Evaluation of thermal control performance of phase change materials for thermal shock protection of electronics

X H Yang*, C H Huang, H B Ke, L Chen and P Song
Science and Technology on Thermal Energy and Power Laboratory, Wuhan Second Ship Design and Research Institute, Wuhan 430205, Hubei province China
E-mail: yangxhcsic@163.com

Abstract. Phase change materials have important application value in the fields of heat storage, cold storage, and thermal shock protection of electronic chips. In particular, in the field of chip thermal shock protection, phase change materials can use the solid-liquid phase change process to absorb a large amount of latent heat, thereby suppressing the temperature rise of the chip and preventing it from overheating. At present, there are mainly three types of common phase change materials: organic, inorganic and metallic phase change materials. There exists significant difference in the thermophysical properties of the three types of materials, and their thermal control performance also have their own characteristics. This paper sorts out the main thermophysical data of the three types of phase change materials. Through theoretical modeling and analysis, the thermal control performance of these materials is quantitatively evaluated and compared. For typical chip thermal shock conditions, the three types of phase change materials are compared, and their typical characteristics are intuitively displayed. The research results can serve as value reference for the development of phase change thermal control technology for chips.

1. Introduction
Phase change materials (PCM) refer to a class of materials that undergo solid-liquid phase change within a certain temperature or temperature range. PCM can absorb or release a large amount of latent heat during their solid-liquid phase transition process, hence it can be used for thermal energy storage. Phase change heat storage has the characteristics of compact structure, large energy storage density, relatively simple system, stable and reliable operation, which can effectively alleviate the mismatch of heat energy supply and use in engineering practice in terms of time and magnitude. PCM can be used in solar energy systems, building energy conservation, power grid peak load shifting (night heat storage), waste heat recovery and utilization, cold chain logistics [1-5].

There are three kinds of PCM: (1) organic PCM, mainly including alkanes, alkane mixtures (paraffin), alcohols, fatty acids, etc.; (2) inorganic PCM, mainly referring to inorganic salts and hydrated inorganic salts; (3) metallic PCM, including alloy and pure metal. The range of use of PCM is different according to its melting point. In general, inorganic PCM are widely used in the field of high temperature heat storage (temperature is higher than 100 °C), such as solar heat storage. Organic PCM are suitable for low and medium temperature fields (0-100 °C), such as thermal control of electronic devices. Water is also a common PCM, its melting point is 0 °C, which can be used to store cold energy, and it is used in the fields of building cooling, food or medicine preservation and transportation. Metallic PCM can be subdivided into low melting point metal PCM (melting point lower than 100 °C) and medium/high temperature metallic PCM (melting point higher than 100 °C).
Among them, metallic PCM with low melting point are a new class of PCM that has emerged recently and attracted the attention of researchers and engineers [6-8], it has high thermal conductivity (about $10^2$ higher than that of inorganic and organic PCM), large heat storage density, and low thermal expansivity. More details about the characteristics of metallic PCM can be seen in our latest review works [9, 10].

In particular, in the field of electronics cooling, PCM can be used for temperature control of electronic devices that work instantaneously or intermittently [11, 12]. When the chip works, heat is inevitably generated, and the PCM absorbs the heat and melts, while its temperature remains almost unchanged. Therefore, the temperature rise of the chip can be effectively suppressed and the device can be prevented from overheating. When the chip stops working, the PCM releases the absorbed heat into the surrounding environment and solidifies, preparing for the next thermal shock. Based on this principle, PCM can be used in the fields of mobile electronic equipment cooling, chip thermal shock protection, electric vehicle battery pack thermal management, constant temperature clothing, and temperature control of aerospace electronics.

At present, there has been a lot of research on chip thermal shock protection technology based on PCM. Among them, organic PCM occupy dominant position, inorganic PCM are rarely investigated, and the research of metallic PCM has risen and developed rapidly in recent years. This article systematically sorts out and compares the main thermophysical data of the three types of PCM, and quantitatively evaluates and compares their thermal control performance through theoretical analysis. Finally, for the typical thermal shock conditions in practice, the three types of PCM are compared, and their typical characteristics are intuitively displayed, which provides a reference for the development of PCM based thermal shock protection technology for electronics.

2. Classification and comparison of PCM

2.1 Organic PCM
Organic PCM are a class of medium-low temperature PCM, which can be divided into two categories: paraffin and non-paraffin. Paraffin refers to the mixture of straight-chain alkane, which generally does not have a specific melting point, its melting point range varies with the composition and proportion of the mixture. In many literatures, alkane compounds are also directly referred to as paraffin. The general expression of alkanes is $\text{C}_n\text{H}_{2n+2}$, generally, as the number of carbon atoms increases, the melting point of alkanes increases, and the latent heat also increases. For example, the melting point of alkane with carbon number between 5-34 gradually increases from 5.5 °C to 75.9 °C. Non-paraffin PCM mainly include fatty acids, esters, alcohols, glycols.

Table 1 lists the main thermal properties of some organic PCM. The latent heat of paraffin PCM is generally about 200-300 kJ/kg, while the value of non-paraffin waxes are generally about 100-200 kJ/kg. The thermal conductivity of organic PCM is very low, generally around 0.2 W/m·K, which severely limits its heat transfer performance. In addition, organic PCM are flammable, and their ignition point is generally around 200 °C, which requires special attention in practical use.
Table 1. Thermophysical properties of some organic PCM [9].

| PCM            | Melting point ($^\circ$C) | Fusion latent heat (kJ/kg) | Density ($\text{kg/m}^3$) | Specific heat capacity ($c_p$ (kJ/kg·K)) | Thermal conductivity ($k$ (W/m·K)) |
|----------------|---------------------------|---------------------------|---------------------------|----------------------------------------|----------------------------------|
| Octadecane     | 28.2                      | 244                       | 814(s)/724(l)$^a$         | 2150(s)/2180(l)                        | 0.36(s)/0.15(l)                 |
| Heneicosane    | 41                        | 294.9                     | 773(l)                    | 2386(l)                                | 0.145(l)                        |
| Tricosane      | 48.4                      | 302.5                     | 777.6(l)                  | 2181(l)                                | 0.124(l)                        |
| Tetracosane    | 51.5                      | 207.7                     | 773.6(l)                  | 2924(l)                                | 0.137(l)                        |
| IGI 1230A      | 54.2                      | 278                       | 880(s)/770(l)             | 2800(l)                                | 0.25(s)/0.14(l)                 |
| Octadecenoic acid | 13                       | 75.5                      | 871(l)                    | 1744(l)                                | 0.103(l)                        |
| Capric acid    | 32                        | 152                       | 1005(s)/878(l)            | 1950(s)/1720(l)                        | 0.153(l)                        |
| Lauric acid    | 44                        | 178                       | 1007(s)/965(l)            | 1760(s)/2270(l)                        | 0.147(l)                        |
| Hexadecenoic acid | 64                        | 185                       | 989(s)/850(l)             | 2200(s)/2480(l)                        | 0.162(l)                        |
| Stearic acid   | 69                        | 201                       | 966(s)/848(l)             | 2830(s)/2380(l)                        | 0.172(l)                        |

$^a$: s: solid; l: liquid

2.2 Inorganic PCM

Inorganic PCM are a class of medium-high temperature PCM, mainly referring to inorganic salts and hydrated inorganic salts. Hydrated inorganic salts are eutectic compounds formed by water and inorganic salts, such as magnesium chloride hexahydrate ($\text{MgCl}_2\cdot6\text{H}_2\text{O}$). The phase change of hydrated inorganic salt is essentially its hydration and dehydration process:

\[
\text{AB} \cdot n\text{H}_2\text{O} \rightarrow \text{AB} \cdot m\text{H}_2\text{O} + (n-m)\text{H}_2\text{O} \quad (1)
\]

\[
\text{AB} \cdot n\text{H}_2\text{O} \rightarrow \text{AB} + n\text{H}_2\text{O} \quad (2)
\]

Where, process (1) is incomplete dehydration process, process (2) is complete dehydration process.

The thermal conductivity of hydrated inorganic salt PCM is generally 2-3 times that of organic PCM, and their fusion latent heat is larger (Table 2), they are non-combustible, and the price is also cheaper than organic PCM. However, the biggest disadvantage of hydrated inorganic salts is that they have serious problem of sub-cooling, which means that the material does not solidify when it cools from the liquid phase to its melting point, it starts to solidify a few degrees or even tens of degrees below the melting point. The existence of sub-cooling seriously affects the heat release (or cold storage) process of the PCM, and sometimes even causes the cyclic heat storage function to fail due to its inability to undergo liquid-solid phase transition. Therefore, in practical use, the sub-cooling should be avoided or reduced as much as possible, solutions include adding nucleating agents and incomplete melting.

In addition, hydrated inorganic salts are prone to phase separation. In an ideal situation, after dehydration of the hydrated inorganic salt, the inorganic salt is completely dissolved in water; when solidified, the water and the inorganic salt crystallize sufficiently, thereby achieving a reversible cycle. However, for many hydrated inorganic salt PCM, the water content is usually insufficient to fully dissolve the salts, the inorganic salts are deposited in supersaturated water and cannot be recrystallized and hydrated. This irreversible dehydration/hydration process is called phase separation. The existence of phase separation causes the PCM to easily precipitate during the melting/solidification process, thereby reducing its effective heat storage capacity and recycling performance.

In addition to sub-cooling and phase separation, there is a problem with inorganic PCM that is corrosion and liquid leakage, that is, the corrosion of structural materials by inorganic salts and the leakage of liquid PCM. At present, an effective method to solve this problem is to synthesize composite PCM. Composite PCM are composed of one or more PCM and other organic or inorganic materials through physical or chemical methods. At present, the preparation methods of hydrated
inorganic salt composite PCM mainly include porous base material adsorption and microcapsule encapsulation.

**Table 2.** Thermophysical properties of some inorganic PCM [9].

| PCM             | Melting point $T_m$ (°C) | Fusion latent heat $\Delta H$ (kJ/kg) | Density $\rho$ (kg/m$^3$) | Thermal conductivity $k$ (W/m·K) |
|-----------------|-------------------------|--------------------------------------|---------------------------|---------------------------------|
| CaCl$_2$·6H$_2$O | 29.9                    | 191                                  | 1802(s)/1562(l)$^a$       | 1.008(s)/0.561(l)               |
| NaSO$_4$·10H$_2$O | 32                     | 251                                  | 1485(s)                   | 0.544                           |
| MgCl$_2$·6H$_2$O | 117                    | 168.6                                | 1569(s)/1450(l)           | 0.694(s)/0.579(l)               |
| NaNO$_3$        | 307                    | 172                                  | 2260(s)                   | 0.5                             |
| KNO$_3$         | 333                    | 266                                  | 2110(s)                   | 0.5                             |
| MgCl$_2$        | 714                    | 452                                  | 2140(s)                   | -                              |
| NaCl            | 802                    | 492                                  | 2160(s)                   | 0.5                             |
| KF              | 857                    | 452                                  | 2370(s)                   | -                              |

### 2.3 Metallic PCM

Metallic PCM include pure metals and alloys, and their melting points cover a wide range, ranging from 0 °C to hundreds of degrees, as can be seen in Table 3. The biggest feature of metallic PCM is their high thermal conduction capability, which is generally two orders of magnitude higher than that of organic and inorganic PCM. High thermal conductivity means excellent heat transfer performance and high heat storage efficiency, hence metallic PCM have attracted much attention in recent years. In the field of high temperature applications, high melting point metal PCM have higher latent heat of phase change (from 300 to 500 kJ/kg) and good cyclic thermal stability, it is expected to replace traditional inorganic PCM in the field of solar thermal storage. Metals with melting point around room temperature are also called low melting point metals or liquid metals, and their latent heat of phase transition is generally within 100 kJ/kg, mainly gallium-based and bismuth-based alloys. Low melting point metal PCM have become a good choice to replace traditional organic PCM for phase change thermal control because of their excellent heat transfer and heat storage capacity.

Metallic PCM are generally denser, which is both an advantage and a disadvantage. High density means that the latent heat of phase change per unit volume is large, that is, the energy storage density is large and the structure is compact. While at the same time, high density means that the weight per unit volume is large, which may be disadvantageous in the application of some flying equipment which requires light weight. In addition, metallic PCM generally have higher prices, which limits their wide application, especially in the case where requires large amounts, and in the field of chip temperature control with small amounts, this problem does not need to be considered. It should be noted that as a commonly used low melting point metal, gallium and their alloys are highly corrosive to the commonly used structural material aluminum, hence in practical use, they should avoid direct contact between the two. Surface coating (such as nickel plating) or coloring oxidation treatment on aluminum structural materials can provide good corrosion protection.
### Table 3. Thermophysical properties of some metallic PCM [9]

| PCM       | Melting point $T_m$ (°C) | Fusion latent heat $\Delta H$ (kJ/kg) | Density $\rho$ (kg/m³) | Specific heat capacity $c_p$ (kJ/kg·K) | Thermal conductivity $k$ (W/m·K) |
|-----------|--------------------------|-------------------------------------|-----------------------|----------------------------------------|-------------------------------|
| Hg        | -38.87                   | 11.4                                | 13546(l)              | 0.139(l)                               | 8.34(l)                       |
| Cs        | 28.65                    | 16.4                                | 1796(l)               | 0.236(l)                               | 17.4(l)                       |
| Ga        | 29.78                    | 80.16                               | 5904(s)/6095(l)       | 0.372(s)/0.398(l)                      | 33.49(s)/33.68(l)             |
| Rb        | 38.85                    | 25.74                               | 1470                  | 0.363                                  | 29.3                          |
| Bi$_{44.3}$Pb$_{22.1}$In$_{19.1}$Sn$_{8.3}$Cd$_{5.3}$ | 47 | 36.8                              | 9160                  | 0.197                                  | 15                            |
| Bi$_{40}$In$_{21}$Pb$_{18}$Sn$_{12}$ | 58.2 | 23.4                              | 9307(s)               | 0.213(s)/0.211(l)                      | 7.143(s)/10.1(l)              |
| Bi$_{31.4}$In$_{48.8}$Sn$_{19.6}$ | 60.2 | 27.9                              | 8043                  | 0.270(s)/0.297(l)                      | 19.2(s)/14.5(l)               |
| K         | 63.2                     | 59.59                               | 664                   | 0.78                                   | 54                            |
| Bi$_{50}$Pb$_{36.7}$Sn$_{13.3}$Cd$_{10}$ | 70 | 39.8                              | 9580                  | 0.184                                  | 18                            |
| Bi$_{52}$Pb$_{36}$Sn$_{18}$ | 96 | 34.7                              | 9600                  | 0.167                                  | 24                            |
| Na        | 97.83                    | 113.23                              | 926.9(l)              | 1.38(l)                                | 86.9(l)                       |
| Bi$_{58}$Sn$_{42}$ | 138 | 44.8                              | 8560                  | 0.201                                  | 44.8                          |
| In        | 156.8                    | 28.59                               | 7030                  | 0.23(l)                                | 36.4(l)                       |
| Li        | 186                      | 433.78                              | 515(l)                | 4.389(l)                               | 41.3                          |
| Sn$_{91}$Zn$_{9}$ | 199 | 32.5                              | 7270                  | 0.272                                  | 61                            |
| Sn        | 232                      | 60.5                                | 7300(s)               | 0.221                                  | 15.08(s)                      |
| Bi        | 271.4                    | 53.5                                | 9790                  | 0.122                                  | 8.1                           |
| Zn$_{52}$Mg$_{48}$ | 340 | 180                              | -                     | -                                      | -                             |
| Al$_{50}$Mg$_{35}$Zn$_{12}$ | 443 | 310                              | 2380                  | 1.63(s)/1.46(l)                        | -                             |
| Al$_{55}$Cu$_{35}$Si$_{5}$ | 571 | 422                              | 2730                  | 1.3(s)/1.2(l)                          | -                             |
| Zn$_{49}$Cu$_{43}$Mg$_{2}$ | 703 | 176                              | 8670                  | 0.42(s)                               | -                             |
| Cu$_{60}$Si$_{50}$ | 803 | 197                              | 6600                  | 0.5(s)                                | -                             |

#### 2.4 Comparison of the main thermophysical properties of different PCM

Figure 1 summarizes the phase change latent heat and melting point distribution of various common PCM. Generally, the latent heat of PCM increases with the increase of melting point, especially for organic PCM, this change trend is very obvious. The application temperature range of organic PCM is generally below 100 °C. The temperature range spanned by metallic PCM and inorganic PCM is relatively wide, ranging from near room temperature to several hundred degrees. In general, the gravitational latent heat of organic and inorganic PCM is relatively large, on the order of $10^2$ kJ/kg, while the latent heat value of metal PCM is an order of magnitude lower.

![Figure 1. Fusion latent heat versus melting point of typical PCM.](image-url)
Figure 2 summarizes the thermophysical properties of various PCM from another viewpoint, and plots the distribution relationship between latent heat and thermal conductivity. There are obvious differences in the thermal conductivity of the three types of materials. The thermal conductivity of organic PCM is generally 0.1-0.2 W/m·K, the value of inorganic PCM is 2-3 times higher, the thermal conductivity of metallic PCM is two orders of magnitude higher, generally in the order of 10 W/m·K. Although the specific latent heat of metallic PCM is relatively low, in practical applications, especially in the field of thermal control, the volumetric latent heat value is sometimes more important than the gravitational latent heat. Figure 3 plots the distribution relationship between the latent heat per unit volume and thermal conductivity of various PCM. The volumetric latent heat of metallic PCM is actually on the same order of magnitude as organic materials, and the volumetric latent heat of some metals are even higher than that of organic PCM. From this point of view, metallic PCM have better thermal properties than organic and inorganic PCM.

Figure 2. Latent heat and thermal conductivity distribution of PCM.

Figure 3. Volumetric latent heat and thermal conductivity distribution of PCM.

3. Thermal control performance evaluation and comparison of PCM

3.1 Figure of merit of PCM

Generally, when designing a phase change thermal control device, we generally believe that the higher the thermal conductivity of the PCM, the greater the latent heat, the better the thermal control performance. However, for a long time, we have been lacking a quantitative theory to evaluate this performance. In 2016, Shamberger [13] provided the figure of merit (FOM) coefficient of PCM by theoretical analysis of the one-dimensional Stefan problem under the first kind of boundary condition:

\[
FOM = \frac{k \rho c_p}{\text{erf} (\lambda)}
\]

The larger the FOM, the stronger the thermal control ability of corresponding PCM. In the study by Shamberger [13], the definition of the FOM of PCM is based on theoretical analysis under constant wall temperature. However, in practical applications, we often encounter situations that are close to a constant heat flow boundary. Therefore, it is more practical to derive the definition of the FOM of PCM from the constant heat flow boundary condition. Here, we give the definition of the FOM of PCM under constant heat flow from the perspective of thermodynamics.

Consider the problem of single-phase melting of a one-dimensional plate with constant heat flow. In the electronic component phase change thermal control situations, the wall temperature of the phase change module generally does not exceed the melting point of PCM, which means that the corresponding Ste number is small (less than 0.2 in most cases). The sensible heat absorption of the
PCM can be ignored, and it can be approximated according to the principle of heat balance and the linear temperature distribution:

$$T(x,t) = \frac{q^*}{k} [s(t) - x] + T_m, \quad q^* t = \rho s(t) \Delta H$$

(4)

It can be obtained that the temperature rise of the phase change module wall relative to its melting point is:

$$\Delta T = T_h(t) - T_m = \frac{q^* t}{k_i \rho_i \Delta H}$$

(5)

It can be seen from Eq. (5) that within a given time $t$ and under given heat flow $q^*$ and, the temperature rise of the wall of the phase change thermal control module is only related to the product of its three main thermal properties ($k_i$, $\rho_i$, $\Delta H$), so we can define such a figure of merit to describe the thermal control ability of the PCM:

$$FOM = k_i \rho_i \Delta H$$

(6)

We will prove that in the case of small $Ste$ numbers, Eq. (6) and Eq. (3) are essentially the same. When the $Ste$ number is small (e.g. $Ste$ is lower than 0.2), the melting constant $\lambda$ is also small, that is to say:

$$\lim_{Ste \to 0} \lambda(Ste) = 0$$

(7)

In addition, the error function erf($\lambda$) can be expanded by Taylor series as:

$$erf(\lambda) = \frac{2}{\sqrt{\pi}} \sum_{n=0}^{\infty} (-1)^n \frac{\lambda^{2n+1}}{n!(2n+1)}$$

(8)

When $\lambda$ is small, it can be approximated by its first term, namely:

$$erf(\lambda) \approx \frac{2}{\sqrt{\pi}} \lambda$$

(9)

Moreover, $exp(-\lambda^2)$ approaches 1, hence one can get:

$$\lambda = \sqrt{\frac{Ste}{2}}$$

(10)

Substituting Eq. (9) and (10) into Eq. (3), one can get

$$FOM = \frac{k_i \rho_i \Delta H}{erf(\lambda)} = \sqrt{\frac{k_i \rho_i \Delta H}{2Ste \pi}} = \sqrt{\frac{k_i \rho_i \Delta H}{2(Th - T_m)}}$$

(11)

Since Eq. (3) is derived under the condition of constant wall temperature, the second term on the right of the equation is actually constant at a given wall temperature, which means that it is only the first term of the formula on the right that determines the thermal control performance of the PCM. It is not difficult to see that Eq. (6) is essentially the same as the figure of merit defined by Eq. (3).

Figure 4 lists the figure of merit ($k_i \rho_i \Delta H$) of some typical phase change thermal control materials. The melting point of the material varies from 28 °C to 60 °C. It can be seen that for organic PCM, the figure of merit is generally on the order of $10^7$ W²s/K·m⁴. For low melting point metal PCM, the figure of merit is $10^2$ of magnitude higher than that of the organic PCM. This also explains in theory why low melting point metals have better phase change thermal control performance than traditional PCM. In particular, it should be noted that the figure of merit value of gallium is as high as $1.6454 \times 10^{10}$ W²s/K·m⁴, which is the highest.

3.2 Thermal control performance comparison of PCM
In order to intuitively show the thermal control performance of the three PCM, a typical chip thermal shock case is simulated here, three typical organic, inorganic, and low melting point metal PCM with similar melting points are adopted, and the temperature rise of the chip is monitored and compared. The three PCM selected here are organic PCM octadecane, inorganic PCM calcium chloride
hexahydrate, and low melting point metal phase change material gallium. The main thermophysical properties are shown in Table 4, assuming that the chip area is 1×1 cm², the heating power is 5 W, the heat pulse time lasts 40 s, and the initial temperature of the whole module is 25 °C.

**Table 4.** Thermophysical properties of three typical organic, inorganic and metallic PCM.

| PCM           | Melting point Tm (°C) | Thermal conductivity k (W/m·K) | Density ρ (kg/m³) | Fusion latent heat ΔH (kJ/kg) | Specific heat capacity cp (kJ/kg·K) |
|---------------|-----------------------|-------------------------------|------------------|-------------------------------|-----------------------------------|
| Octadecane    | 28.2                  | 0.36(s)/0.15(l)               | 814(s)/724(l)    | 244000                        | 2150(s)/2180(l)                   |
| CaCl₂·6H₂O    | 29.9                  | 1.008(s)/0.561(l)             | 1802(s)/1562(l)  | 191000                        | 2730                             |
| Gallium       | 29.78                 | 33.49(s)/33.68(l)             | 5903.7(s)/6094.7(l) | 80160                        | 372.3(s)/397.6(l)                |

Numerical simulation is conducted to quantitatively compare the thermal control performance of the three PCMs. Commercial code ANSYS Fluent is used, enthalpy-porosity method is adopted to consider the solid-liquid phase change process, a half 2D model is used due to the symmetry of the problem for simplicity, uniform heat source is implemented at the heat sink bottom, and the outer surface are thought to be adiabatic, more details of the numerical method can be seen in our former work [14].

Figure 5 shows the chip temperature curve with time during the thermal shock, it can be seen that the temperature control performance of octadecane is the worst, and the chip temperature rises rapidly to 98 °C, which is obviously unacceptable, mainly because the thermal conductivity of octadecane is the lowest, which seriously hinders the heat transfer inside the PCM. The thermal control performance of CaCl₂·6H₂O is better than that of Octadecane, the final temperature of the chip rises to 56 °C. The low melting point metal shows excellent thermal control performance. After the thermal shock, the chip temperature is controlled at 32.3 °C, it shows very good thermal protection for the chip, which is mainly due to its high thermal conductivity and high volumetric latent heat than traditional organic and inorganic PCM.

Figure 6 shows the temperature contour and liquid fraction contour of the three PCM in thermal control modules after the thermal shock (t=40 s). It can be seen that the solid-liquid interface curves of octadecane and CaCl₂·6H₂O are very similar, both of which are parallel to the thermal boundary of the package, and their heat transfer resistance is mainly inside the PCM. The interface distribution and temperature distribution of the low melting point metal gallium are diffused around the heat source, the higher thermal conductivity of gallium effectively promotes the diffusion and heat transfer inside the material, there is no obvious short heat transfer link, the thermal control performance of gallium is the best.

![Figure 4. FOM of some PCM used for thermal control.](image1)

![Figure 5. Thermal control performance of different PCM heat sinks.](image2)
It is worth to note that, under thermal shock condition, the thermal conductivity is significantly more important than the latent and specific heat capacity. Octadecane may have the highest latent heat, but it is considerably meaningless in this case as the speed of absorbing the dissipated heat from the chip is too slow (i.e. low thermal conductivity). On the other hand, Gallium may have the lowest specific latent heat, but it’s high conductivity overcomes this disadvantage. It is also worth to note that in a different case of long exposure of heat, Gallium may not become the best PCM amongst these three under study.

Figure 6. Temperature and liquid fraction distribution of PCM heat sinks.
(a) Octadecane; (b) CaCl2·6H2O; (c) Ga

4. Conclusion
This paper sorts out the main thermophysical data of three types of PCM, organic, inorganic, and metal. Through theoretical modeling and analysis, the definition of FOM of PCM is given. The thermal control performance of the three types of PCM is quantitatively evaluated and compared. Low melting point metals have the highest figure of merit, in which gallium is currently known as the material with the highest value of figure of merit. Aiming at the typical chip thermal shock conditions, the thermal control effects of three typical PCM are compared and simulated, and their typical characteristics are intuitively displayed. Under thermal shock, organic and inorganic PCM seriously hinder the transfer of heat within them, due to their low thermal conductivity, which affects the thermal control performance; low melting point metals can effectively promote the diffusion of heat inside, due to their inherent high thermal conductivity, it can efficiently absorbs the heat of the chip and significantly suppresses the temperature rise of the chip, so it has the best temperature control performance and shows great advantages in chip thermal shock protection.

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