Printable low work function cathode for OLED devices

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Abstract

Commercial conductive metal inks are available, but metals used in these have unsuitable work function for efficient OLED device performance. Metals with low work function tend to oxidize easily, which makes it challenging to develop low work function metal inks. In this research we describe printed low work function Al cathode.

1. Introduction

Low work function cathodes for OLED devices have been traditionally manufactured by vacuum deposition.[1, 2] When manufacturing OLEDs by printing techniques silver ink has been only commercially available conductive ink for this use. However, work function of silver is high, resulting lower device performance.[3] Hence, there is a need for developing suitable low work function metal inks.

However, metals with low work function (e.g. Ca, Li, Ba, Na, Al, Mg) tend to oxidize easily and the oxidized metal surface prevents the ohmic contact between metal particles in the ink resulting poor conductivity. Oxidation has to be prevented during manufacturing of the ink and printing of the OLED device. Also these low work function metals are reactive towards many materials, which limit the choice of solvents, binder materials and additives.

Good contact between emitting layer and cathode is crucial. Therefore the choice of solvent has to be taken into account that it does not dissolve the underlying layer. Also the curing temperature has to be lower than the glass transition temperature of the organic materials and the substrate.

Vacuum deposited aluminum layer has been used as a cathode in OLEDs[4]. Work function of aluminum is 4.2 eV, which is considerably lower than silver (4.6 eV)[5], which has been so far used for commercially available electrically conductive inks. Metallic Al does not oxidize as readily than other low work function elements; hence we chose aluminum as an example for preparation of the low work function conductive ink.

2. Experimental

All manipulations were done in argon or nitrogen atmosphere and used solvents were dried and distilled before use.

Commercial Al metal powder of -325 mesh was ball milled in hexane with 2% w/w of stearic acid. After milling the hexane was removed by evaporation. Conductive ink was prepared using toluene as a solvent and polystyrene as a binder. Ingredients were mixed using high shear mixer to yield uniform dispersion.

Produced conductive aluminum ink was used in gravure and screen printing of the cathode electrode layer of all-printed OLED device.

Gravure printing tests were done in glove box in N_2 atmosphere with IGT table top printability tester with a raster patterned printing cylinder. Screen printing tests were done also in N_2 atmosphere (325 mesh with 17 µm emulsion thickness; 80 mesh with 50 µm emulsion thickness).

OLED device structure in these experiments consisted of a transparent anode electrode, a hole injection layer, a light-emitting layer, and a cathode electrode. On the commercial ITO coated PET substrates was gravure printed PEDOT:PSS. Orange light-emitting layer, MEH-PPV, was gravure printed on the top of PEDOT:PSS. Both layers were gravure printed using table-top IGT printability tester and engraved printing cylinder.[6]

3. Results and discussion

Commercial Al metal powder does not conduct due to oxide layer on metal particles. Ball milling of Al in hexane yields ca 5 µm particle size and a conductive metal powder.

Produced conductive aluminum ink was used in gravure and screen printing experiments. The device structure consisted of modified PEDOT CH8000[6] and MEH-PPV double layer between ITO anode and Al cathode. Both polymers were gravure printed on ITO coated PET foil.

Gravure printing tests of the Al-ink were done in nitrogen atmosphere with IGT table top printability tester using raster patterned (R40) printing cylinder. Figure 1. shows very rough and non-uniform surface of obtained Al layer. This was due wetting and surface energy mismatch problems. Further development of the gravure ink is ongoing. Despite of the poor printing quality, the OLED device showed emission.

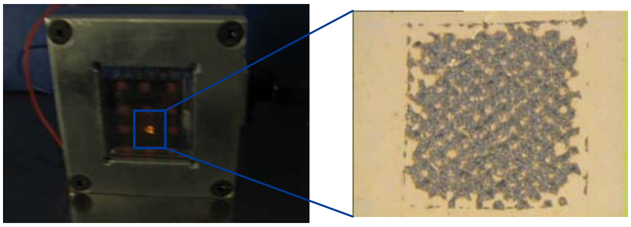

Figure 1. OLED device; gravure printed polymer and Al cathode layers. Size of the pixel is 2x2 mm.

Screen printing of the cathode layer was done with three different screens: 325 mesh, 17µm emulsion; 200 mesh, 17µm emulsion and 80 mesh, 50 µm emulsion thicknesses. Screen printed aluminum layers were characterized using white light interferometer. Due to higher viscosity needed for screen printing ink, it was possible to raise aluminum content of the ink compared to gravure ink. Screen printed aluminum layer was considerably smoother than gravure printed one, although there were still some pinholes when screen with 325 mesh and 17 µm emulsion thickness was used, as seen in Figure 2. Average thickness of the layer was ca 12 µm (Figure 3).

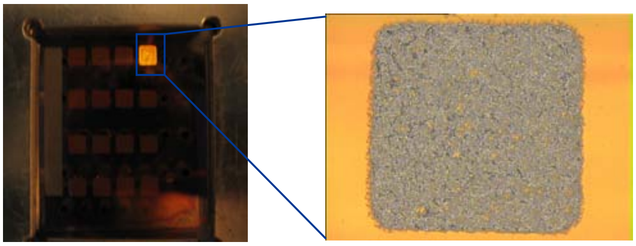

Figure 2. OLED device; gravure printed polymer and screen printed Al cathode layers (325mesh with emulsion thickness 17 µm). Size of the pixel is 3x3 mm.

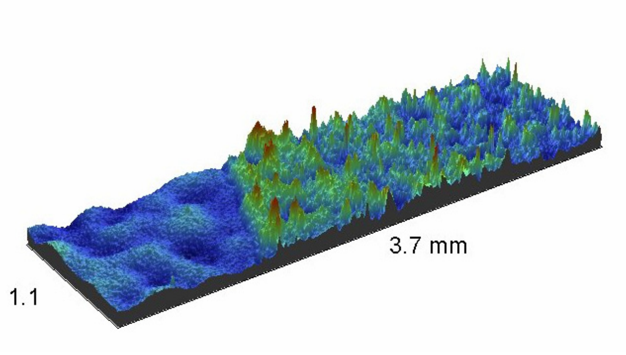

Figure 3. Cross section profile of the screen printed aluminum cathode layer. Mesh count 325, emulsion thickness 17 µm.

Printing of Aluminum cathode with smaller mesh count (200 mesh) and same emulsion thickness (17 µm) yielded average layer thickness of 25 µm and less pin holes (Fig. 4).

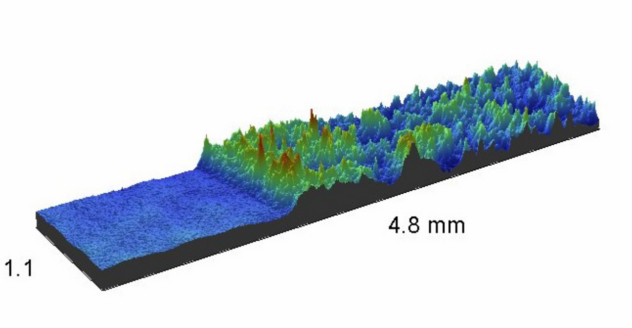

Figure 4. Cross section profile of the screen printed aluminum cathode layer. Mesh count 200, emulsion thickness 17 µm.

Screen printing of cathode with mesh count of 80 and thicker emulsion (50 µm) yielded aluminum layer with no pinholes, with thickness of 40 µm. However, cathode layer is still rough and the performance of the OLED did not improve.

OLED with printed aluminum cathode had turn on voltage at 3.35 V, and the OLED device with evaporated Al cathode had at 3.0 V (Fig. 5.). Current density versus voltage characteristics showed no leakage current at low operating voltage, indicating good compatibility of printed organic and cathode layers.

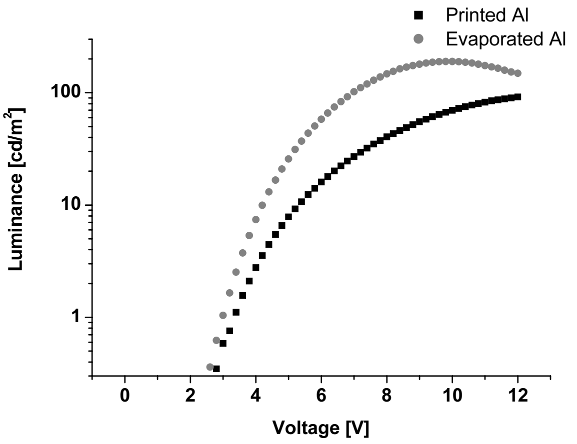

Figure 5. Brightness versus voltage of OLEDs with printed Al and evaporated Al cathode.

4. Summary

The manufacturing of the low work function conductive ink and printing of the cathode layer of all-printed flexible OLED device has been demonstrated. Low work function conductive ink for gravure printing needs still more development to gain uniform electrode layer. However, screen printing the aluminum cathode layer resulted good device performance, close to evaporated one. Device performance can be significantly enhanced by adding small amount of lower work function metal in Al ink. The work of tunable work function metal ink is currently under investigation.

5. Acknowledgement

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6. References

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