The System Design for Improving Semiconductor Refrigeration Performance

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Abstract: According to the working characteristic curve of semiconductor refrigeration chips, the maximum refrigeration capacity and the working current corresponding to the maximum refrigeration efficiency are not consistent. At present, semiconductor refrigeration chips work with a constant current, so it is impossible to keep them in the optimal working state. Because the current corresponding to the maximum refrigeration capacity and the maximum refrigeration efficiency is quite different, in order to improve the performance of semiconductor refrigeration, this paper designs a wide range of adjustable fuzzy control system, which automatically adjusts the current of refrigeration chip according to the temperature of the cold and hot end of the semiconductor refrigeration chip, so that it is always in the best working state.

1. Introduction

Semiconductor refrigeration is a new refrigeration method through DC electric refrigeration. Its main characteristics are no moving parts, no noise, no use of refrigerants, no pollution to the environment and it is a green cold source[1]. Nowadays, the promotion of energy saving and emission reduction policies and the call for environmental protection all over the world, such as Freon and other refrigerants which have destructive effects on the atmosphere will be banned step by step[2], so semiconductor refrigeration technology will be further valued by various countries. However, the efficiency of semiconductor refrigeration is lower than that of mechanical compression refrigeration, which limits its wide use. Therefore, many scholars are committed to improving the efficiency of semiconductor refrigeration.

At present, the research on semiconductor refrigeration mainly focuses on refrigeration materials, refrigeration performance, heat dissipation and application. The optimum value coefficient of materials is an important parameter to measure the refrigeration capacity of semiconductor refrigerators. Pan Yuzhuo et al pointed out that the heat transfer coefficient in semiconductor has a great influence on the refrigeration efficiency[3]. Improving the manufacturing technology of semiconductor materials and improving the optimum value coefficient of semiconductor are the fundamental ways to improve the refrigeration efficiency. In recent years, with the vigorous development of nanotechnology, the application of nanotechnology in semiconductor materials has become one of the research priorities of European, American and Japanese countries in nanotechnology. GMZ Energy of the United States has recently developed a breakthrough new material, which uses nanotechnology, has the advantages of clean and environmental protection, and can improve the refrigeration capacity of air conditioning and refrigerators. In the research of refrigeration performance, because the different factors such as the size and current of the refrigeration sheet have different effects on the performance, scholars at home and abroad find out the specific effects of different factors on the refrigeration performance through the analysis of these factors, so as to take certain measures to improve the refrigeration performance of semiconductor.

At present, semiconductor refrigeration technology is mostly used in direct refrigeration, but it is not well integrated with advanced technology such as computer real-time control technology. In order to improve the refrigeration performance of semiconductor refrigeration control system, the factors affecting the refrigeration performance of semiconductor will be studied in this paper.

2. Semiconductor Refrigeration Principle

The principle of semiconductor refrigeration is shown in Fig. 1. After DC power supply is connected, the current flows from n-type semiconductor to P-type semiconductor, that is, from negative thermoelectric potential to positive thermoelectric potential, which will absorb energy from the outside, so it becomes cold end and the temperature decreases. On the contrary, at the lower junction, the current flows from P-type semiconductor to n-type semiconductor, releasing energy and forming heat. At the end, the temperature rises. A semiconductor cooler consists of several pairs of P-type semiconductors and n-type semiconductors connected in series as shown in Fig. 1, and then connected in series with DC power supply, radiator and other components. After the DC power supply is connected in the graphical way, the top of the thermopile is the cold end, which can be placed in the occasion where cooling is needed to achieve the purpose of refrigeration. At the same time, the hot end of the thermopile should be connected with the radiator, and the heat generated should be continuously emitted, so that the cold end of the thermopile can be continuously refrigerated. This is the working principle of the semiconductor refrigeratory.
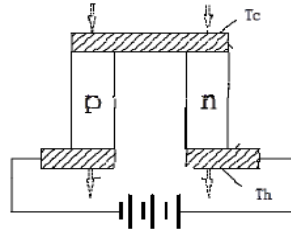

Fig. 1 Semiconductor refrigeration schematic diagram

Through the study of semiconductor refrigeration principle, it can be seen that the factors affecting the efficiency and effect of semiconductor refrigeration are the nature of the material itself, the magnitude of current and the temperature difference between the hot and cold ends.

The refrigeration capacity and refrigeration efficiency have a great relationship with the current and the temperature difference between the hot and cold ends. From the formulas (1) and (2)[4], it can be seen that the refrigeration capacity and refrigeration efficiency are not linear with the current, and there is an optimal matching relationship. The relationship with the temperature difference between hot and cold ends is basically large temperature difference, less cooling capacity and low refrigeration efficiency; conversely, more cooling capacity and high refrigeration efficiency. By studying the influence of different factors on semiconductor refrigeration performance, the optimal refrigeration conditions for different requirements are summarized.

$$Q_0 = \alpha_{ab} T_c I - \frac{1}{2} I^2 R - K \Delta T \qquad (1)$$

$$\varepsilon = \frac{\alpha_{ab} T_c I - \frac{1}{2} I^2 R - K \Delta T}{I^2 R + I \alpha_{ab} \Delta T} \qquad (2)$$

Q_0 — the cooling capacity of a single thermocouple;

ε — Refrigeration efficiency;

α_{ab} — Thermocouple's temperature difference electromotive force rate, namely Sebeck coefficient;

I—working current;

R—resistance of thermocouple;

K—Unit heat transfer capacity of K-thermocouple;

ΔT —Temperature difference between hot and cold junctions;

3. Calculation of Semiconductor Refrigeration Conditions

Formulas (1) and (2) show that the cooling capacity and refrigeration efficiency of

semiconductor refrigerators are related to electric current and temperature difference between cold and hot ends. In practice, the temperature difference between cold and hot ends can not be changed with the working conditions. Therefore, this paper mainly studies the relationship between the cooling capacity and refrigeration efficiency of semiconductor refrigerators and current.

Maximum cooling capacity condition: The maximum cooling capacity condition is obtained on the premise of $\Delta T = 0$. Therefore, when $\Delta T = 0$, Formula (1) can be expressed as follows:

$$Q_0 = \alpha_{ab} T_c I - \frac{1}{2} I^2 R \qquad (3)$$

Formula (3) derives the partial current and makes its derivative equal to zero. In this case, the working current at the maximum cooling capacity can be calculated as follows:

$$I_m = \frac{\alpha_{ab} T_c}{R} \qquad (4)$$

Maximum refrigeration efficiency working conditions: Formula (2) derives the current and makes it equal to zero. The calculated current value is the working current at the maximum refrigeration efficiency. At this time, the obtained current is as follows:

$$I_0 = \frac{\alpha_{ab}(T_h - T_C)}{R(\sqrt{1 + ZT_m} - 1)} \qquad (5)$$

4. Working status of existing semiconductor refrigerators

According to the working characteristic curve of semiconductor chips [5], as shown in Fig. 2 (taking a chip as an example), the working current corresponding to Q_{max} (maximum refrigeration capacity) is the current value calculated by Formula (4); the working current corresponding to ε_{max} is the current value calculated by Formula (5). From Fig. 2, it can be seen that the two currents differ greatly.
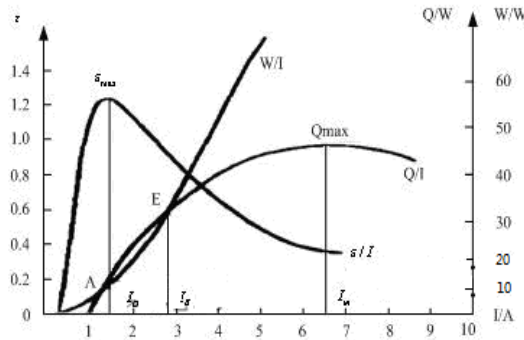

Figure 2 Semiconductor Refrigeration Characteristic Curve

At present, the working current of semiconductor refrigerators determined by higher refrigeration capacity meets the needs of fast refrigeration, but it leads to the shortcomings of low energy efficiency and high power consumption of semiconductor refrigerators.

5. The Semiconductor Fuzzy Control System of wide range current adaptive temperature

Because the temperature difference between the cold end and the hot end of the semiconductor refrigeration chips changes when the semiconductor refrigeration chips are running, it requires that the working current of the semiconductor refrigeration chips varies with the working conditions of the semiconductor refrigeration chips. When the temperature in the semiconductor refrigerator box is different from the set temperature, it is hoped that the semiconductor refrigeration chip will work at the maximum refrigeration capacity. When the temperature in the semiconductor refrigerator box is close to the set temperature, it is hoped that the semiconductor refrigeration chip will work at the

maximum energy efficiency ratio. Therefore, the working current must be adjusted in real time according to the change of the working condition of the semiconductor refrigerator to achieve this purpose.

Because the current I_m corresponding to the maximum refrigeration capacity is quite different from the current I_o corresponding to the maximum energy efficiency ratio,a series-parallel automatic switching control system is designed in this paper. According to the working condition of semiconductor refrigeration chip, the system can automatically adjust the series-parallel mode of semiconductor refrigeration chip, so that its current can change in a wide range between I_m and I_o and the semiconductor refrigeration chip is always in the best working state.
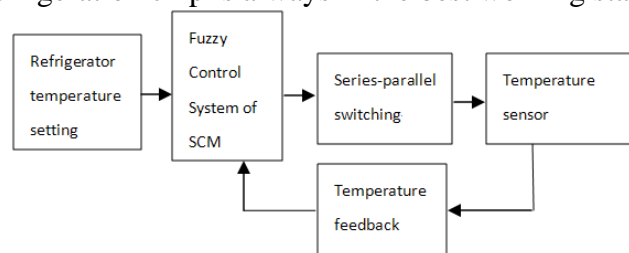
Fig. 3 Semiconductor Refrigerator System Structure

Fig. 3 is the schematic diagram of a semiconductor refrigeration control system with current adaptive temperature[6]. In the figure, the microcontroller is used as the processing center to receive the feedback signals of the temperature sensors at the cold and hot ends and set the temperature in the box. After processing by the internal fuzzy algorithm of the microcontroller, the mode of semiconductor series-parallel connection can be changed, thus realizing the automatic current regulation process of the semiconductor refrigeration chip.

5.1 The Design of Key Technology

The Series and Parallel Automatic Switching. The difference between the current corresponding to the maximum refrigeration capacity and the current corresponding to the maximum energy efficiency ratio of semiconductor refrigerators is so great that the adjustable power supply can't do it. In this paper, a relay controlled by a single chip computer is designed. By automatically changing the series-parallel connection in the semiconductor refrigeration chip, a wide range of precise current can be automatically adjusted.

5.2 The Refrigeration Test

The ambient temperature of the experiment is 25 degrees Celsius, and the cooling temperature of the refrigeration box is set to 10 degrees Celsius.

5.2.1 The Rapid refrigeration stage

In order to simplify the fuzzy refrigeration control system and improve the current stability, the fuzzy control system adopts discontinuous regulation. The cooling stage is divided into two stages, and different currents are output respectively. At first, the temperature inside the box is 25 degrees Celsius, which needs fast refrigeration. The current through the semiconductor refrigeration chip is 5.1A, which makes the refrigeration chip the largest. When the temperature inside the box drops to 15 degrees Celsius, the current through the semiconductor refrigeration chip automatically adjusts to 1.5A. At this time, the refrigeration capacity of the semiconductor decreases and the energy efficiency ratio increases.

5.2.2 The thermal insulation stage

When the temperature reaches the set temperature, the semiconductor refrigeration chip will automatically power off and be in the state of thermal insulation. The current of semiconductor refrigeration chip in thermal insulation state will switch between 0 and 1.4A.

5.2.3 The analysis of test results

Through the semiconductor refrigeration experiment, we get the current state flowing through the semiconductor refrigeration chip as shown in Figure 4.
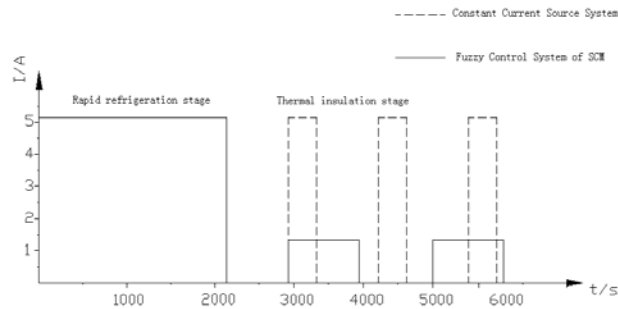

Fig. 4 Contrast chart between adaptive adjustable fuzzy control system and constant current source system

(1) The change range of current is less than 70%. The current of constant current system is switched between 0-5.3A in thermal insulation stage, while the current of fuzzy control system is switched between 0-1.5A in thermal insulation stage, the change range is only 28.3% of that of constant current system.

(2) The frequency of current change is less than 50%: the constant current system works 385 seconds in insulation stage and 766 seconds in shutdown time, while the fuzzy control system works 956 seconds and 1005 seconds in shutdown time. In the same time, the starting times of the fuzzy control system are less than half of the starting times of the constant current system.

(3) The time of maximum refrigeration efficiency is greatly increased: the working current of the constant current system always deviates from the corresponding current of the maximum refrigeration efficiency, while the whole working time of the fuzzy control system in the insulation stage is in the state of the maximum refrigeration efficiency.

6. Conclusion

The Semiconductor Fuzzy Control System of wide range current adaptive temperature not only meets the needs of fast refrigeration in the initial stage, but also meets the needs of maximum refrigeration efficiency in the insulation stage, so that the semiconductor refrigeration is always in the best working state. Therefore, the Semiconductor Fuzzy Control System of wide range current adaptive temperature improves the performance of semiconductor refrigeration compared with the current constant current control system.

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