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Design an Instrument for Measuring Current Using Its Heating Effect

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Abstract

Material science is very important to understand the design and fabrication of measuring physical properties on Science Technology Engineering Art and Mathematic (STEAM) education to create innovative idea. We designed an instrument for measuring current from heat sources of Tungsten wire, Nichrome coil, Thermistor and Thermoelectric cell from information about Thai Young Physicists' Tournament (TYPT) 2019. It was found that the thermoelectric cell can excellently convert heat to electrical current vice versa very good correspond with theory more than Tungsten wire, Nichrome coil, Thermistor.

Keywords: Tungsten wire; Nichrome coil; Thermistor; Thermoelectric cell; Heat convers to electric; STEAM education

Introduction

Heat can change to electrical current vice versa the electrical can change to heat. We need to design an instrument for measuring current using its heating effect by applied voltage with Tungsten, Nichrome, Thermistor and Thermoelectric cell. Vivekananthan Balakrishnan *et al*. analyzed the Joule heating problem of a segmented wire made of copper and nichrome wires with different properties and suspended as a bridge across two fixed ends. The temperature distribution was monitored using an IR thermal camera. The experimental data were in good agreement with the analytical data, validating our model for the design and development of thermal sensors based on multisegmented structures [1]. Y. Ikeda and K. Yoneta calculated the temperature rise of a conductor due to the electric current [2]. N. Athanasopoulos *et al*. reported Joule's first law dictates that when electric current passes through a conductor heat is generated. The scope of this work is to investigate the Joule heating effect of two types of carbon fiber tows in dry form. The tows are used as primary heating elements on various preform structures that require accurate and uniform temperature control, using a DC power supply. The investigated temperatures, ranged from 300 K up to 650 K. A finite difference scheme was developed, in order to predict and quantify the transient phenomenon and is verified against experimental results. In order to exploit in-depth the phenomenon and achieve very good agreement between numerical and experimental results, temperature dependence of thermal and electrical properties (specific heat capacity, total hemispherical emissivity, and volume resistivity) was examined under controlled vacuum environment, ensuring no fiber oxidation [3]. S.K. Thangaraju and K.M. Munisamy simulated the relationship between electrical and Joule heating of metal and semiconductor [4]. S.R. Acherman reported the temperature dependence of electric conductivity for metals in the Nineteenth Century [5]. NTC thermistors are thermally sensitive resistors made from a mixture of Mn, Ni, Co, Cu, Fe oxides. Sintered ceramic bodies of various sizes can be obtained. Strict conditions of mixing, pressing, sintering and metallization ensure an excellent batch-to-batch product characteristic. This semi-conducting material reacts as an NTC resistor, whose resistance decreases with increasing temperature. This Negative Temperature Coefficient effect can result from an external change of the ambient temperature or an internal heating due to the Joule effect of a current flowing through the thermistor. By varying the composition and the size of the thermistors, a wide range of resistance values (0.10 Ω – 1 MΩ) and temperature coefficients (–2 to –6% per °C) can be achieved [6]. S. Ruamruk reported the signal thermal sensor of *p*-$Bi_{0.4}Sb_{1.6}Te_{3.4}$ and *n*-Bi_2Te_3 thermoelectric cell shows similarly K type thermocouple [7]. O. Kahveci *et al*. reported the measurement and prediction of the thermal and electrical conductivity of Al-Zr overhead line conductors at elevated temperatures [8]. From literature reviews, the heat can convert to electrical current and power. In this work, we designed an instrument for measuring electrical current and power by investigating heat effect from Tungsten wire, Nichrome coil, Thermistor and Thermoelectric cell convert to electrical current and power.

Materials and Methods

We designed a printed circuit board (PCB) for put the materials, connecter, adaptor power wire and heat source corresponds with Engineering, Mathematic and Art as shown in Fig. 1(a) Tungsten (b) Nichrome (c) Thermistor and (d) Thermoelectric cell and measured the signal output of resistance, electrical current and electrical power for heat transfer corresponds Science and Technology.

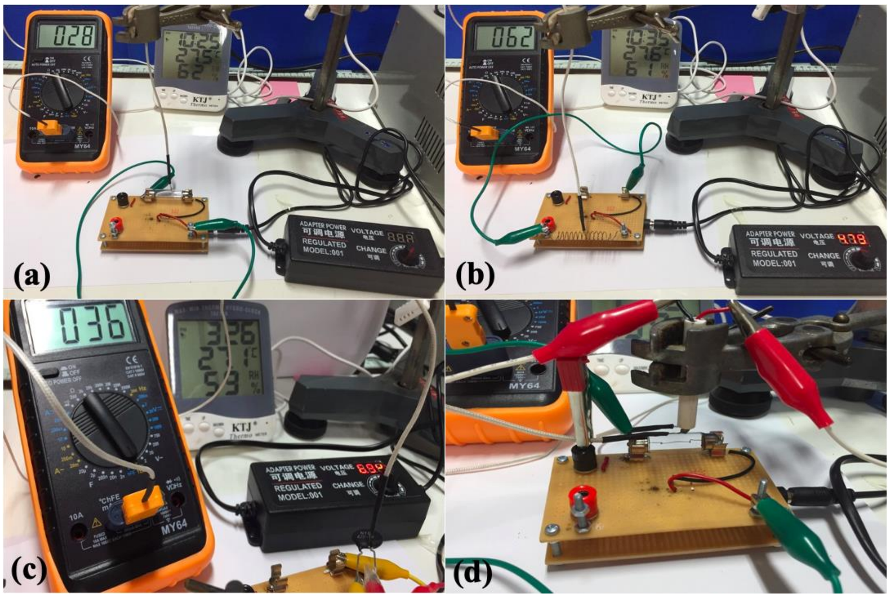

Fig. 1 Set up machine measure resistance, electrical current and electrical power from heat using (a) Tungsten (b) Nichrome (c) Thermistor and (d) Thermoelectric cell.

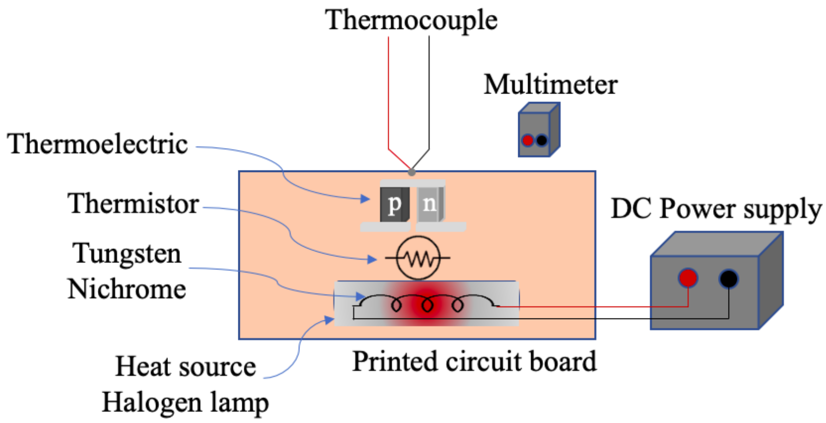

Fig. 2 Schematic diagram of experiments.

The DC power supply (Adaptor power 001, China) was applied with a halogen until voltage values matching with Tungsten resistance at room temperature (KTJ Thermometer, China) then lighting halogen on then measured resistance of Tungsten (Multimeter MY64, China) with increasing voltage and plot graph the relationship on temperature with resistance, as shown in Fig. 1 (a). The Tungsten was changed by a Nichrome coil and Thermistor (NTC Thermistors, AVX, Japan) following same step by step, as shown in Fig. 1 (b) and Fig. 1 (c). The thermoelectric cell (TE-cell) was fabricated by *p*-Sb_2Te_3 and *n*-Bi_2Te_3 thermoelectric materials then applied voltage with TE-cell generating temperature difference (Multimeter MY64, China) using 2 thermocouple type K. On other hand, the TE cell was applied temperature difference (halogen heat source) measuring electrical voltage, as shown in Fig. 1 (d). In addition, we drew schematic diagram of experiment as shown in Fig. 2. The resistance of Tungsten and Nichrome were increased with increasing heat by applied voltage to Tungsten metal, as shown in Fig. 3 (a) and Fig. 4 (a). Because the resistance of metal corresponds with the relationship [3];

$$R_{cond} = R_{ref}[1+\alpha(T-T_{ref})] \tag{1}$$

where R_{cond} is conductor resistance at temperature T, R_{ref} is conductor resistance at reference temperature T_{ref} usually 20 °C, but sometimes 0 °C, α is temperature coefficient of resistance for conductor material as shown in Table 1 [9], T is conductor temperature in degrees Celsius, T_{ref} is reference temperature that α is specified at for the conductor material .

Table 1 Temperature coefficients of resistance at 20 °C.

Metals	Temperature Coefficients of Resistance ; α (per °C)	Specific Resistance (Ω)	Electrical Resistivity (Ωm)
Tungsten	4.40×10^{-3}	33.20	4.90×10^{-8}
Nichrome	1.70×10^{-3}	660	1.10×10^{-6}

The resistance of Thermistor was exponential decreased with increasing heat by applied voltage to Thermistor, as shown in Fig. 5 (a). Because the resistance of semiconductor corresponds with the Steinhart-Hart equation [9];

$$\frac{1}{T} = a + b\ln R = c(\ln R)^3 \tag{2}$$

where *a*, *b*, and *c* are the Steinhart-Hart parameters and must be specified foe each device. *T* is absolute temperature, and R_{semi} is the resistance [9].

$$R_{semi} = \exp\left[(x-y)^{1/3} - (x+y)^{1/3}\right] \tag{3}$$

where $y = \frac{1}{2c}\left(a - \frac{1}{T}\right), x = \sqrt{\left(\frac{b}{3c}\right)^3 + y^2}$. As an example, typical values for a thermistor with a resistance of 3 kΩ at room temperature (25 °C = 298.15 K) are: $a = 1.40\times10^{-3}, b = 2.37\times10^{-4}$ and $c = 9.90\times10^{-8}$ [9].

Thermoelectric materials can convert temperature difference to electrical voltage vice versa electrical voltage to different temperature. We evaluated the resistance, voltage, current and electrical power as following equation (4) – (7) [10];

$$R_{TE} = \frac{\left(\frac{(\rho_p + \rho_n)(l_p + l_n)}{2}\right)}{A_p + A_n} \tag{4}$$

where R_{TE} is the resistance of thermoelectric cell (W), ρ_p is electrical resistivity of *p*-type thermoelectric material (W m), ρ_n is electrical resistivity of *n*-type thermoelectric material (W m), l_p is length of *p*-type thermoelectric material (m), l_n is length of *n*-type thermoelectric material (m), A_p is area of *p*-type thermoelectric material (m^2) and A_n is area of *n*-type thermoelectric material (m^2) [10].

$$E_{emf} = (S_p - S_n)(T_h - T_c) \tag{5}$$

where E_{emf} is volatge, S_p is Seebeck coefficient of *p*-type thermoelectric material (mV K^{-1}), S_n is Seebeck coefficient of *n*-type thermoelectric material (mV K^{-1}), T_h is absolute temperature of hot side (K) and T_c is absolute temperature of cool side (K) [10].

$$I = \frac{(S_p - S_n)(T_h - T_c)}{R_p + R_n + R_L} \tag{6}$$

where I is current, R_p is resistance of *p*-type thermoelectric material (W), R_n is resistance of *n*-type thermoelectric material (W) and R_L is resistance of load (W) [10].

$$P = I^2 R_L = \left(\frac{(S_p - S_n)(T_h - T_c)}{R_p + R_n + R_L} \right)^2 R_L \quad (7)$$

where P is electrical power (W).

Results and Discussion

We found the resistance, electrical current and electrical power from heat using (a) Tungsten (b) Nichrome (c) Thermistor and (d) Thermoelectric cell.

The relationship between resistance with a temperature of Tungsten wire in vacuum capillary, as shown in Fig. 3 (a). The resistance of Tungsten wire was increased with increasing temperature due to applying voltage with Tungsten wire about 3.50 – 10 V indicates that the relationship between resistance with a temperature of conductor good agreement with theory and literature data following by Eq. (1). Since Tungsten wire is a metal when increase temperature it changes into an insulating state. Because the metal has oxidation reaction causes a lack of precision and accuracy also has a limitation. The relationship between temperature radiation with electrical current and electrical power of Tungsten wire, as shown in Fig. 3 (b). The electrical current and electrical power of Tungsten wire were increased with increasing temperature radiation. However, these values are very low in order micro and the heat can't convert to electricity only electricity to heat.

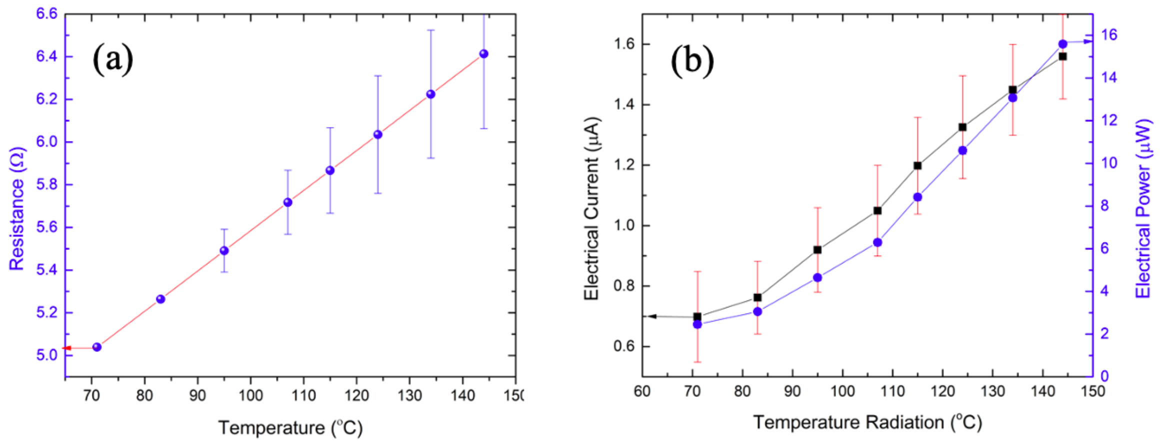

Fig. 3 The Tungsten wire (a) the relationship between temperature with resistance and (b) the relationship between temperature radiation with electrical current and electrical power.

The relationship between resistance with a temperature of Nichrome wire, as shown in Fig. 4 (a). The resistance of Nichrome wire was increased with increasing temperature due to applying voltage with Nichrome wire about 3.50 – 10 V indicates that the relationship between resistance with a temperature of conductor good agreement with theory and literature data as following by Eq. (1). Since Nichrome wire is a metal when increase temperature it changes into an insulating state. Because the metal has oxidation reaction causes a lack of precision and accuracy also has a limitation. The relationship between temperature radiation with electrical current and electrical power of Nichrome wire, as shown in Fig. 4 (b). The electrical current and electrical power of Nichrome wire were increased with increasing temperature radiation. However, these values are very low in order micro and the heat can't convert to electricity only electricity to heat.

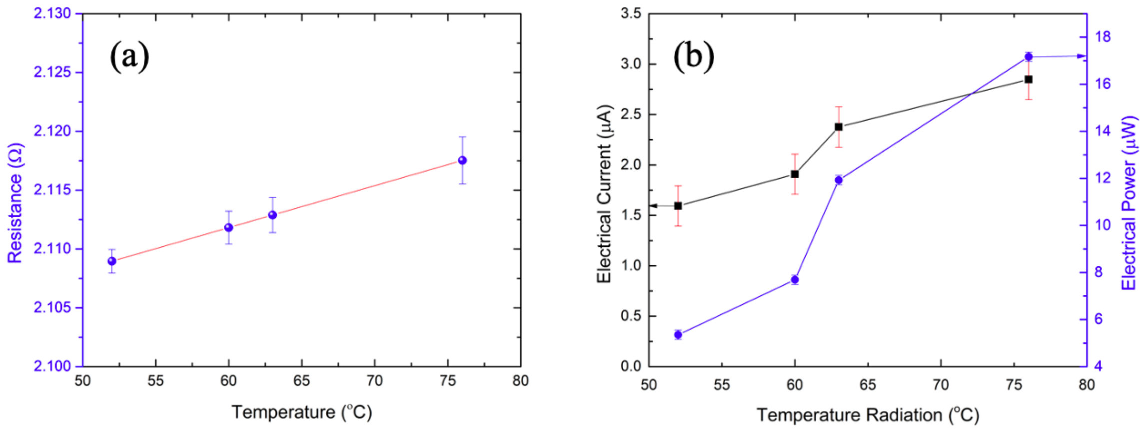

Fig. 4 The Nichrome coil (a) the relationship between temperature with resistance and (b) the relationship between temperature radiation with electrical current and electrical power.

The relationship between resistance with a temperature of Thermistor, as shown in Fig. 5 (a). The resistance of Thermistor was exponential decreased with increasing temperature due to applying voltage with Thermistor about 3.50 – 10 V indicates that the relationship between resistance with a temperature of semiconductor good agreement with theory and literature data as following by Eq. (3). Since Thermistor is a semiconductor when increase temperature it changes into a conductor state. The relationship between temperature radiation with electrical current and electrical power of Thermistor, as shown in Fig. 5 (b). The electrical current and electrical power of Thermistor were increased with increasing temperature radiation. However, these values are very low in order micro and the heat can't convert to electricity only electricity to heat.

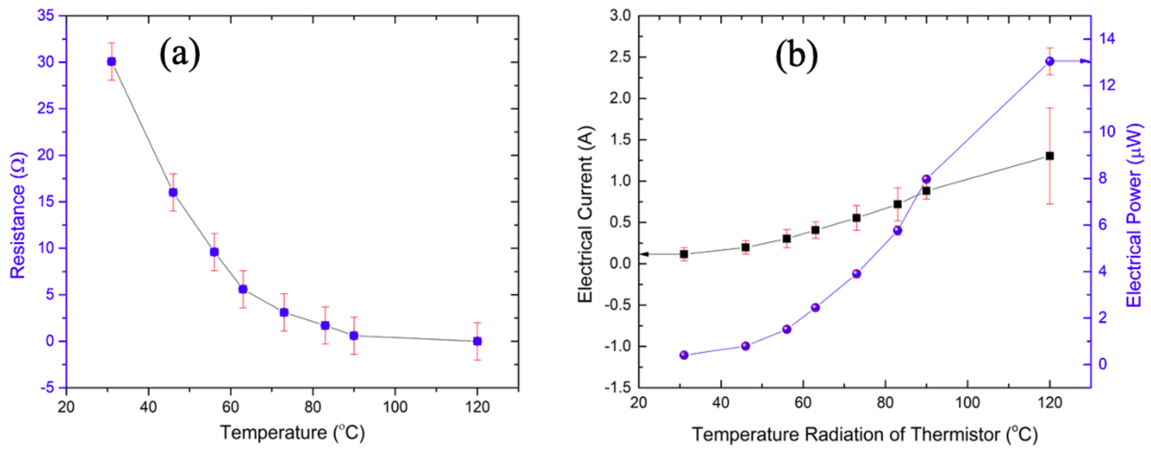

Fig. 5 The Thermistor (a) the relationship between temperature with resistance and (b) the relationship between temperature radiation with electrical current and electrical power.

The relationship different temperature difference with voltage in and out are show in Fig. 6 (a). The voltage in and out were increased with increasing temperature difference indicate good signal heat can convert to electricity. However, V_{in} and V_{out} values are slightly different and more error for V_{out} because thermoelectric materials can directly convert temperature difference to current vice versa convert current to heat by electromotive of electron and hole carries. The relationship between temperature difference with electrical power and electrical current are show in Fig. 6 (b). The electrical power and electrical current were increased with increasing temperature difference.

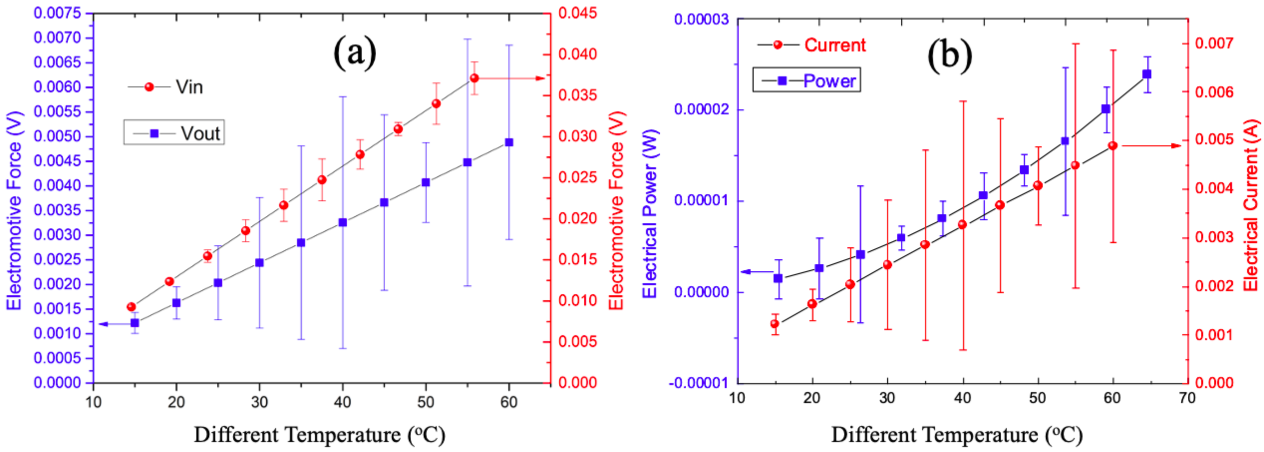

Fig. 6 The Thermoelectric cell (a) the relationship between temperature with resistance and (b) the relationship between temperature radiation with electrical current and electrical power.

Table 2 The comparison of electrical power and error values.

Materials	Electrical Power (μW) at 70 °C	Error (%)
Tungsten	3	30
Nichrome	15	30
Thermistor	3	10
Thermoelectric cell	25	5

Conclusion

The voltage was applied with Tungsten wire and Nichrome coil yield heating and calculate the electrical current but can't measure electrical current when applied heating with Tungsten wire and Nichrome coil with the error of 30%. The voltage was applied with Thermistor yield heating and calculate the electrical current but can't measure electrical current when applied heating with Thermistor with the error of 10%. The voltage was applied with Thermoelectric cell yield heating and calculate the electrical current and can measure electrical current when applied heating with Thermoelectric cell with error the of 5%. So that, thermoelectric materials can directly convert temperature difference to current vice versa convert current to heat by electromotive of electron and hole carries.

Suggestions

The signal from apparatus should be connected with Arduino program get the dada real time and develop to wearable device.

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