Design and implement of the medical semiconductor cooler

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Abstract. Recently, the combined application technology of temperature difference thermoelectric devices, temperature difference thermoelectric refrigeration and temperature difference power generation has made rapid progress. Compared with traditional cooling methods, the widespread use of temperature difference semiconductor cooler based on the Peltier effect in various aspects of small-scale cooling especially medical use, which has made it gain more and more attention. Based on this, a medical semiconductor cooling system is designed in this work. The hardware circuit is based on a single-chip microcomputer system, including several parts such as a temperature sensor measurement system, an LCD display system, and a semiconductor cooler system. The software design includes single-chip microcomputer control program design, temperature acquisition subprogram design, and display subprogram design, then the cooling efficiency of semiconductor cooler and the refrigeration-box was measured, finally it completed and realized the design and temperature control of medical semiconductor cooler.

1. Introduction

With the development of technology, new semiconductor refrigeration technologies have gradually replaced the traditional refrigeration methods, which also improved some of the shortcomings of traditional refrigeration. With its small size, high efficiency, and pollution-free characteristics, it has become a new technology with the most promising applications. In 2011, Wang ZH and others used the inverse problem method to optimize the multi-parameters of the microchannel heat sink. In 2012 Lin TW optimized the shell and tube heat exchanger with a simplified conjugate gradient method. In 2013 Wang XD and others optimized the geometry of the nanofluid-cooled microchannel heat sink under various constraints. At the same time, Meng JH and others studied the transient modeling and dynamic characteristics of thermoelectric coolers [1-3]. In recent years, scholars have also conducted research on semiconductor cooling technology. In 2016, Li Guochao completed the component selection of the solar semiconductor cooling system experimental platform, the design and construction of the system and its performance test [4]. In 2017, Wang Yajuan and other scholars set up a semiconductor refrigeration-box for fruit and vegetable dispatching [5]. In 2018, Lu Jiaoxuan studied and designed a multi-stage precision fast temperature feedback control system based on semiconductor cooling technology [6]. These indicate that the theory and application of thermoelectric cooler are being further studied at home and abroad. This work begins with the theoretical analysis of semiconductor cooler, designs hardware circuits suitable for medical use, then sets up a temperature
measurement system, cooling system and temperature control system, finally the cooling effect of the system was tested and analyzed to provide reliable theory and practical technology for its application.

2. Basic knowledge of the semiconductor cooler

2.1. Basic equation of the semiconductor refrigerator

Semiconductor cooler has also been known as thermoelectric cooler (TEC), which has the advantages of small size, high operation reliability, and accurate temperature control [7]. The cooling system of thermoelectric cooler (TEC) is studied, which mainly including its mathematical model and the parameters of thermal performance.

2.1.1. Heat flux and cooling capacity.

Peltier cooling is the main thermoelectric cooling mechanism, which has two neutralization phenomena of Joule heating and heat conduction effect. The net cooling capacity is Peltier cooling minus these two effects, which is expressed by the heat flux vector \( \vec{q} \):

\[
\vec{q} = \alpha \vec{\alpha} T - k \vec{\nabla} T
\]

where \( \alpha \) is the Seebeck coefficient, \( T \) is the absolute temperature, \( \vec{\alpha} \) is the current density and \( K \) is the thermal conductivity. The ideal equation \( \dot{Q}_C \) of net cooling capacity is

\[
\dot{Q}_C = \alpha \dot{\alpha} C I - \left[ \frac{1}{2} \right] \cdot I^2 R - K \left( \alpha_h - \alpha_c \right)
\]

where \( I \) is the current, \( T_C \) is the low junction temperature, \( T_h \) is the high junction temperature, \( R \) is the resistance and \( K \) is the thermal conductivity.

2.1.2. The ideal equation [8].

Assuming that the Thomson coefficient is negligible, or the Seebeck coefficient is independent of temperature, an accurate solution to the temperature distribution. It can be easy to get from the equation. The temperature distribution of the cold end cooling capacity will become smaller, and the specific formula becomes as:

\[
\dot{Q}_1 = \alpha(T_{avg})T_1 I - \left[ \frac{1}{2} \right] \cdot I^2 R - \left( AK \right) \left[ \frac{L}{\alpha_2 - \alpha_1} \right]
\]

where \( A \) is the cross-sectional area of the thermocouple, \( L \) is the length of the device and the boundary conditions should be \( T(0) = T_1, T(L) = T_2 \).

3. Hardware design and chip selection

3.1. The total hardware construction

The whole structure of the semiconductor cooler system is based on a single-chip microcomputer system, a temperature sensor measurement system, a semiconductor cooler system and a LCD display system [9], which has been shown in Figure 1.

The single-chip microcomputer system is the core of the hardware system which completes the tasks of temperature processing and display. The temperature sensor measurement system detects the real-time temperature of the cooler system which works by receiving control instructions from the single-chip microcomputer. The LCD display system displays the temperature value. The Bluetooth module transfers the data collecting from the microcontroller through to the PC to observe and adjust it.
3.2. The selection of semiconductor cooler and temperature sensor

The model of the thermoelectric cooler and temperature sensor used in this cooler system is TEC103104 and DS18B20. In this design, the power of the thermoelectric cooler is relatively small, for the reason that a simple heat sink and a fan are enough to be used to lose heat. In addition, the thermoelectric cooler should be insulated with a heat insulation pad. At the same time, a thin layer of uniformly thermal grease should apply onto the two sides of thermoelectric cooler to make the thermoelectric cooler have good contact with the radiator and the cooling block. The common digital temperature sensor DS18B20 is relatively cheap, accurate and without an additional AD conversion circuit when it was used, which can be programmed to obtain the digital signal of the temperature.

3.3. Temperature measurement circuit

The DS18B20 temperature sensor with 9-bit resolution is used in temperature measurement circuit, which can achieve multi-point temperature measurement. The measurement range is from -55 to +125 °C and the increment is 0.5 °C [10].

Connection ways for DS18B20 parasitic power supply and external power supply were shown in Figure 2, Figure 3.

3.4. Single-chip microcomputer circuit setting

The STC89C52 single-chip microcontroller is an 8-bit microcontroller with very high performance, and its power consumption is relatively small. It contains 8-byte flash memory that can be used a thousand times repeatedly [11].

The 1602 LCD interface circuit in this work is shown in Figure 4. As shown in Figure 5, the power supply voltage, input voltage, output voltage is 6V/5V/3V respectively, and the maximum output current can reach 2A. It can be seen that the circuit meets the design requirements and the output current depends on the load. Finally, the key circuit was used to control to add or minus temperature value.
4. Software system design

4.1. The design of single-chip microcomputer control program

The main program of the single-chip microcomputer is the core of the entire software design. After the single-chip microcomputer is reset, it would enter the main program to initialize the system firstly. The main program flowchart is shown in Figure 6.

4.2. DS18B20 temperature acquisition subroutine

The whole process of collecting temperature data is that single-chip microcomputer read the data from the sensor firstly and convert the reading data, then read the converted result. It is that the initialization program needs to be called to detect the presence or absence of DS18B20 on the bus when reading the DS18B20. If so, the temperature data conversion is performed. The subprogram flowchart is shown in Figure 7.
4.3. 1602LCD display subroutine flowchart

The display system uses a liquid crystal 1602LCD to display temperature data, whose display subprogram flowchart is shown in Figure 8.

5. Cooling efficiency test and analysis of semiconductor cooler

5.1. Cooling efficiency theoretical analysis of semiconductor cooler

During this experiment, we set the output power supply parameters as: 12V voltage, 3A current, 50% conversion efficiency and select water as the cooling object, and then choose heat conduction way.

After calculating the theoretical cooling power curve is a straight line with a slope of -2.5. Under the above conditions, it is easy to find that the cooling power is $P = 12V \times 3A \times 50\% = 18W$.

5.2. Actual measurement of semiconductor cooler cooling efficiency

The actual input of the semiconductor cooler chip is 12V, 2.65A, and its power is $P = 12A \times 2.65V = 31.8W$. The temperature sensor was placed into water and the original value was set to 11°C. The data records are shown in Table 1. The cooling curve is shown in Figure 9[12].

Table 1. The data of temperature with time

| Time /min | Temperature /°C | Time /min | Temperature /°C |
|-----------|-----------------|-----------|-----------------|
| 0         | 36.6            | 18        | 23              |
| 3         | 34.5            | 21        | 20.6            |
| 6         | 32.3            | 24        | 18.4            |
| 9         | 30.3            | 27        | 16.1            |
| 12        | 27.8            | 30        | 13.8            |
| 15        | 26              | 33        | 11.1            |

Figure 9. The curve of temperature with time

Through experimental data, the actual cooling efficiency of the cooler can be calculated: $W = Pt = 31.8 \times 60 = 1.75 \times 10^5 J$ , $W_{\text{Cold}} = 420 \times (36.6 - 11.1) = 2975 J$ , so its cooling efficiency is: $\eta = W_{\text{Cold}} / W = 1.7\%$.

5.3. Measurement and analysis of semiconductor cooler cooling effect to refrigeration-box [13-14]

To better measure the cooling performance of semiconductor cooler, the air is selected as the cooling object. The 12V, 3A regulated power source is used for test, and the initial value is 36.6 °C. The data records are shown in Table 2. The cooling curve is shown in Figure 10. Compared with the water cooling test, the refrigeration-box cooling speed is faster. The experimental result is in accord with the conclusion that the specific heat capacity of water is much larger than air.

Table 2. The data of temperature with time

| Time /s  | Temperature/°C | Time /s  | Temperature/°C |
|----------|----------------|----------|----------------|
| 0        | 36.6           | 10       | 23             |
| 20       | 34.5           | 135      | 20.6           |
| 35       | 32.3           | 156      | 18.4           |
| 48       | 30.3           | 176      | 16.1           |
| 64       | 27.8           | 194      | 13.8           |
| 82       | 26             | 223      | 11.1           |

Figure 10. The curve of temperature with time
6. Summary
This work proposes and designs a medical semiconductor cooler system, the main features of which is small size, high control accuracy and easy implementation. And completing the cooling control to the water and refrigeration-box. Through analysing and comparing the cooling data, we can know that the cooling speed of refrigeration-box is faster and the cooling efficiency is higher.

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