TEMPERATURE UNIFORMITY ANALYSIS OF HEAT SPREADERS DURING HEATING AND COOLING

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Abstract- Vapour chamber (VC) heat spreader can be applied for thermal cycling, consisting of cycles of repeated heating and cooling of reaction. In this paper, temperature uniformity of multiwell heat spreaders fabricated using Copper (Cu), Silver (Ag), Aluminium (Al), and VC were analysed by CFD software. Thermoelectric (TEC) cooler was used as heat sources, and the spreaders were heated firstly from 25°C to 95 °C, using asymmetric single source mode. Secondly, a heating and cooling process (25°C-95°C-55°C-72°C) under a symmetric six heat sources mode was also studied. The results showed that the VC exhibited greater temperature uniformity compared with the other materials because of its high coefficient of heat conduction.

Keywords- Heat Spreader, Temperature Uniformity, Thermoelectric, Vapour Chamber.

I. INTRODUCTION

In recent years, with the increasing heat dissipation of electrical appliances, efficient cooling systems are required to solve the elevated temperature problems encountered in certain interior areas of electrical devices. Among these cooling technologies, vapour chamber may offer the optimal balance in heat spreading, high heat removal capability, spreading hot spot problems, and maintaining an isothermal heat sink base. Developed in 1983 by Kary Mullis, polymerase chain reaction (PCR) is now a common and often indispensable technique used in medical and biological research labs for a variety of applications. The method relies on thermal cycling, consisting of cycles of repeated heating and cooling of the reaction for DNA melting and enzymatic replication of the DNA. Typically, PCR consists of a series of 20-40 repeated temperature changes, called cycles, with each cycle commonly consisting of 2-3 discrete temperature steps, usually three. The cycling is often preceded by a single temperature step (called hold) at a high temperature (>90°C), and followed by one hold at the end for final product extension or brief storage. The temperatures used and the length of time they are applied in each cycle depend on a variety of parameters. A heat spreader is commonly used to perform PCR, ensuring temperature uniformity during the process, and facilitating the reproduction of large amounts of DNA. Currently, commercial heat spreaders are fabricated using aluminium (Al), copper (Cu), and silver (Ag). An application of VC in PCR was proposed by Schlauibitz et al. in a patent.

Kang et al. performed a simulation to test VCs by using two and six heat sources, operating at various heat powers. The results indicated that the temperature of the six heat sources was more uniform compared with that of the dual heat sources, because of their uniform distribution. When low power is applied, VCs may be easily affected by the environmental temperature, and the temperature rises in a curvy trend. When high power is applied, the temperature rises linearly. Chang et al. used TEC as heater source, and investigated temperature uniformity and heating rate when the spreaders were heated from 25°C to 95°C. Huang et al. used semiconductor cooling chips in gene reproduction, and simplified the model. The simulation results revealed that the semiconductor cooling chips exhibited an optimal operating voltage range. Outside of this range, the cooling chip effect becomes unstable, potentially affecting the temperature uniformity of VCs. The present study used thermoelectric (TEC) coolers heat sources to simulate the temperature distribution of heat spreaders made of Al, Cu, Ag, and VC during heating and cooling process (25°C-95°C-55°C-72°C), attempting to determine which heat spreader yielded the greatest temperature uniformity.

II. CFD SIMULATION METHODS

Fig. 1 Physical model of vapour chamber
The physical model comprised four parts: the upper and lower plates of the heat spreader, a heating element, and a cooling fin (Fig. 1). The heat spreaders had a size of 112 mm × 75 mm × 17.2 mm; the upper plate exhibited 173 holes that were 5 mm in diameter and 10 mm deep, and the lower plate was rectangular. 30 mm × 30 mm TEC cooler was used for heating and cooling operating at a driving current of 3 A. The size of the cooling fin was 112 mm × 75 mm; the substrate was 10 mm thick, and the fins were 40 mm high and 1.5 mm thick, totalling 20 pieces. The heat spreaders were made of Ag, Cu, Al, and VC. The parameters of the Ag, Cu, and Al were obtained from the Icepak database, and the parameters of the VC were obtained following the method of Kang. As shown in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass (kg)</th>
<th>Density (kg/m³)</th>
<th>Specific heat (J/kg-K)</th>
<th>Heat capacity (J/K)</th>
<th>Coeff. heat conduction (W/m-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
<td>0.789</td>
<td>6507</td>
<td>427</td>
<td>337</td>
<td>955</td>
</tr>
<tr>
<td>Cu</td>
<td>1.084</td>
<td>8933</td>
<td>397</td>
<td>430</td>
<td>388</td>
</tr>
<tr>
<td>Ag</td>
<td>1.276</td>
<td>10524</td>
<td>236</td>
<td>301</td>
<td>427</td>
</tr>
<tr>
<td>Al</td>
<td>0.327</td>
<td>2800</td>
<td>900</td>
<td>294</td>
<td>205</td>
</tr>
</tbody>
</table>

The boundary size of the simulation and calculation zone depends on the natural convection conditions. To achieve accurate results, the simulated item must be 1.5 times larger compared with the solid model. To meet the actual conditions, the ambient temperature was set to 25 °C, and the effect of gravity was considered. A Melcor (CP1.0-127-05L) TEC model was established in Icepak. The Melcor TEC exhibited 127 pairs of TEC couples electrically connected in series between two ceramic plates. The material property coefficients of the TEC model, such as the Seebeck coefficient, resistivity, and thermal conductivity, were calculated using the Melcor datasheet.

III. RESULTS AND DISCUSSION

A. Single-heat-source mode

Only one heater in the left lower corner of the heat spreaders and seven temperature observation points were considered in the single-heat-source mode simulation (Fig. 2a). Fig. 2b shows the temperature distribution of the VC heat spreader when a single heat source was used. Fig. 3 illustrates the average temperature (Tave) and compare the temperature differences at seven observation points during the heating (until 600 sec.) of the Ag, Al, Cu, and VC heat spreaders. The dashed line represents the average temperature and the solid lines represent the temperature difference (ΔT). Average temperature...
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The temperature difference (ΔT) was defined as the difference between the individual observation temperature and average temperature, for example (T1–Tave). The heat spreaders exhibited various average temperatures during 600 sec. of heating. The Tave values of the Ag, Al, Cu, and VC at 600 sec. were 127.87 °C, 134.12 °C, 108.69 °C, and 63.97 °C, respectively. The VC exhibited the lowest average temperature. The greatest temperature difference (T5–Tave) was attained when the highest temperature occurred in the centre of the heat source (T5). The smallest temperature difference (T3–Tave) was attained when T3 was located farthest from the heat source. The (T4–Tave), (T2–Tave), (T7–Tave), and (T3–Tave) values were negative, indicating that the T4, T2, T7, and T3 temperatures were lower than the average temperature. The VC exhibited the smallest temperature difference, and thus, the greatest temperature uniformity. This transient asymmetric heating approach can be applied to detail the thermal performance levels of heat spreaders.

B. Six-heat-source mode
Six TEC coolers were used for heating and cooling in this study. Temperature uniformity was assessed by comparing the maximum temperature differences of the heat spreaders and considering 7 temperature observation points. First step consisted of heating the spreader from a temperature of 25 °C to 95 °C, which is held for 10 sec. Then the temperature was lowered to 55°C for another 10 sec. The final step was performed at 72°C for 10 sec. Fig. 4 shows the heating and cooling process (25°C- 95°C- 55°C- 72°C) for spreaders, indicating the complete time of the VC, Ag, Al, and Cu heat spreaders was 84 sec., 98.4 sec., 109.3 sec., and 130.9 sec. respectively. The VC exhibited both the fastest heating and cooling rate.

Fig. 5 shows the temperature uniformity rank based on the maximum temperature difference (Tmax-Tmin) at 95°C, 55°C, and 72°C.

Fig. 5 Temperature uniformity rank based on the (Tmax-Tmin) at 95°C, 55°C, 72°C

Comparing the temperature differences of the materials, indicated that the VC exhibited the greatest temperature uniformity in the six-heat-source mode, followed by the heat spreaders made of Ag, Cu, and Al.

Fig. 6 shows the temperature distribution of VC at 95 °C, 55°C and 72°C. Temperature uniformity is likely...
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CONCLUSION

In this study, the temperature uniformity of multiwell heat spreaders composed of Ag, Cu, Al and VC were simulated and analysed during heating and cooling in natural convection conditions. Both the single TEC and six TEC heat source modes were investigated. The VC exhibited superior temperature uniformity compared with the other heat spreaders during a (25°C- 95°C- 55°C- 72°C) heating and cooling process due to its higher thermal conductivity.

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