

„Hetero-Integration of Emissive Frontplanes onto Si-CMOS Backplanes for Microdisplays & Sensors“

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Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP, Dresden, Germany

About Fraunhofer FEP

Institute figures

Employees	194
Total budget	28,8 Mio. €
Industry returns	11,5 Mio. €
Public funding	9,8 Mio. €
Investment	1,3 Mio. €

(Figures 2021, by April 2022)

Location: Dresden (two sites)



Institute lead



Prof. Dr. Elizabeth von Hauff, Director



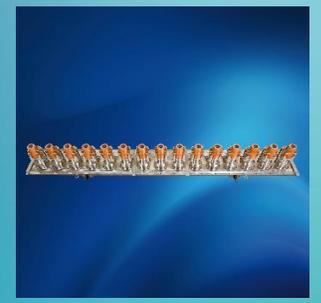
Dr. Uwe Vogel, Deputy Director
Division Director Microdisplays & Sensors



Electron Beam Technology



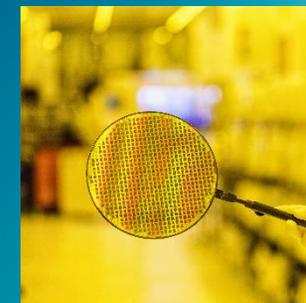
Roll-to-roll
Technology



Technical Key Components



IC Design



Organic
Electronics

Microdisplays & Sensors



Plasma-assisted large-area
and precision coatings

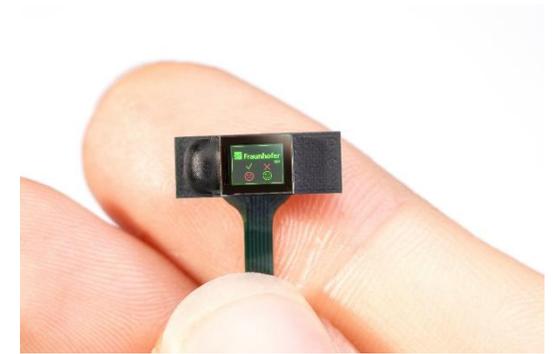
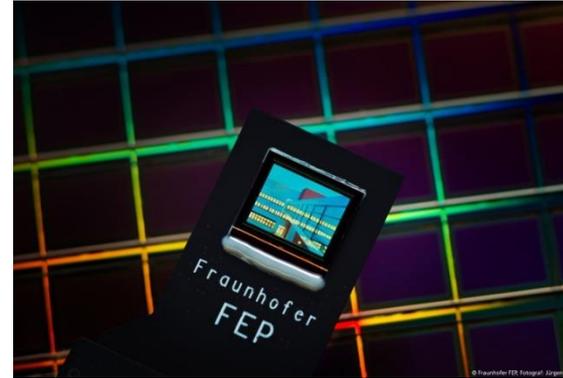
Microelectronics

Core Competences of Fraunhofer FEP

Microdisplays (general)

■ Definition

- Physically very small (<1.3"), yet
 - High information content (TV quality)
 - $\geq 1000\text{ppi}$, i.e. pixel pitch $\leq 25 \times 25 \mu\text{m}$,
 - typically $2.5 \mu\text{m}$ dot pitch (i.e., 2000..3000..5000ppi)
 - Active matrix substrate (mostly CMOS)
 - Low power consumption
 - Enlarged image viewed through magnifying optics



■ Applications

■ Projection

- Rear projection
- Front projection
- Micro projection

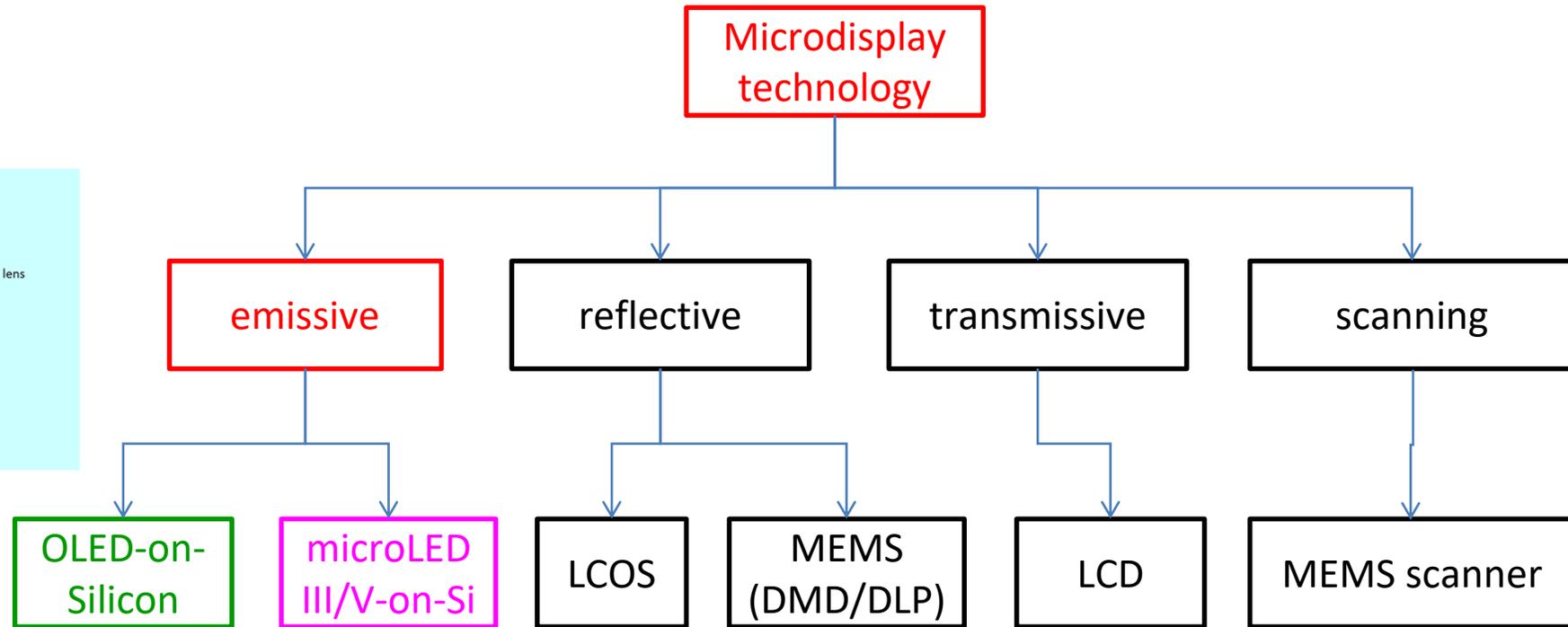
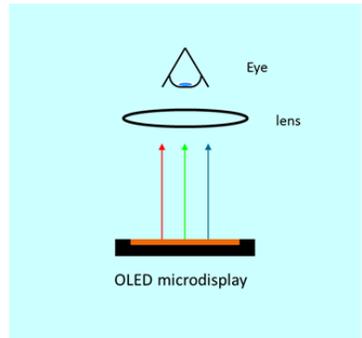


■ Near-to-Eye (NTE)

- Electronic Viewfinder (EVF)
- Hand-held
- Head/helmet Mounted
 - Professional, Consumer
 - Augmented-, Virtual-, Mixed-Reality (AR, VR, MR)

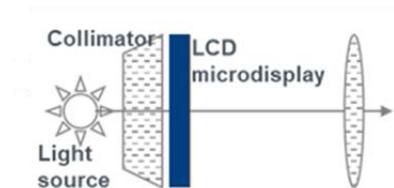
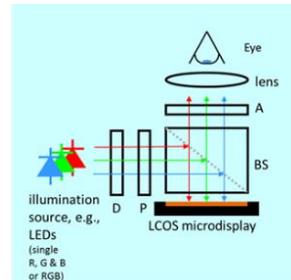


Microdisplay technology



Heterogeneous:
Monolithic
(sole substrate:
OLED-on-CMOS)

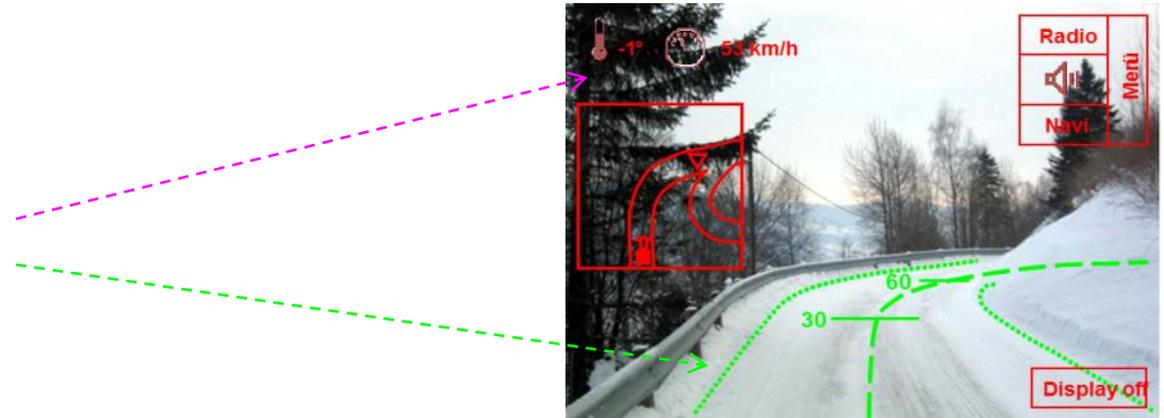
Heterogeneous:
Hybrid
(multiple substrates:
 μ LED+CMOS)



„Smart Eyewear“ (+ head-up Displays)

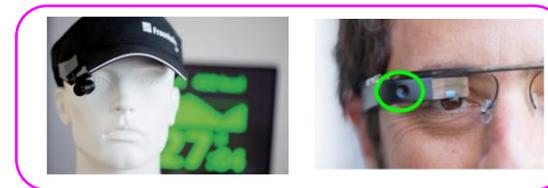
AR vs. VR

- VR: **Immerses viewer** into 3D environment
 - sense of being in another space
- AR: **Supplement or modify direct view** of real world
 - overlay computer-generated graphics/video (or/and other information) in
 - semantic context – “**assisted AR**”
 - semantic and spatial context – “**true’ AR**”



Near-to-eye Displays

- Head-mounted
 - Fully-immersive** (or Video-see-through) -> virtual-reality (VR), mixed-reality (MR)
 - Optical see-through** -> augmented-reality (AR) (also **head-up displays/HUD**)
 - Look-around** (context-aware information display, AR)



	Fully immersive	Optical see-through	Look-around	Head-up (automotive, avionic)
Resolution	>FHD (1080p)	>HD (720p)	QVGA..HD	>F/HD
Luminance	<200cd/m ²	>5000cd/m ²	100..10.000cd/m ²	>10..1.000cd/m ²
Power consumption	<500mW	<100mW	<10mW	>1W
Frame rate	>90Hz	>60Hz	0	>90Hz
Latency	<10ms	<10ms	<10ms	<10ms

O/LED microdisplay CMOS backplane

- Current- vs. voltage drive

- PWM, PAM, combined

- Effects on

- Efficiency

- Color

- Dynamic range

- Pixel cell size

- OLED:

- Single unit (white): 2.5..7V

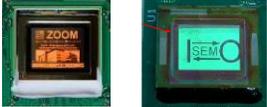
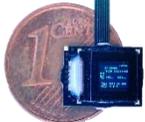
- Multi units: >5V

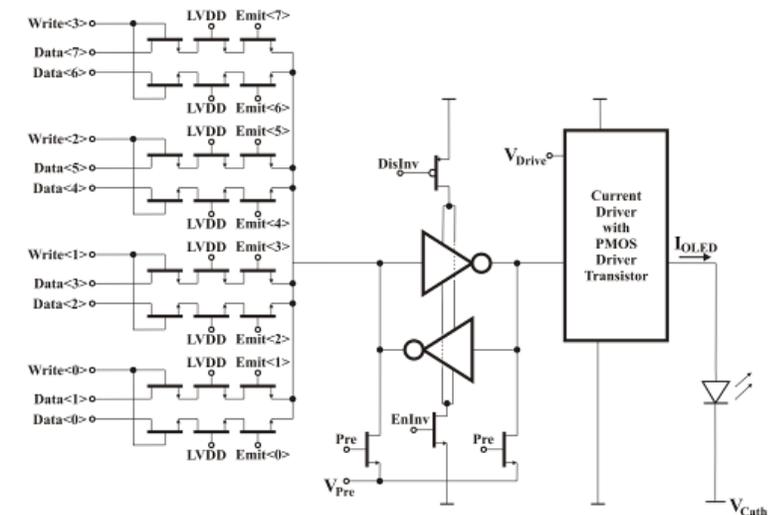
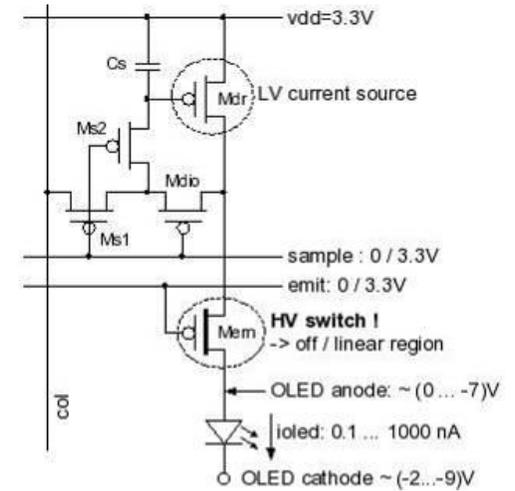
- Efficiency maximum @1..100mA/cm²

- μLED

- 2..4V

- Efficiency maximum @1..10A/cm²

Pixel Cell Principle	Pro	Con
current programmed current memory cell (+ subthreshold scaling) 	pixel cell transistor matching is irrelevant	long programming duration due to small currents
voltage programmed current source cell 	short programming duration	pixel cell transistor matching is important
voltage programmed comparator cell 	small pixel cell	poor linearity power consumption mismatch of driving transistor (V _{th})
digital DRAM pixel cell 	in-pixel D/A conversion simple linearity correction by pulse width	many transistors necessary, temperature compensation needed
digital SRAM pixel cell 	stable storage of bits in-pixel D/A conversion	increased number of transistors



Promise/expectations of μ LED vs. μ OLED

■ Technical/performance

- Higher luminance
- Larger ambient/operating temperature range ($\gg 85^\circ\text{C}$)
- Better current/power efficiency (???)
 - Currently $< \text{OLED@small pixels}$ -> Low-power (???)
- Longer lifetime (reliability) (IF very high-brightness!)
 - No image sticking
- Faster switching (e.g., higher frame rate)
 - mainly for sensors/communication, no real advantage in imaging
- Narrower bandwidth (higher spectral purity)
- Wider wavelength range (IR, UV)
- Tightened emission angle (NTE optics aperture)
- (Short) Coherence
- Higher pixel-density (???)
- Cheaper (???)

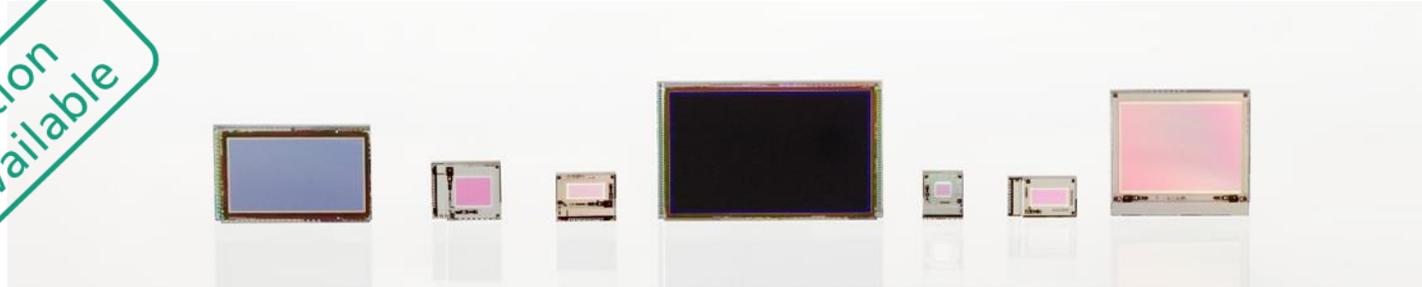
	μ OLED	μ LED
Maturity	high	Low yet
Image quality	high	Tbc: pixel-to-pixel uniformity, color
Power efficiency	high	$< \text{OLED@small pixels}$
Brightness	Mono: High Color: Medium	Mono: Very high Color: Tbc
Cost	moderate	$> \text{OLED}$

■ Economic

- Serve applications not reachable so far, e.g., automotive and aviation HUD, LIDAR, holographic displays, safety/security,...
- Some years of public and industrial R&D funding in technology, devices, applications likely (before maturity)
- Regional, national, EU value chain/sovereignty feasible (process technology closer to established microelectronics)

Characteristics of O/LED microdisplay backplane designs

Evaluation Kits available



	Ultra-low power			Bidirectional	AR	VR
	UUGL1120	UUGL1220	UUGL1320	EBCW1020	HUCW1010	JUCW1010
resolution	304x256	304x128	720x256	800x600	1280x720	1920x1200
dot/pixel pitch	12µm	12µm	5µm	8/16 µm	5.5/11µm	5.5/11µm
color	mono	mono	mono	RGBW	RGBW	RGBW
max. current per pixel	~2µA/pixel (~1,3A/cm ²)	~2µA/pixel (~1,3A/cm ²)	~900nA/pixel (~3,6A/cm ²)	~1µA/pixel (~1,56A/cm ²)	~2.8µA/pixel (~2,3A/cm ²)	~2.8µA/pixel (~2,3A/cm ²)
screen diagonal	0.19"	0.16"	0.15"	0.63"	0.64"	1.0"
data Interface	SPI	SPI	SPI	parallel	parallel	parallel
configuration interface	SPI	SPI	SPI	I2C	I2C	I2C
typ. power consumption	1-3mW	1-3mW	1-3mW	200mW@ 60Hz	100mW@ 60Hz	140mW@ 60Hz

Outlook: O/LED-on-Silicon/microdisplays features and applications

■ high-brightness

- see-through near-to-eye @ sun light condition
- embedded projection, optogenetics (brain/nerve interface)

■ high-resolution

- Pixel densities >10kppi
 - Light-field and holographic displays
 - smaller chip size, lower cost

■ (embedded) sensing

- Single-chip image converter
- Quantum sensors (very-low magnetic fields)

■ (embedded) computing/connectivity

- Edge Vision + Edge AI
- Deep sub-micron CMOS process backplanes on 300mm

■ extended spectral emission and detection range

- UV, IR; α , β , γ : Quantum Dots, μ LED

■ New form factors, e.g., transparent microelectronics

- e.g., smart contact lens display

■ Manufacturing processes: yield, production costs



2.5 μ m dot pitch 1440x1080
OLED microdisplay on 28nm
backplane

-> check SID Display Week
2023 in LA!

Collaboration, Contact

- Devices/technology evaluation (pilot studies)
- System integration (optics, electronics, sensors, communication,...)
- Applications (viewfinder, image converter, AR/VR/MR, sensing, ...), end user
- Technology transfer/licensing
- R&D
 - Customer-/applications-specific components and devices
 - Application specifications
 - Manufacturing technology, pilot-fabrication
 - Private and publicly funded collaborative projects
- **Contact**
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