Discussion on the Application of Phase-change Materials in Heat Dissipation of Electronic Devices

0 Introduction

There are two major trends in the development of electronic products: first, social development requires more complex functions, higher computing rate; second, people require its increasing integration, miniaturization, which lead to greatly reduced heat dissipation area of electronic products, while the heat power increases, resulting in a sharp increase in the heat flow density of electronic devices. Statistics show that since 1970, the performance and density of semiconductor transistors have doubled every 18 months, and its development rate is consistent with the prediction of Moore's law, resulting in a significant increase in heat dissipation and heat dissipation density of electronic devices. According to Moore's law, the heat flow density of future chips can reach 300 W/cm^2. The heat dissipation problem of electronic devices has become a bottleneck restricting the development of the electronics industry, and the heat dissipation technology of electronic devices is facing unprecedented challenges.

1. Heat dissipation methods for electronic devices

Thermal management of electronic devices refers to the control of the operating temperature of electronic devices to ensure the stability and reliability of the equipment. The heat dissipation of electronic devices is divided into active and passive heat dissipation methods, among which the common active heat dissipation methods include air cooling, liquid cooling and thermoelectric cooling, etc., while passive heat dissipation methods include natural convection heat dissipation, heat pipe heat dissipation and phase change heat storage, etc.

In the active cooling method, air cooling is most often used in the form of a heat sink with a fan to form a cooling component. The use of this method is compact, easy to operate, and obvious heat dissipation, but due to the limitations of the form factor and weight, the air volume it provides is limited, so in general, when the heat flow density is less than 1W/cm^2, air forced convection cooling can be used. The liquid cooling heat dissipation system is relatively complex, with a large amount of equipment and high cost, but its high heat dissipation efficiency and tolerable heat flow density are suitable for occasions with high heat flow density, such as in high-performance super electronic computers, military avionics and other equipment. Thermoelectric refrigeration has the advantages of no refrigerant, no mechanical movement, no noise, small size, high reliability and fast response time, but because of its main disadvantages of low efficiency and high cost, it is only suitable for special occasions with compact size and low requirements for refrigeration.

In the passive heat dissipation method, natural heat dissipation is suitable for cooling devices with low heat flow density and low temperature control requirements. When the heat flow density of electronic devices exceeds 0.8 W/cm^2, natural cooling can no longer meet the heat dissipation and temperature control requirements of electronic devices. Heat pipe heat dissipation mainly uses the phase change medium to continuously vaporize and absorb heat in the evaporation and condensation sections of the heat pipe as well as condensation and exotherm to avoid the accumulation of heat in the heat generating parts of the device. The phase-change material thermal management of electronic devices refers to the use of the huge phase change latent heat of the phase change material to absorb the heat emitted during the work of electronic devices, so as to maintain the working temperature of electronic devices near the phase change temperature of the heat storage material, ensure the safe and stable work of electronic devices, and prolong the service life of electronic devices.

2. Introduction to phase-change materials

The principle of heat dissipation system applying phase-change materials is that when the surface temperature of electronic devices rises to the phase change temperature of phase change materials, the phase change materials absorb heat and undergo phase change, and then the latent heat of phase change of phase change materials is used to absorb the heat generated by electronic devices, because the phase change process is approximately constant temperature, electronic devices can maintain a constant temperature in a short period of time, or maintain within the specified temperature range. According to the classification of chemical composition, phase change materials can be divided into organic phase change materials, inorganic phase change materials and eutectic phase change materials. Organic phase change materials mainly include paraffins, alcohols, fatty acids, etc.; inorganic phase change materials mainly include crystalline hydrated salts, molten salts, metals or alloys, etc.; eutectic phase change materials are composed of two or more phase change materials, each of which is melted and crystallized while the components, and the phase change temperature and enthalpy can be obtained by adjusting the content of the components.

The most widely researched and applied phase change materials are organic paraffin-like phase change materials, which are used in paraffin in phase change cold plates for heat dissipation of electronic components, with phase change temperature range usually from 60 to 90°C and enthalpy value from 220 to 260 J/g to meet the temperature control requirements of high heat flow density chips. Compared to inorganic phase change materials and eutectic phase change materials, it has the following advantages:

(1) No subcooling phenomenon.

(2) No phase separation phenomenon.

(3) Non-corrosive, good compatibility with structural parts.

(4) Stable chemical properties and high thermal reliability.

Despite the advantages of paraffin as an organic phase change material, it also has the disadvantage of a low thermal conductivity (about 0.3 W/(m-K)). There are several methods to increase the thermal conductivity of paraffin:

(1) Embedding metal fins, adding metal powder and metal foam in paraffin phase change materials to expand heat dissipation area, improve thermal conductivity and strengthen heat transfer performance.

(2) Compounding paraffin with expanded graphite or adding high thermal conductivity carbon nanotubes, carbon fibers and other materials to enhance the thermal conductivity of composite materials.

Based on this, YOEC YOTT has taken the lead in developing a new type of solid-solid phase change material with high thermal conductivity and high thermal storage density based on solid-liquid phase change material, with no liquid phase generated in the macroscopic phase change process, which can be processed into different thicknesses and shapes (as shown in Figure 1), while the thermal conductivity range is adjustable from 5 to 30 W/(m·K).

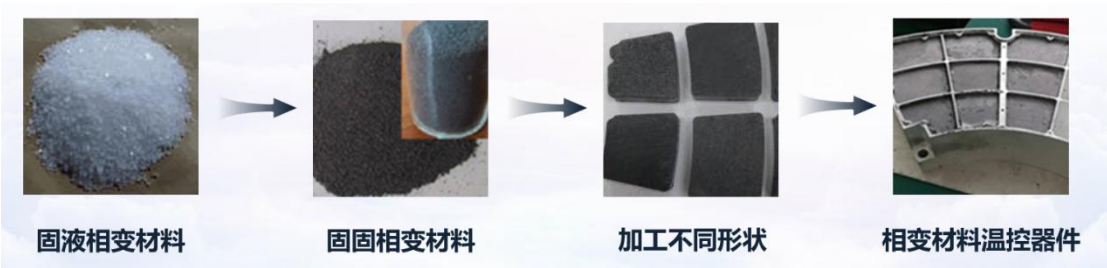

Figure 1 Forming Process of Phase Change Material

3.Application of phase change materials in electronic devices

Phase change material temperature control devices are mainly assembled with heat generating devices in the form of phase change cold plates. When the heat device works to generate heat, the phase change cold plate functions to store heat and control temperature, of which two typical applications are TR component thin wall cold plate and signal processing cold plate.

TR component is the main heat generating component of phased array radar antenna, and the thermal control problem of phased array radar mainly refers to the thermal control problem of TR component. TR component phase change cold plate (see Figure 3) is generally designed with structural bracket integration technology, i.e. structural functional integration. The innovative processing, filling and sealing technology meet the structural strength of the large area thin-walled structure TR components. The high enthalpy phase change material greatly reduces the maximum temperature of the TR component and provides excellent protection for the electronics.

The signal processing system has a high heat flow density and a compact space, so its thermal control problem is prominent. The phase-change cold plate (see Figure 4) is generally designed as a "split" technology with the signal processing section, i.e., heat dissipation and function are separated. The phase change cold plate is filled with high enthalpy phase change material and contains internal fins to enhance heat transfer to meet the heat dissipation requirements for a certain period of time and at a certain power. Thermal interface materials such as thermal gaskets, silicone grease, and reboundable thermal gaskets are used to connect the phase change cold plate to the signal processing plate.

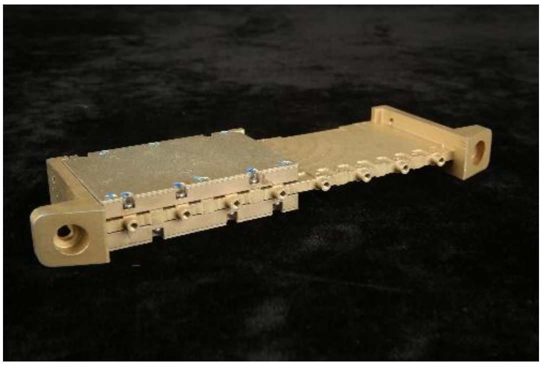

Figure 3 TR Cold Plate Figure 4 Signal Processing Cold Plate

4. Conclusion

Phase change temperature control technology, as a new generation of passive cooling technology, is expected to solve the heat dissipation problems of electronic components with high heat flow density. Based on the temperature control system of phase change materials, a set of design optimization methods for the integration of phase change materials - heat sink - system must be developed to realize the development of a highly efficient temperature control system starting from the materials, with the heat sink as the core device and the optimal working performance of electronic devices as the goal. In the future, it is necessary to continue to overcome the challenges of developing ultra-high thermal conductivity and ultra-high heat storage density phase change materials, to construct heat transfer models and design tools for phase change temperature control materials and structures, to realize the design optimization of thermal management systems. Moreover, based on the simulation and optimization results, the development of typical phase change temperature control structure prototypes and the testing of phase change temperature control structures under real conditions will be carried out through 3D printing and mechanical processing.