Original Article

PVA Nano Composites: Harvesting Electrical Energy from Mechanical Energy Using TENG

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Abstract - Triboelectric Nanogenerators (TENGs) represent a rapidly advancing technology for harvesting mechanical energy and converting it into usable electrical power. Their integration into wearable electronics and self-powered sensing devices has driven interest in optimizing their performance through advanced materials. This study explores the effect of incorporating Yttrium-Doped Cerium Sulphide (Y₂CeS₃) nanoparticles into Polyvinyl Alcohol (PVA) matrices at varying concentrations (0-4%) to enhance the triboelectric output. A systematic characterization approach was employed to investigate structural, morphological, and chemical features of the resulting nanocomposites, using Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), Fourier-Transform Infrared spectroscopy (FTIR), and Energy-Dispersive X-ray spectroscopy (EDX). SEM analysis revealed uniform nanoparticle dispersion within the polymer matrix, indicating effective mitigation of agglomeration and improved interfacial contact-key factors for charge enhancement. XRD results demonstrated minor yet significant changes in crystallinity, suggesting the evolution of structural phases. FTIR spectra affirm the formation of interfacial bonds and functional group interactions between nanoparticles and polymer chains, while EDX verifies successful elemental incorporation and composite homogeneity. Electrical performance analysis indicated a direct correlation between nanoparticle concentration and output voltage, with the highest loading yielding markedly improved power generation. The generated voltage was sufficient to illuminate a series of LEDs, establishing the practical viability of composite-based TENGs. These findings offer critical insights into how nanoparticle integration influences material properties and energy output. The study presents a promising pathway for engineering high-performance TENGs, contributing to advancing efficient, sustainable, and scalable energyharvesting technologies.

Keywords - Electrostatic induction, Triboelectric effect, Energy-Dispersive X-ray spectroscopy (EDX), Fourier-Transform Infrared Spectroscopy (FTIR), Polyvinyl Alcohol (PVA), Scanning Electron Microscopy (SEM), Triboelectric Nanogenerators (TENGs), X-Ray Diffraction (XRD), Yttrium-Doped Cerium Sulphide (Y2CeS5).

1. Introduction

The rapid rate of development of energy harvesting technology has motivated research into new and renewable power generation technologies. Triboelectric Nanogenerators (TENGs) [1, 2] are some of the new technologies that have enormous potential in mechanical energy to electrical power conversion [14]. TENGs are engineered to effectively harvest energy from mechanical movements, such as vibrations, human movements, and external forces by triboelectric effect and electrostatic induction [3, 11]. Their scalability, flexibility, and ability to operate in different modes of operation, including freestanding [3], hybrid configurations, lateral sliding [3, 7], single-electrode [3, 8], and vertical

contact-separation [3, 6], make them viable candidates to power low-power electronic devices [4], including wearable electronics and self-powered sensors.

TENGs consist of two materials with different triboelectric properties. Two materials develop an electric potential when contacted; upon mechanical motion's presence, this potential will separate [15]. The first material captures electrons and becomes negatively charged due to the process, while the second material loses electrons and acquires charging. These two substances divide into two, forming an electric current that is used to generate electrical energy that can be utilized.

While TENGs hold tremendous potential, there are a number of challenges that still stand in the way of their largescale implementation. One of them is how to optimize the triboelectric material properties to attain high energy conversion efficiency. A TENG's efficiency depends on selecting triboelectric materials with high charge transfer capacity, mechanical strength, and cycling stability under mechanical stress. Most traditional materials used in TENGs, such as metals and polymers, have failed to provide satisfactory performance in charge retention and mechanical robustness. Therefore, developing new nanocomposite materials is urgent to improve the triboelectric performance of TENGs while making them robust enough to withstand structural integrity even after prolonged usage.

To bridge this knowledge gap, our research investigates the triboelectric performance of Polyvinyl Alcohol (PVA) and Polypropylene (PP) nanocomposites with Yttrium-Doped Cerium Sulphide (Y2CeS5) nanoparticles. Examine the effects of systematically altering the Y2CeS5 content (0.5% to 4%) in the PVA matrix on chemical, morphological, and structural characteristics of TENG devices to study the structural development of nanocomposite. In addition, the electrical characteristics of the TENG devices in a contact-based TENG configuration can be assessed by tracking the creation of voltage over time during mechanical stimulation. Voltagetime (V-t) analysis is carried out to examine the effect of nanofillers in magnifying the electrical performance of the TENG system. With output voltage, LEDs were illuminated, and a capacitor was charged, and the maximum voltage that could be reached was 300 mV.

By overcoming the most significant material constraints in TENGs, this research will contribute to the extension of current research in the optimization of nanocomposite-based energy harvesters. In order to bridge the gap between theoretical advancements and real-world implementation, the findings of this study could further advance the designs of refined TENGs for sustainable energy harvesting.

2. Materials and Methods of Preparation

The Metals nitrate, namely yttrium nitrate hexahydrate $(Y(NO_3)_3 \cdot 6H_2O)$, cerium nitrate hexahydrate (Ce $(NO_3)_3 \cdot 6H_2O)$ and organic fuel Thiourea (CH₄N₂S). All analytical grade chemicals are procured from Sigma-Aldrich, India, without further purification.

2.1. Yttrium-Doped Ce₂S₃ Preparation

Preparation of Y₂CeS₅ requires a controlled and systematic process by solution combustion synthesis. Solution combustion synthesis is extensively applied to synthesise fine powders of metal sulphides, oxides, and composite materials because it is efficient, cost-effective, and can yield high-purity products with well-defined crystalline structures.

2.1.1. Raw Material Selection and Preparation

The synthesis method starts with carefully selecting precursor materials serving as principal sources of cerium, yttrium, and sulphur. The chemicals applied are:

Cerium Nitrate Hexahydrate (Ce(NO₃)₃·6H₂O) - Serves as cerium source, with Ce³⁺ ions available. Yttrium Nitrate Hexahydrate (Y(NO₃)₃·6H₂O) - Supplies Y³⁺ ions for doping purposes. Thiourea (CH₄N₂S) - Acts as organic fuel and sulphur donor. The precursor chemicals are accurately weighed and calculated using stoichiometric proportions so that there is complete control over product composition. This process is essential to sustain the right chemical balance in the reaction.

2.1.2. Gelation and Dissolution

Following measurement, a homogenous mixture is obtained by dissolving the precursor ingredients in deionized water. Dissolution ensures uniform mixing of metal ions and fuel, critical for consistent phase formation. The obtained solution is then slowly heated on a hot plate at about 50°C for 30 minutes to form a thin, transparent, wet gel. This gelation process is useful in distributing reactants evenly and providing intimate contact between the fuel and metal ions, which is important for the next combustion step.

2.1.3. Combustion Reaction and Gas Evolution

After forming the gel, the mixture is loaded into a preheated muffle furnace maintained at ~500°C. In this raised temperature, a self-sustained combustion reaction occurs. Upon combustion, the organic fuel (thiourea) decomposes and yields gases like carbon dioxide, nitrogen, and water vapor. Rapid liberation of these gases produces a strongly exothermic reaction, thus giving extra heat for burning to continue. Metal nitrates then decompose by producing a spongy intermediate compound called cerium sulphide doped with yttrium.

The reaction can be represented as:

$Ce(NO_3)_3 + Y (NO_3)_3 + CH_4N_2S \rightarrow Y (Ce_2S_3) + CO_2 + N_2 + H_2O$

2.1.4. Grinding and Sintering

Combusted spongy product is subsequently collected with care and ground with an agate mortar and pestle. This grinding process is important for breaking up any big agglomerates and obtaining a uniform particle size. The ground powder is sintered at 900°C for 3 hours to further enhance crystallinity and phase purity. High-temperature treatment aids in:

- Improving the crystalline structure of the final product.
- Enhancing particle densification and phase stability.
- Removal of any residual volatile impurities.

Final Outcome

YTTRIUM-DOPED CERIUM SULPhide (Y_2CeS_3) in the form of fine powder is the final product after sintering, which can be utilized for applications like improving the triboelectric properties of nanocomposites for use in energy harvesting devices.

2.2. Fabrication of Y (Ce₂S₃) with PVA Nanocomposite 2.2.1. Preparation of Polyvinyl Alcohol (PVA) Solution

To form a stable polymer matrix, a solution of 7% PVA was made by dissolving a required quantity of Polyvinyl Alcohol (PVA) in double-distilled water. The solution was constantly stirred for around 2 hours at 60°C to break down the PVA polymer chains completely. The process helps form a homogeneous viscous polymer solution, which becomes the base matrix for the nanocomposite.

2.2.2. Preparation of Polyvinyl Alcohol (PVA) Solution

After making the PVA solution, various concentrations of Yttrium-Doped Cerium Sulphide Nanoparticles $Y(Ce_2S_3)$ were introduced into the solution. $Y(Ce_2S_3)$ concentrations were as follows:

- 0.0% (Pure PVA as a control sample)
- 0.5%
- 1.0%
- 2.0%
- 4.0%

To obtain a uniform dispersion of Y(Ce₂S₃) nanoparticles in the PVA matrix, the mixture was ultrasonicated using a high-frequency ultrasonicate processor. This is necessary for:

- Dispersing nanoparticle agglomerates evenly.
- Improving nanoparticle-matrix interactions, which enhances mechanical and electrical properties.
- Avoiding nanoparticle sedimentation during the solution casting process.

2.2.3. Casting and Drying Process

To produce flawless and smooth films, evenly dispersed nanocomposite solutions were placed into a previously cleaned glass mould. The mixture was left to dry for two days at room temperature after the casting process, during which the solvent progressively evaporated.

Slow Evaporation Guarantees

Prevention of cracking or shrinkage of the film, which can arise from the evaporation of solvents at high rates. Homogeneous distribution of thickness enhances the integrity of the film. After drying was finished, nanocomposite films were extracted from the mould with great care.

2.2.4. Thickness Measurement of Nanocomposite Films

 $Y(Ce_2S_3)$ with PVA nanocomposite films obtained were characterized by the measurement of thickness using a screw

gauge, yielding thickness in the range of 0.015 mm to 0.022 mm.

2.2.5. Utilization for TENG Fabrication and Characterization

The prepared nanocomposite films were used to synthesise Triboelectric Nanogenerators (TENGs). Their morphological, structural, and electrical properties were also investigated using different characterization methods to assess their prospect as high-performance triboelectric materials.

2.3. Fabrication of Y (Ce₂S₃) loaded PVA Nanocomposites-Based TENGs

2.3.1. Device Structural Design and Dimensions

 $Y(Ce_2S_3)$ -loaded TENG based on PVA was made with accurate dimensions of 50 \times 50 mm² to allow uniform triboelectric performance and seamless integration into different applications. The device has a vertical contact-separation mode design for efficient charge transfer upon applying mechanical force.

2.3.2. Bottom Layer Assembly (Tribo-Negative Component)

The lowest layer of TENG consists of several materials responsible for its triboelectric and electrical properties:

- Polypropylene (PP) tape: It is used as the tribo-negative layer, i.e., it exhibits a high affinity for gaining electrons upon being placed into contact with a tribo-positive material.
- Aluminium (Al) foil tape: Serves as the electrode, facilitating charge collection and transfer in the triboelectric process. Al foil is affixed to the PP tape with great care to ensure good electrical contact.
- Polyethylene Terephthalate (PET) film: Serves as the substrate, offering mechanical stability and structural integrity to the bottom layer.

2.3.3. Top Layer Assembly (Tribo-Positive Component) The Top Layer of the TENG Comprises

- Y(Ce₂S₃)-loaded PVA nanocomposite film: Upon contact with the tribo-negative PP tape, this layer easily donates electrons. Y(Ce₂S₃) enhances the triboelectric properties of the PVA matrix by enhancing the surface charge density and electrical output.
- Aluminium (Al) foil tape: Acts as an electrode, just like the bottom layer, to allow charge collection.
- Polyethylene Terephthalate (PET) substrate: Offers mechanical support to the top layer and ensures stability under multiple contact-separation cycles.

2.3.4. Structural Integration and Sealing

In order to obtain a stable and flexible structure, assembled top and bottom layers are curled into an arch shape, thus enabling layers to periodically touch and separate due to mechanical stress, improving the charge transfer process. Edges of both layers are sealed with PET film, which benefits:

- Maintain the structural alignment of layers.
- Prevent displacement or misalignment during repeated operations.
- Enhance the durability and longevity of TENG.

2.3.5. Electrical Contact Formation

To finish the TENG assembly, electric contact is made between the Al foil electrodes and the external circuit, allowing smooth charge transfer during operation. Tribopositive and tribo-negative layers are periodically contacted by mechanical motion in the vertical contact-separation mode of the resultant device, which generates an alternating electrical signal.

3. Working Mechanism of Y(Ce₂S₃)-Loaded PVA-Based TENG

The vertical contact-separation mode, a typical mechanism in triboelectric nanogenerators that efficiently harvest energy, is being worked on by the $Y(Ce_2S_3)$ -loaded PVA-based Triboelectric Nanogenerator (TENG). Using electrostatic induction and the triboelectric effect, electrical charge is transferred when two triboelectric materials come into contact and separate because of recurrent mechanical movement.

3.1. Basic Principle: Triboelectric Effect & Electrostatic Induction

Charge transfer results from the interaction of two materials having dissimilar electron affinities, a phenomenon known as the triboelectric effect. One material becomes positively charged when it loses electrons, and another material becomes negatively charged when it acquires electrons. In this $Y(Ce_2S_3)$ -PVA TENG, the working mechanism follows four key stages:

3.1.1. Initial State (No Contact, No Charge Transfer)

The upper layer (tribo-positive $Y(Ce_2S_3)$ -PVA nanocomposite) and lower layer (tribo-negative PP tape) are initially separated. No charge is developed, and the system is in an equilibrium state.

3.1.2. Contact Electrification (Charge Generation)

The top $Y(Ce_2S_3)$ -PVA layer hits the bottom PP layer when an external mechanical force is applied, such as tapping or pressing. Electrons migrate from the $Y(Ce_2S_3)$ -PVA nanocomposite, which is the tribo-positive layer, to the PP tape, which is the tribo-negative layer due to the triboelectric effect, producing opposing surface charges. PP tape is negatively charged, while $Y(Ce_2S_3)$ -PVA layer is positively charged. At this stage, Aluminium foil electrodes are neutral.

3.1.3. Separation & Induced Potential (Current Flow)

When the external force is eliminated, the top and bottom layers separate due to their structure and elasticity. When aluminium foil electrodes are separated, an electric potential difference is created. Electrons travel over an external circuit from one Aluminium foil electrode to another, producing an electric current that neutralizes this potential difference.

3.1.4. Re-Equilibration (Charge Dissipation & Repeat Cycle)

As the layers keep reciprocating back and forth (because of successive mechanical motion), the cycle repeats from contact to separation. This produces a steady Alternating Current (AC) output, which can be utilized to drive small devices, charge capacitors, or power low-power devices such as LEDs.

4. Characterization

The phase and crystallinity of Y2 with CeSs nanoparticles, PVA/Y2CeS5 + PP nanocomposites, and pure PVA + PP were determined by X-ray diffraction analysis. XRD diffractograms were measured using a radiation source set to 30kV and 20mA at a wavelength of 1.540593. 20 has a range of 19.56 to 19.84. SEM analysis was performed on the samples' surface morphology and microstructure utilizing INSTRUMENT JSM-IT300 in VACUUM MODE HV. This study yielded crucial information about the nanocomposite's structure and dispersion of nanoparticles within the polymer matrix. Functional groups and chemical makeup of nanocomposite materials were assessed using FTIR spectroscopy with an FT/IR-4100typeA. Acquired spectra after FTIR characterization revealed the bonding interaction between polymer matrix and nanoparticles, illustrating possible chemical bonding and changes in structure. In addition, EDX spectroscopy was used to identify the element content of nanocomposite samples at a 12kV voltage magnitude of 250 and resolution of 129.8eV. By verifying the presence of yttrium, cerium, sulphur, and other elements, the EDX test validated the effective incorporation of nanoparticles into the polymer matrix.

4.1. X-RAY Diffraction

This was performed to examine phase composition, crystalline structure, and crystallinity of pure PVA + PP composite prepared, PVA/Y_2CeS_5 + PP nanocomposites, and Y_2CeS_5 nanoparticles. With a characteristic wavelength of 1.540593 Å and an X-ray radiation source set at 30 kV and 20 mA, diffractograms were acquired.

4.1.1. Major Observations from XRD Analysis

The diffraction patterns were recorded in the 2θ range of 19.56° to 19.84° , recording the crystalline properties of materials. The inclusion of Y_2CeS_5 nanoparticles in the PVA matrix caused significant shifts in peak positions and intensity, indicative of successful incorporation and possible interaction between the polymer matrix and nanoparticles. XRD patterns of Y_2CeS_5 nanoparticles validated their crystalline phase, guaranteeing that synthesized nanomaterial was well-organized and possessed a definite crystallographic arrangement. XRD analysis offered key information regarding





Fig. 2 XRD of PVA/ Y2CeS5

Figure 2 depicts the XRD of PVA/ Y_2CeS_5 nanocomposites. The comparison of the graph shows the addition of Y_2CeS_5 nanoparticles in PVA for different doping levels: 0.5%, 1%, 2%, and 4%. From the above graph, welldefined peaks in XRD patterns typically indicate high crystallinity and purity. Different peaks were seen at different angles 2 θ (19.76, 19.64, 19.56, and 19.84). The XRD patterns are confirmed at wavelength 1.540593mm and voltage of 30.00kV with current of 20.00mA. The comparison patterns of pure PVA [12] to PVA/ Y_2CeS_5 nanocomposites clearly show that the addition of Y_2CeS_5 [13] in PVA decreases the intensity of the PVA peak, causing increasing in 2 θ can clearly observe the decreases in approximately 2 degrees to that of pure PVA.

Table 1. XRD structural parameters of PVA/ Y2CeS5

PVA/Y2CeS5	Structural Properties			
Concentration	0.5	1	2	4
20	19.76	19.64	19.56	19.84
dcalc (Å)	4.50053	4.52774	4.54605	4.47196
FWHM (Å)	1.0478	1.2400	0.6783	2.1781
Asymmetry	1.000	1.000	1.000	1.402
ROI	11.75- 26.91	14.57- 24.82	18.11- 22.53	12.03- 26.55
Height (cps)	591.2	486.6	255.9	362.0
Wavelength	1.540593	1.540593	1.540593	1.540593
Breadth (mm)	1.490	1.648	0.806	2.331

4.2. Scanning Electron Microscopy Analysis

The produced PVA/Y_2CeS_5 nanocomposites' surface morphology and microstructure were examined using INSTRUMENT JSM-IT300 in Vacuum Mode HV. SEM micrographs indicated that Y_2CeS_5 nanoparticles were dispersed homogeneously in the PVA matrix. A certain extent of nanoparticle agglomeration was present at higher concentration levels, which may affect electrical and mechanical characteristics. The porous and roughness of the surface of the nanocomposite implied improved triboelectric performance through enhanced effective contact area suitable TENG applications.



Fig. 3(a) Surface nature of PVA/Y₂CeS₅ nanocomposite film with 0.5% of Y₂CeS₅



Fig. 3(b) Surface nature of PVA/Y2CeS5 nanocomposite film with 1% of Y_2CeS_5



Fig. 3(c) Surface nature of PVA/Y2CeS5 nanocomposite film with 2% of Y2CeS5



Fig. 3(d) Surface nature of PVA/Y2CeS5 nanocomposite film with 4% of Y_2CeS_5

The surface nature of PVA/ Y_2CeS_5 nanocomposites film deposited at various concentrations (0.5%,1%,2%, and 4%) was identified using Scanning Electron Microscope (SEM) and can be seen in Figures 3(a), 3(b), 3(c) and 3(d). The SEM pictures of PVA/ Y_2CeS films have been used to understand their morphological behaviours.

Figure 3(a) shows that the nanoparticles are grouped and agglomerated. The Figure 3(d) SEM image produced a bit of evenly dispersed Y_2CeS_5 over the PVA matrix. As the nanocomposite concentration grows, the nanocomposites' porosity can also be observed to increase. At 10, 50, and 100 μ m resolution, nanoparticles dispersed throughout PVA are visible.

4.3. Energy Dispersive X-Ray Spectroscopy Analysis

PVA/Y₂CeS₅ nanocomposite's elemental composition was investigated using EDX with a resolution of 129.8 eV, a working voltage of 12 kV, and a 250x magnification.

4.3.1. Major Observations from EDX Analysis

The EDX spectra revealed the presence of Yttrium (Y), Cerium (Ce), and Sulfur (S), confirming the successful integration of Y₂CeS₅ nanoparticles into the polymer matrix. The presence of Oxygen (O) and Carbon (C) was credited to the PVA polymer, verifying its structural integrity within the composite. EDX findings verified the elemental content and gave quantitative assurance of nanoparticle integration, essential for electrical and triboelectric material performance.

The EDX spectra of PVA/Y_2CeS_5 nanocomposite films are displayed in Figures 4(a), 4(b), 4(c), and 4(d). These spectra verify that the dopant and sample chemical homogeneity are present in the correct ratio. This spectrum shows that Y_2CeS_5 doped PVA sheets contain all elements, including cerium, yttrium, and sulphide.



Fig. 4(a) EDX spectra of PVA/Y_2CeS_{5} nanocomposite film with 0.5% of Y_2CeS_{5}



Fig. 4(b) EDX spectra of PVA/Y2CeSs nanocomposite film with 1% of Y_2CeS_5



Fig. 4(c) EDX spectra of PVA/Y2CeS5 nanocomposite film with 2% of Y_2CeS_5



Fig. 4(d) EDX spectra of PVA/Y_2CeS_s nanocomposite film with 4% of Y_2CeS_s

4.4. Fourier Transform Infrared Spectroscopy Analysis

Chemical structure and functional group interactions in the nanocomposites were assessed using FTIR with FT/IR-4100 type A. The chemical connection between PVA and Y_2CeS_5 nanoparticles was partially revealed by the investigation.

4.4.1. Main Findings from FTIR Analysis

PVA's characteristic absorption bands were seen, including those caused by C-H stretching (2900 cm⁻¹), C=O stretching (1740 cm⁻¹), and hydroxyl (-OH) stretching (about 3300 cm⁻¹). New peaks and vibrational mode shifts confirmed the interaction between the polymer matrix and Y₂CeS₅ nanoparticles. Peaks for Ce-S and Y-S bonds were detected, confirming the successful loading of Y₂CeS₅ nanoparticles into the PVA matrix.



Fig. 5 FTIR spectra of PVA nanocomposites films with 0.5%, 1%, 2%, and 4 % of Y_2CeS_5

Table 2. FTIE	R table for PVA	a nanocomposites	films
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Ssigned Vibrational Bands of PVA		Effects of Y2CeS5 NPs on	
		the bands of composite films	
Spectral bands	Wave number (cm ⁻¹)	Reduced the blue shift and peak intensity to 3700 cm-1.	
-OH stretching	3350-3305	Reduced the blue shift and peak intensity to 2900 cm-1.	
-C-H stretching	2929	Peak intensity is reduced	
-C=O stretching	1724-1740		
-CH2 stretching	1442	Disappeared when NP loading was between 2 and 4%.	
-CH2 stretching	1369	New peaks were observed at 1700 and 530 cm-1, and 2 and 4% NPs vanished.	
C-O stretching	1083	Peak intensity is reduced	

The vibrational bands identified as infrared features are included in the above table, along with the functional groups that contribute to them. The observed changes in asymmetric C-H stretching (2850-3000 cm-1) and -OH stretching vibration (3200-3400 cm-1) corroborate the presence of Y_2CeS_5 nanofiller in the PVA matrix. However, a decrease in the intensities of -OH stretching vibrations and their relative broadening may be due to the electrostatic interaction between PVA's -OH groups and surface charges on the metallic films of additional nanofiller.

As the filler (Y_2CeS_5) concentration rose, peak intensities correlated with C=O significantly reduced. It is possible that the -OH group of PVA and Y_2CeS_5 nanoparticle interacted, as evidenced by the observed changes in the relative intensities and positions of the vibrational peaks. The presence of metal oxide nanoparticles in the PVA matrix explains the visibility of peaks at 3288 and 522 cm-1.

5. Electrical Analysis



Fig. 6 Circuit connected for charging a capacitor using TENG





In this, TENG is connected to the output voltage to a 12uF capacitor and in turn, an LED is connected; at first instance, TENG is subjected to a mechanical input, which, in turn, generates output voltage, and the capacitor gets charged when the TENG has removed the voltage from the capacitor is delivered to output circuit in-turn the LED glows.

5.1. Voltage v/s Time Analysis

The electrical behavior of the Y_2CeS_5 with a PVA-based Triboelectric Nanogenerator (TENG) was examined by studying its voltage-time (V-t) response upon mechanical stimulation. This study obtained information regarding the efficiency of energy conversion, mechanisms of charge transfer, and functional applicability of the developed nanogenerator.

5.1.1. Measurement Setup and Procedure

In vertical contact-separation mode, the TENG gadget produced triboelectric charges by repeated mechanical pressing and releasing actions. A digital oscilloscope was used to measure electrical output in order to track voltage generation over time. The mechanical stimulation frequency and input force were kept constant for a repeatable measurement.

5.1.2. Voltage-Time (V-t) Analysis

The obtained voltage-time (V-t) curve displayed a periodic waveform based on the introduced mechanical motion. The highest voltage produced by the Y_2CeS_5 with PVA-based TENG was 300 mV, which proves efficient charge transfer between the tribo-positive (PVA/Y₂CeS₅) and tribo-negative (PP) layers. The development of Y_2CeS_5 nanoparticles improved the triboelectric performance through enhanced surface roughness and increased charge storage ability.

5.1.3. Energy Storage and Application

The induced voltage was effectively employed to illuminate LEDs and charge a capacitor, reflecting the device's applicability. The energy stored can be utilized for low-power electronic applications, including wearable sensors and selfpowered systems.



Fig. 8 Voltage vs Time graph for PVA 0.5% Y2CeS5



Fig. 11 Voltage vs Time graph for PVA 4% Y₂CeS₅

OriginPro software was used to construct a voltage vs. time graph, which shows that as the concentration of nanoparticles increases, the voltage vs. time gradually increases. At one point in time, the voltage peak can be as high as 300 mV. Compared to other concentrations of Y₂CeS₅ doping, the V-t curve for PVA 4% Y₂CeS₅ produces greater peak values. It is evident that when the concentration of nanoparticles grows, so does the peak voltage value. For example, at 0.5%, the peak voltage is 100 mV; at 1%, it is 170 mV; at 2%, it is 250 mV; and at 4%, it is 300-345 mV. This output is linked to a circuit with an LED and a capacitor. The capacitor is charged using the TENG output, and when the TENG is disconnected, the LED illuminates due to the voltage in the capacitor.



Fig. 12 Output obtained during the operation of TENG from digital oscilloscope

The TENG has been fabricated using PVA and PP. The TENG fabricated is attached to an aluminium electrode, and the whole setup is attached to a Digital Storage Oscilloscope (DSO). It is attached to a PC using OpenChoice Tektronix software. A 12V motor is attached to a source for tapping. The motor is turned ON, and TENG is tapped using the motor. The output of TENG is captured by DSO, and the output waveform is being recorded by the software.

6. Conclusion

Through the investigation of Triboelectric potential of Nanogenerators (TENGs) highlights the sustainable energy harvesting. Incorporating Polyvinyl Alcohol (PVA) and Polypropylene (PP) as triboelectric materials alongside Yttrium-Doped Cerium Sulphide (Y2CeS5) nanoparticles was to improve TENG performance. Through extensive characterization, valuable insights are gained into the nanocomposites' structural, morphological, and chemical attributes. SEM analysis provided insights into the surface morphology and microstructure, revealing nanoparticle dispersion and agglomeration variations within the polymer matrix. XRD analysis offered details on the crystallinity, with peak intensities and 2θ values indicating alterations in crystalline structure with different nanoparticle concentrations.

FTIR spectroscopy identified chemical functional groups, showcasing interactions between the polymer matrix and nanoparticles through peak shifts and intensities. Additionally, EDX analysis validated the successful integration of Y2CeS5 nanoparticles by confirming the elemental composition of the nanocomposites. Our experimental findings showcased a direct relationship between nanoparticle concentration and TENG performance, as demonstrated by fluctuations in output voltage.

In particular, when nanoparticle concentrations increased, an increase in output voltage was noted, suggesting the possibility of increased energy conversion efficiency. The device aims to develop sustainable energy solutions for various applications, including portable electronics and sensor networks, by leveraging TENGs' capabilities. In summary, the study highlights the potential of PVA/Y2CeS5 nano composites to improve TENG performance by providing insightful information about their structural, morphological, and chemical properties. The objective is to enhance knowledge of TENG technology and clear the way for upcoming advancements in energy harvesting and renewable energy sources through rigorous testing and characterization.

6.1. Study Limitations

6.1.1. Limited Output Voltage and Power Density

Although the recorded peak voltage of 300 mV is impressive, it is still insufficient for high-power applications without other power management techniques like circuit optimization or using multiple TENG units stacked together.

6.1.2. Scalability and Practical Implementation

Although the research effectively proves a lab-scale model, large-scale production poses issues of material processing, cost, and incorporation into commercial energyharvesting devices.

6.1.3. Charge Retention and Loss

The charge storage efficiency in the nanocomposite can be compromised by charge leakage and dissipation. It is important to know how the polymer matrix retains and transfers charges over time to enhance performance.

6.2. Future Research Areas

6.2.1. Improving Power Output and Energy Storage

Explore dielectric property changes by incorporating more high-electron-affinity materials to enhance charge storage and separation. Discuss hybrid nanogenerator architectures through the integration of piezoelectric or ferroelectric material to improve power generation. Construct high-efficiency rectification and storage circuits to maximize energy harvesting and utilization.

6.2.2. Mechanical and Environmental Stability Tests

Perform long-term mechanical stability tests to analyze the nanocomposites' stability under prolonged operational modes. Examine the effect of humidity, UV light exposure, and harsh temperatures on the triboelectric performance and material deterioration.

6.2.3. Scalability and Practical Application

Research flexible, stretchable, and wearable designs of the TENG for biomedical and IoT applications. Design a costeffective and scalable manufacturing process, potentially through 3D printing or roll-to-roll processing for mass production.

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