Peltier Effect Based Temperature Controlled System for Dielectric Spectroscopy

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Abstract. The temperature control system was designed and built for application in dielectric spectroscopy. It is based on the dual-stage Peltier element that decreases electrical power and no cryogenic fluids are required. A proportional integral derivative controller was used to keep the temperature stability of the system. A Pt100 temperature sensor was used to measure temperature of the sample mounting stage. Effect of vacuum isolation and water-cooling on accuracy and stability of the system were also studied. With the incorporation of vacuum isolation and water-cooling at 18 °C, the temperature of the sample under test can be controlled in the range of -40 °C to 150 °C with temperature stability ± 0.025 °C.

Keywords: Dielectric spectroscopy; Peltier; PID control; Temperature control;

1. Introduction

Jean Peltier had discovered in 1834 that when the ends of two dissimilar metals are jointed and then one of the joints is heated, the other joint is cooled down [1]. However, various applications of Peltier have start in the 1950s after semiconductor Peltier elements have been discoved [2]. The minimum temperature 149 K (-124.15 °C) of four-step Peltier temperature controlled system has been reported by Huebener and Tsuer [3]. Incorporation of vaccum isolation and water-cooling with the Peltier based temperature controlled sytem designed by Scoth exhibited the temperature stability ±0.2 °C in the temperature regime 8 °C to 60 °C [4].

A proportional–integral–derivative controller (PID controller) is a technique commonly used in the closed-loop feedback control system. The advantages of the PID control that they are flexible to implementation in the microcontroller and relatively cheap. In this work, the temperature control system was designed and built for controlling temperature of sample in the dielectric spectroscopy measurement system. In order to improve performance of the system, the vacuum isolation and water-cooling were incorporated to the system. Characteristics of the system were also tested and reported.

2. Experimental

2.1. Chamber design

The temperature-controlled chamber is divided into two parts as shown in figure 1. The upper part of the chamber is the vacuum zone and the bottom is the cooling fins. Aluminum plate ($4.00 \times 4.00 \times 0.40$ cm^3) was mounted on the ceramic substrate of the Peltier module (AP2-162-1420-1118, European Thermodynamics Ltd.) and used as the sample mounting stage. In order to ensure good thermal conductivity, silicone grease was applied onto ceramic faces of the Peltier module before attached to the chamber and sample mounting stage. Four spring probes were attached to the plastic plates and mounted at the wall of chamber.

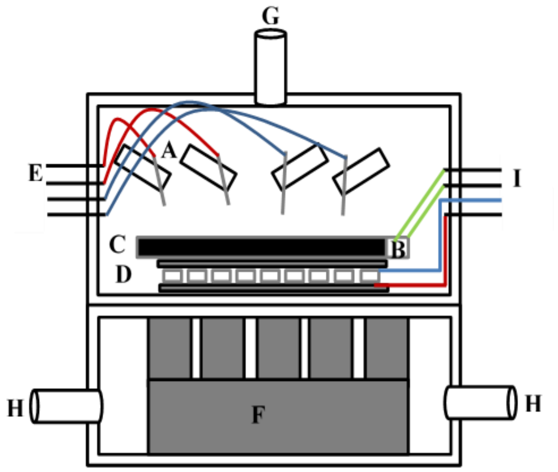

Figure 1. Temperature controlled chamber- A: probes, B: temperature sensor, C: sample-mounting stage, D: Peltier module, E: measurement conncetors, F: cooling fins, G: vacuum connector, H: water inlet/outlet connectors, and I: sensor and power sypply connectors.

2.2 Temperature control

Temperature of the sample mounting stage was detected by a Pt100 temperature sensor (P0K1. 202. 3FW. A. 007, IST, Inc.). The resistance of the sensor was then measured and converted to the temperature by using a microcontroller board (Arduino R3). In order to adjust temperature of the stage to the set point (SP), a proportional–integral–derivative controller (PID controller) was used to calculate current from the power supply (S-60-12, Mean Well) passed through the Peltier module. Block diagram of temperature control system is shown in figure 2.

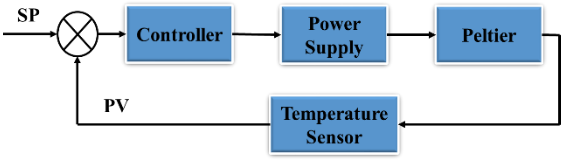

Figure 2. Temperature control block diagram.

2.3 Characteristic evaluation

The accuracy of the temperature control system was evaluated by measuring resistance of standard resistors (Yokogawa 2788). Temperature stability of the system defied as the maximum fluctuation of the temperature one the system has reached the set point was tested for one hour.

2.4 *Dielectric measurement*

Capacitance of material under test was measured by using parallel plate method. The capacitance-frequency characteristics in the frequency regime –40 °C to 140 °C were performed by using a precision LRC meter (Agilent 4284A). The measured capacitance is then used to calculate dielectric constant.

3. Results and discussion

3.1 Characteristic of the system

The maximum heating rate of the stage was test by applying maximum current to the Peltier. As shown in figure 3, the stage can heat up from room temperature to 140 °C with maximum heating rate 0.514 °C/s.

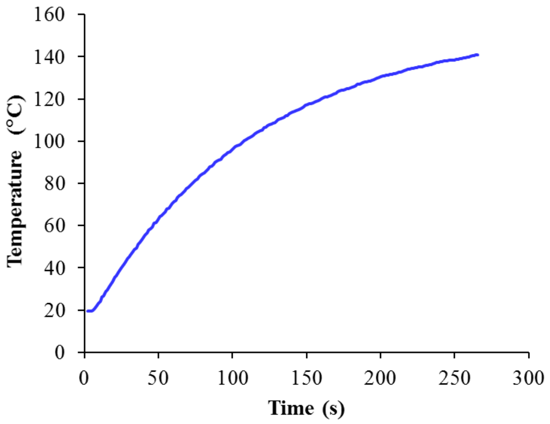

Figure 3. Variations in temperature of sample mounting stage as a function of time when a

direct current of 5 A is passed through the Peltier module.

Temperature accuracy of the system obtained from resistance measurement is ±0.524 Ω corresponding to the temperature 1.36 °C. The tolerance of resistance or temperature measurement is limited by the performance of microcontroller board. Figure 4 shows temperature of sample mounting state at the set point 60 °C for the system with vacuum isolation (1 mbar) and water-cooling (18 °C, 1 l/min). Temperature stability for one hour of the system is ±0.025 ºC. For the system without vacuum isolation and water-cooling, the maximum fluctuation of temperature ±0.18 ºC was observed.

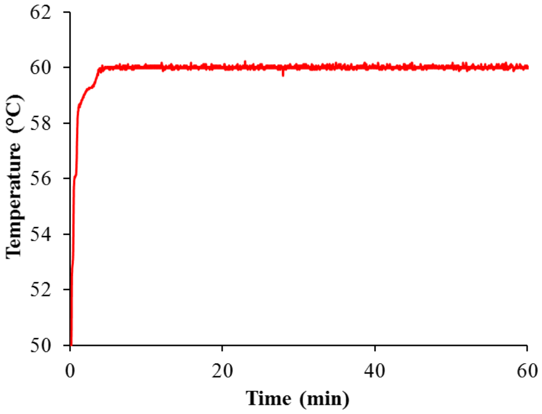

Figure 4. Temperature of the sample mounting stage at the set point 60 °C.

3.2 Temperature dependence of dielectric

Dielectric constants of industry type 5A lead zirconate titanate (PZT-5A:T107-A4E-173, Piezo Systems, Inc.) in the temperature regime –40 °C to 140 °C are plot in the figure 5. In the frequency regime lower than the resonance frequency, dielectric constant of the sample increases with increasing temperature. On the other hand, dielectric constant of the dielectric constant of the sample decreases with increasing frequency. The dielectric constant obtained from this work are comparable to those reported by Hooker [5].

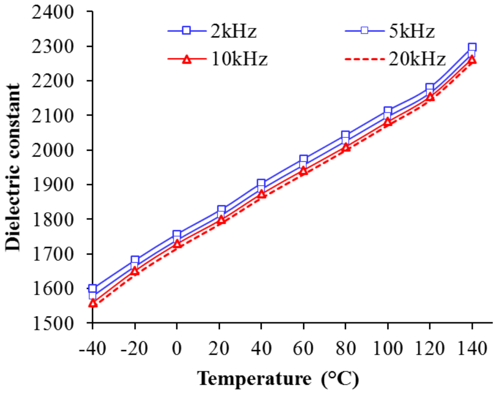

Figure 5. Variation in dielectric constant of PZT-5A as a function of temperature.

4. Conclusions

The Peltier effect based temperature controlled system for dielectric spectroscopy was designed and developed. The temperature of the sample can be set between –40 °C and 150 °C with a temperature accuracy better than ±1.36 °C. The system with vacuum isolation and water- cooling provides stable temperature with the temperature stability better than ±0.025 °C over one hour. The system provides easy and safe operation without cryogenic fluids are required.

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