Study on Temperature Control System Based on SG3525

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Abstract. In this paper, it uses the way of dry bath temperature to heat the microfluidic chip directly by the heating plate and the liquid sample in microfluidic chip is heated through thermal conductivity, thus the liquid sample will maintain at target temperature. In order to improve the reliability of the whole machine, a temperature control system based on SG3525 is designed. SG3525 is the core of the system which uses PWM wave produced by itself to drive power tube to heat the heating plate. The bridge circuit consisted of thermistor and PID regulation ensure that the temperature can be controlled at 37 °C with a correctness of ± 0.2 °C and a fluctuation of ± 0.1 °C.

1. Introduction
The temperature control system is widely used in optical, mechanical, electronic, biochemical analysis and other scientific fields [1]. High-precision temperature control system is one of the key technologies to ensure the accuracy and repeatability. Currently dry bath temperature controlling system is mainly used in the temperature control system [2]. It has the advantage of high thermal conductivity, fast heating of the reaction liquid, stable temperature uniformity, easy maintenance. Thus, dry bath temperature controlling system is increasingly being used in all kinds of equipments.

Most of the temperature control system use MCU digital processor [3,4] as a control center, DS18B20 and other digital temperature sensor chips as temperature sampling. But there are some problems with this design. System itself is a complex system based on MCU control. Each of the control parts must have an accurate time sequence. While MCU-based temperature control also relies on strict time sequence, this will increase the complexity of the control system design so that the reliabilities of the overall control system reduce. Thus, we use the analog control chip SG3525 as the core of the temperature control system, a thermistor with a bridge as a front-end temperature sampling element and the PID control technology to complete the development of temperature system.

2. System structure and control principle
The temperature control system uses dry bath temperature way to heat the microfluidic chip[5] by two upper and lower heating plates directly. The reaction liquid in the microfluidic chip is heated by heat conduction to reach the desired reaction temperature.

Fig. 1 shows the physical map of the heating system. The microfluidic chip is placed on the lower chip holder, The device surrounding the chip holder which is used for the spectrometer positioning is made of metal copper, As shown in Fig. 2, the heating resistance wire is attached to the lower side of the
positioning device as a lower heating plate of the heating system. Above the microfluidic chip there is a heating plate which is fixed at a specific location. When heated, the microfluidic chip is raised and the upper surface of the chip is close to the heating plate. Place the temperature probe in the microfluidic chip. The upper and lower heating plates are also placed a high-precision temperature probe attached to the surface. Monitor the temperatures of the chip and the upper and lower heating plates through the real-time temperature measurement software. After heated to a predetermined temperature, record the temperature which is stable for some time. Next, the chip is dropped to its original position by operation. Record the chip temperature which is already stable for a period of time. By comparing the temperature of the two records, judge the effect of the air flow across the cavity on the temperature of the microfluidic chip.

As shown in Fig. 3 the temperature control system is made up of the bridge temperature measurement circuit[6] controlled by the ordinary voltage source, PWM controlled power drive circuit, adaptive PID control circuit with temperature compensation.

In the experiment, two sets of temperature control system are used to control the temperature of the upper and lower heating plates respectively. Duty cycle variable PWM wave which is produced by SG3525 control chip drives power module to heat the upper and lower heating plates. Thermistors which are placed on the heating plates get temperature of the two heating plates back then through the bridge temperature measurement circuit the temperature of the heating plates can be controlled stably. Finally, when two bridges are balanced, the temperature of the heating plates are kept at a constant value and the control accuracy achieves 0.1 °C by PID control.

It should be noted that the microfluidic chip is made of polycarbonate which has poor thermal conductivity but good insulation. Its thermal conductivity is 0.19W/(mK). Therefore, it is not proportional temperature conductivity when the upper and lower heating plates heat the chip. It can be seen from the experimental observations when the chip is 37 °C, the temperatures of upper and lower heating plates are little higher than 37 °C.
3. SG3525 chip introduction
SG3525 is a full-featured, versatile monolithic integrated PWM chip manufactured by American Semiconductor. It is suitable for a variety of switching power supply control by using constant frequency pulse width modulation scheme. As shown in Fig.4, its internal integrates oscillator, PWM comparator, error amplifier, under voltage lockout circuit, soft start control circuit, the reference voltage generation circuit. Its frequency is adjustable and it can limit the maximum duty cycle. It can increase driving capacity by using push and pull output form. Its salient features [7] are:
(1) Frequency adjustable function: Change external capacitor $C_T$ of Pin 5, external resistor $R_T$ of Pin 6 and resistor $R_D$ between Pin 5 and Pin 7 to adjust the PWM output frequency. As shown in Equation 1:

$$f = \frac{1}{C_T(0.7R_T+3R_D)} \quad (1)$$

(2) Under voltage lockout function
(3) Shutdown function
(4) Soft start function

![Representative Block Diagram](image)

Fig.4 SG3525 internal structure

4. Temperature control circuit design
As shown in Fig.5, SG3525 is the control chip of the circuits, the external circuits are simple. The input voltage VCC is DC 10V~35V. The sawtooth generation circuit in the circuits is composed of RT, CT and internal circuit. Take CT = 0.1uF, RT = 150kΩ, Pin 5 and Pin 7 are shorted. According to the formula $f=1/\left[ C_T(0.7R_T+3R_D)\right]$, calculate that the oscillator output frequency is about 100Hz and PWM output frequency is about 50Hz. The soft-start capacitor access terminate is a 22μF soft-start capacitor. The SG3525 is active only when the soft-start capacitor is charged to its voltage which Pin 8 is high. The left side of Fig.5 is bridge circuit consisted of R3, R12, R13, R19 and thermistor, where R19 is a sliding rheostat ranging from 0-5KΩ. The thermistor has a negative temperature coefficient.
When the environment temperature is 20 °C, the resistance is 10K Ω. Reference voltage VREF= 5.1V , is added to one end of the bridge circuit, the other end is ground. Pin 2 which is fixed voltage value of 2.55V connects e2. Pin 1 connects e1 and the voltage value depends on the selected resistance of the sliding rheostat. The voltage at Pin 1,2 pass through the internal error amplifier of SG3525, and its output, along with the 5-Pin sawtooth and soft-start capacitor, controls the PWM controller to generate square waves. Its output stage is designed for single-ended power supply control. Pin 11 and Pin 14 connect ground. Through the totem pole structure Pin 13 with sink current and pull current up to 200 mA can directly drive the MOSFET. For protection here adds a gate resistor R2= 100Ω. In this design we select IRFL9014 produced by IR Company. When the temperature of the heating plate continues to rise, the thermistor resistance is decreasing .Finally bridge of the left side of Fig.5 gets to balance, Ve1 ≈ Ve2. SG3525 exports stable PWM wave. The temperature of two heating plates remain constant. The temperature of the microfluidic chip is also kept constant by heat conduction. Pin 9 is the compensation side. Generally there are capacitors and resistances between Pin 9 and Pin 1. This part constitutes the PI controller. In this design R51 = 100kΩ, C1 = 1nF. Its specific design circuits are shown in the schematic diagram.

![Fig.5 SG3525 temperature control schematic diagram](image)

5. Experimental results
Make two PCB boards according to Fig.5. Use these two boards to control the upper and lower heating plates respectively. The following is the relevant experimental parameters:

Experimental ambient temperature is 26°C
The resistance of the heating wire of the upper heating plat is 10 Ω, Pin15 VCC=14V
The resistance of the heating wire of the lower heating plate is 20 Ω, Pin15 VCC=18V

Tab.1 is the corresponding relationship of thermistor between temperature and resistance. Temperature characteristic curve of thermistor can be approximated as a linear equation in the 20°C ~ 45°C. As shown in Equation 2:

\[ y = -0.2x + 14 \] (2)
Table 1. Corresponding relationship of thermistor between temperature and resistance

| T(℃) | 20  | 30  | 37  | 40  | 43  |
|------|-----|-----|-----|-----|-----|
| R(KΩ) | 10  | 8   | 6.6 | 6   | 5.3 |

After several experiments, we value upper heating plate R19=5.8KΩ, lower heating plate R19=6.44KΩ. When the bridges balance, the upper temperature of heating plate stabilizes at 41 ℃, the lower at 37.8 ℃. At this point the temperature of the microfluidic chip meets the experimental requirements.

Fig.6 is the temperature curve of upper and lower heating plates. Before heating the microfluidic chip, preheat the machine to increase the accuracy of the experiment. Under the control of SG3525, the upper and lower two heating plates are heated from the ambient temperature of 26 ℃. When the temperature of the upper plate is stabilized at 41 ℃, the temperature of the lower plate is stabilized at 37.8 ℃ (Note: 1 cell in the X axis is equal to 10s)

![Fig.6 The temperature curve of the upper and lower heating plates](image)

Put into microfluidic chip after the temperature stabilization of upper and lower heating plates and the upper surface of the microfluidic chip gets close to the upper heating plate. Fig.7 shows the curve of the temperature of the microfluidic chip over time. The final temperature is stable at around 37.3 ℃.
At this point, make the chip down to the original position. Observe changes of the chip temperature to estimate the influence of the entire cavity of the air flow on the microfluidic chip temperature. As shown in Fig. 8, the temperature is lowered by about 0.3 °C.

**Fig.7** The temperature curve of microfluidic chip

**Fig.8** Comparison of Temperature Curve of Microfluidic Chip before and after Falling
6. Conclusion

After several experimental studies on the temperature control system designed in this paper, we get the inclusion that the reaction solution in the microfluidic chip can be controlled at 37 °C with a correctness of ± 0.2 °C and a fluctuation of ± 0.1 °C. The effect of the entire cavity of the air flow on the microfluidic chip temperature is 0.2 °C to 0.3 °C. The temperature control system based on SG3525 which is designed in this paper meets the requirements of general equipments on the temperature of high precision, high stability, fast response. More importantly, the temperature control system becomes a separate part in the machine which uses SG3525 as a control center. So the system does not need timing control which must be used in digital temperature control. Thus it increases the reliability of the entire system.

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