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Highly-Sensitive BiFeO-Coated ZnO Nanowire Arrays for Flexible Piezoelectric Sensing Applications

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Abstract

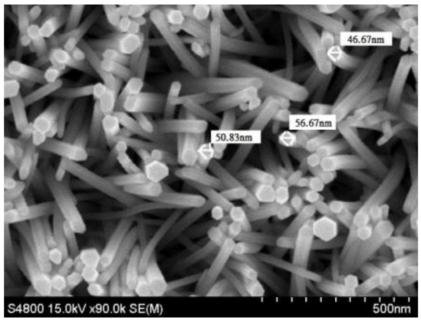
A low-temperature flexible piezoelectric nanowire sensor has been demonstrated in this work. Compared to ZnO nanowire array, the BFO-coated ZnO one exhibits much better piezoelectric characteristics at low temperature process of below 100°C. The novel flexible piezoelectric array features a large piezoelectric output of 322 mV, high sensitivity of 430 mV/ε (%) and low working energy of sub-100 pJ at Mega Hz frequency range.

1. Introduction

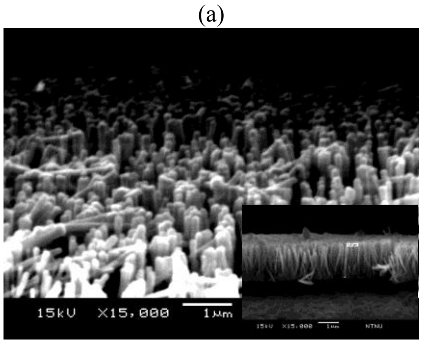
Recently, there is an urgent requirement on the respect of high-resolution imaging systems for dermatologic applications [1], [2]. However, the high frequency operation in medical ultrasonic transducer is a big challenge to reach a high-resolution three-dimensional imaging function [1]. On the other hand, the flexible self-powered tactile sensor has been proposed to detect mechanical energy from human-driven vibration or robot hand, which is important to the development of wearable electronics. In this work, we report a novel highly-sensitive flexible piezoelectric array using ZnO nanwores (NWs) covered with a lead-free $BiFeO_3$ (BFO) to harvest small piezoelectric signal. In addition to environment eco-friendly, the lead-free BFO also has a favorable piezoelectric property at room temperature [3], which is superior to PbZrTiO (PZT) with a stringent requirement of high process temperature. From our results, the BFO-coated ZnO NW array showed strong piezoelectric properties including larger output voltage amplitude and higher strain sensitivity than those of weak piezoelectric ZnO NW one.

2. Experiment

In this work, the ZnO NWs with different length scales were growth by low-temperature hydrothermal process on ITO/polyethylene naphthalate (PEN) substrate. The vertical ZnO NWs were prepared by a mixed solution of zinc acetate (0.05 M) and hexamethylenetetramine (0.025 M) heated at 90℃ for 4 hr. After that, he BFO films were deposited and covered on ZnO NWs by a sputter system using a 40W RF power to form a BFO-coated ZnO NW array. To measure the piezoelectric property, the BFO-coated ZnO piezoelectric array on PEN flexible substrate was bent with different bending radii of curvature. The outputs of the flexible piezoelectric sensor were connected to a broadband sampling oscilloscope to determine the amplitude frequency response. The control ZnO NW piezoelectric sensor was also fabricated for performance comparison. The dimension of ZnO nanowires were characterized by scanning electron microscopy (SEM). Fig. 1(a) showed the SEM images of ZnO NWs grown on silicon substrate. The mean diameters of ZnO NWs varied from 30 to 150 nm were observed. The BFO-coated ZnO NW array with the same hydrothermal process was also performed on flexible ITO/PEN substrate. The corresponding SEM image in Fig. Fig. 1(b) shows that the nanowire length is around 2μm (inset image).



(a)



(b)

Fig. 1. SEM images of (a) ZnO NW on Si substrate and (b) BFO-coated ZnO NW on ITO/PEN flexible substrate.

3. Result and Discussion

Fig. 2(a) shows the schematic plot of NW array with a bending radius. Here, different bending radii were tested on flexible ZnO and BFO-coated ZnO NW arrays to investigate the relationship between output piezoelectric output and bending strain. The piezoelectric signal can be examined at a fixed bias of 1V applied by a source meter. From output results, the variations of voltage amplitudes depending on the strain at bending state are measured by high-speed oscilloscope. The amplitude returns to minimum value when the NW array is under strain-relaxation condition (flat). The measured piezoelectric amplitude can be observed in Fig. 2(b). When applying a bending strain (ε) of 0.75%, the large voltage variation (ΔV) of 322 mV is extracted from BFO-coated ZnO array at a measured frequency of 50 kHz. In contrast, only a small ΔV of 241 mV can be obtained in control ZnO NW array. The ΔV-ε relationship is summarized in Fig. 2(c). The operation mechanism relies on the enhancement of local piezoelectric potential proportionally correlated to bending stress. The piezoelectric behavior of ZnO nanowire based on free charge carrier model has been proposed [4]. The accumulation and screen of charge carriers under bending stress determine the polarization effect since the charges cannot freely move as long as the bending strain is preserved [4]. Such improvement on piezoelectric output of BFO-coated ZnO NW is mainly ascribed to the large piezoelectric effect originated from piezoelectric dipole across strained BFO film. Furthermore, BFO dielectric has stable ferroelectricity and large piezoelectric coefficient even at room temperature, which has been reported before [3].

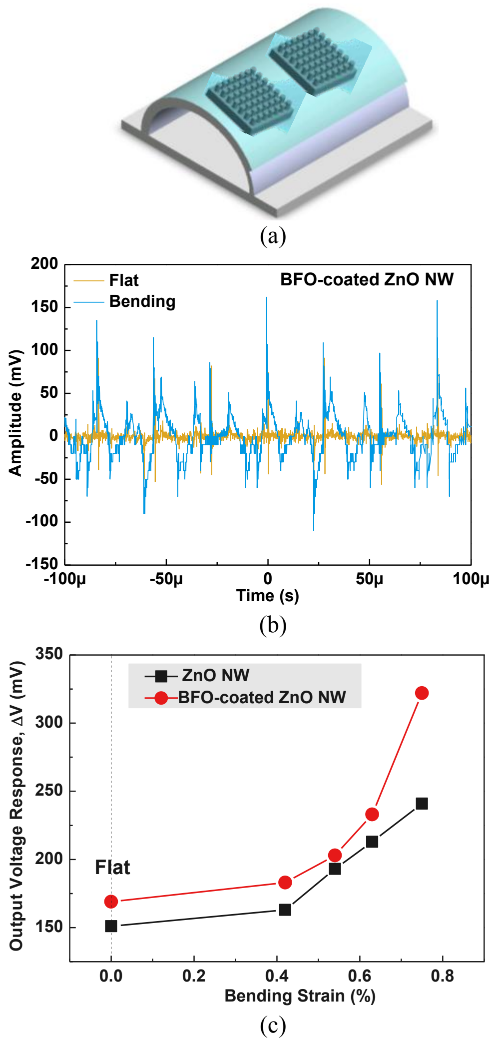


Fig. 2 (a) Schematic plot of sample bending, (b) output amplitude of BFO-coated ZnO NW array, and (c) output voltage responses of ZnO and BFO-coated ZnO NW arrays with varied bending strains, respectively.

In Fig. 3(a), the frequency dependence of piezoelectric property exhibits a large output ΔV at a low frequency of 50 kHz, but largely decreases with increasing frequency. The stronger frequency dispersion observed in BFO-coated ZnO array may be due to the surface charge trapping effect at the BFO/ZnO interface. This is because the sputtering process may result in plasma damage on ZnO NW, which cannot be avoidable. However, the fast piezoelectric response still can be measured at a very high frequency of 10 MHz. From the calculated result, the BFO-coated ZnO NW array achieves relatively high sensitivity of 430 mV/ε (%). Additionally, the energy of piezoelectric energy can be maintained below sub-100 pJ at a frequency range of Mega Hz, as shown in Fig. 3(b), which has the potential to integrate with low-power flexible wearable electronics.

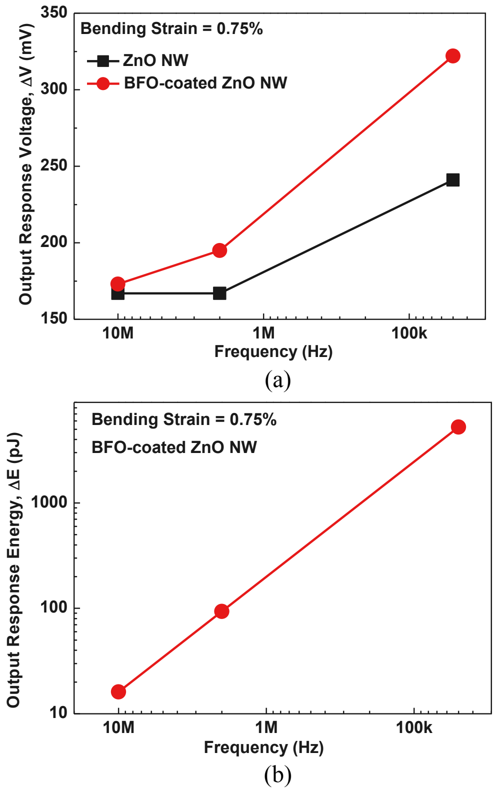


Fig. 3 (a) Output response voltages of ZnO and BFO-coated ZnO NW arrays, respectively, and (b) response energy of BFO-coated ZnO NW array under a bending strain of 0.75%.

4. Conclusion

We reported a highly-sensitive piezoelectric sensor using BFO-coated ZnO NW array. By applying the largest bending strain of 0.75%, the high piezoelectric sensitivity of 430 mV/ε (%) can be achieved, which is larger than 321 mV/ε (%) of control ZnO NW array. Such performance improvement is mainly attributed to the additional polarization charge contributed by BFO to enhance the piezoelectric output of ZnO NW.

References

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