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Structural Design of Micro Heat Pipe Array Temperature Difference Power Generation System

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Abstract

The article applies both semiconductor thermoelectric power generation technology and micro heat pipe array heat dissipation technology to the utilization of waste heat from high heat flux density devices, achieving waste heat recovery and power generation from high heat flux density devices. High heat flux density devices have high heat flux density, micro heat pipe arrays have good heat dissipation ability, while semiconductor thermoelectric power generation technology requires high heat flux density to ensure efficient power generation. This article combines the three organically to achieve efficient waste heat recovery of high heat flux density devices. The experimental results show that the waste heat recovery efficiency of the experimental device is as high as 12%, and the generated electricity can achieve functions such as fan rotation, LED light bulb emission, and incandescent light emission. The entire waste heat power generation system operates with stable performance, no noise, high energy utilization efficiency, and significant energy-saving and emission reduction effects.

Keywords

Microheat Pipe Array; Semiconductor; High Heat Flux Density; Thermoelectric Power Generation.

1. Introduction

The use of energy is indispensable in today's social production and life. With the rapid development of the economy, the demand for traditional energy is constantly increasing. However, due to the fact that most of these energy sources are non renewable, energy scarcity has gradually begun to occur, and an energy crisis is about to come again. At that time, human production and life will be threatened, economic development will stagnate, the balance of the entire ecosystem will be disrupted, and it may also cause social unrest in many countries. So the current energy issue is not only a problem for our country, but also a global concern that must be taken seriously.

With the rapid development of information and computer technology, high heat flux density devices (such as high-power electronic devices, high-power LED lights, high-power lasers, etc.) are becoming increasingly widely used in various industries. They consume a lot of energy while also emitting huge waste heat (the general energy utilization rate is 10% -20%, and the rest of the energy is discharged as waste heat). How to utilize these low temperature waste heat resources and achieve the recovery and utilization of waste heat is a meaningful research topic.

The article takes the waste heat utilization of high heat flux density devices as the research background, and combines the advantages of semiconductor thermoelectric power generation technology and micro heat pipe array heat dissipation technology to achieve waste heat recovery and power generation. In order to verify the waste heat recovery effect of the modified

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device, a waste heat utilization experimental platform was built to experimentally test the efficiency of waste heat recovery power generation.

2. Structure Design

2.1. Microheat Pipe Array

The micro heat pipe array is composed of an external metal foil plate and a liquid heat transfer working fluid inside the tube. Multiple independent micro heat pipes form the experimental heat dissipation device, and each micro heat pipe has many small micro fins inside, which have the functions of increasing the relative surface area of the micro heat pipe array, enhancing the ability to absorb and heat, etc. [1]. The cyclic operation of a micro heat pipe consists of two phase transition processes, vaporization and liquefaction of the liquid. However, during the process of change, there is usually some pressure difference. If these are ignored, the entire internal micro heat pipe is relatively balanced. Because the channels inside the micro heat pipe are relatively small, and the liquid working fluid inside the micro heat pipe has extremely strong saturation pressure during the phase change process, under these two conditions, the speed of liquid to vapor conversion is very fast. The vapor flows inside the micro tube and can continue to liquefy after being cooled at the cold end. The liquid working fluid gradually completes the evaporation process under the action of gravity and capillary action, and flows back to the steam section to complete one cycle. In the process of forming liquid and vapor states, the working fluid continuously repeats the cycle of absorbing and releasing heat. Heat is continuously transferred through the working fluid in the micro heat pipe, and finally the temperature of the micro heat pipe array reaches a stable state, which can be regarded as an isothermal body[2]. Its physical diagram and working principle diagram is shown in Figure 1.

The use of a temperature equalizing body in a micro heat pipe array collection system can, on the one hand, allow the heat from the heat source to be evenly distributed[3], ensuring the stability of the power generation system and preventing problems such as low power generation and equipment damage caused by uneven heating of the micro heat pipe array system. On the other hand, it can increase the temperature difference between the cold and hot ends, increase the output power generation, and enable the temperature difference power generation system to operate more efficiently.

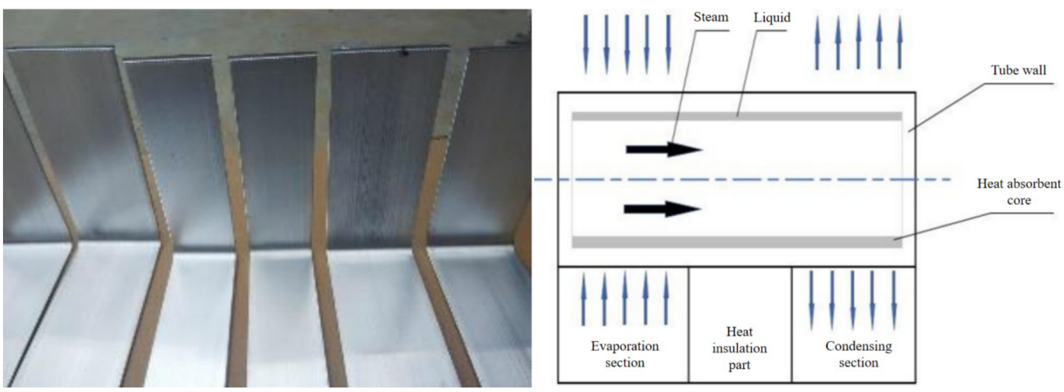

Fig 1. Micro heat pipe physical and working principle diagram

2.2. Differential Temperature Power Generation

The semiconductor generator manufactured by the semiconductor temperature difference power generation module can generate power as long as there is temperature difference. As the temperature difference decreases, the voltage and current will decrease accordingly. The cold surface must be equipped with metal heat sink, and air cooling, water cooling, oil cooling or other cooling measures shall be taken to ensure that the heat from the hot surface can be

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taken away immediately, so as to maintain the temperature difference between the two sides of the power generation module and improve the power generation effect. Different materials and temperature resistance are selected for the temperature difference power generation fin, which has a temperature range of 373.15~873.15K. Therefore, suitable temperature difference fin types are often selected according to specific application conditions. In addition, attention shall be paid to the optimal coefficient and cost of the temperature difference fin during the selection process[4]. In this paper, the Bi_2Te_3 semiconductor temperature difference chip SP1848-27145 is used to select the temperature difference power generation chip. The specific parameters are shown in Table 1, and the physical image of the temperature difference power generation chip is shown in Figure 2.

Table 1. Parameters of thermoelectric generator

External dimensions	40 mm×40 mm
Thickness	3.90 mm
Number of original copies	127
Maximum output voltage/V	3.21V
Internal resistance at room temperature/Ω	2.12Ω
Output power/W	3.11W
Maximum continuous operating temperature/K	397.15K

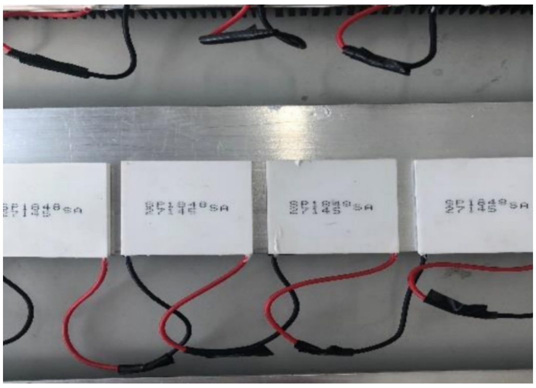

Fig 2. Physical picture of thermoelectric generator

2.3. Overall Structure Design

The overall experimental setup in this paper is shown in Figure 3. It consists of a pressure regulator, a simulated high heat flux heating device, four semiconductor temperature difference power generation sheets, a fan, a high heat conductivity heat pipe and a temperature measurement thermocouple. Four semiconductor power generation modules are used in the experiment. The overall dimension of a single module is 40mm × 40mm × 3mm. There are 127 pairs of PN junctions in total, which have certain high temperature resistance characteristics (the stable operating temperature at the hot end can reach 180 °C, and the maximum short-term impact temperature is 220 °C) [5]. The radiator adopts micro-heat pipe array with capillary suction core, and its starting temperature is 26 °C.

In the experiment, the simulated heat source is connected to generate heat, and the heat will be introduced into the micro-heat tube array radiator through the semiconductor temperature difference generator. When the micro-heat tube array reaches the startup temperature, it will start and work, so the waste heat of the device with high heat flux density will be taken away continuously. In this process, the temperature of the layer close to the LED base is high due to the thermal resistance of the semiconductor, and the temperature of the side close to the micro-

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heat tube array radiator is low, so there is a temperature difference between the two sides, and the semiconductor temperature difference generator continuously outputs electrical energy.

Fig 3. Physical diagram of system design structure

3. Experimental Test and Result Analysis

3.1. Relationship between Temperature Difference between Semiconductor Ends and Voltage

Use a voltage regulator to simulate the temperature of different heat sources, i.e. different heating plates. After a sufficient long time, the temperature will be at a fixed value, and the temperature difference will also be at a fixed value. Measure the voltage generated by the device, and then obtain a set of relationship between the temperature difference under the fixed heat source and the generated voltage [6]. With the same method, adjust the voltage regulator to different voltages to obtain several groups of relations. The data is shown in Table 2. In the table, U is the voltage regulated by the voltage regulator, T_1 is the temperature of the heating plate, T_2 and T_3 are the temperature of the hot end of the micro-heat tube array at different positions, T is the average temperature of the hot end, ΔT is the temperature difference between the two ends, and u is the voltage generated by temperature difference power generation.

Table 2. Relationship between Temperature and Voltage

$U_{(V)}/T_{(℃)}$	T_1	T_2	T_3	T	ΔT	u
60	100	79	73.5	76.25	23.75	2
65	107.5	83.3	78.8	81.05	26.45	2.2
70	120	92.1	86.8	89.45	30.55	2.8
75	132	100.5	94.2	97.35	34.65	3
80	142	107.6	101.2	104.4	37.6	3.2
85	153.5	115.6	108.2	111.9	41.6	3.5
90	168	126.2	118.4	122.3	45.7	3.8

The experimental data is arranged and fitted as shown in Fig. 4, and the relation formula *(1)* is obtained:

From the above, it can be seen that, on the basis of ignoring the experimental error, the temperature difference and the corresponding voltage belong to one-to-one correspondence, which can be approximately expressed by the linear function.

3.2. Relationship of Temperature Difference with Time

From the moment when the power supply is turned on to the time when the system is stable, due to the hysteresis of the micro-heat tube array startup and the change of heat flux, the device

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needs a certain time from startup to the stable working state. In order to better grasp this rule, the temperature change of each point of the device with time is tested. The voltage of the simulated heat source voltage regulator is adjusted to 70V, the power supply is turned on, the time interval is 15s, and the data is shown in Table 3.

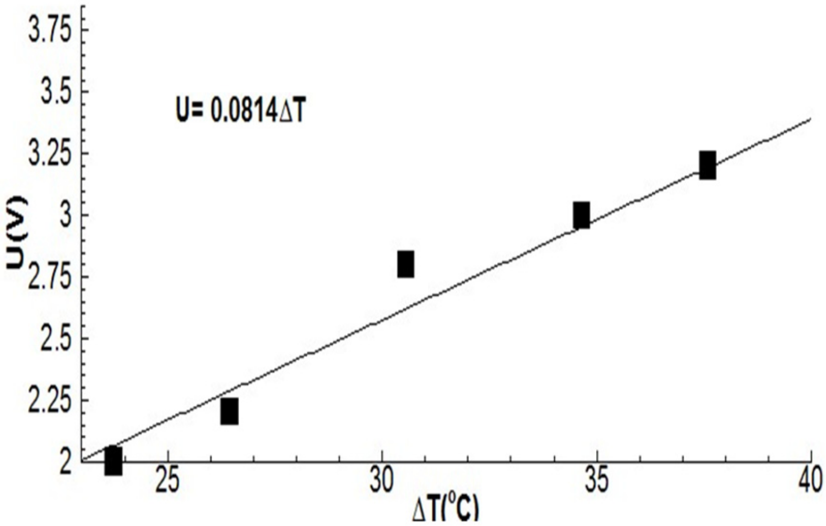

Fig 4. Fitting diagram of the relationship between temperature difference and voltage

$$U=0.0814\cdot\Delta T \tag{1}$$

Table 3. Relationship between Temperature Difference and Time

	t_0=0	t_1=15	t_2=30	t_3=45	t_4=60	t_5=75	t_6=90	t_7=105	t_8=120	t_9=135
ΔT	0	2.7	5.9	8.4	10.4	12.6	14.3	15.8	17.5	18.7
	t_{11}=165	t_{12}=180	t_{13}=195	t_{14}=210	t_{15}=225	t_{16}=240	t_{17}=255	t_{18}=270	t_{19}=285	t_{20}=300
	20.9	21.6	22.6	23.6	24.1	25.1	25.6	26.2	26.6	27.1
	t_{21}=315	t_{22}=330	t_{23}=345	t_{24}=360	t_{25}=375	t_{26}=390	t_{27}=405	t_{28}=420	t_{29}=435	t_{30}=450
	27.4	28	28.3	28.5	28.7	29	29.4	29.6	30	30.1

The fitting data relationship is shown in Figure 5.

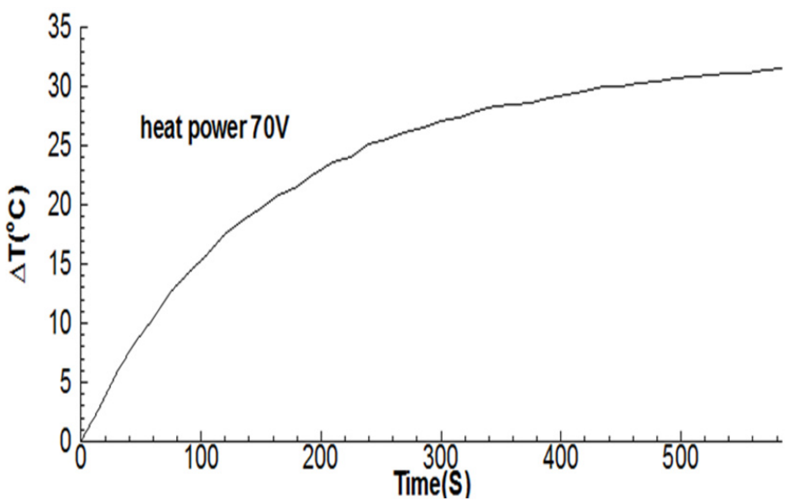

Fig 5. The relationship between temperature difference and time under certain heat source conditions

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Based on the above experimental data and fitting diagram analysis, the following conclusions can be drawn: under the condition of a certain heating power, the temperature of the heating plate and the temperature of the hot end of the micro-heat tube array gradually increase with the change of time, and then become stable. In the experimental data, when the voltage of 70V is stable, the temperature difference reaches 34℃, and the voltage of 2.8V is output.

3.3. Efficiency Analysis

In the experiment, the heat dissipation of the heating plate in the air is neglected. At this time, the temperature of the heating plate has two directions: first, the electric energy E converted into LED; second, the heat is dissipated into the air Q through the micro-heat tube array, then the maximum efficiency of the device is $\eta=(U\times I)/W=(2.8\times 1.27)/30.37=11.7\%$, while the ideal Carnot cycle $\eta=(T_1-T_2)/T_1=1-T_2/T_1=1-(89.5/12.3.5\%)=27.5\%$. In the actual cycle, it is an irreversible non-ideal state cycle, and its efficiency is far less than the theoretical value of the Carnot cycle. Therefore, under the environmental conditions of the experimental device in this paper, the conversion efficiency from low grade energy to high potential energy obtained has been considerable.

3.4. Power Generation under Different Environmental Conditions

When the waste heat power generation device of high heat flux device is applied in the actual project, the cold end of the micro-heat tube array will be in different application conditions. Therefore, in this paper, the forced convection of the cold end of the micro-heat tube array is simulated by the fan and the data is recorded. The data is drawn by data fitting, as shown in Figure 6.

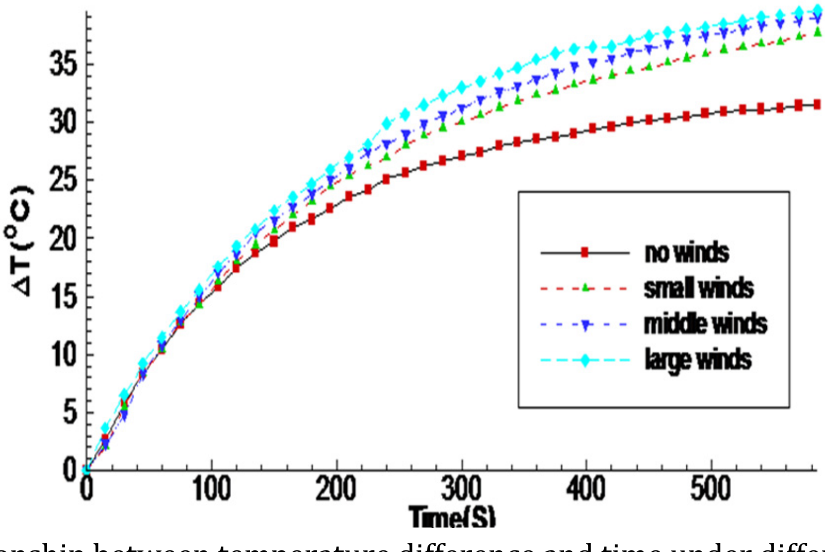

Fig 6. The relationship between temperature difference and time under different wind speeds for the same heat source

From Figure 6 it can be concluded that:

a) Within 120s, the wind speed has little influence on the temperature difference, but it changes obviously afterwards. It can be seen that 120s is the start time of the micro-heat tube array. When the micro-heat tube array is fully started, the wind speed has a certain impact on the heat dissipation of the micro-heat tube array.

b) Under certain heat source conditions, the higher the wind speed is within a certain range, the better the heat dissipation effect of the micro-heat pipe array is, and the bigger the temperature difference is.

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4. Conclusion

(a) Organic combination of semiconductor power generation technology, micro-heat tube array and heat dissipation of high heat flux device can realize partial recovery and cascade utilization of energy by using waste heat for power generation while removing waste heat. In the conversion process, there is no need for mechanical moving parts and additional driving and transmission systems, so the structure is compact, without vibration and noise.

(b) When there is a small temperature difference, the heat energy can be directly converted into electrical energy, and the heat energy can be utilized in a wide temperature range by selecting the appropriate semiconductor material category. At the same time, the device is safe and pollution-free, the thermoelectric materials are free of liquid or gaseous media, and there is no discharge of waste water, waste gas and other pollutants during the energy conversion process. It is an energy utilization device with almost zero emission to the environment.

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