Supplementary information

An Automatic Apparatus for Simultaneous Measurement of Seebeck Coefficient and Electrical Resistivity

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Content

S1. Main panel of LabVIEW GUI for the measurement

The primary display panel functions as the central platform showcasing an array of data, consisting of seven dynamic data charts. The real-time temperature chart provides an instant overview of temperature readings at both the cold and hot ends. Through the employment of two thermocouples, the system constantly monitors the temperatures at these respective points. These real-time measurements are then seamlessly transmitted to the Graphical User Interface (GUI) via the data acquisition system, as visually represented in Figure S1. Embedded within the logical framework of the data acquisition system is the assessment of whether the recorded temperature aligns with the defined precision range of the target temperature. To illustrate, if the specified target temperature stands at 40°C, with a precision boundary of ±0.05°C, the system evaluates whether the recorded temperature (denoted as T) falls within the range of 39.95-40.05°C. The I-V profiles across the sample can be further categorized into the real-time I-V chart and the all-time I-V chart. The real-time I-V curve provides a graphical representation of the current flowing through the sample and the corresponding voltage drop values during a single cycle of applied AC voltage. And the all-time I-V curve illustrates the intricate relationship between voltage and current within a specific temperature step. Key parameters such as resistance (slope) and Seebeck voltage (intercept) are obtained from these two charts. The remaining four charts located at the bottom present the relationship between resistance, resistivity, Seebeck voltage, and Seebeck coefficient with respect to the average temperature of the sample at each stable stage. These charts present the average values of characteristic variables for each temperature step, providing valuable insights into the experimental data. Lastly, the icons displayed at the bottom of Figure S1 represent the real-time measurement results. This panel provides a comprehensive view of the experimental data and enables the analysis of key parameters.

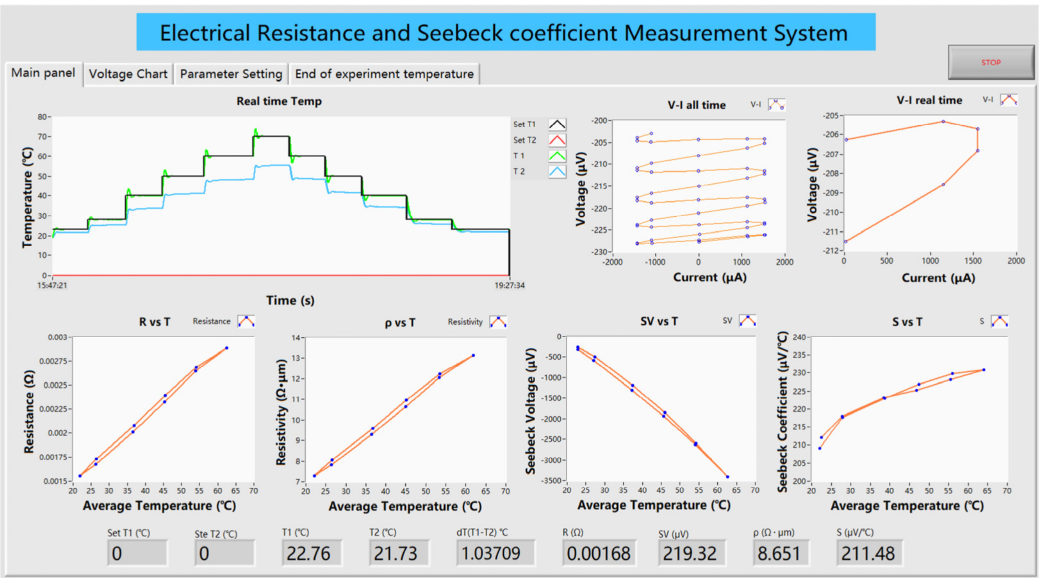

Figure S1. Main panel of LabVIEW GUI for the measurement.

S2. Parameter setting panel of LabVIEW GUI for the measurement

The parameter setting panel allows users to pre-configure important parameters. The file setting encompasses definition of name and path for three types of experiment data. The temperature setting specifies the temperature gradient and accuracy for the cold and hot ends. Within the PID setting, users can configure the proportional gain (Kc), integral time (Ti, min), and derivative time (Td, min) for the heaters' PID gains. Within the PID setting, users can configure the proportional gain (Kc), integral time (Ti, min), and derivative time (Td, min) for the heaters' PID gains. The output percentage of the PID can be converted via D/A conversion to control the DC voltage sources (EA-PS 2042-10 B). Subsequently, the controlled power supply is employed to regulate the functionality of the heater. The sampling setting facilitates the selection of physical channels for the NI 9211 temperature module and NI 9215 voltage input module, along with the definition of threshold values for these modules. It also includes thermocouple details, such as thermocouple type and operating temperature range. An essential functionality in this setting involves the execution of Keithley SCPI commands to enable data interaction between third-party hardware and LabVIEW, achieving the desired data acquisition capability. The geometric parameters of the sample can be defined. The Seebeck and resistance parameters setting allows users to set up electrical circuit parameters and durations, including the AC voltage and series resistance for the calculation of the sample's resistivity and Seebeck coefficient, and the stable time (t_{Stable}) required for temperature accuracy and the record time (t_{Record}) for data calculation.

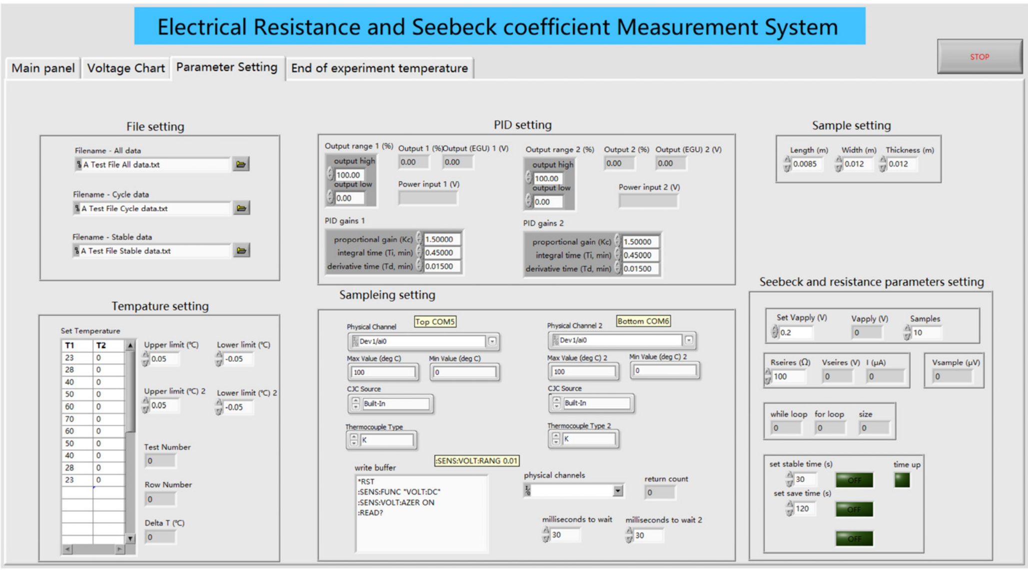

Figure S2. Parameter setting panel of LabVIEW GUI for the measurement.

S3. Voltage chart panel of LabVIEW GUI for the measurement

The voltage chart panel displays the sinusoidal voltage applied by the circuit, the calculated current, and the voltage data obtained from the series resistance and the sample. These data are collected by the data acquisition (DAQ) system and the Keithley instrument. The panel is divided into real-time signals and full-cycle signals. The V_{apply} and $I_{Circuit}$ charts serve as visual aids to provide the dynamic changes in AC voltage and current within the circuit, respectively. The AC voltage is generated utilizing the NI 9263 voltage output module, while the current is calculated based on the voltage drop across the series resistance. The voltage across the series resistance is collected through the NI 9215 voltage input module and depicted as V_{series} in Figure S3. The voltage disparity between the cold and hot ends of the sample is effectively showcased through the utilization of Vsample, which is acquired and measured using Keithley instrumentation. The collaborative functionality of these charts allows users to monitor the voltage variations and current measurements during the experiment.

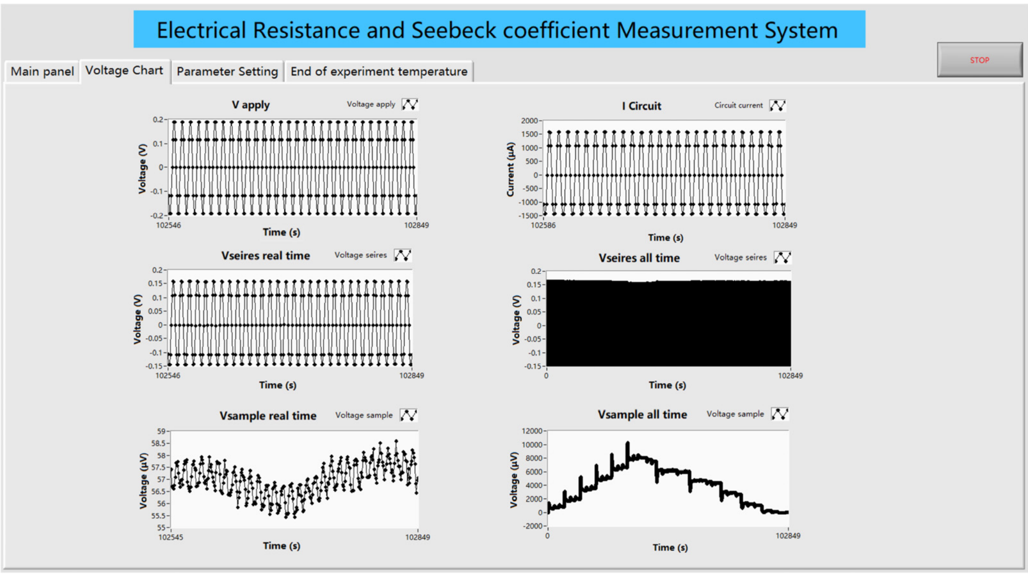

Figure S3. Voltage chart panel of LabVIEW GUI for the measurement.

S4. End of experiment panel of LabVIEW GUI for the measurement

Lastly, the end-of-experiment temperature panel monitors the sample's surface temperature until it cools down to room temperature. This panel ensures that the experiment is completed and allows users to track the temperature recovery process of the sample.

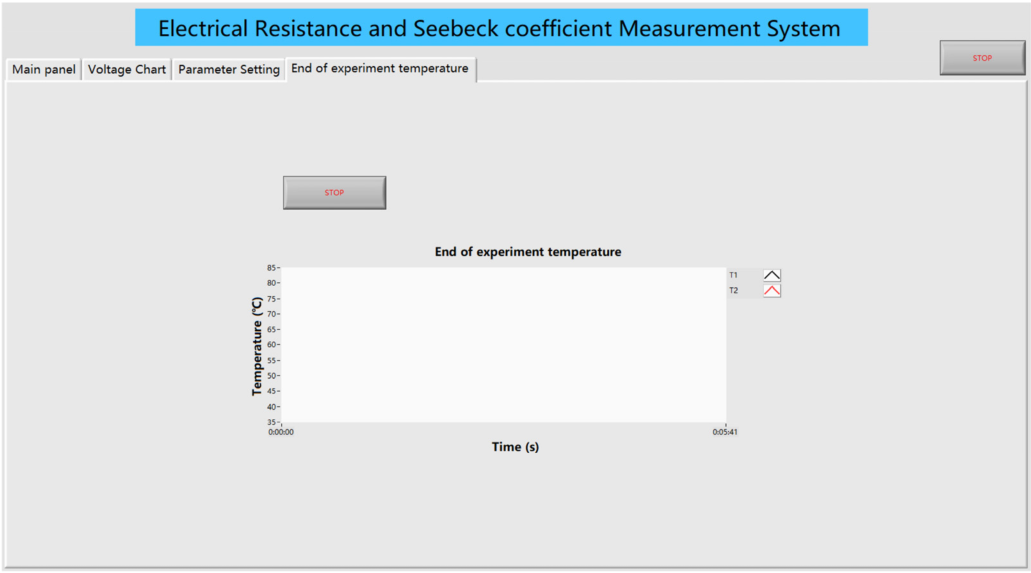

Figure S4. End of experiment panel of LabVIEW GUI for the measurement.

S5. LabVIEW algorithm and data acquisition logic for single temperature step measurement

As shown in Figure S2 and S5, within the parameter configuration interface of the program, it is imperative to establish predefined values for both the stabilization duration (t_{Stable}) and the data recording duration (t_{Record}). The t_{Stable} value signifies a process designed to detect temperature stability. This process evaluates whether the temperatures at the hot and cold ends of the sample align with the predetermined temperature range and accuracy specifications. On the other hand, t_{Record} pertains to the phase where the program commences the collection and retention of steady-state data, with the duration of t_{Record} governing the extent of data acquisition. Once the real-time temperature falls within the specified accuracy range, and the operational time meets the predetermined stable time t_{Stable}, the system advances to the data recording phase. Upon achieving a temperature state that aligns with the prescribed record time t_{Record}, the system then proceeds to present the conclusive outcomes for the designated t_{Record} duration.

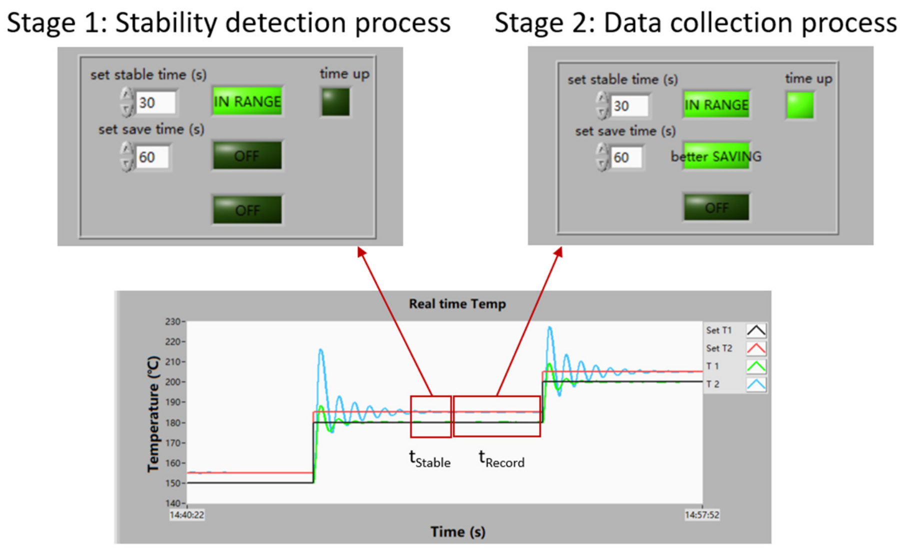

Figure S5. LabVIEW algorithm and data acquisition logic for single temperature step measurement.