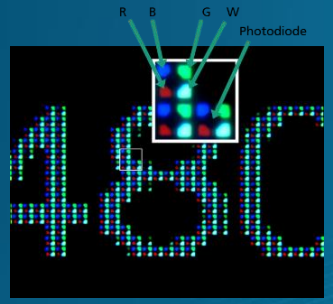

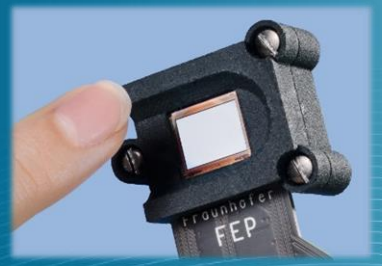

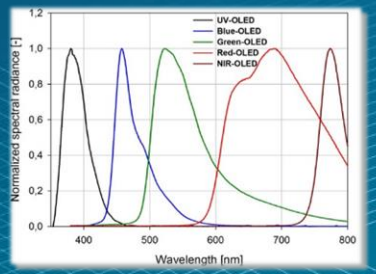

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FEP

Fraunhofer-Institut für Organische Elektronik, Elektronenstrahl- und Plasmatechnik FEP

„O/LED Microdisplays for AR/VR/MR: Requirements and Features”

Dr. Uwe Vogel & colleagues

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

Plasma-assisted large-area and precision coatings

Microdisplays & Sensors

Microelectronics

Core Competences of Fraunhofer FEP

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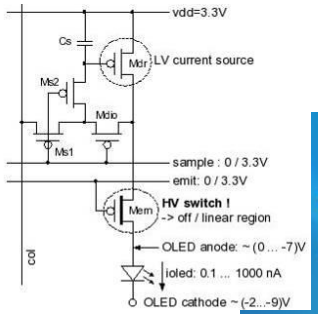
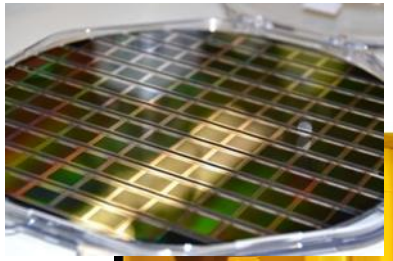
X-on-Silicon/CMOS: Core competences

- Backplane IC design
  - silicon foundries processes
    - Sub- (200mm) & deep-sub-micron (300mm)
  - Mixed-signal
  - mainly for micro-displays & optoelectronic sensors
- 200mm X-on-silicon wafer line for frontplane processing
  - Monolithic
    - Organic semiconductors
      - OLED, OPD
    - Quantum dots
    - NVC diamonds (quantum sensing and computing)
    - Barrier layers, thin-film encapsulation
    - Silicon photonics
  - hybrid
    - Compound semiconductors, e.g., µLED
    - Liquid-crystals
  - Electro-optical wafer-level and device testing
  - 300mm roadmap





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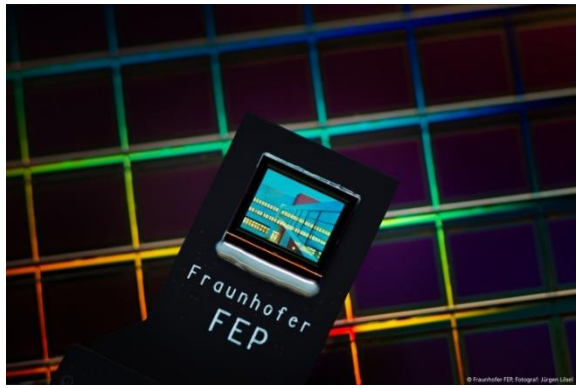
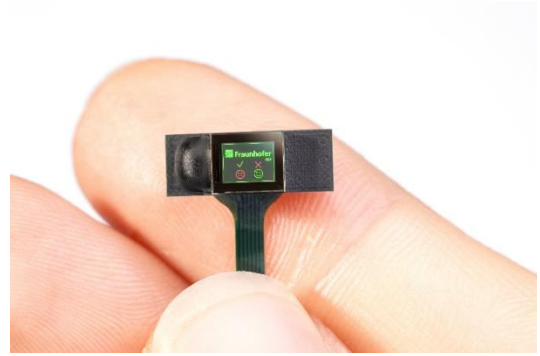
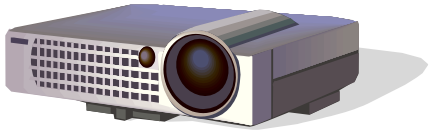
Microdisplays (general)

- Definition
  - Physically very small (<1.3”), yet
    - High information content (TV quality)
      - ≥1000ppi, i.e. pixel pitch ≤25x25µm,
      - typically 2..5µm 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)



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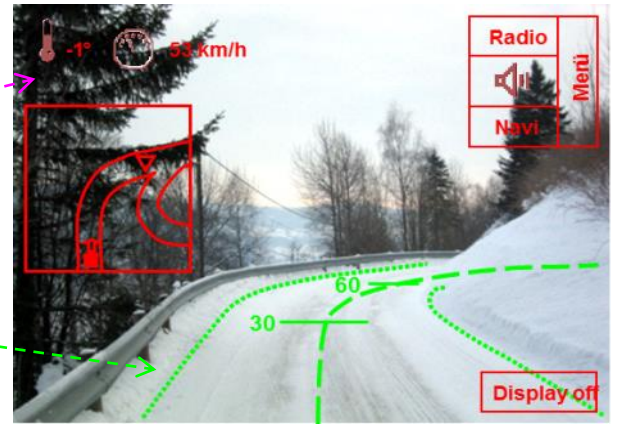
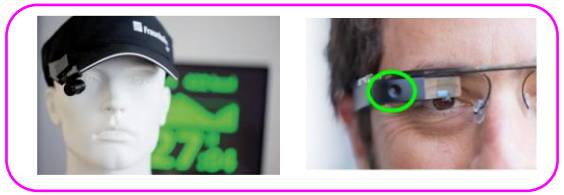
„Smart Eyewear“ (+ head-up Displays)

- 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/m²	>5000cd/m²	100..10.000cd/m²	>10..1.000kcd/m²
Power consumption	<500mW	<100mW	<10mW	>1W
Frame rate	>90Hz	>60Hz	0	>90Hz
Latency	<10ms	<10ms	<10ms	<10ms



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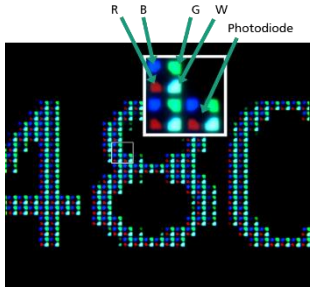
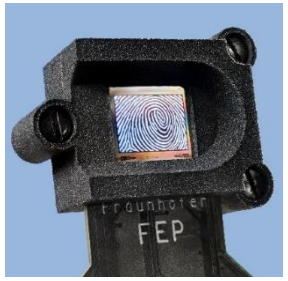
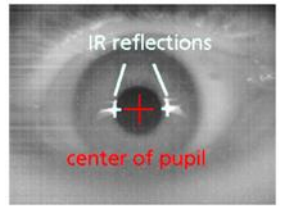
OLED-on-Silicon/CMOS: Features, devices and applications

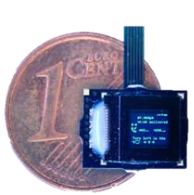
- **Bi-directional**
  - Display and image sensor in single chip
    - AR, VR, Eye-tracking
    - Optical fingerprint, Surface inspection, medical



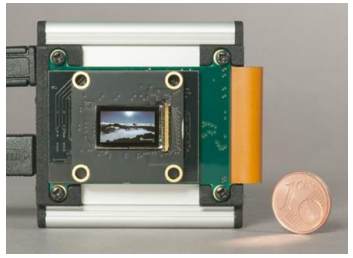




- **ultra-low power**
  - Wearables, electronic viewfinder, assisted-reality



- **large-area**
  - very high-definition (>FHD)
  - VR, AR, micro-projection



- **NIR imager**
  - Organic photodiodes (OPD) on silicon CMOS
- **embedded sensors**
  - Gas or liquid process monitoring, e.g., O2, pH

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OLED-on-Silicon/CMOS: Features, devices and applications

- Bi-directional
  - Display and image sensor in single chip
    - AR, VR, Eye-tracking
    - Optical fingerprint, Surface inspection, medical
- ultra-low power
  - Wearables, electronic viewfinder, assisted-reality
- large-area
  - very high-definition (>FHD)
  - VR, AR, micro-projection
- NIR imager
  - Organic photodiodes (OPD) on silicon CMOS
- embedded sensors
  - Gas or liquid process monitoring, e.g., O2, pH
- ***Production- and Field-proven***

ActiveLook smart glasses (Image: ActiveLook)

Example customer products

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Microdisplays & Sensors

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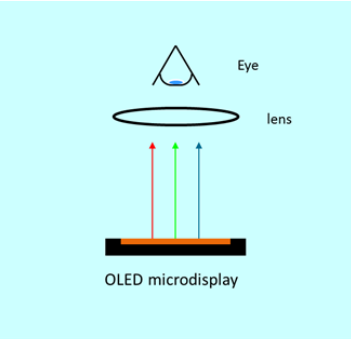
Microdisplay technology



- Microdisplay technology
  - emissive
    - OLED-on-Silicon
    - microLED III/V-on-Si
  - reflective
    - LCOS
    - MEMS (DMD/DLP)
  - transmissive
    - LCD
  - scanning
    - MEMS scanner

Heterogeneous:

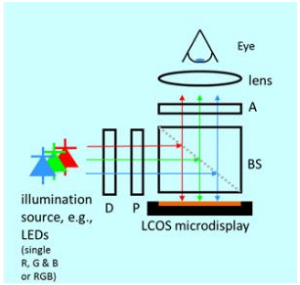
Monolithic

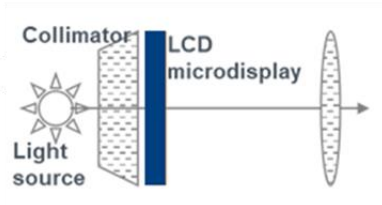
(sole substrate: OLED-on-CMOS)

Heterogeneous:

Hybrid

(multiple substrates: µLED+CMOS)





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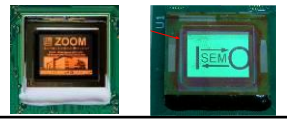
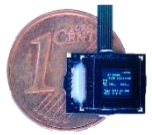
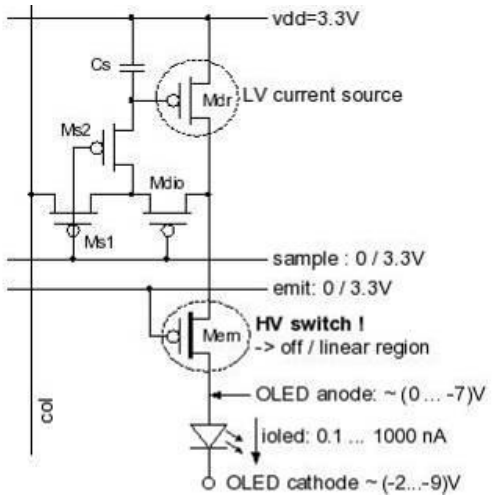
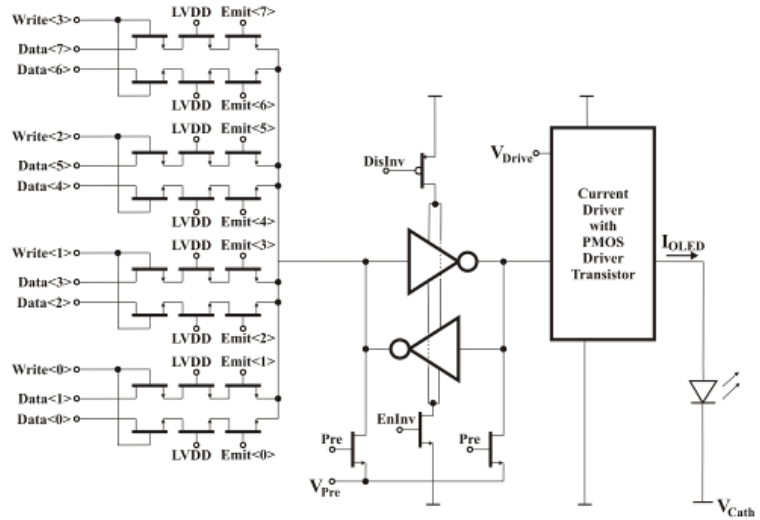
O/LED microdisplay CMOS backplane

- 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 (Vth)
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





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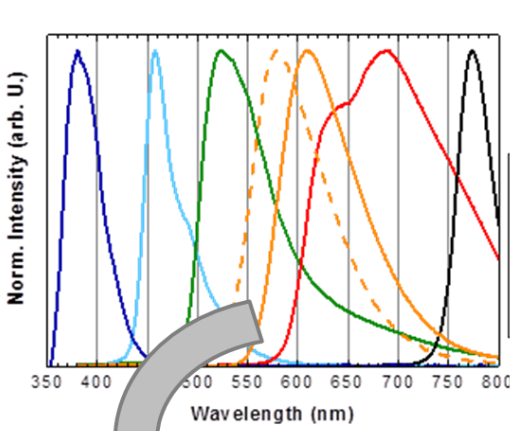
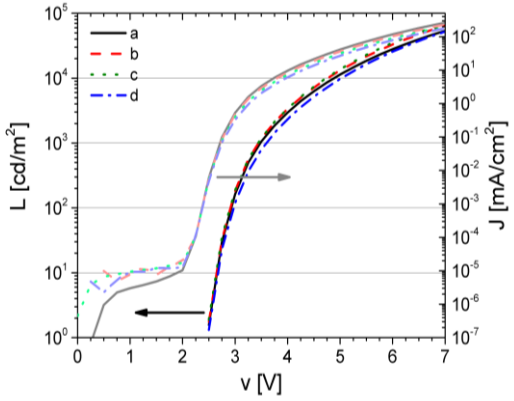
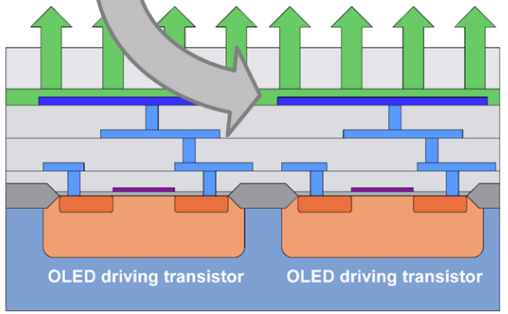
OLED-on-Silicon

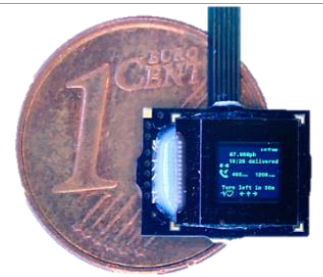
- Highly-efficient OLED light source (“frontplane”) on silicon CMOS (“backplane”)
- High-res microdisplays (dot pitch about 2..5..50..µm) & optoelectronic sensors
- Multi-spectral
  - VIS (red, orange, yellow, green, blue,…), NIR, UV
  - Tunable peak wavelengths & spectral widths
  - High luminance (>20.000 cd/m²) for monochrome emitters (spec. red..yellow/orange..green)
- Fast switching (µs..ns)
- Very low power consumption (backplane architecture and frontplane efficiency)

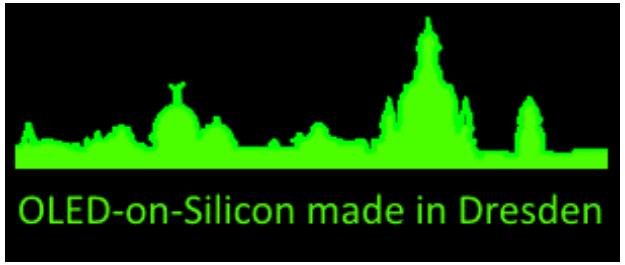


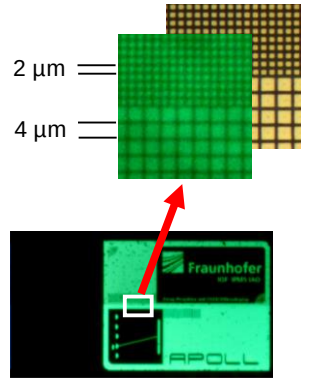




OLED-on-Silicon: cross-section with unpatterned OLED on top







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Promise/expectations of µLED vs. µOLED

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

	µOLED	µLED
Maturity	high	Low yet
Image quality	high	Tbc: pixel-to-pixel uniformity, color
Power efficiency	high	< OLED@small pixels
Brightness	Mono: High Color: Medium	**Mono: Very high** Color: Tbc
Cost	moderate	> OLED

- Economic
  - Serve applications not reachable so far, e.g., automotive and aviation HUD, LIDAR, holograhic 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)

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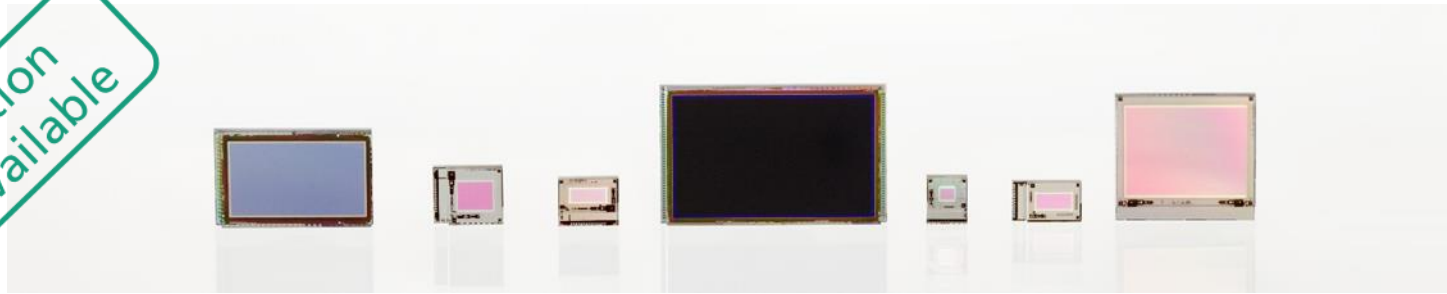
Characteristics of O/LED microdisplay backplane designs

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/cm²)	~2µA/pixel (~1,3A/cm²)	~900nA/pixel (~3,6A/cm²)	~1µA/pixel (~1,56A/cm²)	~2.8µA/pixel (~2,3A/cm²)	~2.8µA/pixel (~2,3A/cm²)
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

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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, µLED
- New form factors, e.g., *transparent microelectronics*
    - e.g., smart contact lens display
      - See SPIE Digital Optics, June 25..29, Munich
- Manufacturing processes: yield, production costs

2.5µm dot pitch 1440x1080 OLED microdisplay on 28nm backplane
(+ µLED, LCOS)

-> SID Display Week 2023!

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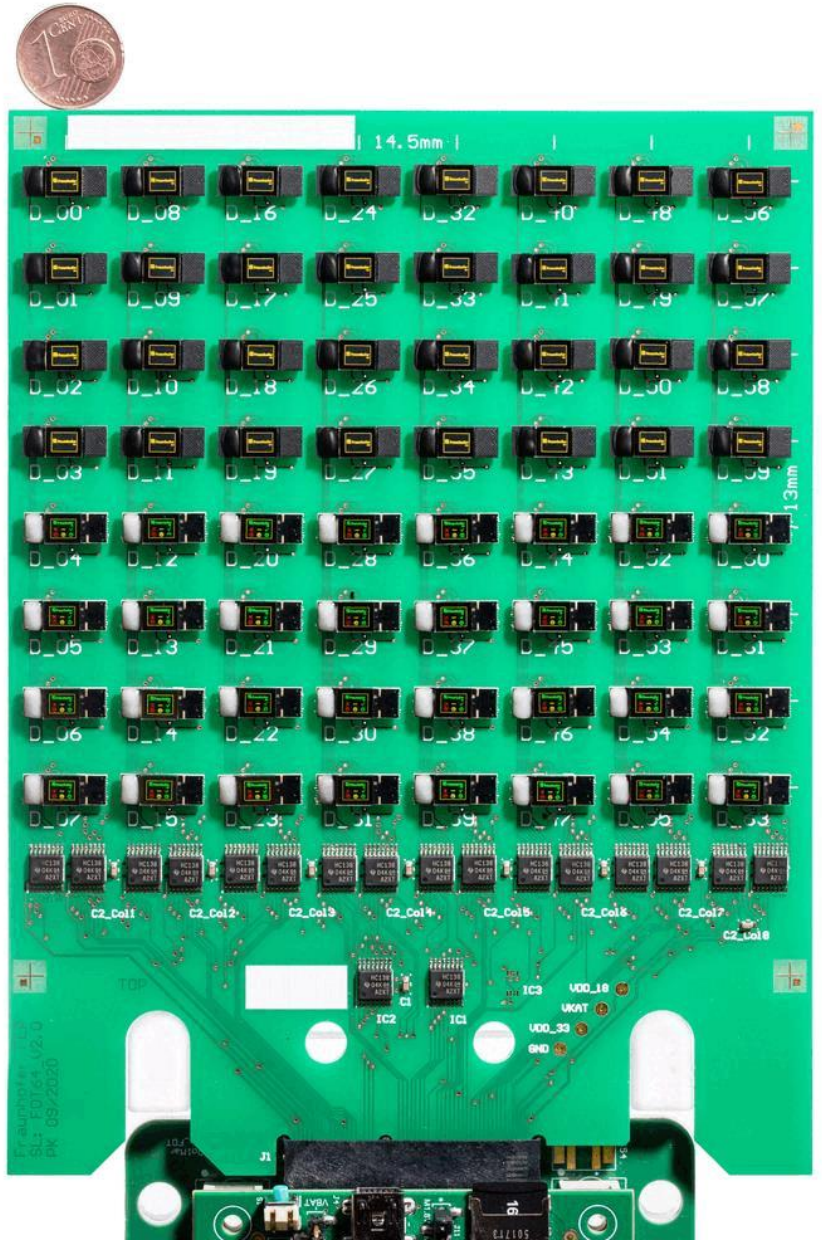
Collaboration, Contact

- 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
  - Dr. *Uwe Vogel*
    - Deputy Institute Director
    - Division Director „Microdisplays and Sensors“
    - Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP
      - Maria-Reiche-Strasse 2, D-01109 Dresden, Germany
      - phone: +49-351-8823-282, +49-151-12174078
      - email: uwe.vogel@fep.fraunhofer.de



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