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Proceeding Paper

Design and Development of a Fully Sustainable Piezoelectric Energy Harvester from Bio Waste Prawn Shell †

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Abstract: In this work, a biocompatible and fully sustainable, self-poled green energy harvester is designed from the exoskeleton of prawn fish. The prawn shells (PS) are collected from the biowaste of a local seafood processing plant. Shell surfaces are properly cleaned with DI water to remove any loose debris or contaminants. A strong chelating agent Ethylenediaminetetraacetic acid (EDTA), that can effectively bind to metal ions is used to remove the mineral content and metal ions from the shell surface. Any trapped water content on the PS surface is dissipated by keeping the sample at room temperature for 24 hours. The PS contains 20%–50% calcium carbonate, 20%–40% protein and 15%–40% chitin, where the chitin nanofiber acts as an active piezoelectric element. The X-ray diffraction peak obtained at $2\theta^0 = 9.24^0$ and 19.4^0 confirms the presence of crystalline intersheet α-chitin and intrasheet β-chitin that possess piezoelectricity. The PS energy harvester of a very small surface area "10 mm x 8 mm" fabricated as silver-prawn shell-silver layer, generates 480 mV output voltage only by finger taping longitudinally on its surface. Optimizing the electrical load, the piezoelectric generator can generate 470 mV output across 500 kΩ and harvest 441.8 nW of output power at applied mechanical stress only by finger taping at 2 Hz.

Keywords: Energy harvesting; Piezoelectricity; Biowaste; Prawn shell; Chitin nanofiber

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1. Introduction

Self-powered devices have now become inherently necessary for regular life to avoid the limitations of battery-operated devices. Battery has a limited lifetime and requires recharging periodically which is difficult where power sources are not available, or devices that are placed in difficult to access locations. Thus, self-powering devices can overcome the limitation of battery-operated devices and increase ability in real time applications. Now a days, research on clean energy harvesting draws most researchers' attention concerning the increasing global pollution [1]. Ambient mechanical energy is a huge free and unused energy source that dissipates in terms of force, pressure, vibration from industrial machines etc. [2]. Research and development for converting mechanical to electrical energy has been accelerated by three methods viz. 1) Electrostatic, 2) Electromagnetic and 3) Piezoelectric, where piezoelectric energy conversion is widely used due to its self-generating ability, high electromechanical coupling factor, lightweight, flexibility etc. [3,4]. However, the selection of appropriate material for harvesting energy is a crucial task to maintain its flexibility, efficiency, ease of availability and eco-friendliness. Although there are several organic and inorganic piezoelectric materials, for instance, PZT, KNN, PVDF, ZnO has been extensively explored and utilized, some of them are toxic, non-ecofriendly, non-biocompatible, non-biodegradable and most importantly not easily available. In addition, the synthesis and fabrication of piezoelectric sensors require long and hazardous chemical processes. Again, to enhance the piezoelectric property, sometimes high electrical poling is required, which is a tedious and challenging task for the manufacturer [5].

Therefore, exploring alternative materials, especially those which are eco-friendly, nontoxic, biocompatible, and cost-effective is now prominent. Materials that are derived from biowaste sources can be sustainable and cost-effective approaches. Biological materials exhibit highly ordered structures but low symmetry lacking an inversion center. Thus, the majority of biomolecules possess an inherent piezoelectric property. Guerin et. al. surveyed the piezoelectric behaviour of different biological sources for instance- viruses, egg shells, fish bladder, fibre silk, glycine, collagen, chitin etc. and harvested an extensive amount of output voltage [6]. Karan et. al. fabricated a bio-inspired piezoelectric energy harvester from the abundant membrane of calcified egg shell. The thin, porous membrane is a rich source of collagenized fibrous that contributes to piezoelectricity for energy generation [9].

In this paper, a piezoelectric energy harvester fabricated from prawn shells is investigated as it avails chitin nanofiber in its surfaces. The crystalline structure is confirmed by P-XRD analysis. The shell surface morphology is studied using FESEM. Finally, the piezoelectric output voltage generated by the harvester is optimized with different electrical loads to achieve maximum output voltage.

2. Materials and Methods

2.1. Sample Preparation and Device Fabrication

The sample collection and harvester fabrication process are described below:

- The shells are collected from the biowaste of a local sea food processing plant.
- The shells are first cleaned with DI water to remove any loose debris or contaminants Third bullet.

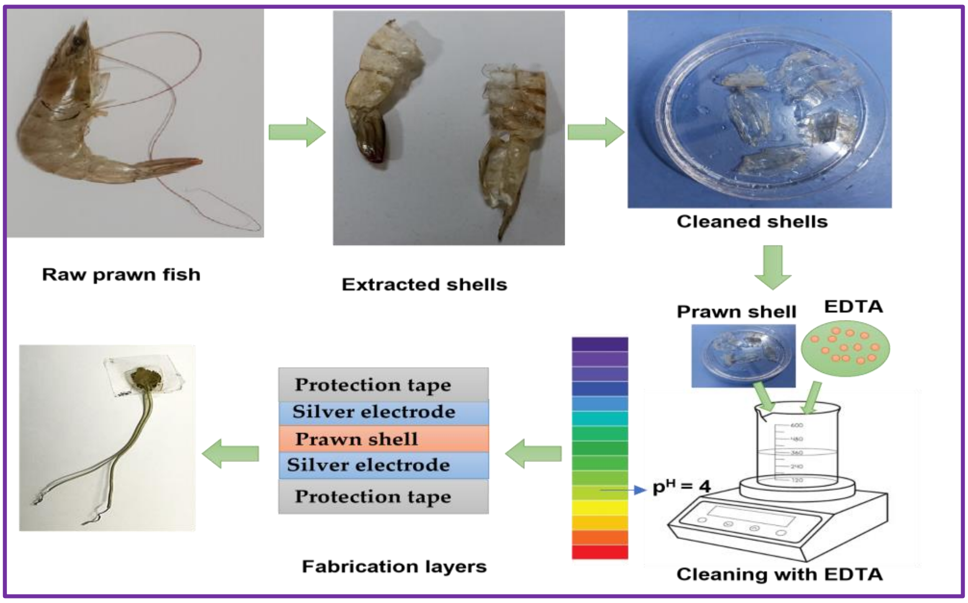
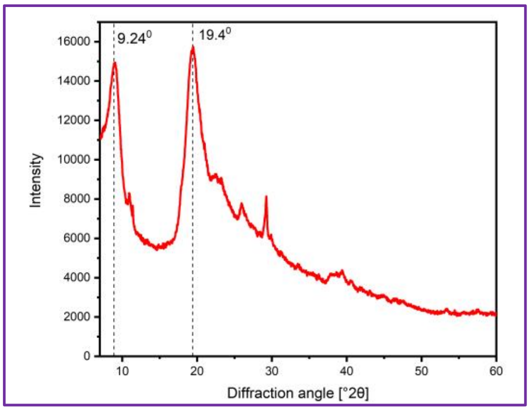
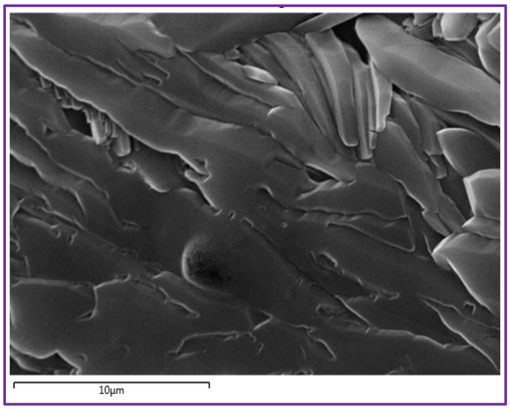


Figure 1. The processing and fabrication of piezoelectric energy harvester from prawn shell.

- Further, the shells are cut into pieces and cleaned in an 8M EDTA solution at room temperature using a magnetic stirrer at 700 rpm and pH 4. EDTA is a strong chelating agent that can effectively bind to metal ions and facilitate their removal from the shell's surface.
- A small surface area of "10 mm x 8 mm" is taken for the energy harvester fabrication.
- Further, conductive silver paste is used as the top and bottom electrodes and is deposited using the brush painting method. Moreover, two copper lead wire is connected for external electrical interfacing. The energy harvester fabrication process is shown in Figure 1.



(**a**)



(**b**)

Figure 2. (**a**) X-ray diffraction peak and(**b**) FESEM view of the processed prawn shell.

2.2. Characterization

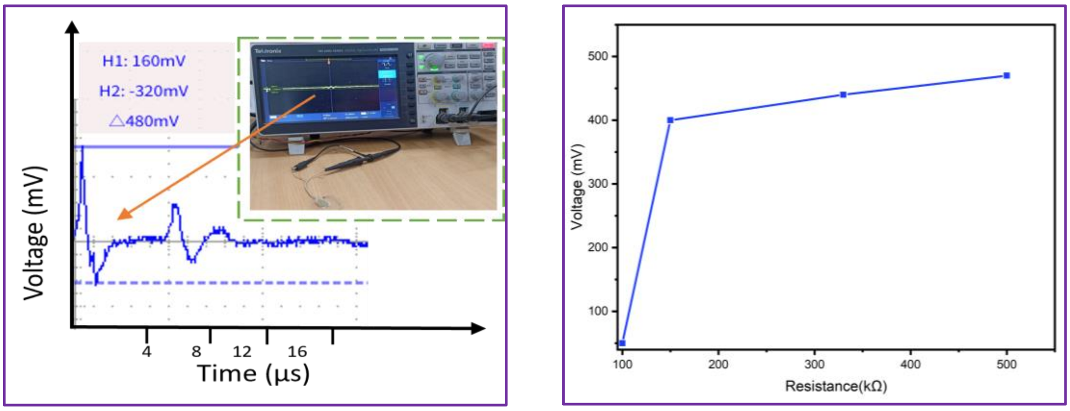
The prawn shell film is characterised using X-ray diffraction to confirm the presence of crystalline structure. The prawn shell contains 20%- 50% calcium carbonate, 20%-40% protein and 15%-40% chitin, where chitin nano fibre acts as an active piezoelectric element [7]. As shown in Figure 2(a), the two diffraction peak at 9.24^0 and 19.4^0 confirms the presence of the crystalline element intersheet α-chitin and intrasheet β-chitin that possess inherent piezoelectric properties and the key reason for piezoelectricity of prawn shell [8]. Field Emission Scanning Electron Microscope (FESEM) view of the prawn shell surface is shown in Figure 2(b). The shell surface is constituted of multiple layers overlapping on each other.

3. Results and Discussions

The harvester output is an AC voltage measured using a Digital Storage Oscilloscope (TBS 2000) on the application of mechanical stress. Mechanical stress is employed with simple finger taping at a frequency of 2 Hz. On each finger taping, 480 mV of open circuit output voltage is obtained as shown in Figure 3(a). Further, to obtain optimum output, the harvester output is tested with varying load resistances from a range of 150 kΩ to 500 kΩ as shown in Figure 3(b). The output voltage of 470 mV is obtained across a 500kΩ load with a harvested power of 441.8 nW at each finger tap.

4. Conclusions

The piezoelectric property of prawn exoskeleton film is studied. The x-ray diffraction peak obtained at 9.24^0 and 19.4^0 confirmed the presence of crystalline chitin nanofiber that contributes to the piezoelectric activity. Output voltage of 470 mV is obtained across 500 kΩ and harvested 441.8 nW of output power. Besides being used as an energy harvester, it can also be used as a sensor for motion monitoring, impact monitoring etc.



(**a**) (**b**)

Figure 3. (**a**) Open circuit output voltage obtained on applied mechanical stress and(**b**) Sensor output across different load resistances.

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Conflicts of Interest: The authors declare no conflict of interest.

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