

ENHANCEMENT OF THERMOELECTRIC PROPERTIES INDUCED BY CO IN ZnO

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Abstract

ZnO-based thermoelectric material shows high Seebeck coefficient, low electrical resistivity and low thermal conductivity. ZnO doped with Co can increase thermoelectric properties. $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) material were synthesized through solid state reaction (SSR) method. The powder precursor of ZnO and Co_3O_4 were mixed by ball milling in deionized water for 2 h, calcined at 1073 K and sintered at 1423 K for 5 h. The crystal structure was analyzed by X-Ray Diffraction (XRD) technique. The microstructure was observed by scanning electron microscopy (SEM). The Seebeck coefficient and electrical resistivity were measured by steady state method. This study found that the XRD patterns of $Zn_{0.9}Co_{0.1}O$, $Zn_{0.8}Co_{0.2}O$ and $Zn_{0.7}Co_{0.3}O$ phase which matched of PDF#00-061-0685 indicating a hexagonal structure space group of P63mc (186). The SEM results revealed that the grain size of materials arrangement changed after sintering. The thermoelectric properties of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) had a Seebeck coefficient at a maximum value of $-2442 \mu V/K$ condition of $Zn_{0.8}Co_{0.2}O$ which was able to enhance a Seebeck coefficient value of $-474 \mu V/K$ of ZnO and electrical resistivity value of $57.02 \Omega \cdot m$ which was enhanced from $5.72 \Omega \cdot m$ at 473 K condition of $Zn_{0.7}Co_{0.3}O$ comparing to ZnO. The powder factor was enhanced in all doping. It was confirmed that the samples were n-type thermoelectric materials which was in a semiconductor group.

Keywords: Synthesis, Zinc cobalt oxide, characterization, thermoelectric material, Thermoelectric properties

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Introduction

Zinc oxide materials have been receiving significant attention in recent years because of their unique physical and chemical properties, such as high chemical stability, high electrochemical coupling coefficient, broad range of radiation absorption, and high photostability (Kolodziejczak-Radzimska *et al.*, 2014). Its high thermal and mechanical stability at room temperature make it attractive for potential use in electronics, and laser technology (Dong *et al.*, 2010). In other words, their features were found to promote an achievement of high performance materials for various applications in many field of nanotechnology (Maensiri *et al.*, 2006; Seetawan *et al.*, 2011). Recently, many studies have been conducted in order to understand the microstructure, electrical properties and thermoelectric properties of ZnO for application, for example, the varistor ceramics (Seetawan *et al.*, 2011). In addition, the variety methods for ZnO production, sol-gel technique, solid state reaction method, and spark plasma sintering technique, makes it possible to obtain products with particles in shape, size, spatial structure, and a material for semiconductor device applications. These methods were described as follows: The $Zn_{1-x}Co_xO$ polycrystalline nanoparticles with different ($x = 0.03, 0.05, 0.1, 0.15, 0.2, 0.25, \text{ and } 0.3$) compositions have been synthesized using the sol-gel technique (Dong *et al.*, 2010). The $Zn_{1-x}Co_xO$ ($x = 0.01, 0.05$ and 0.1) bulk ceramics have been also prepared through a two-step, solid state reaction method combined with spark plasma sintering technique (Seo *et al.*, 2012; Arda *et al.*, 2014). In spite of the recent rapid developments, controlling the electrical conductivity of ZnO has remained a major challenge. While a number of research groups have reported achieving n-type ZnO, there are still problems concerning the electrical resistivity of the n-type conductivity (Kolodziejczak-Radzimska *et al.*, 2014).

In this work, we report an attempt to increase Seebeck coefficient and to reduce the electrical resistivity of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2,$

0.3) bulk ceramics which were prepared by solid state reaction method.

Experimental

The $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) was synthesized by solid state reaction method and sintered pellet. Zinc oxide powder (ZnO) and Cobalt oxide Powder (Co_3O_4) was used for the precursor powders in this experiment. The precursor powder was mixed by ball milling in deionized water to dry and hand for 2 h, then was calcined at 1073 K for 5 h and pressured at 6.86 MPa by hydraulic, sintered at 1423 for 5 h ambient in atmosphere. Crystal structure characterized by $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) was analyzed by X-ray diffraction from 20° to 80° (2θ) with $CuK\alpha$ radiation utilizing a Shimadzu diffract meter XRD-6100. The powder size was obtained from scanning electron microscopy. Electrical resistivity and Seebeck coefficient were also measured in the temperature range 303-473 K measure of TRC-ZTM2 ambient in the atmosphere. The power factor was calculated from measured parameter.

Results and Discussion

X-ray diffraction pattern at room temperature of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) sintered at 1423 for 5 h ambient in atmosphere are shown in Figure 1. The diffraction peaks, indexed by comparison, was PDF#00-061-0685 indicating a hexagonal structure space group of P63mc (186) (Seo *et al.*, 2012).

The temperature dependence of the Seebeck coefficient as shown Figure 2 was measured by $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) in temperature range 303 K- 473 K. The Seebeck coefficient maximum value was $-2442 \mu V/K$ condition of $Zn_{0.8}Co_{0.2}O$, increased Seebeck coefficient value $-474 \mu V/K$ of ZnO at 473 K. The Seebeck coefficient was negative which confirmed the n-type thermoelectric materials of the samples (Maensiri *et al.*, 2006).

The temperature dependence of electrical resistivity of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) as

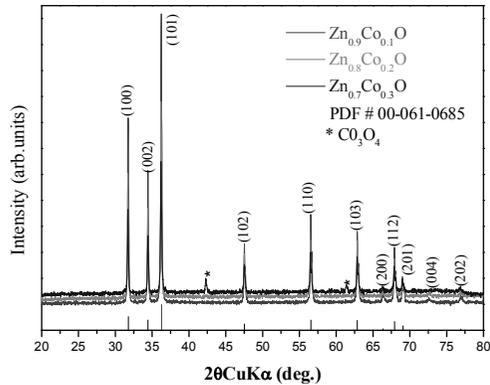


Figure 1. X-ray diffraction pattern of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) sintered at 1423 for 5 h

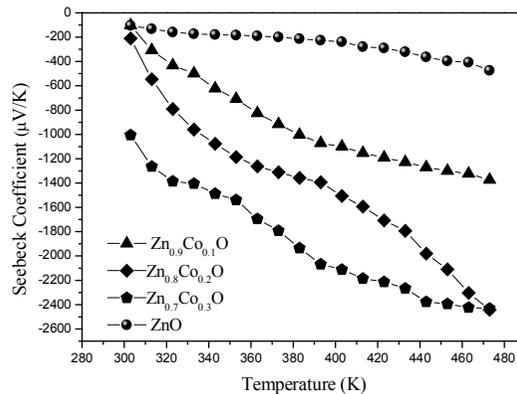


Figure 2. Temperature dependence of the Seebeck coefficient of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) sintered at 1423 for 5 h

shown in Figure 3 was measured in temperature range of “303 K- 473 K”. The electrical resistivity value was $57.02 \Omega\cdot m$ condition of $Zn_{0.7}Co_{0.3}O$ which increased electrical resistivity value $5.72 \Omega\cdot m$ of ZnO at 473 K.

Figure 4 shows the temperature dependence of power factor of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) which was measured in temperature range 303 K- 473 K. The value of power factor was $8.03 \mu W/mK^2$ condition of $Zn_{0.7}Co_{0.3}O$ which increased $3.34 \mu W/mK^2$ of ZnO at 473 K.

Figure 5 shows a scanning electron microscope (SEM) image of microstructure for $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) powder which was calcined at 1073 K for 5 h, and sintered at 1423 for 5 h ambient in atmosphere. These images exhibited the typical morphology of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) obtained through the solid state reaction. As a result, the grain size of materials arrangement changed after sintering.

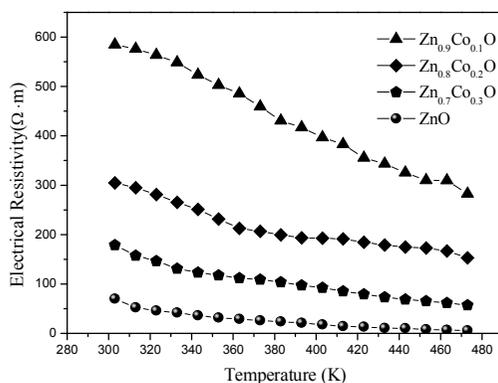


Figure 3. Temperature dependence of the electrical resistivity of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) sintered at 1423 for 5 h

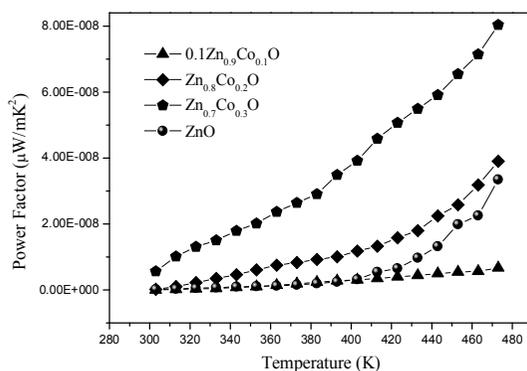


Figure 4. Temperature dependence of the power factor of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) sintered at 1423 for 5 h

Conclusions

$Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) were successfully synthesized using solid state reaction method. Results showed phase of X-ray diffraction patterns matching PDF#00-061-0685 indicating a hexagonal structure space group of P63mc (186). The Seebeck Coefficient, electrical resistivity, and powder factor were enhanced in all doping. Therefore, it could be confirmed that the samples were n-type semiconducting thermoelectric materials.

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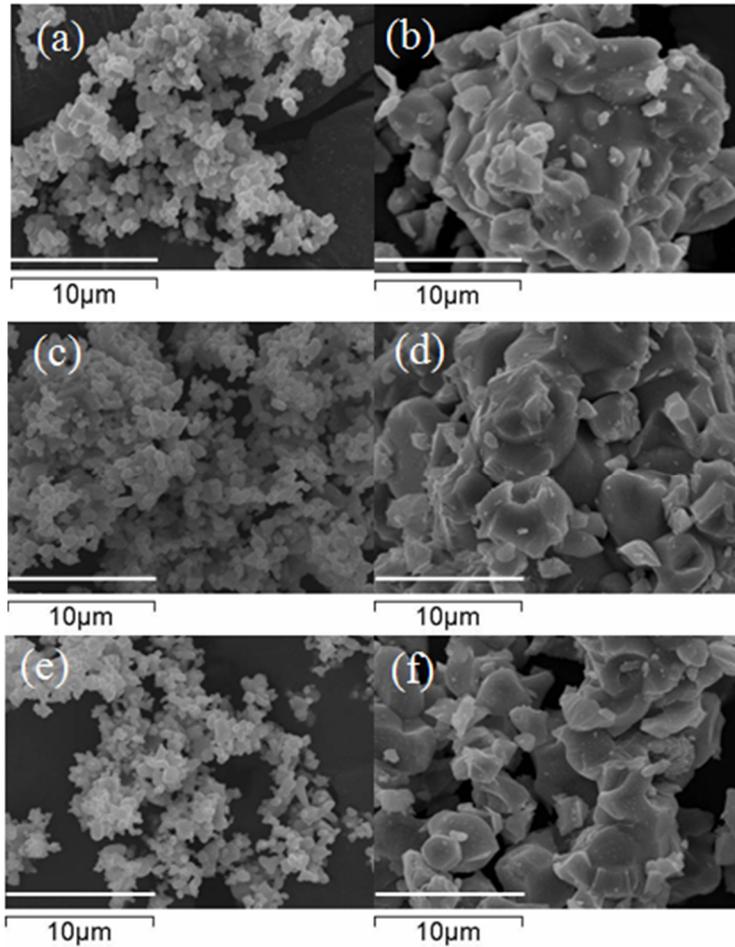


Figure 5. SEM image of $Zn_{1-x}Co_xO$ ($x = 0.1, 0.2, 0.3$) (a) $Zn_{0.9}Co_{0.1}O$ calcined, (b) $Zn_{0.9}Co_{0.1}O$ sintered, (c) $Zn_{0.8}Co_{0.2}O$ calcined, (d) $Zn_{0.8}Co_{0.2}O$ sintered, (e) $Zn_{0.7}Co_{0.3}O$ calcined, (f) $Zn_{0.7}Co_{0.3}O$ sintered respectively

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