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Experimental Study on Enhanced Interfacial Heat Transfer By Liquid Metal

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Abstract

The development of science and technology provides the necessary foundation for the construction of intelligent ships and modern ships. Of course, there are still some problems to be solved for intelligent ships, because with the development of micro-nano electronic technology, the integration degree of various chips can be rapidly improved. Thermal interface material, also known as interfacial heat conduction material, is a kind of material that widely uses electronic heat dissipation. And thermal interface materials is as a filling material, the effects on the tiny space between cooling device and electronic components of the hollow surface uneven and produce high-performance materials, which increases the contact area between the solid surface, thus improve the cooling performance of the electronic components because of poor wettability of liquid metal, hard to practical application. In this paper, through the experimental method, to improve the practical application effect of liquid metal, to solve the problems encountered in the practical application of liquid metal. Part of the experiment is to improve the wettability of liquid metal by adding magnetic particles and non-magnetic particles, and then explore the influence of magnetic field on the thermal conductivity of liquid metal. The other part of the experiment is to repeatedly daub and rinse the surface of the experimental matrix through acid solution, so as to improve the wetting effect between it and the liquid metal and improve the heat dissipation performance of the liquid metal.

Keywords

Thermal interface material; Liquid metal; Wettability.

1. Quotation

Heat transfer is a common phenomenon in nature. If there is a temperature difference between the two places, there will be a natural transfer of heat to achieve a dynamic equilibrium. In heat conduction, the characterization of the thermal conductivity of materials is measured by the thermal conductivity coefficient, and it is very important to accurately obtain the material parameters [5, 6]. Nowadays, we mainly obtain the thermal conductivity through experiments. Although there are a variety of measurement methods, the measurement accuracy, sample size and the required conditions are different from each other [7]. According to the different materials used, test requirements and accuracy, the thermal conductivity measurement methods can be divided into steady state method and non-steady state method according to the operating mechanism.

2. Experimental Principle

The steady-state method is used to measure the thermal conductivity [8,9]. In the test, after the temperature distribution on the tested sample reaches the stable-constant value, the heat

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conduction stability can be guaranteed to reach one-dimensional conduction before the measurement. Based on the heat flow and temperature gradient on the unit area of the sample, we can calculate the thermal conductivity of the material [10, 11]. The formula [12] involved in its testing principle is as follows:

$$\lambda = B \bullet \frac{Q}{\Delta T / L} \tag{1}$$

Among them; λ represents the thermal conductivity of the model to be measured, and its unit is W/ (m. K);B represents the instrument constant, which is related to the type of pattern used and to the test device; Q is the heat flux, the unit is W/ ㎡;△T represents the temperature difference between the two ends of the temperature gradient of the sample to be tested, and the unit is K; L represents the distance between the two ends of the sample to be tested, expressed in units of m.

Steady-state method is based on Fourier law, which is easy to operate and simple to calculate. It is a common method to measure thermal conductivity. However, considering the difficulty of constructing the temperature gradient, it takes a long time in the process of use. In reality, the more common steady-state testing methods include protective hot plate method, round tube method, heat flow meter method, etc.

3. Overview of Experimental Machine

Figure 1. The experimental apparatus

The experimental apparatus is shown in the figure 1. The experimental instrument DRL-III thermal conductivity tester adopts the heat flow method in the steady state method to measure the thermal conductivity of the material. DRL-III thermal conductivity tester is composed of 1 test host and 1 high precision constant temperature water tank. It is connected with a computer and used as a complete set. The reason why the heat flow method is chosen to measure the thermal conductivity of the material in the experiment is that this method has low cost, high accuracy of measurement results and short test cycle.

The DRL-III instrument has the functions of automatic pressure measurement, automatic thickness measurement and automatic experimental control, which can effectively reduce the experimental error caused by human operation. At the same time, the instrument uses 6 point temperature gradient detection, the dynamic temperature change record is more accurate, improve the test accuracy. In the measurement of thermal conductivity and thermal resistance of materials and contact thermal resistance at the interface, the instrument adopts the optimized mathematical model to improve the testing accuracy.

3.1. The Main Parameters of The Experimental Instrument

Table 1. The main parameters of the experimental instrument.

The sample size	The Sample thickness	Coefficient of thermal conductivity	Accuracy of the test	Displacement measurement	The power supply
≤Φ30mm	0.02-20mm	0.05~45 W/m*k	0~1000N	0~40mm	Voltage: 220V

3.2. Test Steps of The Instrument

3.2.1 Measurement of thermal conductivity of the sample to be tested

1, sample preparation: when treating the test sample preparation, the sample diameter prepared is better equal to or less than 30mm, because the diameter of the test head is 30mm.When the thickness of the test sample is very thin, we can stack multiple test samples. If we want to measure some paste or powder samples, we can add a circular frame and place the material in the frame for measurement. The frame shall be made of materials with low thermal conductivity. When using this instrument to measure, if the sample can not be stacked test, then the thermal conductivity coefficient is error, the error is affected by the contact thermal resistance of the test head and the contact surface of the sample to be tested.

2, sample loading: before the sample loading, we should test the instrument for pressure zero and displacement zero processing. First press the loading button, adjust the upper test head to the distance of the lower test head 1~2mm, and then press the pressure reset, the pressure reset processing. Then continue to load the instrument to the pressure value we need, and then reset the displacement. After displacement clearing, we placed the test sample to be tested on the lower test head and fixed it well.

3. We control the hot end temperature of the sample to be tested by input the hot pole temperature to be set by computer software. For the temperature we will set, enter the "Set temperature" column, and then click the "Run" button to start heating. The operation interface is shown in Figure 2.

4. According to the diameter of the sample to be tested, we calculate its area perpendicular to the direction of heat flow, and then input the calculated value into the column of "sample area".

5. If the thickness of the sample to be tested is known, we can choose to manually input the thickness or we can directly carry out the sixth step operation.

6. After the sampling is finished and the relevant parameters are set, we can click the "Start Experiment" button to carry out the measurement experiment. Once the instrument has started the experiment, it will enter the automatic test mode. After the temperature reaches a steady state, the instrument will record the data in three periods, each of which is 200s long. If there is a large temperature fluctuation in the middle, the instrument will record again. After a group of experiments, we click "Continue Experiment" to carry out experiments on samples of different thicknesses. After completing all the experiments, click "Complete Experiment" to end the experiment and get the experimental data.

7. Press the "Generate Report" button, and the experiment report can be printed and output for saving.

8. After the measurement of other experiments to be tested, we can repeat steps 3-4-5-6-7 for the experiment.

3.3. Disadvantages Of Routine Instrument Testing paste

This paper is mainly to test the thermal conductivity of liquid metal and thermal silicone grease. Liquid metal and thermal silicone grease are paste. According to the instructions of the instrument, we need to add a frame with low thermal conductivity to test the thermal conductivity of paste. Using this method, the paste to be tested is in direct contact with the copper metal test head, which needs to take into account whether the paste will cause dirt on the test head, resulting in damage to the test head. Test head damage will directly affect the test results, resulting in serious deviation of the measured data, and the cost of replacing the test head is very high. Traditional thermal conductivity silicone grease smear on the test head, can be used to wipe clean alcohol, will not produce dirt on the test head. However, the liquid metal will adhere to the copper metal test head and it is difficult to completely wipe clean, resulting in the damage of the test head. On the other hand, when using the frame to directly measure the paste thermal interface material, the test instrument can not eliminate the contact thermal resistance between the paste material and the test head, thus increasing the test error. Combined with the above two reasons, we can not use the method of adding a frame to conduct experiments when measuring the thermal conductivity of liquid metal.

4. Principle of The Experimental Method

Thermal conductivity is an inherent property of the substance itself. When a substance is determined, its thermal conductivity is fixed. In this experiment, one-dimensional steady-state method is used to measure the thermal conductivity of thermal interface materials. Therefore, we assume that heat is uniform and passes through thermal interface materials in a single vertical direction. Therefore, we can obtain the body thermal resistance when heat passes through thermal interface materials according to Fourier law, and we can obtain the formula according to the definition:

R body is the body thermal resistance of thermal interface materials; BLT is the thickness of the thermal interface material; Ktim is the thermal conductivity of the thermal interface material.

According to the above formula, we can measure the body thermal resistance and thickness of the thermal interface material to obtain its thermal conductivity. At the same time, in order to avoid the direct contact between the thermal interface material and the test head of the instrument, we can set up a sample bracket to the thermal interface material between two copper sheets, and then put the sample bracket between the test head to test its overall thermal conductivity. At this time, the thermal interface material is not in complete contact with the copper sheet, and the upper and lower copper sheets are not in complete contact with the test head, resulting in four contact thermal resistances R1, R2, R3 and R4.At this point, the total thermal resistance R of the sample bracket can be expressed by the following formula: $R_{总} = R_{体} + R_1 + R_2 + R_3 + R_4$.

Namely:

$$R_{总} = \frac{BLT}{K_{TIM}} + R_1 + R_2 + R_3 + R_4$$

At this point, the thermal resistance model of the sample bracket can be expressed as figure 2.

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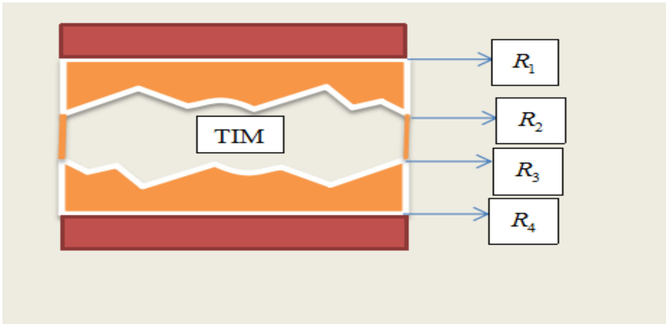

Figure 2. Thermal resistance model of sample bracket

The DRL-III thermal conductivity tester we use in the experiment uses a test head with a diameter of 30mm, so we use a copper sheet with a diameter of 30mm to design the sample bracket. The sample bracket mainly consists of four parts, namely the upper metal sheet, the lower metal sheet, the metal wires of different diameters (named as No. 1 and No. 2 wire respectively) and the insulation ring. The structures are shown in Figure 3.

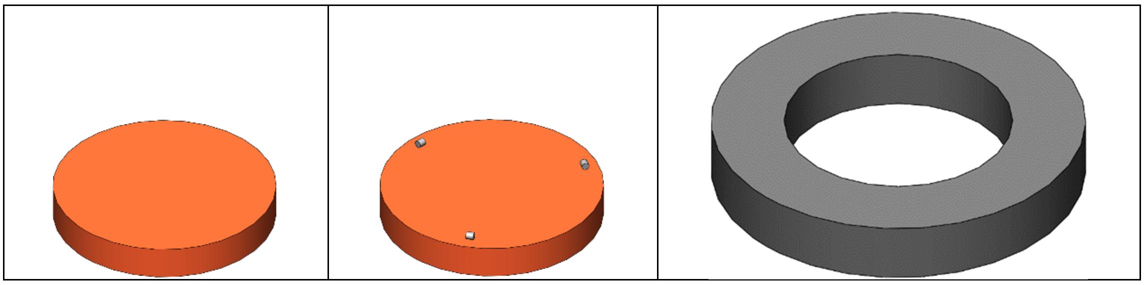

Figure 3. Schematic diagram of each part of the sample bracket

According to the above sample preparation and measurement process, the overall thermal resistance RTOT, 1 and RTOT, 2 and the overall thickness L1 and L2 of No. 1 and No. 2 samples can be obtained. Thermal resistance network analysis was conducted on the overall thermal resistance of No. 1 and No. 2 samples, and the results were shown in Figure 5 and Figure 6.

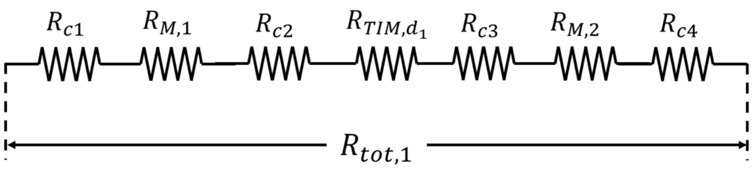

Figure 4. Sample 1 overall thermal resistance network analysis

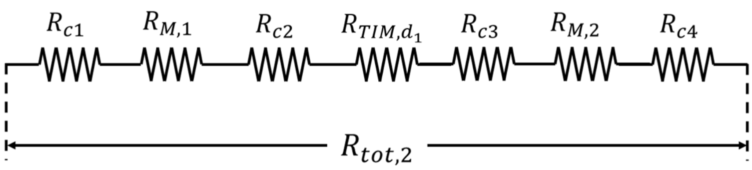

Figure 5. Sample 2 overall thermal resistance network analysis

By figure 4, Rtot, 1 consists of seven parts, including Rc1 on thermal contact resistance between metal with measuring arm, RM, 1 is the thermal resistance of metal itself, Rc2 for the thermal contact resistance between metal and paste material, RTIM, d1 for d1 paste thickness material's thermal resistance, Rc3 to paste material and the thermal contact resistance between metal,

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RM, 2 for the thermal resistance of metal itself, Rc4 for measuring arm with the thermal contact resistance between metal.

Through the above experimental scheme, we only need to measure two groups of samples with different thicknesses, then we can calculate the thermal conductivity coefficient of thermal interface material, which is convenient and fast, and reduces the experiment cycle. If the previous scheme is adopted, we need to measure several groups of data, and then carry out fitting calculation to get the thermal conductivity.

We will use 0.2mm wire to prepare sample 1, and then use 0.5mm wire to prepare sample 2. Then we used the measurement method designed in this paper to carry out three groups of measurements on the samples prepared by pure liquid metal respectively, and the experimental results obtained are shown in table 2.

4.1. The Thermal Conductivity of Liquid Metal is Measured

Table 2. Measurement results of thermal conductivity of pure liquid metal

Sample number	Test pressure	Heat flow	Sample thickness	The overall thermal resistance
sample1	70	21.97	10.03	736.0
sample1	70	22.30	10.03	727.0
sample1	70	22.32	10.03	726.0
sample2	70	19.37	10.34	916.0
sample2	70	19.35	10.34	917.0
sample2	70	19.37	10.34	916.0

According to the measured data in figure 7, the thermal conductivity of pure liquid metal is measured as W/ MK by calculation and experimental error analysis. The experimental results are significantly lower than the true thermal conductivity of liquid metal, and the thermal conductivity of liquid metal Ga67In20.5Sn12.5 as reported by Mei is 13.6W/mK. Through the measurement of thermal conductivity silicone grease with known thermal conductivity coefficient, it is proved that there is no problem with our experimental method. This result is caused by the poor wettability between the liquid metal and the copper sheet. As shown in table 2, the liquid metal does not fit perfectly with the copper sheet, and the poor wettability makes the liquid metal have obvious aggregation phenomenon. The agglomeration phenomenon makes the liquid metal can not be evenly distributed on the surface of the copper sheet, so the gap between the two copper sheets can not be fully filled, resulting in the experimental results far lower than the liquid metal thermal conductivity and poor experimental repeatability

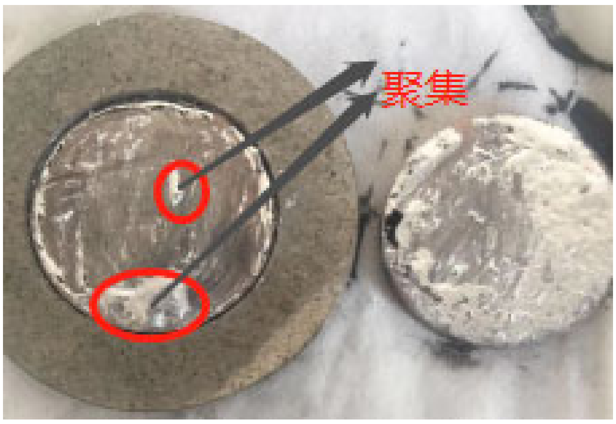

Figure 6. Pure liquid metal sample

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5. Improvement Methods for Wettability of Liquid Metals

Measurements of pure liquid metal show that the wettability of liquid metal and copper sheet is very poor. Poor wettability means that the liquid metal has a large contact Angle with the solid surface and cannot fit well with the solid surface, thus increasing the thermal resistance of the air, which leads to a very small thermal conductivity measurement result of the liquid metal. We first put two pieces of copper into the ultrasonic oscillator containing ethanol, ultrasonic cleaning, remove the magazine on the surface of the copper. Then put the clean copper sheet flat in the glass container, and then pour a certain amount of dilute hydrochloric acid into the lower surface of the copper sheet, soak for 1 hour. Then take out the copper, with a test tube will be a small amount of dilute hydrochloric acid drops in the copper soaked in the dilute hydrochloric acid side, and then use forceps clip to clean cotton cloth repeatedly wipe.

5.1. The Treated Copper Sample Will be Prepared to Measure the Thermal Conductivity

We coated pure liquid metal on the surface of copper sheet treated with dilute hydrochloric acid, and then prepared three layers of experimental samples for measurement. The liquid metal sample obtained after acid solution treatment is shown in Figure 7. Compared with before modification, the liquid metal can flatten to the copper surface better, and the wettability is improved.

Figure 7. Liquid metal sample modified by acid solution

We tested the modified samples, and the measured results are shown in table 3.

Table 3. Measurement results of thermal conductivity of pure liquid metal

Sample number	The test pressure	Heat flow	Sample thickness	The overall thermal resistance
sample1	70	30.39	9.98	332
sample1	70	30.33	9.98	333
sample1	70	30.33	9.98	333
sample2	70	29.742	10.54	370
sample2	70	29.741	10.54	370
sample2	70	29.742	10.54	370

According to the measured data in figure 7, the thermal conductivity of the pure liquid metal of copper sheet treated with dilute hydrochloric acid is W/mK by using the formula. The thermal conductivity of liquid metal measured after treatment with dilute hydrochloric acid is greatly improved compared with that measured without treatment in Section 5.1, which is basically consistent with the thermal conductivity of liquid metal Ga67In20.5Sn12.5 as reported by Mei, which is 13.6W/mK.According to the comparison of the experimental results, it can be concluded that the treatment of copper sheet with dilute hydrochloric acid can improve the wettability of the surface of liquid metal and copper sheet, reduce the contact Angle, make the liquid metal can better fit the surface of copper sheet and reduce the contact thermal resistance.

Conclusion: Through the experimental measurement of the modified copper sheet, it is found that the thermal conductivity of the copper sheet and the liquid metal sample prepared by the treatment of dilute hydrochloric acid has been greatly increased, which proves that the use of acid solution can improve the wettability of the copper sheet and the liquid metal.

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