Hindawi Publishing Corporation
Mathematical Problems in Engineering
Volume 2015, Article ID 174872, 8 pages
http://dx.doi.org/10.1155/2015/174872

Research Article

The Variations of Thermal Contact Resistance and Heat Transfer Rate of the AlN Film Compositing with PCM

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Received 1 October 2014; Accepted 11 December 2014

Academic Editor: Mo Li

The electrical industries have been fast developing over the past decades. Moreover, the trend of microelements and packed division multiplex is obviously for the electrical industry. Hence, the high heat dissipative and the electrical insulating device have been popular and necessary. The thermal conduct coefficient of aluminum nitride (i.e., AlN) is many times larger than the other materials. Moreover, the green technology of composite with phase change materials (i.e., PCMs) is worked as a constant temperature cooler. Therefore, PCMs have been used frequently for saving energy and the green environment. Based on the above statements, it does show great potential in heat dissipative for the AlN film compositing with PCM. Therefore, this paper is focused on the research of thermal contact resistance and heat transfer between the AlN/PCM pairs. According to the experimental results, the heat transfer decreases and the thermal contact resistance increases under the melting process of PCM. However, the suitable parameters such as contact pressures can be used to improve the above defects.

1. Introduction

The trend of microelements and packed division multiplex is obviously attractive for the research and development department in the electrical industry. To realize the above objects, the high heat dissipative and the electrical insulating device have been popular and necessary.

It is well known that AlN remain stable under the high temperature conditions. Moreover, the thermal conduct coefficient of aluminum nitride is several times larger than the other related materials [1–3]. As a result, it is used popularly for the heat dissipation in the electrical industry. In addition to the above functions, AlN film also has fine electrical insulating properties to avoid the risk of a short circuit of electronic equipment [4–7]. These advantages are always attractive for the research and development department of the electrical corporations [8].

Furthermore, phase change materials (i.e., PCMs) are known as very special materials since they can absorb and store the heat energy as they change their phases, for example, from solid to liquid, and then release that heat energy when they change back to their phase, for example, from liquid to solid. This special property makes the materials very useful in thermal storage applications in general and very valuable in the heat dissipation systems [9, 10]. The green technology of composite with PCMs is worked as a constant temperature cooler. Therefore, PCMs have been used frequently for the saving energy and the green environment. Based on the above statements, it does show great potential in heat dissipative for the AlN film compositing with PCMs.

Moreover, using continuous responses of triboelectrification and friction coefficient to monitor the dynamic frictional behaviors between the metal materials has been developed successfully by the authors [11]. The experimental results have shown that the thermal contact resistance is obviously determined by the real contact areas between the interfaces of the metal pairs [12]. The most important parameters for the real contact areas are normal loads and surface hardness of the materials. However, the defects of material crystals always significantly influence the heat transfer of AlN [1–7]. Therefore, it is necessary to clarify the relationships between the structure of AlN/PCM and the efficiency of heat transfer. Based on the above expressions, this paper is focused on the research of heat conduction and thermal contact resistance

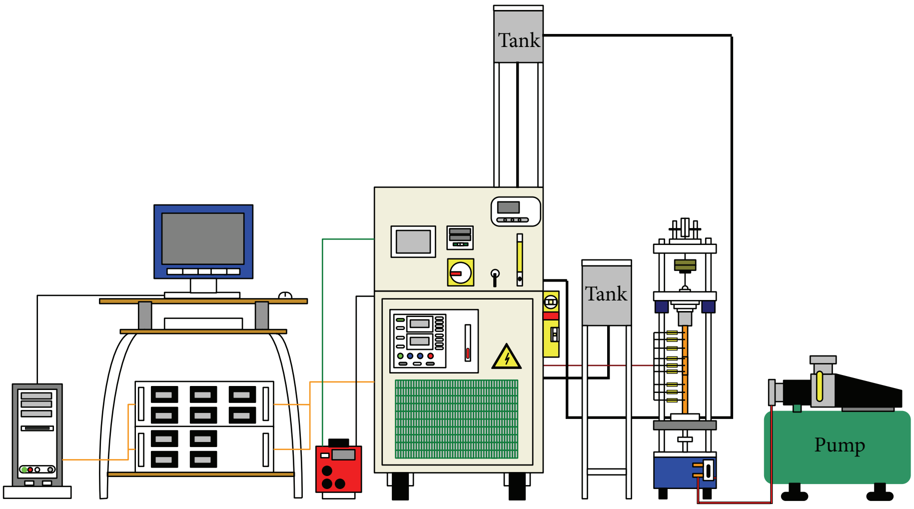


Figure 1: The schematic diagram of the thermal contact resistance tester with the measuring systems.

between the pair of AlN/PCM and the copper material by referring the results of thermal contact resistance between the interfaces in the previous paper [12].

2. Experimental Equipment and Procedures

2.1. Experimental Equipment. The schematic diagram of the thermal contact resistance tester with the measuring systems is shown in Figure 1. The voltage signals from the measurement points of the ten thermocouples were transferred to a temperature extractor. As a result, the temperatures at each measuring point can be obtained by the calculations and the calibrations. Based on the above results, the thermal contact resistance and the heat transfer rate can therefore be analyzed by the following three mathematical formulas as shown in Section 2.3.

The main parts of the experimental apparatus have been shown in Figure 2. The loading system contains the following elements: one-way pneumatic valve by manual control, with a pneumatic cylinder. The gas comes from a 1HP air compressor. Copper is used as the main heat transfer channel: The heat transfer stick (Φ 20 mm × 110 mm, drilling Φ 1.4 mm × deep 10 mm) × 2; Copper substrate (Φ 20 mm × 20 mm, drilling Φ 1.4 mm × 10 mm depth) × 1.

The ceramic glass fibers are used as an insulator ($k = 0.036\,\mathrm{W/m^\circ C}$). Moreover, the heating apparatus included the three heating poles. The fitting counterweights (1 kgw × 3, 5 kgw × 2, and 10 kgw × 1) were used to maintain the equilibrium of the contact pressure. Besides, an ice water maker and a water circulating pump were disposed as the temperature regulator.

2.2. Test Specimens. The experimental specimens were made of AlN thin flakes compositing with PCM. Physical properties of the test specimens are shown in Table 1. The thickness of AlN is about 0.7 mm. The melting point of the PCM is 80°C under the standard atmosphere. The design of the test specimens is shown in Figure 3(a). AlN thin flakes, PCM, copper substrate, and the heat transfer stick are shown in Figures 3(b) and 3(c).

Table 1: Physical properties of AlN and Cu.

	AlN	Cu
Melting point (°C)	2200	1082
Thermal conductivity (W/m°C)	140–180	398

2.3. Experimental Procedures. Two kinds of thermal contact resistance are investigated in this study. The data from the upper measuring point is R_1 and that from the lower point is R_2. There are several factors for R_1 and R_2, such as pressure, temperature, hardness, and surface roughness. Therefore, it is necessary to analyze and calculate the experimental parameters step by step.

The formula of the heat transfer (k):

$$q = -kA\frac{dT}{dx} = \frac{T_a - T_b}{R_c}. \tag{1}$$

The formula of the thermal contact resistance (R):

$$R_1 = \frac{T_{a1} - T_{a2}}{q}, \qquad R_2 = \frac{T_{b1} - T_{b2}}{q}. \tag{2}$$

Moreover, the related temperatures are obtained by the following:

$$\frac{T_1 - T_2}{X_1 - X_2} = \frac{T_3 - T_4}{X_3 - X_4}. \tag{3}$$

In this study, the heating temperatures were set as 40°C, 50°C, 60°C, and 70°C. Moreover, the temperature of the cold water circulating system was fixed as 10°C. Before each experiment, the warming time for the experimental equipment was set as 4 hours. Normal loads were set as 0.5 kgw and 1.5 kgw; that is, the corresponding pressures

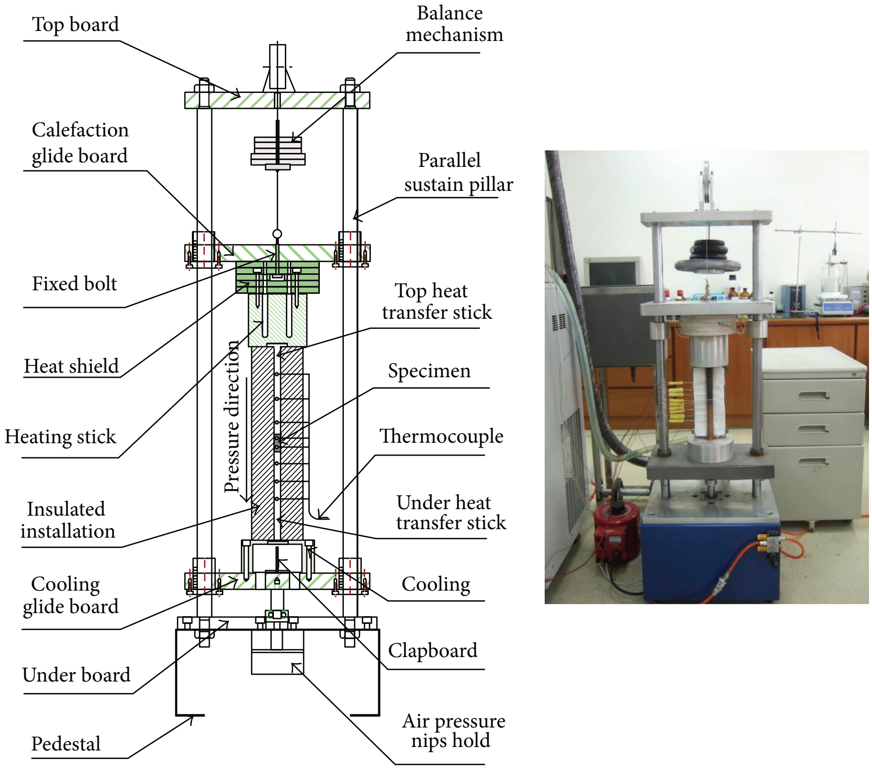


FIGURE 2: The main parts of the experimental apparatus.

were 16 kPa and 48 kPa. The average temperature during the experimental period was 25 ± 3°C, and the average relative humidity was about 65%.

3. Results and Discussions

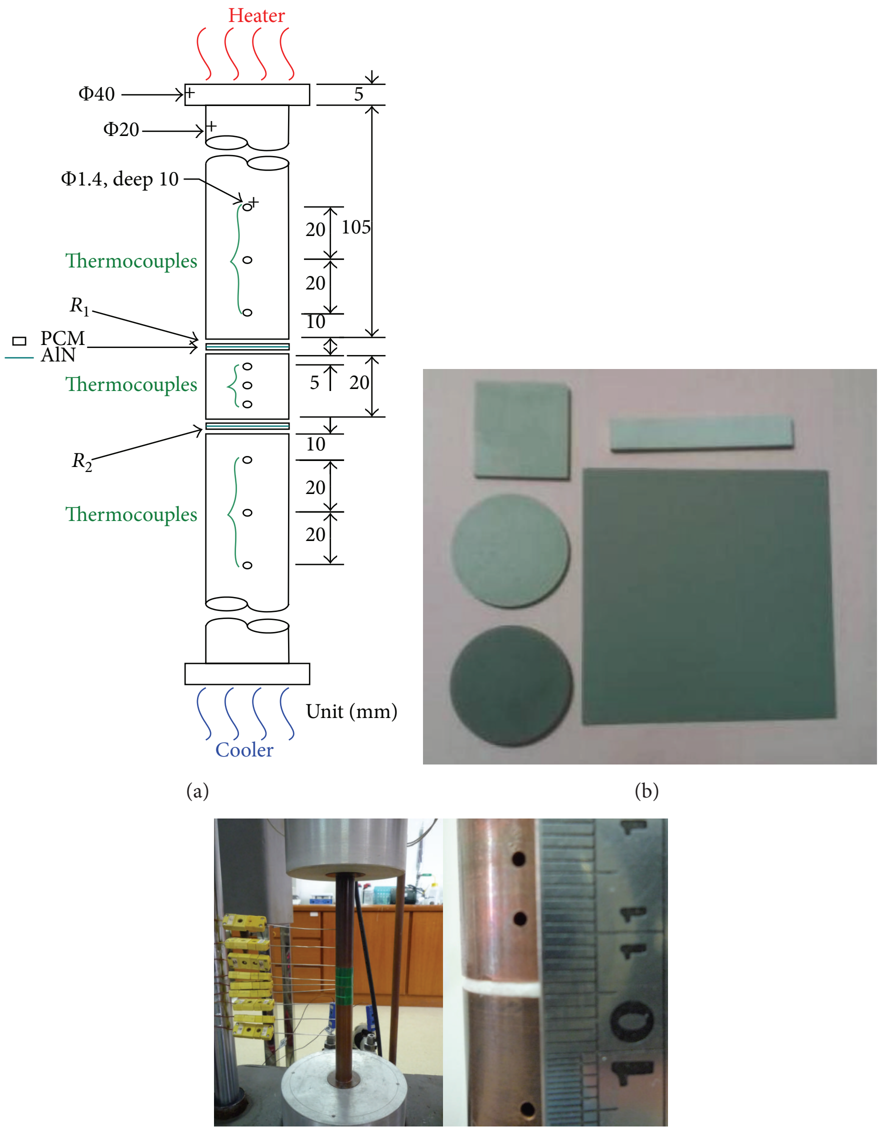
3.1. Experimental Results under Lower Contact Pressure. Figure 4 shows the effects of heating temperatures on thermal contact resistances for Cu/PCM-AlN/Cu under 16 kPa (0.5 kgw). It is seen from this figure that the thermal contact resistance (R_1) increases from 1.4 to 1.9°C/W with the heating temperature increasing from 40 to 50°C. Furthermore, the thermal contact resistance further increases to about 3~3.5°C/W when the heating temperature is in the range of 60~70°C. Similar tendency can be found for the thermal contact resistance (R_2). The above results can be reasonably explained by the fact that the melting point of the PCM should decrease with increasing the contact pressure. Beyond the experimental time of 3600 s, the PCM had melted in the interface under a constant contact pressure when the heating temperature reaches 70°C. Therefore, not only heat transfer but also heat convection occurs between the interfaces. As a result, the thermal contact resistance shows complex variations in the range of 60~70°C.

The effects of heating temperatures on heat transfer rates for Cu/PCM-AlN/Cu under 16 kPa (0.5 kgw) are shown in Figure 5. This figure shows that the heat transfer rate is about 9~10 W when the heating temperature is in the range of 40~50°C. However, the heat transfer rate significantly increases from 7 to 11 W with the heating temperature increasing from 60 to 70°C.

Furthermore, it is seen from Figure 6 that the thermal contact resistance of Cu/PCM-AlN/Cu is about 3.5°C/W under steady state. However, it shows only 2°C/W under steady state for Cu/PCM/Cu in Figure 7. Moreover, the temperature difference between T_{a1} and T_{a2} is about 20°C.

From the above experimental results, it is apparent that the AlN film between Cu/PCM and AlN/Cu increases the thermal contact resistance and decreases the heat transfer rate when the heating temperature is smaller than 70°C. However, the thermal contact resistance is shown to be smaller and stable when the heating temperature reaches 70°C. Moreover, the corresponding heat transfer rate also is shown to be larger. These can be reasonably explained by the fact that PCMs fuse at a higher temperature. Therefore, the air holes are filled by the softened PCM. In order to verify the above phenomenon under higher pressure, the experimental results under 48 kPa were measured.

3.2. Experimental Results under Higher Contact Pressure. Figure 8 shows the effects of heating temperatures on thermal contact resistances for Cu/PCM-AlN/Cu under 48 kPa (1.5 kgw). It is seen from this figure that the thermal contact resistance (R_1) increases from 1.4 to 1.7°C/W with the heating temperature increasing from 40 to 50°C. Moreover, the thermal contact resistance further increases to about 2.1~2.9°C/W when the heating temperature is in the range of 60~70°C. Similar tendency can be also found for the thermal



(a)

(b)

(c)

Figure 3: (a) The size and shape of the specimens, (b) AlN flake, and (c) AlN film compositing with PCM.

contact resistance (R_2). The effects of heating temperatures on heat transfer rates for Cu/PCM-AlN/Cu under 48 kPa (1.5 kgw) are shown in Figure 9. This figure shows that the heat transfer rate is about 8~9.5 W when the heating temperature is in the range of 40~50°C. However, the heat transfer rate significantly increases from 10.5 to 12 W with the heating temperature increasing from 60 to 70°C.

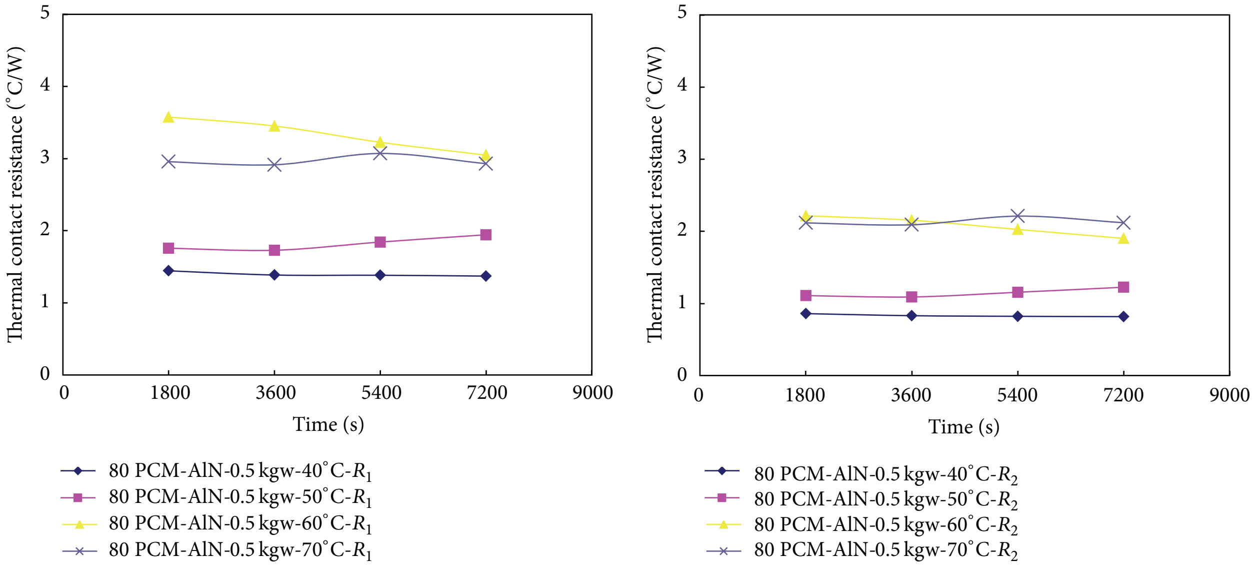
Compared to the above results under 16 kPa, the variations of thermal contact resistance and heat transfer rate are similar. Moreover, the real contact areas significantly increase with increasing the contact pressure. Therefore, the thermal contact resistance decreases and the heat transfer rate increases under the higher contact pressure.

Furthermore, it is seen from Figure 10 that the thermal contact resistance of Cu/PCM-AlN/Cu is about 2.5°C/W under steady state. However, it shows only 2°C/W under steady state for Cu/PCM/Cu in Figure 11. Moreover, the temperature difference between T_{a1} and T_{a2} is about 20°C.

Compared to the two cases of Cu/PCM-AlN/Cu and Cu/PCM/Cu, the thermal contact resistance increases and the heat transfer rate decreases under the higher temperature. However, the thermal contact resistance decreases and the heat transfer rate increases due to the fact that the air holes are filled by the softened PCM under the higher contact pressure. This indicates that the PCM had fused at this temperature and pressure. Not only heat transfer but also heat convection occurred between the interfaces.

4. Conclusions

The thermal contact resistance and the heat transfer rate of Cu/PCM-AlN/Cu and Cu/PCM/Cu were experimentally



(a) R_1 thermal contact resistance

(b) R_2 thermal contact resistance

FIGURE 4: Effects of heating temperatures on thermal contact resistances for Cu/PCM-AlN/Cu under 16 kPa (normal load of 0.5 kgw). (a) R_1 and (b) R_2.

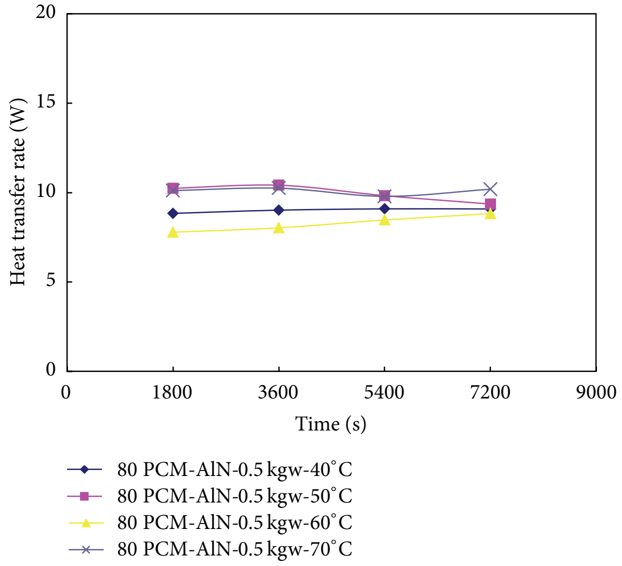
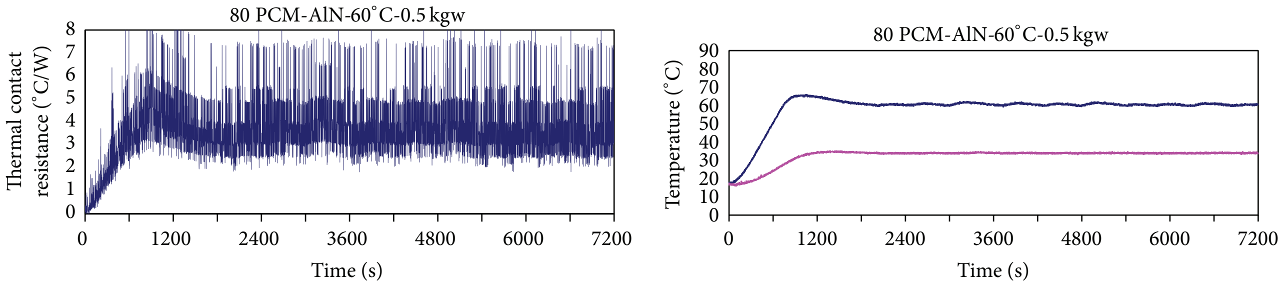


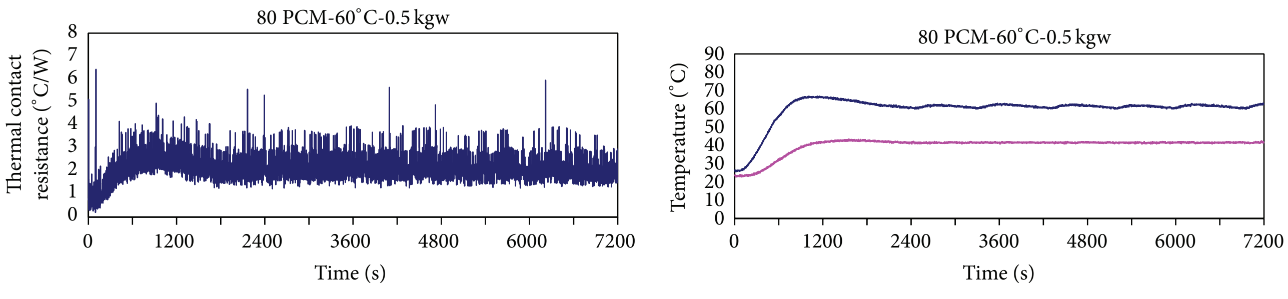
FIGURE 5: Effects of heating temperatures on heat transfer rates for Cu/PCM-AlN/Cu under 16 kPa (normal load of 0.5 kgw).



(a)

(b)

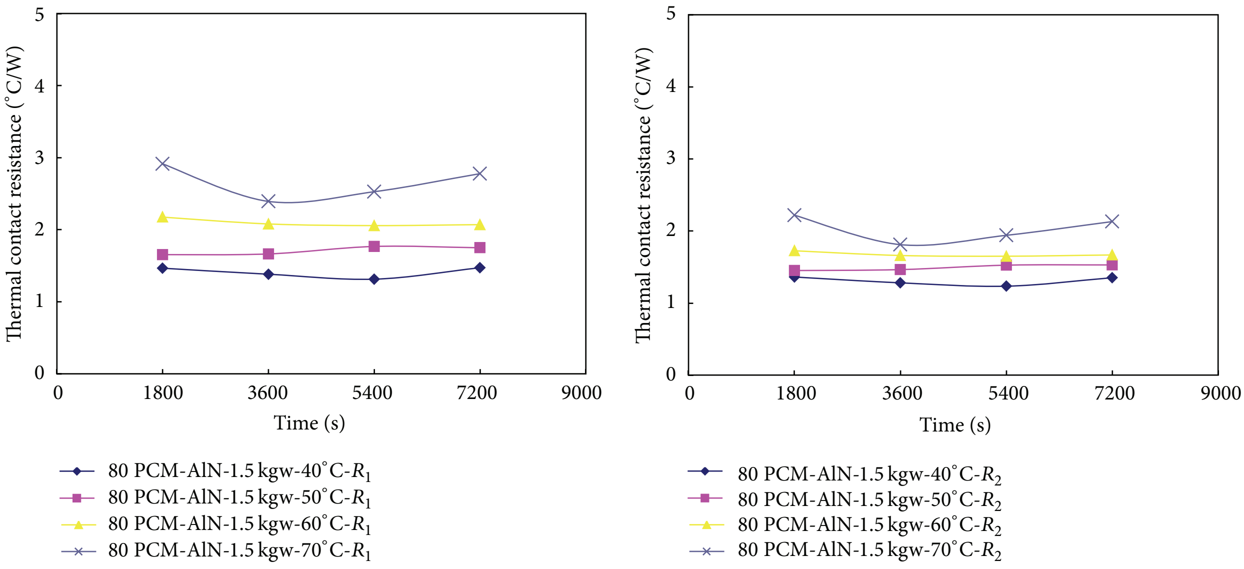
FIGURE 6: Variations of thermal contact resistance and temperature for Cu/PCM-AlN/Cu under 16 kPa (normal load of 0.5 kgw).



(a)

(b)

Figure 7: Variations of thermal contact resistance and temperature for Cu/PCM/Cu under 16 kPa (normal load of 0.5 kgw).



(a) R_1 thermal contact resistance

(b) R_2 thermal contact resistance

Figure 8: Effects of heating temperatures on thermal contact resistances for Cu/PCM-AlN/Cu under 48 kPa (normal load of 1.5 kgw). (a) R_1 and (b) R_2.

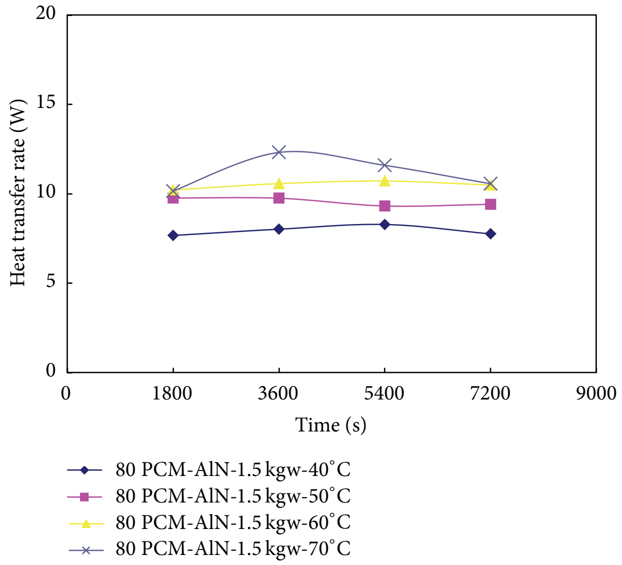


Figure 9: Effects of heating temperatures on heat transfer rates for Cu/PCM-AlN/Cu under 48 kPa (normal load of 1.5 kgw).

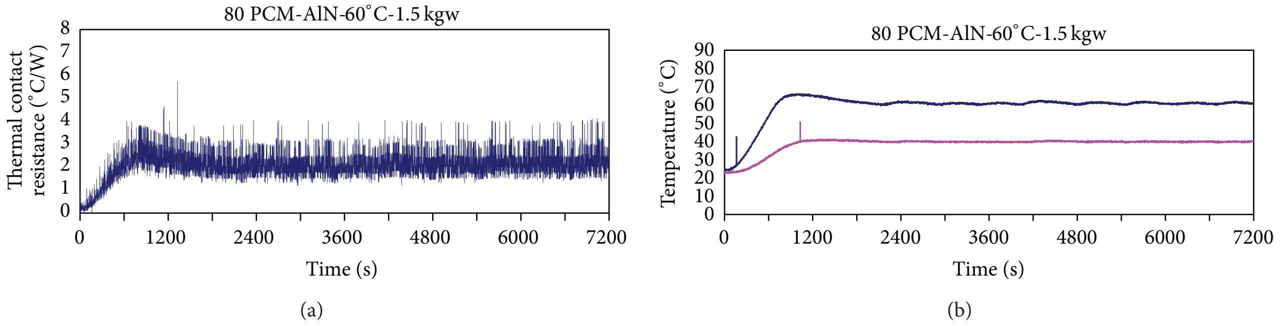


Figure 10: Variations of thermal contact resistance and temperature for Cu/PCM-AlN/Cu under 48 kPa (normal load of 1.5 kgw).

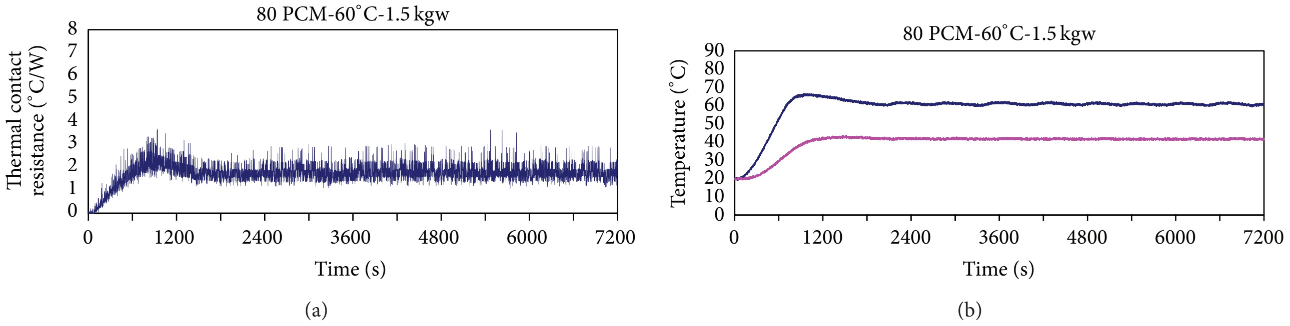


Figure 11: Variations of thermal contact resistance and temperature for Cu/PCM/Cu under 48 kPa (normal load of 1.5 kgw).

investigated in this study. From the experimental results, the following conclusions were drawn.

(1) The AlN film between Cu/PCM and AlN/Cu increases the thermal contact resistance and decreases the heat transfer rate when the heating temperature is smaller than 70°C.

(2) The real contact areas significantly increase with increasing the contact pressure under the melting process of PCM. Therefore, the thermal contact resistance decreases and the heat transfer rate increases under the higher contact pressure.

(3) The heat transfer decreases and the thermal contact resistance increases under the melting process of PCM. However, not only heat transfer but also heat convection occurs between the interfaces at 70°C and 48 kPa. Therefore, the higher contact pressures can be used to improve the above defects.

Conflict of Interests

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

Acknowledgment

The authors would like to express their appreciation to the National Science Council in Taiwan for their financial support under Grant no. NSC 101-2221-E-168-014.

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