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Heat Dissipation Performance of Porous Copper with Elongated Cylindrical Pores

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The purpose of this paper is to investigate heat dissipation performance of porous copper with long cylindrical pores fabricated by a unidirectional solidification method. Three samples with porosity of 29.87%, 34.47% and 50.98% were chosen and cut into size of 60 mm (length) × 26 mm (width) × 2 mm (thickness) along the vertical direction of pore axis. Their heat dissipation performance was evaluated by a nonsteady method in air and compared to those of not only bulk copper but also bored coppers with porosity of 30.61% and 32.20%. It is found that the porous copper dissipated heat faster by a forced air convection than that by natural convection from 80 °C to room temperature and both porosity and pore size play an important role in the performance for the porous copper. Furthermore, the heat dissipation rate is higher when the forced air was circulated along the specimens than that perpendicular to the specimens for the porous copper. It is revealed that porous copper with bigger porosity and a proper pore size possesses a higher heat dissipation rate. It is concluded that the porous copper with elongated cylindrical pores has larger heat dissipation performance than both the bulk copper and the bored copper, which is attributed to its higher specific surface area. Application of the porous copper for heat dissipation is promising.

KEY WORDS: Porous copper; Heat dissipation; Porosity; Pore size

1. Introduction

Heat dissipation in high power electronics and laser diodes faces serious challenges under the trend of high frequency, miniaturization and growing capacity. Generally, a novel heat sink or a heat dissipation-assisted equipment with large heat transfer performance has to be attached to a power device or a laser diode for a normal temperature level[1].

Among various types of heat sinks, those utilizing micro-channels with channel diameters of several tens of microns are expected to have excellent cooling performance because a higher heat transfer capacity was obtained with smaller channel diameters[2]. Recently, porous metals have been considered as preferable for three-dimensional micro-channels, and a promising alternative for compact heat exchangers due to the high surface area density, superior thermodynamic characteristics and good mechanical properties[3–7]. Among porous materials such as sintered porous metal, cellular metal and fibrous composite, the porous metal with elongated cylindrical pores, which is also called gasars[8] and lotus-type porous metal[9,10], is preferable for heat sinks due to small pressure drop of cooling water flowing through the pores[11]. It has been reported that the lotus-type porous copper heat sink showed a very large heat transfer coefficient of 8 W/(cm^2 K) under the velocity of 0.2 m/s of cooling water[2], which is 1.7 times higher than that for the micro-channels and 6.5 times higher than that for the conventional groove fins. Chen et al.[12] reported that the porous copper heat sink with pore length about 20 mm has a heat transfer coefficient of 5 W/(cm^2 K) when its porosity is 29% and mean pore diameter is 400 μm, which can be increased to 6.5 W/(cm^2 K) after cutting the porous copper along the vertical direction of pore axis into two section. Their observation implies that the length of pores may play an important role in the heat transfer

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coefficient of the porous metal. By the theoretical analysis, Chen et al.[13] predicted that the porous copper used for heat sink with excellent heat transfer performance should have the following porous structure: the pore diameter is 0.1−0.6 mm; the porosity is 30%−70%.

The porous metal with elongated cylindrical pores has shown an excellent heat transfer performance with a liquid as heat transfer medium[14]. However, knowledge with air as heat transfer medium is absent on the porous metal. Actually, most of the investigations and applications on heat transfer for porous metals were performed with air, due to the high pressure drop associated with liquids[15]. In the present work, heat dissipation performance of the porous copper with elongated cylindrical pores with air as heat transfer medium was firstly investigated with consideration of the effects of porosity and pore size on heat flow. Secondly, the effect of forced air convection on heat dissipation performance of the porous copper was examined. Finally, the results mentioned above were discussed.

2. Experimental

2.1. Sample preparation

The porous copper was fabricated by a vacuum-assisted and pressurized casting apparatus, comprised a high-purity graphite crucible (172 mm in inside diameter, and 320 mm in length), a middle-frequency induction heating coil and a mold (135 mm in inside diameter, and 380 mm in length) with a water-circulated chiller under bottom and a thin ceramic wall adjacent to the lateral side of the mold for the solidification from the bottom to top only. The crucible in the apparatus was placed perpendicularly with respect to the axis of a funnel and the mold. After the chamber was evacuated to 0.5 Pa, high-purity copper (99.99 wt%) was melted in the crucible by middle-frequency heating under 0.1 MPa of hydrogen to a temperature of 1603 K, additional hydrogen and argon were introduced into the chamber and a pressurized condition was maintained at 1603 K for 2400 s. The purity of each gas used was 99.999%. The pressure values during melting and solidification in this work were 0.2 and 0.5 MPa for hydrogen (p_{H_2}), while 0.1, 0.3, 0.5 MPa for argon (p_{Ar}), as listed in Table 1. Then the apparatus was rotated by 90 ° to pour the melt into the mold through the funnel, in which the metal liquid was solidified unidirectionally. The details about this apparatus and the fabrication technique were given in our previous paper[16].

2.2. Characterization

The porous copper ingots were cut in transverse section using an electric discharge machine (DK7763, Longhao digital-controlled machine Corp., China) between 30 mm and 130 mm from the bottom and further cut into some plates with size of 60 mm (length) × 26 mm (width) × 2 mm (thickness) along the vertical direction of pore axis.

Table 1 Fabrication conditions for the porous copper samples

Sample	p_{H_2} (MPa)	p_{Ar} (MPa)	Porosity (%)	Pore size (μm)	Pore density (cm^{-2})
L1	0.2	0.1	50.98	668.4	182
L2	0.2	0.3	34.47	329.6	229
L3	0.5	0.5	29.87	190.0	467

The porous copper specimens were examined using optical technique on the cross section. Three images on each sample were analyzed by using an SISC Image Analyzing software (KYKY Technology Development Ltd., China) for determining the pore size and the pore density. The porosity of the porous copper specimens was evaluated from their weights and volumes. The average values of porosity, pore size and pore density of the three porous copper samples are also listed in Table 1.

2.3. Heat dissipation performance measurement

A nonstandard and nonsteady method was employed to evaluate heat dissipation performance for the porous copper plates. Fig. 1 shows the schematic view of the experimental apparatus for the measurement. Hot water with temperature of 80 °C was poured into a cylindrical plastics cup with both bottom and side thermally insulated. A pure aluminum base was employed as the top cover with one side connected to the hot water. Eight sheets of the porous copper specimens were stacked and soldered to the aluminum base with tin on the other side. In addition, aluminum foil was inserted between the copper plates and the ditch of the aluminum base for reducing contact thermal resistance between them. A thermometer was inserted into the hot water through the aluminum base to measure its temperature. A fan (Lileng-815, Rongzhifa Electronic Co., Ltd., China) was located with a distance of 20 cm for a forced air circulation along or perpendicular to the porous copper plates with air speed of 2 m/s.

In this system, a certain amount of heat is considered to be transferred and dissipated through the aluminum base, the porous copper specimen to air, which can be calculated by mass, temperature drop of the hot water. The dissipated heat through the porous copper plates is available if the part through the aluminum base can be deducted. It is the advantage of this method that the heat dissipation at different temperature from 80 °C to room temperature can be evaluated.

3. Results and Discussion

3.1. Calculation of heat dissipation of the copper plates

The temperature variation of the water with aluminum base and copper plates is compared to that with aluminum base only under a forced air convection perpendicular to the copper plates as shown in Fig. 2. It is indicated that the temperature drops

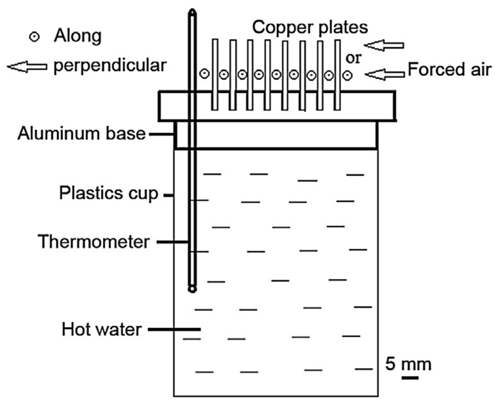

Fig. 1 Schematic view of the experimental apparatus for the heat dissipation measurement.

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