mechanically alloyed in the high-energy planetary ball milling for 6 h in Ar. The morphology of composite powders was similar, as shown in Fig. 1.

W-Cu composites were processed in an EOS M270 facility equipped with a 200 W Yb(Ytterbium) fiber laser, the diameter of beam spot is 100 μm, and the wave length is 1060–1090 nm. Table 1 shows the optimal process parameters of the four kinds of composite powders. The specimens prepared for metallographic observation, roughness measurement and hardness measurement with the dimension of 10 mm × 10 mm × 6 mm. The specimens for thermal conductivity and thermal expansion coefficient were made into cylinders shape with Φ12.7 mm × 2 mm and Φ4 mm × 45 mm, respectively. The original powder was used to test specific heat. Each kind of specimen was prepared five pieces and the result was expressed using the mean value.

The density (ρ) of the SLMed sample was measured by Archimedes principle with deionized water, the relative density was calculated by the measured value divide the theoretical value. The surface morphology and microstructure characteristic were investigated by Field emission scanning electron microscope (FESEM). The sample section was polished follow the rules of metallographic procedures, then immersed in the mixed solution composed of $NH_3 \cdot H_2O$(10%,10 ml), $H_2O_2$(10%,10 ml) and distilled water (20 ml) for 20s. The thermal diffusivity (α) was measured by laser flash method using a thermal analyzer, and the specific heat ($C_P$) was measured by a differential scanning calorimeter (DSC). The thermal conductivity was calculated as a function of ρ, α, $C_P$ mentioned above. The thermal expansion coefficient (CTE) was measured by thermal-mechanical analyzer. The roughness was

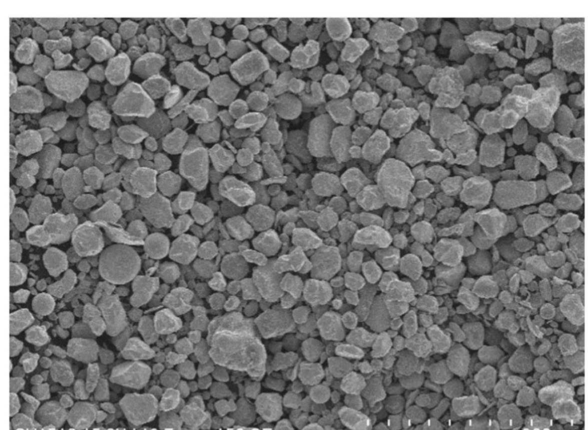


**Fig. 1.** SEM morphology of W-70 wt.% Cu composite powder.