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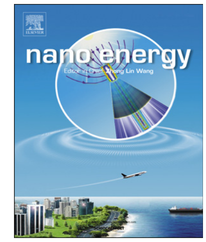

REVIEW

Triboelectric nanogenerators as self-powered active sensors

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Abstract
The development of internet of things and the related sensor technology have been a key driving force for the rapid development of industry and information technology. The requirement of wireless, sustainable and independent operation is becoming increasingly important for sensor networks that currently could include thousands even to millions of sensor nodes with different functionalities. For these purposes, developing technologies of self-powered sensors that can utilize the ambient environmental energy to drive the operation themselves is highly desirable and mandatory. The realization of self-powered sensors generally has two approaches: the first approach is to develop environmental energy harvesting devices for driving the traditional sensors; the other is to develop a new category of sensors – self-powered active sensors – that can actively generate electrical signal itself as a response to a stimulation/triggering from the ambient environment. The recent invention and intensive development of triboelectric nanogenerators (TENGs) as a new technology for mechanical energy harvesting can be utilized as self-powered active mechanical sensors, because the parameters (magnitude, frequency, number of periods, etc.) of the generated electrical signal are directly determined by input mechanical behaviors. In this review paper, we first briefly introduce the fundamentals of TENGs, including the four basic working modes. Then, the most updated progress of developing TENGs as self-powered active sensors is reviewed. TENGs with different working modes and rationally designed structures have been developed as self-powered active sensors for a variety of mechanical motions, including pressure change, physical touching, vibrations, acoustic waves, linear displacement, rotation, tracking of moving objects, and acceleration detection. Through combining the open-circuit voltage and the short-circuit current, the detection of both static and dynamic processes has been enabled. The integration of individual sensor elements into arrays or matrixes helps to realize the mapping or parallel detection for

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multiple points. On the other hand, the relationship between the amplitude of TENG-generated electrical signal and the chemical state of its triboelectric surface enables TENGs to function as self-powered active chemical sensors. Through continuous research on the TENG-based self-powered active sensors in the coming years to further improve the sensitivity and realize the self-powered operation for the entire sensor node systems, they will soon have broad applications in touch screens, electronic skins, healthcare, environmental/infrastructure monitoring, national security, and more.

Contents

Introduction

Self-powered sensing

Information technology is a major driving force for the modern world's development in the past decades. The collection and exchange of information rely on various types of sensors with different functionalities. The construction of large-scale sensor networks and systems can help to realize "internet of things", which correlate objects and devices to large databases and networks (the internet). By replacing the traditional finite number of discrete sensors with a large number of independent and mobile sensors distributed in the field, a statistical analysis of the signals collected through the internet can provide precise and reliable information, so that effective strategies can be taken in responding to the change in the environment. In a lot of cases, the sensor nodes are distributed across a wide range of area or embedded/implanted in closed locations, so that they need to operate wirelessly for important applications in implantable biosensors, patient monitoring, environmental and structure monitoring, and national security [1]. For these systems, it is very important for the sensor nodes to have the capability of operating independently, sustainably and maintenance-free. However, under the context of the current technology, most of sensors need power sources for driving their operations, which is a major limitation for realizing the aforementioned features for the wireless sensor networks. These power sources cannot be simply provided by batteries for two reasons: (i) the number of sensors to be involved in the sensor network will be huge and their locations could be difficult to track, so replacing individual batteries would represent a tremendous, even impossible task; and, (ii) the periodic replacement of batteries will create a huge amount of materials that are environmentally unfriendly and potentially hazardous to human health.

Therefore, realizing self-powered operation for the sensor nodes in the wireless sensor networks is critically