Flexible Quantum Dot Light Emitting Diodes based on Copper Nanowires/Poly(P-Phenylene Benzobisoxazole) Composite Electrode

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Abstract. Flexible quantum dot light emitting diodes have attracted widespread attention due to their many advantages such as low cost, color tunability, and high luminance efficiency. Among flexible electrodes, copper nanowires have attracted much attention due to their high electrical conductivity, simple fabrication process, and low cost. However, the oxidation and poor film quality of copper nanowires films are the barrier that restrict their practical application. In this paper, polyethylene terephthalate/copper nanowires/poly(p-phenylene benzobisoxazole) composite flexible electrode can solve the problems of oxidation and high surface roughness of copper nanowires, which improves the performance of flexible quantum dot light emitting diodes.

1. Introduction
With the development of smart wearable technology, flexible electronic devices have attracted widespread attentions. It is imminent to develop a flexible transparent electrode with high transmittance and high electrical conductivity. [1-3] Indium tin oxide (ITO) is the most widely used and mature technology. But because of its inherent fragility, it is no longer compatible with future flexible electronics.[5,6] Research on high-conductivity flexible transparent electrodes is imminent. Copper nanowires (CuNWs), as a transparent conductive layer, has good light transmission, conductivity, flexibility, and low cost.[7,8] However, its susceptibility to oxidation and high surface undulations have become shortcomings restricting the industrial application of CuNWs in the field of optoelectronic devices.

There is a large P conjugate system between the benzene ring and the oxazole ring in the poly(p-phenylene benzobisoxazole) (PBO) molecular chain, and there is a strong P electron delocalization and resonance stabilization in the molecular chain. These characteristics make PBO have good photophysics performance. The advantages of PBO as an optoelectronic device are high stability and high-quality films with high orientation. This article uses PBO to protect the network of CuNWs, and embeds CuNWs to form a polyethylene terephthalate(PET)/Cu NWs/PBO composite electrode. The shortcomings of oxidation and high surface roughness of the flexible substrate of CuNWs are improved. Device performance based on CuNWs/PBO composite electrode improved a lot. The structure of the device is shown in Figure 1 below. A flexible QLED was prepared using PEDOT: PSS as the hole injection layer, PVK as the hole transport layer, CdSe/CdS/ZnS as the light emitting layer, ZnO: Mg as the electron transport layer, and Al as the anode.
2. Result and Discussion

2.1. The Effect of PBO on the Roughness of PET/Cu NWs

High surface roughness is an inherent defect of metal nanowire conductive films. For optoelectronic devices, especially QLEDs and OLEDs, higher surface roughness will cause layer-to-layer penetration, resulting in higher leakage current, and it is easy to damage the device under high voltage. The root of the high roughness of metal nanowire films is mainly the stacking between nanowires. This paper uses PBO embedded CuNWs to solve the problem of high surface roughness of electrodes. The surface of the PET/Cu NWs flexible transparent conductive film has large fluctuations, but surface undulation of the PET/Cu NWs/PBO composite film is basically within 5 nm, as shown in Figure 2a, the roughness is only 1.85 nm. The undulation of ITO conductive film is also within 5 nm, and the roughness is about 1.64 nm, as shown in Figure 2b. This proves that PET/Cu NWs/PBO composite flexible transparent conductive film has excellent low roughness, which lays a solid foundation for the subsequent preparation of QLED.

![Figure 1. Structure of QLED device](image)

![Figure 2. AFM images of (a) PET/Cu NWs/PBO, (b) ITO](image)
2.2. Effect of PBO on Electrode Stability
CuNWs conductive film is susceptible to oxidation and leads to poor stability, which is the main problem restricting its industrial application. It determines whether the optoelectronic device can run for a long time. When the CuNWs are directly in contact with water and oxygen in the atmosphere on the surface of the glass substrate, at room temperature or high temperature and high humidity conditions, the surface of the CuNWs will be rapidly oxidized, forming an oxide layer on the surface. The oxide layer hinders electron transport between the nanowires, which drastically degrades the conductivity of the film, and eventually causes the film to lose its conductivity. In order to solve the problem of oxidation of CuNWs, covering the surface with a layer of non-conductive semiconductor oxide PBO can greatly improve its anti-oxidation ability, thereby increasing the device life.

2.3. Device Performance
We use optimized electrodes to make QLEDs. The results are shown in the figure 3. It can be seen that the composite electrode improved the luminance and efficiency of the device. The QLED based on the PET/CuNWs electrode has only 6050 cd/m² and 1.77 cd/A, while the device based on PET/CuNWs/PBO electrode increases 164% and 201%, reaching 9000 cd/m² and 4.25 cd/A. We attribute it to the improvement of electrode oxidation resistance and the reduction of surface roughness, which increased charge mobility and reduced leakage current, the number of electrons and holes is more balanced, thereby improving the performance of the device.

![Figure 3: Device performance. (a) luminance. (b) current efficiency](image)

3. Conclusion
In this thesis, PBO was spin-coated on the surface of the CuNWs conductive film to make a composite PET/CuNWs/PBO flexible transparent electrode. The composite flexible transparent conductive electrode exhibits excellent conductivity, mechanical flexibility, and oxidation stability, even can be compared with ITO conductive films. We prepared red QLED device which using PET/CuNWs/ PBO composite flexible transparent electrode as the positive electrode. The device showed good performance, maximum luminance increased by 164% to 9000 cd/m², and the current efficiency reached 3.56 cd/A, increased 201%. Compared with devied based on PET/Cu NWs, performance has improved a lot. We hope that PET/Cu NWs/PBO composite flexible electrode will show wider application prospects and research value.

4. References
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