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Enhanced Power factor of nanoZnO doped Portland Cement

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Abstract:
Background:*Over 60% of energy produced in the Thailand is wasted as heat, which can be directly converted into electrical energy using TE materials through Seebeck effects discovered by Thomas Seebeck [1]. TE technology has been used in military and aerospace applications as a reliable, safe, and durable power source for many space programs to the outer solar systems [2].*
Materials and Methods: *Portland cement of SCG (PC-A), TPIL (PC-B), TPIL299 (PC-C), Lion (PC-D), Lotus (PC-E) and Eagle (PC-F) were used raw materials. Mix Portland cement with water in ratio 2:1 by weight in square shape block and dry in air for 48 h. The ZnO were doped on PC-C in 10, 20, 30, 40 and 50 % by weight by identical process with PC sample preparations.*
Results: *All samples show thermoelectric behavior namely generating more electrical voltage when different temperature increasing. The average electrical resistivity of PC-B reveals lowest value about 0.75Ω cm while PC-E obtained highest value about 0.79Ω cm. The highest Seebeck coefficient and power factor were found in PC-C bulk sample about 55.43 μV/K and 4 nW/m·K^2 at room temperature, respectively. The Seebeck coefficient, electrical resistivity and power factor of ZnO doped PC-C show all value higher than undoped samples. The 40% ZnO doped PC-C shows highest value of power factor about 16.87 nW/mK^2 at room temperature which higher than undoped about 4 times indicating that nanoZnO can be enhanced power factor together with transport properties.*
Conclusion:*The PC bulk samples were successfully prepared by mixing PC from 6 company with water in ratio of 2 : 1 on square shape block and then dry in air for 48 h. The thermoelectric properties were measured by two probe method. All samples show thermoelectric behavior namely generating more electrical voltage when different temperature increasing. The lowest electrical resistivity was found in PC-B bulk sample. The highest Seebeck coefficient and power factor were found in PC-C bulk sample about 55.43 μV/K and 4 nW/m·K^2 at room temperature, respectively. The Seebeck coefficient, electrical resistivity and power factor of ZnO doped PC-C show higher than undoped samples. The 40% ZnO doped PC-C shows highest value of power factor about 16.87 nW/mK^2 at room temperature. Although the power factor of samples shows small value but if consider the abundantof material, it is interesting to continue to develop this group of materials.*
Key Word: *Thermoelectric properties, Portland cement, Zink oxide, Harvesting energy*

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I. Introduction

Over 60% of energy produced in the Thailand is wasted as heat, which can be directly converted into electrical energy using TE materials through Seebeck effects discovered by Thomas Seebeck[1]. TE technology has been used in military and aerospace applications as a reliable, safe, and durable power source for many space programs to the outer solar systems[2]. However, the potential of using TE technology for thermal energy harvesting in civil infrastructures has not been explored, despite a large quantity of waste heat is available including thermal storage in concrete structures, building envelopes, and waste heat in heating, ventilation, and air conditioning (HVAC) systems. For instance, the surface temperature of the concrete infrastructure can increase up to 60°Cin hot climate, while the air temperature remains at 32°C. This opens up an opportunity for using TE technology to scavenge the wasted thermal energy into electricity. The thermoelectric materials have been developed for solution of energy problem. The cement is the large scale of materials in the world. Jian Wei *et al*. enhanced thermoelectric efficiently of cement by doped with metallic oxide microparticles (5 wt% Bi_2O_3 powders) and obtained the Seebeck coefficient about 100.28 μV/K^3. Furthermore, the power factor 7.85 × 10^{-4}μW/mK of expanded graphite/carbon fiber cement composites was also reported by Jian Wei *et al*.[4]. Moreover, thermoelectric figure of merit (ZT) was reported 9.33 × 10^{-5} by cement doped with carbon nanotubes[5]. Then this research is study thermoelectric properties of Portland cement doped with nanoZnO for increasing Seebeck coefficient and electrical conductivity and for possibility of cement thermoelectric application.

II. MaterialsAnd Methods

Portland cement of SCG (PC-A), TPIL (PC-B), TPIL299 (PC-C), Lion (PC-D), Lotus (PC-E) and Eagle (PC-F) were used raw materials. Mix Portland cement with water in ratio 2:1 by weight in square shape block and dry in air for 48 h. The ZnO were doped on PC-C in 10, 20, 30, 40 and 50 % by weight by identical process with PC sample preparations. All samples were cut in size of 2 × 2 × 2 cm^2 for characteristic. The schematic diagram of experiment shows in Fig. 1. Crystal structure of samples were measured by X-ray diffractometer with 20–70 of 2θ using CuKα radiation at 40 kV, 30 mA with a scanning speed of 5°/min at 2θ steps of 0.02°. The microstructure was observed by scanning electron microscope (JEOL, JSM-7600F Prime), this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions (using EDS). The samples were connected to Cu plat by silver paint for thermoelectric properties measurement including Seebeck coefficient and electrical resistivity by steady state method as show in Fig. 2.

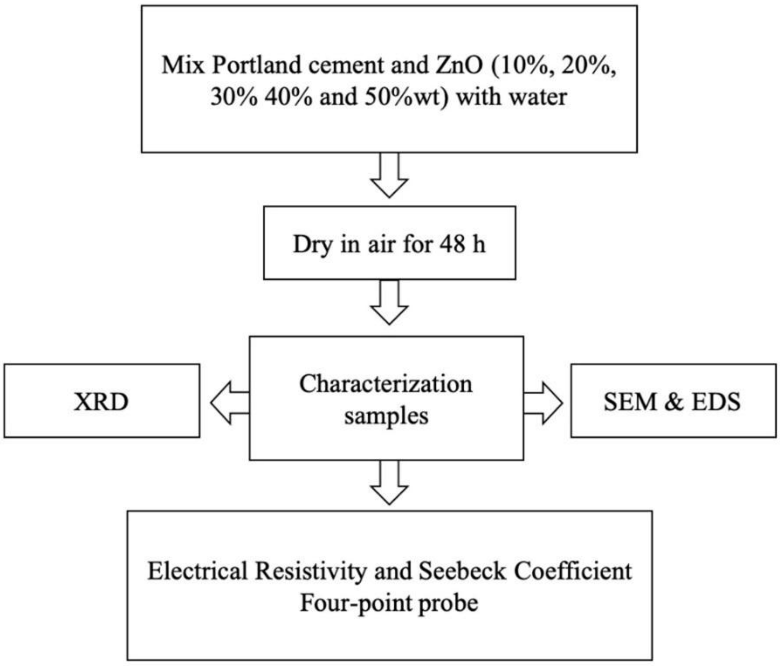

Fig.1 Schematic diagram of experimental procedure.

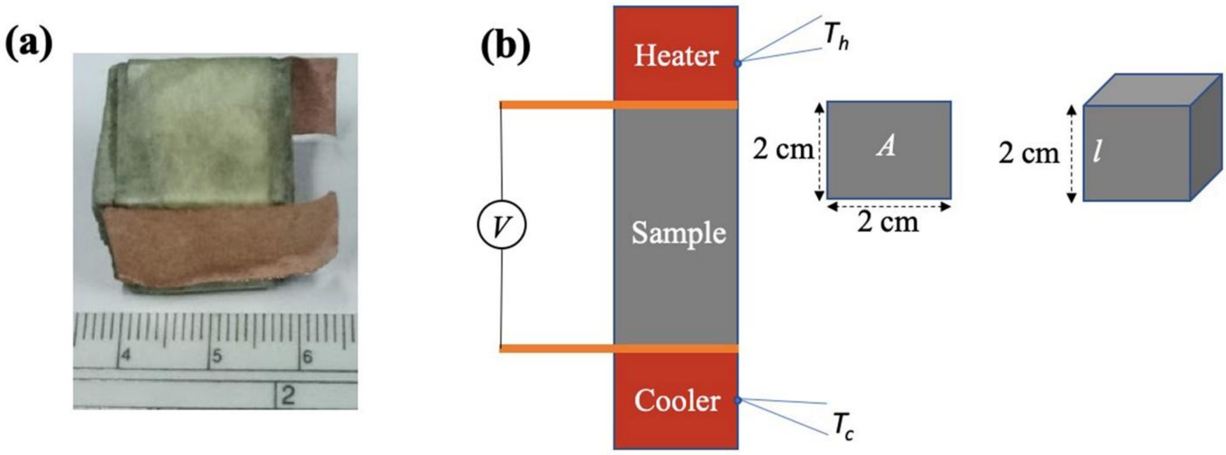

Fig.2 Portland cement bulk samples of (a) Cu electrode connecting and (b) diagram of electrical resistivity and Seebeck coefficient measurement

III. Results

The XRD patterns of PC-A (green line), PC-B (pink line), PC-C (orange line), PC-D (blue line), PC-E (red line) and PC-F (black line) show in Fig.3. All samples agree with ICDD number 00-055-0739 (Ca_3SiO_5) except PC-C due to secondary phase of SiO_2 was observed. The crystal structure of all samples shows monoclinic structure with space group number PC-7. It can be seen that main element of Portland cement included Ca, Si and O. Figure 4 shows XRD pattern of ZnO doped PC-C (10 – 50 wt%) agreeing with PC-C for main phase and ZnO for secondary phase. The ZnO patterns were increased with amount of doped increasing. Figure 5 shows SEM images of (a) PC-A, (b) PC-B, (c) PC-C, (d) PC-D, (e) PC-E and (f) PC-F bulk samples. The bulk samples exhibit different particle size about 2 – 10 μm and PC-A show biggest particle size about 10 μm. The microstructures of 10 – 50 wt% ZnO doped PC-A show size of particle decreasing when increases ZnO content effect to Seebeck coefficient value larger as shown in Fig. 6. The EDS mapping of 10, 20, 30, 40 and 50 wt% ZnO doped PC-A is shows in Fig. 7 (a – e). The element of Zn, Ca, S, Ni, Si, Cu, Cl, Ti, C and O exhibit good distribution indicating that completely mixing method. The intenseness of Zn element (pink color) increased with increasing doped content.

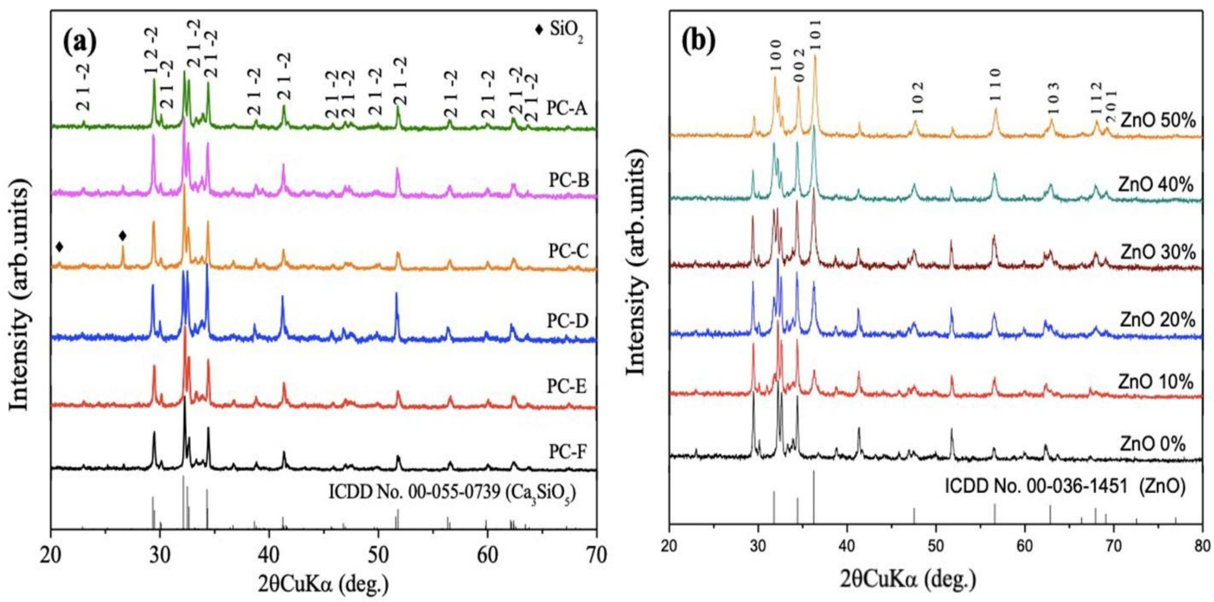

Fig. 3 XRDpatterns of (a) PC powders samples (b) ZnO doped PC powders samples.

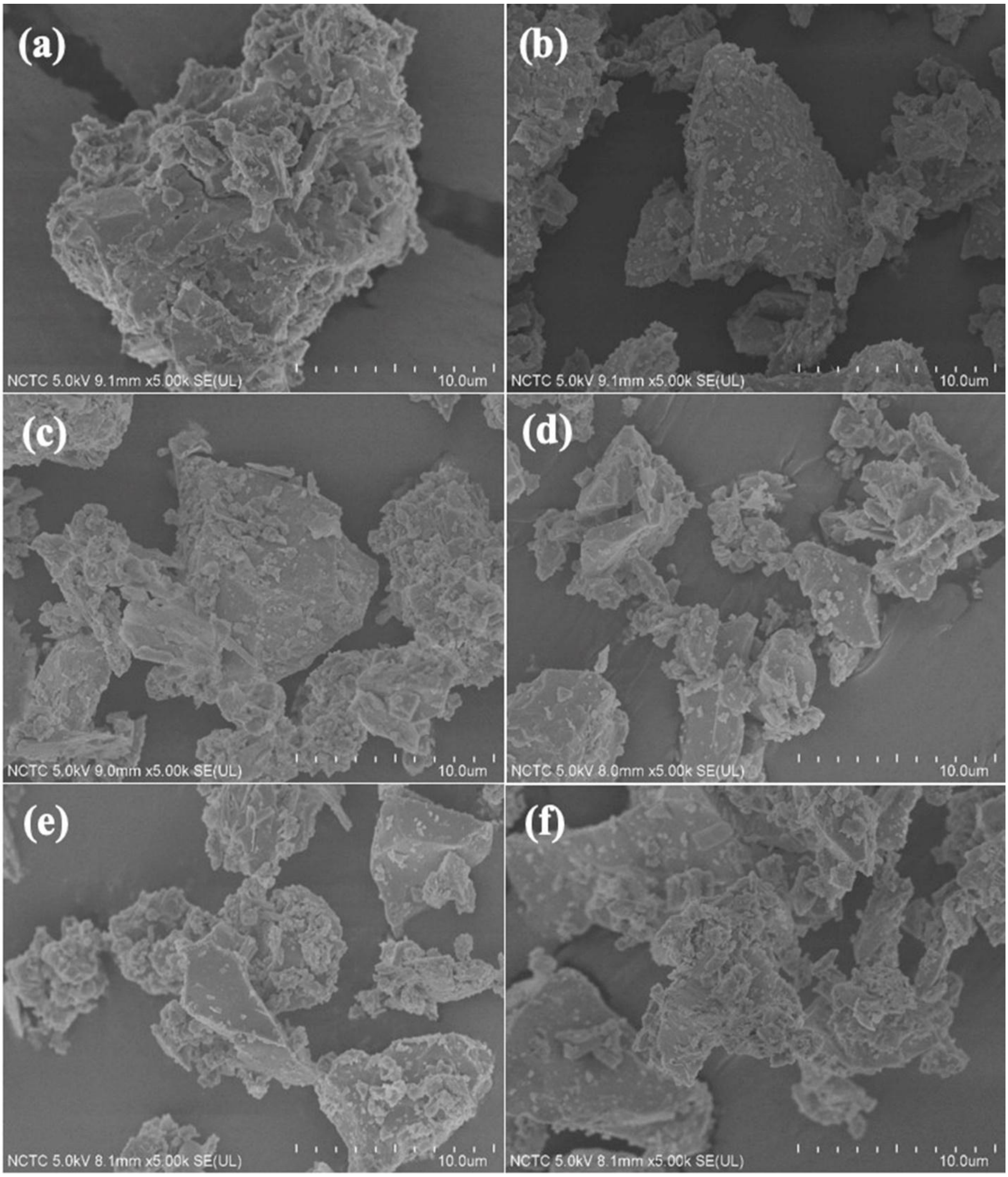

Fig. 4. SEM images of (a) PC-A, (b) PC-B, (c) PC-C, (d) PC-D, (e) PC-E and (f) PC-F bulk samples.

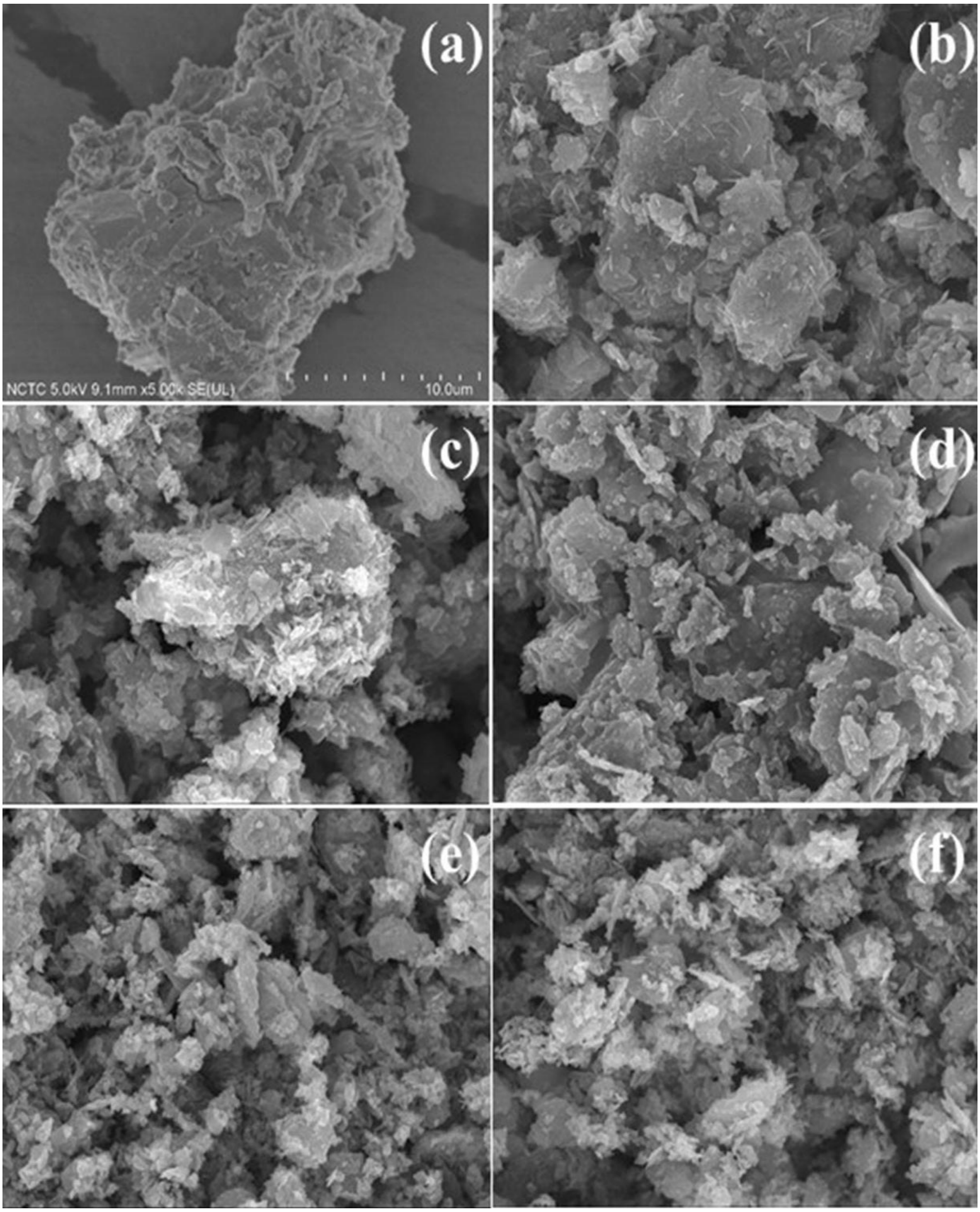

Fig. 5. SEM images of (a) 0% ZnO doped PC-A, (b) 10% ZnO doped PC-A, (c) 20% ZnO doped PC-A, (d) 30% ZnO doped PC-A, (e) 40% ZnO doped PC-A and (f) 50% ZnO doped PC-A bulk samples.

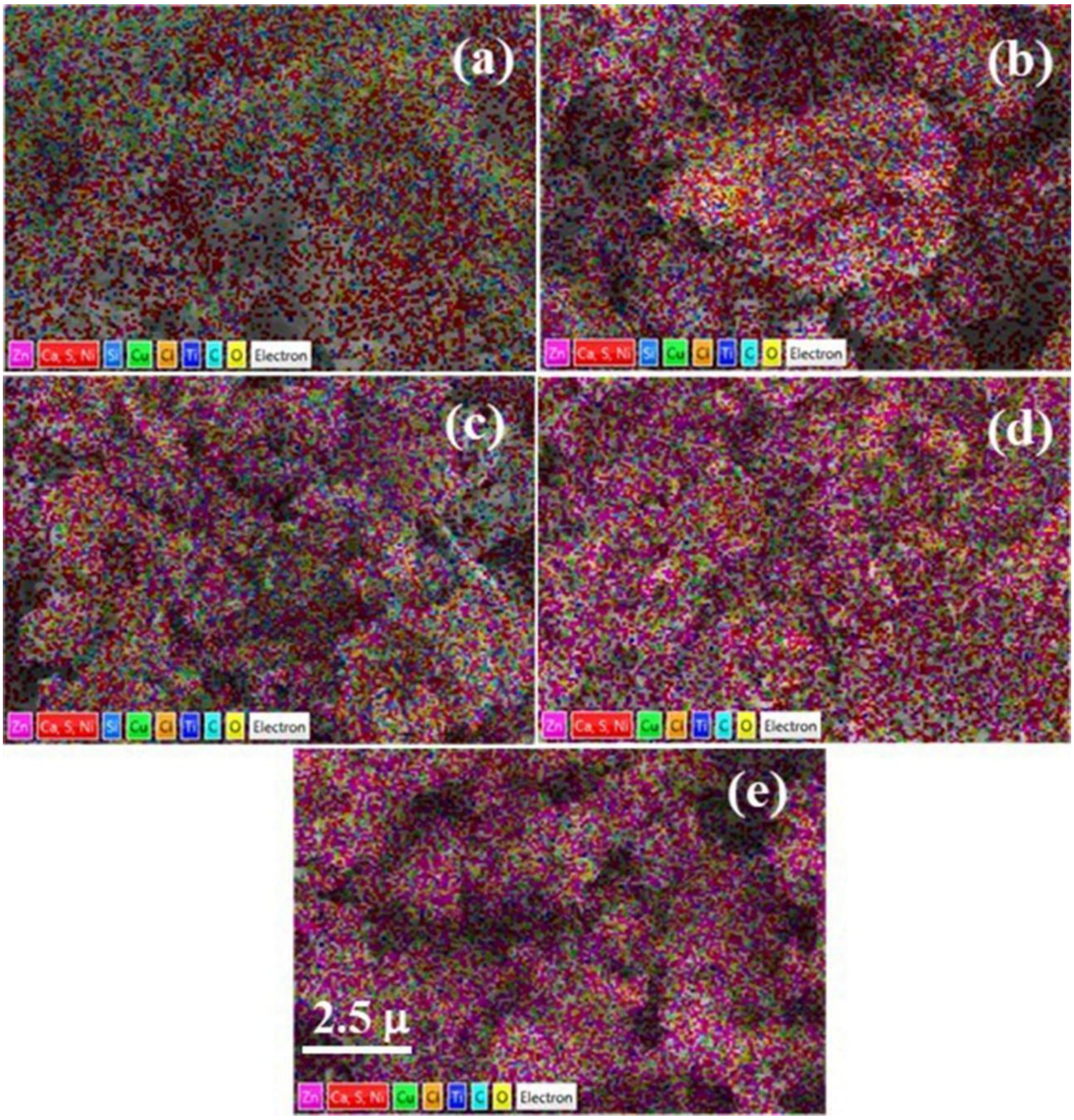

Fig. 6. EDS mapping of (a) 10% ZnO doped PC-A, (b) 20% ZnO doped PC-A, (c) 30% ZnO doped PC-A, (d) 40% ZnO doped PC-A and (e) 50% ZnO doped PC-A bulk samples

Thermoelectric properties

The thermoelectric properties including Seebeck coefficient (S) and electrical resistivity (ρ) were measured at room temperature. The schematic diagram of S and ρ shows in Fig. 5 (a) and (b), respectively. The S measurement was applied heat on the top and cooling on bottom of PC bulk sample to generate different temperature from 0 to 10 K then measuring voltage output. The electrical resistance (R) was measured for calculating ρ ($\rho = RA/l$, where A is cross section area and l is distance of sample) as shown in Fig. 8 (b)

The relationship between voltage and different temperature at room temperature shows in Fig. 7 (a).The voltage of all samples shows increased with different temperature increasingdue to thermoelectric material behavior[6]. The slop of graph between voltage and different temperature is Seebeck coefficient ($S = \Delta V / \Delta T$, where ΔV is voltage and ΔT , different temperature) as shown in Fig.7 (b). The Seebeck coefficient of all samples exhibit positive value indicating that p-type thermoelectric materials and shows higher than literature data[7,8,9]. The Seebeck coefficient of PC-B bulk sample obtained highest value about 55.43 μV/K while PC-F bulk sample shows lowest value about 49.27 μV/K. The electrical resistivity dependent on different temperature of PC bulk samples at room temperature shows in Fig.7 (c). The electrical resistivity of all samples excepting PC-C decreased when different temperature increasing demonstrates being a semiconductor material. The average electrical resistivity of PC-B reveals lowest value about 0.75Ω cm while PC-E obtained highest value about 0.79Ω cm but higher than literature data[8] as shown in Fig. 7 (d). The power factor ($PF = S^2 / \rho$) of PC bulk samples was calculated from Seebeck coefficient and electrical resistivity. It was found that, PF of all samples obtainedvalue in the nanoscale which is very small value, however the PF value of this work shows higher than literature data[8]. The PC-C shows highest value about 4 nW/m·K^2 at room temperature as shown in Fig.7.

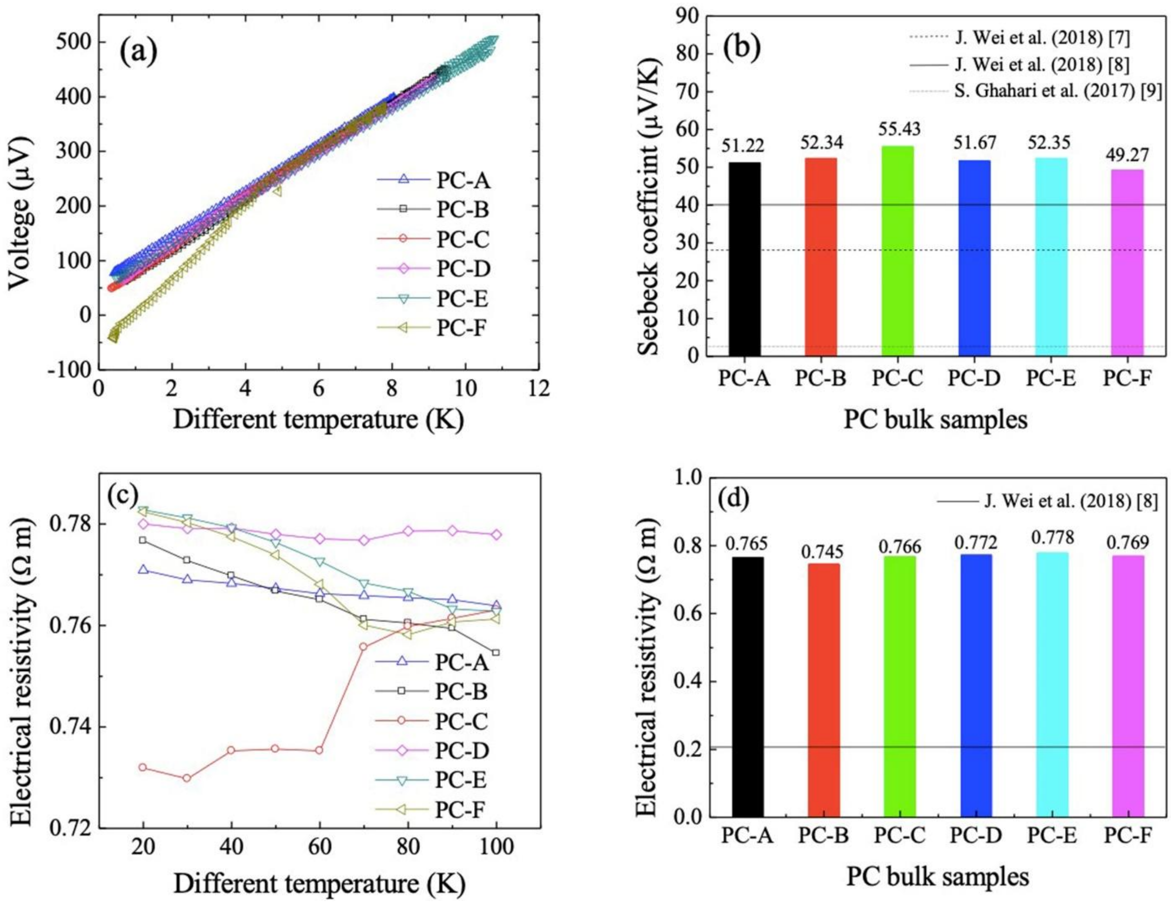

Fig. 7. (a) The relationship between voltage and different temperature, (b) Seebeck coefficient, (c) The relationship between electrical resistivity and different temperature and (d) Electrical resistivity of PC bulk samples

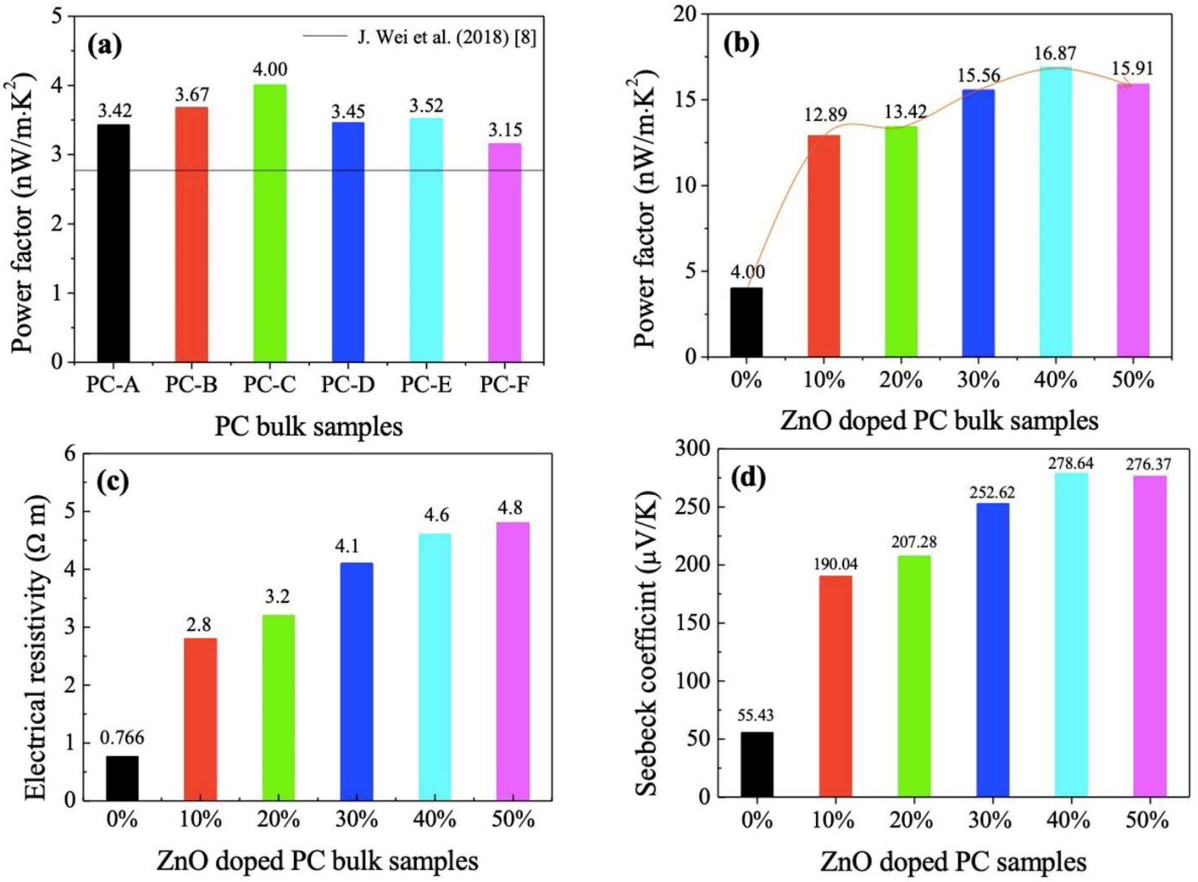

Fig. 8. (a) the power factor of PC bulk samples, (b) the power factor of ZnO doped PC bulk samples, (c) the electrical resistivity of ZnO doped PC bulk samples and (d) the Seebeck coefficient of ZnO doped PC bulk samples.

The Seebeck coefficient of ZnO doped PC-C show in Fig. 8. It was found that the Seebeck coefficient show large enhancement value when doped with ZnO. The positive value of Seebeck coefficient indicate p type thermoelectric materials due to most hole carriers. The Seebeck coefficient of all doped sample show higher than undoped indicating that effective carrier mass increasing, which is in accordance with Eq. 1.

$$S = \frac{8\pi^2 k_B^2}{3eh^2} m^* T \left(\frac{\pi}{3n_H} \right)^{\frac{3}{2}}, \tag{1}$$

where m^* is effective carrier mass, k_B is the Boltzmann constant, T is temperature, h is the Planck constant, e is the electron charge and n_H is Hall carrier concentration.

The ZnO doped effected to increasing the Seebeck coefficient until 40% and then decreasing. The 40% of ZnO doped PC-C obtained highest value of Seebeck coefficient about 278.64 μV/K at room temperature. The electrical resistivity of ZnO doped PC-C show higher than undoped and increased with ZnO increasing namely the carrier mobility decreased as shown in Fig. 8, which is in accordance with Eq. 2.

$$\rho = \frac{1}{\sigma} = \frac{1}{n_H e \mu_H} \tag{2}$$

where σ is electrical conductivity and m_H is Hall mobility.

The power factor of doped samples shows large enhancement value and increased with ZnO until 40 %. The power factor of 40% ZnO doped PC-C show maximum value about 16.87 nW/mK^2 at room temperature which higher than undoped about 4 times as shown in Fig.7.

IV. Conclusion

The PC bulk samples were successfully prepared by mixing PC from 6 company with water in ratio of 2 : 1 on square shape block and then dry in air for 48 h. The thermoelectric properties were measured by two probe method.

All samples show thermoelectric behavior namely generating more electrical voltage when different temperature increasing. The lowest electrical resistivity was found in PC-B bulk sample. The highest Seebeck coefficient and power factor were found in PC-C bulk sample about 55.43 μV/K and 4 $nW/m{\cdot}K^2$ at room temperature, respectively. The Seebeck coefficient, electrical resistivity and power factor of ZnO doped PC-C show higher than undoped samples. The 40% ZnO doped PC-C shows highest value of power factor about 16.87 nW/mK^2 at room temperature. Although the power factor of samples shows small value but if consider the abundant of material, it is interesting to continue to develop this group of materials.

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