Research progress of air-cooled heat dissipation technology

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Abstract. Air cooling is a kind of cooling method, which uses air as a medium to cool objects that need to be cooled. It is usual to increase the surface area of the object that needs to be cooled, or to increase the rate of air flowing through the object per unit time, or to use the two methods. In recent years, there have been some emerging technologies that improve the heat dissipation efficiency by improving the heat transfer efficiency of the air-cooled front end. Based on the analysis of the current research trend of air-cooled heat dissipation technology, a detailed review of typical air-cooled heat dissipation technologies from three aspects of materials, structure and emerging technologies is expected to provide relevant references for the further research and optimization of laser wireless energy transfer technology.

1. Introduction

As a key component of the laser wireless energy transmission system, the improvement of its photoelectric conversion efficiency is one of the breakthrough points of laser wireless energy transmission technology. However, the energy conversion efficiency of the current laser battery does not exceed 50%, and the laser energy that has not been converted into electrical energy is accumulated in the form of heat energy, which further reduces the conversion efficiency of the laser battery. This article refers to the existing air-cooled heat dissipation technologies and development trends of electronic equipment, chips, motors, etc., and provides a detailed review of air-cooled heat dissipation technologies that may be suitable for laser batteries from three aspects: materials, structures, and emerging technologies.

2. Material

The heat dissipation methods of photovoltaic cells are mainly divided into passive and active. Among them, the passive type has attracted the attention of many scholars due to its high reliability. Tao Ma [1] et al. discussed cooling methods for maintaining better photovoltaic performance, and introduced the latest concept of PV-PCM systems for thermal regulation. For ordinary solar cells, Elden [2] and others installed an air flow channel with a heat collector on the back of the battery to form a "solar chimney (SCC)". For concentrating solar cells, passive cooling has high reliability and is the first choice for cooling. In recent years, phase change materials have been widely used in passive thermal management. Phase change heat storage utilizes the latent heat of the material to achieve energy storage and utilization, which is an effective way to alleviate the mismatch between energy supply and demand in terms of time, intensity and location. According to research by Yun [3], heating devices are used in buildings in winter and natural ventilation systems in summer to control the PV temperature at the same time. The results show that, compared to 76.7°C in the absence of ventilation, the temperature of the ventilated photovoltaic module reaches 55.5°C, and the photovoltaic efficiency is...
increased by 15%. M.M. Islam [4] et al. evaluated the recent thermal management technology of photovoltaic systems based on phase change materials. It is found that the photovoltaic thermal phase change material system provides 33% higher (up to 50%) heat storage potential than conventional photovoltaic hot water systems, and has a 75% to 100% longer heat available time and approximately 9% production upgrade. The temperature reduction of the photovoltaic thermal phase change material system is also better than that of the conventional photovoltaic hot water system. Di Su [5] et al. comparatively studied hybrid photovoltaic solar collectors with phase change materials. It is found that the overall efficiency of the photoelectric heat collector in the “upper phase change material” mode is 10.7% higher than that in the “no phase change material” mode. The biggest feature of the phase change material is that it can be recycled. When the sun is irradiated, the phase change material melts and absorbs heat. When there is no sun, the previously stored heat can be dissipated through natural convection.

As the most commonly-used heat dissipation material, heat sinks are often used for heat dissipation of some electrical components. Its low price, good thermal conductivity and heat dissipation design can greatly ensure that the heat of electrical components can be dissipated in a timely and effective manner. In the process of making the thermal conductive sheet, it is divided into materials such as silver, copper, aluminum, etc. according to the thermal conductivity. However, it is not difficult to find that silver exists as a precious metal, and the cost of using silver as a heat sink is relatively high. Generally, only sophisticated and expensive instruments will be used, usually copper and aluminum. However, in the actual application process, the weight of copper is too large, and the difficulty of plasticity is high, and aluminum is too soft to be used directly. Therefore, the material that is often used is aluminum alloy, which is lightweight, high in strength, good in hardness, not easy to deform and relatively cheap, and can be widely used on a large scale.

Graphite heat sink is a brand-new heat-conducting and heat-dissipating material. Its crystal grains are arranged relatively regularly and can conduct heat evenly in two directions. Its sheet-like structure can also adapt to the surface of various electronic components and is mostly used in consumer products. Electronics, if necessary, can also play a huge practicability in the application of power electronic components. Nowadays, in the process of graphite heat conduction solutions, because of its combination of heat dissipation and heat insulation properties, it has become the most cutting-edge choice in heat dissipation materials. Graphite thermal conductive material provides a high-performance solution for the heat dissipation management of power electronic components. It can use the excellent thermal conductivity of the thermal conductive graphite sheet itself to meet the heat dissipation problems of various electronic components and provide a new type of thermal conductivity solution. The latest technical support enables it to better serve the field of heat dissipation of electronic components, and provides material support for more refined and scientific heat conduction design, so that the latest heat conduction graphite heat dissipation scheme presents a new application prospect and is effectively solve the heat dissipation design problems of various electronic equipment.

3. Structure

3.1. Flat heat pipe cooling
The flat heat pipe is a type of heat pipe, and the flat heat pipe has more prominent advantages than the general heat pipe, and its shape is very conducive to the heat diffusion of the concentrated heat source. A flat heat pipe structure called a vapor chamber is shown in Figure 1. The working principle is that the flat heat pipe is a vacuum cavity with capillary structure on the inner wall. The cavity is evacuated and filled with working fluid. When heat is transferred from the heat source to the evaporation zone, the working fluid in the cavity is in a low vacuum environment. The phenomenon of liquid phase gasification will begin to occur in the medium. At this time, the working fluid absorbs heat energy and rapidly expands in volume. The gas phase working fluid will quickly fill the entire cavity. When the gas phase working fluid touches a relatively cold area, it will condense. This phenomenon releases the heat accumulated during evaporation. The condensed liquid phase working medium returns to the
evaporation heat source due to the capillary adsorption of the capillary structure. This process will repeat itself in the cavity, and the cycle can take away the heat generated by the module. Compared with traditional heat pipes, flat heat pipes have the following advantages: ① can effectively solve heat dissipation and reduce temperature gradient; ② flat heat pipes can achieve high thermal conductivity by reducing thermal resistance, ensuring rapid and timely heat transfer; ③ using heat pipe substrates instead of metal substrates can greatly strengthen the thermal diffusion of the substrate and the isothermal property of the hot plate are also beneficial to reduce thermal resistance and provide conditions for integrated packaging with electronic components. For this reason, flat heat pipes are becoming a hot area of research in the heat pipe industry and heat pipe manufacturers at home and abroad.

3.2. Honeycomb cooling

In nature, the veins of plants, the wing veins of insects, the distribution of rivers, and the network of animal lungs can all be described approximately by fractal structures. This fractal structure is the evolving structure of nature, and its resistance, heat exchange, and heat transfer are all described. It is a relatively superior structure, which provides a solution for the design of the cooling structure inside the spindle system. Based on fractal theory, Xia [6] designed a spindle temperature control structure of a tree-shaped fractal flow channel, and compared the heat dissipation effect with the traditional spiral flow channel in terms of pressure drop, temperature uniformity and performance coefficient. Evaluation and found that the tree-like fractal flow channel structure has a lower pressure drop and a more uniform temperature distribution. Dong Tao et al. [7] designed a fractal micro-pipe network heat exchanger with a honeycomb-like structure, and proved through experiments that the honeycomb-like structure pipe network has a higher Nusselt number and a lower flow rate than the parallel array structure pipe pressure drop. Tang Fan et al. [8] introduced the honeycomb heat dissipation structure into the substrate design of the LED special-shaped lamp, which effectively improved the natural convection heat transfer effect and enhanced the heat dissipation capacity of the lamp. Liu et al. [9] found that the use of a honeycomb structure in a compact heat exchanger can significantly improve the heat transfer effect of low pressure drop.

**Figure 1.** Flat heat pipe structure.

**Figure 2.** The basic structure of the honeycomb house [10].
The honeycomb structure in nature is composed of regular hexagonal units, closely arranged, exquisite structure, and has the characteristics of low material and high strength. According to Mandelbrot’s research on the fractal structure in nature, the fractal microfluidic network with a honeycomb-like structure has excellent heat and mass transport characteristics; at the same time, the regular hexagonal structure can be "evenly densely laid" on any geometrical plane, and the network perimeter is the smallest. The cooling jacket of the spindle system is a circular ring structure. In order to improve the overall cooling effect and temperature uniformity of the system, the bionic flow channel structure of the cooling jacket of the spindle system designed according to the honeycomb structure is shown in Figure 2.

According to the characteristics of the honeycomb cell structure, this structure introduces a similar fractal flow channel heat dissipation structure, and the flow channel structure in the cooling jacket is arranged according to the honeycomb flow channel, and the position and the normal of the honeycomb flow channel can be adjusted in the area where heat dissipation needs to be strengthened. The size and number of hexagonal units increase the heat dissipation and cooling effect and make the temperature distribution more uniform. The characteristic of the cooling jacket structure of the main shaft system of the honeycomb bionic flow channel is that the flow channel is composed of a number of honeycomb channel sections on both sides and a flow section in the middle. The outlet and inlet of the coolant are distributed in the upper and lower middle, on both sides of the inlet and outlet. A number of honeycomb annular flow channels are symmetrically distributed and according to a preset ratio. The coolant flows in from the inlet, flows from the straight-through section to both sides into the honeycomb flow channel, and then flows out through the outlet of the straight-through section below.

4. Emerging technologies

4.1. Liquid metal cooling
In 2002, researcher Liu Jing from the Technical Institute of Physics and Chemistry of the Chinese Academy of Sciences first proposed a computer chip heat dissipation method using low-melting metal or its alloy as a cooling medium. The proposal of this new working medium opened up a new field for computer chip heat dissipation. Ma Kunquan [11] theoretically deduced the thermal conductivity formula of liquid metal, predicted its resistivity and thermal conductivity, and verified the predicted results with experiments. In addition, he has done in-depth research on the viscosity and surface tension of liquid metals, including NaK alloys and GaIn alloys. In order to strengthen the heat transfer of the liquid metal and its alloys, they also added nanoparticles to the liquid metal and studied the thermophysical properties of this special fluid. In 2014, Li Peipei et al. [12] used numerical simulation methods to study the self-driving heat transfer performance based on the thermosiphon effect of liquid metal at room temperature. The study found that the cold end wall temperature, loop diameter, and loop direction affected the heat dissipation method. Both flow and heat transfer performance have an impact. Among them, the cold end wall temperature has no effect on the flow of liquid metal, but it will reduce the hot end wall temperature; when the total heat load remains unchanged, as the loop diameter increases, the liquid metal flow rate and hot end wall temperature are equal it decreases accordingly the increase of the angle between the loop and the horizontal plane will increase the flow rate of the liquid metal and reduce the temperature of the hot end wall.

4.2. Micro slot group heat dissipation
As an emerging electronic chip cooling technology based on evaporative phase change heat dissipation, microgroove group heat dissipation technology has attracted the attention and research of domestic and foreign scholars. In foreign countries, G Hestroni [13] designed a triangular micro-slot group phase-change heat dissipation system; Qu and Mudawa [14] designed a rectangular micro-slot group phase-change heat dissipation system. In China, Zhao Yaohua of the Institute of Engineering Thermophysics of the Chinese Academy of Sciences [15] designed an open rectangular micro-slot group phase change heat dissipation system and conducted in-depth research on it from both
theoretical and experimental aspects. Its working principle is that the heat sink of the radiator is engraved with micro-channels, and a certain amount of 2-Methylpentane and methanol mixed working fluid is injected after a certain vacuum is drawn inside. When the heat of the electronic chip is transferred to the heat sink of the radiator, under the action of capillary force, the mixed working fluid is sucked into the microgroove for heat exchange, and the generated vapor is condensed inside the arcuate heat dissipation surface to complete a heat dissipation cycle. Wu Yue [16] designed a set of micro-slot group phase-change heat sink for high-power LED heat dissipation based on the analysis of the influence on the performance of the micro-slot group phase change heat sink. Compared with the traditional LED heat sink, this device has the advantage that it can effectively reduce the operating temperature of the LED, is light in weight, small in size, low in cost, and easy to industrialize.

4.3. Synthetic Micro Spray and vibration cooler

Synthetic Micro Spray and vibrating cooler are a kind of microfluidic device first proposed by Coe [17]. The working principle is that the diaphragm is driven by electromagnetic force or piezoelectric to vibrate up and down. The vibration frequency is between 100 and 200 Hz. The gas working medium is sucked in or ejected due to the pressure change in the cavity, thereby forming a continuous jet outside the hole. field. The maximum jet velocity in the mainstream zone can reach 30m/s. As far as air cooling is concerned, the cooling performance of synthetic micro-jets is 2 to 3 times higher than that of fans, and the energy consumption is less than half of that of fans [18]. The reason why the cooling efficiency of the synthetic micro-jet can be improved is that it can effectively destroy the thermal boundary layer, so as to better mix the surrounding cooling gas with the boundary layer gas, and ultimately greatly improve the wall heat transfer coefficient. Because synthetic micro-spraying mostly uses gas, its cooling efficiency cannot yet meet the needs of extremely high power, such as chip cooling with a heat flow density of more than 100W/cm², while the use of liquid spray cooling can significantly improve the cooling efficiency. Water spray cooling chip technology is a new technology proposed by American Hewlett-Packard scientists to spray water to cool chips. Studies have shown that this method can not only effectively dissipate heat, but also achieve different degrees of cooling on different parts of the metal plate by controlling the nozzles. Vibration refrigerator is a refrigerator that uses piezoelectric crystals to atomize and spray liquid to the hot end, and at the same time uses a method similar to a gravity heat pipe to achieve liquid return, thereby realizing self-circulation. At present, the cooling capacity of the cooling device with a diameter of 50 mm and a height of 20 mm has reached 420 W/cm². Synthetic micro-jet will have broad application prospects in chip cooling, especially in the heat dissipation of portable electronic products, but atomization pressure, fluid velocity, micro nozzle geometry, choice of cooling medium vaporization parameters, cooler and chip packaging, the integration of the drive pump and the cooler and other processes need to be further studied.

5. Conclusions

In a word, when dissipating the device and its equipment, the first thing is to choose a suitable thermal conductivity material according to the actual situation. Generally speaking, it is to choose aluminum with light weight and good thermal conductivity, and copper materials can also be selected according to the actual thermal conductivity requirements. At the same time, the heat dissipation structure is optimized according to the basic principles of thermodynamics, and some emerging technologies and new materials can be used to make the heat dissipation of the device more efficient according to its own conditions, so as to ensure that the operating temperature of the related equipment can always be stable and safe. Guarantee its normal operation within the range.

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