# $MnO-Fe_2O_3-SiO_2$-BaO-OTHERS THERMOELECTRIC MINERAL

Weerasak Somkhunthot*, Areerat Dawongsa, Watcharin Detkunthong and Porntip Kirathan

*Program of Physics, Faculty of Science and Technology, Loei Rajabhat University 42000, Thailand*

*Received 20 December 2015; Revised 27 December 2015; Accepted 30 December 2015*

## ABSTRACT

Thermoelectric mineral specimens has been found in Ban Muang Thong, Moo 9, Chiang Kom Subdistrict, Pak Chom District, which is located in the northern part of Loei Province, northeastern of Thailand. Mineral sample was prepared as powder and bulk solid form by crushing, calcination and annealing, pressure and sintering, cutting and polishing. Mineral powder was used to analyze the chemical composition and phase identification using x-ray fluorescence (XRF) and x-ray diffraction (XRD), respectively. XRF and XRD results indicated that a mineral sample comprised $MnO-Fe_2O_3-SiO_2$-BaO-others. Bulk sample of 0.33 cm width, 0.41 cm length, 1.70 cm height and 2.46 g/cm$^3$ density was used to measure and calculate the thermoelectric properties and efficiencies at room temperature in air. It was found that a mineral sample was n-type conduction. The thermoelectric power, electrical resistivity and thermal conductivity were –282.3±2.5 μV/K, 29.4±1.3 Ω·m and 230.1±11.8 W/m·K, respectively. The electrical power factor of ~$10^{-9}$ W/m·K$^2$ and thermoelectric figure of merit of ~$10^{-11}$ K$^{-1}$ were obtained.

KEYWORDS: *$MnO-Fe_2O_3-SiO_2$-BaO-others, Thermoelectric mineral*

* Corresponding authors; e-mail: weerasak1963@yahoo.co.th, Tel.&Fax +6642835238

## INTRODUCTION

Thermoelectricity is a renewable energy and clean form by using non-polluting thermoelectric devices it can directly convert heat to electricity. The materials for conversion of thermoelectric energy are two recognized types of charge carrier, such as positive (p-type) and negative (n-type) charges. Thermoelectric materials depend on properties such as the thermoelectric power ($S$) [1,2,3], electrical resistivity (ρ) [4,5,6] and thermal conductivity (κ) [2,7,8] for viable use. Efficiency can be obtained from the $S$, ρ and κ which are given by the thermoelectric figure of merit $Z = S^2/\rho\kappa$, where $S^2/\rho$ is referred to as the electrical power factor ($P$). Performance of materials is usually characterized in terms of their dimensionless figure of merit $ZT$, where $T$ is the absolute temperature [2,3,9].

The search for thermoelectric materials with high efficiency is important that the compounds of metal oxides were interested. In this research, Local mineral $MnO-Fe_2O_3-SiO_2$-BaO-others has been found in Loei Province, Thailand. Mineral sample was prepared as powder and bulk form by crushing, calcination and annealing, pressure and sintering, cutting and polishing. Chemical composition and phase identification of power sample are reported. Thermoelectric properties and efficiencies of bulk sample are presented.

## MATERIALS AND METHODS

Mineral was crushed and calcined at 373 K in air for 3 h. Calcined powder was crushed and mixed with polyvinyl alcohol in 5 g : 1 mL ratio and annealed at 373 K in air for 1 h. Annealed powder was crushed and pressed into bulk solid at the pressure of 200 kg/cm$^2$ in air before subjected to sintering stage. Bulk precursor was sintered at 573 K in air for 3 h. Subsequently, sintered bulk was cut and polished to determine thermoelectric properties and efficiencies. Mineral specimens, powder and bulk samples are shown in Fig. 1.

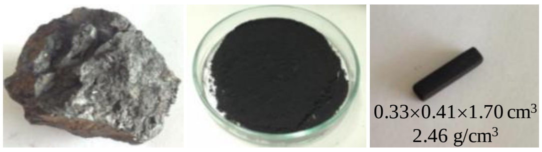


**Fig. 1.** Mineral specimens, powder and bulk samples.

Powder sample was used to analyze the chemical composition and phase identification using X-Ray Fluorescence Spectrometer (XRF-Philips PW-2404) and X-Ray Diffractometer (XRD-6100 Shimadzu), respectively.

Bulk sample was used for determination of thermoelectric properties and efficiencies at Science Center, Loei Rajabhat University (LRU). Firstly, the hot probe experiment and the standard steady state measurement were used to determine the type of charge carrier and thermoelectric power ($S$) which can be considered from the relation between thermoelectric voltage ($\Delta V$) and temperature difference ($\Delta T$). The $S$ is given by given by $S = \Delta V/\Delta T$ [1,2,3]. Secondly, electrical resistivity ($\rho$) was measured by the current ($I$) and voltage ($V$) characteristics. It can be estimated by use of the equation, $\rho = RA/l$, where $R$ is the resistance ($R = V/I$), $A$ and $l$ are the cross-sectional area and length of bulk sample, respectively [4,5,6]. Thirdly, the steady state technique was used to find thermal conductivity ($\kappa$). The heat flux density ($\Phi_Q$) between two ends of bulk solid can be given by the Fourier's law, $\Phi_Q = \kappa(dT/dx)$, where $dT/dx$ is the temperature gradient along the path of the heat flow [2,7,8]. Finally, the thermoelectric efficiencies can be examined from the material's electrical power factor ($P = S^2/\rho$) and thermoelectric figure of merit ($Z = S^2/\rho\kappa$) [2,3,9].

## RESULTS AND DISCUSSION

XRF result is given in Table 1. From this table found that a mineral specimens included the MnO (59.65%), $Fe_2O_3$ (18.35%), $SiO_2$ (11.15%), BaO (7.51%), $Al_2O_3$ (1.15%), $TiO_2$ (0.51%), $K_2O$ (0.40%), CaO (0.31%), MgO (0.27%), ZnO (0.23%), $SO_3$ (0.13%), $P_2O_5$ (0.12%), $Na_2O$ (0.11%) and SrO (0.11%). XRD pattern is shown in Fig. 2. From this figure exhibited that the phases of compounds (PDF # Number) such as MnO (04-0326), $Fe_2O_3$ (76-1821, 89-7047), $SiO_2$ (89-8934, 89-5416) and BaO (01-0746). XRF and XRD results indicated that a local mineral sample comprised the MnO-$Fe_2O_3$-$SiO_2$-BaO-others.

**Table 1**. Chemical composition of mineral specimens.

| 1. Compounds | 2. Concentrations (%) |
|---|---|
| Sodium oxide ($Na_2O$) | 0.11 |
| Magnesium oxide (MgO) | 0.27 |
| Aluminum oxide or Alumina ($Al_2O_3$) | 1.15 |
| Silicon dioxide or Silica ($SiO_2$) | 11.15 |
| Phosphorus pentoxide ($P_2O_5$) | 0.12 |
| Sulfur trioxide ($SO_3$) | 0.13 |
| Potassium oxide ($K_2O$) | 0.40 |
| Calcium oxide (CaO) | 0.31 |
| Titanium dioxide ($TiO_2$) | 0.51 |
| Maganese oxide (MnO) | 59.65 |
| Iron (III) oxide or Feric oxide ($Fe_2O_3$) | 18.35 |
| Zinc oxide (ZnO) | 0.23 |
| Strontium oxide (SrO) | 0.11 |
| Barium oxide (BaO) | 3. 7.51 |

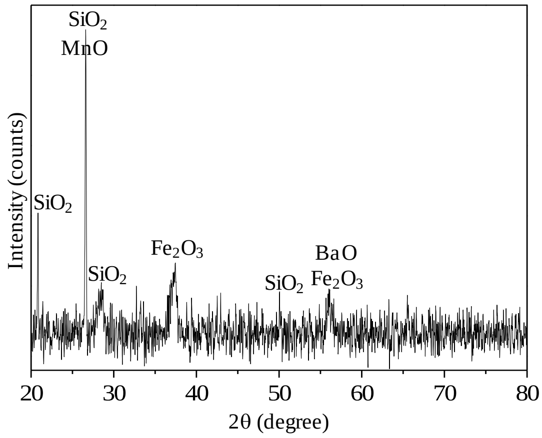


**Fig. 2.** XRD pattern of mineral sample.

Thermoelectric properties and efficiencies of a bulk sample were determined in air at room temperature. The hot probe experiment exhibited that a bulk sample showed n-type conduction, as shown in Fig. 3. The thermoelectric voltage decreased with increasing temperature difference from $\Delta V = -4.0$ mV at $\Delta T = 13.6$ K to $\Delta V = -22.5$ mV at $\Delta T = 82.7$ K. The $S$ of $-282.3\pm2.5$ μV/K is obtained. Measurement result of resistivity is shown in Fig. 4. The plot exhibited the good ohmic $I$-$V$ characteristics. The $\rho$ value obtained from this $I$-$V$ plot is $29.4\pm1.3$ Ω·m. The relation between the heat flux density and temperature gradient is shown in Fig. 5. The $\kappa$ value of $230.1\pm11.8$ W/m·K was determined. Calculation results gave the values of power factor and figure of merit were about $10^{-9}$ W/m·K$^2$ and $10^{-11}$ K$^{-1}$, respectively.

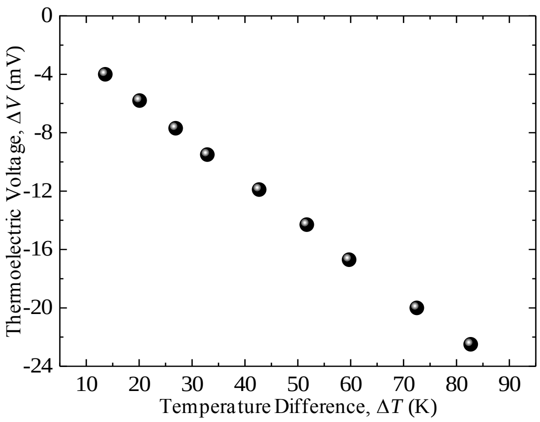


**Fig. 3.** Thermoelectric voltage as a function of the temperature difference.

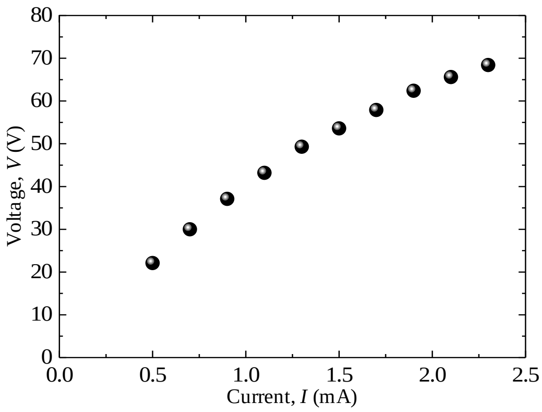


**Fig. 4.** Electric current-voltage characteristics for measuring resistivity.

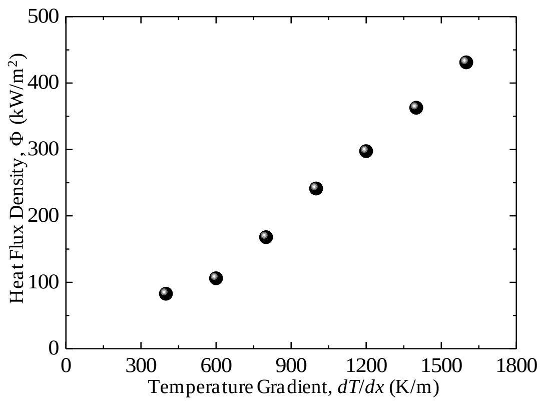


**Fig. 5.** Heat flux density as a function of the temperature gradient

## ACKNOWLEDGEMENTS

This work was financially supported by the Loei Rajabhat University (LRU) and the National Research Council of Thailand (NRCT). The National Metal and Materials Technology Center (MTEC) and Thermoelectric Research Center (TRC), Sakon Nakhon Rajabhat University (SNRU), Thailand, are acknowledged for the XRF and XRD analysis.

## REFERENCES

[1] http://www.eng.fsu.edu/~dommelen/quantum/index.pdf **(20-12-2015)**

[2] G.S. Nolas, J. Sharp, H.J. Goldsmid, Thermoelectrics: Basic Principles and New Materials Developments, Springer, Verlag, Berlin, Heidelberg, **2001**.

[3] D.M. Rowe, Thermoelectrics Handbook Macro to Nano: 1 General Principles and Basic Considerations, CRC Press, Boca Raton, **2006**.

[4] D.K. Schroder, Semiconductor Material and Device Characterization, 3rd ed., John Wiley & Sons, Inc., Hoboken, and New Jersey, **2006**.

[5] J.G. Webster, Electrical Measurement, Signal Processing, and Displays: 7 Electrical Conductivity and Resistivity, CRC Press LLC, Boca Raton, **2004**.

[6] H.D. Young, R.A. Freedman, University Physics with Modern Physics, 13th ed., Addison-Wesley, San Francisco, **2012**.

[7] S.J. Blundell, K.M. Blundell, Concepts in Thermal Physics, Oxford University Press, New York, **2006**.

[8] D.V. Schroeder, An Introduction to Thermal Physics, Addison Wesley Longman, San Francisco, **2000**.

[9] C. Wood: *Rep. Prog. Phys.* 51, **1988** 459-539.