Synthesis of Thermoelectric Carbon Black-Bismuth Telluride Nanocomposite Film by Electrochemical Deposition

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ABSTRACT: The inclusion of the carbon black (CB) nanoparticles in the bismuth telluride matrix improved the thermoelectric properties as compared to the pristine bismuth telluride film. This paper presents a method to synthesis a new bismuth telluride nanocomposite film with the inclusion of CB nanoparticles by electrodeposition process. An improved suspension and dispersion of PDDA-coated CB nanoparticles in the electrolyte solution is achieved to synthesis better deposition of dispersed CB nanoparticles in the nanocomposite film. Up to 3.7 wt.% of the CB has been successfully deposited in the nanocomposite film with reduced problems on the aggregated deposition. The deposition rate of the nanocomposite film is reduced almost half at 0.065 µm/min as compared to the pure bismuth telluride film due to the existence of polymer coated on the nanoparticles that contributed to less efficient of deposition.

Keywords: *Thermoelectric film; Nanocomposite; CB nanoparticles*

1. INTRODUCTION

The thermoelectric research could become more demanding in recent trending of advanced internet of thing (IoT) technologies due to their various unique characteristics which allow direct conversion between heat and electricity. The overall performance of a thermoelectric (TE) material can be analyzed by figure of merit (*ZT*) and high *ZT* value involves a combination of high Seebeck coefficient, high electrical conductivity and low thermal conductivity.

Nanocomposite plays a crucial role in improving thermoelectric performance, especially on the electrical conductivity. In addition, the nanocomposite route can gain benefits on the mechanical properties [1]. Nguyen et al. proved that thermoelectric properties can be improved through the inclusion of gold nanoparticles in nanocomposite materials. The Seebeck coefficient of bismuth telluride (Bi_2Te_3) nanocomposite film increased seven times higher than the pristine Bi_2Te_3 [2]. Chen et al. mentioned that through incorporating Ag nanoparticles into the Bi_2Te_3 nano powders, the electrical conductivity can significantly increase due to the increased of carrier electron concentration [3].

Carbon black (CB) nanoparticles could provide the same benefits as other carbon-based nanomaterials in thermoelectric nanocomposites by increasing the electrical conductivity and decreasing the thermal conductivity at the same time [4]. Bi_2Te_3 film could achieve high electrical conductivity property with the inclusion of CB nanoparticles by increasing charge carrier mobility [5]. This study introduces a new development of Bi_2Te_3 nanocomposite film with inclusion of CB nanoparticles through the electrodeposition. To date, there has been no detailed description on the synthesizing technique especially on the prior deposition process which is on the electrolyte preparation electrolyte to counter the problem on the aggregated deposition. This paper also presents the effect of deposition rate with existence of the CB nanoparticles.

2. METHODOLOGY

The electrolyte solution prepared in this study consists of 3.2 mM Bi^{3+} and 7.2 mM $HTeO_2^+$ in HNO_3. The desired CB nanoparticles is mixed in the electrolyte solution by ranging the concentration from 0.02 to 0.025 g/ℓ. The mixing process underwent rigorous stirring condition and was sonicated intermittently to ensure the optimum result of the CB nanoparticles dispersion and suspension in the electrolyte solution. The synthesized nanocomposite film on the working electrode was established at -90mV of the applied potential in the three-electrode cell of potentiostatic electrodeposition system. Prior to these processes, the CB nanoparticles was coated with the Poly(diallyldimethylammonium chloride) (PDDA). The nanoparticles were mixed and sonicated in the diluted PDDA to ensure the nanoparticle's surface were fully covered by the polymeric molecules. Then, the CB nanoparticles in the PDDA solution went through the filtration process to filter the excessive PDDA solution. The surface morphology and the element composition were analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) respectively.

3. RESULTS AND DISCUSSION

Figure 1 depicts the improvement that has been made for the CB nanoparticles dispersion and suspension in the electrolyte solution. The improved electrolyte contains better stability of dispersed CB nanoparticles due to reduce effect of Van de Waals attraction force between the nanoparticles [6]. The reduced attraction force was achieved because the coated polymer acted as a comparable repulsion force. Furthermore, the existence of free polymer in between the nanoparticles established the depletion stabilization and sustained the dispersion stability [7].

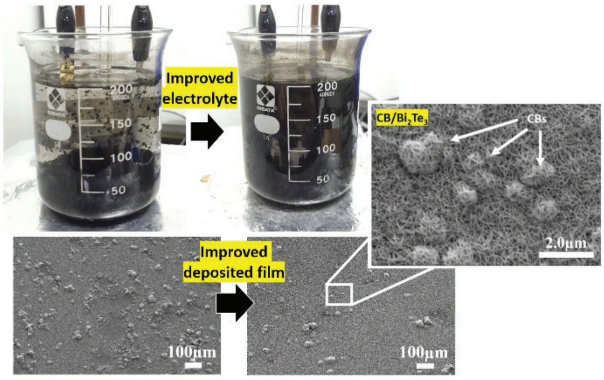

Figure 1 The improved dispersion and suspension of CB nanoparticles in the electrolyte solution and the improved deposited film of higher dispersion of CB nanoparticles

The improved deposited CB/Bi_2Te_3 nanocomposite film with better deposited of dispersed CB nanoparticles is shown in Figure 1. A lot of aggregated CB nanoparticles deposited in the film while using less stable CB nanoparticles dispersion in the electrolyte solution. The stability of CB nanoparticles dispersion was observed after 1 hour without stirring and sonication. It can clearly be seen that in the higher magnification image, the CB nanoparticles that had been enveloped by Bi_2Te_3 matrix were well deposited with less aggregation problem. In this study, up to 3.7 wt.% of CB nanoparticles in the CB/Bi_2Te_3 nanocomposite films had been successfully synthesized with 1-2% error of atomic percentage due to Bi_2Te_3 phase ratio.

Table 1 shows the comparison of deposition rate between the pristine Bi_2Te_3 film and CB/Bi_2Te_3 nanocomposite film. All the electrochemical deposition setup is unchanged except the stirring speed. In general, higher stirring speed of solution will result in higher electrodeposition rate due to hydrodynamics condition. However, the dispersion rate of the nanocomposites reduced significantly even there is a factor of stirring condition (no hydrodynamics effect on the pure Bi_2Te_3 deposition). In contrast with the capability of uncoated CB nanoparticles as a conductive catalyzer, the polymer coated on the nanoparticle reduced the efficiency of deposition thus decreasing the rate of Bi_2Te_3 crystals growth [8].

Table 1 Deposition rate comparison

Film	Stirring Speed (rpm)	Deposition rate ($\mu m/min\ 10^{-2}$)
Bi_2Te_3	0	11.3 ± 0.6
CB/Bi_2Te_3	100	6.5 ± 0.6

4. CONCLUSION

This study synthesized CB/Bi_2Te_3 nanocomposite films by electrochemical deposition with improved stability of dispersed CB nanoparticles in the electrolyte solution. The successfully deposited films contented up to 3.7 wt.% of CB nanoparticles with reduced problem on aggregated nanoparticles deposition. The deposition rate of the nanocomposites films reduced about 42% compared to pristine Bi_2Te_3 deposition even in the hydrodynamics condition.

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