Integration Of OLEDs And Display Drivers On PCBs

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For the first time, the possibility of reconciling printed circuit board production and assembly with OLED preparation and encapsulation has been demonstrated. The OLED, covered with a barrier layer, is mounted on the front side of the printed circuit board, while the driver assembly is done at the back side directly behind the display. The challenge was to provide an electrode surface on which to layer an OLED onto the front side of the assembled board. The combination of new assembly principles, highly efficient OLED devices and improved integration aspects opens the door to new commercial applications both for OLED devices and printed circuit boards, including signage and lighting.

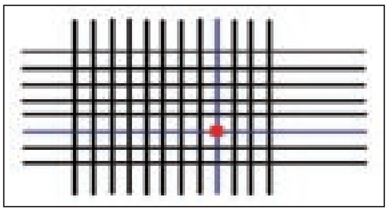


Figure 1 – Diagram of a passive matrix

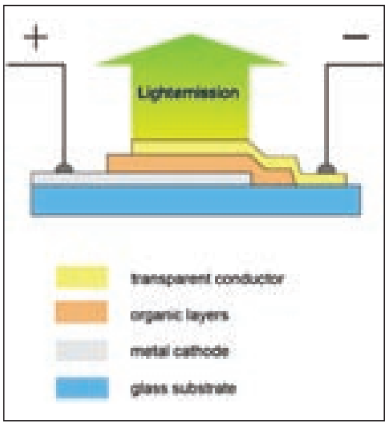


Figure 2 - Schematic view of an top-emitting OLED

Organic light-emitting diodes (OLEDs) can be used to produce very flat light sources of any colour on suitable substrate material. This substrate is limited only by its stability.

Up to now, OLEDs have only been used with rigid systems on glass surfaces. Now, researchers at the Dresden-based Fraunhofer Institute for Photonic Microsystems (Fraunhofer IPMS) have integrated OLED displays, their accompanying driver electronics and the controller onto a printed circuit board, in order to realise compact and cost-efficient display systems. Since PCB materials are generally opaque, a top-emitting structure is required.

Moreover, the IPMS project aimed to achieve high temperature stability, which would make it possible to assemble the controller after the OLED has been mounted. The OLED functions can thus be tested prior to circuit assembly, greatly reducing the quota of rejects and lowering unit production costs. Last but not least, researchers at IPMS aimed to achieve highly efficient OLEDs. High efficiency has two requirements: utilising highly efficient triplet emitter materials and doping of the OLED transport layers. This reduces the required voltage by half as compared to OLEDs without transport layer doping. This is a great advantage especially for mobile devices, since battery longevity directly depends on the OLED's efficiency.

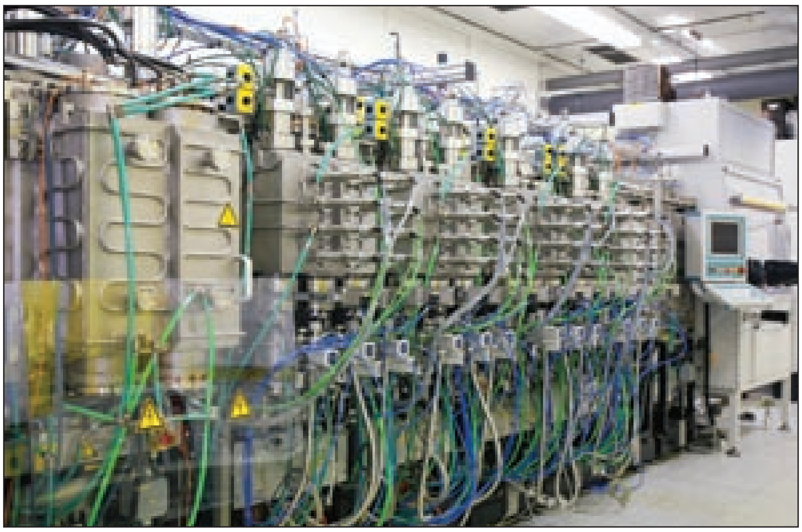
The structure of an OLED

An organic light emitting diode is composed of a number of different organic materials. These lie on top of each other in very thin, nano-scale layers. The outer layers at the top and bottom of this "sandwich structure" are provided with electrodes. At least one of these contacts must be transparent in order to allow the passage of the light. Depending on which of the contacts is transparent, the OLED is called bottom-emitting (through the substrate material) or top-emitting (through the cover contact). By structuring the contacts, simple displays can be constructed.

OLED driver

Each pixel of the OLED display is situated at the intersection of a row

Figure 3 - Photograph of the OLED In-line System VES 400/13



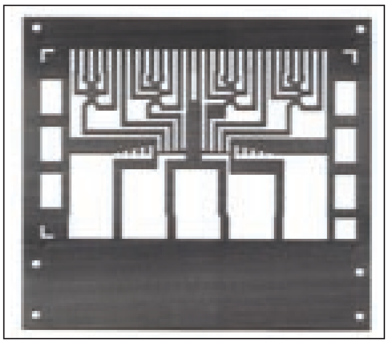


Figure 4 - Shadow mask for the ITO deposition (126 mm x 112 mm)

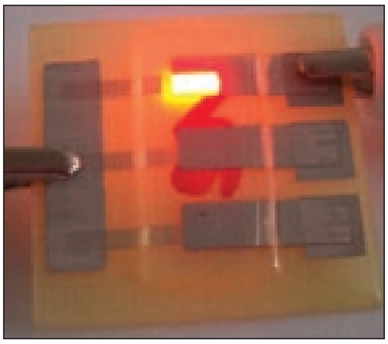


Figure 5 - Photograph of a red top-emitting OLED

and a column (Figure 1) and can be separately switched on or off (that is, bright or dark) by a matrix control. Applying a current to such a point produces an electrical field which causes the pixel to emit light. For OLED operation, the row control raises all OLEDs in a row to a defined electrical potential, while the column contacts provide the required voltage. Thus, rows emit light one at a time. The rows are activated in sequence in order to produce an entire picture. An individual OLED is switched on for only a fraction of a second. This means that the OLED must operate at a greater brightness compared to continuous operation mode.

For the electrical control of the OLED display, an OC2 display controller is used. This ASIC has been specially developed by the Fraunhofer IPMS in order to operate organic passive-matrix OLED displays. The display controller is able to drive displays up to an optical resolution of 128x64 pixels. The pixel information saved in the bit map memory is reproduced time-multiplex on up to 64 rows. The electrical current applied to the columns (up to 128) can be varied. Each column can be assigned a current from any of three separately adjustable sources. Thus, the display can be operated in three different modes: monochrome (grey scale), area colour and full colour (RGB). The OC controller drives the columns via a pulse width modulated signal. This allows to generate one, 16 or 256 levels of brightness, respectively. In order to increase the output current, several columns can be connected. The total output current then equals the sum of the individual column currents (max 500 µA). The display controller is assembled via flip chip technology on the back of the printed circuit board.

Figure 7 - L-I-V characteristic green OLED

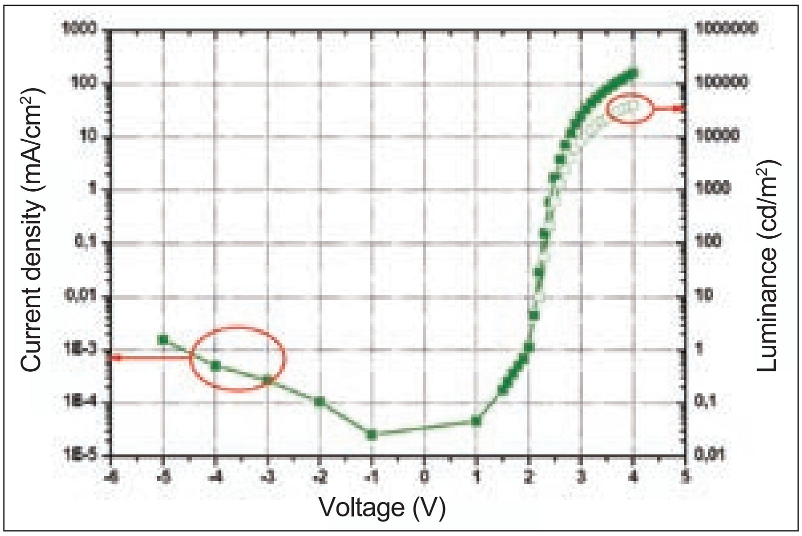
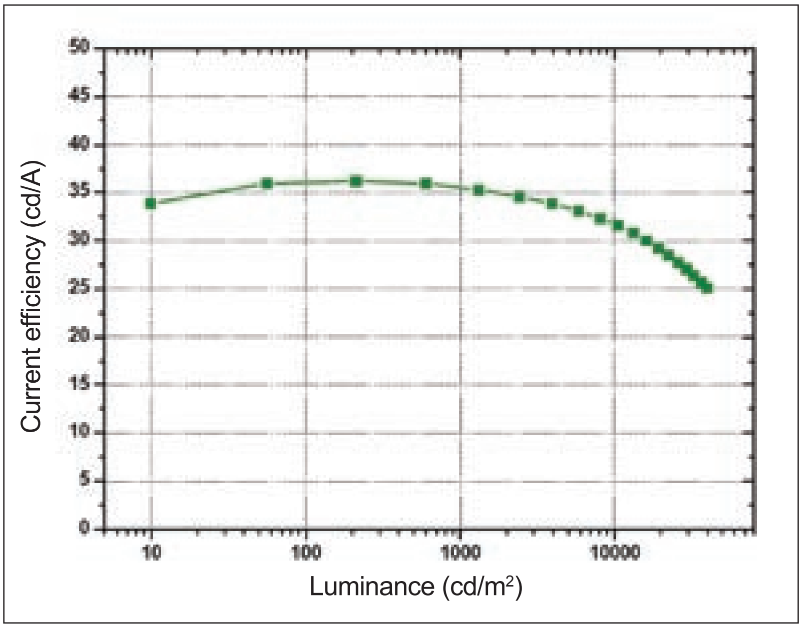


Figure 8 - Current efficiency of green OLED



Top-emitting OLEDs

Top-emitting OLEDs emit light through the cover contact (Figure 2). Therefore, a transparent substrate is not required, unlike with bottom-emitting OLEDs. This is advantageous because it allows to mount OLEDs on nearly any surface, if the necessary barrier layers are provided.

In-line system for OLED manufacturing

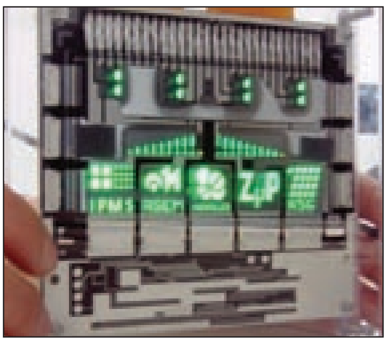
OLEDs were prepared using a new vertical in-line system for OLED manufacturing (Vertical Evaporation System VES 400, Applied Films). It is the very first vertical in-line coating system for small molecule OLEDs using evaporation technology. The system is pictured in Figure 3.

The VES is designed to coat substrates with a width of 300 mm and a height of up to 400 mm. The system realises a continuous substrate flow concept with linear sources for organic material and metal deposition. The advantage of the vertical design over a horizontal one lies in fewer particles and little or no bending of the masks and substrate. The base pressure of the system is less than 5 x 10-6 Pa.

The VES 400 exhibits a versatile design due to a modular arrangement of different chambers. The function of each chamber depends on how the chamber door is equipped. Each door can be equipped with heaters, linear etch sources and up to two standard magnetron sputtering sources for ITO (indium tin oxide), metal or dielectric layers. Up to three linear evaporation sources for organic materials can be added per door, and two sources for metals. The number of chambers and sources required depends on the specific application. The tool at the Fraunhofer IPMS Dresden is equipped with a linear ion source, two sputtering sources, two metal evaporators and 12 organic sources.

The organic sources can be arranged parallel or tilted. The parallel arrangement can be used to deposit different layers with different functions, or to deposit the same material if thick films or high deposition rates are required. The tilted arrangement is used for co-evaporation, e.g. to deposit a doped organic layer. Every source can be controlled independently.

Figure 9 - Demonstrator OLED on PCB consisting of a digital clock and a symbol row in the lower part. The middle structures only serve for testing purposes



OLED integration on printed circuit board

A top-emitting OLED was deposited on the opaque printed circuit board. The anode is the first layer on the substrate, i.e. the printed circuit board. The most important characteristics of the anode material are a low surface resistivity and a high electron work function. These are necessary in order to achieve high current densities and to operate the OLED with high efficiency.

The standard material used is ITO. The anode is precipitated by means of a sputtering process. During the standard process, the anode is precipitated onto the entire surface of the substrate. Afterwards, it is structured by a wet chemical process. However, printed circuit boards consist of glass fabric soaked with epoxy resin and laminated with a copper coating. Both the copper and the base material of the plate are not resistant to the standard etching compounds used for ITO.

This meant finding new procedures for structuring the anode. The anode needs to receive its shape during the sputtering process. The only solution is to use shadow masks.

The technology of layering e.g. organic OLED materials by evaporation through shadows masks has been sufficiently mastered. However, we had little experience with sputtering through shadow masks. In the course of this project, such a sputtering process was developed and optimised. Figure 4 shows the sputtering mask for the ITO precipitation.

Shadow masks were also used for the subsequent organic material precipitation. As cathode material or cover contact, an ytterbium layer was vapour-deposited. Finally, the board was encapsulated by a cover glass.

Characteristics of the assembled OLEDs

In the course of this project, OLEDs were at first assembled on test vehicle substrates. The substrates consisted of a square FR4-laminate with 25 mm sides and a thin glass layer of 100 µm as the topmost layer (Figure 5).

Conductive silver pads were screen-printed to form the OLED contacts. The OLED layer stack and the contacts were applied by thermal evaporation of the material in a vacuum. Finally, the OLEDs were placed in a nitrogen glovebox and encapsulated with cover glass in order to protect them from humidity and oxygen. Their performance was measured in air and at room temperature.

On the test vehicle substrates, red and green OLEDs could be realised. Later on, further testing took place on glass substrates, since these were more compatible with the existing measuring equipment. However, the OLED design was the same.

The measurement showed that high efficiency and low voltage could be achieved. Figure 7 shows the voltage-dependent luminance output of one of these OLEDs.

The brightness levels relevant for passive-matrix displays could be achieved at an operation voltage of approximately 3V. The current efficiency is shown in Figure 8.

High current efficiency makes it possible to operate the OLEDs at low working currents, thereby reducing the energy dissipation on the inlets to the OLEDs. This is very important for passive-matrix displays, because their inlets are particularly long and thin. Thus, on the test vehicle substrates, it was possible to show that printed circuit board substrates can in principle be used as OLED substrates, and that losses of efficiency or supply voltage are not to be expected.