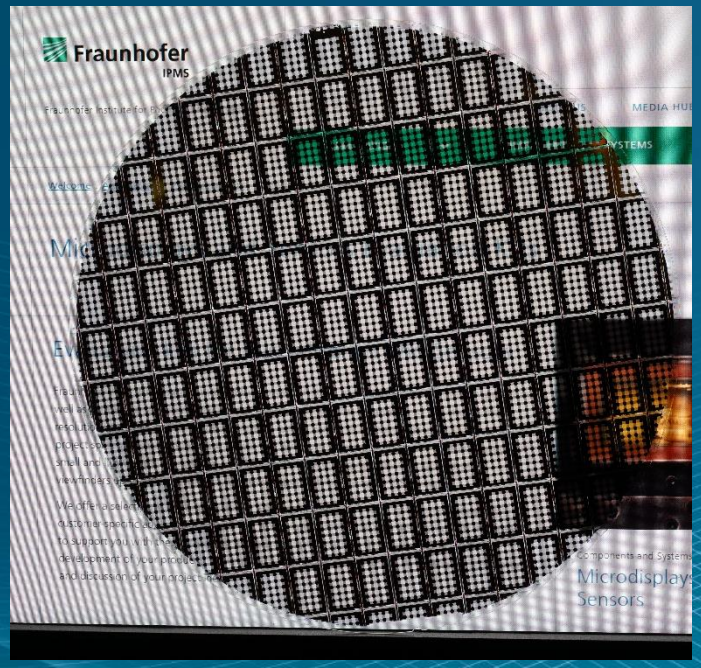

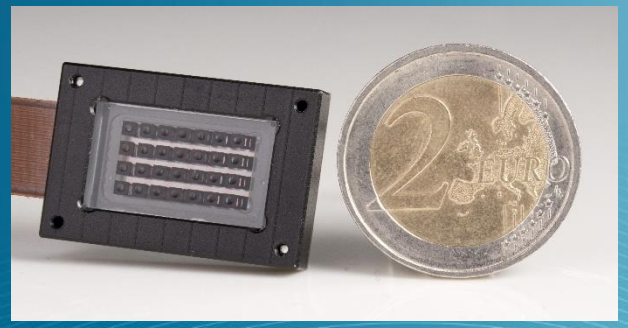

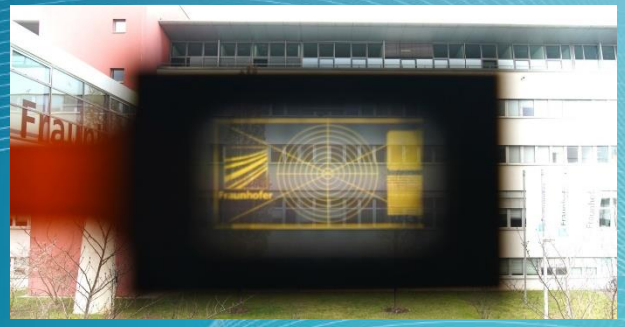

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Fraunhofer-Institut für Photonische Mikrosysteme IPMS

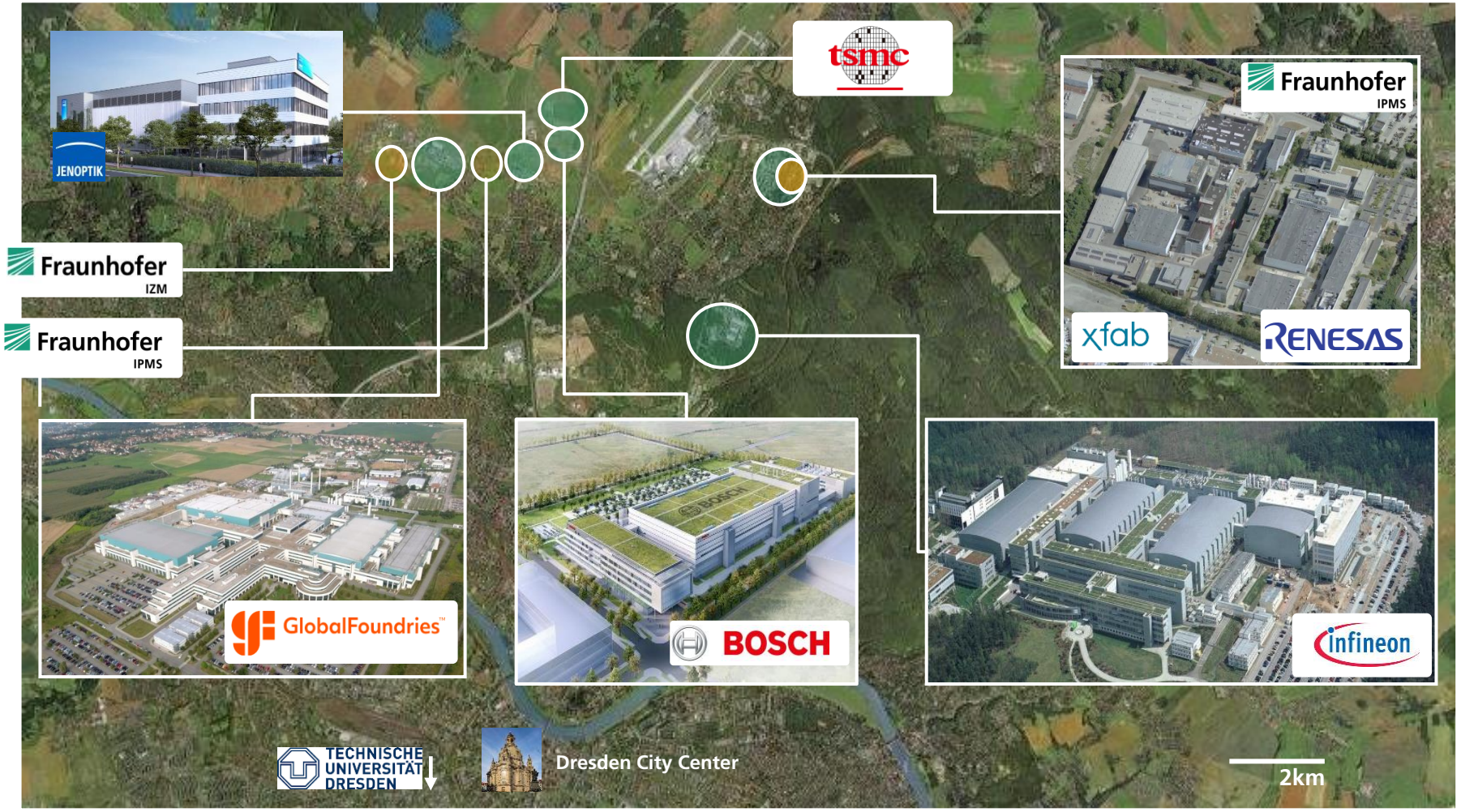
„Semi-transparent CMOS backplane for advanced near-to-eye microdisplays - in optical see-through augmented-reality"

Dr. Uwe Vogel (Head of Business Unit „Microdisplays & Sensors")
P. Wartenberg, B. Richter, S. Brenner, J. Baumgarten, S. Lenk, K. Fehse, D. Schlebusch, M. Törker, A. Fritscher, J. Zeltner, C. Schmidt, M. Rolle, S. Damnik, M. Metzner, J. Mütze, F. Schuster

Fraunhofer Institute for Photonic Microsystems IPMS, Dresden, Germany
(group recently moved from Fraunhofer FEP to IPMS)

Silicon Saxony -

The Heart of European Microelectronics Beats in Dresden



Silicon Saxony

Every third chip produced in Europe comes from Saxony.

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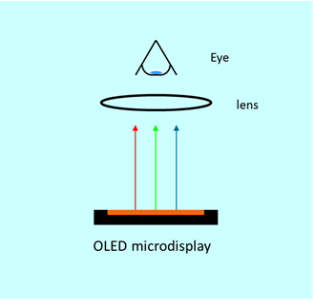
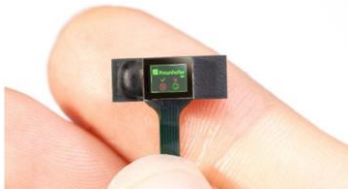
Microdisplay technology

Light source = image modulator





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

Heterogeneous:
Hybrid
(multiple substrates: µLED+CMOS)

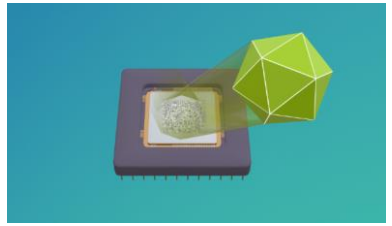
-> Make those transparent!

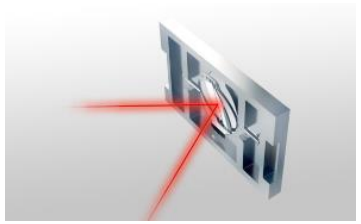
Microdisplay technology

- Emissive (non-transparent)
  - OLED-on-Silicon
  - microLED III/V-on-Si
- reflective
  - LCOS
  - MEMS SLM (DMD)
- transmissive
  - LCD
- scanning
  - MEMS scanner

Light source ≠ image modulator

-> separate devices





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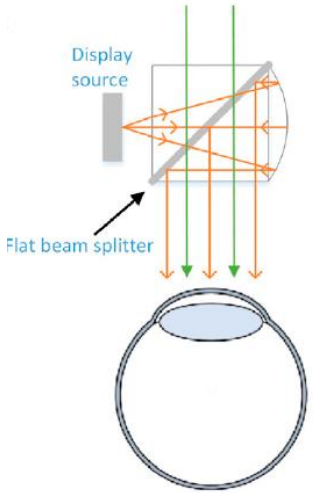
Current optical see-through optics approaches (in brief)

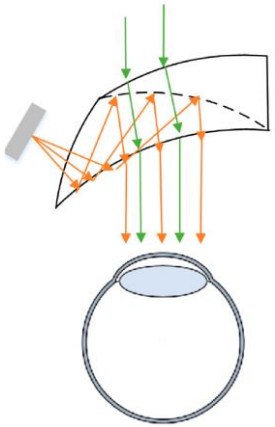
- Common challenge
  - Optimize FOV, high-resolution (ppi, ppd), brightness, color, weight, optical efficiency, eyebox, slim form factor, focus cue, mutual occlusion, manufacturing/cost -> simultaneously
- Major types of optical see-through setups so far:



45° flat combiner, beam splitter, bird-bath

Pro: simple

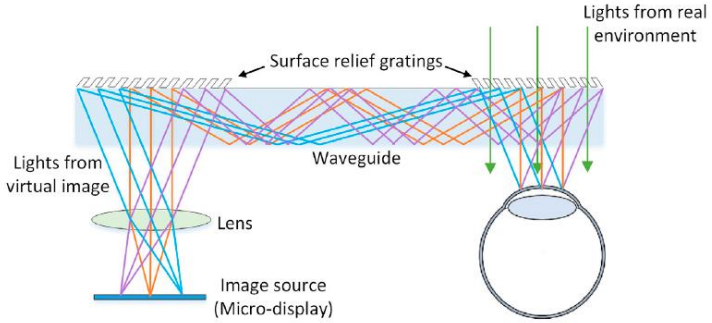
Con: form factor vs. FOV, efficiency, distortion



Freeform

Pro: compact

Con: VAC



Waveguides/HOE (diffractive, reflective, HOE,...)

Pro: good trade-off in form factor, eyebox, cost

Con: FOV, low efficiency (often narrow emission required)

Others, e.g.,

- pinlight,
- metasurface,
- transmissive mirror,
- polarization

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Xia X, Guan FY, Cai Y and Magnenat Thalmann N (2022): Challenges and Advancements for AR, Optical See-Through Near-Eye Displays: A Review. Front. Virtual Real. 3:838237. doi: 10.3389/frvir.2022.838237

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Current optical see-through optics approaches (in brief)

- Waveguides typically require high-luminance light sources (due to low optical efficiency)
  - -> LCOS, MEMS-SLM, micro-LED
- Drawback: light engine high power consumption
  - e.g., Goertek 0.13“, Monochrome green: 1W, RGB: 2.4W[1]
- -> too much power consumption for WEARABLES!
  - assume <1Wh battery capacity, >12h continuous operation
  - -> entire electronics (incl. controller, wireless interface,...) <20mW -> light engine <5mW![2]
- Waveguides commonly exclude „OLED“ for emissive display engine
  - Too wide emission spectrum
  - Too low luminous flux

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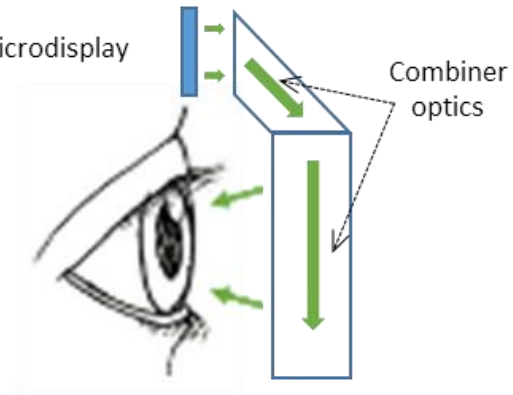
[1]Angus Wu "A novel display solution for XR Metaverse glasses", Proc. SPIE 12450, SPIE AR, VR, MR Industry Talks 2023

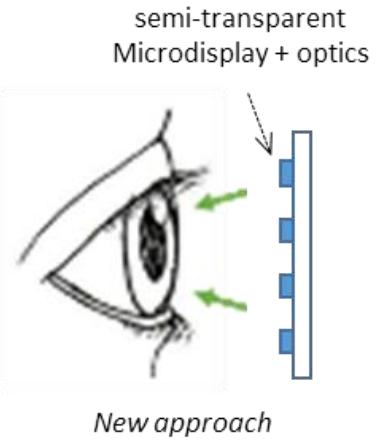
[2]Eric Marcellin-Dibon „High efficiency OLED microdisplays and the AR paradigm”, SPIE DOT (2023)

Low-power in AR: Alternative optics concept required

- Semi-transparent, emissive microdisplay backplane
  - -> display becomes the combiner
  - -> no significant optical losses anymore!
  - -> moderate light engine luminous flux required only
    - OLED sufficient
      - OLED-on-Silicon mature already
    - µLED valid
      - when µLED-on-Silicon becomes mature



State-of-art



New approach

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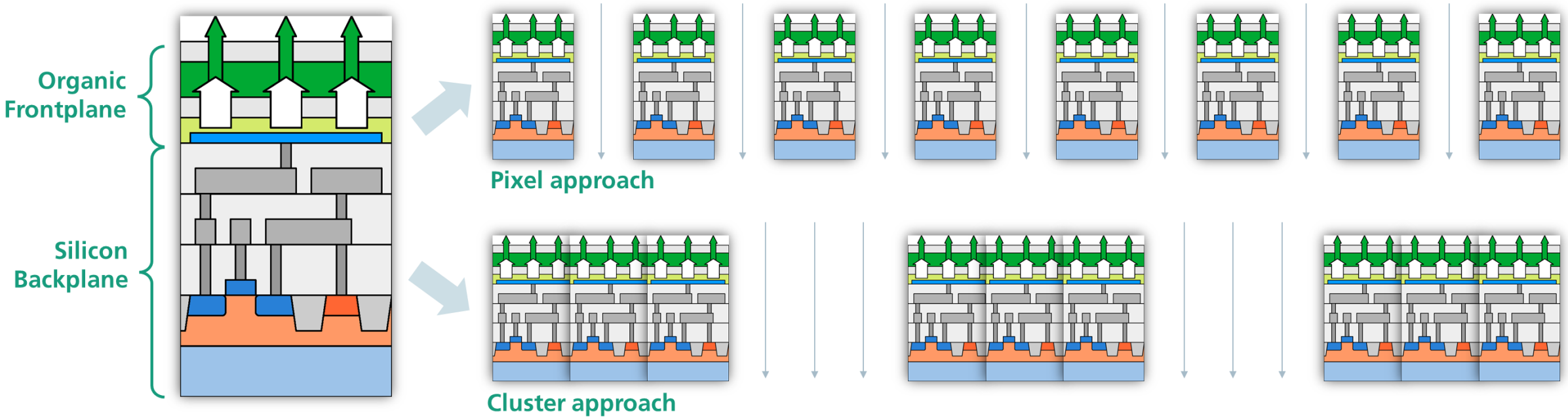
Optical Setup: Sparse „Pixel“ vs. „Cluster“ approach

-> Leave backplane (and frontplane) transparent circuit layout spaces in between „pixels“ or „clusters“



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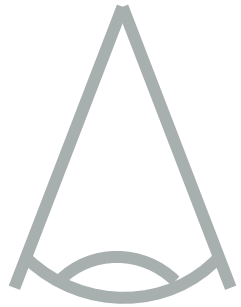
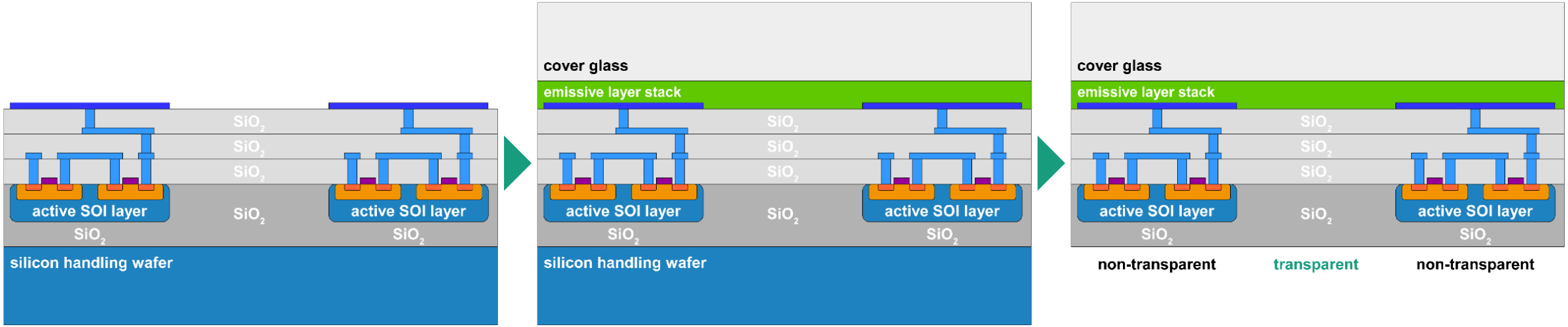
OLED-on-SOI Transparency Technology



Orientation in NTE-ST optics

- „SOI“: Silicon-on-insulator
  - thin active silicon on SiO2 (vs. bulk silicon)



SOI-CMOS wafer

SOI-CMOS wafer with OLED or other emissive frontplane

SOI-CMOS wafer with OLED and removed handling wafer realizing transparency

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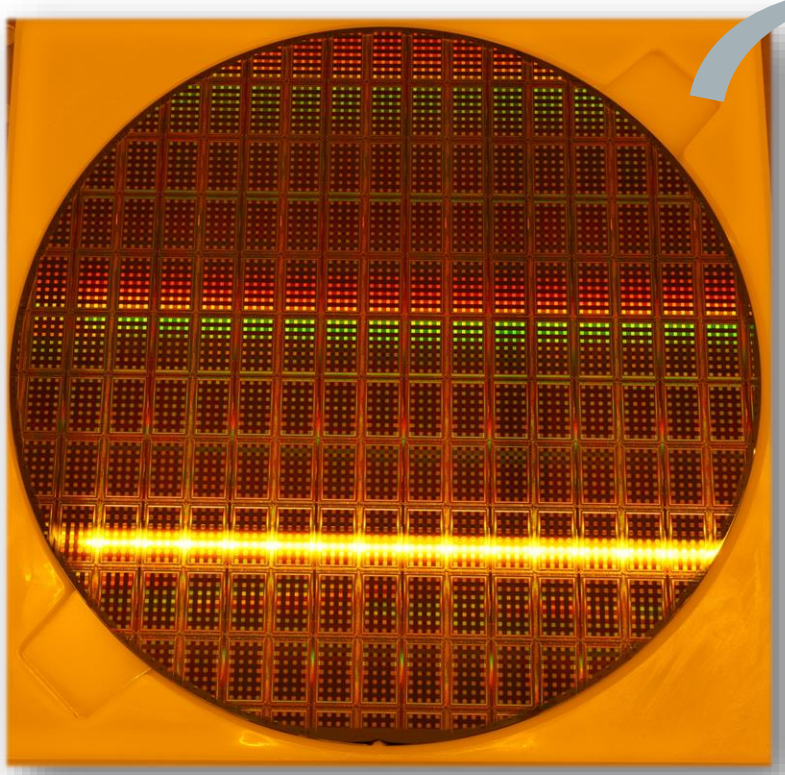
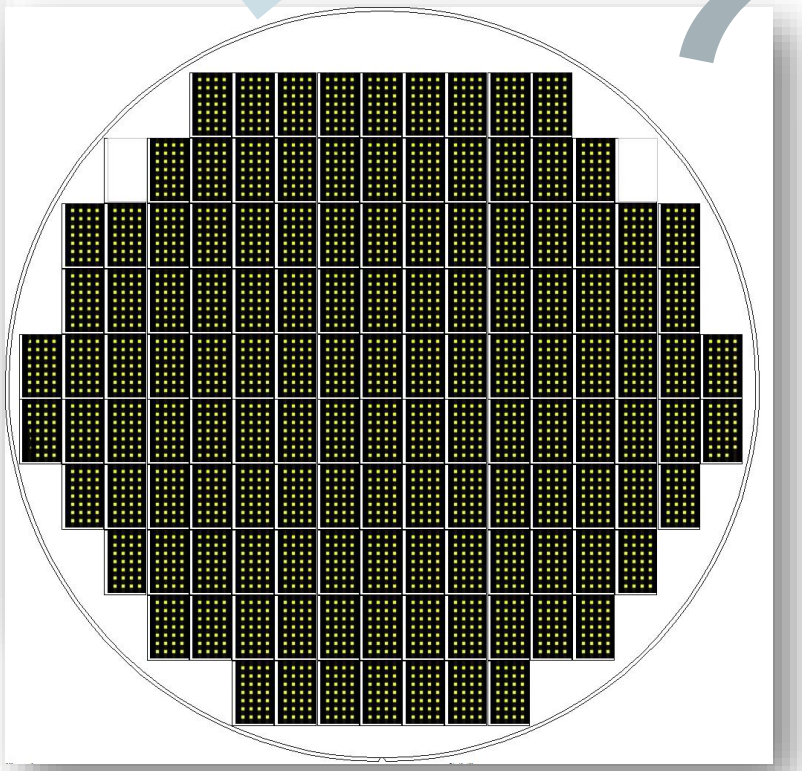
Results Waferlevel Integration

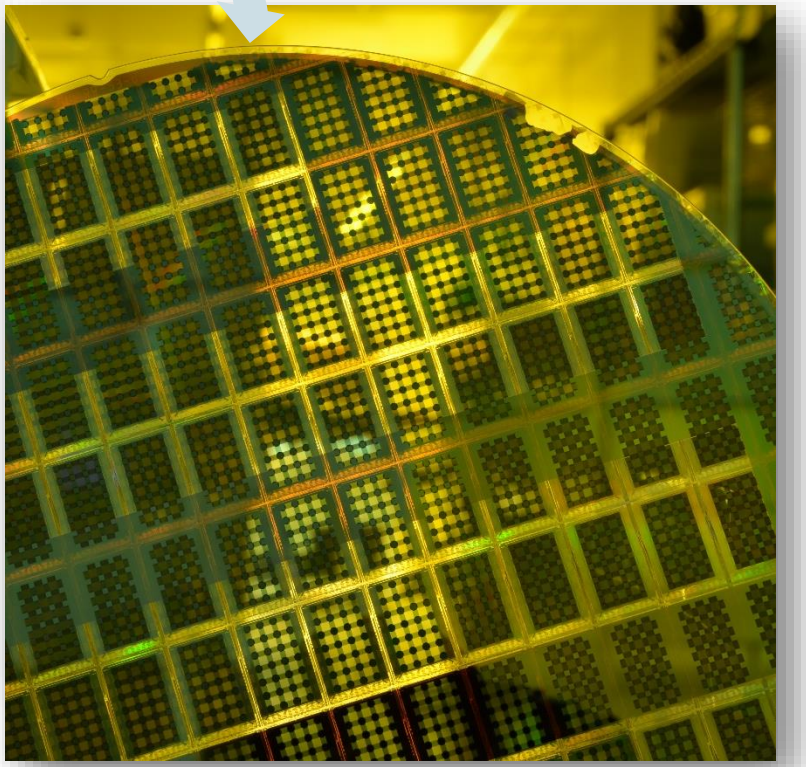


SOI CMOS wafer

OLED integration



Transparency process



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Initial Samples: „cluster“ approach semitransparent display

Pixel Parameter	Value
No. of clusters	7 x 4
Cluster resolution	256 x 256 x monochrome or 128 x 128 x RGBW
Size of pixels in a cluster	896 um x 896 um
Sub-pixel size	3.5 um
Driver circuitry type	Common-cathode

Optical Parameter	Value
In-transparent cluster size	Circular with 1.3 mm diameter including pixels and light shield to avoid stray light
Cluster pitch	2.24 mm in both directions
Cluster aperture based maximum achievable transparency	73.5%

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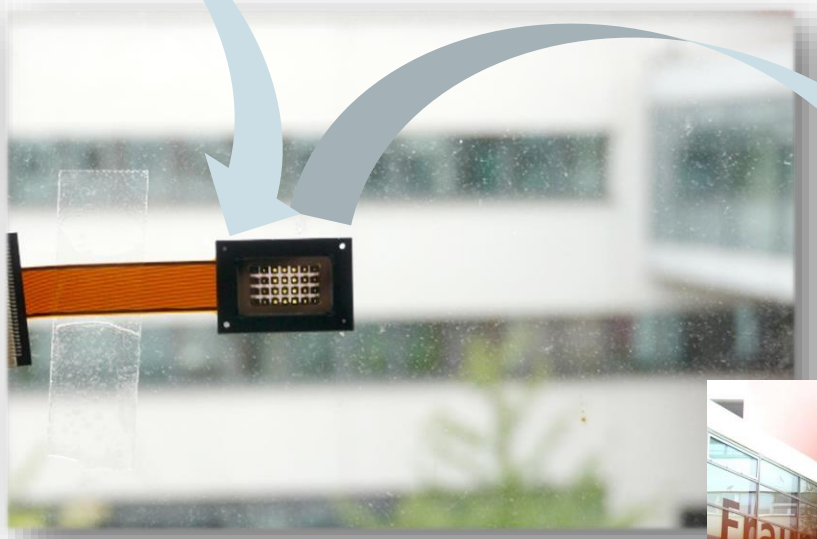
Initial technology demonstrator with micro-optics

Micro-optics supported by Fraunhofer IOF



Initial AR demo with optics

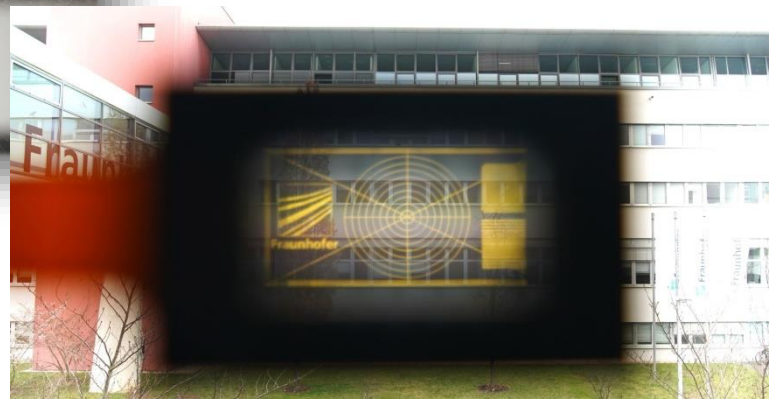


Image taken trough optics

- Initially monochrome amber OLED stack for **luminance up to 35knits**
- recent 22% (SPIE Digital Optical Technologies 2023)
- Current transparency 45%
  - Shown at IMID'24 and IDW'24

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Philipp Wartenberg, Bernd Richter, Stephan Brenner, Johannes Zeltner, Christian Schmidt, Judith Baumgarten, Andreas Fritscher, Simone Lenk, Martin Rolle, Michael Törker, and Uwe Vogel "High-brightness OLED-on-silicon on semitransparent CMOS backplane for advanced near-to-eye microdisplays", Proc. SPIE 12624, Digital Optical Technologies 2023, 1262416 (7 August 2023); https://doi.org/10.1117/12.2675479

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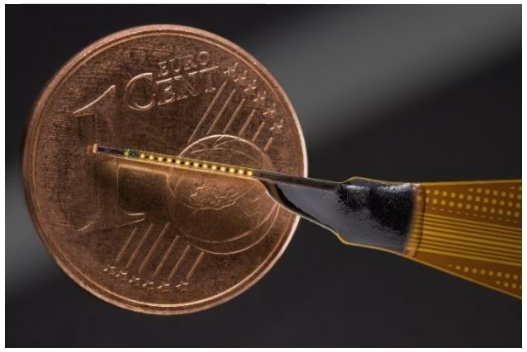
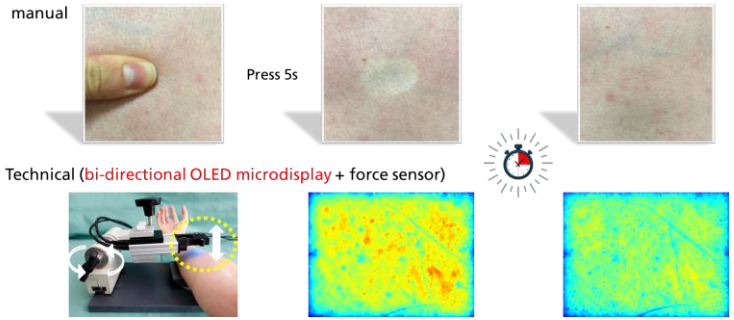
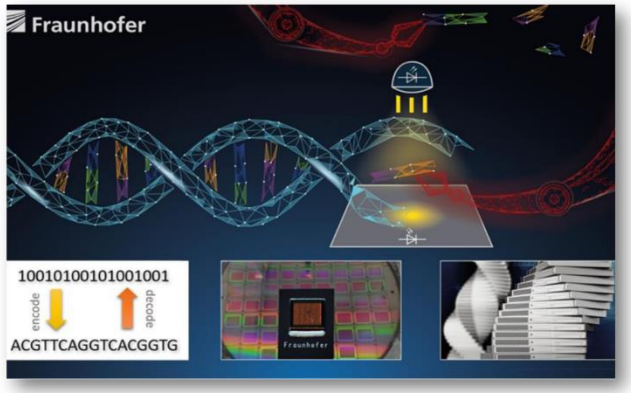
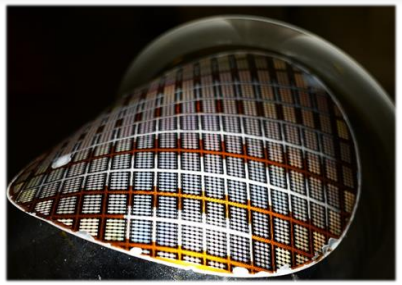
Outlook: O/LED-on-Silicon/microdisplays features and applications

- high-brightness
  - see-through near-to-eye @ sun light condition
  - embedded projection
  - Medical and biologial applications, e.g., optogenetic brain/nerve interfaces, emergency medicine, microbiological synthesyis
- 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 (LVDS, MIPI, Bluetooth)
- extended spectral emission and detection range
  - UV, IR; α, β, γ; µLED
- New form factors, e.g., *transparent & curved microelectronics*
    - e.g., smart contact lens display
- Manufacturing processes: yield, production costs









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Thanks for your attention!

- Public funding references:
  - Fraunhofer MAVO „HOT“ (840092)

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    - Head of „Microdisplays and Sensors“
    - Fraunhofer Institute for Photonic Microsystems IPMS
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