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Piezoelectric ZnO Thin Films & Their Application for Micro Energy Harvesting Devices

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Abstract

Recently, much attention has been paid to mechanical energy as a feasible and sustainable power source for independently self-powered wireless flexible/wearable devices or systems. At the same time, many investigations on the energy harvesting devices have been made due to their strong potential for flexible/wearable electronics applications. It is expected that a variety of smart electronic devices will come closer to us and play an important role in enhancing people's life styles and making their social activities more convenient. [1] Most of smart electronic devices will be ubiquitous and available, whenever and wherever, to the users. From this perspective, more innovative and energy efficient flexible/wearable devices using ambient renewable energy need to be developed that are more self-powered, environmentally friendly, biocompatible and sustainable.

On the other hand, the physical and electrical properties of zinc oxide (ZnO)-based materials and related devices have been intensively investigated along with their synthesis and fabrication. [2] In particular, the preferential adoption of ZnO for nanogenerators (NGs) fabrication seems to be attributed to its good properties in biocompatibility, voltage-current nonlinearity, catalytic activity, chemical stability, resistance to high temperature electronic degradation. More recently, many researches have been made in an effort to develop even more innovative micro-energy harvesting devices such as ZnO-based nanogenerators incorporating piezoelectric ZnO nanomaterials and nanostructures. Flexible piezoelectric ZnO-based nanogenerators appear to be very attractive energy-harvesting devices, exploiting mechanical energy that is generated randomly over a wide frequency range in the environment surrounding us. Especially, the vertically-integrated flexible nanogenerators (VINGs) based on ZnO materials have been studied due mainly to their high compatibility in process technology with conventional complementary metal oxide semiconductor (CMOS) technology and structural simplicity and robustness, etc. Two key issues for the VINGs design are both forming more reliable potential barriers and increasing conversion efficiency for the inherently n-type ZnO semiconductor. [3]

In this work, we present our research results obtained in the process of developing more energy-efficient devices, including the fabrication of ZnO-based VING devices which are implemented on flexible substrates. [4, 5] First, we investigated an in-situ N-doping approach to modulate the free-carrier density in inherently n-type-grown ZnO films, as shown in figure 1. Then, we fabricated free carrier-modulated thin film-based flexible nanogenerators (NZTF-FNGs), showing a significantly larger performance improvement, as compared to the conventional ZnO thin film-based flexible nanogenerators (CZTF-FNGs). [4] This is believed to be due to the substantial suppression of the screening effect in the bulk of the ZTFs and the formation of more reliable Schottky barriers at the interfaces caused by an N-doping process. Moreover, the NZTF-FNGs were verified to be well-qualified for micro-energy harvesting applications. Thus, this N-compensatory doping approach seems to be very useful for developing high-quality micro energy harvesting devices.

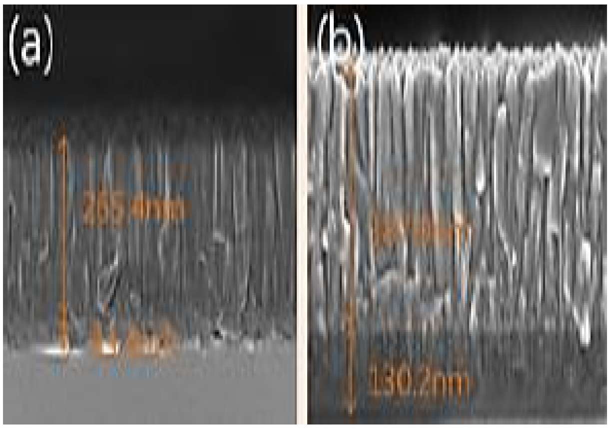

Fig 1. ZnO films with thicknesses of (a) 265nm & (b) 387nm, respectively (for example).

Furthermore, we studied the performance improvement of ZnO thin film-based FNGs through the design and selection of insulating interlayer materials. Here, an aluminum nitride (AlN) insulating layer was newly adopted as an electron blocking layer in the device design. The use of AlN thin interlayer at the interface between the ZnO nanorods (NRs) and the contact electrode resulted in higher output voltages. [5] In addition, the effects of the AlN thickness on the electric potentials and the output voltages of FNGs were studied. Particularly for the ZnO thin film-based FNGs with the bottom AlN interlayer of 30nm thickness, the average of the best peak-to-peak output voltages was ~1.4V under the periodic bending/release motions of a strain condition. This approach will contribute to the further improvement in the performance of ZnO-based flexible nanogenerators suitable for the future flexible/wearable electronics applications.

In summary, we fabricated a new ZnO/AlN-stacked piezoelectric nanogenerator, based on the formation of ZnO nanostructures using nitrous oxide (N2O) gas and the adoption of an AlN film layer. The fabricated nanogenerators showed a significant improvement in their output voltages. This approach could help pave the way for more efficient micro-energy harvesting devices with many applications in portable communications, healthcare & environmental monitoring and self-powered wearable electronics, etc.

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