

# MEMS TECHNOLOGIES DRESDEN

TECHNOLOGY DEVELOPMENT, PILOT-FABRICATION AND FOUNDRY SERVICES

Harald Schenk/ Michael Müller/ Johannes Kade

Fraunhofer Institute  
Photonic Microsystems IPMS  
Dresden, Germany  
[www.ipms.fraunhofer.de](http://www.ipms.fraunhofer.de)

R&D for CMOS compatible  
MEMS/MOEMS, pilot production  
220 scientists and engineers

1500m<sup>2</sup> MEMS/CMOS Cleanroom  
750m<sup>2</sup> OLED Cleanroom  
400m<sup>2</sup> OLED on CMOS Cleanroom



---

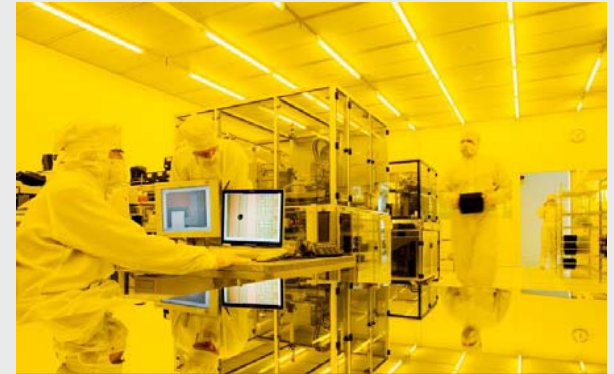
# AGENDA

---

- **MEMS Services**
- Technology Toolset
- Selected Processes
- Solutions
- Detailed Equipment List

# OUR BUSINESS MODELL: *From R&D TO Pilot-Fabrication*

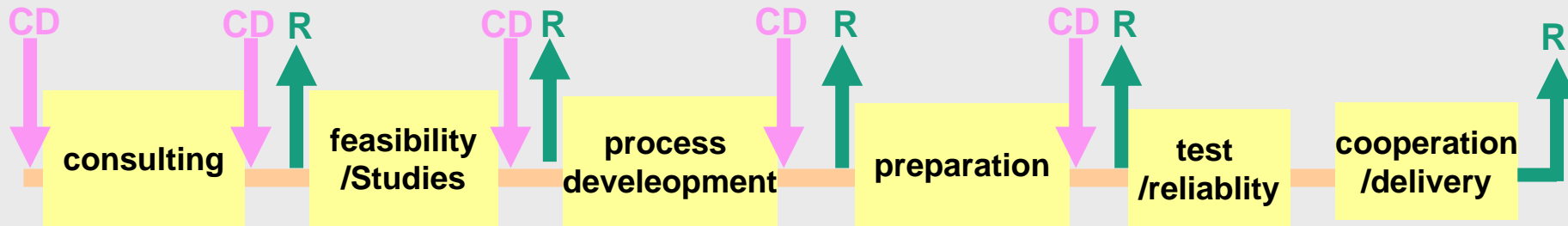
- Consulting service
- Complete process development
- Demonstrators and Prototypes
- Pilot-Fabrication
- Foundry Services
- Interworking: tool sharing/ manpower sharing/ ext cooperations



MEMS Technologies Dresden



## Flexible value chain [CD=customers demand; R= result]



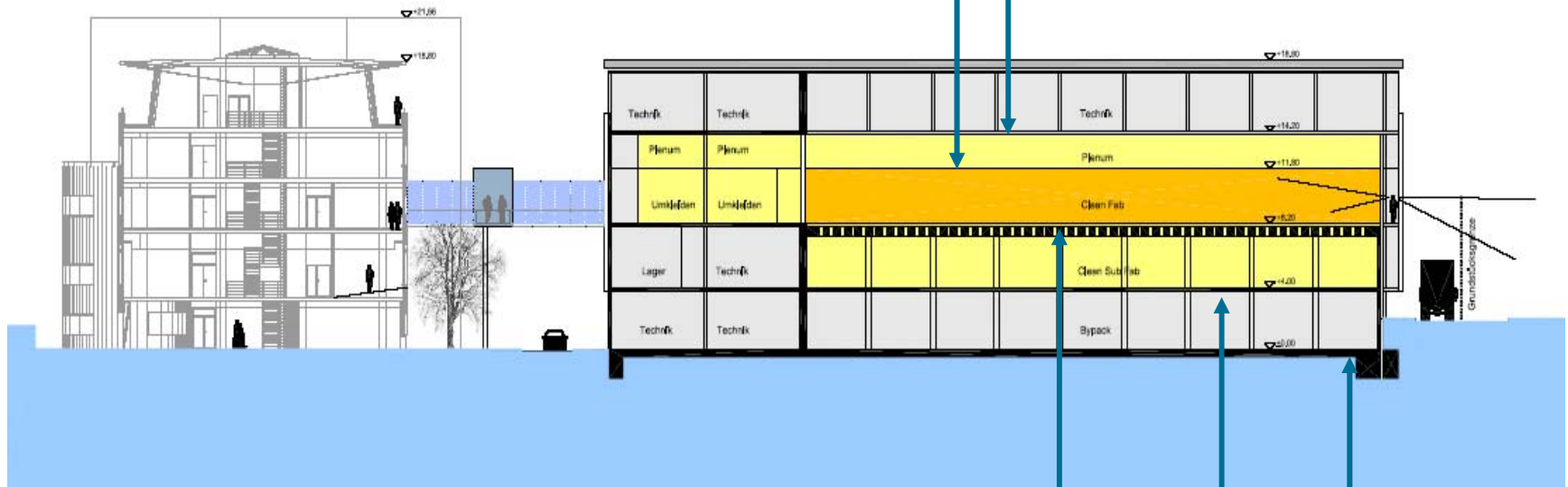
# MEMS CLEAN ROOM

- 1500 m<sup>2</sup>, class 10
- complete 6" Wafer line
- 3 shift (5x24) operations for R&D and pilot fabrication
- PPS based planning and documentation
- ISO 9001:2008 certification since 2003



# MEMS/MOEMS-CLEAN ROOM: INFRASTRUCTURE

Air condition system/ cooling systems



Clean room, Class 10

Supply level, media

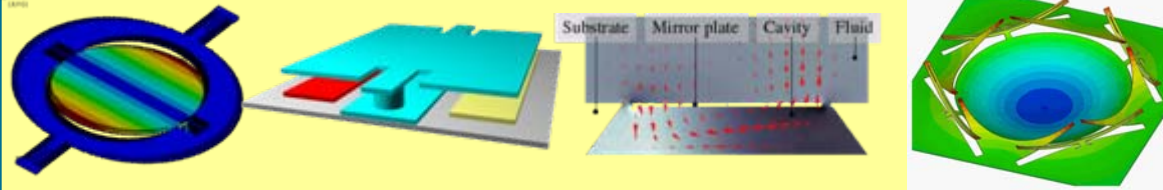
Supply level, media + logistics

# AGENDA

- MEMS Services
- **Technology Toolset**
- Selected (Core-) Processes
- Best Practice Solutions (success stories)
- Detailed Equipment List

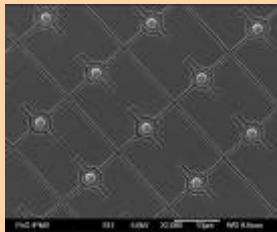
# TOOLSET meets customer needs

## 1: MEMS/MOEMS Design and Simulation



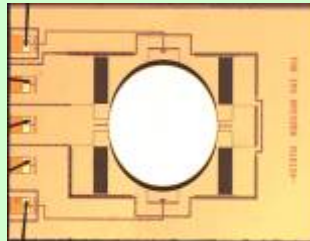
## 2: Surface MEMS Technology

- MEMS on CMOS-Backplanes
- Application: Spatial Light Modulator



## 3: Bulk MEMS Technology

- 3- dim. Structures in Silicon
- Applications: MEMS Scanner Pressure Sensor



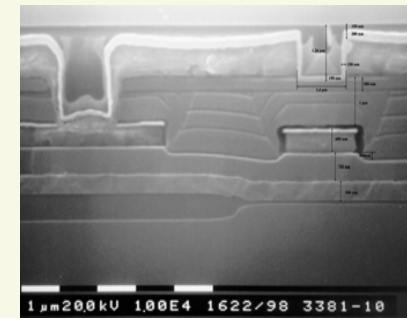
## 4: OLED-on-CMOS

- OLED Integration on CMOS
- Application: Microdisplays and Sensor applications



## 5: CMOS

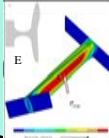
- HV- CMOS- Process
  - Application: Backplane for Spatial Light Modulator
- Active silicon (IR Sensors)



# 1: MEMS/MOEMS Design and Simulation

## Structural mechanics

- ✓ hinges
- ✓ cantilevers
- ✓ dynamical behaviour
- ✓ inertial effects
- ✓ optimization algorithms
- ✓ stress/load analysis
- ✓ linear and non-linear effects



## Modal analysis

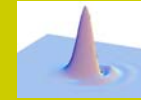
eigenmode analysis for wanted und interfering modes



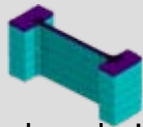
- ✓ flexible modular FEM model generation for 1D or 2D-scanning mirrors, translation mirror
- ✓ pre-stress modal analysis to include additional nonlinear constraints

## Optics

- ✓ Bragg mirrors
- ✓ AR/HR coatings
- ✓ influence of mirror deformation on optical properties
- ✓ point spread function (PSF)
- ✓ modulation transfer function (MTF)

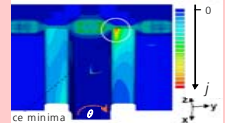


## Coupled field



magneto-structural analysis  
electro-thermal analysis  
structural-thermal or structural-thermal-electric analysis  
piezoelectric or piezoresistive analysis

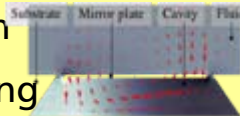
## Piezoresistivity



- ✓ structure mechanics / electric interaction
- ✓ load dependent resistance & voltage
- ✓ stress-, electric- and current-field distribution
- ✓ normal and sheer stress transducer concepts
- ✓ structural and doping level optimization

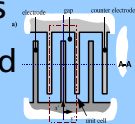
## Fluid mechanics

- ✓ friction
- ✓ damping
- ✓ fluidic flow analysis
- ✓ flow profiles
- ✓ fluid / structure interaction
- ✓ non-linear effects
- ✓ optimization

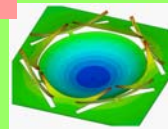


## Electrical field

- ✓ Steady-state current conduction analysis
- ✓ time-transient electric field analyses
- ✓ electrical field distribution
- ✓ 2D- or 3D-FEM-field models
- ✓ capacitance simulation for complex structures
- ✓ electrostatic forces

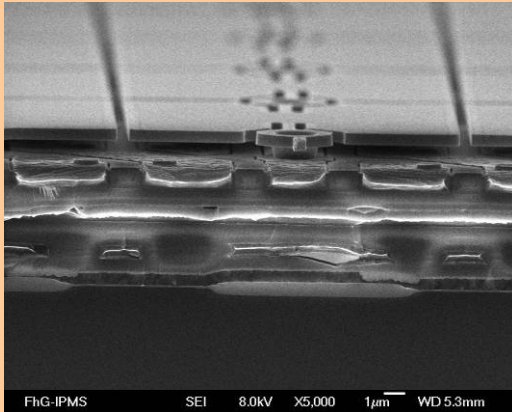


## Piezo electricity



- ✓ electric / structure mechanics interaction
- ✓ multilayered material stack deformation profiles
- ✓ voltage dependent deformation of bi- and multimorph layers
- ✓ thermal stress optimization
- ✓ layered stack optimization

## 2: SURFACE MEMS TECHNOLOGY



Surface MEMS Technology= Fabrication of sensors & actors on the wafer surface

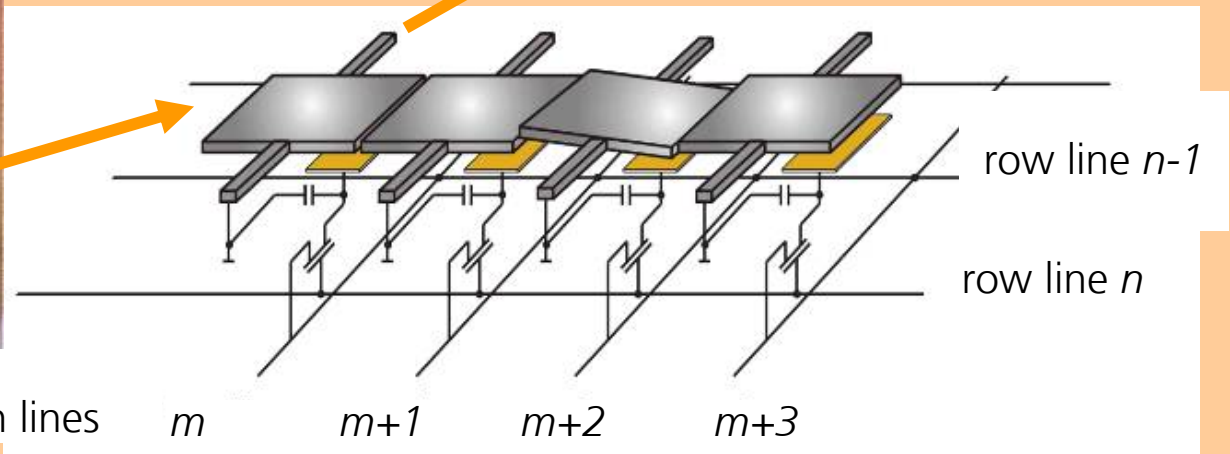
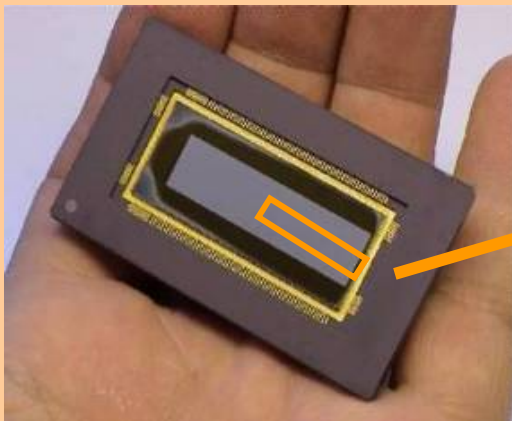
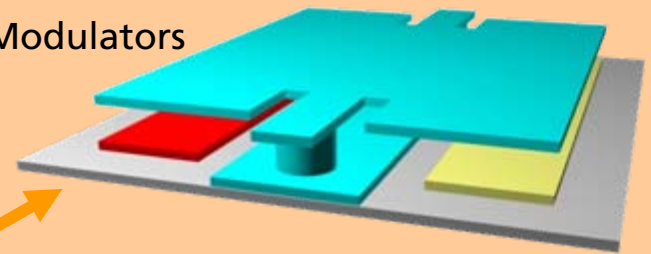
MEMS on CMOS Integration for free standing structures on Si- Substrates

Application: Spatial Light Modulators

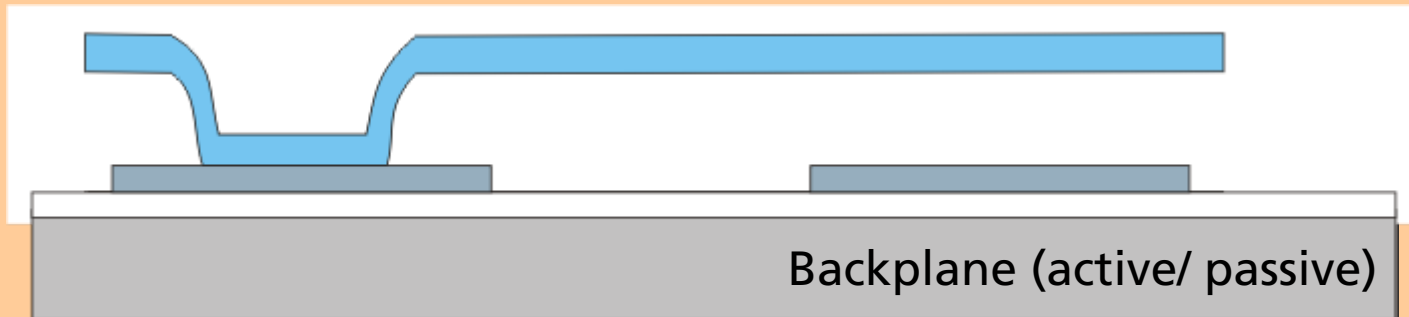
16 μm pitch

2048 x 512 pixel

2 kHz frame rate



## 2: SURFACE MEMS TECHNOLOGY/ PRINCIPLE



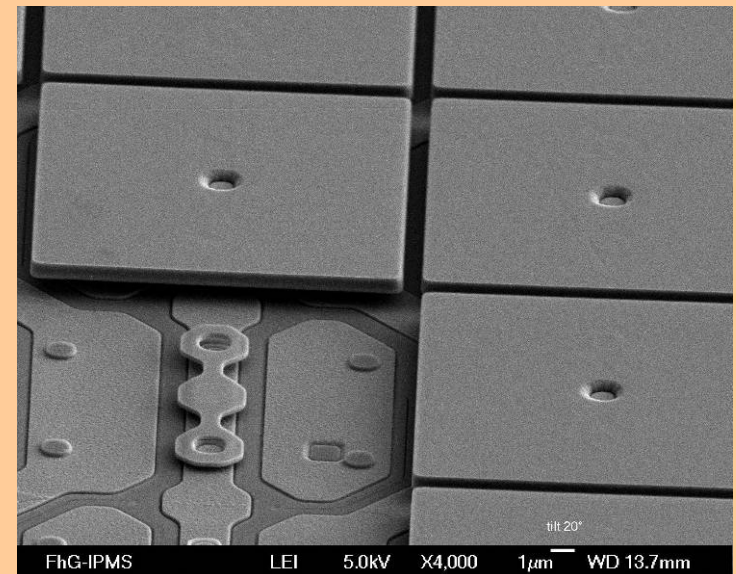
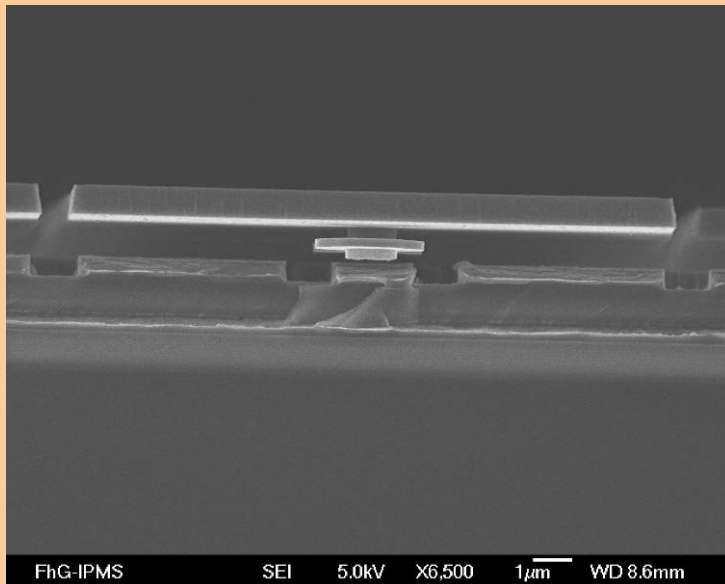
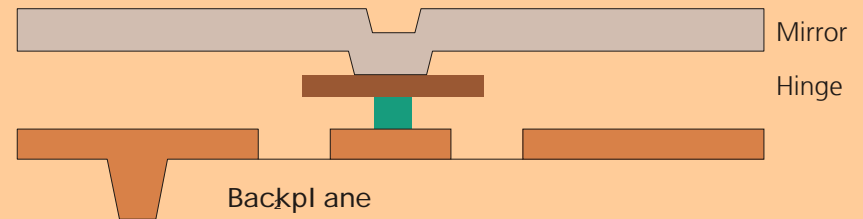
1. Substrate / Backplane with contact system available [ $<450^{\circ}\text{C}$  limited]
2. Deposition+planarisation of a sacrificial layer [Polymer, $\text{SiO}_2$ ,Si...]
3. Patterning of sacrificial layer [actuators mech fixing, el. contact]
4. Deposition of actuator material [Al,Alloys,aSi...stacks]
5. Patterning of actuator [actuator geometry]
6. Release of sacrificial layers / Uncovering of actuator [dry etching]

Principle is expandable for multi level MEMS

## 2.:SURFACE MEMS TECHNOLOGY

### Spatial Light Modulator Architecture

- Hidden hinge actuators
- Inorganic sacrificial layers
- Actuator: amorphous materials
- Mirror: Al- Alloys, Stacks



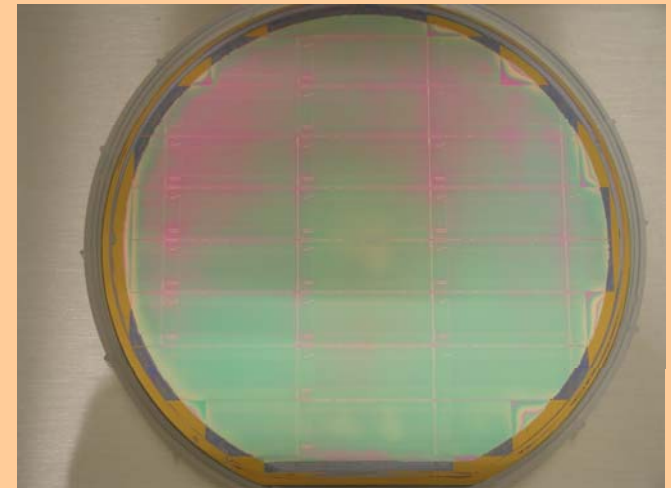
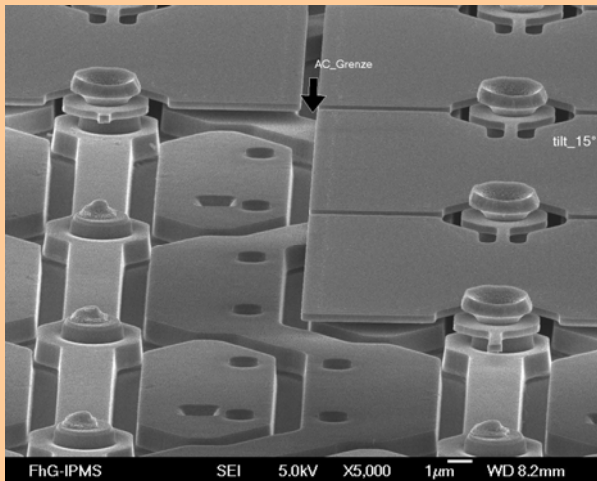
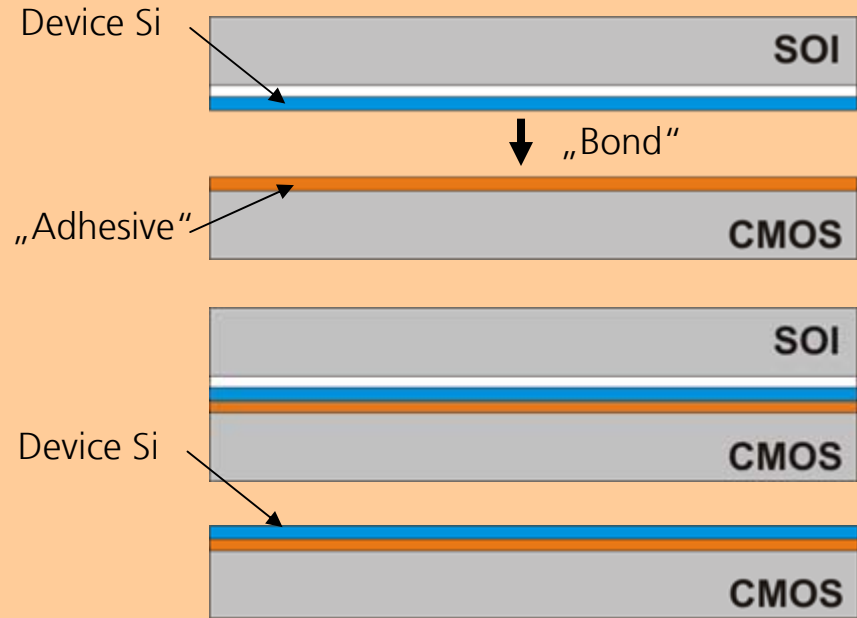
# 2.: SURFACE MEMS TECHNOLOGY

## Development of c-Si actuators

- Drift free c-Si actuators on CMOS wafers
- Layer transfer bond (adhesive and direct bond)

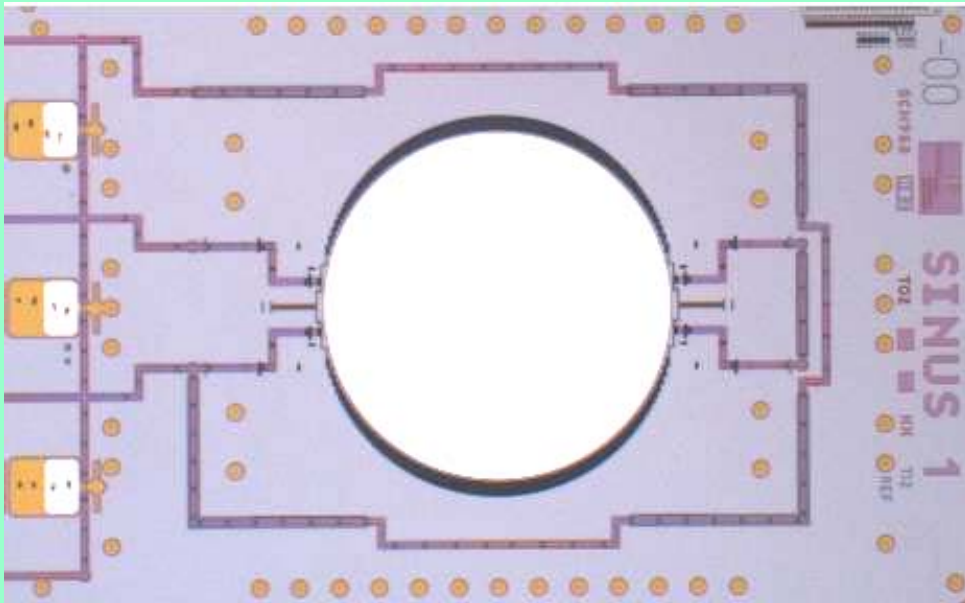
## Status

- Test with adhesive bond structures are fabricated
- Process development in progress
- Direct bond under development

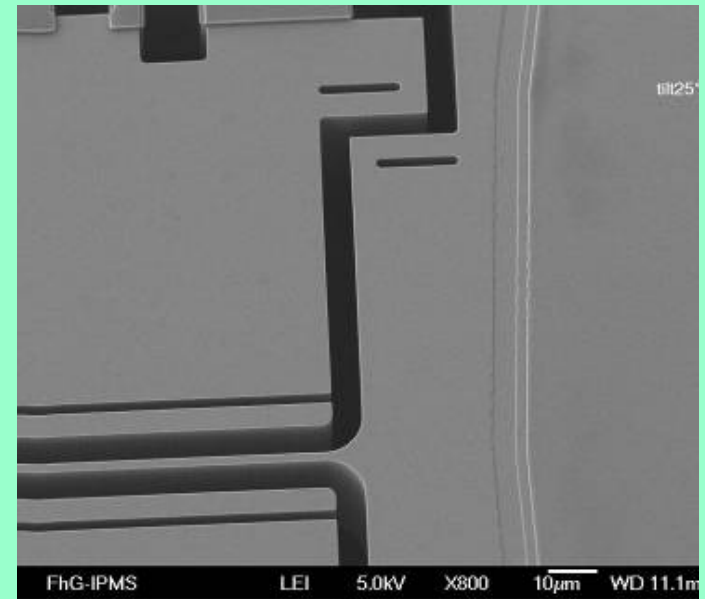


### 3.: BULK MEMS TECHNOLOGY

Bulk MEMS Technology= Fabrication of sensors & actors out of the wafer's material (bulk) itself

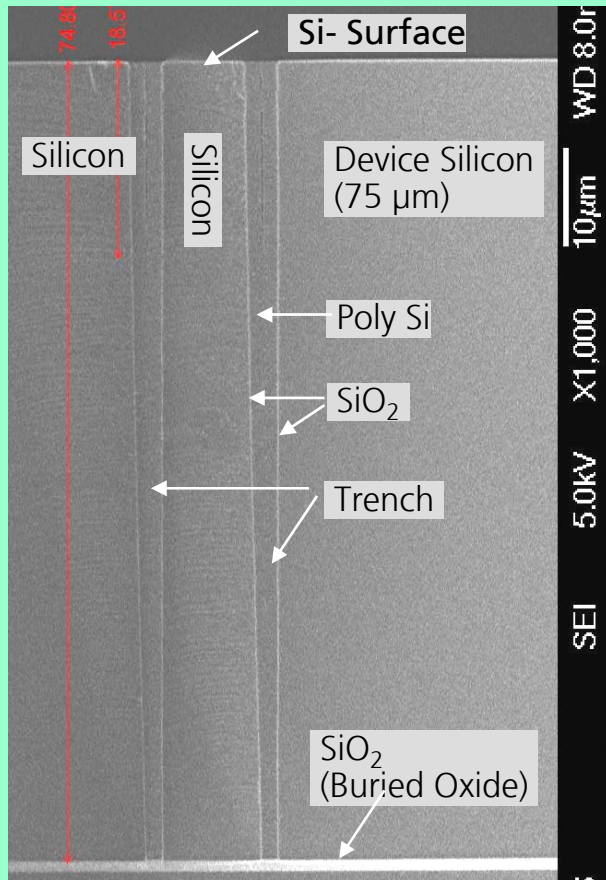


MEMS Scanner



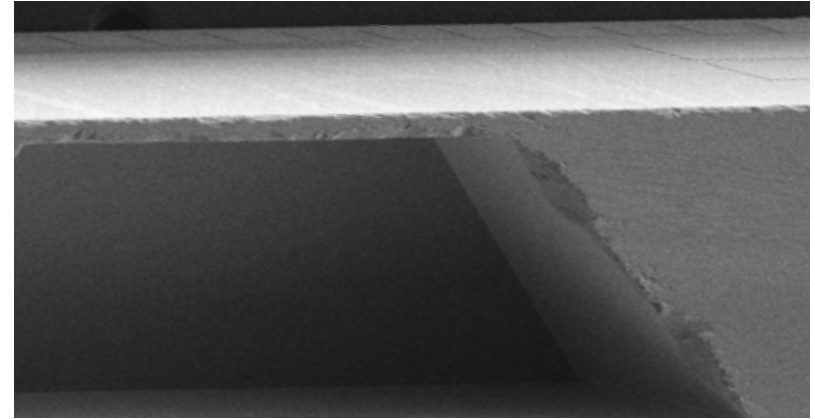
Hinges of MEMS Scanner

# 3.: BULK MEMS TECHNOLOGY

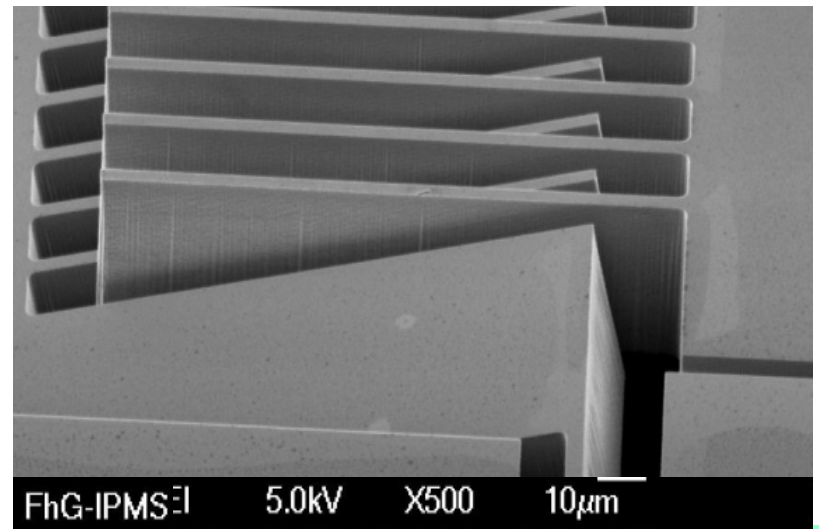


Insulated Silicon

Grooves & Membranes



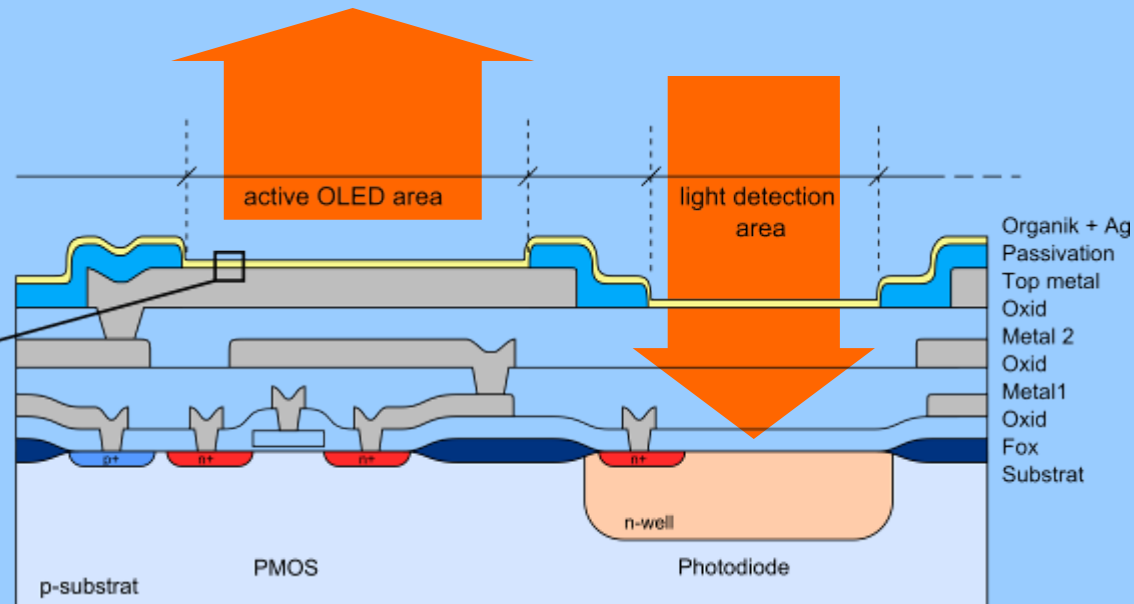
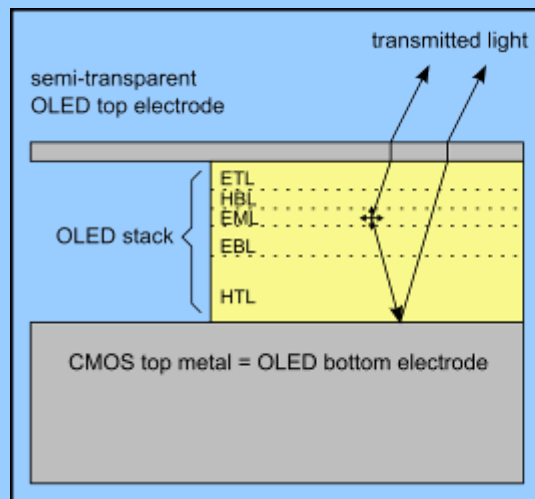
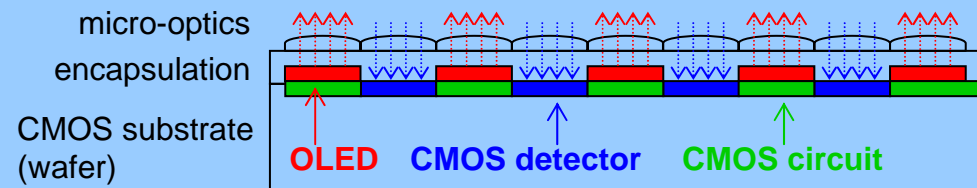
Movable Silicon



# 4. OLED on CMOS

- highly-efficient OLED light source in/on CMOS
  - OLED deposited on top of Si-CMOSsubstrate/wafer
  - OLED layers extremely thin (~100nm)
  - arbitrary shapes
  - all colors monochrome, white, NIR
  - excellent current/power efficiency (low-voltage, low-power)
  - good/improving lifetime (several 10kh)
  - self-emissive
  - fast response time (MHz)
- electronics feature integration
  - driving, acquisition, processing, control
- sensor co-integration
  - CMOS-compatible sensors
    - **embedded photodetectors**
    - M(O)EMS,...

- embedded photodetectors
  - CMOS photodiodes
  - lower level than OLED
  - side-by-side with active electronics devices
  - emission and detection can be operated in parallel or sequentially
- possibly shaping of OLED emission characteristics (angular, spectral width)



## 4.:OLED-on-CMOS: Device **Manufacturing**

### **CMOS**

- (so far) 1.0, 0.6, 0.35, 0.18 $\mu$ m processes
- integrated, mixed-signal circuit design by IPMS
- wafers contract-manufactured at silicon foundry providers (e.g., X-FAB)

### **OLED** post-processing

- SUNICEL plus200 at IPMS/COMEDD

SUNICEL plus200 by Sunic System, Ltd. (Korea)

- Pilot production tool for PM and AM OLED displays (RGB) on glass and silicon
- Substrates:
  - **Silicon** and quartz **wafer: Ø150 mm, Ø200 mm**, thickness: 0.6 to 0.8 mm
  - Glass: up to 200 x 200 mm<sup>2</sup>, thickness 0.7 to 1.1 mm
  - wafer level deposition
    - chip and block reticle level possible
  - reference substrates

### Configuration

- 7 process chambers
- 12 organic sources
- 5 inorganic sources
- 2 PVD sources
- Ar/O<sub>2</sub> plasma activation

### Encapsulation

Cycle time: ~ 60 min

Pilot capacity: ~ 6000 wafers/a



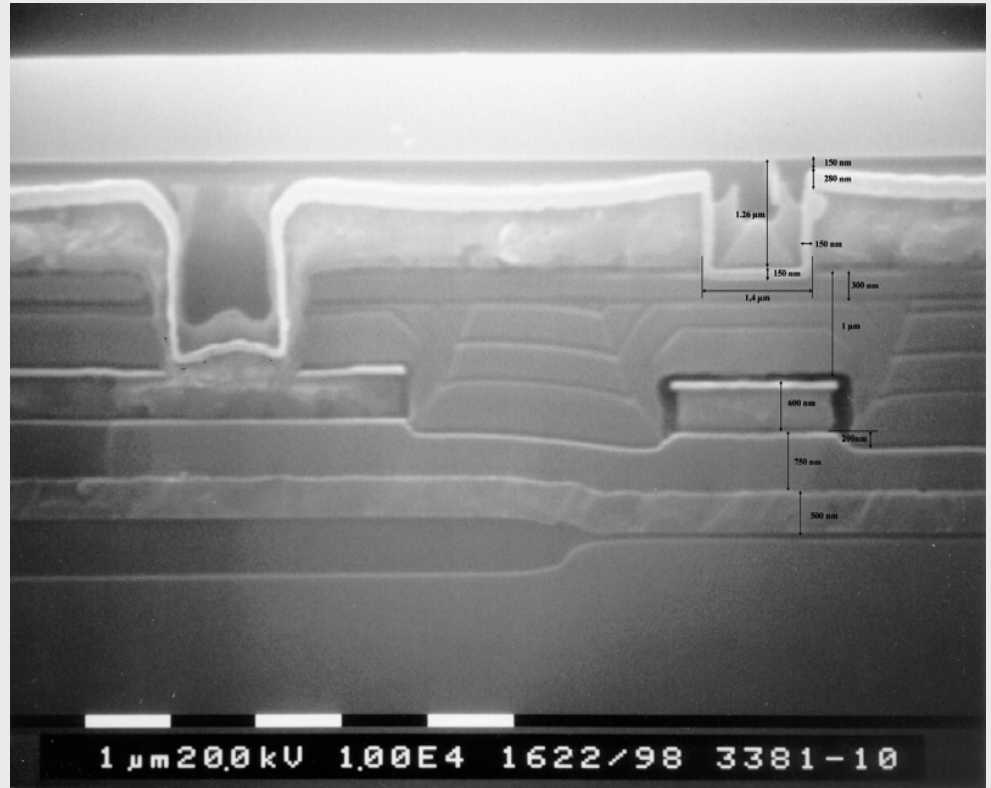
# 5.:CMOS & „active“ Silicon

## HV-CMOS-Technology

- Double well CMOS process
- Electric strength 45 V
- ILD- Planarization (CMP)
- Application: Control circuit for Micro Mirror Arrays

## “Active” Silicon

- PiN- Photo diodes
- FET with  $\text{Ta}_2\text{O}_5$  and  $\text{HfO}_2$ - Gate -> ISFET



# AGENDA

- MEMS Services
- Technology Toolset
- **Selected (Core) Processes**
- Solutions (success stories)
- Detailed Equipment List

# Lithography

## Stepper

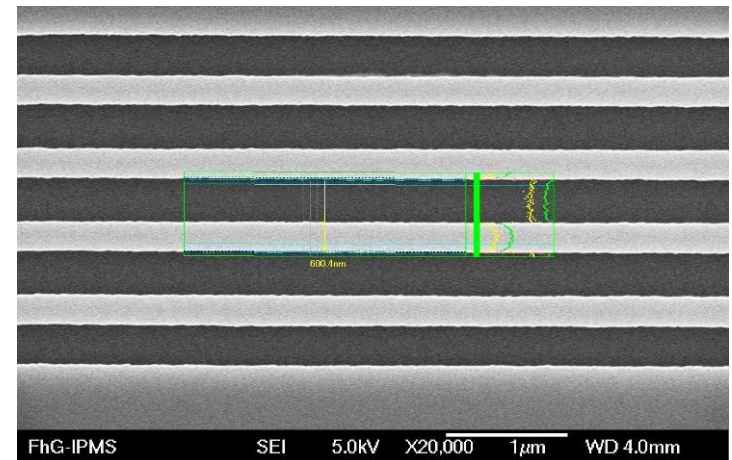
- NSR-2205i 14E2/ Nikon
- CD: Lines & Spaces 300 nm, Holes 400 nm
- Overlay: 40 nm (Field Image Alignment (FIA))
- Exposure Field: 22 x 22 mm<sup>2</sup>

## Mask Aligner

- MA 150 BSA/ Suss
- CD: 3  $\mu$ m
- Front Side & Back Side Processes



Stepper: NSR-2205i 14E2



Resist, Lines & Spaces, Grid= 600 nm

# Lithography/ Coating

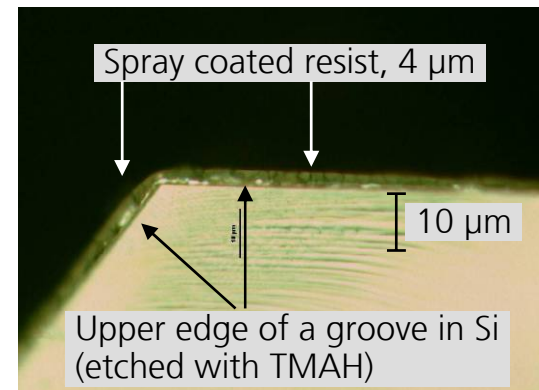
## Spin Coater

- Coater/ Dev-l-line SK-80BW-AVP/ DNS Resists
- Gamma 80 Spin Coater/ Süss Polyimide, BCB



## Spray Coater

- Gamma Alta Spray Coater/ Süss
- Conformal resist deposition for high topology
- Lithography in deep structures (i.e. 300  $\mu\text{m}$  deepness)

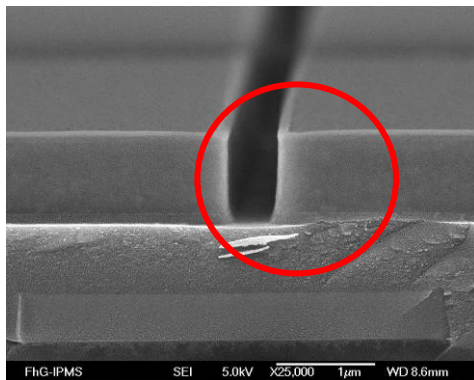


Spray resist at high topology

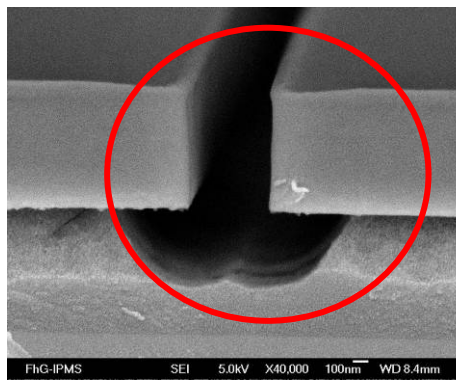
# RELEASE PROCESSES

## Release Processes

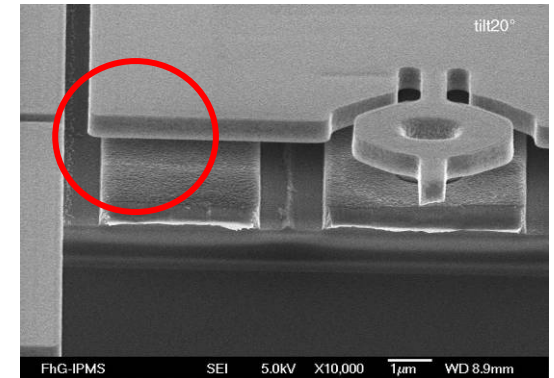
- X-SYS-3B:6/ Xactix: Si etch (XF2)
- MEMS-CET/ Primaxx: SiO<sub>2</sub> etch (HF vapour)
- Application: Release processes in Surface MEMS Technology
- Isotropic etch process
- Vapor etch for sticking free release of microstructures
- High selectivity to Al- Alloys



Before release



After start of release



Release is finished

# CMP

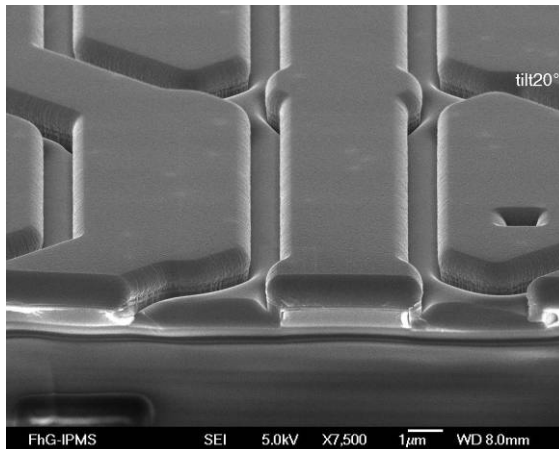
## Chemical Mechanical Polishing (CMP)

MIRRA/ Applied Materials

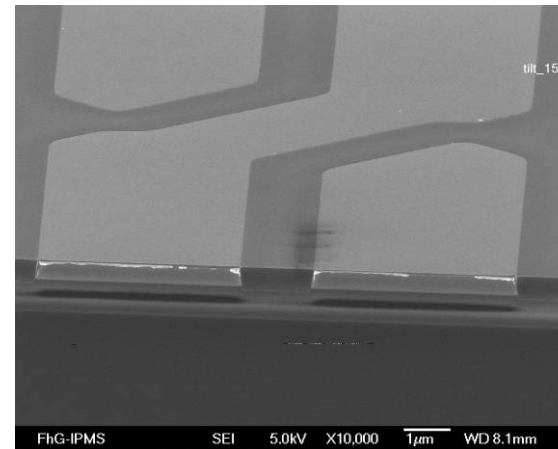
nTrepid/ Strasbaugh

Planarization of surfaces by polishing for:

- Photolithography
- High reliability of metallization
- Smooth surfaces in nm scale for mirrors in UV- applications



a-Si on metal line as sputtered



a-Si on metal line after CMP

# DEPOSITION / PVD

## **Sigma 204/ Aviza**

- Metallization for contact systems
- Al, AlSiCu, Ti, TiN

## **CS400/ Von Ardenne**

- MEMS- Materials
- Al, TiAl, Al-Alloys (Mirror, Hinges)
- SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> (Barriers, optical coatings)
- a-Si (Sacrificial layer)
- AlNi (piezoelectric actor)

## **Alcatel 610/ Alcatel**

- Chemical Sensors
- Ta, Ta<sub>2</sub>O<sub>5</sub>, HfO<sub>2</sub>
- Evaporation

## **PLS 570/ Balzers**

- Al, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>



Sputter tool CS400

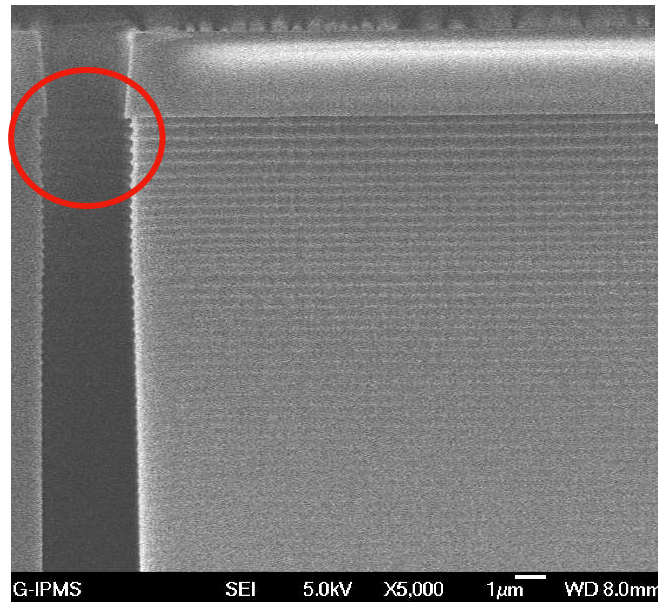
# DRY ETCH (Silicon)

## Deep Silicon Etch (Bosch Process)

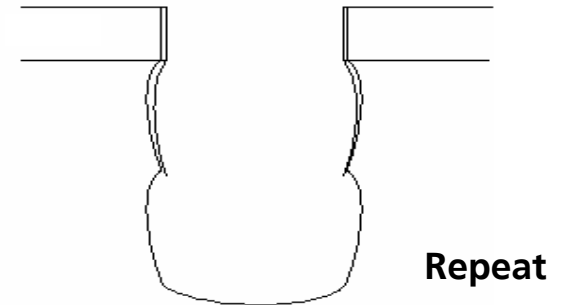
- Omega fxP & Omega I2L/ Aviza
- High density / low pressure

### Etch Process

- Net anisotropic profile
- Scallop on micro-scale
- High aspect ratio



## Isotropic Etch Step



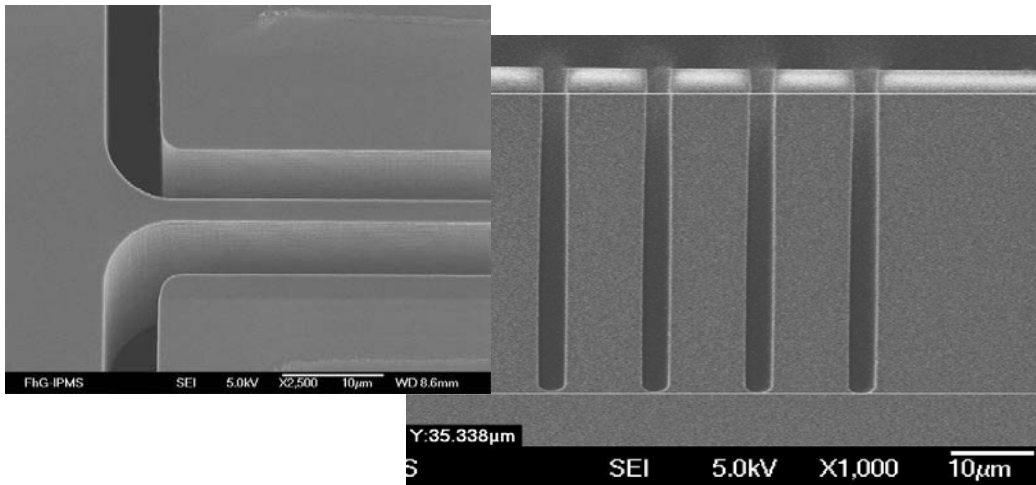
# DRY ETCH (Silicon)

## Fine Deep Trenches

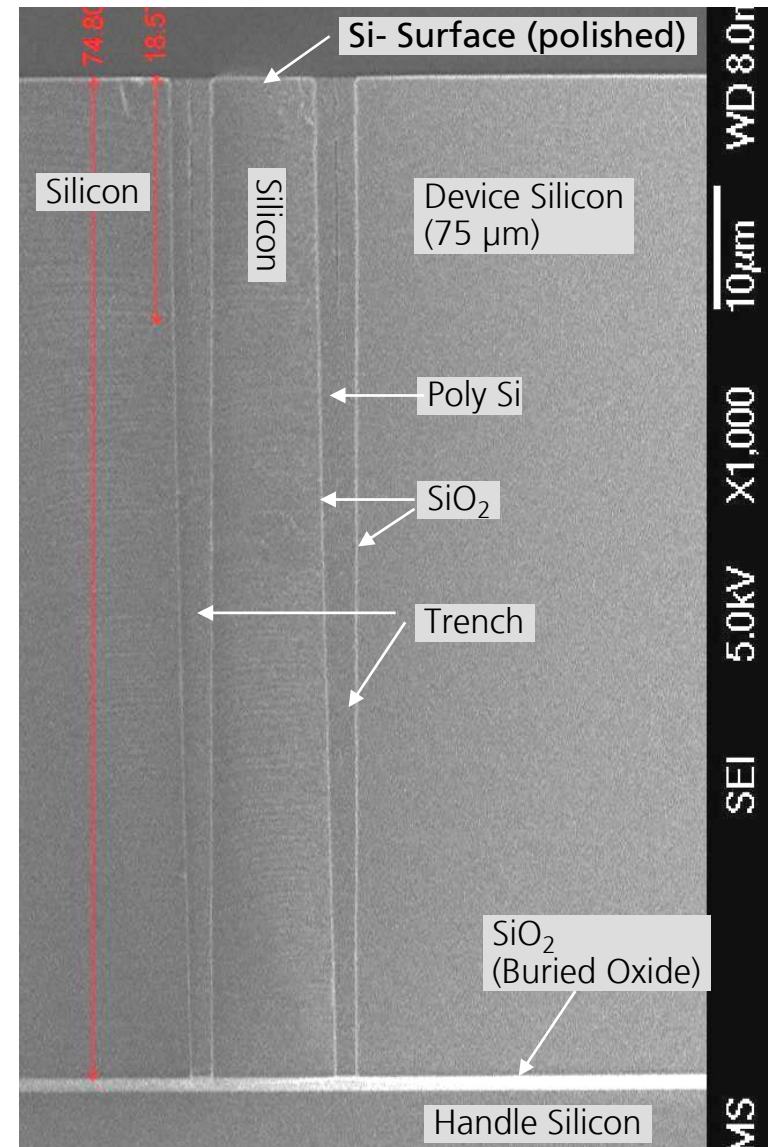
- Isolation trenches (dielectrically insulated Si)
- Free movable Si structures

## Grooves

- Membrane etch



Vertical Trenches for movable Si- structures

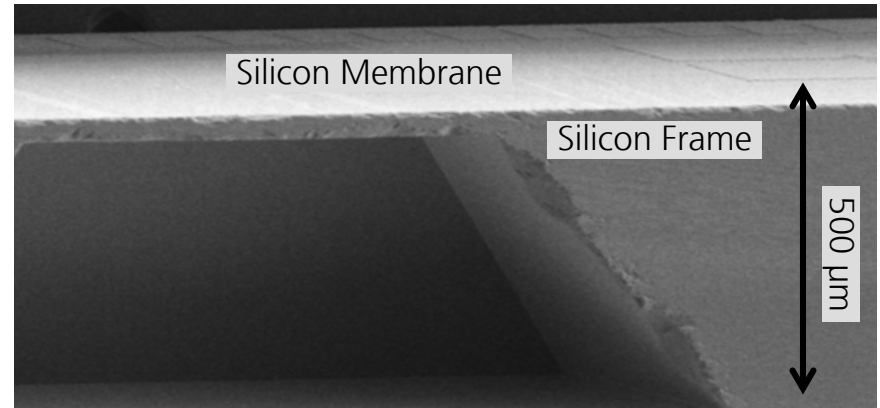


Insulation trench, positive Profile  
2.5 μm wide, 75 μm deep (SOI- Wafer)

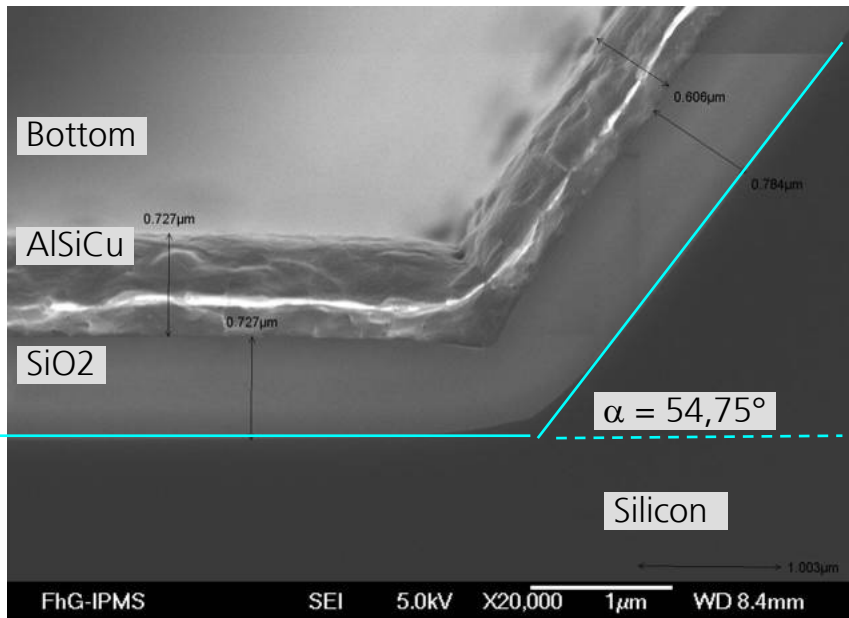
# WET ETCH

## Silicon Wet Etch

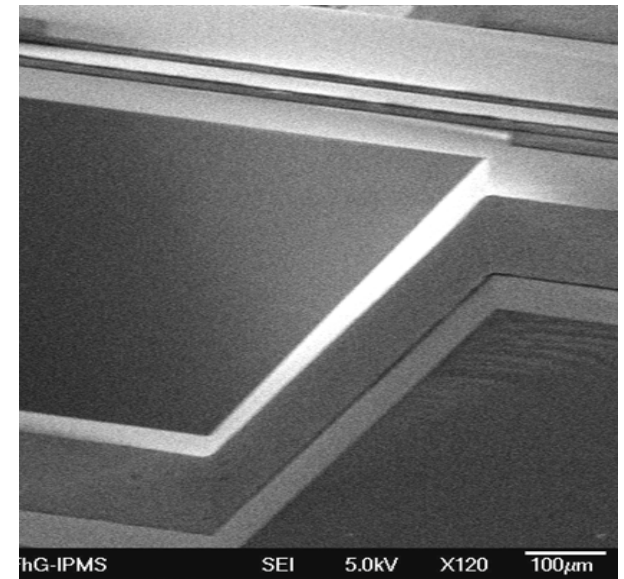
- anisotropic Si Etch: TMAH, KOH
- +/- 3  $\mu\text{m}$  accuracy at 500  $\mu\text{m}$  depth
- Grooves & Membranes



Silicon membrane, KOH etched



Silicon groove, TMAH etched

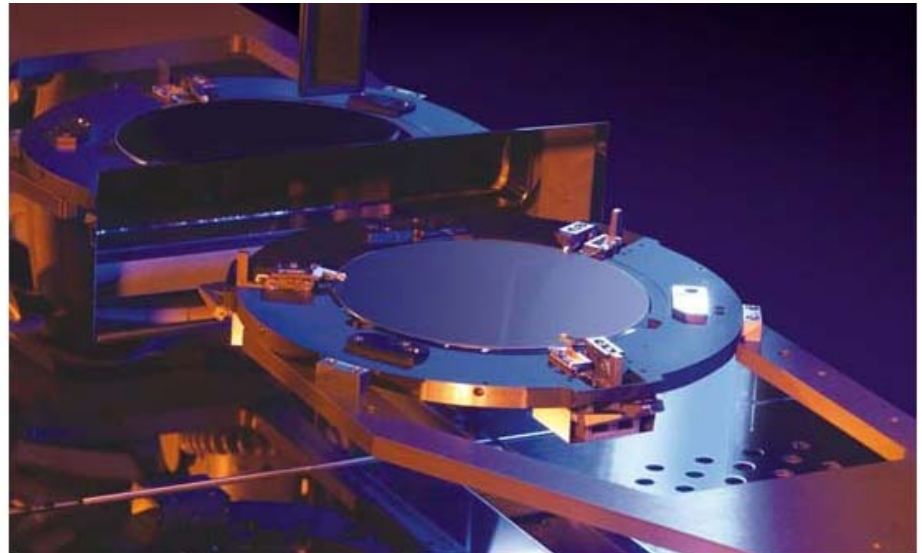
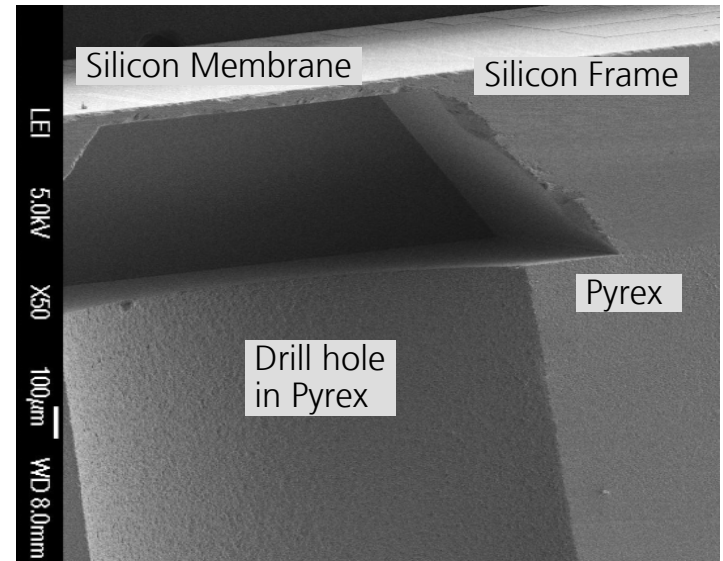


Metal line in a 200 $\mu\text{m}$  deep Silicon groove

# BACK END

## Anodic wafer bonding

- SB6 Wafer bonder/ BA6 Bond aligner/ Süss
- Glass (Pyrex, Borofloat) - Silicon-compound
- Performed at 300 ... 500 °C with about 1.2 kV
- Stable mechanical connection between
- Silicon and glass due to SiO- bonds
- Application: pressure sensor
- **Wafer dicing tool** DISCO 651
- Dicing of Silicon- Glass- Compound
- Open aluminum MEMS-structures



# AGENDA

- MEMS Services
- Technology Toolset
- Selected Processes
- **Solutions (success stories)**
- Detailed Equipment List

# SPATIAL LIGHT MODULATORS

## Technology

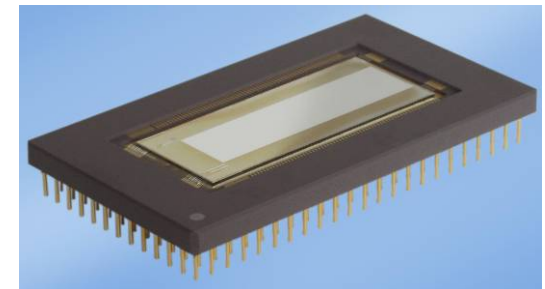
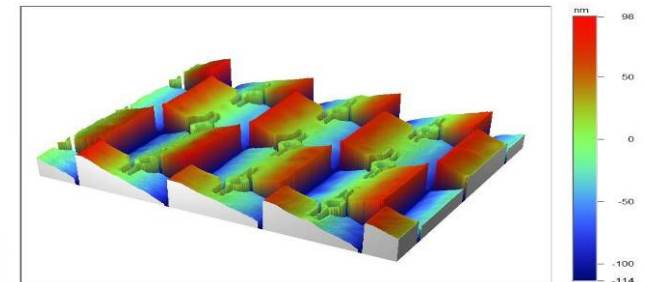
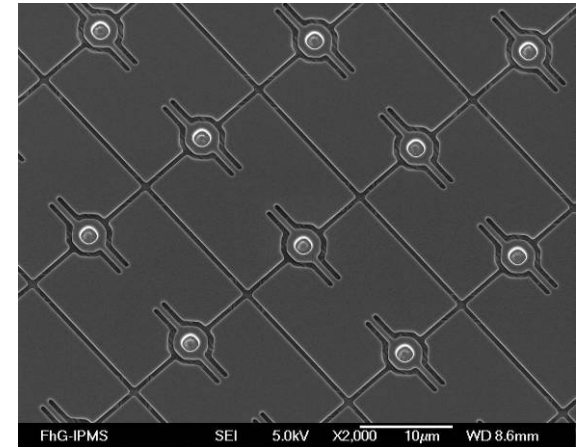
- CMOS-Back plane: C5090
- Surface micromachining
- Technical parameters
  - 16  $\mu\text{m}$  pitch
  - 2048 x 512 pixel
  - 2 kHz frame rate

## Application

- Microlithography
- Structured Illumination



 MICRONIC LASER SYSTEMS



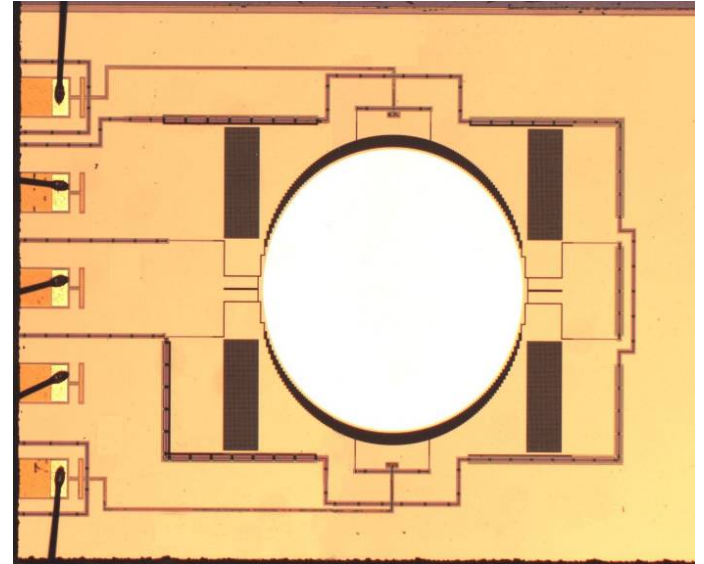
# SCANNING MIRRORS

## Technology

- Bulk micromachining
- 1D-Scanner,..+grid, 2D Scanner
- Frequencies: 0.2 ... 35 kHz
- Diameter: 0.5 ... 3.0 mm
- Deflection angle: up to +/- 34°  
(136° optical scan range)

## Applications

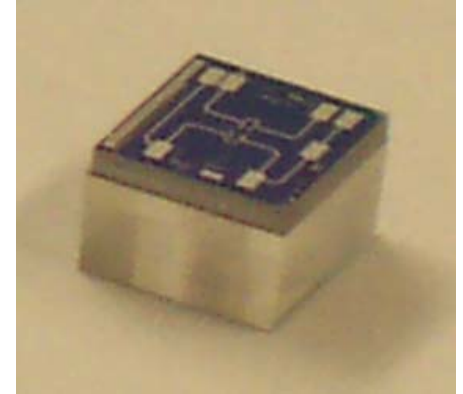
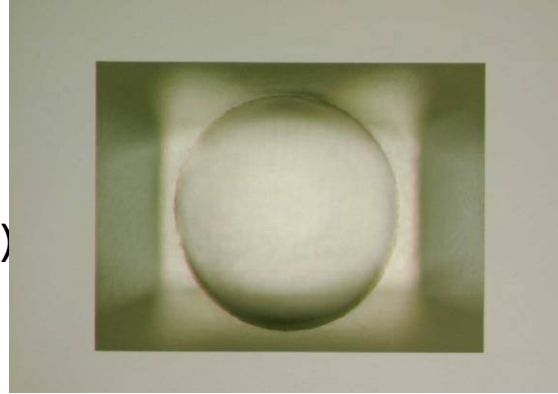
- Bar code reading
- Spectroscopy
- $\mu$ -Projectors (cell phones)



# PRESSURE SENSORS

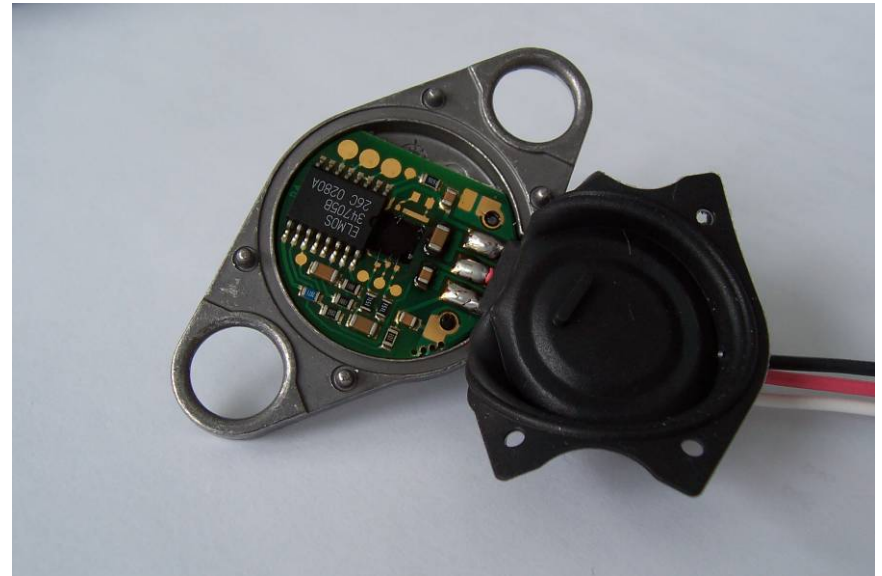
## Technology

- Piezo- resistance, SOI (dielectrically insulated resistors)
- Si- Membrane
- anodic bonded Pyrex wafer on wafer back side



## Application

- Automotive: Oil pressure in automatic gear boxes
- 0...11 bar, overpressure 60 bar



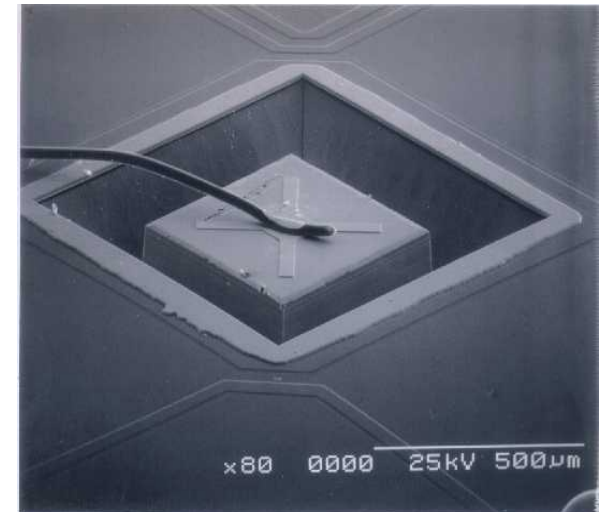
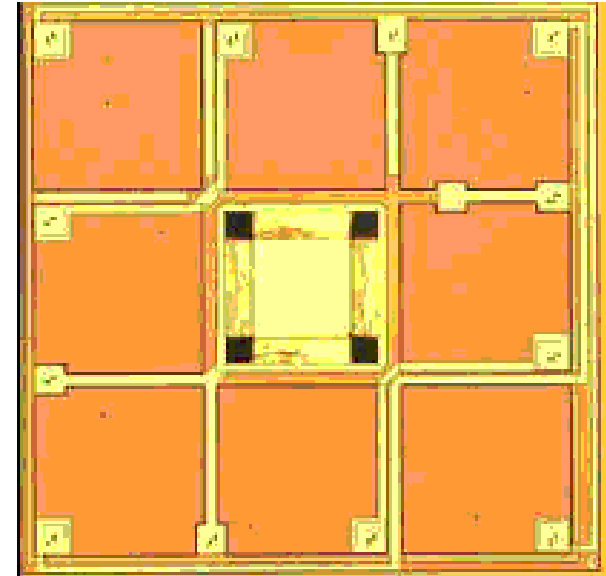
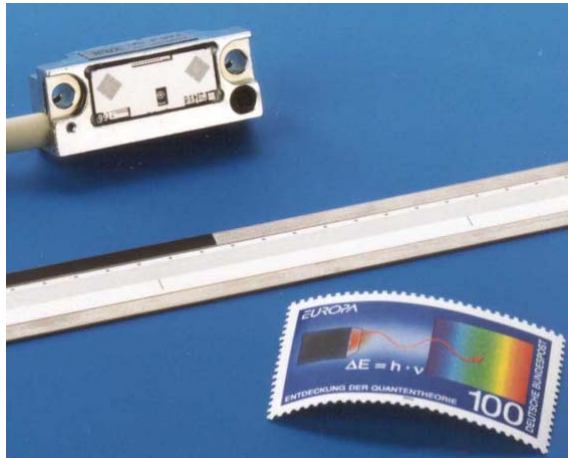
# MEMS/MOEMS Products at IPMS / Photodiodes

## Technology

- PIN-Diode
- Metallised Groove  
(Depth: 220 µm)

## Application

- Linear measurement systems for machine tools  
(0.1 µm resolution)



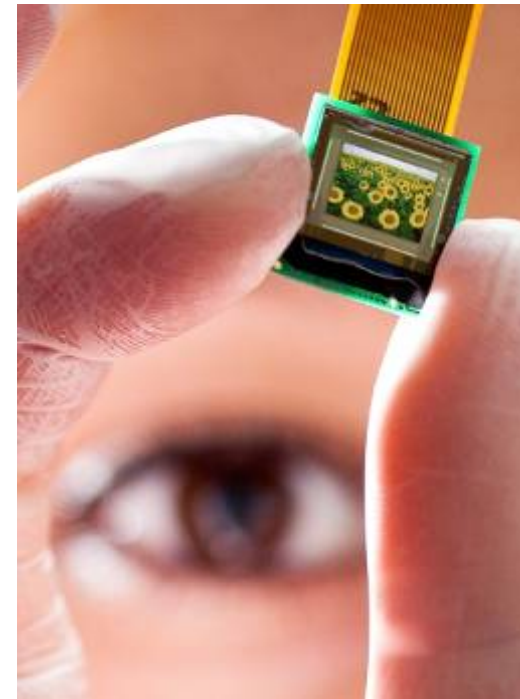
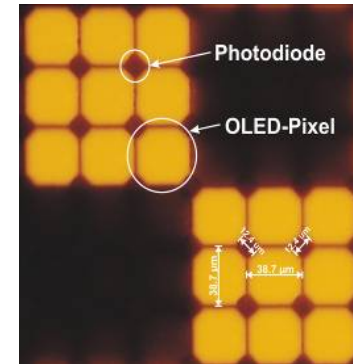
# OLED-on-CMOS (microdisplays)

## Technology

- OLED (small-molecule) on 0.18 $\mu\text{m}$  CMOS
- QVGA (320x240) with embedded camera
- VGA (640x480)
- Active area 7x5mm<sup>2</sup>
- Chip size 12x11mm<sup>2</sup>

## Applications

- Head-mounted Displays
  - w/ integrated eye-tracking
- Micro-projection
- Electronic viewfinder
- Optical inspection



# OLED-on-CMOS (sensors)

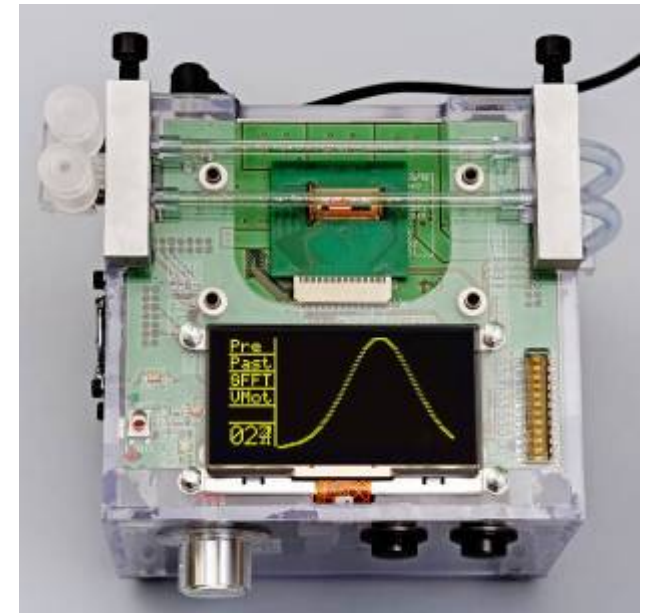
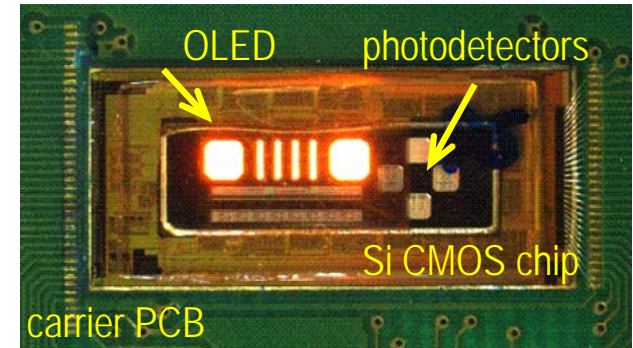
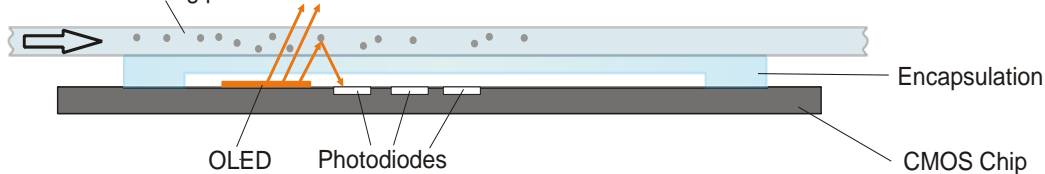
## Technology

- OLED (small-molecule) on 1 $\mu$ m CMOS
- arbitrarily patterned illumination
- embedded CMOS photodetectors

## Applications

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

Capillary with flowing transparent fluid and reflecting particles



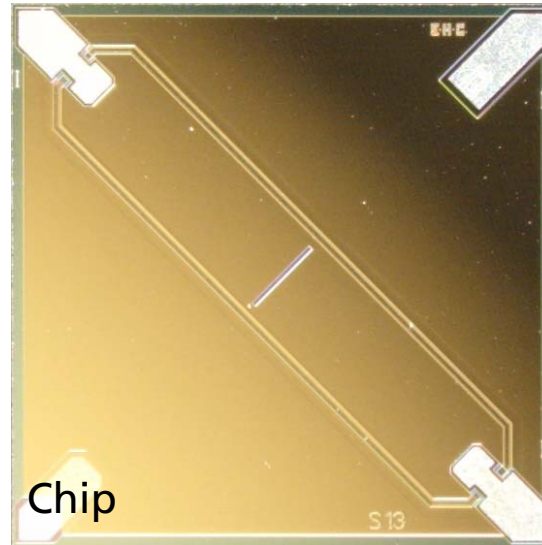
# ION SENSITIVE FET (ISFET)

## Technology

- p- MOS
- Ion sensitive interface: Ta<sub>2</sub>O<sub>5</sub>
- Resist Lift- off

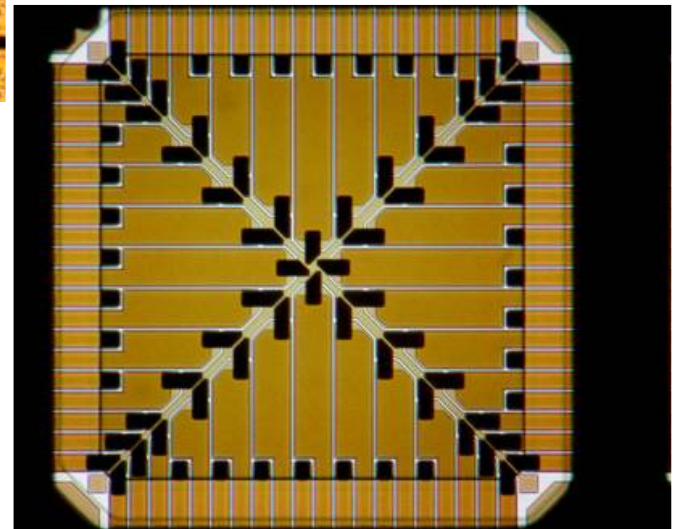
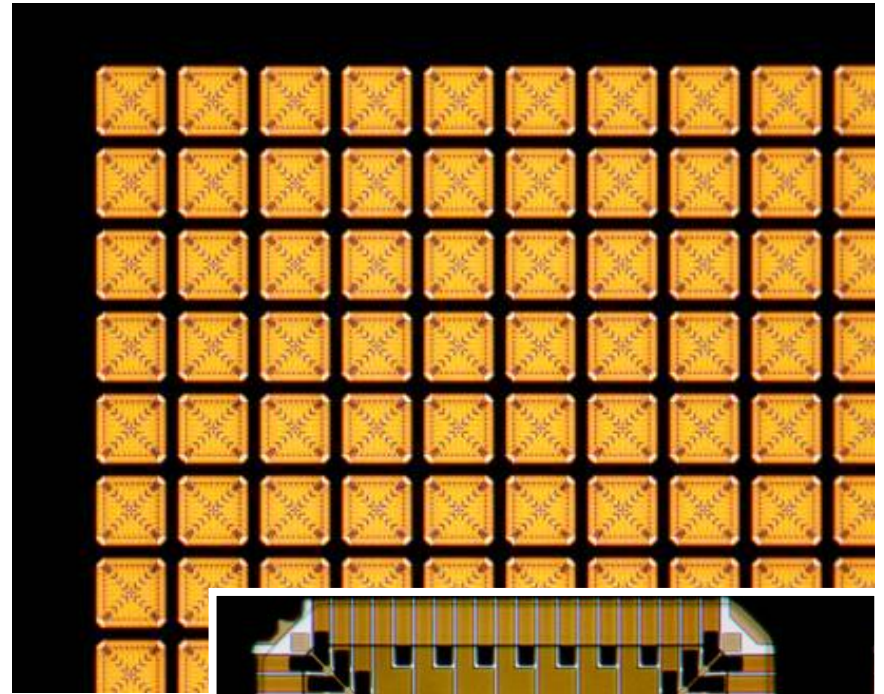
## Application

- Measurement of H<sup>+</sup> concentration in hydrous liquids
- pH- Measurement (environment, instrumentation, medical)



# FOUNDRIY SERVICE (1)

- Membrane etch for IR- Sensors
- Test substrates for bumping
- Deposition of stress compensated stacks
- Deposition (PE-CVD, Oxidation, ...)
- OLED/ OFET- Substrates



# FOUNDRIY SERVICE(2): test and characterisation

## Example for currently services:

- transponder calibration
- characterisation MOEMS
- end test diced wafers

Mixed signal test system

■ FALCON M3670\_GL



Waferprober

■ EG4090μ+



**Substratprober**

■ PA300



Probecard + cabel-interface



switchboard

■ Keithley 4200-UL-LS-72



colorimetry sensor/camera

■ LMK 98-4

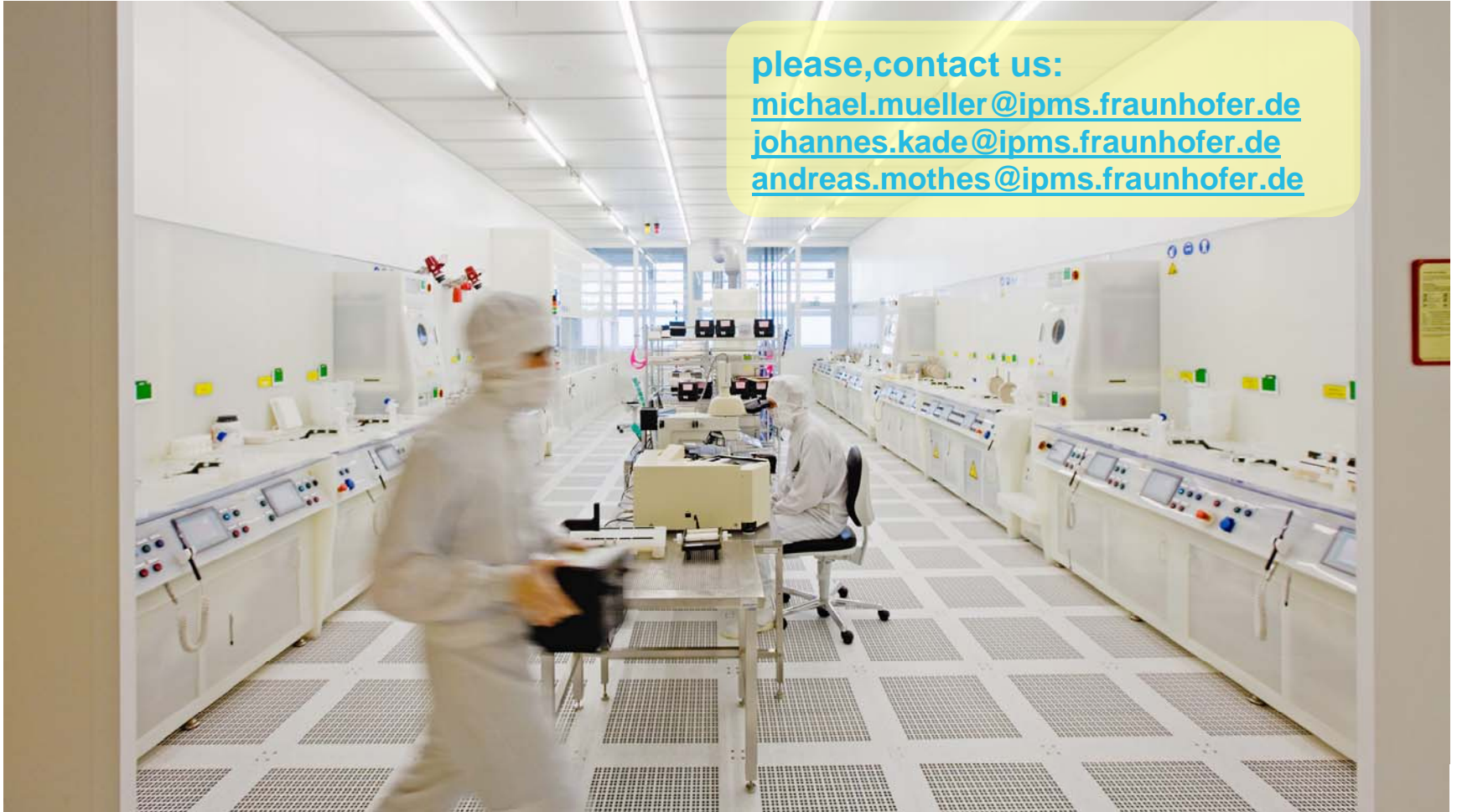


# AGENDA

- MEMS Services
- Technology toolset
- Selected Processes
- Solutions
- **Detailed Equipment List**

# THANK YOU FOR YOUR ATTENTION!

please, contact us:  
[michael.mueller@ipms.fraunhofer.de](mailto:michael.mueller@ipms.fraunhofer.de)  
[johannes.kade@ipms.fraunhofer.de](mailto:johannes.kade@ipms.fraunhofer.de)  
[andreas.moes@ipms.fraunhofer.de](mailto:andreas.moes@ipms.fraunhofer.de)



# EQUIPMENT for MEMS and CMOS (1)

<b>Lithography</b>	Stepper	NSR-220Si 14E2   Nikon
	Mask aligner	MA 150 BSA   SUSS
	Nano Imprinting Stepper	NPS 300   SUSS
	Coater/Dev-I-line	SK-80BW-AVP   DNS
	Spin Coater (Polyimide, BCB)	Gamma 80 Spin Coater   SUSS
	Spray Coater (high topology)	Gamma Alta Spray Coater   SUSS
	Spray Coater (high topology)	EV101   EVG
	UV-Stabilizer	Fusion 200 PCU Polo   Axcelis
<b>Deposition</b>	PE-CVD (USG, PSG, BPSG, Silicon nitride)	P5000   Applied Materials
	PE-CVD/SA-CVD	Centura   Applied Materials
	LP-CVD (Poly-Si, SR nitride, TEOS, Oxynitride)	E1550 HAT 320-4   Centroterm
	PVD Sputtering (Al, TiAl, SiO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> , a-Si, HfO <sub>2</sub> )	CS400   Von Ardenne Anlagentechnik
	PVD Sputtering (Al, AlSiCu, Ti, TiN)	Sigma 204   Aviza
	PVD Sputtering (Ta, Ta <sub>2</sub> O <sub>5</sub> , HfO <sub>2</sub> )	Alcatel 610   Alcatel
	Evaporation (Al, SiO <sub>2</sub> )	PLS 570   Balzers

# EQUIPMENT for MEMS and CMOS (2)

<b>Furnaces</b>	Horizontal Furnace Anneal	Interterm
	Horizontal Furnace Oxide	Interterm
	Horizontal Furnace POCl <sub>3</sub> Doping	Interterm
	Horizontal Furnace Reflow	Interterm
	RTA	Heatpuls 8108   Metron
<b>Dry Etch</b>	Etch (Oxide, Nitride, Poly-Si, deep Si)	Omega fxP   Aviza
	Etch (Al alloys)	TCP 9600   LAM
	Etch (deep Si)	I2L   Aviza
	Etch (deep Si)	ASE   STS
	Resist Strip	BobCat 2085   Axcelis
	Resist Strip	Plasma System 300   PVA Tepla
	Resist Strip	Type1   Axcelis
<b>Wet Etch and Cleaning</b>	Wet Etch (Silicon oxide, Silicon nitride, Al)	Tauchbeckenlinie   Ramgraber
	Wet Etch (anisotropic Si: TMAH, KOH)	Tauchbeckenlinie   Ramgraber
	Wet Strip	Solvent Spray Processor   Semitool
	Wafer Cleaning	Automatic Tool   Ramgraber
	Cleaning processor (High velocity spray, scrubber)	3300ML   SSEC

# EQUIPMENT for MEMS and CMOS (3)

<b>Chemical Mechanical Polishing (CMP)</b>	CMP (Silicon oxide, Polyimide, a-Si)	MIRRA   Applied Materials
	CMP (Silicon oxide, Poly-Si, a-Si)	nTrepid   Strasbaugh
	Scrubber	DSS 200 On Track   LAM
<b>Vapor Etch for MEMS Release</b>	Si Vapor Etch (XeF <sub>2</sub> )	X-SYS-3B:6   Xactix
	SiO <sub>2</sub> Vapor Etch (HF)	Primaxx
<b>Analysis/Metrology</b>	Film Thickness Measurement System	NanoSpec 9100   Nanometrics
	Film Thickness Measurement System	NanoSpec 8000 X   Nanometrics
	Scanning Electron Microscope	JSM-6700F   Jeol
	Atomic Force Microscope	Nanoscope D3100   Veeco
	Ellipsometer	VB-400   Woollam
	X-Ray Diffractometer	D5000   Siemens
	Scanning Near-field Microscope SNOM	MV4000   Nanonics
	FTIR Microspectroscopy System	FTIR6700+Continuum   ThermoFischer
	Tunable Diode Laser System	TLB   NewFocus
	White-light Interferometer	NT8000 Wyko   Veeco
	White-light Interferometer	NT1100   Veeco
	White-light Interferometer	NV7300   Zygo
	Surface Scan	µScan   Nanofocus
	Twymen-Green-Interferometer	µPhase   Fisba

# EQUIPMENT for MEMS and CMOS (4)

<b>Masks</b>	E-Beam Writer (5", 6", 7" blanks)	ZBA31   Vistec
	Mask Cleaner	HMR900   Hamatech
<b>Packaging</b>	Wafer Saw	DISCO 651   Disco
	Bonder (Anodic and Adhesive Bonding)	SB6e   SUSS
	Bond Aligner	BA6   SUSS
	Dispenser	Schiller
	Wire Bonder	Bondjet 810   H&K
<b>Test and Characterization</b>	Mixed-Signal Tester	ST-M3650   SZ
	Sensor Actuator Test System	AP200   SUSS
	Automatic Inspection System	SUSS
	Electro optical Test system	several
	Pressure burst testsystem	several
	Vibrometer	MSV 300   Polytec