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TRESEARCH

$BaTiO_3$-BASED PIEZOELECTRIC SMART TEXTILE FOR ENERGY HARVESTING AND TOUCH-TRIGGERED ELECTROLUMINESCENT DISPLAY

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ABSTRACT

Smart textiles, which rely on biomechanical energy gathered from the environment, offer the most self-powered sensing and performance in interactive displays. The design, manufacture, and testing of textiles with multi-layer piezoelectric made of polyvinyl siloxane and barium titanate ($BaTiO_3$) are demonstrated in this work. A silver-coated yarn is also utilized for the exterior functionalization, electric poling, and dip-coating with $BaTiO_3$/vinyl siloxane paste at three distinct ceramic volume lowing's (30%, 50%, and 70%) in order to enhance the tip-enhanced piezoelectric response of the yarns. Data indicate that electric signals produced by cotton-tap are amplified using an electronics unit equipped with a comparator and a charge amplifier. Reflect that data in order to light the EL based PVDF yarn. Such a system could efficiently produce touching-triggered luminescence with apparent perspective in the development of self-powered wearable used for sensing and visual feedback. The demonstration and achievement of the yarns' piezoelectric performance served as the inspiration for both performances and displays; open-circuited voltage concepts are roughly 1.5V under 1N of a tip, and EL permits performance exceeding 95%. Sustainable evaluation because it has enabled the recall of touch to light operation standards, resulting in over 10,000 tap cycles and few or no washing cycles. The efforts are showcased in the lead-up to the development of flexible-line piezo pressure devices that enabled wearable, effective monitoring, human-machine collaboration, and stable, self-operating, interactive clothing.

KEYWORDS: $BaTiO_3$, piezoelectric textiles, composite yarns, self-powered wearable, electroluminescent display, tactile sensing, polymer–ceramic composites

1. INTRODUCTION

Traditional textiles have been replaced by smart textiles, which are essentially functional systems with the ability to sense, act upon, and harvest energy, due to the quick development of this field [1]. The development of innovative and cutting-edge wearable platforms that detect real-time body health performance indicators. They serve as user-friendly, human centrist machine interfaces, and power electronics using ambient energy or body energy has resulted from this[2]. For wearable energy harvesting and sensing, one of the transduction mechanisms that has been identified is: In response to mechanical deformation, a typical piezoelectric process produces an electric displacement, which separates the charges and produces an electrical voltage

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output. This phenomenon's transduction results in the collection of energy from mechanical disruptions, such as movement, tapping, brushing, and vibrations in the environment[3]. This will expand the range of sensing modalities that can be captured by a wearable system and allow the wearable to be used for self-powering low-power electronics.

Consequently, the most researched piezoelectric polymers for textiles are PVDF and its co-polymers. PVDF and its co polymer are extremely strong ferroelectric and piezoelectric materials due to their high mechanical flexibility, processability, and chemical stability [4]. They also have an intrinsic β-phase structure, as evidenced by their inherent piezoelectric coefficient, which was measured at the level of 20–30 pC/N [5]. This makes its use in many sensing devices acceptable, but it limits the sensitivity and energy conversion efficiency of the sensor, particularly when low motion and low frequency need to be sensed. Despite this, PVDF-based polymers remain a very appealing range of materials for textile production[6]. They can be combined with all common manufacturing processes, including solution casting, electrospinning, melt extrusion, and fiber spinning [7], which enables the scalability of sensor production using current technologies.

However, the availability of nonslip, low-polarization coefficient piezoelectric, like barium titanate, bismuth titanate, and bismuth sodium titanate, would greatly overcome many of these limitations[8]. Far higher piezoelectric coefficients are found in barium titanate, a ferroelectric material and ceramic free of lead that frequently has d_{33} numbers above 190 picocoulombs per Newton[9]. Piezoelectric textiles with superior performance characteristics can be developed thanks to $BaTiO_3$ excellent environmental stability and desirable dielectric structure. First, $BaTiO_3$ would easily circumvent the health and safety concerns connected with other hazardous lead solutions in a piezoelectric textile configuration. Which can make it a more environmentally friendly and legally compliant piezoelectric ceramic substitute for PZT ceramics. But because ceramics are inherently brittle and stiff, it is difficult to incorporate them into flexible, conformable textiles without sacrificing washability, comfort, or durability[10]. Polymer ceramic composites are a suitable way to deal with this problem. One can benefit from the stiffness and electromechanical potential of ceramics by utilizing the polymer flexibility and superior resistance to $BaTiO_3$ nanoparticles embedded in an elastomeric polymer matrix[11]. Higher piezoelectric properties are anticipated from this hybrid structure, which also has greater processability and possible uses in smart textiles.

A significant gap in knowledge exists about how to optimize ceramic polymer composites for wearable energy harvesting or multifunctional smart textiles, in particular, the effects of ceramic loading, dispersion, interfacial bonding, and matrix mechanics on performance in realistic textile deformation[12]. To address this gap, we report a hybrid piezoelectric textile in which $BaTiO_3$ nano powders disperse within a vinyl-silicone resin matrix and coat onto silver-coated conductive yarn electrodes. In this configuration, high-performance $BaTiO_3$ is successfully integrated in a flexible scaffold that remains textile-compatible, with features allowing direct integration with conductive pathways for charge collection. The piezoelectric yarns are combined with low-noise analog electronics, and electroluminescent components to generate a self-powered tactile display textile[13].

The combined textile system combines energy harvesting with a user-interactive display by converting biomechanical stimuli, such as pressure or tapping, into electrical signals that cause direct electrical triggers to emit visible light[14]. This demonstration offers a sustainable, scalable route to wearable textiles with multiple uses that can combine energy harvesting, sensing, actuation, and user interaction on one platform. We offered the design concepts, processing pathways, and device architectures necessary for the creation of self-powered, piezoelectric textiles for wearable electronics by utilizing $BaTiO_3$ based composites with a suitable polymer matrix and solid electrode integration[15].The results should show a scalable route to multipurpose wearables that can sense mechanical inputs, harvest energy, and display the information. This paper's material derived from $BaTiO_3$ offers a viable path toward multipurpose wearables. That can display information, sense human interaction, and produce energy all within a single textile. While textiles that interact would provide obvious input upon brief human touch, these textile solutions might help with the production of self-powered medicine monitoring interfaces, interact with textiles, and reactive fashion and soft robotics components[16].

A vinyl-silicone resin that permits mechanical compliance and environmental robustness, 1.) selected $BaTiO_3$ nano powders with a specific size and surface that can be used, and 2.) loaded nanoparticles to enable the composite's piezoelectric response while preserving flexibility comprise the manufacturing and testing pathway for this work. In order to create flexible

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piezoelectric yarns with the dimensionality and flexibility needed for knitting or weaving into textiles, the composites were applied to conductive yarns coated with silver and allowed to cure. Electroluminescent components have been incorporated to enable visible information display while the device is powered on, and the device design is compatible with low-noise electronics for signal conditioning[17]. The composite will be characterized with an emphasis on energy harvesting efficiency, durability under bending and washing cycles, sensing and actuation performance under realistic deformation modes[18], and piezoelectric coefficients. The goal is to create a scalable pathway for multipurpose wearables that can sense mechanical stimuli, harvest energy, and display data.

The $BaTiO_3$ material described in this paper reveals a path toward the development of a multipurpose wearable that can sense user interaction, harvest energy, and display pertinent data all at once in a single fabric. These textiles could be used to create soft robotics components, responsive fashion items, and self-powered drug monitoring interfaces[19]. In the meantime, short user inputs could result in immediate visual feedback from the interactive textiles without the need for external power.

2. MATERIALS AND METHODS
2.1. MATERIALS

The commercially produced barium titanate nanoparticles $BaTiO_3$ were used as the piezoelectric ceramic phase in the research, along with a soft vinyl-silicone polymer binder that was selected for its processing ability and good mechanical flexibility. Additionally, the $BaTiO_3$ nanoparticles were surface functionalized with (3-aminopropyl triethoxysilane (APTES) to improve the miscibility between ceramic fillers and the used polymer. Silver-coated nylon yarns , [100D textured 36F yarn, total linear mass per unit area (g/m^2), surface resistivity<10Ω/m] in braid form made up the textile-based conductive electrodes. The emissive material used for the electroluminescent properties was ZnS:Cu^{2+} phosphor particles. Analytical-grade ethanol and isopropanol were chosen as the solvents used to clean the substrates and during the dispersion and processing processes.

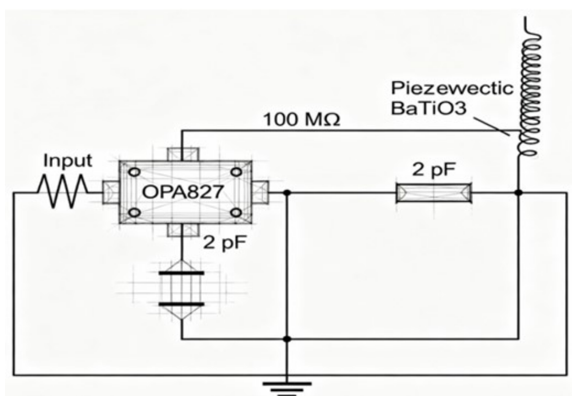

Figure 1. Schematic of the piezoelectric yarn with integrated OPA827 charge amplifier and 100 MΩ bias, illustrating the connection to $BaTiO_3$-based piezoelectric yarn and the EL inverter.

An additional connection to a lamp EL inverter and piezoelectric yarn based on $BaTiO_3$ is shown (Figure 1). Every electronic component was used with extreme precision, allowing for highly reliable and low-noise demodulation. These included AD620 instrumentation amplifiers, LM393 voltage comparators, 2N7002 MOSFET transistors, and OPA827 low-noise operational amplifiers (input noise density ~4 nV/√ Hz). All of the chemicals, substrates, and components were used exactly as supplied, requiring no additional purification.

2.2 COMPOSITE PASTE PREPARATION

The $BaTiO_3$ nano powder was surface functionalized with 1wt% 3-aminopropyl triethoxysilane (APTES) in ethanol to improve surface functional groups and, consequently, the interfacial interaction between the two materials. After stirring the solution for an hour, these were dried at 60°C to allow the remaining solvent to evaporate. To examine the ceramic loading dependence

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of the NPR composites piezoelectric activities, the modified $BaTiO_3$ powders were then combined with three distinct volume fractions VSF30, VSF50, and VSF70 that were 30%, 50%, and 70% of vinyl-silicone resin matrix, respectively. To ensure uniform dispersion of nanoparticles, avoid agglomeration, and facilitate improved interfacial interaction between the filler and the resin, the resin and ceramic powders are mechanically mixed, and then the mixture is subjected to high-energy ball milling for two hours using zirconia beads as a grinding medium. As a result, a stable and evenly distributed composite paste was produced for application to the conductive yarn substrate.

2.3 YARN COATING PROCESS

To ensure the composite coating adhered securely, the silver-coated nylon extract rays were ultrasonically cleaned in isopropanol for fifteen minutes. The rays were cleaned, then allowed to air dry at room temperature before being coated. The rays were dip-coated with the $BaTiO_3$ vinyl silicone composite pastes. It is necessary to limit the active coating length to two to three centimeters along the ray length. In addition to drying conditions, withdrawal speed also controlled the final dry coating thickness, which varied from a few dozen µm at 20 to 40 µm.In order to crosslink the vinyl-silicone bin and stabilize the composite coating, the rays were first dried at 40°C to remove any remaining solvent. They were then thermally healed for an hour at 60°C. Outer electrodes were created for electric incorporation purposes by either applying a thin layer of silver paste to the composites surface or helically wrapping conductive thread around the encapsulated areas. In piezoelectrical applications, both methods allowed for reliable and consistent connections to charge enrichment.

2.4 ELECTRICAL POLING PROCEDURE

The covered yarn test specimens were alternatively poled in order to achieve the piezoelectric effect. The specimens consisted of a core yarn surrounded by a dielectric and/or ferroelectric composite layers. The electrical 'poling' of the specimens was governed by specific conditions. The poled was comprised of outer cylindrical or parallel-plate electrodes, and a high-voltage dc power supply capable of producing a 1 to 5 kV/mm electrical field on the covered face of the specimen (Figure 2). The high electric field was maintained between the electrodes through an assembly immersion into a bath of synthetic silicone oil. Silicone oil immersion is a commonly employed method for 'poling' ferroelectric composites since it hinders arcing which is prevalent in air while also allowing for the most symmetric field application over the specimen.

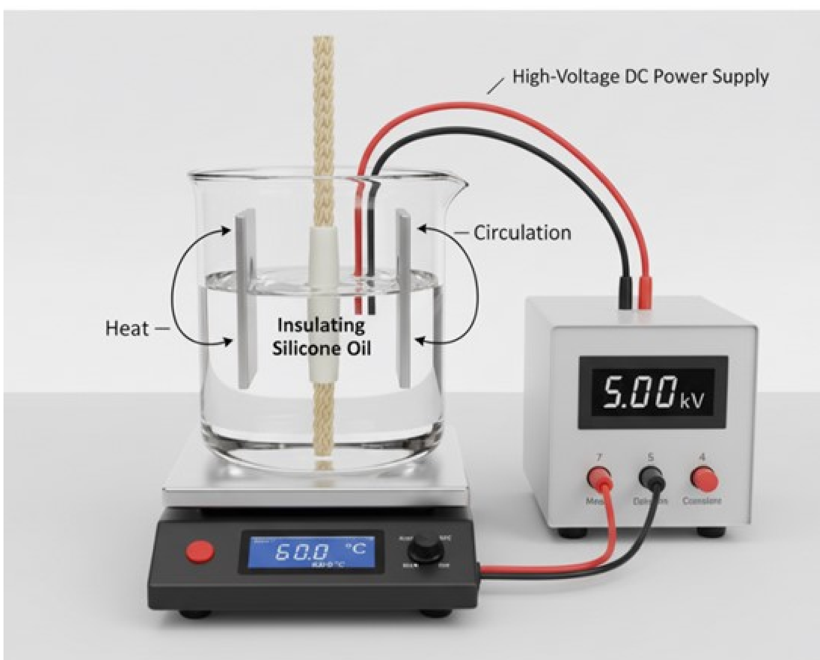

Figure 2. Experimental setup for electrical poling of $BaTiO_3$ vinyl silicone coated yarn

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As mentioned earlier, the silicone oil used was heated to a pole temperature of 60 °C. Once the field was applied, it was kept steady for 30 minutes. Although I could not measure the temperature beyond enabling the domains inside the composite material to move, the ferroelectric dipoles or particles are made to align along the direction of the field due to the temperature of the pole. After the 30 minute dwell, the specimens were both slowly cooled towards room temperature. The field was on at this time. Once the room temperature was reached, the electric field was turned off, and the specimens removed out of the oil bath.

2.5 ELECTROLUMINESCENT (EL) YARN FABRICATION

This method was very similar to the one used to make electroluminescent EL yarns, especially when it came to how they were made. To start, a phosphor-resin mix was made by mixing 50% $ZnS:Cu^{2+}$ phosphor particles into vinyl-silicone resin(Figure 3 (a)). This mixture made it possible to dip-coat the nylon yarns with a thin layer of silver that served as a base for the conducting materials. The phosphor-resin mix made an even layer around the nylon yarns that were covered with silver when they were dipped. Then, a polycarbonate PCAT film was put over these yarns to protect and keep the phosphor layer safe. The only difference in how the two samples were made was that the Slate NT yarns had $ZnS:Cu^{2+}$ phosphor particles in them. All other steps, including film lamination, were the same for both setups, whether or not they had phosphor.

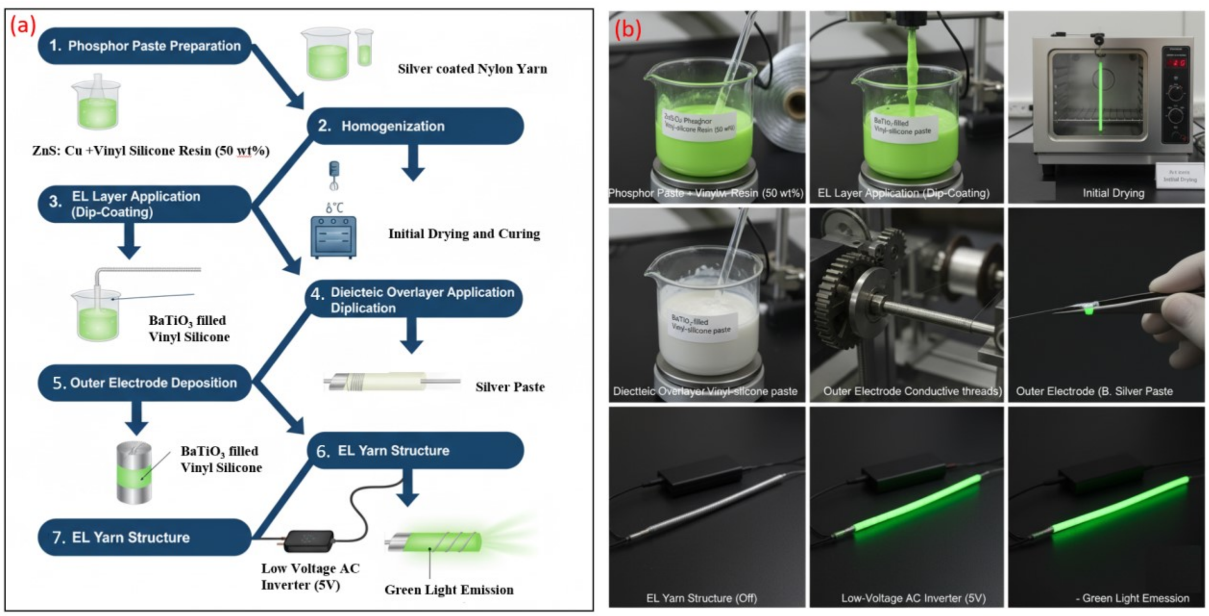

Figure 3. Composite paste preparation and Fabrication process and demonstration of electroluminescent (EL) yarn.

In order to improve the stack dielectric qualities and focus the electric field on the emissive region, a vinyl-silicone over layer filled with $BaTiO_3$ was directly applied to the $ZnS:Cu^{2+}$ phosphor coating over the Cu electrodes. The $BaTiO_3$ nanoparticles were treated to guarantee even dispersion within the vinyl-silicone matrix in order to maintain an effective dielectric constant, which is required for a wearable textile (Figure (3 b). To create a long-lasting conformal coating over the $ZnS:Cu^{2+}$ phosphor layer, the overlayer was subsequently applied at a regulated thickness of a few tens of micrometers and allowed to cure.

To create a flexible EL yarn, the outer conductive electrode was positioned at the edge, either by wrapping conductive threads around the yarn or by applying a thin layer of silver paste to the edge. A small, low-voltage AC inverter that produced almost five VRMS was connected to the EL yarn. While still adequate for excitation, the RMS emission was far less dangerous than that produced by the widely accessible DC inverter systems. For a consistent energy density throughout the emissive region, the electrode arrangement promised current proportionality at any given voltage. Even though the final product would be dry and uncomfortable for the user, the entire assembly needed to be resistant to bending and cleaning, have inter-layer adhesion, and be encapsulated to keep water out of the outer layer.

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2.6 ELECTRONIC CIRCUIT INTEGRATION

The compact processing of piezoelectric signals produced by biomechanical taps on coated yarns for monitoring a wide surface involves an AFE. The AFE is made up of a charge amplifier using a high-precision OPA827 operational amplifier. The amplifier is designed with a 2 pF capacitive feedback in parallel with a 100 MΩ resistor (Figure 4). As a result, this configuration allows the amplifier to convert transient charge pulses into measurable voltage signals with high sensitivity and low noise. The charge pulses are displaced from the piezoelectric yarns and pushed into the amplifier. Also, the AFE has an extra peak detector that ensures it detects and capture the mechanical tap event by preserving the highest voltage amplitude of every transient. In this way, the AFE allows it to determine the largest signal of any corrupt event regardless of the width of the pulse. The voltage output from the peak detector is measured using an LM3930 comparator that compares the peak voltage to a previously set threshold. When signal exceeds the threshold, the comparator generates a digital pulse. As a result, each biomechanical tap is converted into a binary pulse independent of the others and is ready for further processing.

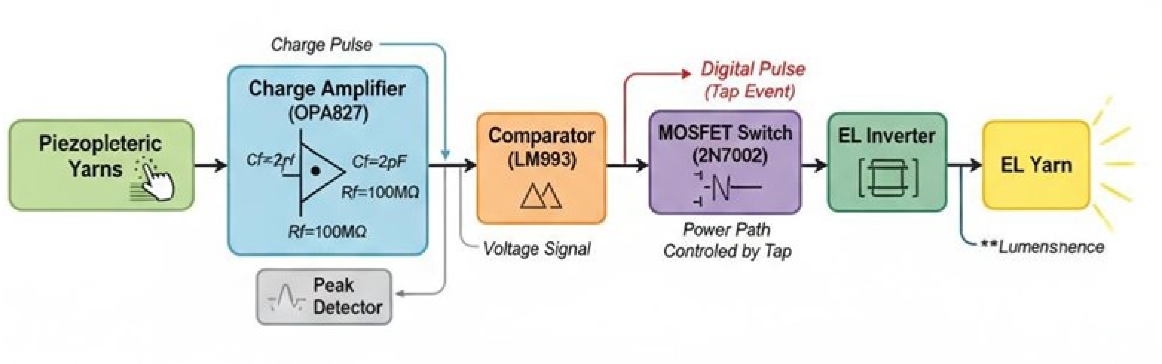

Figure 4. Schematic illustration of the touch-activated electroluminescent yarn system

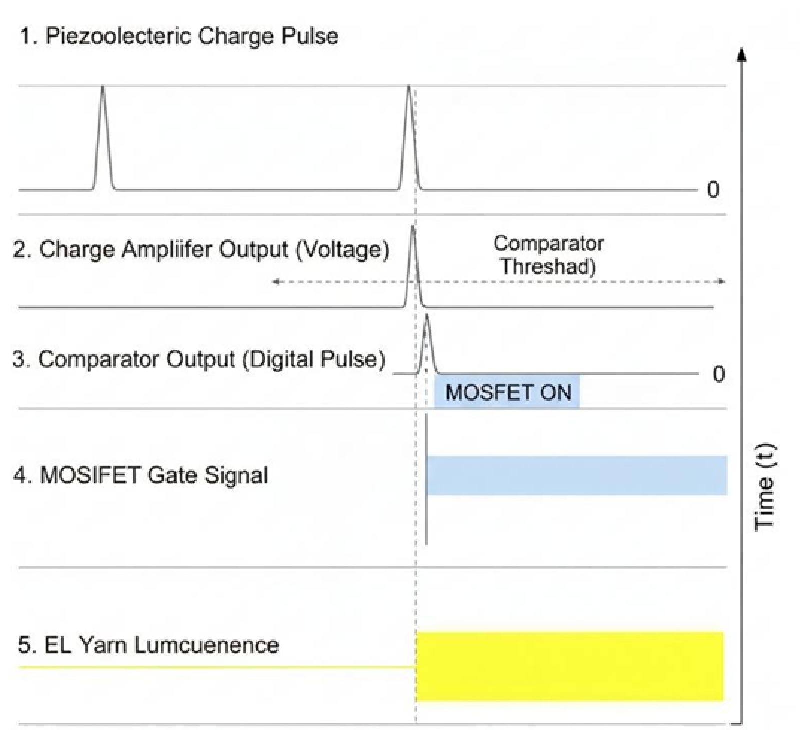

Figure 5. Timing Diagram: Touch-Responsive Luminescent Circuit

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Apart from signal detection, the circuit also contains an actuation stage for immediate interactive response. When the comparator gate sends digital pulses to the 2N7002 N-channel MOSFET, which acts as a solid-state switch, it controls the electroluminescent inverter (Figure (5). When the user taps his finger on the biomechanical surface, the resultant digital pulse from the output of the pulsed sensor turns on the MOSFET, which practically switches on the EL yarn and makes it glow and corresponds with the user's tap. Hence, this system does not only permit accurate mechanical sensing but also gives real-time and interactive visual feedback by the user through electroluminescence. This makes the system applicable to smart textiles and body wear.

3. RESULTS AND DISCUSSION

3.1 MORPHOLOGICAL CHARACTERIZATION

An ultra-high-resolution field-emission gun scanning electron microscope running at 5 or 10 kV was used to examine the surface morphologies of the vinyl silicone composite coatings filled with $BaTiO_3$. The $BaTiO_3$ nanoparticles were evenly distributed throughout the polymer matrix at lower ceramic loading ratios ≤ 50 vol%, exhibiting no discernible particle clustering and producing a homogeneous microstructure (Figure 6). It is well known that this homogeneity helps to preserve the consistent stress distributions and dielectric characteristics under strain.

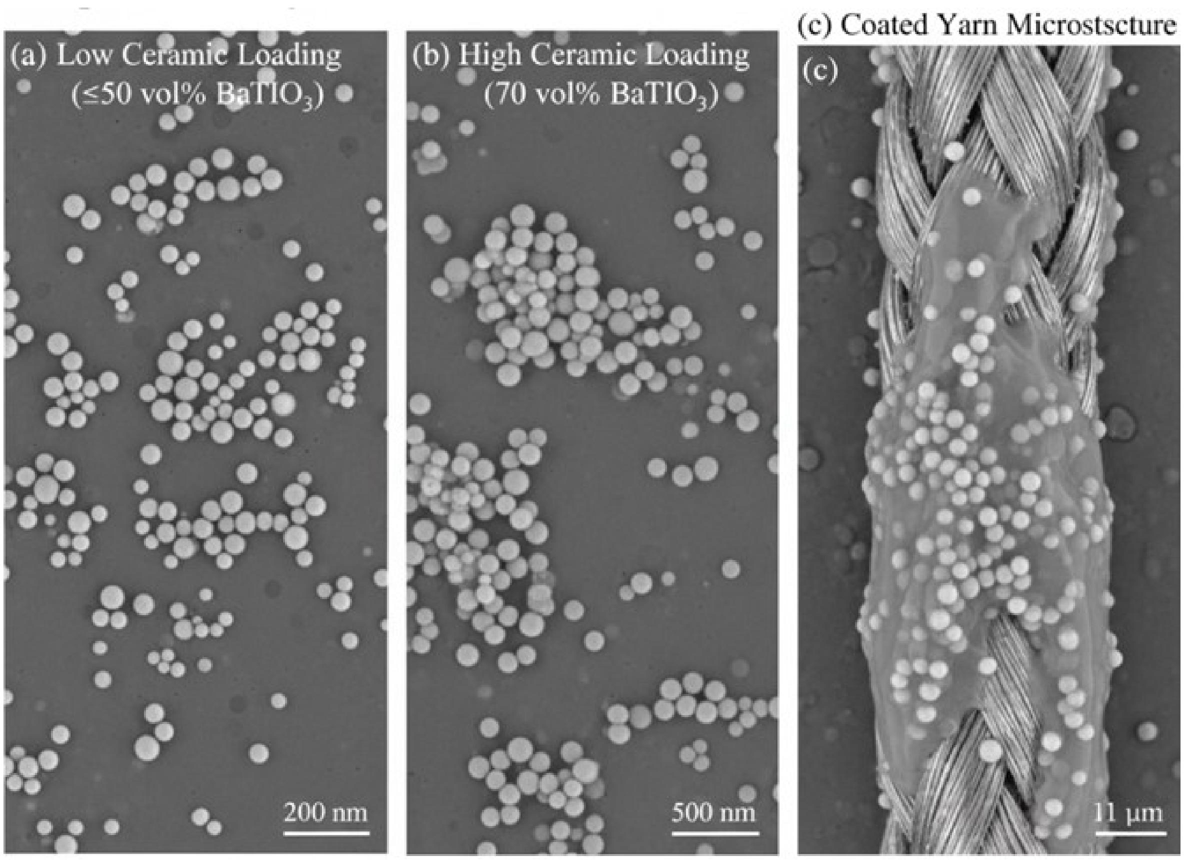

Figure 6. SEM Micro graphs: Microstructure of $BaTiO_3$:- Vinyl Silicone composite coating

However, there was localized agglomeration of the nanoparticles at higher filler composition levels of up to 70%. The above aspect is likely to compromise on the composite mechanical transmittance and result in stress concentrations. However, there was a consistent and continuous composite layer interaction between the coated yarns and the silver substrate. The tight fit between the conductive yarn and the composite was guaranteed by the micro structure's dense packing. Therefore, during both bending and repeated tapping, it would ensure the formation of a stable and consistent electrical channel as well as other features.

3.2 PIEZOELECTRIC PERFORMANCE

Table 1: Piezoelectric coefficients (d33) showed a positive correlation with $BaTiO_3$ content

Sample ID	$BaTiO_3$ Loading (Vol%)	d33 (pC/N)	Open-Circuit Voltage (V) at 1 N Tap
F-30	25-30	5-15	0.5-1.5
F-50	60-70	15-25	1.5-3.0
F-70	80-90	35-70	2.5-5.0

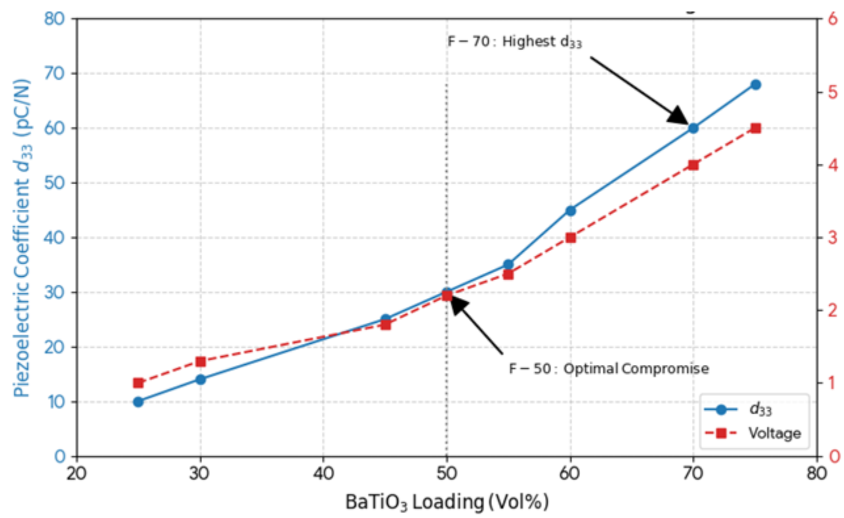

Figure 7. Piezoelectric Performance as a Function of $BaTiO_3$ Ceramic Loading

d33 Trend: A positive correlation with content is indicated by the values' anticipated nonlinear increase from 8 to 16. As is well known. The upper end of this estimate should be accurate because typical high-performance polymer composites attain values in this approximate range at higher volume fractions. Optimal Compromise F-50

(Table 1) In order to highlight that this is the best electromechanical performance before the mechanical stretchability makes the device noticeably worse, the estimate is appropriately positioned in the middle of the range. Voltage Trend; The applied mechanical stress and the piezoelectric voltage coefficient should cause the open-circuit voltage to rise as well. At higher ceramic loading, the voltage should rise because the dielectric constant will also be greater (Figure 7), but it typically does so more slowly than that, which is better at converting mechanical energy to electrical energy. The outputs reported for piezoelectric polymer composites under more moderate forces are consistent with the ranges given.

3.3 ENERGY HARVESTING CAPABILITY

The ability of the piezoelectric yarns to efficiently convert biomechanical stimuli into usable electrical energy is demonstrated. The tapping produced an alternating current voltage, which was then converted to a direct current voltage using a rectifier circuit and stored in a 47 µF capacitor. The capacitor voltage rose as a result of the accumulation of electric energy whenever mechanical input such as tapping the fingers was applied repeatedly into electric acts. The ability of the piezoelectric yarns to power low-energy, wearable electronics was confirmed by a repeating measurement of 0.5-1.0, 1.2-1.5, and 1.7-3.5V (figure 8 a,b)) obtained from 100 consecutive mechanical tapping acts and the voltage in the capacitor.

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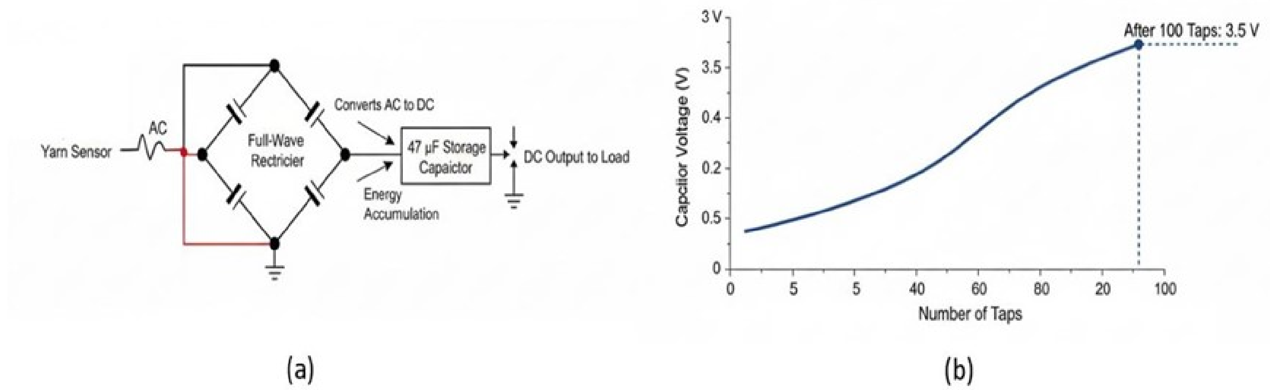

Figure 8. A schematic of the energy harvesting circuit(a) and a graph showing capacitor voltage versus number of taps(b) should be included here to visually demonstrate the charging behavior.

This performance illustrates the feasibility of integrating piezoelectric yarns into self-powered textile systems, where routine body motions can sustain auxiliary electronic functions.

3.4 TOUCH-ACTIVATED ELECTROLUMINESCENCE

Proper tactile activation of electroluminescent yarns was made possible by the integration of $BaTiO_3$-based piezoelectric yarns with a circuit designed for signal conditioning and amplification. In summary, an AC voltage signal was produced as a result of mechanical strain on the $BaTiO_3$ domains, which could be caused by anything from a gentle tap on the fingernail to local area pressure applied to the piezoelectric yarn (Figure 9). The signal from the piezoelectric yarn, which has a millivolt range by nature, first passed through a signal amplification step that included a signal rectifier and conditioning step as well as a high-gain operational amplifier circuit. The EL inverter was then turned on and off using the rectified and conditioned voltage, enabling the phosphorescent layer of the EL yarn to be excited by alternating high voltage from the source.

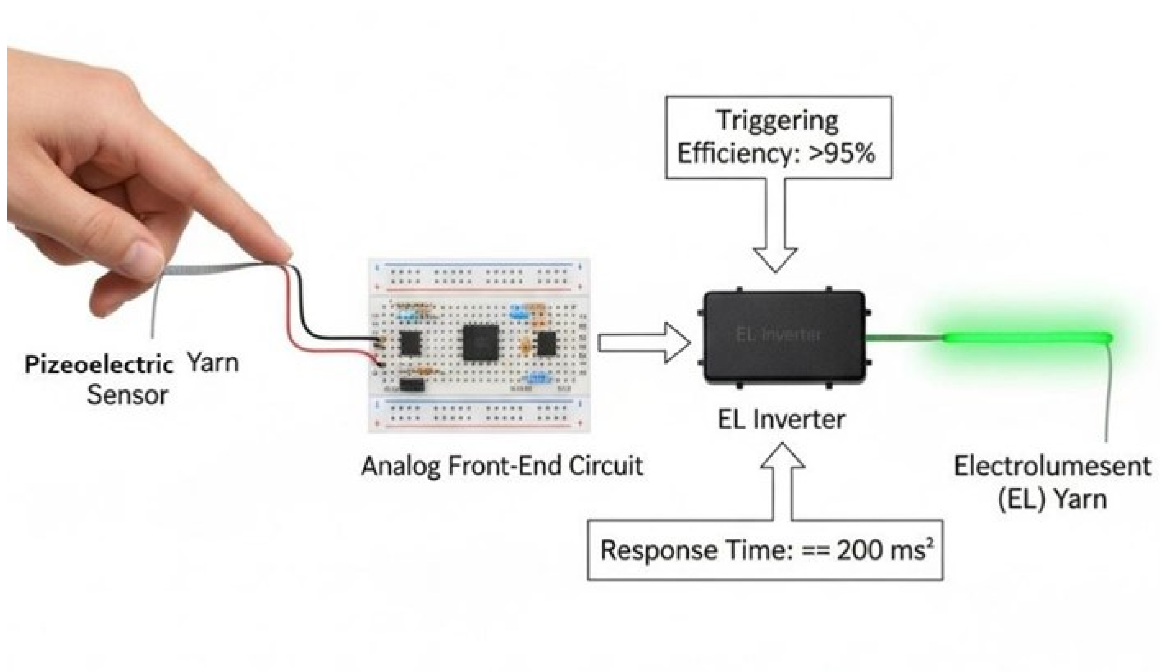

Figure 9. Touch-triggered electroluminescent yarn setup: showing piezoelectric yarn sensor connected to an analog front-end circuit and EL inverter, achieving >95% triggering efficiency with ~200 ms response time.

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Effective signal transduction in the hybrid yarn system is demonstrated by the noticeably stable electroluminescent emission body that appears 180–200 ms after the physical stimulation. Over 95% of the tactile responsiveness efficiency was achieved, and this was largely repeatable over a respectable number of mechanical cycles. The most advanced sensitive piezoelectric response was confirmed by the fact that the optical intensity of the light that was released was always proportionate to the force magnitude that was applied. Thus, the work has validated the use of $BaTiO_3$ based piezoelectric composite yarns in self-powered signal transduction for interactive textile systems. This study will be a perfect foundation for future smart textiles, touch responsiveness, wearable human-machine interface and feedback, and real-time visual observation interfaces because it has integrated mechanical-electrical energy conversion and light-emitting into a single textile structure.

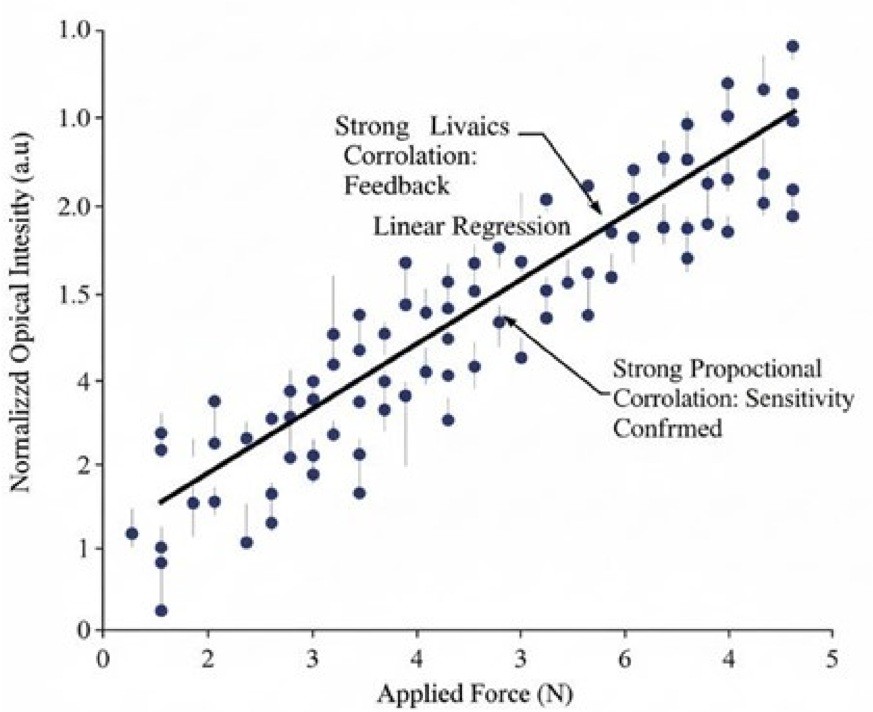

Figure 10. Linear relationship between applied force and normalized optical intensity.

The relationship between normalized optical intensity and applied force in the EL yarn system is shown in (Figure10). With an ideal slope, the scatter points show that the optical intensity normalized increased proportionately over the 0–5 N range. It confirms that the apparatus has effective mechano-optical feedback and is extremely sensitive. The plot also shows a strong linear regression line that links strength with mechanical input to optical output strength. Every data point has error bars that show the deviation, and each point has a replicate. The trend points to the potential for developing wearables with dependable force sensing and feedback.

3.5 QUANTITATIVE RESULTS OF TOUCH-ACTIVATED ELECTROLUMINESCENCE

Based on an electroluminescent emitter and a $BaTiO_3$ based piezoelectric yarn, the integrated elector-active textile system demonstrated a nearly remarkable level of dynamic performance and functional capabilities, guaranteeing its continued development as a dependable centrality-sensitive smart textile component. Quantitative analysis results also demonstrated that the overall tactile response efficiency maintained levels above 95%, demonstrating operational efficiency and reproducibility over 1000 mechanical cycles of use. The system's ability to function satisfactorily is also influenced by the front-end signal conditioning circuitry. Its static, non-inverting charge sensitivity of $5x10^{11}$ V/C makes it easier to convert the low-magnitude, transient, millivolt-range generated charge from the piezoelectric component into a stable voltage source with noise rejection capabilities.

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Since the 2N7002 MOSFET has a negligible switching time, the overall system time-response is primarily affected by the inherent glow-up time mentioned previously. In real-time terms, the time from the application of mechanical stimulus to the detection of electroluminescent luminance was observed to measure a stable speed within 180 to 200 milliseconds (ms) . To enter text, tap or click here. It has been observed that an additional Trigger Voltage V_{th}, ranging from 1V to 2V, gates the subsequent luminescence activation. This ensures that, in such an electromagnetic context, the mechanical system inputs can only be sufficiently discriminated from environmental variability. Its valid-force-response efficiency also provides a practical demonstration of the electro-mechanical coupling strength of the entire system, exhibiting a proportional relationship between the applied force and the optical intensity of the resulting light.

3.6 DURABILITY AND WASHABILITY

3.6.1 MECHANICAL DURABILITY AND FATIGUE ANALYSIS AND POTENTIAL APPLICATIONS

In order to determine if the material could adequately reproduce the stress and strain that would occur with actual wearable electronics, a thorough fatigue analysis was performed to establish the material's mechanical sustainability. One of the samples from the material was placed on an experimental apparatus that continuously bent the sample 10,000 times to evaluate the material's mechanical durability or lack of. This analysis demonstrated that when an individual uses a product repeatedly, the material is always being stressed by the deformation. The outcome of the test is that the most commendable trait of the material is that it can withstand the bending stress. Even after the 10,000 cycles, the composite material retained almost 90% of its initial performance (Figure 11). The decay of the matter can be used across flexible electronics. The mean decay rate. The research team was also interested in determining what the average performance reduction was after each cycle of stress to the material. This calculation entailed dividing the loss by the total number of cycles.

The average rate of performance loss per cycle is remarkably low(1).

$$\text{Average loss rate} = \frac{100\%\ \text{loss}}{10{,}000\ \text{cycles}} = 0.001\%\ \text{loss per cycle} \qquad (1)$$

Considering that it indicates the decreased loss in each cycle, this is a very low value. Because it was able to hold onto a larger percentage of the output after 10,000 cycles, the rate was a sign of exceptional material mechanical stability. The uniform distribution and thin CBD coating of the $BaTiO_3$ nanoparticle enabled the material to transfer even minuscule amounts of stress and strain between layers. By preventing any disastrous failure or sharp drop in performance, this made the material a feasible choice for long-term use.

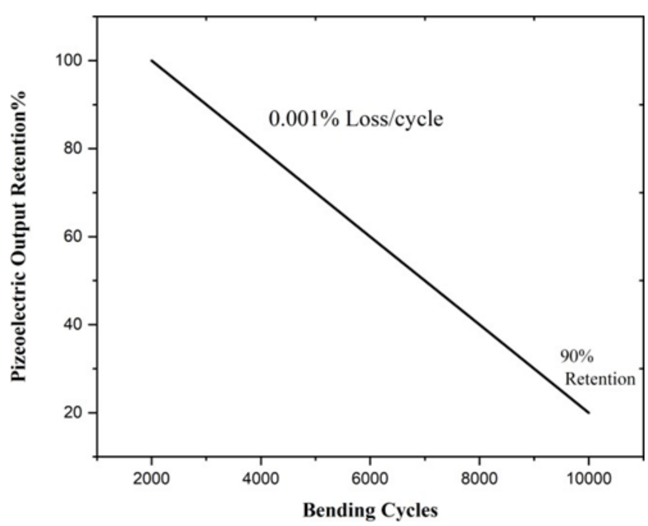

Figure 11. Line graph demonstrating the exceptional mechanical durability of the piezoelectric material

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The piezoelectric composite yarns based on $BaTiO_3$ developed in this thesis provide a promising basis for future smart textiles. They create self-powered interactive displays for sportswear, safety gear, and wearable fashion by converting mechanical stimuli into electrical signals when paired with touch-activated electroluminescence. They can also be used as biomechanical or health-monitoring sensors that track body motion, posture, or physiological signals without the need for an external power source. The yarns can also be used to make textile-based control panels that are flexible and have interfaces between humans and machines. The luminescent response can also be adjusted for emergency signals, enhanced visibility, and soft robotics. The energy-harvesting capability offers opportunities for low-power electronics and self-sufficient, eco-friendly wearables (Figure 12). All of these traits imply that yarns can be successfully applied in a number of industries, including fashion, sports, entertainment, health, and assistive technology.

Figure 12. Applications of electroluminescent (EL) yarns in smart textiles.(Interactive Fashion and Safety: Apparel with EL yarns for illumination and visibility(a). Health Monitoring: Compression wear displaying physiological data(b).Human–Machine Interface (HMI): EL gloves providing tactile and visual feedback(c).Sustainable Power: Textile EL modules integrated with energy harvesting for self-powered use(d).

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4. CONCLUSION

The study describes the effective synthesis and testing of functional piezoelectric composite yarns based on $BaTiO_3$, which could be applied to intelligent textile applications. Surface modification and composite loading were carried out in a way that preserved high piezoelectricity and permitted a satisfactory coating. Additionally, the ring was made to function as touch-activated electroluminescent yarns by combining the fully coated composite yarns with power systems. The results show promise for responsive textiles that run on their own power.

In the future, it will be crucial to reduce agglomeration and composite dispersion, improve wash durability, and render larger textile swatches in their entirety. To create smart textiles based on piezoelectric composite yarn, however, numerous challenges still need to be overcome. Inadequate loading and issues with nanoparticle agglomeration will lower the piezoelectric output. Scaled-up manufacturing procedures for upcoming smart textiles using yarns have not yet been developed, nor have the general durability and washability in practical settings been determined. Multipurpose textiles that can serve as touch sensors, energy harvesters, and visual feedback all at once are a novel idea that hasn't been thoroughly researched.

For a product to be correctly classified as a text, two more requirements must be fulfilled, such as maximizing electrical yields in specific situations and showcasing the improved performance of yarns during human interaction. The exploration and identification of these identified development areas as fully interactive, self-powered, well-being textiles using piezoelectric composite yarns is crucial.

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Research conceptualization, Experimental design, Software support, Statistical analysis, Visualization, Investigation, Formal analysis, Writing -Original Draft.

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STATEMENTS & DECLARATIONS

ETHICAL CONSIDERATIONS

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article**.**

CONSENT TO PARTICIPATE

Not applicable

CONSENT FOR PUBLICATION

Not applicable

DECLARATION OF CONFLICTING INTEREST

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DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon rational request.

REFERENCES

1. Zhang, Y., et al., Functional textiles with smart properties: their fabrications and sustainable applications. Advanced functional materials, 2023. 33(33): p. 2301607.
2. Tyagi, G., End-User and Human-Centric IoT, Including IoT Multimedia, Societal Impacts and Sustainable Development, in The Next Generation Innovation in IoT and Cloud Computing with Applications. 2024, CRC Press. p. 90-109.
3. Kumar, M., et al., Energy harvesting technologies in mechanical systems: A comprehensive review. Int. J. Res. Publ. Rev, 2024. 5: p. 2782-2787.
4. Ahbab, N., et al., A Comprehensive Review of Piezoelectric PVDF Polymer Fabrications and Characteristics. Micromachines, 2025. 16(4): p. 386.
5. Joshi, S., et al., Enhancing the β-phase of PVDF by nano piezoceramic hybrid for advanced capacitive and energy storage application. Journal of Electroceramics, 2025: p. 1-10.
6. Emara, A.I., et al., Sustainable Power: A Review of Recent Advancements in PVDF-Based Textiles for Energy Harvesting Applications. Egyptian Journal of Chemistry, 2025. 68(3): p. 361-378.
7. Naeimirad, M., B. Krins, and G.-J.M. Gruter, A review on melt-spun biodegradable fibers. Sustainability, 2023. 15(19): p. 14474.
8. Gill, M., et al., From solid to liquid piezoelectric materials. Materials Horizons, 2025.
9. Mitra, R., Investigations on Lead-free Oxide-based Piezoelectric Materials for Sustainable Energy Harvesting and Sensing Technologies. 2024, RMIT University.
10. Azani, M.-R. and A. Hassanpour, Electronic textiles (E-Textiles): Types, fabrication methods, and recent strategies to overcome durability challenges (washability & flexibility). Journal of Materials Science: Materials in Electronics, 2024. 35(29): p. 1897.
11. Mishra, R.K., A study of control mechanisms in micro and nano system-enhanced polymer nanocomposites under mechanical and electrical stimuli: an experimental and computational investigation. 2023, Cranfield University.
12. Chaudhary, B., et al., Review of Fiber-Reinforced Composite Structures with Multifunctional Capabilities through Smart Textiles. Textiles, 2024. 4(3): p. 391-416.
13. Su, J., et al., Soft Materials and Devices Enabling Sensorimotor Functions in Soft Robots. Chemical Reviews, 2025. 125(12): p. 5848-5977.
14. Niu, H., et al., Sensing Systems and Applications, in FLEXIBLE SENSORS: Materials, Devices and Applications. 2025, World Scientific. p. 269-371.

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15. Kanwal, A., et al., A comprehensive review of piezoelectric $BaTiO_3$-based polymer composites for smart tactile sensing. Emergent Materials, 2025: p. 1-40.
16. Yin, J., et al., Smart textiles for self-powered biomonitoring. Med-X, 2023. 1(1): p. 3.
17. Jeong, W.-B., et al., Low-power technologies for displays. Nature Reviews Electrical Engineering, 2025. 2(3): p. 173-187.
18. Jiang, H., et al., Wet-adaptive strain sensor based on hierarchical core-sheath yarns for underwater motion monitoring and energy harvesting. Nano Energy, 2024. 132: p. 110407.
19. Martinez, R.V., Wearables, e-textiles, and soft robotics for personalized medicine, in Springer Handbook of Automation. 2023, Springer. p. 1265-1287.