Flexible, transparent and low resistance cathode with work function tuned multilayer structure for organic light-emitting diodes (OLEDs)

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Recently, there has been growing interest in flexible and transparent displays with organic light-emitting diodes (OLEDs). Especially for next generation displays, flexible and transparent electrodes are indispensable, and for this reason, they are being actively investigated in many studies. For the anode part, carbon nanotubes (CNT), silver nanowires (AgNW), metal meshes and graphene have been studied and some have been fabricated and applied in devices. Transparent devices require not only a transparent anode but also a transparent cathode. Typically, a magnesium:silver (Mg:Ag) cathode has been used in transparent devices. However, due to the high reactivity of Mg, such cathodes can affect the active layer of the OLEDs. In addition, various electron injection layer (EIL) on indium tin oxide (ITO) electrodes are still being actively studied. But in that case, ITO has poor mechanical flexibility, so it is not suitable for flexible displays.

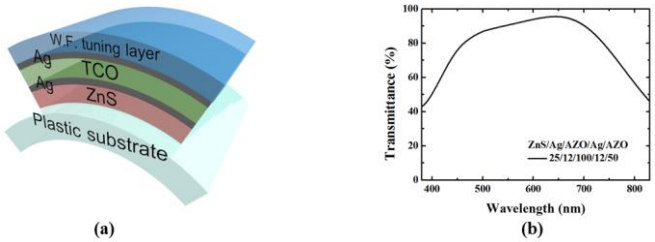

Fig. 1. (a) Structure of the multilayer cathode on plastic substrate, (b) simulated transmittance of ZnS/Ag/AZO/Ag/AZO multilayer film in the visible range

In this study, we present a flexible and transparent cathode with low resistance using a multilayer structure. In previous works, the flexible and transparent multilayer anode adopted a dielectric / metal / transparent conductive oxide (TCO) / metal / dielectric (D / M / O / M / D) structure[1]. In the multilayer configuration, the cathode needs a low work function to inject electrons and a high energy bandgap for transparency. However, it is hard to find materials which have low work function and large energy bandgap. Another problem is that if the thickness of the fifth layer increases, it blocks current due to high resistivity and as a result decreases the efficiency.

As an improved alternative, we suggest a multilayer cathode which consists of a zinc sulfide (ZnS) / silver (Ag) / TCO / silver (Ag) / work function (W.F.) tuning layer. The first ZnS layer was used as the seed layer[2]. The second Ag layer and the fourth Ag layer were used as the conduction layer. The main role of the third TCO layer was to establish the electrical connection between the two separated Ag layers[3]. As a result, the Ag / TCO / Ag structure is more transparent and conductive than a single Ag layer[3]. The fifth layer is TCO:Cs_2CO_3. The main purpose of Cs_2CO_3 is to lower the work function to inject electrons into the organic materials. The main role of the TCO is to link the Ag / TCO / Ag and organic materials, to increase the efficiency of the OLEDs. This structure also provides good mechanical flexibility. Therefore, the proposed ZnS / Ag / TCO / Ag / TCO:Cs_2CO_3 cathode may be applied to flexible and transparent OLEDs.

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