Eco-Materials Processing and Design XV

Edited by
Banh Tien Long, Hyung Sun Kim, Jian Feng Yang,
Tohru Sekino and Soo Wohn Lee

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Preface

Ecomaterials, or "Green materials" are those designed to minimize environmental impact, while or maintaining or maximizing materials performance with reducing environmental burden. Ecomaterials research is an interdisciplinary field that scientists and engineers with background among chemistry, physics, and materials such as metals, ceramics, polymers, and carbon are involved in understanding the environmental consciousness in industries and motivating ecological researches. It is the goal of the meeting organizers to bring together experts in these various areas to provide a symposium to promote the exchange of ideas that will occur when workers in diverse materials concentrate on the whole spectra of ecology, eco-processing, recycle, energy harvest, energy saving, and environmental protection. This volume contains papers presented the fifteen symposium on ecomaterials processing and design (ISEPD), which was held in January 15-17, 2014 at the Hanoi University of Science and Technology in Hanoi, Vietnam.

We would like to thank the generous financial support so far through the Core University program between the Korea Science and Engineering Foundation and the Japanese Society of the Promotion Science (JSPS) for this series international conferences from 2000 to 2007. From 2009 to 2013, the A3 foresight Program among the National Research Foundation in Korea, the JSPS in Japan, and the National Natural Science Foundation of China in China. After these two important programs, the Global Research Laboratory Program in Korea between the Sun Moon University in Korea and the Osaka University in Japan has helped the some part of financial support such as speakers' flight tickets since 2010 year. Finally we are grateful to all participants who attended the ISEPD2014 conference and authors who submitted their manuscripts on time.

Editors

Banh Tien Long, Hyung Sun Kim, Jian Feng Yang, Tohru Sekino, Soo Wohn Lee

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Characterization of Cast Iron Scrap Chips toward β-$FeSi_2$ Thermoelectric Materials

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Keywords: β-$FeSi_2$, Cast iron scrap chips, Thermoelectric properties, Recycling process.

Abstract. The upgrade recycling process of cast-iron scrap chips toward β-$FeSi_2$ is regarded as an eco-friendly and cost-effective production process. It is useful for reducing the material cost in fabricating β-$FeSi_2$ by utilizing the waste that is obtained from the manufacturing process of cast-iron components. In this research, β-$FeSi_2$ was successfully obtained from cast iron bscrap chips and showed good thermoelectric performance in Seebeck coefficient and electrical conductivity which is around 70% to almost 100% compared to β-$FeSi_2$ that was prepared from pure Fe and other publications. The thermoelectric power factor was achieved 90% performance compared to other literatures and β-$FeSi_2$ prepared from pure Fe.

Introduction

Semiconducting iron silicide (β-$FeSi_2$) has received a great attention as a cost-effective and environment-friendly thermoelectric material consists of abundant and economical raw material [1,2]. As well it has high potential in high temperature oxidation resistance [3,4]. On the other hand, cast-iron is one of the most popular metallic materials for mechanical components. Since cast-iron consists of mainly iron with carbon and silicon, scrap chips of cast-iron (C.I.) may be good starting material for preparing β-$FeSi_2$. Upgrade recycling process which is an eco-friendly and cost-effective production process. By utilizing the cast iron waste from the machining process of cast-iron component, the material cost to fabricate β-$FeSi_2$ is reduced and at the same time the said industrial waste is recycled. In this research, the thermoelectric performance of β-$FeSi_2$ made from cast iron scrap chips of undoped, Co-doped (n-type) and Al-doped (p-type) were evaluated.

Experimental Procedure

The undoped, p-type and n-type β-$FeSi_2$ powders were prepared by a solid state reaction technique of cast-iron (C.I.) scarp chips, silicon grains (99.99%), powders of dopant element Co (99%) for n-type and Al (99%) for p-type. The numerical chemical compositions were cast-iron (C.I.):Si= 1:1.86 for undoped ones, cast-iron (C.I.):Co:Si= 0.98:0.02:1.86 for n-type and cast-iron (C.I):Al:Si= 1: 0.09:1.77 for p-type. The names of the prepared samples in the present study are P. Undoped : $FeSi_2$ prepared with pure Fe, C.I. Undoped= C.I.-$Si_{1.86}$ that prepared with C.I. scrap, P. Co Doped= $Fe_{0.98}Co_{0.02}Si_2$ prepared with pure Fe, C.I. Co Doped= $C.I._{0.98}$-$Co_{0.02}$-$Si_{1.86}$ that prepared with C.I. scrap, P. Al Doped= $FeAl_{0.09}Si_{1.91}$ prepared with pure Fe and C.I. Al Doped= C.I.-$Al_{0.09}$-$Si_{1.77}$ that prepared with C.I. scrap. The powder mixture was prepared by using a mortar and milled for 1 d using the planetary ball milling. The powder mixture undergo a solid state reaction at 1100^{o}C for 3 d in vacuum. The reacted powder was consolidated by using a pulsed electric current sintering technique at 900-1000^{o}C for 10 min in vacuum to under an uni-axial pressure of 80 MPa. The sintered samples were annealed at 900°C for 5 d in vacuum to obtain the β-$FeSi_2$ phase. Sintered samples were characterized by using X-ray diffraction (XRD) and scanning electron microscopy (SEM) and energy dispersion X-ray spectroscopy (EDXS). The electrical conductivity and Seebeck coefficient of sintered β-$FeSi_2$ were measured by a standard four probe method and the steady-state temperature gradient with commercial apparatus (ZEM-2, Ulvac Co.) at temperature ranging from room temperature to 800°C in a stream of He gas.

Result and Discussion

The XRF analysis of the cast iron bulk in Table 1 indicates that the sample is mainly consists of iron with 5.99 mass % of carbon, 2.05 mass % of silicon and minor elements such as magnesium, manganese, phosphorus and sulphur, which are the typical elemental contents of cast iron product. Fig. 1 shows the XRD patterns of annealed β-$FeSi_2$ undoped, Co-doped and Al-doped specimens from pure Fe and cast iron scrap chips. It is observed that for all samples, the dominant peaks were β-$FeSi_2$ [5]. XRD patterns proved that the α+ε structures in all samples have been almost completely transformed to β phase after annealing 900°C for 5 d.

Table 1 XRF composition of elements in the cast iron bulk.

Element	mass %
Carbon (C)	5.99
Silicon (Si)	2.05
Minor elements: Mg, Mn, P, S	< 0.1
Iron (Fe)	Balance

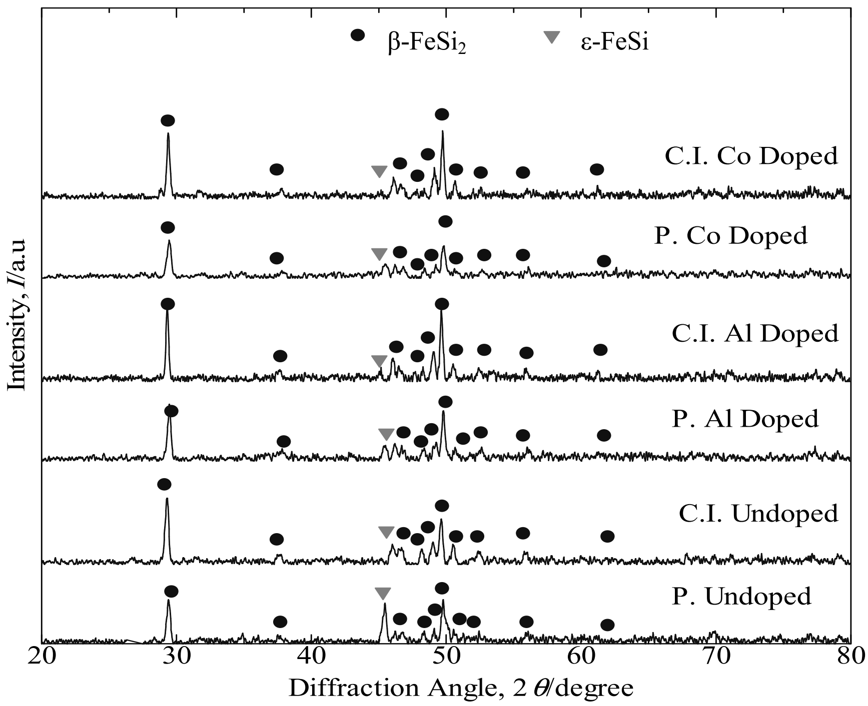
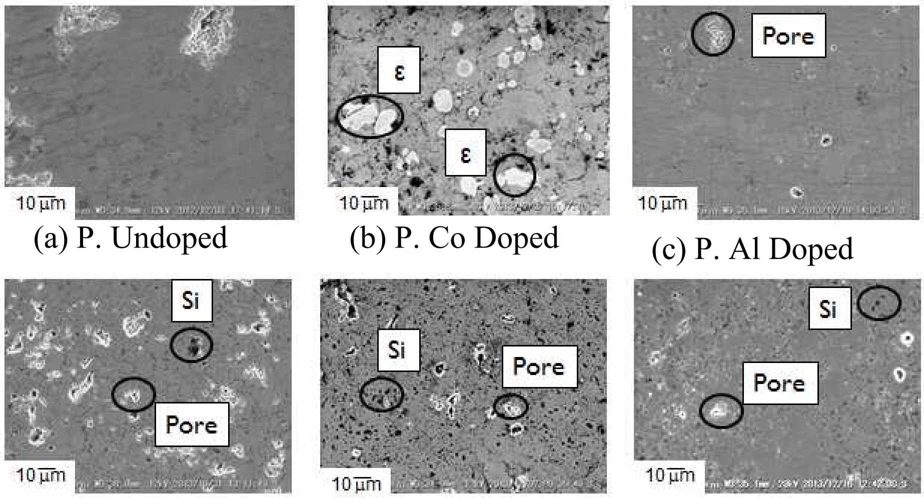


Fig. 1 XRD patterns of annealed β-$FeSi_2$ samples at 900°C for 5 d.

Fig. 2 shows the microstructure for the annealed samples of undoped, Co-doped and Al-doped β-$FeSi_2$ from pure Fe and cast iron scrap chips. The open porosity observed for both samples was below 1% after the sintering process. From the SEM images (d) and (e) (C.I. Undoped and C.I. Co Doped), Si-rich phase [6] (black dot) with some small pores (white dot) were observed.



(a) P. Undoped (b) P. Co Doped (c) P. Al Doped

(d) C.I. Undoped (e) C.I. Co Doped (f) C.I. Al Doped

Fig. 2 SEM microstructures of annealed β-$FeSi_2$ samples at 900°C for 5 d.

Fig. 3 shows the thermoelectric properties of the annealed β-$FeSi_2$ samples that were evaluated from room temperature to 800°C. The electrical conductivity of annealed β-$FeSi_2$ decrease with increasing the measuring temperature until 400°C and then increase with the further temperature increase [7]. By comparing the electrical conductivity obtained by others and the samples prepared from pure Fe, the values of β-$FeSi_2$ from cast iron scrap chips are 70% (p-type) and almost 100% (n-type) performance. Furthermore, the Seebeck coefficient of Co-doped and Al-doped β-$FeSi_2$ from cast iron scrap chips were obtained 90% to almost 100% performance compared to the samples prepared from pure Fe and reported studies.

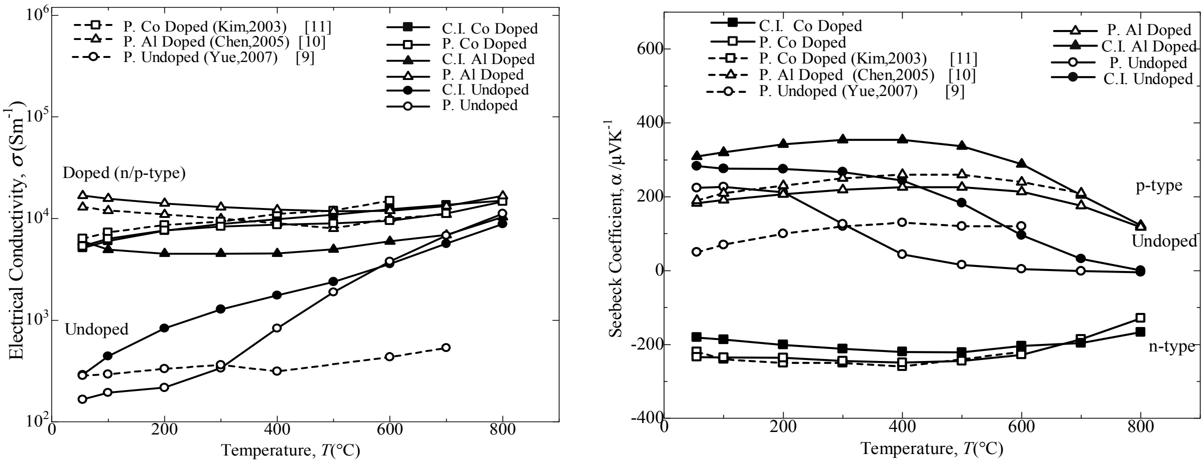


Fig. 3 Electrical conductivity and Seebeck coefficient of annealed β-$FeSi_2$ samples.

Fig. 4 shows the thermoelectric power factor of the annealed β-$FeSi_2$ samples. It is commonly used to evaluate the performance of thermoelectric materials as kind of figure of merit and is easily obtained by the combination of Seebeck coefficient and electrical conductivity [8]. By comparing the thermoelectric power factors of other publications and that from pure Fe, the values of β-$FeSi_2$ from cast iron scrap chips are 90% performance. Thus, β-$FeSi_2$ from cast iron scrap chips shows positive