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Full paper

Transparent and flexible piezoelectric sensor for detecting human movement with a boron nitride nanosheet (BNNS)

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ABSTRACT

For the development and application of wearable electronics, a transparent and flexible piezoelectric sensor (TFPS) system is an important component considering the physical motion energy of the human body. This work newly proposes a transparent and biocompatible boron nitride nanosheet (BNNS) material with a TFPS device. The TFPS device is based on BNNS as a piezoelectric active component and PDMS as a flexible element. The device is able to generate electrical energy from mechanical push force and human movement; it has an output voltage of 22 V, output current of 75 nA, output power of 40 μW (power density: 106 μW/cm^3), and energy conversion efficiency of 12.6%. In addition, the TFPS device based on BNNS (1.0 wt%) is proposed as a significant step toward devices which are self-powered by the biomechanical movement of the human foot, neck, wrist, and knee, converted into electric energy in various signal forms. It will be deployed as a body-movement sensor.

1. Introduction

Piezoelectric energy-harvesting technologies based on human activities offer strong potential to realize sustainable operation without an external battery [1–3]. To power these devices, energy-harvesting applications from body movements may be sufficient to drive the operation of a NG (nanogenerator) owing to their extremely low power consumption requirements [4–9]. By converting mechanical energy from human activity, wearable, sustainable electrical power generators can be powered by different types of human movements, with the devices crafted from flexible, bio-capable and durable materials. Polyvinylidene fluoride (PVDF) has been widely used for NGs as a flexible piezoelectric material [10–12]. A single PVDF nanofiber-based NG generates 5–30 mV of voltage and 0.5–3 nA of current under stretching and releasing motions [13]. Many researchers have focused on biocompatible piezoelectric materials which use flexible energy harvesters [14–18]. The first reports were recently published on the use of lead-free biocompatible boron nitride nanotubes (BNNTs), which exhibit excellent electrical, mechanical, and thermal properties and are believed to have god high-temperature resistance (about 800 °C in air), a shading function, and piezoelectric capabilities [19–22]. In a recent report, theoretical BNNTs with flattening deformation were proposed as having electrical responses from insulating to semiconducting [23]. In addition, Jafari et al. suggested numerical and analytical examinations of the effective piezoelectric properties of BNNTs to fabricate, by means of the FEM, piezo-nanocomposite films made of unidirectionally aligned BNNTs in a non-piezoelectric polymer matrix [24]. However, there is little information pertaining to energy-harvesting characteristics using mechanical vibration with BNNS; therefore, it is necessary to confirm how much electric power is produced. Therefore, we believe that the study of BNNS to generate self-powered devices may lead to new materials for such devices. Flexible generators can easily harvest energy from the deformations of muscles and joint when a human moves because they move naturally along with the movement of the human. From human movement energy, self-powered sensors for real-time monitoring can be realized. Moreover, the piezoelectric generator can meet the necessary conditions of a wearable device, such as not disturbing human movements while retaining its characteristics. For wearable devices, biocompatibility is another important factor because these devices are in direct contact with the skin or body of a human.

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