Design of a Small Temperature Control System Based on TEC

Hui Huang, Shimin Fu, Peng Zhang, Likai Sun
The 49th Research Institute of China Electronics Technology Group Corporation, Harbin, China
Huanghui959@126.com

Abstract—**In this paper, we design a small temperature control system based on thermoelectric cooler (TEC), which uses proportional integral differential (PID) compensation network to control and drive the TEC module used as a temperature compensation element, and adopts a dedicated control chip, MAX1978, to conduct semiconductor refrigeration closed-loop automatic control. In room temperature environment, the temperature range of the temperature control system is 5℃ to 55℃, which can be continuously adjusted with the accuracy of up to 0.5℃. The system has the advantages of small volume, low power consumption, high efficiency, high integrated level, long service life, no noise, no mechanical movement, rapid and flexible refrigerating and heating, high precision temperature control, no need of refrigerant, no pollution to the environment, and not only provides a practical method to improve the temperature stability of semiconductor laser diode and rapidly reach a steady state, but also provides the beneficial reference to the similar temperature control system.**

Keywords- TEC; MAX1978; temperature control; PID

I. INTRODUCTION

Temperature control technology is a very important industrial technology. In the traditional temperature control technology, heating and cooling are often discrete. Generally speaking, heating uses the method of converting electric energy or chemical energy into thermal energy, and the electric heating element such as resistance wire, heat resistance have widely application in the industry. According to applications, refrigeration consist of air-cooled, water-cooled and compression type refrigeration. In certain situations, temperature control system often need to have heating and cooling functions at the same time, then the temperature control method is very convenient. And the semiconductor temperature control system which uses the thermoelectric cooler as the executive device of the temperature control can convert the refrigeration and heating by changing the direction of the current flow through the cooler, which is very convenient. Meanwhile, due to the semiconductor temperature control system using the Peltier element, so compared with the traditional temperature control method, it also has the advantages of small volume, light weight, long service life, no noise, no mechanical movement, rapid refrigeration, high precision temperature control, no need of refrigerant, no pollution to the environment [2].

In this paper, we design a small temperature control system based on thermoelectric cooler, which uses proportional integral differential compensation network to control and drive the TEC module used as a temperature compensation element, and adopts a dedicated control chip, MAX1978, to conduct semiconductor refrigeration closed-loop automatic control. The advantages of semiconductor temperature control system make it have an important role in the fields of semiconductor lasers, medical treatment, requiring constant temperature [3].

II. TEMPERATURE CONTROL ANALYSIS OF TEC

A. The working principle of TEC

The principle of semiconductor refrigeration which is also known as thermoelectric refrigeration is mainly the use of the Peltier effect of the Peltier elements. Peltier effect is that when the current I through the closed loop combined by two different materials, the one end of the joint of the material will absorb the heat Q_p, the other end will emit heat Q_p. This heat of absorption or release is called the Peltier heat whose size is determined by the formula (1) and endothermic or exothermic is determined by the direction of the current.

$$Q_p = \pi \cdot I \tag{1}$$

Including: π is Peltier coefficient related thermoelectric power and $\pi = (\alpha_1 - \alpha_2) \cdot T$. α_1, α_2 is respectively the thermoelectric power of two kinds of materials, T is the temperature of the relevant joint. In fact, Peltier elements at work not only produce the Peltier effect, but also can produce other four kinds of effects that is Seebeck effect, Joule effect, Thomson effect, and Fourier effect. Therefore, the cooling capacity of Peltier elements should be the result of the mixture of these five effects. In these five kinds of effects, influences of Thomson effect and the Fourier effect is relatively weak and negligible [4]. We only consider the effect of Peltier effect, Joule effect, in addition to the impact of heat conduction. Heat produced by Joule effect is

$$Q_j = \frac{1}{2} I^2 \cdot R \tag{2}$$

Including: R is the resistance of the semiconductor refrigerator. Heat transfer from the hot end to the cold end is

$$Q_e = K(T_1 - T_2) \tag{3}$$

Including: K is the rate of thermal conductivity of semiconductor refrigerator. T_1 , T_2 is respectively the temperature hot end and cold end. So the heat absorbed or released by the Peltier elements is

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$$Q = \pi \cdot I - \frac{1}{2} I^2 \cdot R - K(T_1 - T_2) \quad (4)$$

Semiconductor refrigerator puts a P-type semiconductor and a N-type semiconductor welded into a couple with copper piece, as shown in Figure 1. When semiconductor refrigerator connects the DC power supply, electronics start from the negative to P-type semiconductor where absorb heat and then go through the N-type semiconductor where emit heat. Electronics each go through a NP module, heat was sent from one side to the other side. There is heat sinking phenomenon in 2, 3 end of copper connecting piece which called the cold end and there is exothermic phenomenon in 1, 4 end of copper connecting piece which called the hot end. When DC electric go through refrigerator, cold end will cool down which can be used for cooling and temperature of hot face will gradually increase whose heat can be sent to the ambient heat through the radiator. If the current direction is changed, the opposite function can be realized. If cooling or heating power is large in the application, the multi-stage semiconductor refrigerator can be adopted [5].

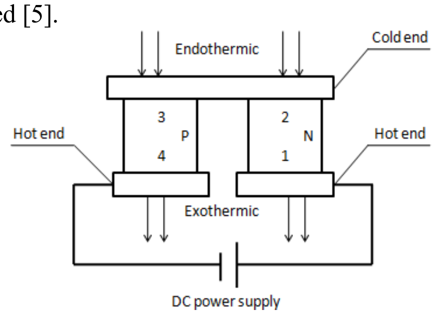

Figure1. Semiconductor thermocouple

B. Temperature control method of TEC

When using semiconductor cooler control temperature, we only need to control the current. Changing the direction of the current can achieve the conversion between heating and cooling and changing the size of the current can be adjusted to the size of the heat of absorbing or releasing [6].

The refrigeration capacity of the semiconductor refrigerator is affected by the ambient temperature. The lower temperature limit a semiconductor refrigerator can reach is not the same under different ambient temperature conditions.

The Joule effect and heat conduction influence the cooling effect of the semiconductor refrigerator. Semiconductor cooler should use a fan for heat dissipation in the cooling condition, reducing the influence of the refrigeration effect because of Joule effect and heat conduction.

III. STRUCTURE DESIGN OF TEMPERATURE CONTROL SYSTEM

The installation of the temperature control system module is shown in Figure 2. The laser diode is fixed on an aluminum heat conducting plate which is provided with a thermistor. The cold surface of semiconductor refrigerator is close to aluminum heat conducting plate connected with the laser diode and the heat surface of semiconductor refrigerator is close to a large heat sink whose opposite is fan. In this way, the heat generated by the semiconductor refrigerator will be spread through the heat sink and fan. The thermistor must provide accurate temperature signals to the temperature control system. In order to improve the accuracy, thermal grease is used to fill the void between thermistor and aluminum. In this way, we not only ensure good contact, but also prevent the slide of thermistor. TEC and the heat sink are composed of the refrigeration platform, which can not only be used to cool a laser diode, but also can be used in other small environment cooling field.

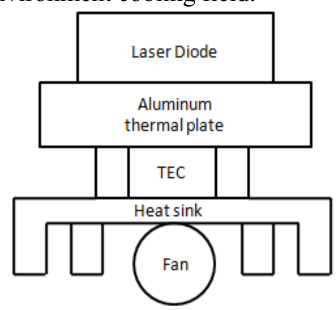

Figure2. Schematic diagram of temperature control system structure

In order to ensure good heat conduction properties, in installation we should as far as possible increase the contact area of the components and reduce contact resistance so as to improve the heat transfer effect. The contact surface of each surface evenly should be coated with a layer of thin thermal grease, which can reduce 25 ~ 30% of thermal resistance. Fan is used to be air-cooled, which makes the radiator fins direction parallel to the direction of flow. Heat sink is based on copper material with big heat transfer coefficient and the radiating fins are made of aluminum alloy material. The combination of the radiating fins and the heat sink increases contact area between the heat sink and the air, and the air flow through the fins form a vortex so that the heat passed over from the heat sink is rapidly emitted into the air.

IV. HARDWARE CIRCUIT DESIGN OF TEMPERATURE CONTROL SYSTEM

A. Overall scheme design

The basic principle of small temperature control system is that the cold side of the TEC directly contacts with controlled temperature device and the thermistor is used for real-time measurement of temperature change, in addition the single-chip microcomputer controls the proportional, integral and differential (PID) controller of the MAX1978 chip which integrates a chopper type operational amplifier with ultra low temperature drift and a integrating amplifier. PID controller adjusts the operating current loaded on the TEC which executes heating or cooling, depending on the direction of the current, so that the temperature remains at a preset temperature. The temperature control system has high precision, fast response, good stability, and can adapt to the change of external temperature [7]. Design diagram of temperature control system hardware circuit is shown in Figure 3.

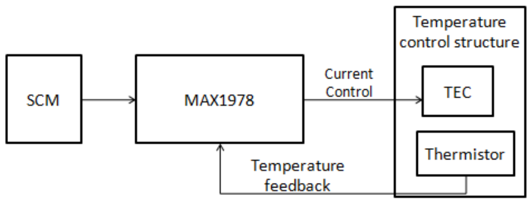

Figure3. Design diagram of temperature control system hardware circuit

B. MAX1978 circuit

MAX1978 is the smallest, the safest and the most accurate temperature control microchip for TEC modules. MAX1978 has a high level of integration with the control loop and power tube FET integrated on the same chip, and minimizes external circuitry, so that the whole temperature control system is more compact. Chips have the choice of 500 kHz and 1 MHz switching frequency of the MOSFET. Unique ripple cancellation methods of the chips not only reduce circuit noise, but also optimize the efficiency and size of the chips. At the same time, the switching speed of the internal MOSFET has been optimized to reduce noise and electromagnetic interference (EMI). The direct output of MAX1978 is current rather than voltage, which can directly eliminate inrush current. Independent current and voltage limit of heating and cooling provides the most secure protection for the TEC, so that the whole temperature control system is more secure and reliable. Single power supply makes it possible for TEC to provide bipolar ± 3A output current in order to achieve no "dead zone" temperature control and avoid nonlinear problems at low currents work. MAX1978 integrates a chopper type operational amplifier with ultra low temperature drift and a integrated amplifier, which constitutes a proportional-integral (PI) or proportional-integral-derivative (PID) controller and is capable of maintaining a temperature stability of ± 0.001 ℃. MAX1978 temperature control block diagram is shown in Figure 4 [8].

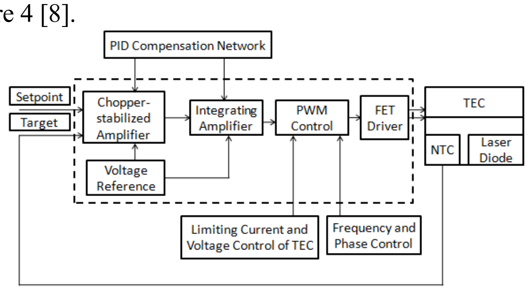

Figure4. MAX1978 temperature control block diagram

C. Hardware circuit design

MAX1978 temperature control hardware circuit schematic is shown in Figure 5. The part of temperature control is composed of R2, R3 and R4 (thermistor), and PID compensation network consists of R5, R6, R7, C9, C10, C11. High-precision temperature control is achieved by PID compensation circuit parameter settings.

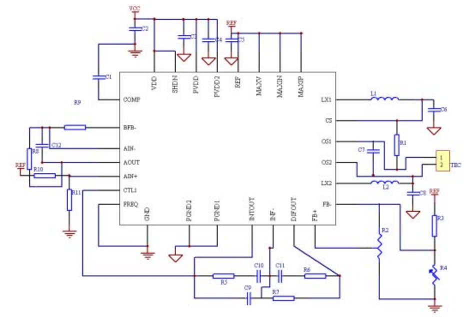

Figure5. MAX1978 temperature control hardware circuit schematic

D. PID control algorithm design

PID compensation network based on MAX1978 chip is the most critical part of the TEC temperature control, which directly affects the speed of response and control accuracy of the temperature control system. In order to solve the contradiction between the regulation speed and the regulation accuracy, PID parameters must be continuously optimized. The equation of PID regulator is shown in formula (5) below.

$$u(t) = K_P e(t) + T_I \int_0^t e(t)dt + T_D \frac{de(t)}{dt} \tag{5}$$

Including: K_P, T_I and T_D are respectively proportional gain coefficient, integral gain coefficient and differential gain coefficient. Since the PID controller has three available parameters, K_P, T_I and T_D, therefore, different combinations of controllers can be achieved in the case of taking different gain coefficients. PID controller schematic is shown in Figure 6.

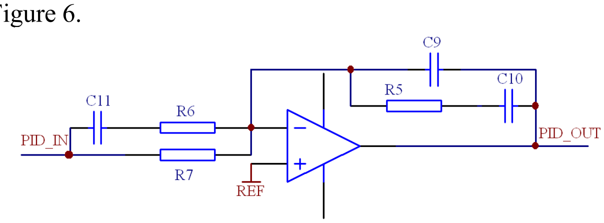

Figure6. PID controller schematic

In the temperature control system, R6 largely play a role in limiting current and C9 play a role in the compensating phase, which enhances the stability of the circuit. R7, R5, C11, C10 determines the proportional gain coefficient, the integral gain coefficient and the differential gain coefficient of the PID circuit. The formula (6), formula (7) and formula (8) can be obtained.

$$K_P = 50\left(\frac{R5}{R7} + \frac{C11}{C10}\right) \tag{6}$$

$$T_I = R5C10 + R7C11 \tag{7}$$

$$T_D = R5C11 \frac{R7C10}{R5C10+R7C11} \tag{8}$$

The proportional gain coefficient, the integral gain coefficient and the differential gain coefficient play a decisive role in temperature control system. In this paper, empirical formula Z-N is adopted to obtain the three parameters, as shown in formula (9), formula (10) and formula (11).

$$K_P = \frac{1.2T}{K\tau} \tag{9}$$

$$T_I = 2\tau \tag{10}$$

$$T_D = 0.5\tau \tag{11}$$

Including: T is inertia time constant, τ is the delay time. According to the step response curve of the thermal inertia test, we can draw the T and τ values which can be brought into the equation so that we can obtain the values of R7, R5, C11, C10, R6, C9.

V. EXPERIMENTAL TEST

In this experiment, the temperature of control system gradually rise from 0 ℃ to 55 ℃ with recording temperature data every 5 ℃ once. Then repeat 10 times and compute average value. The ambient temperature is 24 ℃. Table 1 shows the results of the experiment.

Table 1 Temperature deviation of temperature control system (unit: ℃)

Serial Number	Temperature Setting Value	Temperature Sampling Value	Deviation
1	0	0.43	0.43
2	5.0	5.44	0.44
3	10.0	10.36	0.36
4	15.0	15.42	0.42
5	20.0	20.31	0.31
6	25.0	25.45	0.45
7	30.0	30.34	0.34
8	35.0	35.43	0.43
9	40.0	40.42	0.42
10	45.0	45.41	0.41
11	50.0	50.33	0.33
12	55.0	55.44	0.44

As it can be seen from Table 1, in the range of 0 ~ 55 ℃, the maximum deviation of the temperature control system is 0.45 ℃, which is less than 0.5 ℃.

Table 2 presents the results of the temperature stability of the temperature control system. Set the temperature control system for continuous operation 2 hours at 35 ℃ with recording temperature data every 10 minutes once.

Table 2 Temperature stability of temperature control system

Serial Number	Time/min	Temperature/℃
1	0	35.44
2	10	35.43
3	20	35.43
4	30	35.43
5	40	35.45
6	50	35.42
7	60	35.42
8	70	35.42
9	80	35.43
10	90	35.41
11	100	35.42
12	110	35.43
13	120	35.42

As it can be seen from Table 2, during the 2 hours, the maximum temperature of work surface is 35.45 ℃ and the minimum value is 35.41 ℃. The maximum temperature float value is 0.04 ℃, which is less than 0.05 ℃.

After testing, the temperature range of the control system can be achieved in 5 ℃ ~ 55 ℃ at room temperature of 24 ℃. The temperature range is related to ambient temperature. In addition, it is can be observed that the temperature control system decline from room temperature to 5 ℃ is less than 1 minute and rise from 5 ℃ to 55 ℃ is just 2 minutes. Therefore, heating and cooling is very rapid.

VI. CONCLUSION

In this paper, we present a small temperature control system based on TEC. At room temperature of 24 ℃, the temperature control range is 5 ℃ ~ 55 ℃, which can be adjusted continuously and the accuracy is up to 0.5 ℃. The system has the advantages of small size, low power consumption, high efficiency, high integration, long life, no noise, no mechanical movement, flexible heating or cooling, high-precision temperature control, without refrigerant, no environmental pollution. It can improve temperature stability of the semiconductor laser diode and quickly reach steady operation state.

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