Dual Mode OLED for mobile application

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Abstract

Dual Mode technology has been developed as a new technology that allows to use a self-emissive display under full sunlight conditions. The new technology connects a LCD-like remissive operation mode in sunlight to an OLED-like self-emissive operation in the dark. In the recent years, the focus of development has shifted towards the possibility of full colour operation.

1. Introduction

Organic light emitting diode (OLED) technology has come up as a new technology to create brilliant colour displays with large viewing angle and low power consumption.

The main product field for market entry is small-to medium size displays for mobile applications. Typical products include mobile phones, PDAs and laptop computers.

All of these products face the challenge of potential outdoor use under strong sunlight conditions.

Samsung SDI has started to develop a new technology that can cover both the indoor as well as the outdoor operation regime of a flat panel display. This technology is called *Dual Mode Display*.

Dual Mode technology can merge the advantages of OLED technology, like high brilliance, high contrast and fast response time under indoor conditions with a reflective-type appearance in sunlight.

2. Photoluminescence Quenching

Operation under strong sunlight requires a reflective-type display mechanism. In a dual-mode display, the light that is seen by the viewer is not simply a reflection but rather sunlight that is converted into photoluminescence (PL) radiation. Like in electroluminescence (EL), each emitter material has its characteristic PL spectrum and–colour. For organic singlet emitters, the PL spectrum is virtually identical to the EL spectrum. By proper choice of the emitter materials, the colours for the R,G,B subpixel, respectively, can be generated without the need for an extra colour filter.

The operating principle of the display device is shown in Fig. 1.

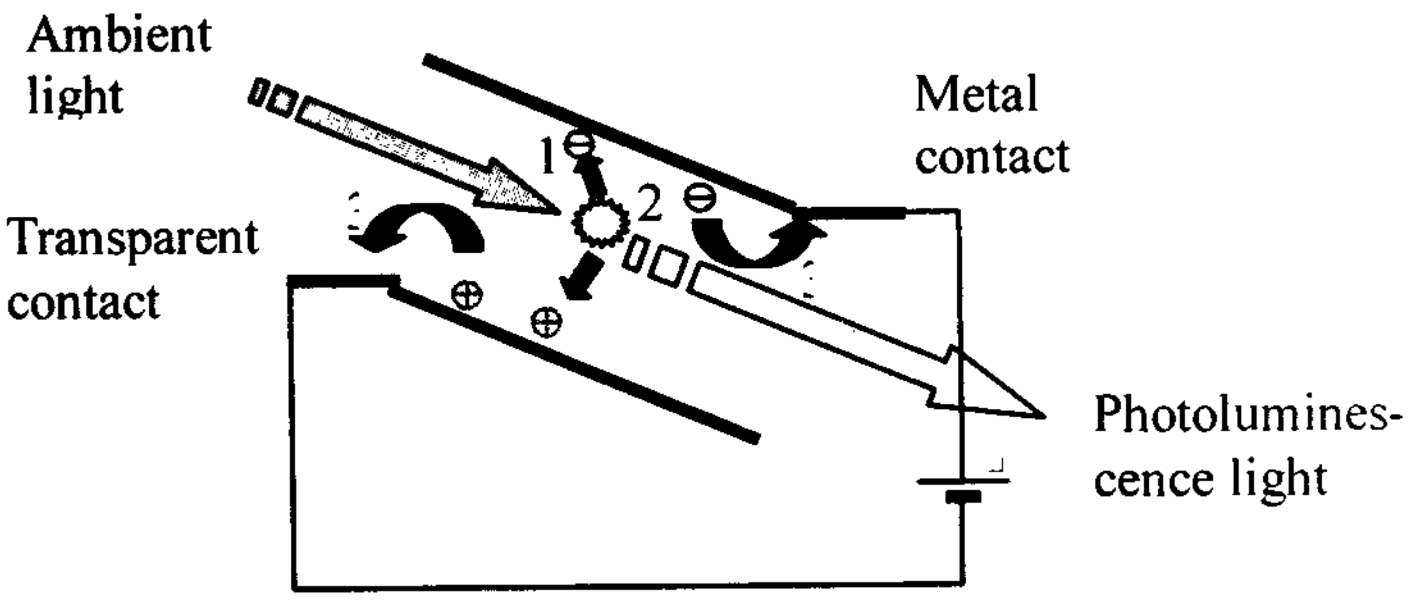

Fig 1 : Photoluminescence quenching operation of a PQD device

(1) Ambient light is absorbed and creates an excited state

The excited state can either decay radiatively (2) or dissociate into charge carriers (3) under the influence of an applied electric field. The charge carriers are extracted by the contacts. The branching ratio between radiative decay and dissociation can be controlled by the electric field.

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It is important to note that in organic light-emitting semiconductors, the light conversion happens via a two-stage process. Ambient sunlight is used to create an optically excited state in the semiconductor. After a characteristic lifetime of typically one nanosecond, the excited state decays while it gives off photoluminescence light.

In order to control the brightness by an electric signal, we use the effect of photoluminescence quenching by an electric field [1,2].

In brief, the excited state is destroyed by the electric field before light emission can occur. The result is the production of charge carriers which will be swept out by the applied field. In Fig 1, this mechanism will change the effective photoluminescence quantum yield (PL yield). The associated issue of power efficiency will be addressed below.

The quenching mode has an inverted characteristic compared to an OLED device. While an OLED appears bright when the pixel voltage is on, a quenching device will appear dark when the pixel is activated. With reference to the physical mechanism of operation, the devices that make up the display will be called Photoluminescence Quenching Device (PQD) in the following.

3. Current state of development

3.1 Contrast

The theoretical maximum for the contrast is given by the degree of photoluminescence quenching that can be achieved in ideal conditions. Ideal is a situation where all the incoming light is absorbed by the emitter material, which will then emit its characteristic photoluminescence spectrum. This is the case when monochromatic blue or ultraviolet light is used.

A typical quenching curve is shown in Fig. 2. A quenching value of 80 % corresponds to twenty percent of the initial brightness remaining, and a contrast of 5.

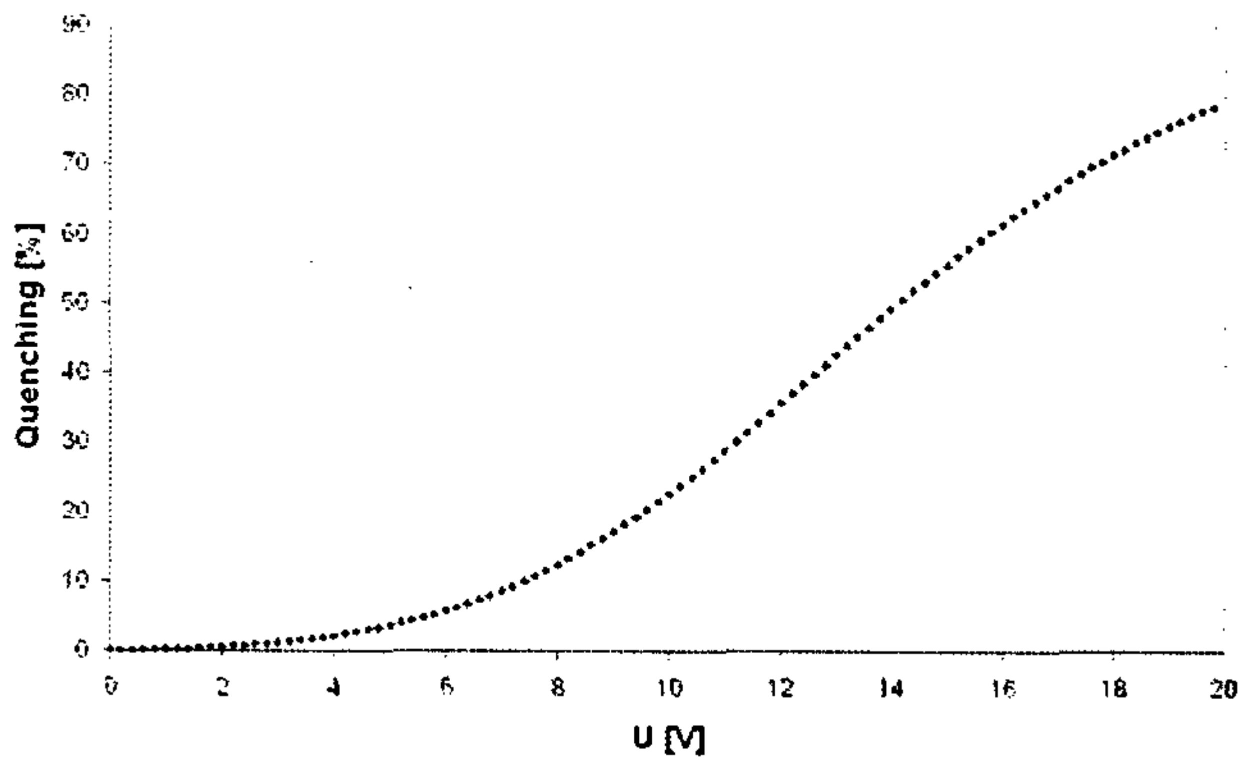

Fig. 2: Typical quenching characteristic of a green emitter. 80% quenching corresponds to 20% of remaining brightness

Under sunlight conditions, additional white light is present which cannot be absorbed by the emitter material. This white light content will lower the contrast. In our experiments, we see typical contrast values in sunlight exceeding three. Please note that the onset voltage for quenching is crucial in order to allow efficient operation in the self-emissive regime.

3.2 Power consumption

As mentioned before, a PQD device has an inherent steady state power consumption due to the generation of charge carriers. With reference to the definition of luminous efficiency and power efficiency for large area-emitters like OLEDs, a similar definition has been created for PQD structures.

The main difference arises due to the fact that in a PQD device, power is consumed to lower the brightness rather than to increase the brightness, like found in the OLED case. If we use the difference in brightness between bright and dark state of the pixel as the calculation basis, we arrive at an efficiency that is directly comparable to the OLED case. Fig 3 shows a representative curve for a green emitter material.

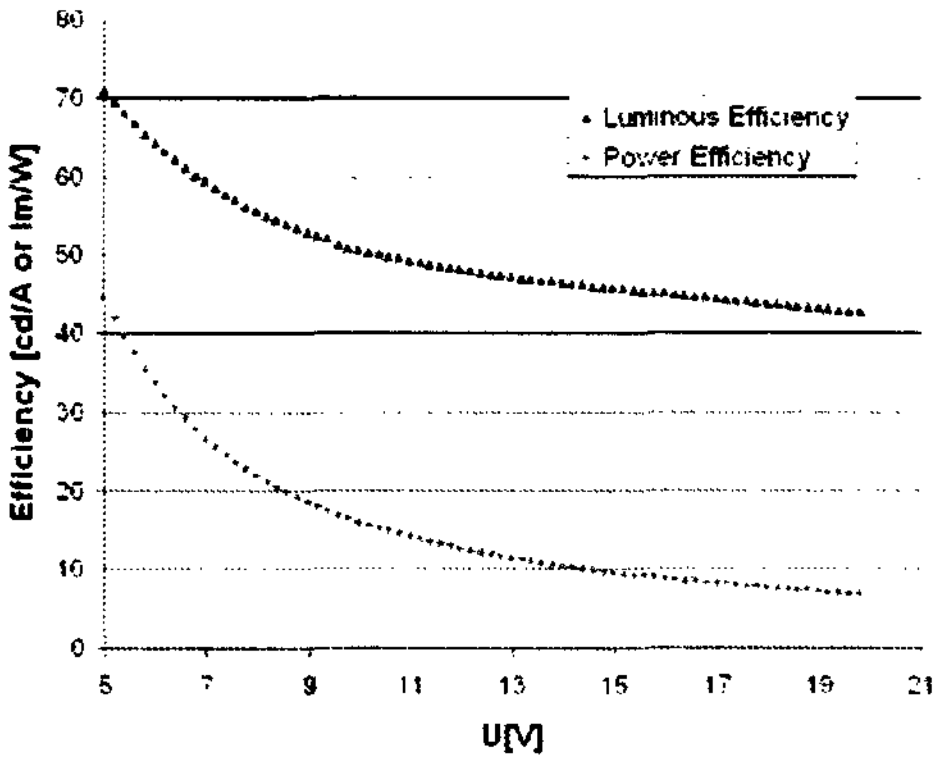

Fig 3: Efficiencies in quenching mode. For calculation of the efficiency, the reduction in brightness is used rather than a created brightness.

Please note that here the emitter material is a singlet emitter.

Following the classical picture of spin statistics, a singlet OLED emitter has only 25% of the theoretical quantum efficiency of a triplet-emitting material. A wide range of publications has confirmed the notion that triplet OLED emitters are several times more efficient than singlet emitters.

It is worth to highlight that in the PQD case, very high quantum (luminous) efficiencies can be achieved even without the involvement of specialized triplet emitter materials. In fact, this is caused by the different energy pathway. Only excited singlet states appear in the energy balance, without the involvement of spin statistics. The energy flow is shown in more detail in Fig. 4

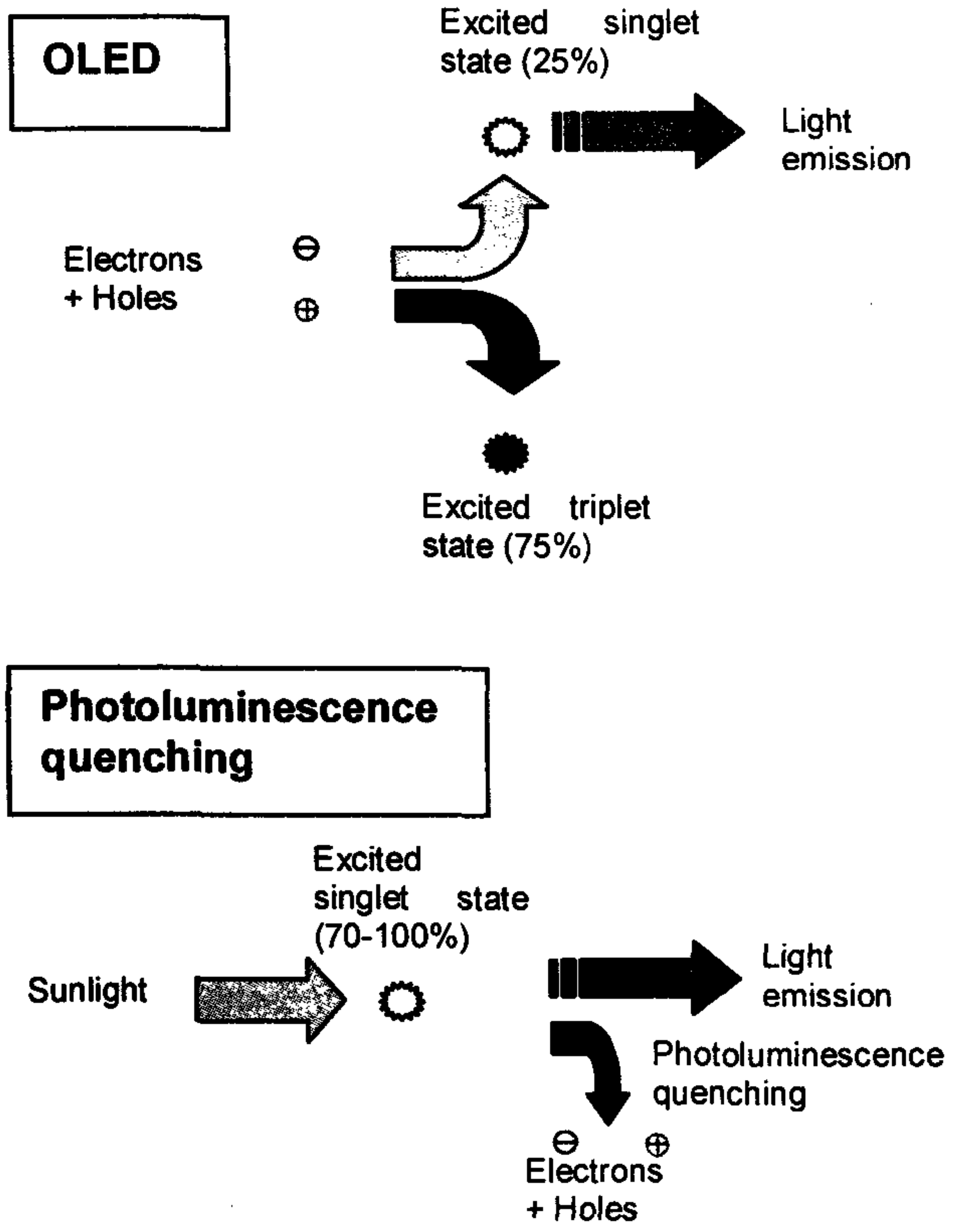

Fig. 4: Energy flow in the OLED (top) and PQD (bottom) case for a singlet emitter material. In the OLED case, typically only 25% of the used charge carriers can be used to create light.
In a PQD, singlet states are directly created by light emission. Charge carriers are only created by singlet excited state splitting, thus contributing to power consumption with a theoretical quantum yield up to 100 %.

3.3 Colour and brightness

The clear goal for a display application of dual mode technology will be a full colour display. For realizing RGB capability, the achievable brightness, colour coordinates and contrast per subpixel will govern the overall colour saturation.

The subpixel brightness is influenced by a multitude of factors. Amongst the most important is the degree of ambient light harvesting. A blue emitter will need deep blue or ultraviolet light that can be filtered from the incoming ambient light.

Furthermore, optical cavity effects influence both colour and brightness. Here, we have a situation where both light harvesting and light outcoupling will be influenced by the cavity.

The investigation of the achievable colour space is currently under way. Typical values of the gamut are now in the range of 10% of the PAL standard, with the future goal being 20%.

Brightness is a key argument for sunlight readability. The brightness of re-emitted photoluminescence light is proportional to the intensity of incoming sunlight. Typically, we achieve a brightness of 800 cd/m^2 in 200000 lux sunlight conditions for a green emitter.

4. Conclusions and outlook

Dual Mode technology is on the way to fill the gap of sunlight readability that classical OLED technology cannot serve yet. In view of the developments ahead, optical device tailoring and material innovation will be the key enablers to bring this technology to the market.

5. References

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