

UNIVERSITI TEKNOLOGI MARA

**FABRICATION OF ALIOVALENT
(ALUMINUM, TIN, TANTALUM)
AND ISOVALENT (COBALT,
MANGANESE) DOPING
ENGINEERED ZINC OXIDE-BASED
NANOCOMPOSITE FILM FOR
TRIBOELECTRIC
NANOGENERATOR
APPLICATIONS**

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PhD

February 2025

ABSTRACT

Triboelectric nanogenerator (TENG) has been explored as a potential candidate for energy harvesting applications, converting mechanical energy from the surrounding environment to electricity. However, the performance issues of the TENG are primarily attributed to the selection of triboelectric materials used and the adverse effects of high humidity on its functionality, restricting the practical expansion of TENG applications. With the motivation to reduce environmental pollution and the increasing demand for sustainable energy solutions, this research aimed to investigate the generation of electricity by utilizing synthesized zinc oxide nanopowder integrated with polystyrene waste (ZNP/wPS) nanocomposite film as a triboelectric layer for TENG applications. The effects of isovalent and aliovalent dopants (Mn^{2+} , Co^{2+} , Al^{3+} , Sn^{4+} , and Ta^{5+}) on the ZNP/wPS nanocomposite film were systematically investigated to optimize the electrical output performance of the TENG. The ZNP and isovalent and aliovalent doped ZNP (Y-ZNPs) were successfully synthesized via the low-temperature solution immersion method whereas the ZNP/wPS and Y-ZNP/wPS nanocomposite films were prepared by a simple dry-casting method. The wPS was sourced from an unused packaging box labelled with the code PS-6. Further, the stearic acid (SA) treatment was employed to enhance the hydrophobicity of both nanocomposite films. Comprehensive characterization of the synthesized materials, including ZNP and Y-ZNPs and their corresponding nanocomposite films (ZNP/wPS and Y-ZNP/wPS), both before and after SA treatment, was conducted using FESEM and TEM for surface morphology analysis, XRD and HRTEM for structural properties, EDS, FTIR and XPS for surface chemical composition analysis and WCA for wettability properties. The TENG were fabricated in a vertical contact-separation configuration using Kapton film as the negative triboelectric layer paired with various positive triboelectric layers including wPS film, ZNP/wPS nanocomposite film, Y-ZNP/wPS nanocomposite film, SA treated ZNP/wPS nanocomposite film and SA treated Y-ZNP/wPS nanocomposite film. The TENG performance was determined using custom-build solenoid tapping system that provided external force onto the fabricated TENG devices. The experimental results demonstrated progressive enhancements in TENG performance. The ZNP/wPS TENG showed a twofold increase in output voltage (8 V) compared to the wPS TENG. Further improvement was achieved with the aluminum doped ZNP/wPS (AZNP/wPS) TENG, which exhibited a twofold voltage increase (16 V) relative to the ZNP/wPS TENG. Subsequently, the SA treated AZNP/wPS TENG yielded the highest open-circuit voltage of 20 V with a power density of $39 \mu\text{W}/\text{cm}^2$, comparable to values reported in the literature. These findings highlight the cumulative benefits of incorporating ZNP, aluminum doping, and SA treatment in enhancing TENG performance. SA treatment significantly enhanced the hydrophobicity of the nanocomposite films, with SA treated ZNP/wPS and SA treated AZNP/wPS films exhibiting water contact angles of 135° and 140° , respectively. Both nanocomposite films demonstrate potential as efficient mechanical energy harvesters with high electrical output and excellent surface wettability. Furthermore, the fabricated TENGs demonstrated practical applications in sensing, biomechanical motion detection, and powering portable electronics. This novel approach, incorporating wPS with ZNP in TENG devices, holds significant potential for advancing circular economy principles and supporting sustainable development goals through innovative waste management and energy harvesting solutions.

ACKNOWLEDGEMENT

Alhamdulillah. All praise to Allah for granting me the strength and perseverance to undertake and complete this challenging PhD journey. I would like to express my profound gratitude to my supervisor, Professor Ir. Ts. Dr. Mohamad Hafiz Mamat, for his exceptional guidance, unwavering support, and continuous inspiration throughout my research journey. The completion of my thesis would not have been achievable without his exceptional supervision. I deeply appreciate his dedication to nurturing my growth, even in the face of my challenges and limited experiences. I would also like to extend my sincere appreciation to my co-supervisors, Assoc. Prof. Dr. Muhamad Kamil Yaakob (Faculty of Applied Science, UiTM), Ts. Dr. Farariyanti Parimon (Faculty of Engineering, UMS), and Dr. Nagamalai Vasimalai (B.S. Abdur Rahman Crescent Institute of Science & Technology, India). Their unwavering support and valuable contributions have been instrumental in my success. This research was funded by UiTM Shah Alam through the Research Entity Collaboration (KEPU) Grant (600-RMC/KEPU 5/3 (018/2021)) and the Strategic Research Partnership (SRP) Grant (100-RMC 5/3/SRP INT (020/2022)). I am truly grateful for the opportunities provided.

This thesis has successfully and reached completion thanks to the unwavering support and encouragement of many wonderful individuals. I would especially like to acknowledge my dear research colleagues: Ir. Dr. Musa, Dr. A. Shamsul Rahimi, Ms. Nurul Izzati, Mrs. Nurul Syafiqah, Mr. Megat Danial Aizat, Mr. Yousif, and Mr. Wan Muhammad Dzhahirul. I am also grateful to the technical staff at the NANO-ElecTronic Centre (NET), particularly Mr. Suhaimi, Mr. Norsham, Mr. Asrul, and Ms. Nurul Fakhirah, for their invaluable assistance during the measurement and characterization phases of my research.

I want to express my deepest gratitude and heartfelt appreciation to my parents. Their sacrifices, unwavering support, and relentless prayers have been the foundation that has enabled me to reach this significant milestone in my life. I would also like to dedicate a special acknowledgment to my beloved husband, Muhammad Aliff bin Rosly, for standing by my side through both the easy and challenging times. I am incredibly thankful for the love and smiles from my children, Anis Safiyyah, Anas Sufyan, Aisha Sumayyah, and Amina Sumayyah, who have endured the hardships alongside me. Finally, I extend my sincere thanks to everyone who has played a role, directly or indirectly, in the successful completion of my PhD journey.

“So verily, with the hardship, there is relief.” – Al-Insyirah verse 5

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CHAPTER 1

INTRODUCTION

1.1 Research Background

During the past few decades, the exponential advancement of wireless sensing systems, seamlessly integrated with the Internet of Things (IoT) and cutting-edge nanotechnology, has been extensively implemented across various domains [1, 2]. The miniaturization, enhanced functionality, and portability of sensors and electronic devices stand as pivotal criteria driving the progress of IoT. Despite these advancements, the majority of commercial electronic devices and sensors still rely heavily on external batteries as their primary power source. However, traditional batteries fall short of fulfilling the sustainable power demands due to their limited lifespan [3, 4].

Harnessing environmental mechanical energy as a renewable power source—such as human movement, vibrations, breezes, falling raindrops, and water waves—presents a promising solution for providing sustained and clean energy to these sensors and electronic devices. Nanogenerators, which are innovative energy-harvesting devices capable of converting ambient energy sources into electricity, emerge as a formidable candidate for powering small electronic devices and sensors [5-8]. For nanogenerators to be widely adopted, they must exhibit a straightforward design, low cost, lightweight, durability, and adaptability for various applications, including wearable technology and IoT sensors.

Triboelectric nanogenerators (TENGs) have been demonstrated to proficiently convert wasted mechanical energy in the environment into useful electricity, boasting high output electrical performance [9, 10]. Despite this, the commercial development of TENGs is significantly hindered by their limited output performance. Research has shown that enhancing the surface charge density of materials is vital for improving the electrical performance of TENGs [11-13]. In line with this, extensive studies have been conducted focusing on: (1) discovering new materials with superior nanogenerator performance, (2) fabricating diverse micro-nano structures on material surfaces, (3) implementing physiochemical modifications, and (4) innovating device design and power management strategies. These efforts have markedly enhanced the output