OLED ON CMOS: WHAT ABOUT THINNING AND BENDING?

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OUTLINE

• Introduction
• OLED, thin-film encapsulation technologies
• Curved microdisplay enabled using a new dedicated packaging
• Results
• Conclusions
CEA-LETI’s FACILITIES

Cluster tool OLED fabrication

Grenoble (Minatec Campus), 8000 m² clean room facilities
200 and 300 mm

Glovebox connected to evaporation cluster tool

Organic semiconductors (small molecules, HTM, ETM, EML...)

Lesker deposition system + GB + ALD Infinity

Fast ALD Infinity 200 since 2016 (Encapsulix)

ALD for thin-film encapsulation of OLEDs since 2006
(for OLED applications)
WHAT NEED FOR CURVED DISPLAYS?

**TV DISPLAYS**
- no optics, curvature is marketing appeal

**SMARTPHONES DISPLAYS**
- no optics but curvature can reduce the reflectance in user’s eyes ➔ improved readability in outdoor applications

**MICRODISPLAYS**
- optical engine mandatory ➔ which impact of curvature onto optical engine footprint, design and image quality?

Increasing need for curved sources (1D or 2D)
WHAT BENEFIT FOR OPTICAL ENGINE?

Curved sensor → System miniaturization and simplification
Same concept applies for curved microdisplay

Optimization using Zemax® tool with same optical performances

[1]
WHAT IS AN OLED?

OLED = electrical charge to photons converter
Used in display technology (competitor to LCD) and Solid-State Lighting (SSL)

Thin-film encapsulation

-100-200 nm

[Source: Universal Display Corporation]

OLED-based microdisplays (CMOS-based device)

[Source: Emagin]

OLED-based displays in smartphone/TV

[Source: LG, V30, 6” AMOLED]

OLED-based lighting panels

[Source: acuity Brands]
DARK SPOTS IN OLED


OLED + TFE, t + 400 h, no dark spots (good encapsulation)

An Al film would be a high barrier (low permeation) if one can make an evaporated film without defects

OLED + TFE, t + 400 h, dark spots (bad encapsulation)

\[ 2\text{Al} + 3\text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3 + 3\text{H}_2 \]
\[ 2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^- \]

\[ 4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3 \]
THIN-FILM ENCAPSULATION: WVTR

WVTR (OLED) < $10^{-6}$ g/m²/day

Contrary to food packaging, lag time is important because water contact with device must be avoided

ENCAPSULATION TECHNOLOGIES

2 kinds of encapsulation: solid (rigid lid barrier, glass or metal) and monolithic (thin-film barrier)

Cavity = \( N_2 \) gas

Future trends (allows bending if substrate plastic or thin mineral, glass, Si...)

Commercially available (smartphones, TVs)

CEA-LETI’s HIGH BARRIER BASED ON ALD PROCESS (OLED-TEST)

LETI thin-film encapsulation concept

<table>
<thead>
<tr>
<th>Testing modules</th>
<th>0 h</th>
<th>166 h</th>
<th>504 h</th>
<th>1033 h</th>
<th>1516 h</th>
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<tr>
<td>C4</td>
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<td>C5</td>
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<td>M4, with laminated film</td>
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<td>M5, with laminated film</td>
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Blue OLED after 1516 h at 85 °C/85% RH

High reliability of OLED encapsulated with multilayer TFE
No WVTR value, only OLED-test but probably 10^{-6} g/m²/day

IV and LV characteristics of an OLED module (with Gen 1 TFE, no lid) at t₀ (red line), after 504 h (blue line) and 1500 h (black line) at 85 °C/85% RH

Chip size 9 x 5 mm²

[Source: Jean-Yves Simon PhD (2013), LETI]
CURVED CMOS-BASED DEVICES, STATE-OF-ART

1Sony, 2014 Symposium on VLSI Technology Digest of Technical Papers (2014)

2B. Guenter et al., ‘Highly curved image sensors: a practical approach for improved optical performance’ Optics Express 25 2 (2017) 13010

CMOS Spherical curvature

- lens system could be simplified (reduced costs)
- Increase in light intensity at the sensor and noticeable reduction of vignetting effects at the lens edges (reduced edge aberrations)
- According to Sony, the new system curved sensor/lens can double the sensitivity at the edges of the image circle and by a factor of 1.4 at the centre of the image circle

Few developments on curved CMOS imagers since first Sony’s work in 2014; no curved microdisplay (as far as we know)
B. Chambion et al., ‘Tunable curvature of large visible CMOS image sensors: Towards new optical functions and system miniaturization’ IEEE 66th Electronic Components and Technology Conference (2016) 178

C. Gaschet et al., ‘Curved sensors for compact high-resolution wide field designs’ SPIE (2017) 10376

Full electro-optical characterization including:
- Dark noise (e-)
- Conversion factor (DN/e-)
- Dark current (e-/s)
- Fixed pattern noise (% of full swing)

Standard electro-optical response of curved sample; No impact of curvature on electro-optical response

Main difference between image sensor and OLED microdisplay, OLED IS VERY FRAGILE!
GENERAL PROCESS ROUTE FOR OLED MICRODISPLAY THINNING

Usual process route (pick & place, expensive, no bending allowed)

New process route (LOMID, collective hard coat, cheaper, allows bending)

Glass lid replacement by HARD COAT process → allows parallel process (cost ↓) and bending
WAFFER LEVEL THINNING (WLT)

« Thinning last » only after OLED process
Chip Level Thinning (CLT) also performed after
OLED process* (but cost ↑)

*: OLED process = OLED deposition + TFE + HC
IVL CHARACTERISTICS (TESTING VEHICLE, WOLED, WLT PROCESS)

IVL characteristics of a white OLED made on a thinned Si substrate following WLT process (circles) and following CLT process (squares) with 45 mm radius of curvature; inset: EL spectrum of the white OLED at 2000 cd/m²
CONTRAST MEASUREMENT WITH THIN PACKAGING

Packaging using a hard coat solution (Thin, < 10 µm)

Packaging using glass lid (Thick, 700µm)

Thin-film packaging allows a dramatic increase of image contrast, especially for graphics content at high brightness levels

Does it allow bending?

Courtesy MicroOLED
THINNING AND BENDING RESULTS (MAIN ACHIEVEMENTS IN LOMID PROJECT)

Thinned and curved dummy, CLT
Si/AIG3/TFE/HC

Winter 2016

Thinned OLED testing vehicle (9 x 5 mm²), CLT
OLED/TFE/HC

Summer 2016

Thinned Maryland chip*, CLT
CMOS/OLED/TFE/HC
+1 addressed curved chip (many defects)

Dec 2016

Thinned Maryland chip + 45 mm curved, WLT
Thinned LOMID chip* + 45 mm curved, CLT
CMOS/OLED/TFE/HC

Winter 2018

Thinned Maryland + 45 mm curved, CLT
CMOS/OLED/TFE/HC

Summer 2017

Thinned testing vehicle, WLT
OLED/TFE/HC

Spring 2017

*Maryland chip: 0,38”, WVGA resol, mono yellow
LOMID chip: 1”, WUXGA resol (1920 x 1200), 2300 ppi, mono green
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Thank you for your kind attention