Research on the stability of flexible devices

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Abstract. Since the flexible substrates are all organic plastics, the main problem in the manufacture of flexible devices is the mismatch and low adhesion between inorganic semiconductor crystals and organic plastics, so the detection stability under mechanical stress is an important factor affecting the performance of flexible ultraviolet (UV) photodetectors (PDs). In order to improve the detection stability of flexible UV PD, the substrates of polyethylene terephthalate (PET) and polyimide (PI) are used as flexible devices respectively for comparative study, and the growth material is selected with the piezoelectric effect ZnO-based material as the main research object. It is found that the ZnO film with AlZnO (AZO) buffer layer on the PI substrate has almost no cracks or peeling off. In addition, after 100 times of bending tests on PI substrate devices, although the detection performance is reduced compared with the detection performance before bending, it still maintains relatively high detection stability.

1. Introduction
Flexible electronic devices have attracted a lot of attention with lower manufacturing costs, light weight, and better mechanical properties, and have been used in environmental monitoring, thin-film solar cells, etc [1, 2]. With the emergence of human wearable and implantable electronic devices, flexible devices are flourishing. Although flexible electronics have made great progress in the past few years, their stable performance is still far from satisfactory.

To date, most researches have focused on the structural design of flexible devices [3-5]. In order to enhance the stability of flexible devices, few people pay attention to the choice of flexible device substrates, which is actually a key factor affecting flexible electronic devices. Once the working environment of the flexible device changes, such as the presence of external forces, or changes in physical conditions, the deformation of the substrate of the flexible device or the film rupture and shedding phenomenon is inevitable. Therefore, the stability of the flexible device largely depends on the structural characteristics of the organic substrate itself, such as the elastic modulus, residual stress, and the bonding strength of the film substrate [6-9]. Because most of the failures of flexible devices can be attributed to the weak bond strength between the flexible substrate and the film, enhancing the bond strength of the film substrate is the focus of our research.

In this work, we studied PET and PI as substrate ZnO-based film UV PDs and conducted four sets of experiments. Both sets of experimental XRD based on PET grown ZnO showed a strong (002) diffraction peak, but the cracks in the film were already covered with the entire device after bending test.
The same test was carried out on PI, and the ZnO film growing directly on PI had the lowest adhesion rate, fell off during the growth process, and fell off more seriously after bending test. Although the overall crystallization of ZnO film with buffer layer AZO on PI is not high, the film performs best after bending test, and its UV PD also shows good stability.

2. Experimental Section

2.1. Preparation of thin film devices
First, the PET and PI substrates were washed with acetone, ethanol and deionized water for 10 minutes. Secondly, AZO (ZnO doped with 3 wt % Al₂O₃) and ZnO thin films were prepared from AZO targets and ZnO targets by radio frequency (RF) magnetron sputtering. The AZO deposition chamber was pumped to a vacuum of 5×10⁻³ Pa, the sputtering power and working pressure were 150 W and 12 Pa, respectively, and the Ar flow rate was 60 sccm. The ZnO deposition chamber was evacuated to a vacuum of 5×10⁻⁴ Pa, and the sputtering power and working pressure were 150 W and 0.6 Pa, respectively, and the flow ratio of Ar and O₂ was 40:10 sccm. Third, a direct current (DC) magnetron sputtering was used to prepare an Au film on top from an Au target (99.99%). Finally, use UV exposure photolithography and wet etching process to make the device.

2.2. Characterization and measurement
The crystal structure of four experimental films was determined by the Rigaku Ultima VI X-ray diffraction instrument (XRD). A scanning electron microscope (SEM) image was presented to four sets of experimental film surfaces using the JEM-6710F instrument. The silicon PD is calibrated using the Zolix DR800-CUST measurement system to determine the response curve.

3. Results and Discussion
Figure 1 shows an X-ray diffraction diagram of four sets of experiments on a pure ZnO, ZnO film with a buffer layer AZO, grown on PET and PI flexible substrates. It can be seen from Figure 1(a), (b) and (d) that the hexagonal phase (002) of the ZnO film has a strong X-ray diffraction peak, while Fig. 1(c) has no corresponding diffraction peak. The bonding strength between ZnO and PI substrate is weak. Under the action of AZO, the adhesion rate of the ZnO film is improved, and the corresponding diffraction peak also appear.

Figure 1 (a) XRD spectrum of ZnO film sputtered directly on PET. (b) XRD spectrum of the AZO buffer layer and ZnO film is sputtered in PET. (c) XRD spectrum of ZnO film sputtered directly on PI. (d) XRD spectrum of the AZO buffer layer and ZnO film is sputtered in PI.
In Figure 2 (a), it is clear that the hexagonal phase structure of the ZnO film is evenly distributed on the PET substrate, which is consistent with the diffraction peak strength of the XRD. Figure 2(c) shows that the surface particle size of the ZnO film is uneven, with a few cracks, but the entire film is uniform. However, after the bending test of the two sets of samples, large surface cracks appeared in the ZnO film. Figure 3(a) The surface morphology of the ZnO film directly deposited on the PI substrate. It is obvious that the film began to fall off before the bending test. After the bending test, the film fell off in a large area, as shown in Figure 3(b) . Figure 3(c) shows the surface morphology of the ZnO film in the presence of the AZO buffer layer. Many hillock structures are scattered on the film, but the film is continuous and uniform as a whole. Figure 3(d) is the surface morphology of the AZO/ZnO film after bending test. The film has microcracks, most of which are intact.

Figure 4 (a) and (b) show the PD spectral responsivity curves characterized by unstrained and tensile strain under 10-60V bias. The responsivity under tensile strain is slightly higher than that of unstrained
under the same bias voltage (Figure 4(c)). This is due to the piezo-phototronics effect of ZnO [10, 11]. When strain is applied, piezoelectric polarization charges are generated at the interface, which greatly improves the optical response of the device. Figure 4(d) is a comparison diagram of the responsivity before and after the bending test. After the bending test, the responsivity is significantly lower than before the test, but the decrease is relatively small, indicating that the PI/AZO/ZnO device has good stability.

4. Conclusions
In summary, through the comparison of PET and PI two organic substrates to device stability, it is found that PI/AZO/ZnO film reaction is the best, and its PD passed the bending test, showing good stability.

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