$Bi_4Ti_3O_{12}$ based sustainable Yarn type-Piezoelectric Nanogenerator as a Cost-effective Battery-free Breath sensor

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1. Introduction

For the smart and simple self-powered application, we need a device which can generate electrical energy from any kind of mechanical strain available in our daily life and surrounding environment. In this case, we have nanogenerators which can convert mechanical energy into useful electrical energy and they are classified generally into piezoelectric nanogenerators and triboelectric nanogenerators. Piezo materials consist of crystals, ceramics, polymers and recently some 2D materials (1,2). The piezoelectric materials have usage in various fields like FeRAM, piezo catalysis and various sensors. Here in the present case we followed layer-by-layer cost effective brush coating method in fabricating flexible yarn based piezoelectric nanogenerator (FY-PNG) for energy harvesting as well as battery free breath sensor.

2. Body of abstract

Aurivillius phase, bismuth layer structured ferroelectrics (BLSF) bismuth titanate nanoparticles ($Bi_4Ti_3O_{12}$ NPs) was synthesized by sol-gel technique for effective conversion of mechanical energy into useful electrical energy. The basic structural studies XRD and Raman confirms ferroelectric orthorhombic phase of the prepared $Bi_4Ti_3O_{12}$ NPs. The FY-PNG device generates V=60 V and Isc=0.4 µA with the power density of 18.5 mW/m^2 upon the mechanical force of 1 N. The proposed device further demonstrated for non-invasive self-powered breath sensor with different devices and testing subjects under slow/fast and constant breathing conditions. The efficient piezoelectric material, cost-effective process, eco-friendly nature of PNG and its energy conversion will partially solve energy crisis and possible to implement for self-powered sensor applications.

Key Words: Piezoelectric nanogenerator, $Bi_4Ti_3O_{12}$ nanoparticles, PVDF, Breath sensor.

3. Results and discussion

Figure 1 shows the FY-PNG device fabrication. The flexible yarns were wedged on a rigid base to keep them straight. The inner Ag electrode was coated twice using the pre-mixed Ag paste with the brush-coating technique for achieving the homogeneous coating. Next, the BiTO slurry was prepared using pyrrolidine and as-synthesized BiTO NPs. The PVDF matrix layer (20 wt%) deposited onto the $Bi_4Ti_3O_{12}$ NPs coating to control the brittleness of the $Bi_4Ti_3O_{12}$ NPs during flexing, contributed to the generated electricity due to the piezoelectric nature of PVDF, and acted as an insulating layer to control short-circuiting between the inner and outer Ag electrodes. Finally, a PDMS layer was coated onto the device structure (Ag/PVDF $Bi_4Ti_3O_{12}$ NPs/Ag/yarn) to protect and isolate the device from physical damage and external influences such as temperature and humidity (3). The inset photographs of Fig.1 show an as-fabricated FY-PNG device whose flexible nature was demonstrated by bending using simple hand force.

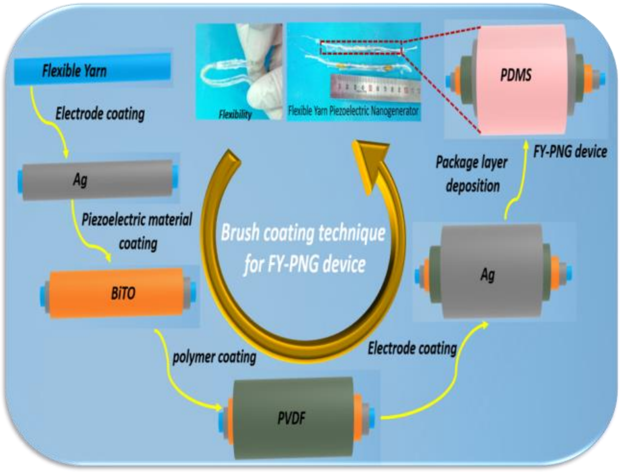

Figure 1. Schematic illustration of the FY-PNG device fabrication

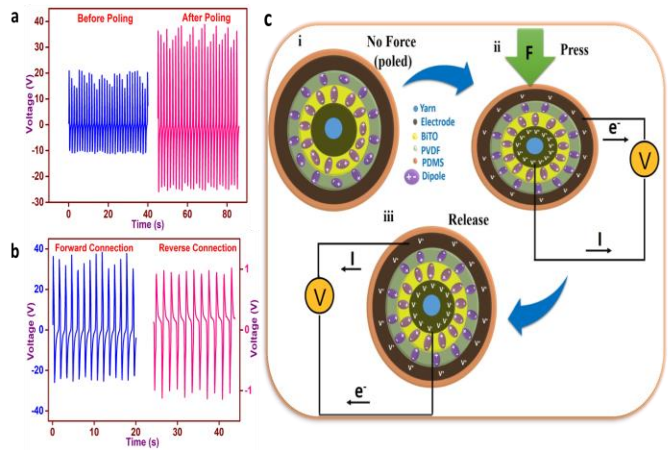

Figure 2. (a) Open circuit voltage of poled and un-poled FY-PNG upon 1 N force. (b) Switching polarity test of FY-PNG upon 1 N force. (c) Possible working mechanism of FY-PNG device.

The electrical measurements from the CPNG device were done with an electrometer. The electrical response of the FY-PNG device with and without electrical poling and under constant mechanical force was investigated; the comparative outputs are shown in Fig. 2a. Before electrical poling and with a 1 N applied force, the FY-PNG device generated a peak-to-peak open-circuit voltage of 28 V and after poling it raised to 60 V. The Fig.2b shows the performed switching polarity test to identify, if the generated electrical output of the device derived from the device or from an external source. The proposed working mechanism of the FY-PNG device consists of three basic steps; i.e., no force but poled, perpendicular force acting, and a releasing force acting (Fig. 2c).

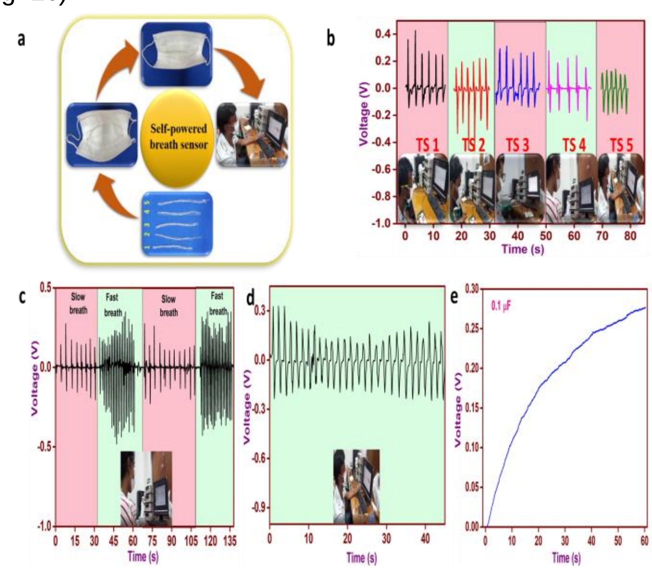

Figure 3 (a) Demonstration of self-powered breath sensor (SPBS) using FY-PNG device and its device location in the breathing mask. (b) SPBS sensing with different test subjects (TSs). (c) Cyclic stability of SPBS output responses over slow and fast inhale/exhale conditions. (d) High stability of SPBS output voltage response over a period of 45 s. (e) Charging commercial capacitor (0.1 μF) using the FY-PNG output upon the continuous inhale and exhale breath conditions.

The FY-PNG demonstrated as a real time self-powered breath sensor as shows in Fig.3.

4. Conclusion

In summary, high output performance flexible yarn-based piezoelectric nanogenerator (FY-PNG) device was fabricated using the cost-effective, layer-by-layer brush-coating technique. It successfully demonstrated that the FY-PNG can function as a self-powered breathing sensor (SPBS) to monitor slow and fast breathing of a human.

Acknowledgement

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