Nano Energy 30 (2016) 180–186

Contents lists available at ScienceDirect

Nano Energy

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

A rationally designed output current measurement procedure and comprehensive understanding of the output characteristics for piezoelectric nanogenerators

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ARTICLE INFO

Keywords:
Piezoelectric nanogenerators
Measurement technique
Output characteristics
Working mechanism

ABSTRACT

Scavenging energy by piezoelectric nanogenerators (PENG) has been spotlighted as a promising approach to convert tiny mechanical energy into electricity. Many works have been done to improve the measurement techniques as well as reveal the output characteristics of PENGs. However, for the precise measurement of the output current, there still remains uncertainty stems from the effect of strain rate when applying mechanical impact onto PENGs. Herein, a theoretical derivation is performed to prove the existence of the maximum peak current (MPC) for PENGs, which is not influenced by strain rate but only determined by the magnitude of the applied force and inherent parameters of PENGs. A rationally designed procedure is proposed to measure the MPC with high accuracy and stability, from which an analytical model describing the MPC is established. The influence of device capacitance and the applied force on the output characteristics of PENGs are revealed, from which essential rules pertaining to the characterization and optimization for PENGs are proposed. Through this study, we can get comprehensive insight into the output characteristics of PENGs and acquire new guidelines for purpose design of PENGs and corresponding power management circuits.

1. Introduction

There has been an ever increasing demand to harvest energy from ubiquitous mechanical resources due to the urgency of developing sustainable renewable energy sources which are environmentally safe [1,2]. In particular, energy harvesting from piezoelectric nanogenerators (PENG) is a promising approach to convert tiny mechanical energy into electricity [3–5]. Various piezoelectric materials such as ZnO, $BaTiO_3$, polyvinylidene difluoride (PVDF) and $Pb(Zr,Ti)O_3$ have been utilized to fabricate PENGs with different structures and improved performance [6–15].

PENGs is very different from other energy harvesting devices such as electromagnetic generators and solar cells, which can produce continuous and regular electricity. The output electric signal of PENG is AC rather than DC, as pulsed-like signal is the result of the deformation of the piezoelectric component caused by the external mechanical movements [4]. In general, when PENGs are subjected to cyclic mechanical deformations, the generated current or voltage are recorded and the peak values of the output current or voltage are commonly employed to evaluate performance of PENGs [2], which are termed as the output current or voltage of PENGs [16]. Many works have been done to advance the measurement techniques as well as reveal the output characteristics of PENGs [17–19]. Specifically, Briscoe et al. [20] pointed out that the output power estimated merely from open-circuit voltage and/or short-circuit current of PENG is quite misleading and cannot provide a complete picture of the output of these devices. Su et al. [21] developed an analytical model to describe output voltage of PENGs, and suggested that the resistance of the voltmeter should be reported for voltage measurement of the piezoelectric devices. In spite of these improvements, there still remain problems in measuring the output current or voltage of PENG. In previous reports, the output current is dependent on the strain rate of

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http://dx.doi.org/10.1016/j.nanoen.2016.10.004
Received 4 August 2016; Received in revised form 18 September 2016; Accepted 4 October 2016
Available online 05 October 2016
2211-2855/

the piezoelectric component [4,18,22,23]. Fast strain rate produces larger current while slow strain rate results in reduced ones. This uncertainty definitely brings in considerable deviation to precise measurement of the output current. It is difficult to compare the performance of PENGs with alternative materials and structures under different strain conditions. To this end, more stable evaluation metrics and valid measurement techniques is necessary to be developed.

In present work, a theoretical derivation is performed to prove the existence of the maximum peak current (MPC) for PENGs, which is not influenced by strain rate but only determined by the magnitude of the applied force and inherent parameters of PENGs. We further demonstrate that the MPC can be measured by a rational designed measurement procedure. Upon the measurement of the output current with much improved accuracy via the designed procedure, an analytical model describing the MPC is derived and verified, from which the determinative factors for the MPC can be defined. The influence of device capacitance and the applied force on the output characteristics of PENGs are revealed, from which essential rules pertaining to the characterization and optimization of PENGs are proposed. This work demonstrates new understanding for the output characteristics of PENGs in several aspects, providing innovative guidance for performance evaluation and purposely design of PENGs.

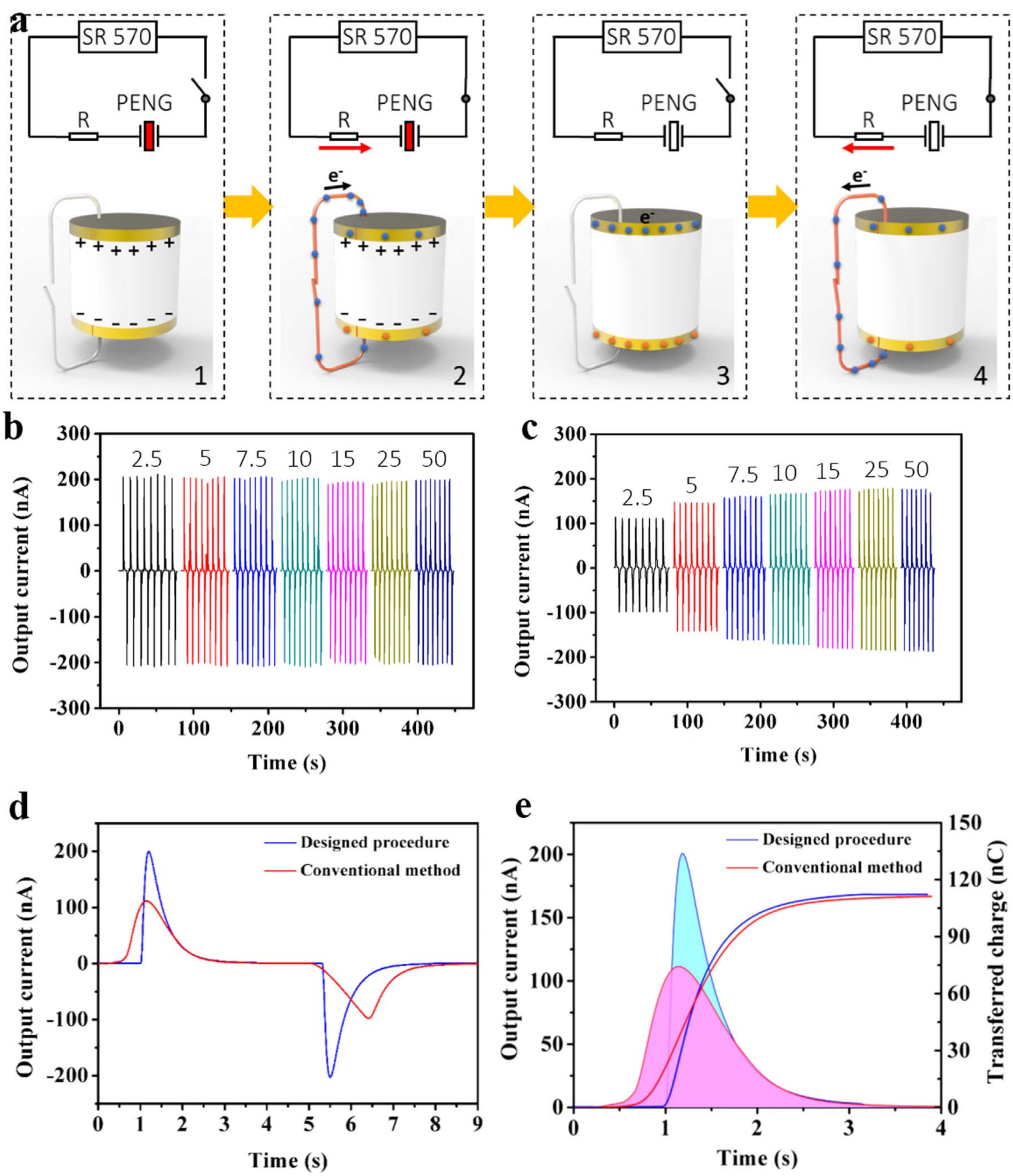

Fig. 1. Comparison of the rationally designed and conventional procedure. (a) Schematic illustration of the rationally designed measurement procedure. (b) Output current-time curves recorded by the designed procedure as varying the velocity of impacting weight from 2.5 mm s^{-1} to 50 mm s^{-1}. (c) Output current-time curves recorded by conventional procedure under the same conditions as (b). (d) The enlarged current-time curves of a single cycle measured with the impact velocity of 2.5 mm s^{-1}. (e) Corresponding transferred charge during half cycle by the rationally designed and conventional procedure, respectively.