MATERIAL AND MICROMECHANICAL PROPERTIES EFFECT ON BISMUTH TELLURIDE NANOCOMPOSITE FILM WITH GRAPHENE-CNF INCLUSION

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ABSTRACT: Thermoelectric (TE) is one of the interesting fields of study due to distinct characteristics on electrical energy generation from wasted heat retrieval. Bi_2Te_3 is facing challenge in thermoelectric performance which does not really fit up and sustaining at its own micromechanical properties in film condition. The objective of this study is to enhance the micromechanical characteristics of Graphene-CNF/Bi_2Te_3 nanocomposite films. The process involves the addition of different amounts of carbon nanofibers (CNFs) into the nanocomposite using 3-electrode setup of electrochemical deposition. The deposited carbon achieves up to 3.8wt.% compared to the baseline reference of carbon wt.%. It determined that the deposition of CNFs increased as the weight percentage of carbon increased. Micromechanical properties are analysed using ultra-micro indentation device for evaluation of young's modulus and hardness. This study achieves 100% higher compared to pristine Bi_2Te_3 of hardness and 34% increment of young's modulus with inclusions of CNF. The advantage of CNFs has been verified through a comparison of Graphene-CNF/Bi_2Te_3 nanocomposite films and pristine. In addition to the Hall-Petch effect, which restricts plastic deformation, the robust reinforcing impact of carbon nanofibers (CNFs) further enhances the mechanical properties.

KEYWORDS: *Semi-conductor; Thermoelectric; Electrodeposition; Nanocomposite; Micromechanical Properties*

1.0 INTRODUCTION

Recent interest has centred on thermoelectric (TE) devices due to rapid development of micro-electromechanical system (MEMS) for advanced sensors and transducers [1-2]. As an alternative, thermoelectric (TE) materials can convert heat and electricity in a small, non-moving component [3]. TE businesses are growing due to IoT, energy harvesting, and self-powered micro-macro devices. TE efficiency and production methods may limit TE progress, especially in thin film fabrication. Most TE materials are evaluated using the ZT figure of merit, which considers Seebeck coefficient (S), electrical conductivity (σ), and thermal conductivity (κ). Thermoelectric (TE) thin films convert energy poorly near 300K. Thus, TE material ZT performance diminishes more in low-temperature applications.

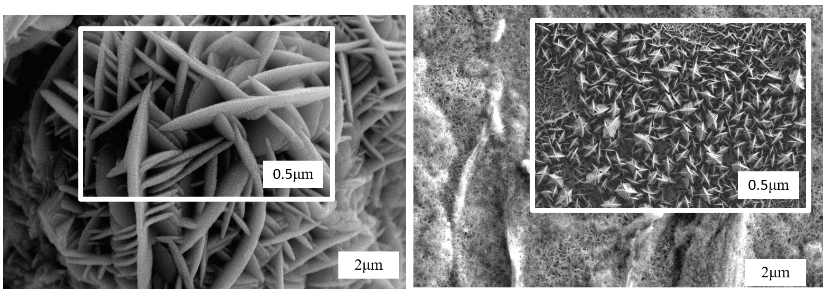
Nanocomposite film research has extended to improve thermal and mechanical properties. Its thermoelectric properties make Bismuth Telluride (Bi_2Te_3) useful in energy harvesting and electrical devices. Adding graphene and CNFs to the Bi_2Te_3 matrix may improve these properties [4]. Bismuth Telluride nanocomposite films containing graphene and carbon nanofibers will be characterised and micromechanically evaluated. Mechanical and electrical conductivity characterise graphene, a two-dimensional carbon allotrope. Renewable cellulose nanofibers (CNFs) make composites more sustainable. These CNFs increase composite mechanical properties, enhancing sustainability. Previous research examined how graphene and CNF improve Bismuth Telluride's thermal and mechanical characteristics [1,5]. SEM, EDX, and ultra micro-indentation will characterise nanocomposite films' material and micromechanical properties. We will learn about nanocomposite interface interactions and build novel materials with unique features for numerous technological applications from this research. The Bi_2Te_3 nanocomposite with graphene and CNF may enable improved materials, energy conversion, electronics, and other applications [1,6]. This study provides an insight of Graphene and CNF inclusion in the Bi_2Te_3 matric synthesis by electro co-deposition method toward the effect of materials and micromechanical characteristics.

2.0 METHODOLOGY

The electrolyte solution for depositing Graphene-CNF/Bi_2Te_3 nanocomposite films was made by dissolving Bi and Te in acid to form a Bi-Te ion solution. Combining graphene powder with deionized water and sonicating. To improve electrolyte dispersion, carbon nanofibers (CNFs) were functionalized with PDDA by filtration. The Bi-Te ion solution was aggressively mixed with graphene dispersion and PDDA-coated CNFs to create a consistent electrolyte. The nanocomposite films were made utilising a three-electrode electrochemical deposition. The Graphene-CNF/Bi_2Te_3 nanocomposite was pulsed electrodeposited after cyclic voltammetry (CV) determined the appropriate voltage. The deposited films were annealed to improve crystalline structure and stability. SEM and EDX spectroscopy were used to analyse the surface shape and composition of deposited Graphene-CNF/Bi_2Te_3 nanocomposite films.

3.0 RESULT AND DISCUSSION

The nanocomposite films displayed in Figure 3.1 a more uniform and smaller needle-like crystal structure in comparison to the pure Bi_2Te_3 films (a). By introducing CNF nanoparticles into Bi_2Te_3 (b), the size of the needle-like crystals decreased, while maintaining a consistent Bi/Te atomic ratio up to a CNF content of 3.8wt.%. Nevertheless, exceeding this amount of CNF content resulted in the composite material being too rigid right after the electrodeposition procedure.



(a) (b)

Figure 3.1: SEM micrographs of electrodeposited film surfaces. picture (a) shows Bi_2Te_3 and picture (b) shows Graphene-CNF/Bi_2Te_3. SEM images of the Bi_2Te_3 and Graphene-CNF/Bi_2Te_3 films original surfaces are shown in the figure.

Graphene-CNF/Bi_2Te_3 nanocomposite films elemental composition is summarised in Table 3.1. EDX analysed the composition. The maximum nanocomposite film weight is CNF-3.8wt.%. Attempts were made to increase the ratio, however the composite structure proved too stiff even after electrodeposition. CNF improve composite mechanical properties, increasing durability and stiffness during electrodeposition. The matrix material, electrodeposition conditions, and composition affect nanocomposite lifespan. The Bi/Te atomic ratio remained stable in the presence of varied amounts of CNF nanoparticles, and the atomic percentage error, based on the Bi_2Te_3 phase's stoichiometric ratio, was constantly below 3.0%. The optimal Bi_2Te_3 ratio (40:60) had an acceptable atomic percentage error of 3% for the Bi-Te ratio. Bi-Te ratio deviation should not exceed 5% from the pristine one. TE performance not affected.

Table 3.1: Element composition of electrodeposited films from EDX analysis

Electrolyte	Graphene Content in electrolyte (g/L)	Cellulose nanofiber (CNF) content in electrolyte (g/L)	Electrodeposited film	Composition in the deposited film		
				Carbon (wt.%)	Bi:Te (at%)	Atomic percentage error due to Bi_2Te_3 phase ratio (%)
I	0.00	0.0	Bi_2Te_3	0.0	38:62	±2.0
II	0.75 [1]	0.0	Bi_2Te_3/Graphene	1.6	37:63	±3.0
III		1.0	Bi_2Te_3/Graphene-CNF (3.80wt.%)	3.8	42:58	±2.0

Figure 3.2 demonstrates that nanocomposite films have higher hardness and Young's modulus than pure Bi_2Te_3 films. Due to the strong interfacial adhesion with the Bi_2Te_3 matrix, carbon nanofibers (CNFs) operate as reinforcing elements, effectively impeding localised plastic deformation. The nanocomposite film with 3.8wt.% CNF shows the highest micromechanical properties, with 100% higher hardness and 34% higher Young's modulus than pure Bi_2Te_3. The Van der Waals force that arises at the interface between Bi_2Te_3 and CNFs results in a stable interfacial bonding that enables the transfer of load from the Bi_2Te_3 matrix to the CNFs [7].

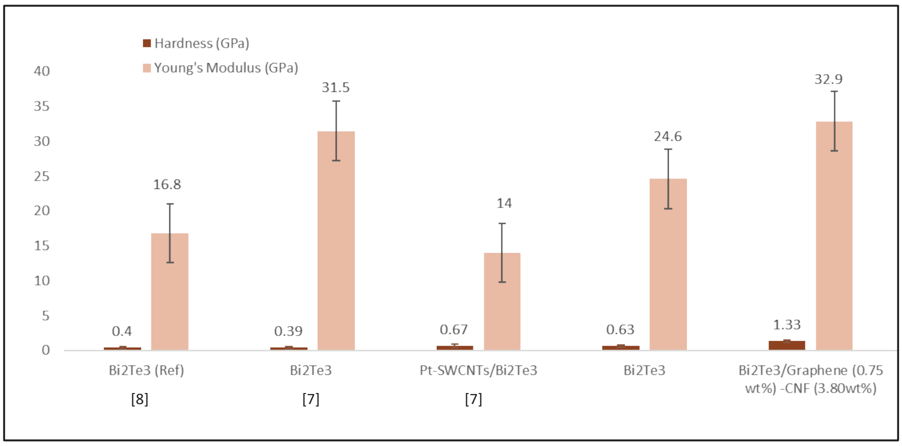


Figure 3.2: Measured hardness and Young's modulus of Bi_2Te_3 and Graphene-CNF/Bi_2Te_3 films

4.0 CONCLUSION

The nanocomposite films displayed a more uniform and diminutive needle-like crystal structure in comparison to the pure Bi_2Te_3 films. Furthermore, the Bi/Te atomic ratio remained constant up to a CNF content of 3.8wt.%. However, enhancing the CNF content further resulted in a significant increase in the stiffness of the composite material. The nanocomposite films exhibited increased hardness and Young's modulus in comparison to the original Bi_2Te_3, which can be attributed to the reinforcing influence of the CNFs and their robust interfacial bonding with the Bi_2Te_3 matrix. The nanocomposite film containing 3.8% CNF exhibited the most favourable micromechanical characteristics. Any further increase in CNF content resulted in excessive stiffness of the material.

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