Microelectronic Engineering 110 (2013) 282–287

Contents lists available at SciVerse ScienceDirect

Microelectronic Engineering

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

Enhanced charge generation of the ZnO nanowires/PZT hetero-junction based nanogenerator

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ARTICLE INFO

Article history:
Available online 26 February 2013

Keywords:
ZnO
PZT
Piezoelectricity
Hetero-junction
Nanogenerator

ABSTRACT

We fabricated an alternative nanogenerator device with distinguished structure. Representative piezoelectric materials of ZnO nanowires and PZT thin films were tried to be combined to form a hetero-junction structure for fabrication of an alternative nanogenerator device to possibly obtain a synergy effect and then improved performance. The ZnO nanowires were grown by a hydrothermal synthesis technique and then PZT thin films were deposited on the surface of the ZnO nanowires by rf magnetron sputtering process. The PZT thin films were annealed to be crystallized with different conditions for post-deposition thermal treatment process. The hetero-junction structure was polarized by a *Corona* poling process to obtain a unidirectional orientation of dipole moments to enhance their piezoelectric property. Structure and morphology of the grown ZnO nanowires were investigated to achieve appropriate characteristics to achieve performance improvement for the resulting nanogenerator device. To confirm effect of the hetero-junction structure on improvement of power generation performance of the resulting nanogenerator device, current generating properties were comparatively investigated with those of nanogenerator device with only ZnO nanowires or PZT thin films as active piezoelectric component, respectively. The nanogenerator device with a hetero-junction structure of ZnO nanowires/PZT revealed distinctively improved average currents of 270 nm, which is quite higher than those of the nanogenerator devices with pristine ZnO nanowires, or with pristine PZT thin films, respectively. Possible factors contributed to improvement of the current generation properties were discussed for the presented nanogenerator device.

1. Introduction

Recent advances of technologies have been accompanied by drastic increase of energy consumption and various kinds of reports have been devoted for introduction of alternative energy generation technologies. Technologies of green energy harvesting and self-powered energy sources would be one of those promising methodologies for the alternative energy sources. Among them, piezoelectric materials have been studied to be prepared by nanotechnologies for possibly enhancing their piezoelectric effect in various energy-harvesting devices. A new power-generator device applying enhanced charge carrier generation of one dimensional piezoelectric nanomaterials has been reported as so-called nanopiezoelectronics by numerous research groups including the Wang group at the Georgia Institute of Technology [1–4]. The nanopiezoelectronics are based on an energy conversion mechanism of nanogenerator device, by which mechanical energies are converted to an electrical energy. To date, ZnO, PZT, and $BaTiO_3$ are representative materials for preparation of one-dimensional structure to combine piezoelectricity and semiconducting property for obtaining a synergy effect to enhance power generation performance [4–6]. Up to now, the Prof. Wang and his group have reported several research reports for nanopiezoelectronics using combination of ZnO and PZT nanowires [7–10]. Nanogenerators based on ZnO nanowires can be prepared relatively easily by hydrothermal synthesis process at low temperature, and their power generation performance could be improved by controlling material properties of grown crystalline nanowires as well as by alteration of those device structure designs. However, the base material of ZnO has relatively low piezoelectric coefficient of ~12pC/N, and hence, realization of a high performance nanogenerator using ZnO nanowire might be quite limited. To overcome such shortage of material property of ZnO, material property alteration via appropriate impurity doping and/or multi-layer stacking using different material with higher piezoelectric coefficient could be tried to obtain higher power generation performance. On the other hand, nanowires of crystalline PZT could be prepared by hydrothermal

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http://dx.doi.org/10.1016/j.mee.2013.01.058

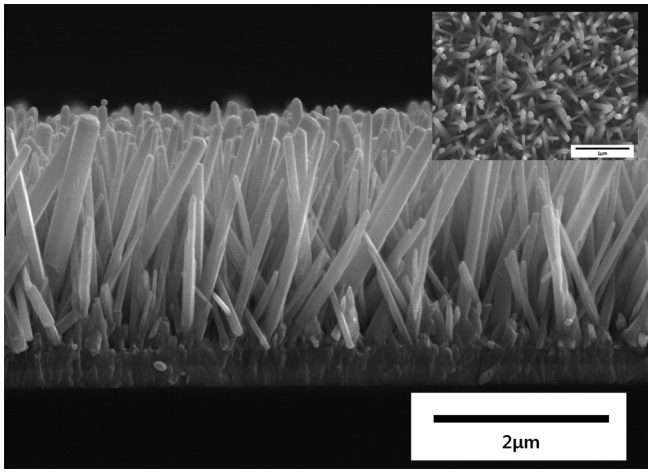

Fig. 1. FE-SEM image of the ZnO nanowires grown by hydrothermal synthesis.

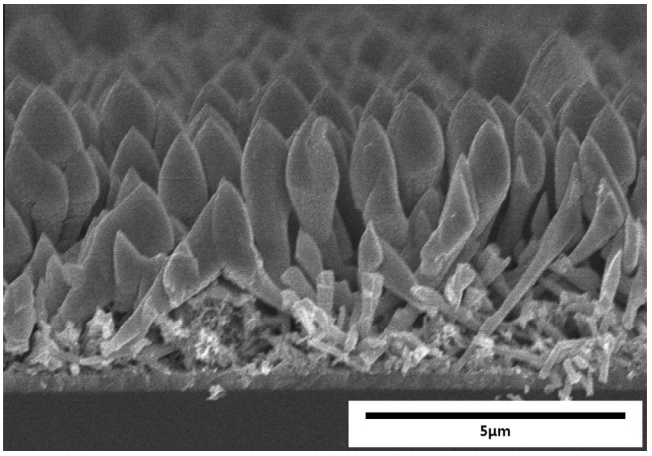

Fig. 3. SEM image of the hetero-junction structure of ZnO nanowires/PZT.

synthesis technique to achieve high power generation performance utilizing higher piezoelectric coefficient of PZT. However, hydrothermal synthesis of PZT might be quite difficult due to several limitation factors: choice of appropriate substrate; deteriorated reproducibility; complicated synthesis process. Therefore, several approaches have been tried for realization of ZnO/PZT hetero-junction structure [11–13]. Those hetero-junctions have been mainly either a composite of power-to-powder, or a stacking of layer-to-layer [14–16]. Distinct enhancement of polarization characteristic and capacitance value have been reported up to now [17,18]. Nevertheless, practical application for realization of those electrical characteristic has not yet been reported for nanogenerator devices based on those studies [17]. This study aims for realization of a new hetero-junction structure of ZnO nanowires and PZT thin films to fabricate a nanogenerator device to achieve a synergy effect, by which disadvantages of each material could be minimized and improved power generation performance could be achieved. Electrical characteristics of the resulting nanogenerator devices were studied and improved power generation performance was discussed to be confirmed.

2. Experimental

Commercially available ITO coated glass (Corning; 200 nm thick ITO) substrates were used. The substrates were cleansed by using conventional semiconductor cleansing process and then seed layers were coated on the ITO coated glass substrates by rf magnetron sputtering process using an Al-doped ZnO target (AZO; 2 wt.% Al + 98 wt.% ZnO). Material characteristic of the seed layer is critical for density and diameter of synthesized nanowires [19,20]. Seed layer of a 40-nm-thick AZO thin film was prepared in this report to minimize density of the grown nanowires and to obtain diameter of those as smaller than 50 nm. The thickness was decided after experimental results.

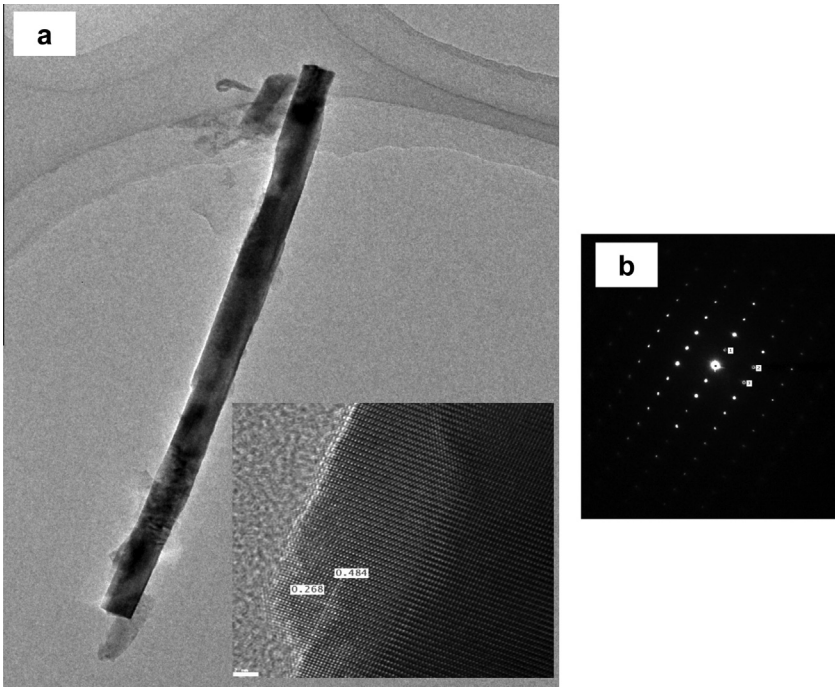

Fig. 2. TEM image (a) and SAED pattern (b) of the ZnO nanowires grown by hydrothermal synthesis.