Highly-efficient embedded organic light emitter for CMOS optoelectronics

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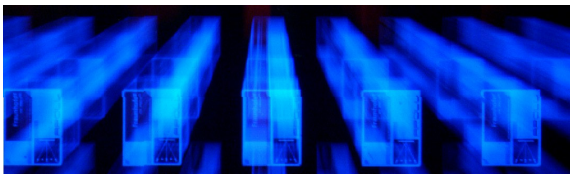
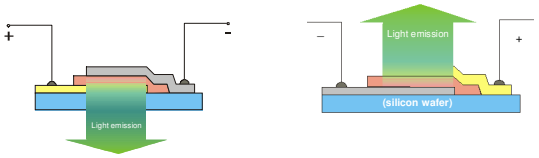


Outline

- Introduction
- OLED-on-CMOS: Applications
- OLED Microdisplays
- Technology
- Conclusion

Introduction to organic LEDs - OLEDs



bottom-emitting

- Lighting
- Medium and large display ⇒ TFT

transparent conductor
organic layers
metal cathode
substrate

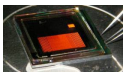
top-emitting

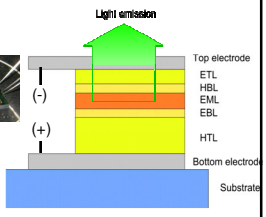
- OLED-on-CMOS

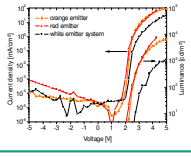
Introduction: OLED-on-CMOS (1)

Top-emitting p-i-n OLED:

- highly-efficient OLED light source in/on CMOS
- based on small molecules (NOVALED AG)
- evaporated on Si-wafer
  - sub-structuring by shadow mask >100µm
- all colors monochrome, white, NIR
- doped charge transport layers
  - low operating voltage
- transparent top electrode
- extremely thin (~100...300nm)
- excellent current and power efficiency (low-voltage, low-power)
- fast response time (MHz)



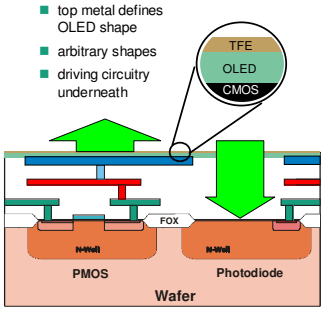




	Voltage [V] @100 cd/m²	Voltage [V] @1000cd/m²	Current efficiency [Cd/A] @100cd/m²	lifetime @1000cd/m²
red	2.4	3.1	14.1	
ora	2.5	3.2	11.6	12.000
white	3.2	4.7	5.7	

Introduction: OLED-on-CMOS (2)

- CMOS top metal = OLED bottom electrode
  - top metal defines OLED shape
  - arbitrary shapes
  - driving circuitry underneath

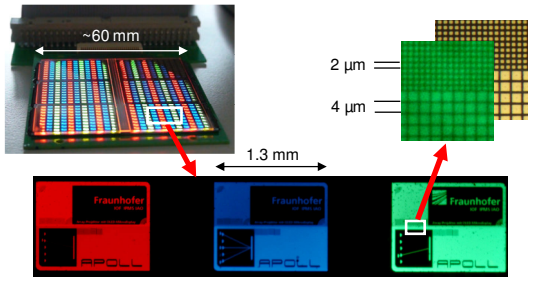


CMOS cross-section with OLED on top

- CMOS integration of electronic features
  - driving
  - acqusition
  - processing
  - control
- Co-integration of CMOS-compatible sensors
  - embedded photodetectors
  - temperature
  - magnetic (Hall)
  - MEMS,...

Example: OLED-on-CMOS testchip

- no active circuit, hardwired pattern (3 metals)
- separate deposition of monochrome RGB-OLED (shadow mask)
- pixel sub-structuring: shape of CMOS top metal



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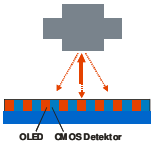
OLED-on-CMOS: Applications

sensors

- optical sensors
  - fluorescence, color, flowmetry, photoplethysmography,...
  - light barriers (reflective)
- embedded illumination for image sensors
  - patterned illumination possible
  - optical finger-print, lab-on-chip,...
- opto-coupler



microdisplays

- microdisplay
  - HMD, mobile/micro-projection, elec) viewfinder,...
- *bidirectional* microdisplay (display + embedded image sensor)
  - interactive HMD
  - optical inspection,...

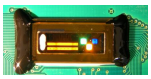
hypoled

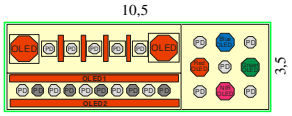
ISTAR

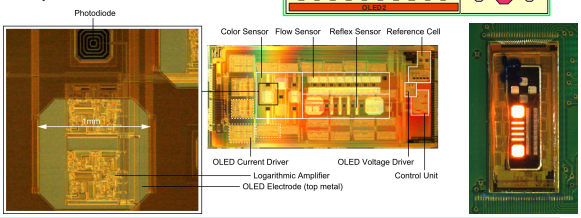
SEMO

OLED-on-CMOS: Sensors

- CMOS photodetectors (PD) and embedded OLED illumination, excitation
- three types of optoelectronic sensors:
  - reflection light barrier (top left)
  - flow sensor (bottom left)
  - color sensor (right)
- circuitry underneath OLED electrodes

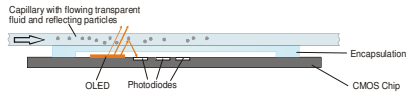


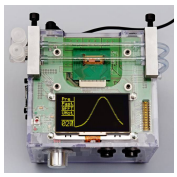




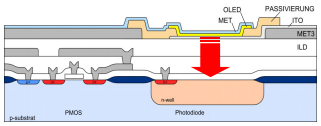
OLED-on-CMOS: Sensor applications

- Particle flow sensor
  - OLED stripes for fluid illumination and 8 photodiodes
  - light reflection depending on local fluid velocity and particle density
  - analyzing photocurrents and correlation functions, the fluid particle velocity can be calculated





- Opto-coupler



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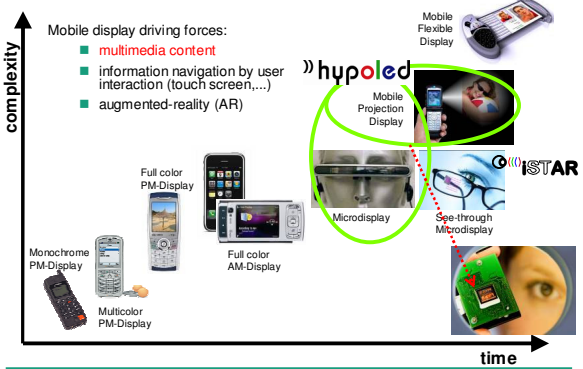
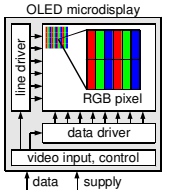
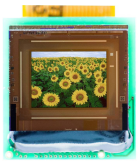
Mobile Display Dilemma



OLED microdisplay: Overview

- Physically very small, but
  - high information content (TV quality)
  - low power consumption
  - enlarged image viewed through magnifying optics
- Active-matrix substrate
  - data is stored inside pixel: analog/digital
  - sub-pixel size: {(4x4), 4x12, 8x8, 36x36} µm²
  - OLED pixel current: pA...nA
  - sub-structuring of display pixel with monochrome colors not possible
  - combination of white OLEDs with colour filter
- Applications
  - projection (rear, front, micro)
  - near-to-eye (NTE)
    - electronic viewfinder
    - head mounted

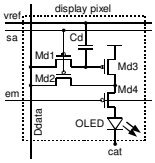


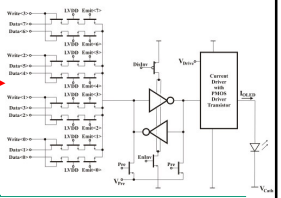


OLED microdisplay: Pixel concept

- small pixel pitch (≤12um RGB)
- OLED: current driven pA...nA, Lum~ioled
- grayscale realization: analog / digital

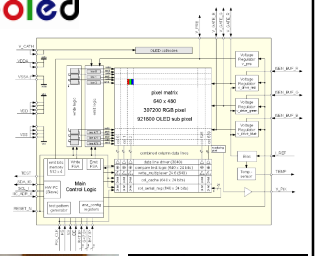
	Pixel Cell Principle	Advantage	Disadvantage
analog	current programmed (+subthreshold scaling) „ZOOM"	pixel cell transistor matching is irrelevant	long programming duration due to small currents
analog	voltage programmed	short programming duration	pixel cell transistor matching is important
digital	digital DRAM pixel cell hypoled ISTAR	- no D/A conversion - simple linearity correction by PWM	many transistors + DRAM refresh necessary
digital	digital SRAM pixel cell	- no D/A conversion - stable storage of bits	Increased number of transistors

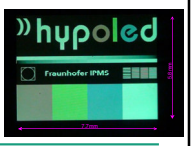




OLED microdisplay: hypoled

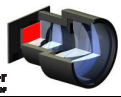
- full color VGA (640x480) OLED microdisplay
- pixel cell
  - digital DRAM pixel cell
  - luminance control by PWM
  - sub-pixel: 4x12µm²
- 24 bit parallel video interface
- 50/60Hz frame rate
- configuration of color, contrast and gamma correction via I²C
- high brightness
  - up to 10,000 nits for monochrome green (micro-projection)
  - 1,000 nits for RGB color (HMD)
- 0.18µm CMOS foundry process
- core supply, digital I/O interface 1.8V
- negative OLED cathode voltage (max. -5.5V)
- active area 7.7x5.8mm²
- chip size 12x11mm²

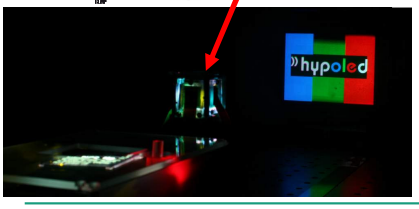




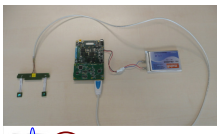
hypoled : Applications

- head-mounted display (HMD)
- RGB micro-projector





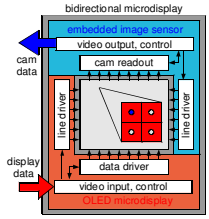
MediaBox (DVB-T, DVB-H, WLAN)

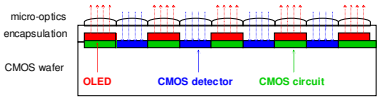


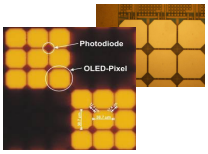
Bidirectional OLED microdisplay: Overview

"Bidirectional" functionality:

- OLED microdisplay + embedded image sensor
  - nested display and camera pixel
- embedded CMOS photodiodes
  - lower level than OLED
  - side-by-side with active electronics devices
- local optical crosstalk possible
- emission and detection can be operated in parallel or sequentially

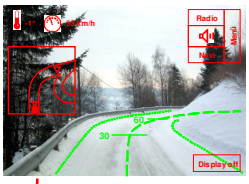


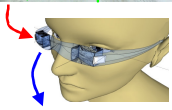


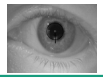


Bidirectional OLED microdisplay: HMD appl.

- conventional, unidirectional microdisplay
  - **displays an image**
  - OLED-on-CMOS microdisplay
- bidirectional microdisplay
  - displays an image and **detects another image** on the same device
  - OLED-on-CMOS microdisplay + embedded image sensor
- HMD application: aimed at tracking the eye movement with respect to
  - user's sight (consciously and unconsciously)
  - user's (situation) awareness (unconsciously)
- gaze-based human-display-interaction
  - visual Input-/Output-Device (I/O) for personal information management (PIM)
  - interactive augmented-reality (AR) applications







Bidirectional see-through HMD

Applications

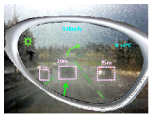
Automotive
- mission-critical information
- navigation
- safety (gaze monitoring)

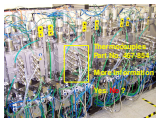
Mobile Communication
- telecom
- mobile multimedia
- tourist information

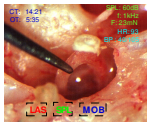
Industry
- mobile maintenance

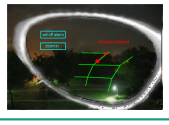
Medicine
- surgery support

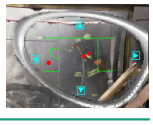
Security
- disaster management
- mobile surveillance
- mission control









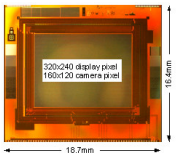


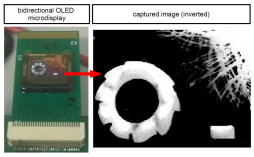
Bidirectional OLED microdisplay: 1st prototype "ZOOM"

OLED-Microdisplay
- Resolution monochrome QVGA (320 x 240)
- Grayscale 8 Bit, datainterface digital
- Pixel analog, pitch 36µm
- Peak luminance adj.: 100...20.000cd/m²
- Viewing area 11,5 x 8,6mm²
- Chipsize 18.7x16.4mm²

Image sensor
- Resolution 160x120 pixels (QQVGA)
- Photoactive area 8x8µm², linear readout
- Quickcapture I/F (w/ external ADC)

General
- Power Supply 3.3V
- OLED Supply-9..0V
- Configuration via I2C
- Samples in lab, eval. kit expected Q1/2011

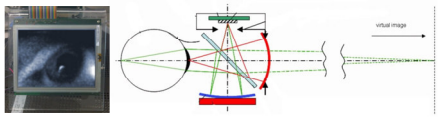




Bidirectional OLED microdisplay: ZOOM-HMD

- see-through HMD
  - semitransparent mirror
  - separate optical pathes for display (VIS) and camera (NIR) → filters
- PDA-like host with embedded computer
  - embedded Linux
  - image processing → eye-tracking
  - user interfaces/interaction + app.

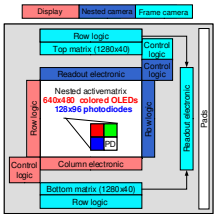
captured eye-scene

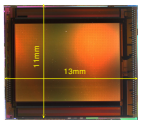


virtual image

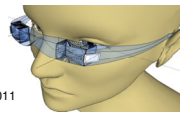
Bidirectional OLED microdisplay: "iSTAR"

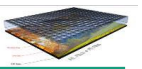
- full-color VGA 640x480
  - Sub-pixel 8x8µm
  - ≤1000 nits
- embedded/intersected camera
  - 128x96 pixel
- frame camera
  - top + bottom 1280x40
  - microlenses
- interface display / camera
  - parallel + sync signals
  - configuration via I2C
- dimensions
  - active area 10.2x7.7mm²
  - chip size 13x11mm²
- volume-capable processes
  - CMOS: 0.18µm (foundry)
  - OLED: COMEDD pilot line
- first samples in lab, demo expected Q1/2011





iSTAR chip micro-photograph





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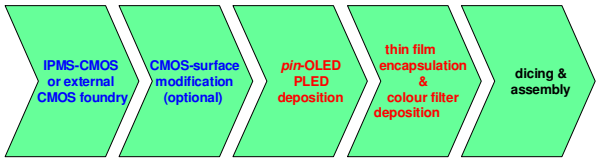
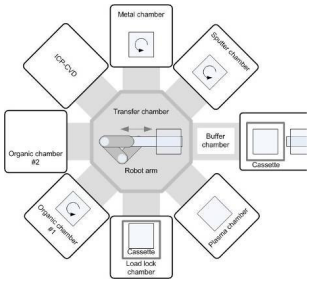
OLED-on-CMOS: Manufacturing process flow

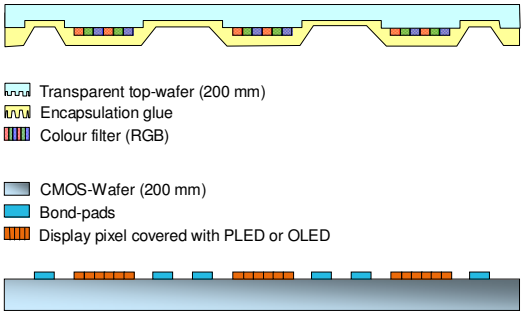


The whole process chain is available at COMEDD to prepare OLED microdisplays.

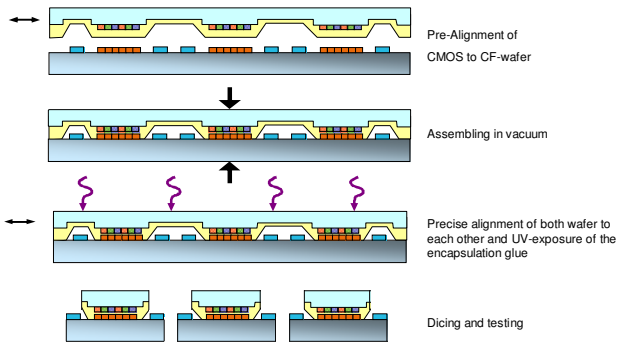
SMALL MOLECULE *pin*-OLED DEPOSITION SYSTEM SUNICEL *PLUS*200 @ IPMS



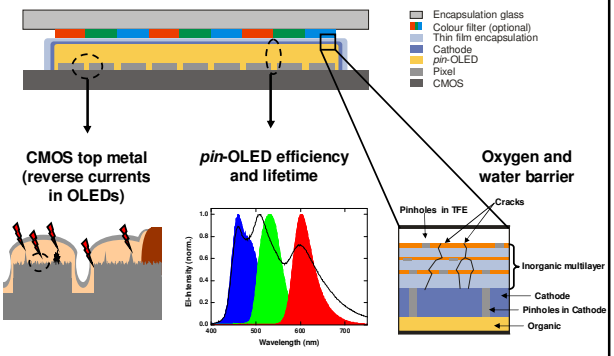
Microdisplay components



Microdisplay production steps



MAIN RESEARCH TOPICS FOR OLED MICRODISPLAYS



COMEDD EQUIPMENT FOR OLED AND OPV

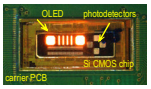
COMEDD	Prototype line Rigid substrates	Pilot line Rigid / Flexible substrates	Pilot line OLED-on-CMOS	Roll-to-Roll
Substrate size	200 x 200 mm²	370 x 470 mm² (Generation2)	150 or 200 mm diameter	300 mm width
Substrate type	Glass	Glass/laminated foil	Si/CMOS wafer	Metal foil
Cycle time	120 minutes	3 minutes	60 minutes	
Pilot max. volume Substrates/ year		80,000	6000	
Pilot max. volume area		13,000 m²		
Prototype/R&D	Ready	Ready	Ready	2010
Ready for Pilot production		2010	2010	

Outline

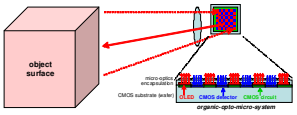
- Introduction
- OLED-on-Silicon: Sensor applications
- OLED Microdisplays
- Technology
- Conclusion

Conclusion

- p-i-n type OLED on adapted TiN/Al electrodes well suitable for OLED-on-CMOS
  - <5.0V @ 1000cd/m² → CMOS w/o HV option for high brightness
  - co-embedded light sources, photodetectors, signal processing
  - optical cross-coupling effects to be avoided



- opto-sensor applications
  - patterned illumination/excitation and image/response detection/analysis
  - fluorescence, color, opto-coupler
  - lab-on-chip



- bidirectional OLED microdisplay
  - display and image sensor in a single device
  - eye-tracking in near-to-eye applications
    - interactive head-mounted displays
    - optical surface inspection

Acknowledgement

- Work was in parts sponsored by
  - European Commission within the HYPOLED project
  - Federal Ministry for Education and Research of the German government "ZOOM"
  - Fraunhofer Internal Programs "iSTAR"
- Thanks to our collaborative project partners: X-FAB; Fraunhofer IOF, IOSB, IGD.
- Thanks to many more contributors at IPMS and our students!

See demo during break!

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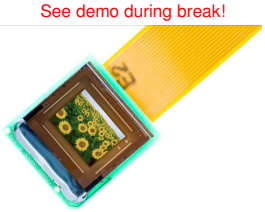

Thank you for your attention!