Nano Energy (2015) **14**, 102–110

Available online at www.sciencedirect.com

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

High sensitivity wrist-worn pulse active sensor made from tellurium dioxide microwires

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Received 15 October 2014; received in revised form 27 January 2015; accepted 5 February 2015
Available online 14 February 2015

KEYWORDS
TeO_2;
Microwires;
Pulse active sensor;
Nanogenerator;
Wrist-worn

Abstract
We have demonstrated the practicality of an ultrasensitive wrist-wear pulse active sensor that was first made using tellurium dioxide triangular microwires. The unusual growth direction of the α-TeO_2 triangular microwires was governed by a [110] axis. The α-TeO_2 microwires belong to the tetragonal structure with a space group of $P4_12_12$. Due to the gravitational force effect, the triangular microwires were encapsulated by polydimethylsiloxane (PDMS) and underwent a natural gravity-driven settling process during the PDMS solidification process, leading to the triangular microwires being placed on the substrate with a randomly horizontal orientation. When a compressive stress was applied to the α-TeO_2-PDMS composite film, the shear forces were formed on the microwires' surface along with the [110] and/or $[\overline{1}\overline{1}0]$ poling axis. As a result of the antisymmetric element of e_{14} and $-e_{25}$ in the α-TeO_2 structure, the triangular microwires have created an obviously piezoelectric potential (piezopotential) $\sim$3.2 V that was perpendicularly established along with the poling axis. On the basis of the unique triangular morphology and its physical properties, the piezopotential of the α-TeO_2 will not be canceled out even if the microwires' tips are pointed towards each other. Thus, the piezopotential can be accumulated across the top and bottom electrodes of the nanogenerator (active sensor). The α-TeO_2 triangular microwires can be acted upon as a useful active sensor for detecting the tiny physical motions, for instance, a pulse driven sensor, air pressure, and touchless control of smart devices.

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http://dx.doi.org/10.1016/j.nanoen.2015.02.009
2211-2855/

Introduction

The wrist-worn device, along with health-care management, is rapidly growing in importance today. The nanogenerator [1], and active sensors [2,3], are offering a new and promising way in the application for detecting any environmental change and personal health-care management. Currently, energy harvesting through piezoelectric and triboelectric methods have been explored as a prospective solution to gather the irregular mechanical energy and turn it into electricity which is used in our daily life. These techniques were able to power the LEDs [4,5], nanosensors [6,7], and other low-powered consumption devices [8,9]. Among them, the active sensors have successfully analyzed the physical motions, for instance, muscle-driven sensor [10], wind-velocity detector [11], and human-machine interfacing devices [12]. Over the past decade, one-dimensional (1D) microwires have been extensively demonstrated in piezotronics [13,14] and energy harvesting devices [15] using non-centrosymmetric wurtzite structures, such as ZnO [4], GaN [16], InN [17], and ZnS [18]. These materials possess a common spontaneous polarization along with the [0001] direction. When an external force was applied in the [0001] direction, the crystal domains created a significant piezopotential along with the [0001]. In addition to the wurtzite structure, the highly powered-output nanogenerators made from ferroelectric materials, such as $ZnSnO_3$ [19-21], $BaTiO_3$ [22], $NaNbO_3$ [23], and $Pb(Zr,Ti)O_3$ [24], becomes more noticeable for the application in energy harvesting devices. However, there is no net piezopotential output unless the random ferroelectric crystal domains are poled by applying a direct current voltage across the ferroelectric material. The alignment of the poling crystal domains are dependent upon the poling parameters, such as poling voltage, temperature, and time, is held on the ferroelectric material. Moreover, how the electric field poling parameters affect the piezoelectric property still remains a critical issue and is essential for piezotronics devices usage [25,26]. Thus, it takes a great deal of consistent effort to develop the high performance of the piezotronic devices and energy harvesting nanogenerators.

In this work, the α-TeO_2 triangular microwires were synthesized on a silicon substrate by a vapor transfer process at 500 °C. Unlike wurtize structures, which exhibited a commonly spontaneous polarization along with the [0001] axis, the non-centrosymmetric α-TeO_2 has a unique growth direction along with the [110] axis. The PDMS-triangular microwires composite underwent a natural gravity-driven settling process during the solidification process [21], leading to the triangular microwires being randomly distributed on the substrate's surface with a horizontal orientation. When the α-TeO_2-PDMS composite film was sustained by a compressive stress, the induced shear-force was then exerted in the $\langle 110 \rangle$ directions. Subsequently, the α-TeO_2 triangular microwires established their piezopotential perpendicularly along with the [110] direction. On the basis of our theoretical calculations, the corresponding polar quantities of the α-TeO_2 along with the poling axis did not cancel each other out. Thus, the piezopotential of the triangular microwires can be accumulated across the top and bottom electrodes of the nanogenerator. The triangular microwires were then capsulated by the polydimethylsiloxane (PDMS) to fabricate the wearable and skin-attachable devices, which successfully analyzed the tiny physical motions, for instance, a pulse driven sensor [27] and a touchless control of smart devices.

Experimental section

The source material of the tellurium powder (Te, purity: 99.9%) with the Au-coated silicon substrate was placed in an

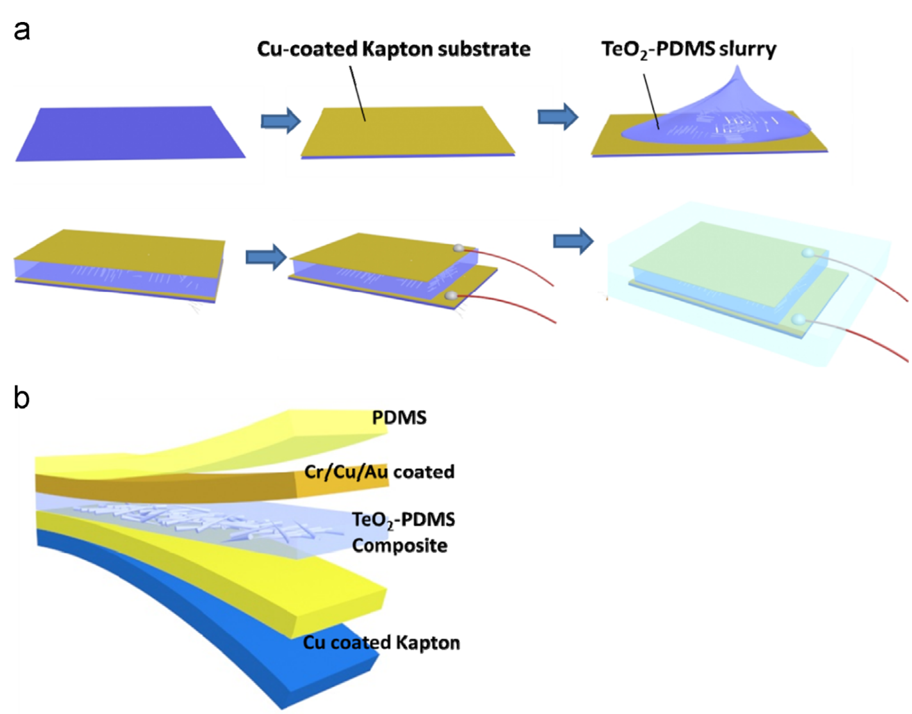

Figure 1 (a) The α-TeO_2 triangular microwires mixed with PDMS for preparing the microwires-PDMS composite active sensor. (b) The schematic diagram of cross-sectional active sensor of the α-TeO_2 triangular microwires-PDMS composite film.