Nano Energy 27 (2016) 306–312

Contents lists available at ScienceDirect

Nano Energy

journal homepage: www.elsevier.com/locate/nanoen

Performance-enhanced triboelectric nanogenerator using the glass transition of polystyrene

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ARTICLE INFO

Article history:
Received 11 May 2016
Received in revised form
30 June 2016
Accepted 2 July 2016
Available online 8 July 2016

Keywords:
Triboelectric nanogenerator
TENG
Glass transition
Polystyrene
Nano-to-micro structure
Contact-electrification

ABSTRACT

A triboelectric nanogenerator (TENG) offers improved output power for enhanced performance and throughput at a low cost as a type of practical energy harvester. In this work, a novel method which enhances the output power with the aid of a nano-to-micro morphology and which reduces the fabrication cost via the simple process of the glass transition of a polystyrene (PS) substrate is introduced. The glass transition of the PS quickly produces the nano-to-micro morphology within 1 min with only a heating process in an air environment. The pristine PS substrate was crumpled in a uniaxial or biaxial direction when heated to a temperature of 170 °C. Thus, the throughput is notably increased without the use of complicated fabrication processes or high-level equipment. The power enhancement effects of the proposed TENG were characterized. Under the optimized condition, the fabricated nanogenerator showed a fourfold increase in both the open-circuit voltage and short-circuit current due to the fourfold enhancement of the surface charge density arising from the crumpled structure compared to a control device without a nano-to-micro structure on the PS substrate. In this case, 160 serially connected light-emitting diodes (LEDs) were successfully illuminated with the optimized device, which was 2 cm by 2 cm in size.

1. Introduction

In recent years, energy harvesting technology has attracted a great deal of attention by virtue of the rapid growth of low-power electronics such as wearable devices and wireless sensor networks [1]. Thus far, most of these electronic devices rely on batteries for electric power. However, batteries require regular replacement, which is unlikely to be carried out owing to the explosive growth of the number of these devices and their application areas. Moreover, this task is complicated when these devices are used in remote areas which are difficult to access. An energy harvester can serve as a solution to the abovementioned problems by scavenging ambient otherwise wasted energy and then converting it to usable electrical energy. Among the various ambient energy sources, mechanical energy is the most ubiquitous and abundant. Many mechanical energy harvesters have been intensively developed based on electromagnetic [2–5], piezoelectric [6–9], and triboelectric [10,11] approaches. Among energy harvesters, the triboelectric nanogenerator (TENG) has demonstrated proven practicality due to the high power, low cost, a high degree of freedom when selecting appropriate materials (nearly all materials), as well as their simple structures and fabrication simplicity [12,13].

For practical use of the TENG, enhancement of the output power is an important issue to be resolved [14–18]. The most critical factor determining the output performance of the TENG is the surface charge density on the dielectric surface. As the surface charge density increases, a greater larger potential difference is induced by external mechanical excitation. Subsequently, the total amount of electrons passing through the electrode must increase to balance the potential difference, i.e., to create an equilibrium state. A morphology on the nano-to-micro scale at the surface can increase the surface charge density due to the enlarged effective contact area. In this sense, many previous works have introduced a range of solutions to increase the surface charge density. These include organic polymer etching [19–22], metal nano-morphologies [15,16] and other methods [23–25].

Herein, a polystyrene (PS) based triboelectric nanogenerator (PS-TENG) is proposed. An increasing the surface charge density is achieved without the utilization of complex fabrication processes, specified materials or high-level equipment. The PS creates the nano-to-micro morphology via uniaxial or biaxial shrinkage when the applied temperature exceeds 150 °C, which is the glass

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http://dx.doi.org/10.1016/j.nanoen.2016.07.001
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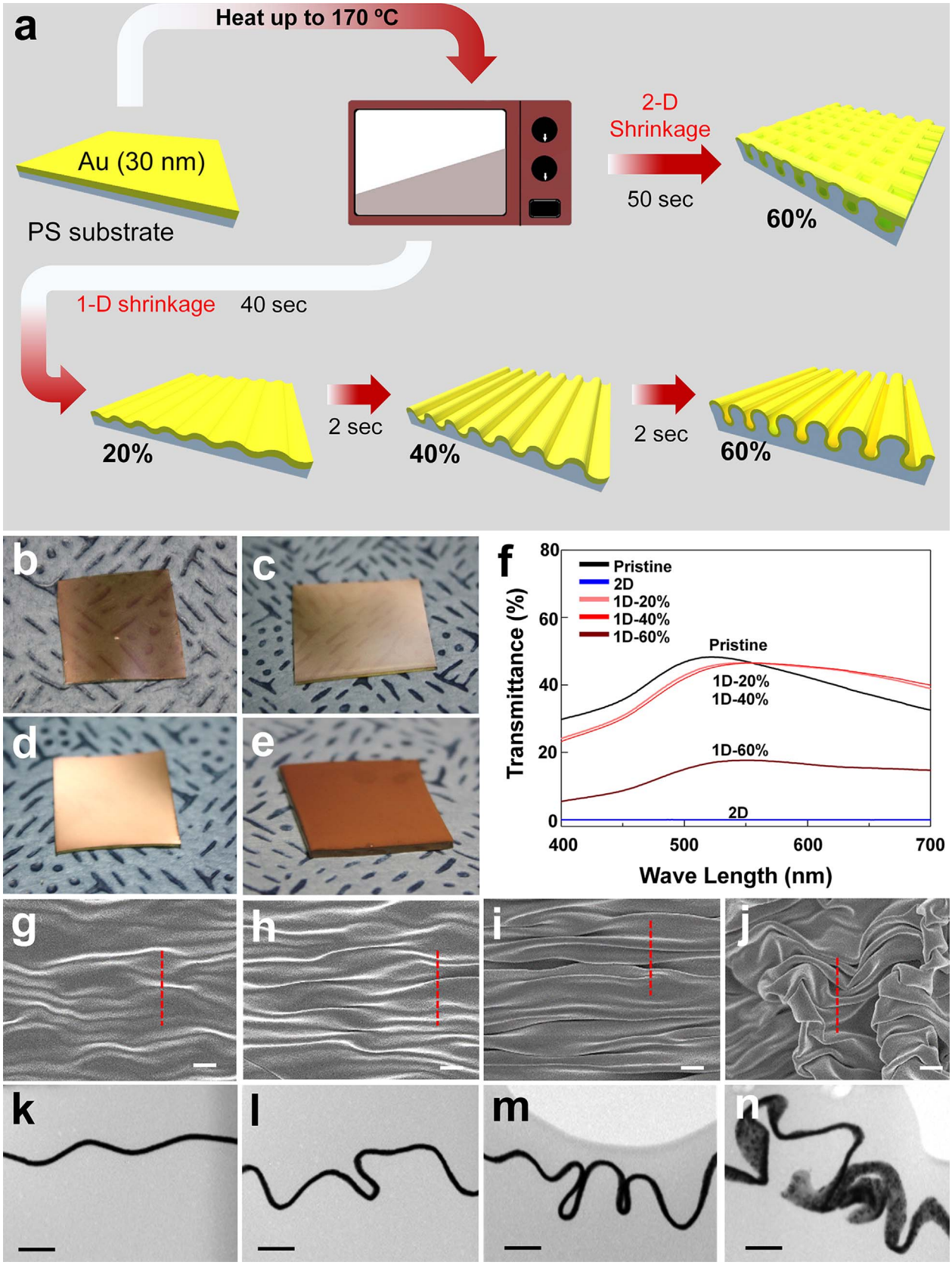

Fig. 1. (a) Schematic of the crumpled Au/PS contact electrode. Optical photographs of the (b) 2D, (c) 1D-20%, (d) 1D-40% and (e) 1D-60% Au/PS film samples. (f) The transmittance of each Au/PS film measured using ultraviolet visible spectroscopy. Top-view SEM photographs of the (g) 1D-20%, (h) 1D-40% and (i) 1D-60% and (j) 2D Au/PS film samples. Cross-sectional TEM photographs of (k) 1D-20%, (l) 1D-40%, (m) 1D-60% and 2D Au/PS films along the yellow dashed line. All scale bars are 500 nm. (Black and white bars represent 200 nm. Red dash lines represent the TEM cross-sections.).