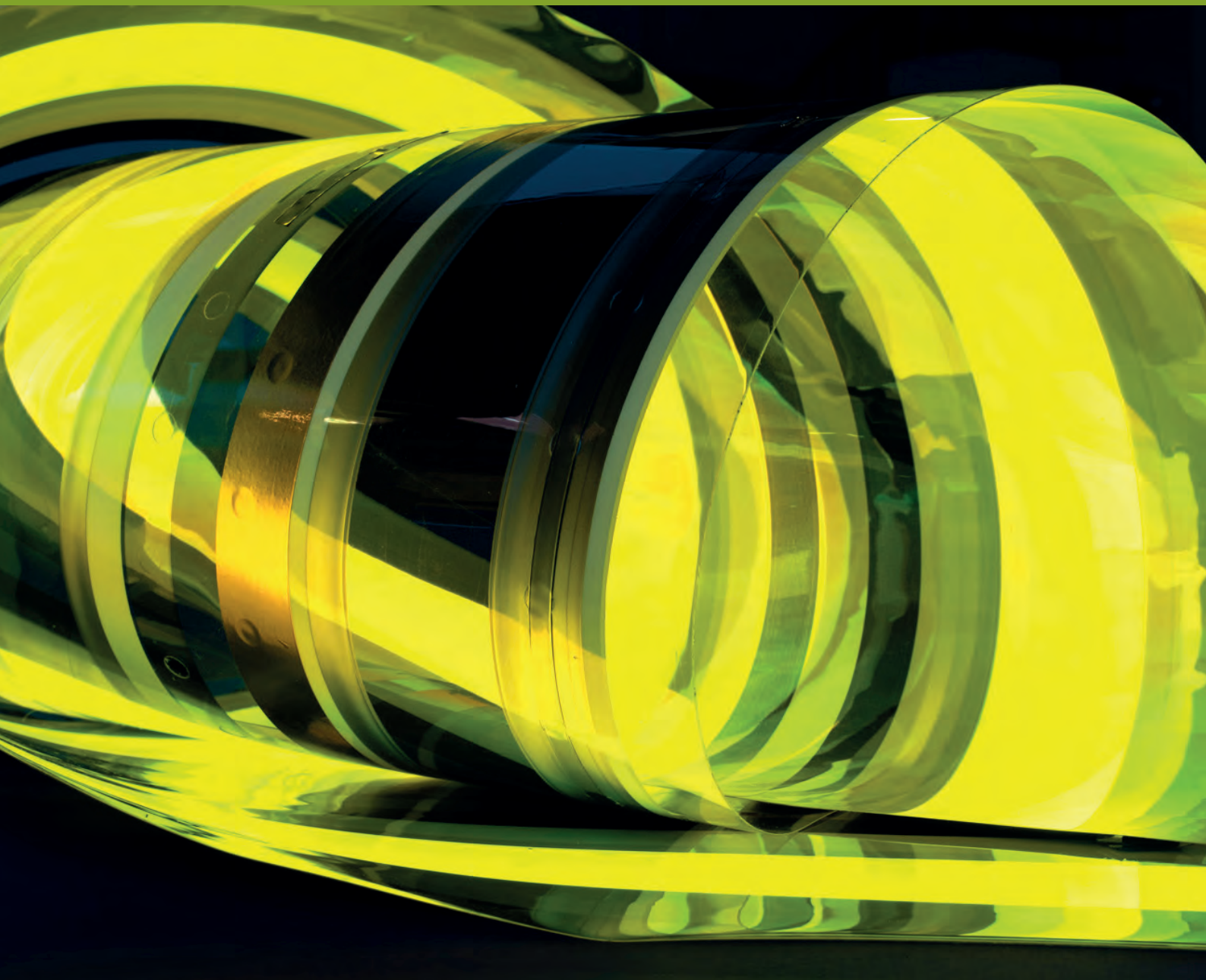
Fraunhofer
FEP

FRAUNHOFER INSTITUTE FOR ORGANIC ELECTRONICS, ELECTRON BEAM AND PLASMA TECHNOLOGY FEP

ORGANIC ELECTRONICS

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PROFILE

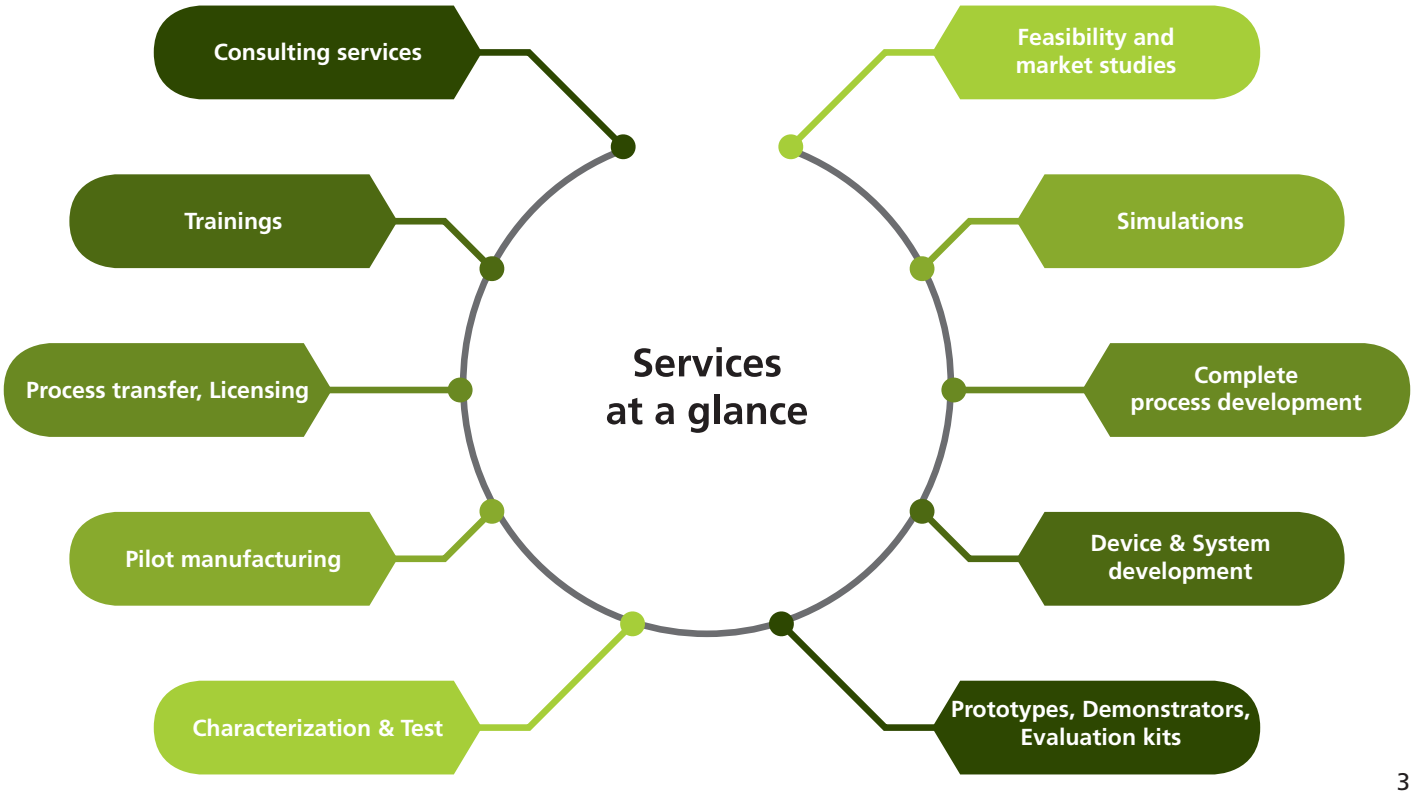
Fraunhofer FEP combines research and development works for technologies and processes for the fabrication of organic elecronic components based on semiconducting hydrocarbon compounds.

Our focus lies on the process development for the deposition and structuring of thin organic layers as well as on encapsulation and system integration. Pilot manufacturing lines for sheet-to-sheet, wafer, and roll-to-roll processing are available for this purpose.

The portfolio ranges from the creation of layouts on glass or flexible substrates to OLED-on-silicon technology (wafer) and component integration up to the development of ultra-high barrier films for encapsulation.

These components are used in organic light-emitting diodes (OLED) for lighting and microdisplays, in organic photodiodes (OPD) for sensors, organic photovoltaics (OPV) and organic thinfilm transistors (OTFT), which serve for a broad range of applications entering industrial production as well as consumer goods applications e. g. in information technology, wearables, automotive, medical and environmental as well as safety technologies.

The institute provides full service along the whole value chain – from feasibility studies, system design, integration up to upscaling and technology transfer or licensing. Our development work is augmented and supported by the acquisition and coordination of projects funded by the state and federal governments as well as the European Union.



FLEXIBLE ORGANIC ELECTRONICS

TECHNOLOGY & DEVICES

Development for sheet-to-sheet (S2S) and roll-to-roll (R2R) processes for:

- OLED (organic light-emitting diodes)
- OPV (organic photovoltaics)
- OPD (organic photodiodes)
- OFET / OTFT (organic field-effect / thin-film transistors)

TECHNICAL DATA

Substrate material

- Rigid glass
- Ultra-thin flexible glass
- Metal foil
- Polymer web
- Biodegradable web
- Further materials on request

Substrate sizes

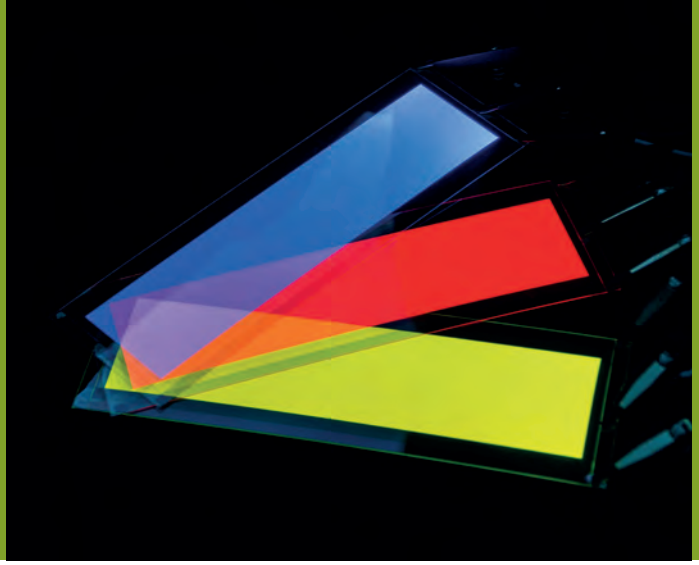
- Sheet-to-sheet (S2S) processing: 200 × 200 mm²
- Roll-to-roll (R2R) processing: band width up to 300 mm

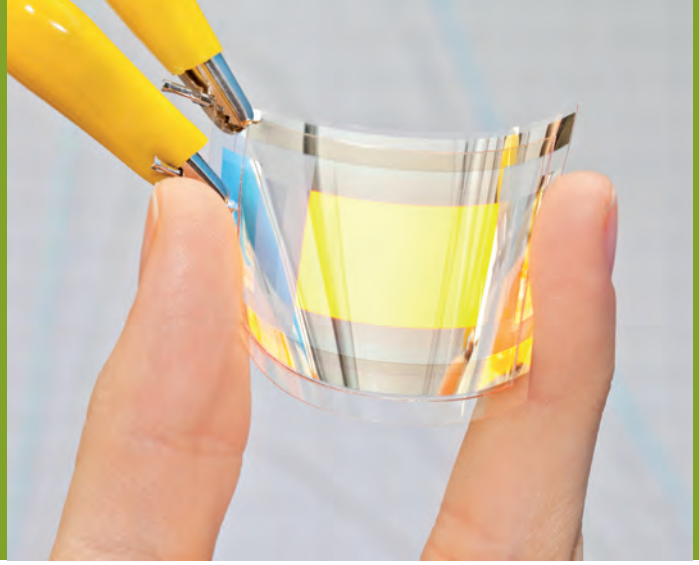
APPLICATIONS

- Interior lighting, smart buildings, automotive lighting
- Lighting in textiles and wearables
- Signage
- Displays and Wearables
- Medical applications, light therapy
- Sensorics
- Packaging
- Biodegradable electronics

TECHNICAL OPTIONS & INTEGRATION

- System integration e. g. in textiles, dashboards, etc.
- Combination of OLED and OPD/OPV
- Biodegradability and biocompatibility
- Segmentation of the active area
- Laser inscription of logos, text or patterns into the active area
- Area and mixed colors for dynamic signage applications
- Variable color
- Microstructures





SHEET-TO-SHEET PROCESS TECHNOLOGY

TECHNOLOGY

- Vacuum thermal evaporation (VTE)
- Organic vapor phase deposition
- Atomic layer deposition (ALD)
- Slot die coating
- ITO sputtering
- Screen printing (metal and passivation layer)
- Gravure printing
- Lamination of barrier films
- Laser ablation/laser patterning
- Thin-film encapsulation
- Foil and glass encapsulation
- Scribe and break
- Foil lamination (ambient or inert)
- Automated optical inspection
- Customized wet cleaning
- Etching

APPLICATIONS

- OLED lighting
- Organic Photovoltaics (OPV)
- Organic Photodiodes (OPD)
- All modules available on flexible or rigid substrates
- All modules available transparent or opaque
- Segmentation, laser patterning, shapes possible
- Evaluation kits „OLED Design Kit MONARCH“ and „O-BUTTON“ available

TECHNICAL DATA

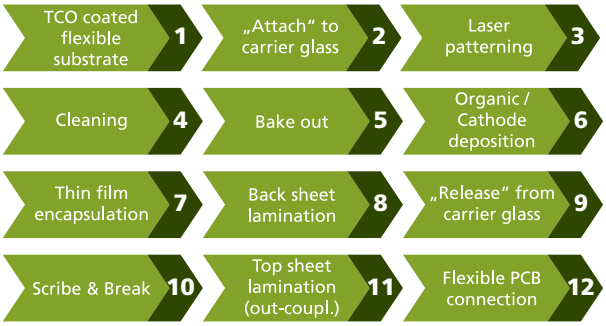
Substrate material	Size	Thickness
Rigid glass	200 × 200 mm²	0.7 … 2.0 mm*
Ultra-thin flexible glass	175 × 175 mm²	50 … 100 µm**
Metal foil	200 × 200 mm²	50 … 500 µm
Polymer web	200 × 200 mm²	50 ... 150 µm
Further materials on request		

* *further thicknesses possible on request*
** *without additional laminate*

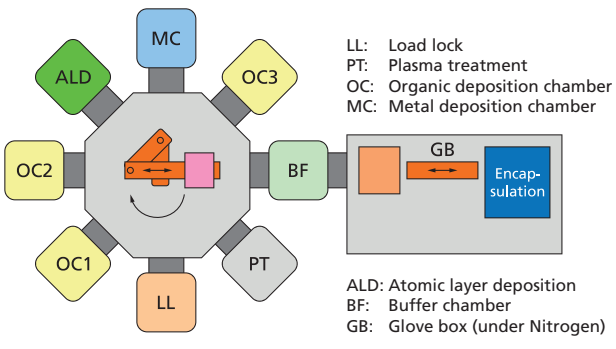
PROCESS EQUIPMENT

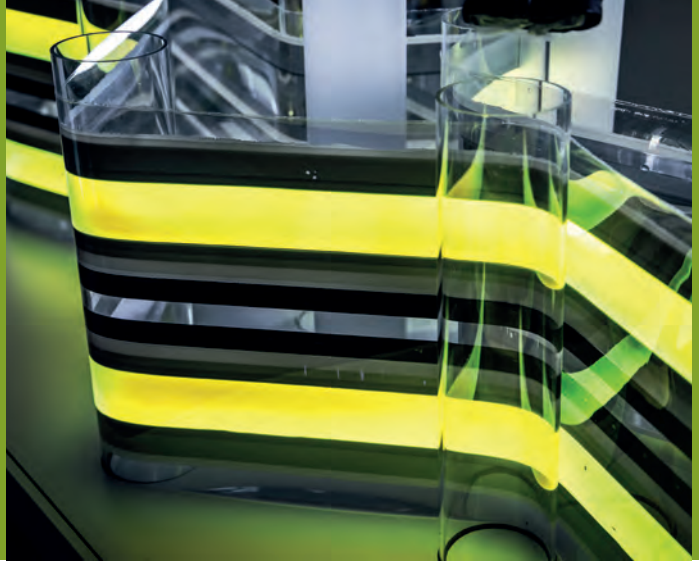
OLED manufacturing: S2S process flow for ultra-thin glass (UTG)

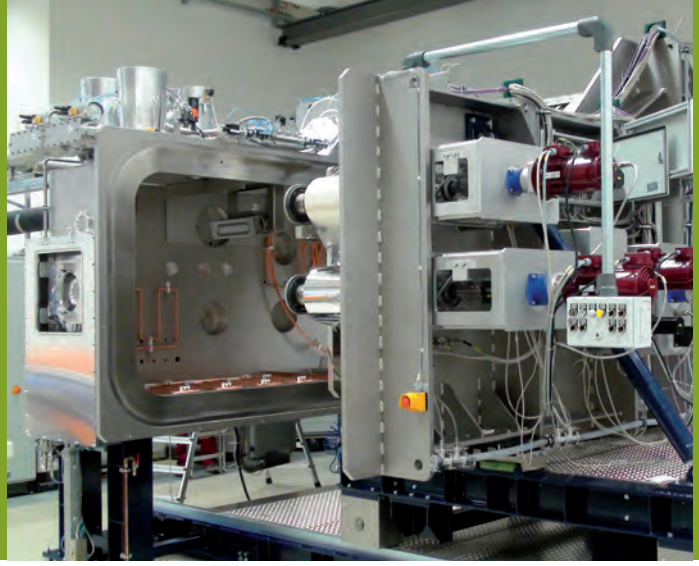
Carrier glass: 200 × 200 × 0.7 mm³ | Substrate: 100 µm UTG | Back sheet: 100 µm UTG



Layout of the sheet-to-sheet vacuum coating plant







ROLL-TO-ROLL PROCESS TECHNOLOGY

TECHNOLOGY

- Organic electronic devices on metal band, plastic web, ultra-thin glass
- OLED small-molecule evaporation
- Sputtering process of metals and metal oxide layers
- Plasma pre-treatments
- Flexo printing and slot-die coating
- Web cleaning
- Lamination of barrier films
- Roll-to-roll inspection system

APPLICATIONS

- OLED lighting
- Organic Photovoltaics (OPV)

TECHNICAL DATA

Substrate material	Size	Thickness
Ultra-thin flexible glass	Band width up to 300 mm	50 ... 100 µm*
Metal foil		up to 500 µm
Polymer web		50 ... 500 µm
Further materials on request		

* *with / without carrier substrate*

ROLL-TO-ROLL PROCESS EQUIPMENT

R2R inspection system

Substrate inspection 1

Vacuum coating 4

R2R vacuum coater

Structuring 2

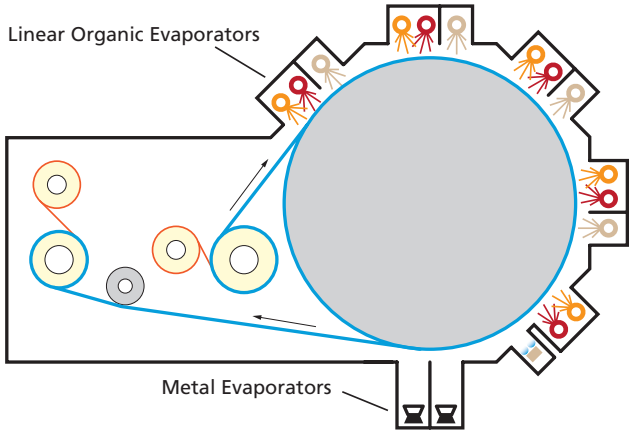
Encapsulation 5

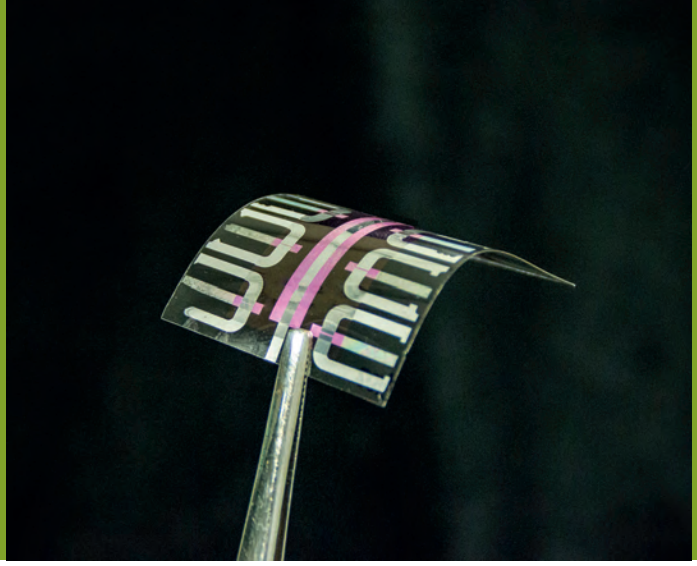
R2R printing and lamination unit (N_2)

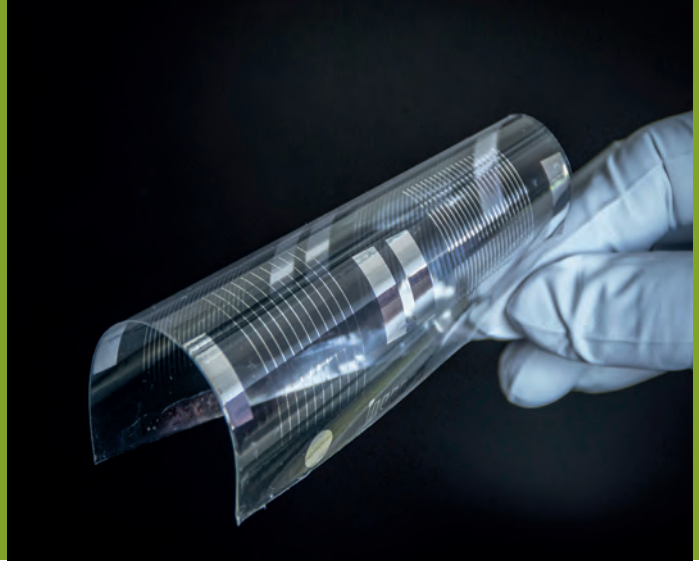
Substrate inspection 3

OLED characterization 6

Layout of the roll-to-roll vacuum coating plant







BIODEGRADABLE ELECTRONICS

TECHNOLOGY

- Based on vacuum technology
- Development of conductor paths and organic thin-film transistors
- Magnesium deposition by high vacuum thermal evaporation
- Development of processes for suitable pretreatment of substrates by combining drying, plasma treatment and use of seed layers
- Display of finely structured conducting paths in high quality as first results

TARGETS & OUTLOOK

In addition to biodegradable conductor paths, other components are being developed in the project in collaboration with the Fraunhofer Institutes ENAS, IBMT, ISC and the Fraunhofer Project Group Recyclable Materials Cycles and Resource Strategy:

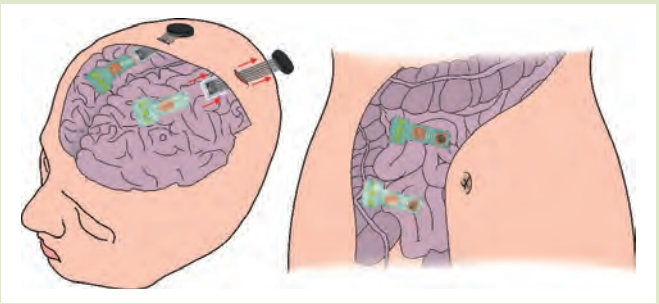
- Biodegradable conductor structures
- Biodegradable electrode contacts for electrical signal derivation or stimulation
- Biodegradable thin film transistors and circuits
- Biodegradable barrier layers as water and gas barrier and electrical insulation layers

These system elements are to be integrated monolithically into a flexible thin-film component.

WATCH THE VIDEO ON YOUTUBE!

APPLICATIONS

- Biodegradable implants that perform their function for a limited period of time and then dissolve completely
- Realization of implantable assistance systems with active therapeutic and/or diagnostic functionality and application-specific limited duration of use
- Agriculture, animal husbandry, biotechnology and food industry
- Development of essential components for biodegradable electronic components, e. g. used in implants as part of the Fraunhofer internal project „bioElektron“

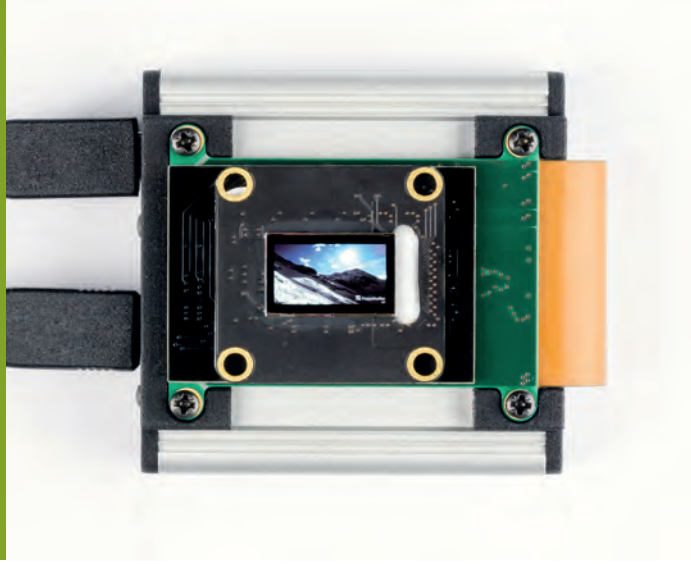


BENEFITS

- Reduction of the ecological footprint
- Reduction of surgical interventions
- Cost reduction for patients
- Additional benefits in the field of neurostimulation, visceral surgery and pre-surgical diagnostics

Germany Land of Ideas Landmark 2018

The research on biodegradable electronics within the Fraunhofer joint project bioElektron was awarded as one of the 100 places within the „Land of Ideas 2018“ in Germany.



MICRODISPLAYS AND WEARABLES

TECHNOLOGY & EQUIPMENT

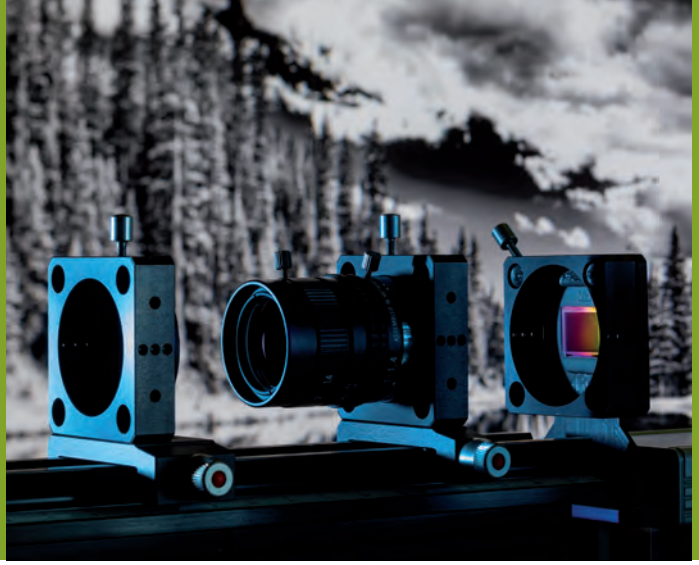
- CMOS technology on 200 mm wafer
- Pilot line OLED / PLED-on-silicon (8“ silicon wafers)
- Silicon-CMOS backplane IC design (CMOS processes 0.6 ... 0.11 µm)
- Process development of small-molecules (OLED) and polymers (PLED)
  - Vitex thin-film encapsulation
  - Organics evaporation & solution processing
  - Metal sputter & thermal evaporation
  - E-Beam, etching, lift-off or shadow masks
  - Shadow-mask fine alignment with ± 10 µm accuracy
- 1:1 lithography processes for layer structuring (organic, inorganic)
- Orthogonal photolithography
- Barix™ encapsulation
- Fully automated wafer bonding
- Wafer prober for electro-optical characterization
- Ellipsometer for thin-film characterization
- Lamination of foil onto wafer for flexible devices
- Silicon-CMOS/OLED interface definition (with silicon foundry)
- Encapsulation including wafer-level color filter integration
- Various substrates possible (glass, silicon wafer, foil, ...)
- Optical inspection, further device characterization tools

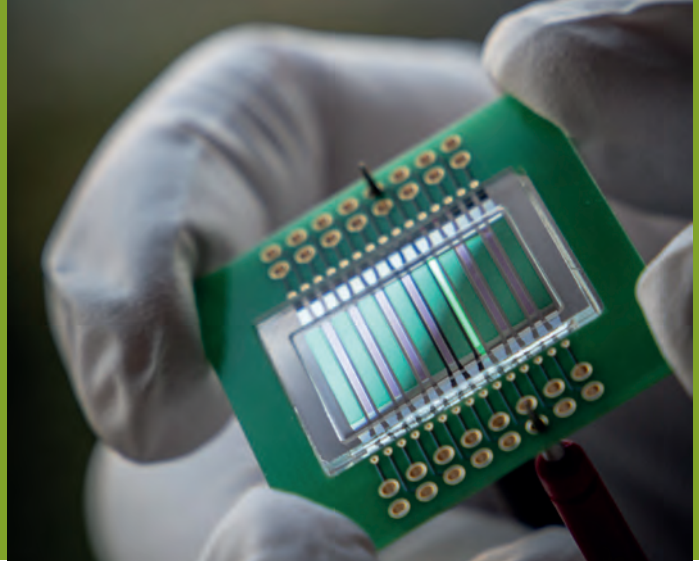
DEVICES

- OLED microdisplays (QVGA, VGA, SVGA, XGA, 304 × 256 ultra-low power, 720p, WUXGA)
- Bidirectional OLED microdisplays (with embedded image sensor)
- OLED as silicon-embedded patterned light source and CMOS photodetectors
- Silicon-CMOS backplane
- System design for electronics, optics

APPLICATIONS

- Bidirectional OLED microdisplays
  - for wearables and smart data glasses (Augmented/Virtual Reality (AR, VR)) for improved human-machine interaction e. g. industry 4.0, logistics, fabrication
  - as an aid for visually impaired people
  - for optical fingerprint sensors
- OLED microdisplays for projection applications (rear, front, micro)
- Ultra-low power OLED microdisplays
  - for wearables (e. g. fitness trackers, monitoring of vital parameters in medical applications)
  - or assisted vision (e. g. in Industry 4.0)
- Near-to-Eye
  - electronic viewfinder (EVF)
  - hand-held
- OLED microdisplays emitting in the visible and NIR region
- OLED as silicon-embedded patterned light source and CMOS photodetectors
- Biosensors





ORGANIC PHOTODIODES

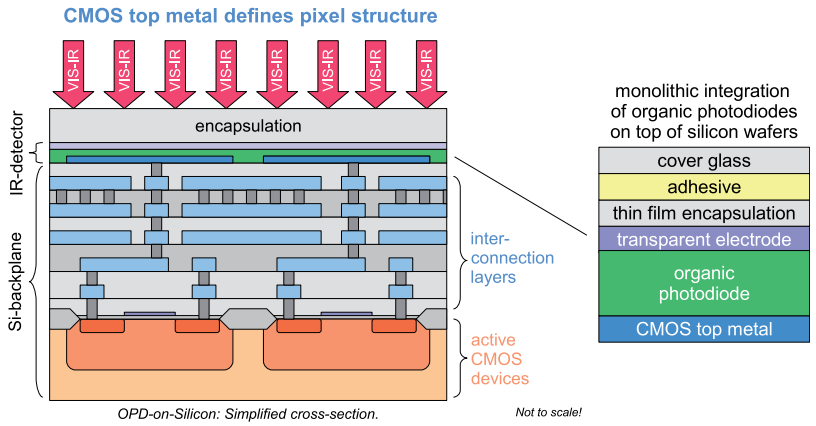
TECHNOLOGY

Organic photodiodes on silicon

- Monolithic integration of OPD on high performance CMOS readout circuits at wafer-level
- CMOS-sensor with enhanced spectral behavior
- Adjustable wavelength, spectral width
- High fill factor w/o microlenses

Organic photodiodes on further substrates

- OPD produced on glass substrates for analytical applications
- Modification for specific applications
- Application specific geometries
- Customized adaption of spectral sensitivity and device areas
- Structuring of organic components arbitrarily
- Integration of OPD on polymer films feasible
- Combination with OLED for analytical applications



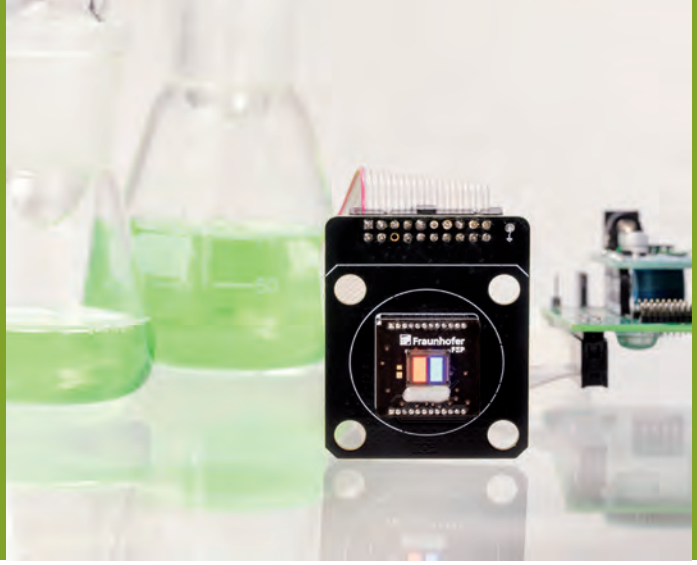
OPD-on-Silicon: Simplified cross-section.

PARAMETERS

- Substrates:
  - rigid glass
  - silicon wafer
  - polymer films
  - further substrates on request
- Sizes of OPD:
  - from small pixels up to large surfaces
  - pixel pitch on CMOS e. g. 16 µm × 16 µm
  - resolution of sensorchip on CMOS: 800 × 600
- Shape of OPD: customized
- Wavelength: 300 nm (ultraviolet, UV)
- Up to 850 nm (near infrared, NIR)
- Temperature range: -20°C – +65°C

APPLICATIONS

- OPD-sensors for quality control of foodstuffs
- Combination OPD+OLED for analysis of quality characteristics and contaminants in liquids
- Medical applications
- Environmental analysis
- Fingerprint sensors
- Cameras with high light sensitivity
- Flat and flexible X-ray detectors with high resolution
- Optimized and miniaturized biosensors
- Planar color sensors for quality assurance



SENSORS

TECHNOLOGY

- Optoelectronic devices based on OLED-on-silicon technology
- Monolithic integration of OLED layers on top of silicon CMOS backplanes
- Design as highly-integrated micro-scale optical illumination components and detection units on smart single chips
- Realization by single elements (e. g., OLED + photodiode combination), in segments or arrays

ACHIEVEMENTS

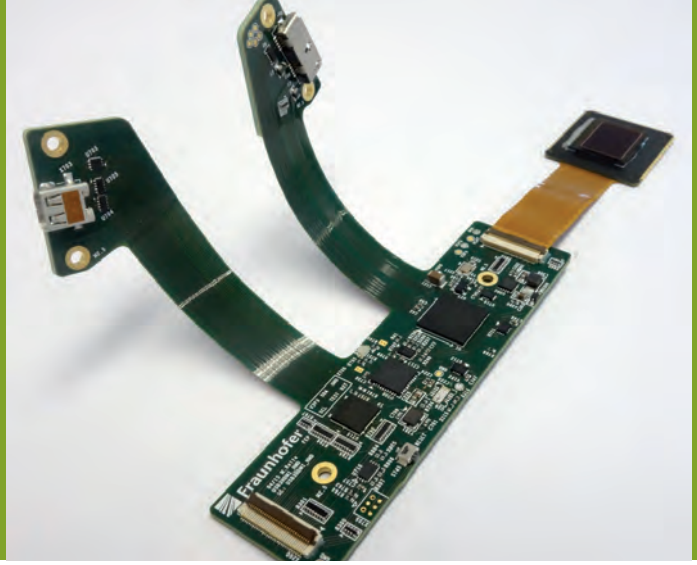
- Bidirectional devices
- Brightness: > 1000 cd / m²
- OLED emitter in RGB / NIR / UV
- Customer specific display and camera resolution, e. g., QVGA, XGA, ...
- Active matrix diagonal size typically < 1,0"
- Customer specific sensor platform e. g. as oxygen sensor

APPLICATIONS

- **Fingerprint sensor**
  - OLED for controlled finger illumination
  - Photodiodes detect papillary lines as well as sweat pores with high resolution
  - Microdisplay can still work as imaging device for notification, branding, ...
- **Particle flow sensor**
  - OLED stripes for fluid illumination and photodiodes for detection
  - Light reflection depending on local fluid velocity and particle density
  - Analyzing photocurrents and correlation functions, the fluid particle velocity can be calculated
- **Optical inspection**
  - Patterned illumination and detection of pattern distortion
  - Dimensional optical measuring of surface topology
- **Opto-coupler**
  - OLED as embedded light source for integrated opto-couplers (e. g., in drivers, controllers, …)
- **Biosensors**
  - OLED for fluorescence excitation
  - Photodiodes for detection
- **Position and inclination sensor**
  - based on bidirectional OLED microdisplay (OLED + photodiodes)
  - compact, highly integrated optical distance and inclination sensor
  - compact device for easy integration
  - applying inverse confocal principle

OUR OFFER

- OLED-on-silicon device integration
- R&D in OLED-based integrated optoelectronics
- Electronics design (backplane with integrated circuitry/ASIC), control, interface, ...
- System design (sensor electronics, packaging, module)
- Product development and qualification
- Pilot production (small to medium volume fabrication)



IC AND SYSTEM DESIGN

TECHNOLOGY

- Development of integrated circuits and modules through application-specific adaption of CMOS processes
- Analog, digital, mixed-signal
- Typical CMOS processes: 0.13 µm / 0.18 µm / 0.35 µm
- Industry-compatible circuit simulation, layout design, verification
- Implementation in mixed, analog, digital CMOS processes of silicon circuit foundries
- Coordination with external silicon wafer manufacturer, test and start up
- Development of discrete electronics
- Based on commercial ICs, FPGA, microcontroller etc.
- Concept, system design, schematic, PCB layout
- Software design
- C, C++, VHDL
- Microcontroller firmware, embedded systems, application software
- Prototype fabrication, transfer to pilot production

COMPONENTS

- Microdisplay and sensor backplane
- Driving and readout electronics for microdisplays, sensors, OLED and organic photodiodes (OPD)
- Device driver, software libraries and applications

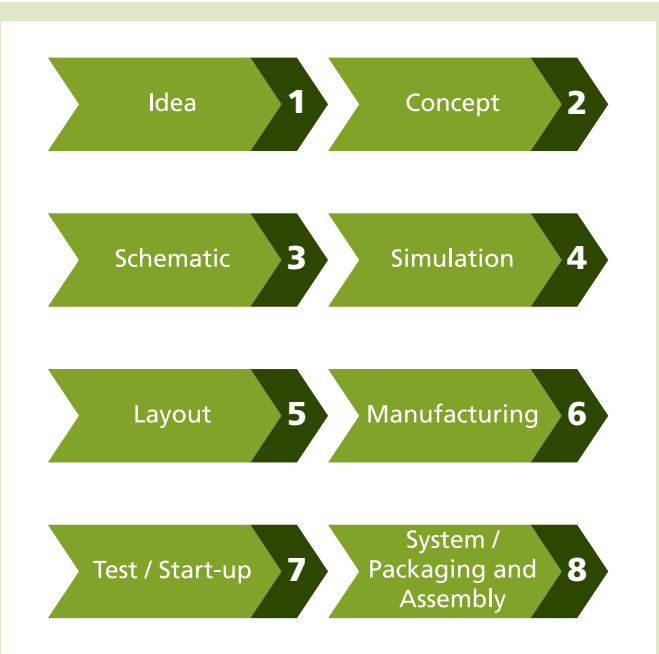
APPLICATIONS

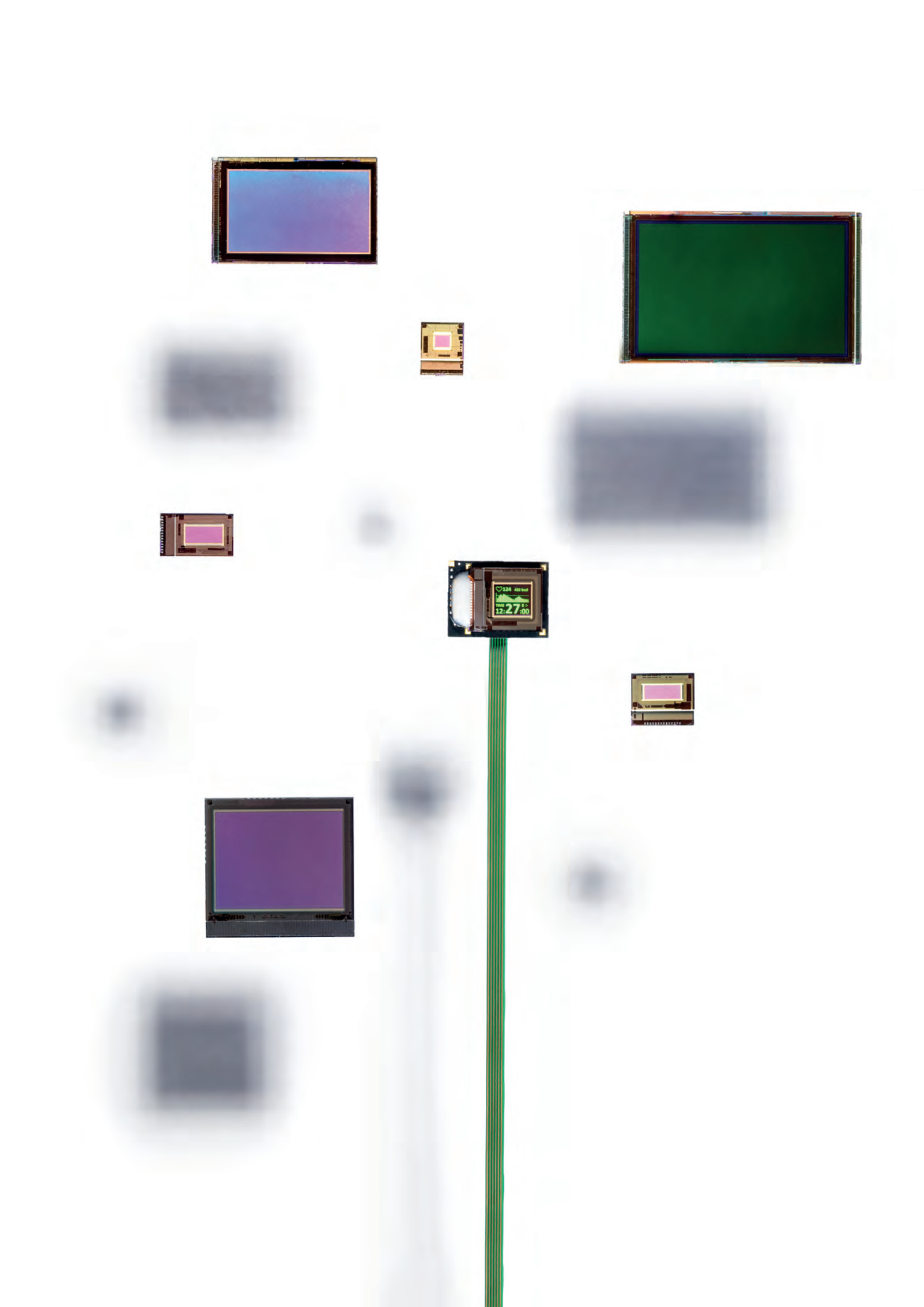
- Head mounted displays
- Image processing, focus on eye-tracking
- Sensors
- Lab on chip
- Alternative technologies:
  - Quantum Dots (QDs)
  - Liquid-crystal-on-silicon (LCOS)
  - Micro-LEDs
  - Read-out-options for sensitive layers
- In medical or biotechnology branch (optical sensors for fluorescence-based monitoring
- In optogenetics

DEVICE CHARACTERIZATION

- Electro-optical device testing
- Spectroscopic ellipsometry with:
  - Ellipsometer WOOLLAM M-2000F at 1 nm up to 25 nm thin layer, wave length range: 245 – 1000 nm, 200 mm wafer chuck, smaller samples possible, fully automated stage (x, y, z), automated alignment (Align 200), option: 50 µm focusing probes
  - Filmetrics F50 reflectrometer for measurement at 30 nm up to 50 µm thick layers (wavelength range 380 – 1050 nm)
- Electro-optical characterization with Wentworth wafer prober:
  - Luminance-Current-Voltage (LIV)-measurement on 200 mm wafer level
  - Automatic wafer and chip measurement using probe cards
- Wafer prober provided by EVERBEING INT´L Corporation

FROM IDEA TO WAFER

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CHARACTERIZATION AND ANALYTICS

CHARACTERIZATION METHODS

Photometric

- 1 m-integrating sphere measurements (absolute spectral radiant flux and related parameters, e. g. luminous efficacy and color coordinates)
- Near field goniometer measurements (angular dependent absolute spectral radiance and related parameters, e. g. luminance and color coordinates)
- Calibrated CCD camera measurements (spacial luminance distribution)
- Video photometer for determination of the homogeneity of the luminance distribution
- UV/VIS spectrophotometer for measurements of transmission and reflection
- Fluorescence spectrometer for measurements of emission and excitation spectra

Films and devices

- Lifetime and reliability testing of OLED modules
- IR imaging for thermal characterization and failure analysis
- Climatic chamber testing
- Outdoor ageing test
- Coulometric permeation measurement (BRUGGER WDDG, Mocon OX-TRAN)
- Calcium-mirror test for WVTR and defect characterization
- Elaborate measuring systems for determination of the operational lifetime of OLED devices
- (Roll-to-roll) particle and defect inspection
- Mechanical bending and strain tests
- TDLAS (HiBarSens) WVTR measurement at up to 85°C / 85% r.h. for WVTR ≥ $1 \cdot 10^{-5}$ g/m²d
- Particle measurement tool Surfscan 7700 by KLA-Tencor
  - analysis of structured and unstructured wafers
  - detection of defects / particles ≥ 0.15 µm
  - 30 mW Argon ion laser, wavelength: 488 nm
  - variable input polarization

Electro-optical tests

- Spectroscopic ellipsometry with:
  - Ellipsometer WOOLLAM M-2000F at 1 nm up to 25 nm thin layer, wave length range: 245 – 1000 nm, 200 mm wafer chuck, smaller samples possible, Fully automated stage (x, y, z), Automated alignment (Align 200), Option: 50 µm focusing probes
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Spectroscopic thin-film

- Transmission and reflection spectroscopy in UV-VIS-NIR range
- Variable angle spectroscopic ellipsometry
- Photoluminescence spectroscopy
- Thin-film modelling for analysis of spectroscopic data

Solar cells

- Solar cell test system (IV-characteristics with sun simulator)
- Photocurrent mapper


2.000 kg
SWF
1.000 kg

ROLL-TO-ROLL BARRIER AND ELECTRODE FILMS

TECHNOLOGY

Technology	Productivity (line speed) [m/min]	WVTR at 8°C/90% r.h. [g/(m²d)]
Hollow-cathode plasma-assisted evaporation (HAD)	600	1
Reactive sputtering of oxides	1	0.0005
Multi-layer stack: sputtering + wet coating of ORMOCER®	1	0.0002
Multi-layer stack single pass: sputtering + arcPECVD	≥ 4	0.005
Atomic layer deposition	static process	< 0.001

APPLICATIONS

- Permeation barrier films
- Encapsulation for organic electronic devices
- Flexible smart packaging
- Organic photovoltaic devices
- Electrochromic systems
- Thin-film energy harvesting and energy storage devices
- Holographic systems on polymers
- Sensors and flexible/organic transistors
- Quantum dot and OLED lighting and displays
- Wearables and other flexible electronic devices

OUR OFFER

- Evaluation of polymer substrates for barriers
- Sampling, material provision and feasibility studies
- Roll-to-roll pilot production of barrier film rolls
- Adaption of barrier films to specific applications
- Functional film design and deposition (including electrodes, adapted optics or protection layers)
- Product integration
- Key components for barrier layer deposition
- Direct thin-film encapsulation of devices
- Barrier film and device characterization

EQUIPMENT

labFlex® 200

- 220 mm web width
- Sputtering and PECVD
- Roll-to-roll OLED encapsulation without roller contact of coated side

coFlex® 600 and novoFlex® 600

- 650 mm web width (pilot scale)
- Sputtering, PECVD and evaporation
- Multilayer deposition in one run
- Web speed up to 10 m/s
- Double-side coating

atmoFlex 1250

- 1200 mm deposition width
- Slot die coating, e-beam curing, lamination
- 1250 mm substrate width
- Web speed up to 150 m/min
- Planarisation layers
- R2R lamination/encapsulation

FOSA LabX 330 glass

- Sputtering on flexible glass, polymer film, metal foil
- up to 330 mm deposition width
- Substrate temerature up to 350°C
- up to 4 coating zones
- Dual anode sputtering
- Front-side touchless

OUTLOOK

THE FUTURE OF FLEXIBLE ORGANIC ELECTRONICS

Electronic components, microsensors and communicating smart devices are part of our everyday life. Economy, health and safety systems at all levels depend on the latest technologies and are driven and influenced by current developments. The trend is increasingly towards smaller, smarter, interconnected, ultra-flexible or even biodegradable components for the electronics of tomorrow.

At the same time, however, in addition to rapid progress and the factors of availability of resources, their extraction as well as manufacturing methods, environmental impact and disposal are increasingly being questioned. Sustainable and resource-saving technologies, safe and compatible electronics for highly integrated functions are the future.

For these new technologies, for the development and production of electronic applications of the future, flexible and organic electronics represent an environmentally friendly and cost-effective as well as effective and resource-saving alternative.

With our research we want to support future technologies and implement sustainable but above all application- and industry-oriented ideas for future applications with flexible organic electronics.

Get in touch and discuss your ideas with us! We will be happy to support you in the implementation and development of your customer-specific requirements. Following you will find a rough overview about some of our future research focuses.

FLEXIBLE ORGANIC ELECTRONICS

- Seamless tiling, backside contact
- Novel outcoupling concepts
- Next generation transparent conducting layer (ITO replacement)
- Heterogenic system integration
- Development of biodegradable and biocompatible electronic devices for absorbable implants etc.
- Short-lifetime systems for low-cost applications
- Single-use applications
- Low-voltage stack systems for autonomous applications
- Stretchable or 3D-OLED
- Processability of OLED (injection moulding technology)
- Perovskite deposition by vacuum co-evaporation for high-performance large area organic perovskite devices for lighting, energy and pervasive communications

OLED-ON-SILICON

- Smart microdisplays (e. g., embedded eye-tracking)
- R,G,B-micropatterning full color / without color filter
- Cost-efficient manufacturing techniques
- High brightness, high resolution microdisplays
  - see-through data glasses under sun light condition
  - embedded projectors e. g. in smartphones
  - HD content
  - smaller chip sizes for lower costs
- Extended temperature range for sensors
- Extended spectral emission and detection range (UV/VIS/NIR, non-OLED sources (QDs, µLED)
- Applications e. g. for food quality, point-of-use diagnostics, ... Extended spectral emission/detection (UV, IR, ...)
- Inorganic color filters
- Organic photodiodes in UV/VIS/NIR
- Lithography structuring of organic layers
- Bendable devices
- New form factors:
  curved surfaces, non-square shapes, irregular pixel arrays, transparent backplanes, integration into flexible substrates

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PI-SCALE
SHAPING THE FUTURE IN OLED LIGHTING

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and the ISO 9001.