

# Enhanced Thermoelectric Power Factor of Electrodeposited Bismuth Telluride with Inclusion of Pt nanoparticles and SWCNTs

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**ABSTRACT** – The use of appropriate thermoelectric materials at room temperature condition such as bismuth telluride ( $\text{Bi}_2\text{Te}_3$ ) is capable to convert efficiently the surrounding small heat energy to electrical power by adapting the thermoelectric effect. Based on recent studies, the electrodeposited  $\text{Bi}_2\text{Te}_3$  film does not produce a good thermoelectric power factor ( $PF$ ) as compared to bulk condition. The  $PF$  which composes from generated voltage and electrical conductivity plays a critical role to determine the thermoelectric material efficiency. The inclusion of Pt nanoparticles and single-walled carbon nanotubes (SWCNTs) in the  $\text{Bi}_2\text{Te}_3$  film improved the  $PF$  value 1.8 times higher than the pristine  $\text{Bi}_2\text{Te}_3$ .

## 1. INTRODUCTION

Waste heat from surrounding or human body can be converted to electrical energy through thermoelectric generator (TEG) devices. This energy harvester device provides an adequate small amount of power for small to micro devices such as wearable electronics, wireless sensors, and Internet of Things (IoT) micro-systems [1,2]. The TEG devices employs the thermoelectric effect which directly converted the temperature difference to electrical voltage. The significant electrical potential generated from a material due to condition of temperature difference is known as Seebeck effect and the brief explanation of the effect is illustrated in Figure 1.

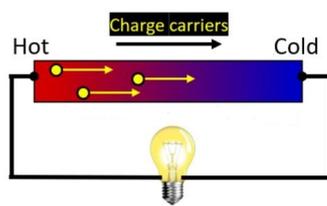


Figure 1 Seebeck effect illustration on a thermoelectric material. The movement of charge carriers due to temperature difference establishes the electric current.

Results from recent studies demonstrated lower electrical power factor ( $PF$ ) of electrodeposited  $\text{Bi}_2\text{Te}_3$  as compared to bulk condition [3-6]. The calculation of  $PF$  is composed from Seebeck coefficient and electrical

conductivity in a material. A low  $PF$  could significantly reduce the overall thermoelectric performance which is called the thermoelectric figure of merit,  $ZT$ . The  $ZT$  value can be quantified from the  $PF$  and thermal conductivity values as following expression,

$$PF = S^2 \sigma \quad (1)$$

$$ZT = PF/\kappa \quad (2)$$

where  $S$  is Seebeck coefficient,  $\sigma$  is electrical conductivity and  $\kappa$  is thermal conductivity.

This work presented an electrodeposition approach to embed both Pt nanoparticles (Pt-Nps) and single-walled carbon nanotubes (SWCNTs) in a  $\text{Bi}_2\text{Te}_3$  matrix. A new nanocomposite film that incorporates both nanomaterials Pt-Nps and SWCNTs could increase the  $PF$  value as compared to the pristine  $\text{Bi}_2\text{Te}_3$  film. The inclusion of Pt-Nps is expected to increase the Seebeck coefficient of  $\text{Bi}_2\text{Te}_3$  film due to lower density of electron [7]. Same goes to SWCNTs incorporation, the Seebeck coefficient provided a significant increment of Seebeck coefficient on  $\text{Bi}_2\text{Te}_3$  as the previous study [8] and even contributes to a stronger structure of the film [9].

## 2. METHODOLOGY

The Pt-SWCNTs/ $\text{Bi}_2\text{Te}_3$  nanocomposite films were prepared using a three-electrode potentiostatic electro-codeposition system. An acidic electrolyte solution that contained bismuth-telluride ions was mixed with surface-charged Pt-Nps and SWCNTs. Pt-Nps that were commercially stabilized with polyvinylpyrrolidone were functionalized by ionic groups of the acidic electrolyte. Meanwhile the SWCNTs have been pretreated with polyelectrolyte before being mixed with the electrolyte. This process turned the uncharged SWCNTs to a positively net charged element. Up to 0.9 wt.% of Pt-Nps with range of 4.8 wt.% of carbon content (as represented deposited SWCNTs) in the composite films have been successfully synthesized.

All deposited films were peeled and transferred to epoxy layer. Seebeck coefficient and electrical conductivity have been measured using steady state Seebeck measurement and four-probe resistivity measurement systems, respectively. Meanwhile the elemental composition was characterized by X-ray

spectroscopy (EDX).

### 3. RESULTS AND DISCUSSION

The Seebeck coefficient and electrical conductivity of the nanocomposite films have been measured near room temperature and compared with a pristine electrodeposited  $\text{Bi}_2\text{Te}_3$  film. It was found that the power factor,  $PF$  of the nanocomposite film showed higher values than that of the pristine electrodeposited  $\text{Bi}_2\text{Te}_3$  film and the maximum value recorded at 0.6 wt% of Pt-Nps as shown in Figure 2.

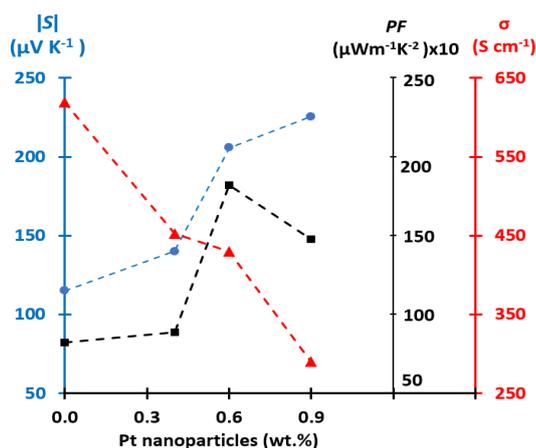


Figure 2 Deposited Pt nanoparticle concentration dependence of Seebeck coefficient, electrical conductivity, and power factor. All nanocomposite films had 4.8 wt.% of SWCNTs.

The increment of power factor is largely contributed by higher value of Seebeck coefficient. Even though the electrical conductivity at higher concentration of Pt-Nps decreased, a significant rise of Seebeck coefficient still provided an increase for the power factor. The existence of Pt-Nps in  $\text{Bi}_2\text{Te}_3$  film reduced the n-type carrier concentration possibly by increasing holes carrier as stated by Faleev and Leonard [10], subsequently increasing the Seebeck coefficient as proven from the previous study [6].

The relationship between the carrier concentration and the Seebeck coefficient is quite typical in semiconductor materials; for example, if the amount of charge carrier in a material is low, the material tends to have high Seebeck coefficient [11]. The typical relationship explained the significant reduced of the electrical conductivity at the film with 0.9wt% Pt-Nps. This contributes to the decrease of  $PF$  value due to lower value the electrical conductivity. The inclusion of SWCNTs along the Pt nanoparticles in the  $\text{Bi}_2\text{Te}_3$  film likely enhanced the reduction of charge carrier of the film and further increase the Seebeck coefficient inline with the results from previous studies [8,12].

### 4. CONCLUSIONS

The results of this study indicate that the enhanced value of thermoelectric power factor ( $PF$ ) can be obtained on electrodeposited  $\text{Bi}_2\text{Te}_3$  film by incorporating appropriate amount of Pt nanoparticles

and SWCNTs. The inclusion of both nanomaterials significantly increased the value of Seebeck coefficient which is almost twice than the pristine  $\text{Bi}_2\text{Te}_3$  film. The significant increase of the  $PF$  will contribute on high value of overall thermoelectric performance. In addition, by successfully incorporates SWCNTs, the present study on new nanocomposite of Pt-SWCNTs/ $\text{Bi}_2\text{Te}_3$  film could experience some improvement on mechanical strength properties.

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