P-224: Damage-Free Cathode Coating Process for OLEDs

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Abstract

OLED displays require the growth of inorganic films over organic films. The inorganic film sometimes manifests as cathode metal (bottom-emission displays), or as the optical enhancement layer (OEL, in top emission displays). Sputtering is the first process of choice in both cases due to simplicity, low cost and scalability. However, plasma damage of the organic underlayers prevents sputtering from being routinely used. A closed-drift ion beam sputtering process was found effective in growing inorganic films with negligible damage to the organic underlayers.

1. Introduction

In top-emitting OLED displays, the cathode metal is made as thin as possible to allow maximum light transmission while still serving as an electron injector. Overlaying the thin cathode metal is an optical enhancement layer (OEL) whose function is to provide higher light extraction efficiency. Indium Tin Oxide (ITO) or other oxides or nitrides are ideal candidates for the OEL material, especially if some degree of thin film encapsulation is also desired.

For an OEL material which cannot be evaporated (such as ITO), a plasma-based deposition process is needed. Sputtering is a robust manufacturing process, and is a process of choice for most industries. Conventional sputter deposition of ITO has been shown to degrade the efficiency and lifetime of the OLED device due to the flux of charge particles and high energy atoms impinging on the device [1-6]. Thick protection layers are used to alleviate the damage but that puts a severe constraint on the design of the OLED stack. Other groups use very low deposition powers (and rates) that increase TAC time considerably.

In bottom-emitting OLED displays, the cathode metal itself is preferably deposited using sputtering. Here the damage to the organic layers will be more severe, as there is no protection for the electron transport layer (ETL), and minimal protection of the emissive layer (EML) under the ETL.

Our objective was to develop a process for depositing the inorganic layers, whether metal, nitride or oxide, on top of organic layers without degrading device performance.

2. Ion Beam vs. Magnetron Sputtering

In conventional Magnetron sputtering (MS), the wafer is exposed to the plasma, allowing electrons and ions to bombard the growing film. In addition, two other high energy species bombard the growing film: reflected gas neutrals and the sputtered flux itself. For these reasons, organic films typically used in OLEDs are not compatible with sputter deposition processes, as they suffer damage from charge particles as well as the high energy flux. In Ion Beam Sputtering (IBS), the wafer is not exposed to the plasma, which is contained in the ion source. Furthermore, the geometry of deposition can be used to avoid high energy particles of any kind. These differences are illustrated in Figure 1. The only charges reaching the wafer in an ion-beam system (figure 1b) are secondary electrons from the target. These can also be reduced considerably using a magnetic trap at the wafer (not shown).

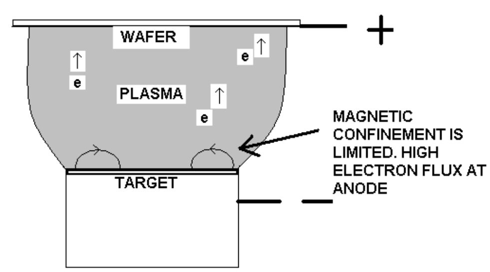

Figure 1a: Magnetron Sputtering

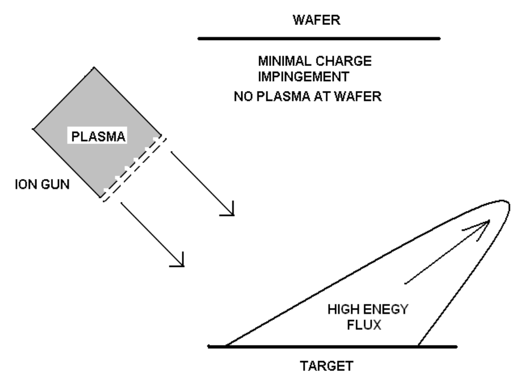

Figure 1b: Ion Beam Sputtering

3. The Iontron Ion Beam Gun

In the ion beam gun used in this study, the triangular geometry of a conventional IBS system is combined into a unit that simulates the parallel plate geometry of an MS system, to allow scaling up the gun for flat panel displays. The Iontron is shown in cross-section in Figure 2. The target is mounted in the center, and receives ion flux from all around it at roughly 45 degrees to its surface. The ion beams are generated from a closed-drift hall source and extracted from a slit. The closed-drift ion source was supplied by Micron Surface Technology, Inc. under the trade name Iontron^{TM}.

There are some important features that make this gun ideally suited for OLEDs work. Firstly, the configuration is parallel-plate, which is easy to scale up. Second, the high energy deposition flux and reflected neutrals are diverted away from the wafer. Third, secondary electrons from the target are prevented from reaching the wafer by means of a magnetic trap placed near the exit point of the gun. See Appendix for details.

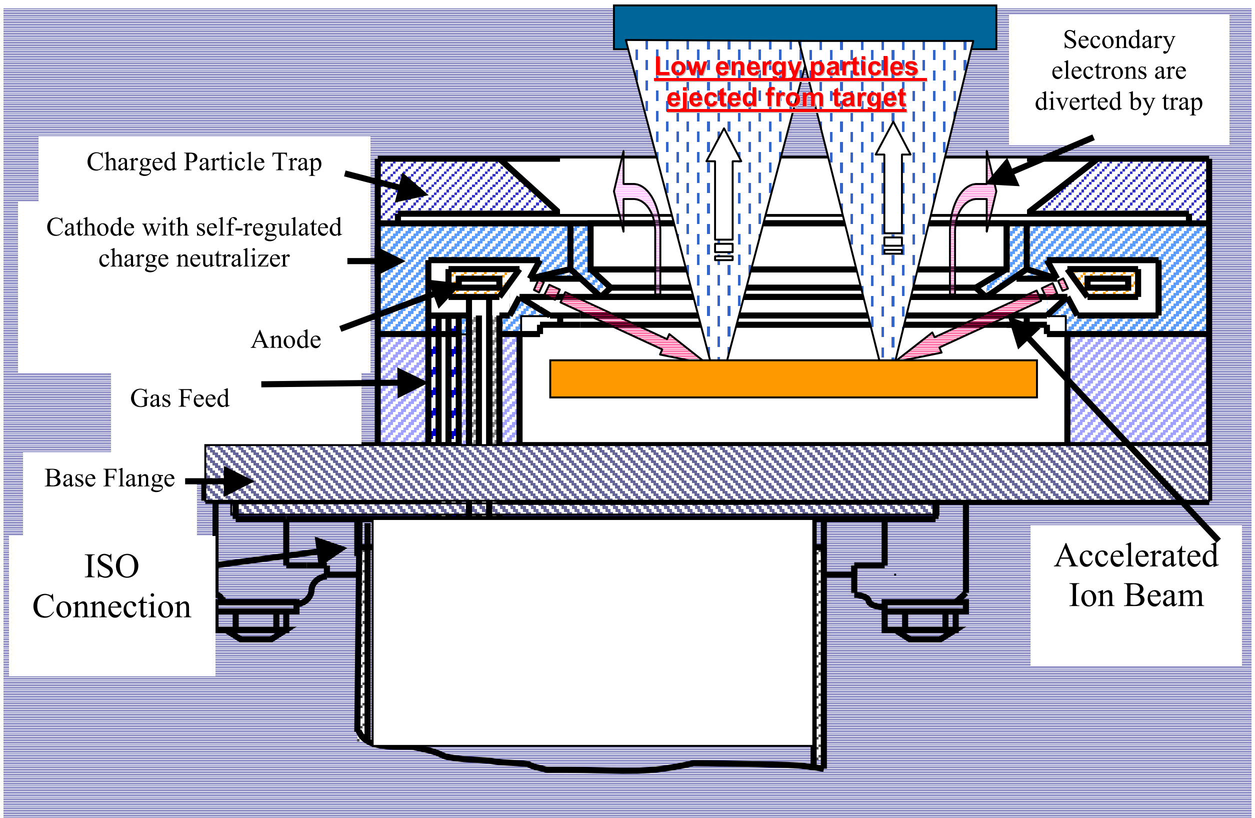

Figure 2: Schematic of the Iontron Ion Beam gun showing salient features

The resulting flux of depositing material is low energy and charge-free, ideal for OLED organic layers that are sensitive to any charge particle impingement.

4. Results and Discussion

For evaluating the effectiveness of the Iontron, blue OLED devices with layers up to the EIL were built. The device stacks were thus composed of Anode/ HIL/ HTL/ EML/ ETL/EIL. The cathode metal was deposited to a thickness of 1kÅ, making it opaque. Three types of samples were created: one using conventional evaporation for the cathode metal, one using conventional magnetron sputtering for the cathode metal, and the third using Iontron IBS for the cathode metal.

In Figure 3, various graphs are shown that capture the full L-I-V characteristics of the devices after the deposition of 1kÅ cathode metal film at 1Å/sec over the EIL of the OLED devices. The organic emissive layer was covered with a 10nm Alq_3/1nm LiF bilayer.

From the graphs it can be seen that the devices with ion beam sputtered metal were very similar to the controls. Only a slight loss of efficiency and a concomitant rise in voltage were seen. The magnetron sputtered devices however were essentially destroyed by the process: the efficiency dropped to 0.5 Cd/A from 3 Cd/A, and the voltage became prohibitively high. Devices did not reach 100 Cd/m^2 even at 7V.

The data thus indicate that the IBS process with an electron trap is a far superior process to conventional magnetron sputtering when applied to sensitive substrates. As far as the OEL in a top-emitting device is concerned, no damage was observed to the device with the presence of a thin metal cathode composed of 1nm Al/20nm Ag as protection (data not shown). However, top-emitting devices could potentially suffer damage if there is less metal protection or if rates higher than 1Å/sec are desired for the sputtered layer. In the case of the more stringent cathode metal deposition, less than 10% loss of each device property was seen with no protection for the underlying organic layers when using the Iontron gun.

5. Acknowledgments

The author would like to acknowledge the help of Michael Gutkin of Micron Surface Technology for providing the Iontron Ion Beam gun and schematics.

6. Conclusions

Ion beam sputtering allows for a wider choice of materials for the growth of inorganic materials on top of organic layers, with negligible degradation. Top-emitting as well as bottom-emitting displays would improve, and the cost burden would be less for manufacturing as the Iontron is a scalable gun. The process can also be used in other applications where sensitive organic layers need to be protected.

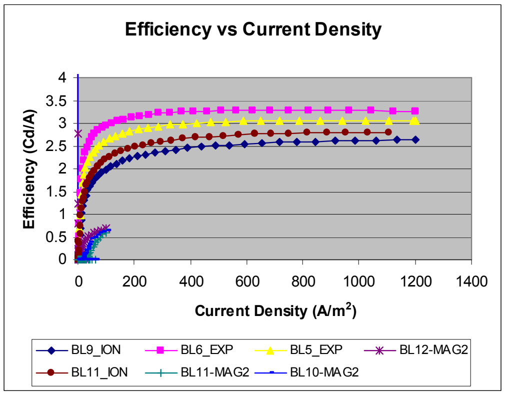

Figure 3a: Efficiency vs. current density. EXP: evaporation controls; MAG2: magnetron sputtered; ION: ion beam sputtered

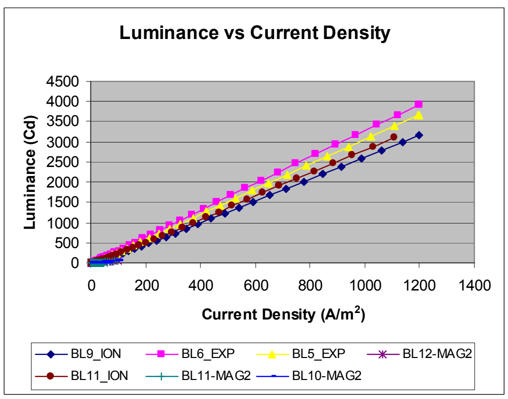

Figure 3b: Luminance vs. current density. EXP: evaporation controls; MAG2: magnetron sputtered; ION: ion beam sputtered

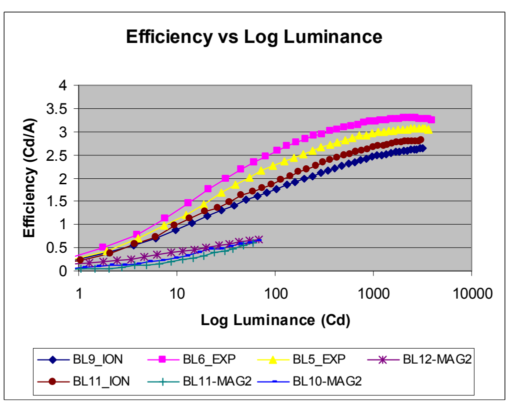

Figure 3c: Efficiency vs. luminance. EXP: evaporation controls; MAG2: magnetron sputtered; ION: ion beam sputtered

7. Appendix

The effectiveness of a strong magnetic trap is seen in Table 1. Electron and ion energies were also measured using a cylindrical energy analyzer through a 15mm opening in the wafer. There is

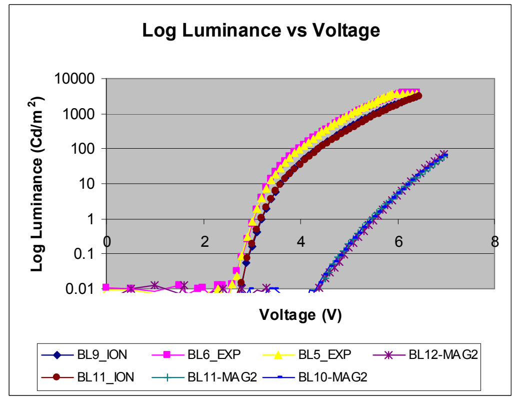

Figure 3d: Luminance vs. voltage. EXP: evaporation controls; MAG2: magnetron sputtered; ION: ion beam sputtered

a 2 order of magnitude lowering of ion and secondary electron current density to the wafer with a magnetic trap present. This is due to the Lorentz force acting on the electrons by the magnetic field.

IONTRON DATA		150mm wafer	
	Current	Current Density	Average Energy
No magnetic trap			
Electrons	4-7 mA	20-40 uA/cm²	60 eV
Ions	3-5 mA	15-30 uA/cm²	300 eV
With magnetic trap			
Electrons	10-30 uA	50-170 nA/cm²	10 eV
Ions	30-50 uA	170-300 nA/cm²	300 eV

Table 1: Data for charge particle impingement on the wafer using an Iontron gun with and without a magnetic trap.

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