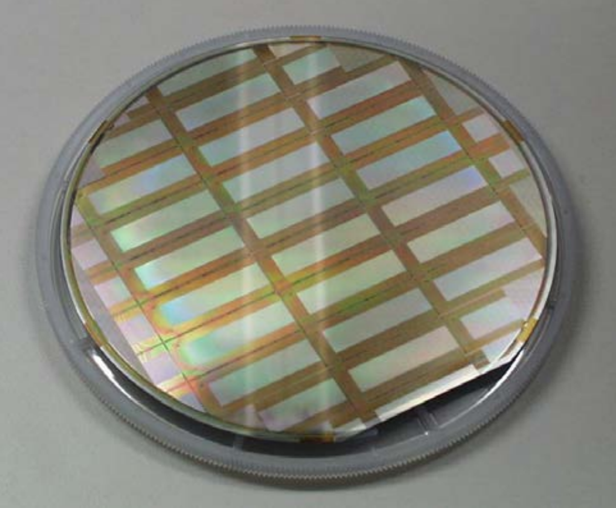

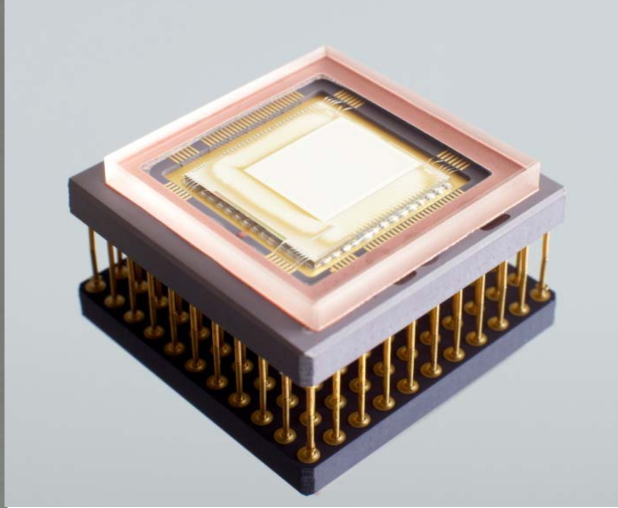

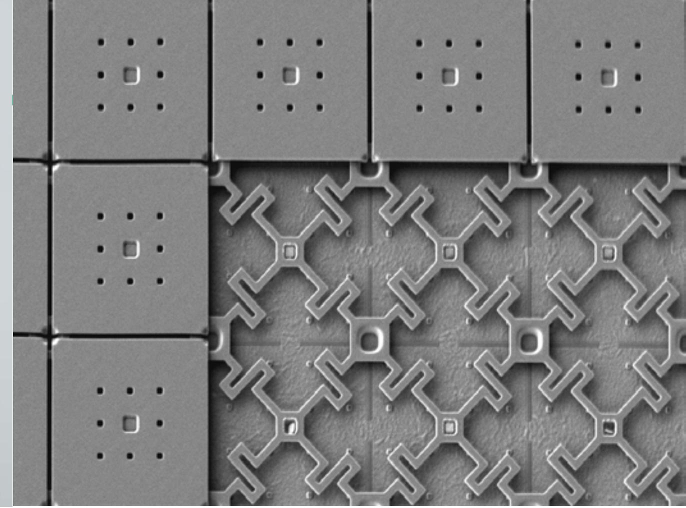

Micro Mirror SLM

Workshop
Spatial Light Modulators SLM
Technologies and Applications
27. October 2017

Michael Wagner

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

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Fraunhofer Institute for Photonic Microsystems (IPMS)
Maria-Reiche-Str. 2
01109 Dresden (Germany)

Outline

- Introduction
  - Fraunhofer Gesellschaft / Fraunhofer IPMS
- Micro Mirror Arrays
  - Overview
  - Device architecture
  - Operation characteristics
- Applications in Optical Pattern Generation
  - Laser mask writing for optical micro lithography
  - Laser Direct Imaging (LDI)
  - Laser Marking/Engraving
- Applications in Optical Imaging and Wavefront Control
  - Microscopy
  - Adaptive Optics
- Summary

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Fraunhofer Gesellschaft Background

Fraunhofer in General

Public German R&D Institution

Application/industry oriented research

International cooperations

Approx. 24,500 employees

69 separate institutes

40 locations in Germany

Various offices outside Germany

Fraunhofer Institute for Photonic Microsystems (IPMS)

Located in Dresden, Germany

Research/development/pilot fabrication of innovative photonic microsystems

5 business units

Approx. 350 employees

2 cleanrooms

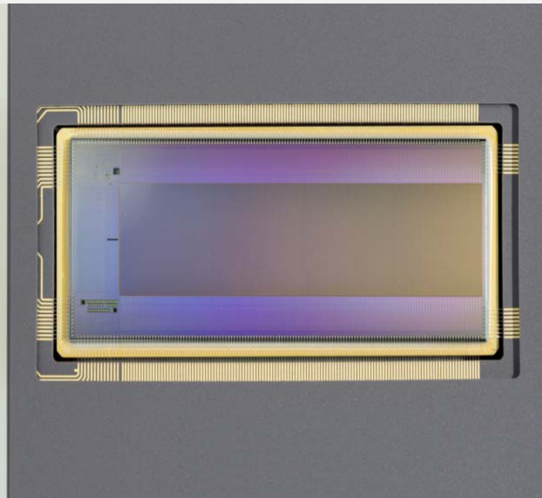
Fraunhofer IPMS cleanrooms

MEMS Technologies at Fraunhofer IPMS

MEMS/ MOEMS

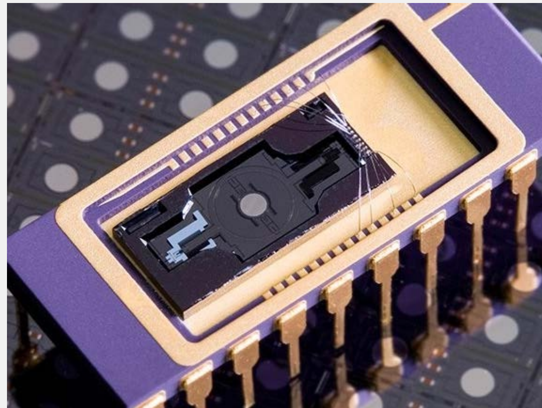
Surface MEMS Technology

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



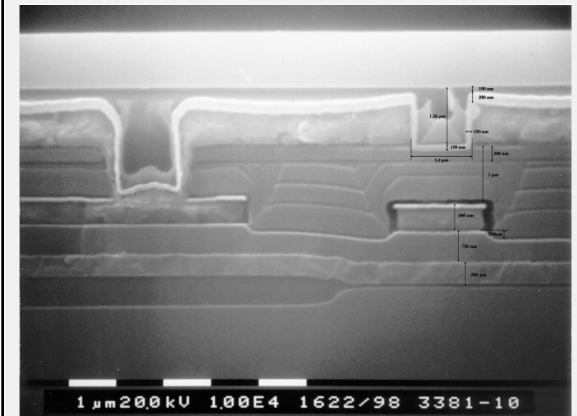
Bulk MEMS Technology

- 3- dimensional Structures in Silicon
- Applications:
  - MEMS Scanner
  - Pressure Sensor
  - Micro-optics



CMOS

- High-Voltage- CMOS- Process
- Application:
  - Backplane for Spatial Light Modulator



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Classification Parameters of MEMS SLM

Light Modulation in Reflection

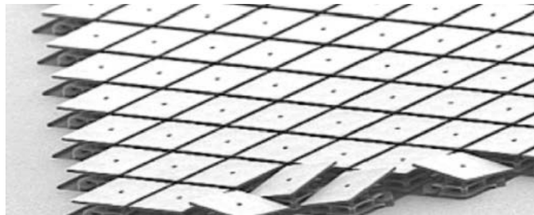
- Mirror architecture: continuous membrane, segmented micro mirrors
- Number of actuating elements, 1D/2D pixel arrangement
- Electrical architecture: on-chip electronics, passive (no on-chip electronics)
- Size of actuating element (pixel pitch)
- Type of actuation:
  - one axis (tilt), piston
  - two axis (tip tilt), combinations of piston and tilt
  - digital deflection, analogue deflection
- Modulation depth (e.g. stroke of a piston micro mirror)
- Mirror switching speed (resonance frequency)
- Matrix frame rate
- Wavelength / wavelength range
- Illumination intensities
- ...

> - There is a large variety of MEMS SLM design and technology options.
> - Application requirements define SLM specifications.

Highly Integrated / High Resolution MEMS SLM
(Micro Mirror Arrays, MMA)

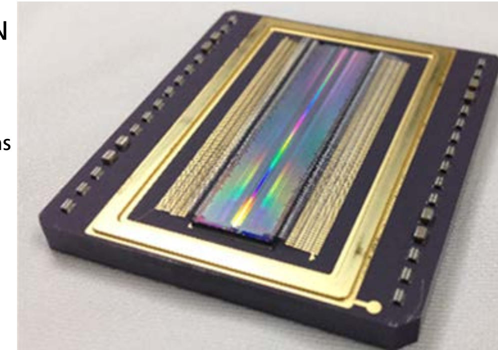
Digital 2D MMA
DMD™
TEXAS INSTRUMENTS
www.TI.com
- 2D SLM, binary tilt
- ~20-30kHz framerate
- Wavelength range: >355nm

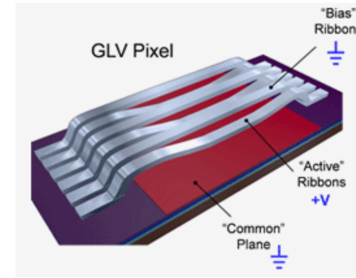
DMD™, var. versions: e.g. 2560x1600 Pixels



Analog 1D MMA
GLV™
Silicon Light Machines / SCREEN
www.siliconlight.com,
- 1D SLM, 1088 or 8192 pixels
- up to 250kHz frame rate
- analog piston movement of ribbons

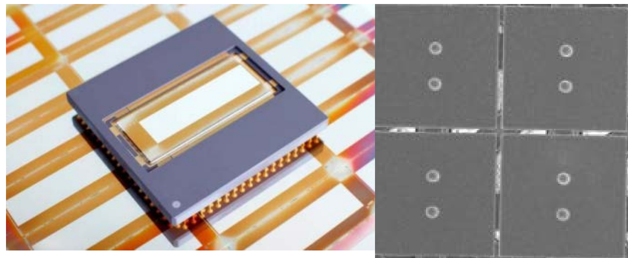
8192 x 1 Pixel GLV (G8192)



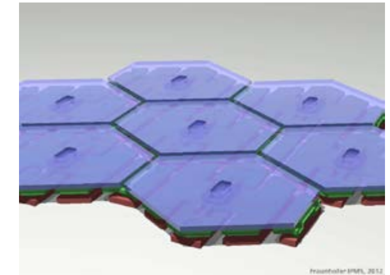


Analog 2D MMA
ASLM1M
Fraunhofer IPMS
- 2048 x 512 pixels, analog tilt
- 2kHz framerate
- Optimized for 248nm,

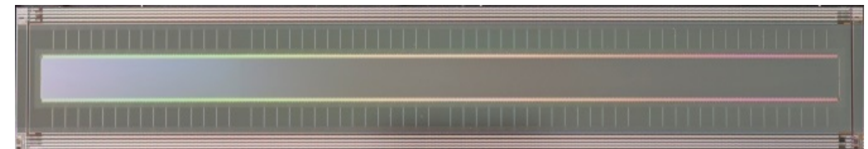
ASLM1M
2048 x 512 Pixels



Analog 1D MMA
ASLM8k
Fraunhofer IPMS
- 8192 pixels, analog tilt
- up to 1MHz framerate
- optimized for 355nm laser



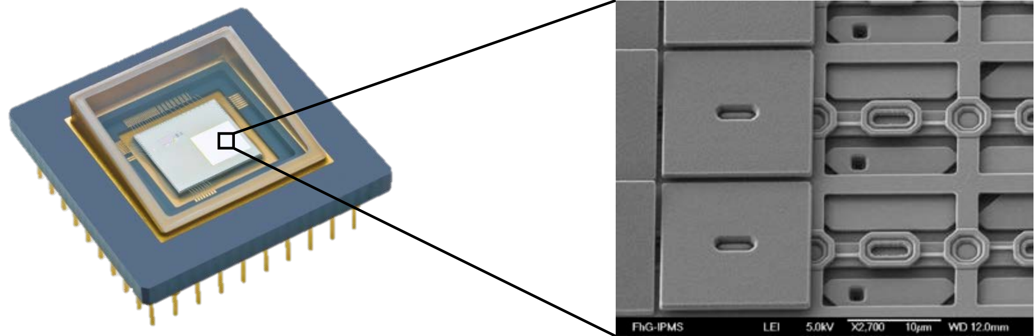
ASLM8k, 8192 x 1 Pixels



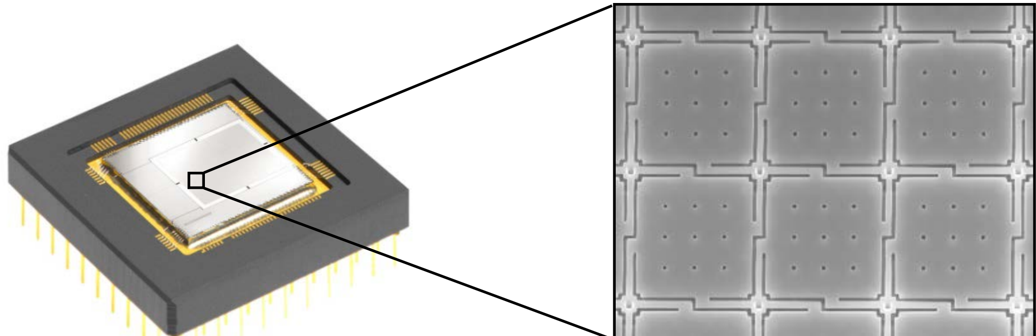
Fraunhofer IPMS Micro Mirror Arrays

Further device examples

- 256 x 256 tilt mirror array
  16 µm pixel size
  1kHz frame rate



- piston mirror array
  optical phase control

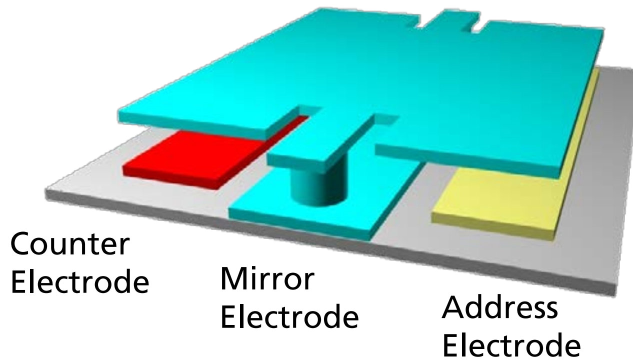


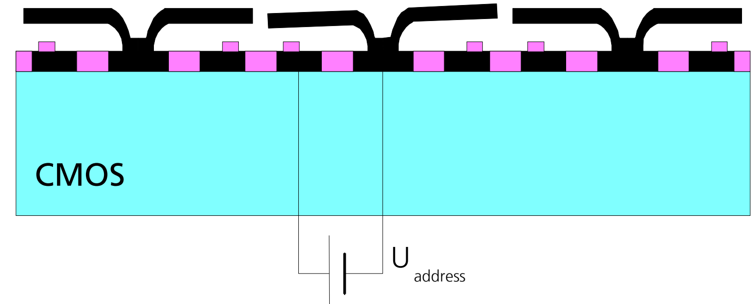
MEMS micro mirror array SLM

- High modulation speed
- DUV to NIR wavelengths
- Polarization independent

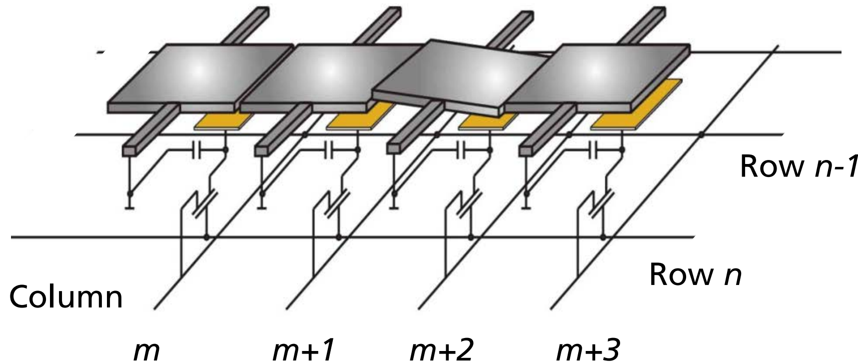
Large Scale Integration - Active CMOS Matrix Addressing

Micro mirror schematic

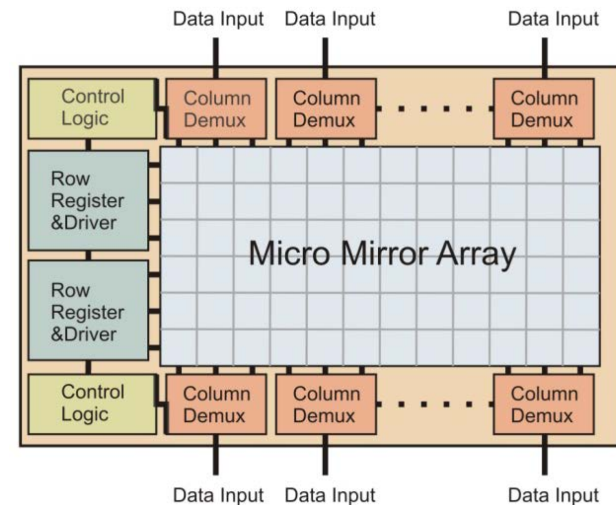




Schematic cross section



Pixel electronics with mirrors on top



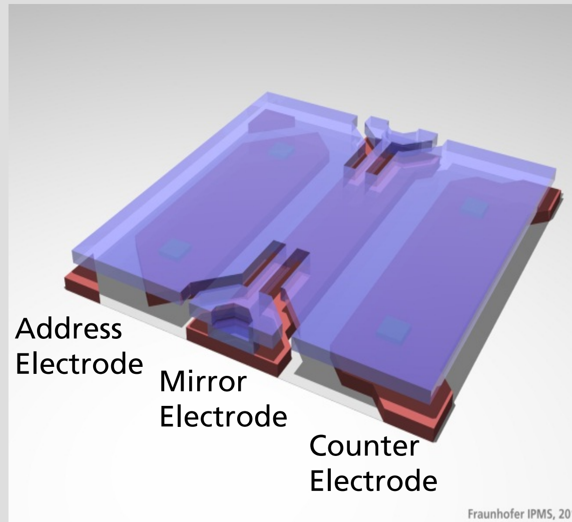
MEMS SLM block diagram

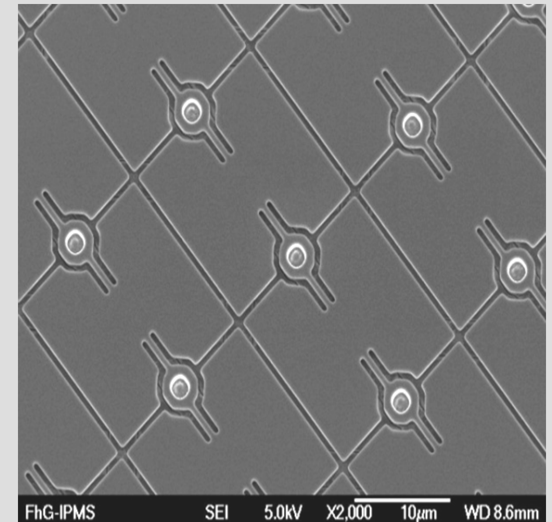
Mirror Architectures

1-Level-Actuator

Monolithic integration of Al-alloy actuators
or

Heterogenous integration of mono-Si actuators (e.g. wafer bonding)





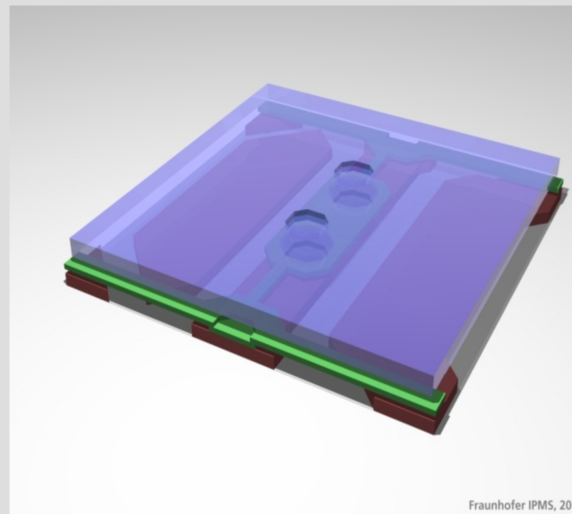
2-Level-Actuator

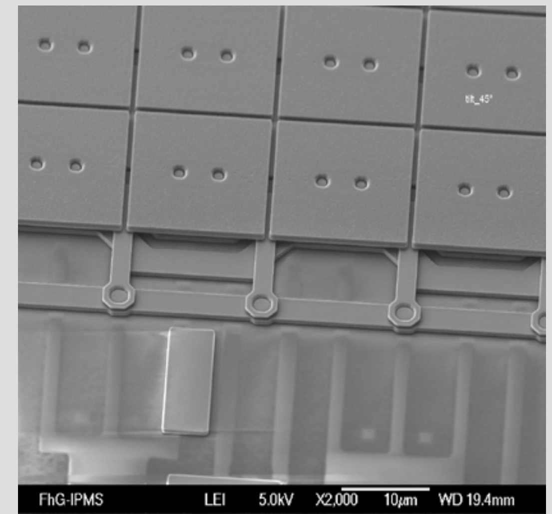
Separation of mirror & spring; independent optimization (layer thickness, material)

highly planar mirrors

reflective coatings

high optical fill factor





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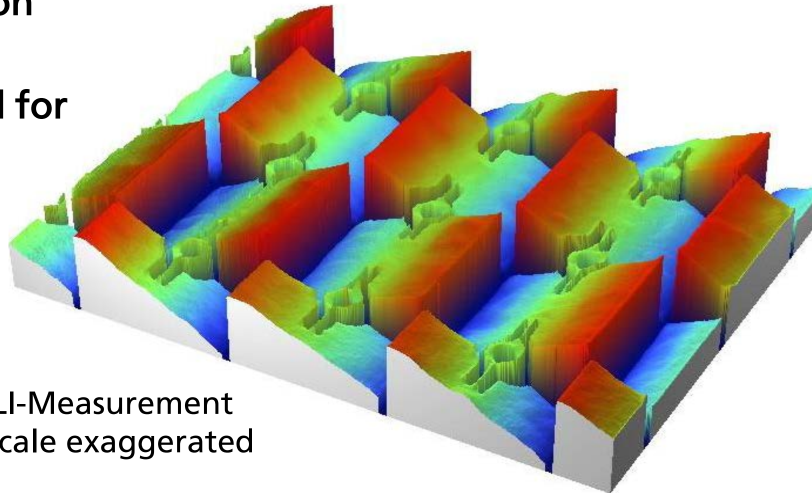
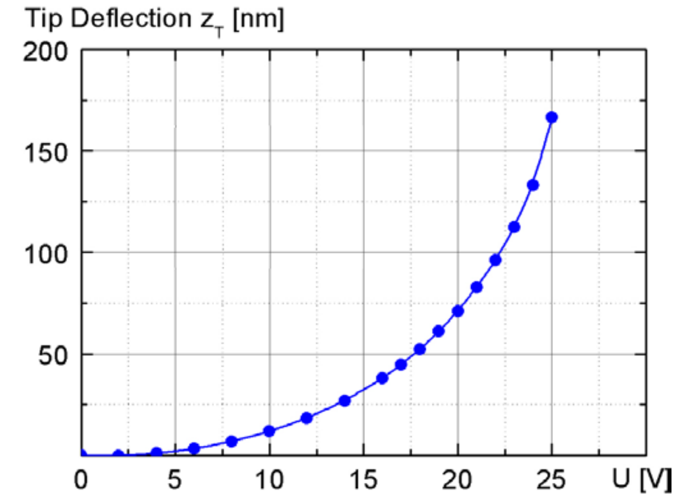
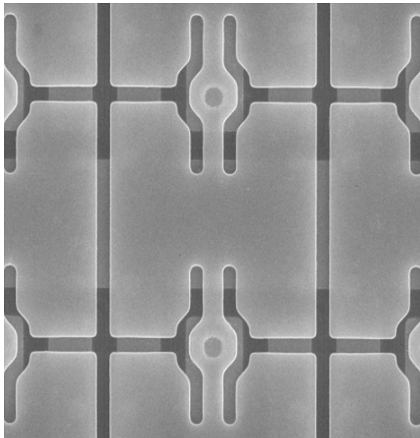
Characteristics of 16µm Tilt-Mirrors

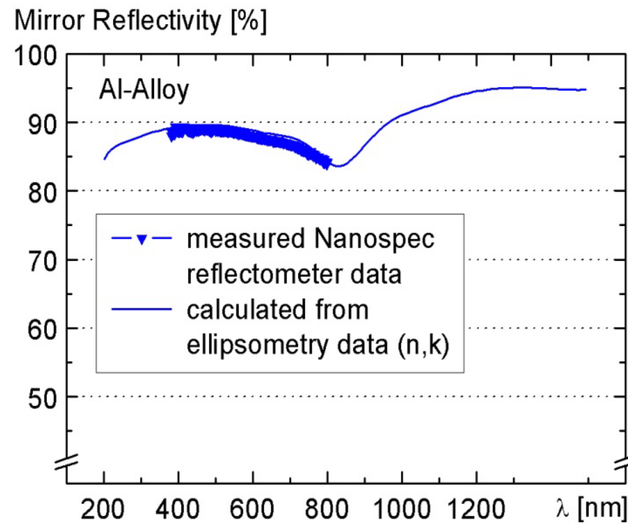
- **Tip deflection > 150 nm**
- **λ/4 required for max. image contrast**

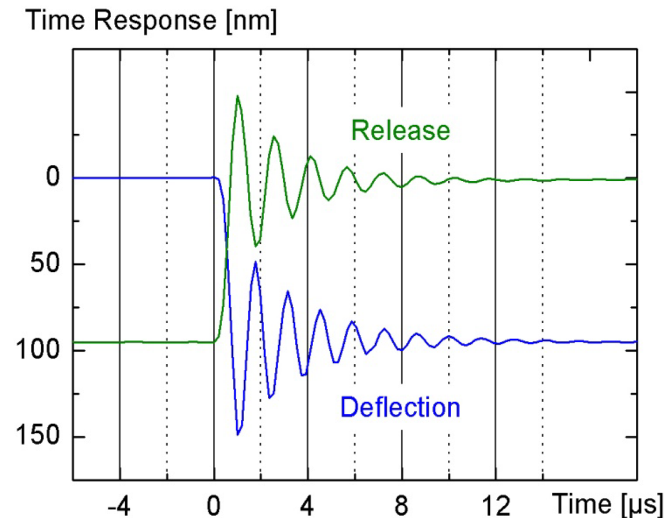


WLI-Measurement
z-scale exaggerated

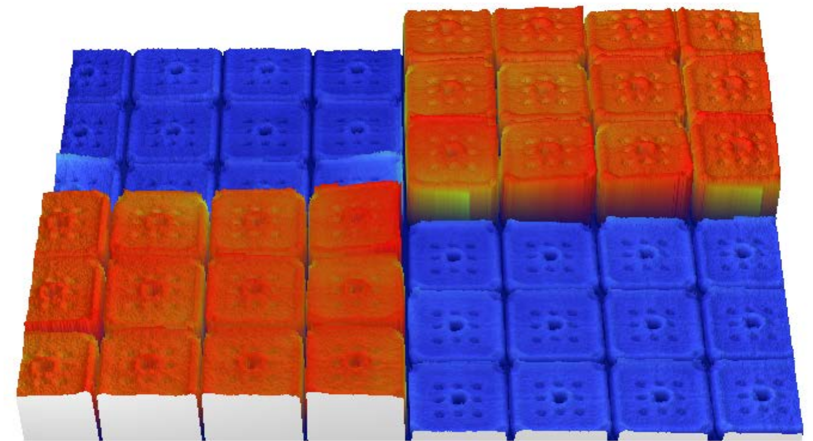




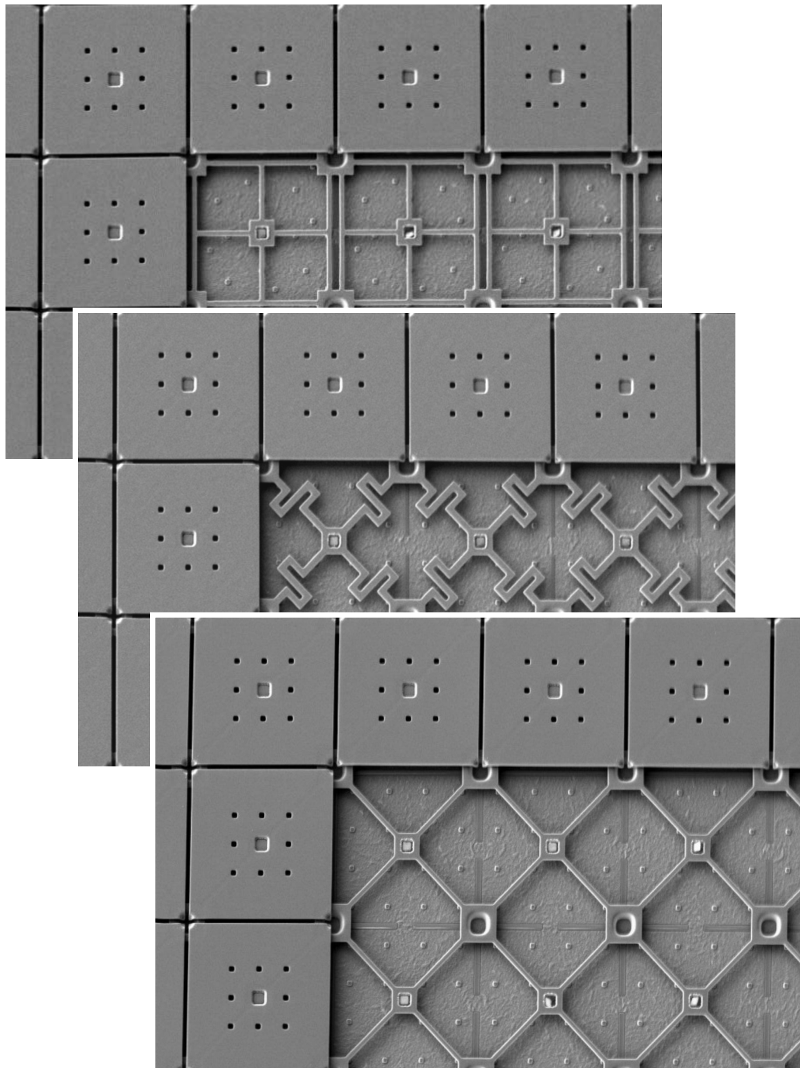




Different 2-Level Piston Mirror Designs



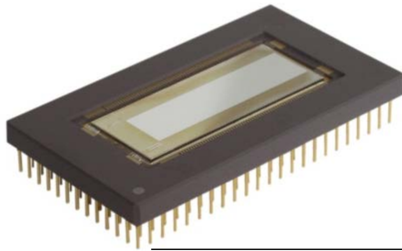
Surface topography of piston type micro mirrors (blockwise deflected & non-deflected)

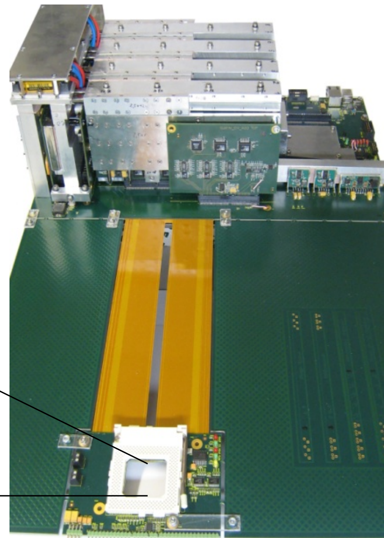


SEM Pictures of piston type micro mirrors

Address Electronics + Control Interface

- Drive Electronics for 1M Tilt Mirror SLM





- Supports all necessary data transfer and control functionalities
- Signal processing
  - input data conversion to SLM address voltage levels
  - data preparation according to SLM programming scheme
- Ethernet data interface

- Customer Evaluation Kit 256 x 256 tilting mirrors

- Complete SLM Tool-Kit
- Electronic driving board
- Software for PC
- Separate chip mount with flex extension

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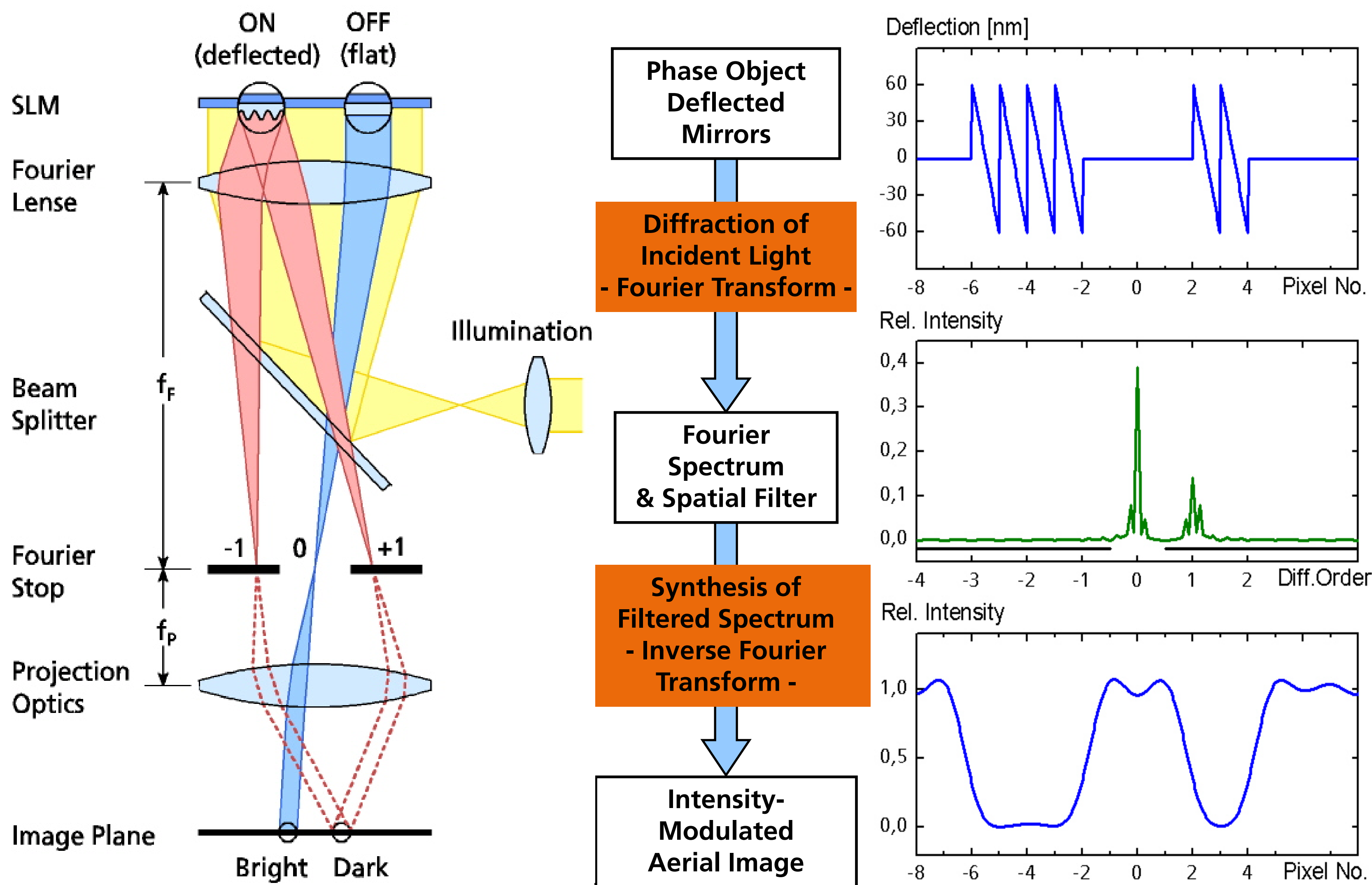
Principle of Optical Image Formation

Tilt mirrors



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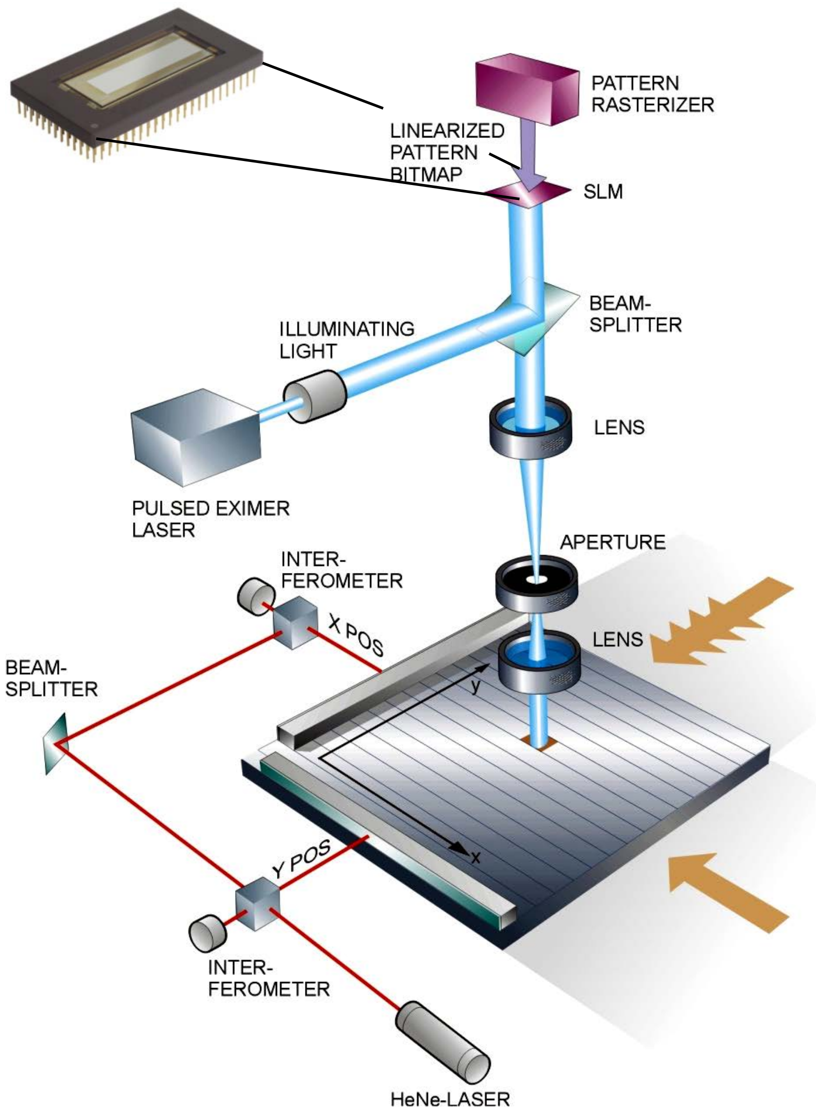
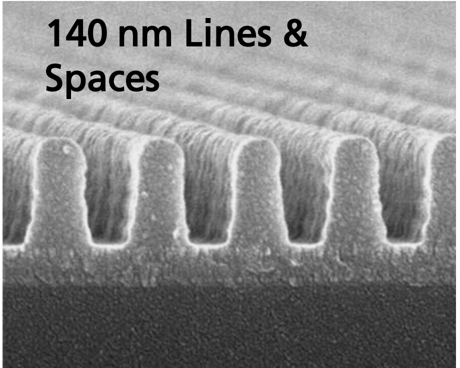
Laser Mask Writing: Operation Principle & Results



Sigma Series MYCRONIC
SLM-based semiconductor mask writer

Pattern in resist



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Laser Direct Imaging (LDI)

Mycronic LDI-Tool

- Lithography for semiconductor backend and PCB manufacturing

(Annual Report Micronic Mydata 2010)

1-Dimensional LDI SLM

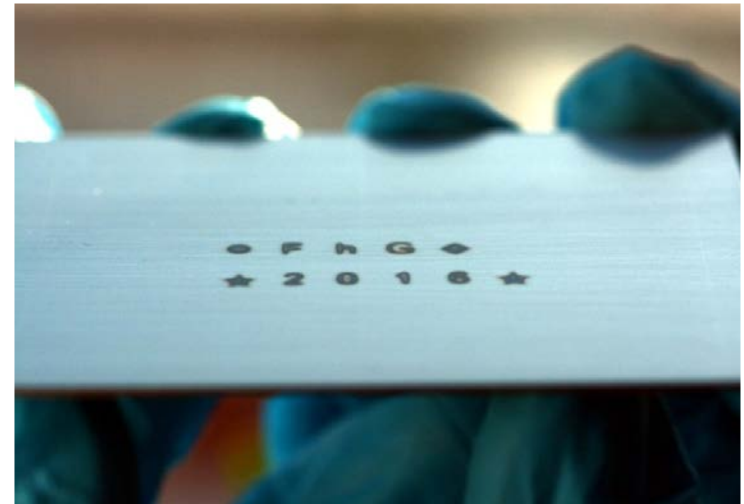
- 8000 logical pixels
- about 2.2 Mio. high speed micro mirrors

Fast Laser Marking/Engraving via Micro Mirror Arrays

Fraunhofer internal project, institutes IPMS and IWS (Dresden)

- First experiments using DUV-Laser

PVC substrate



Stainless steel substrate

Flexible PCB substrate

Fraunhofer IWS

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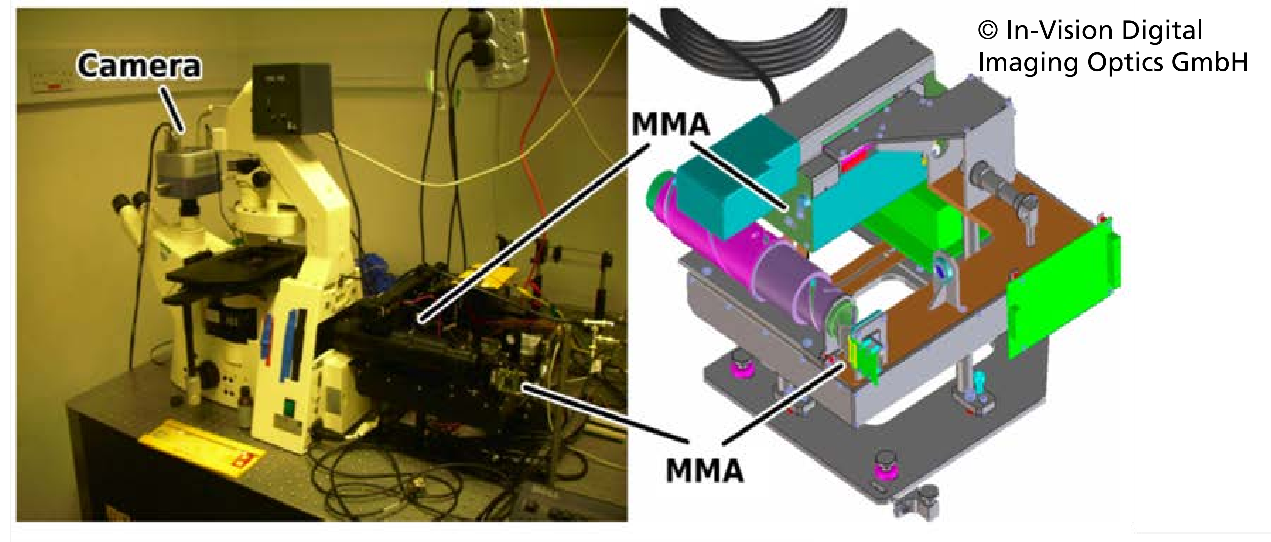
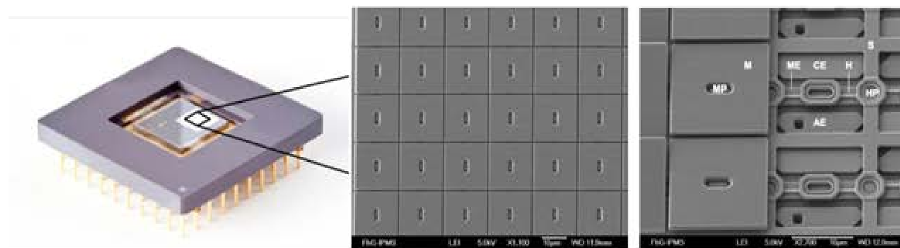
Spatio-Angular Control of Microscopy Illumination

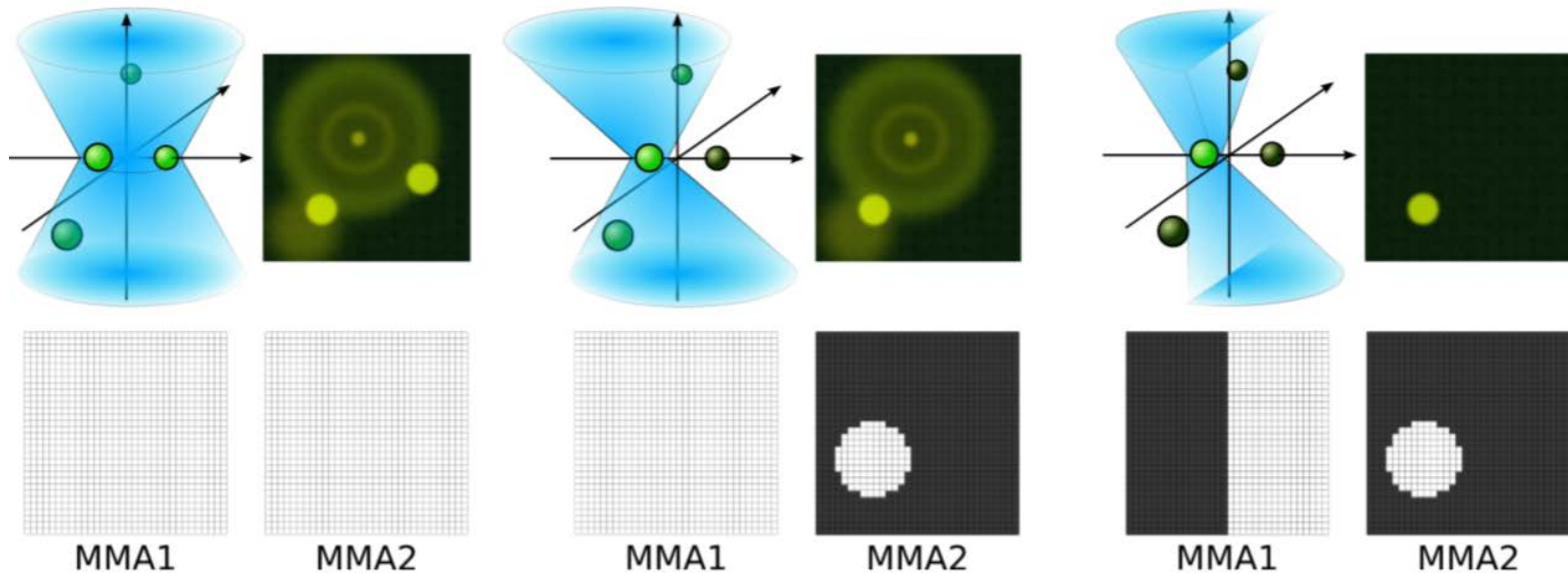
- Hardware setup: Variable microscope module

- Public funded project »MEMI-OP«
- Cooperation with Institut Pasteur (Paris)
- Potential spectrum 240-800nm (first time with deep-UV option)



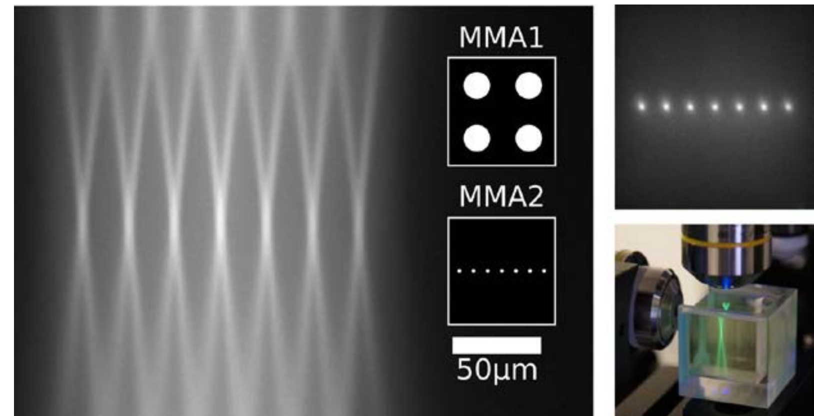


Spatio-Angular Control of Illumination

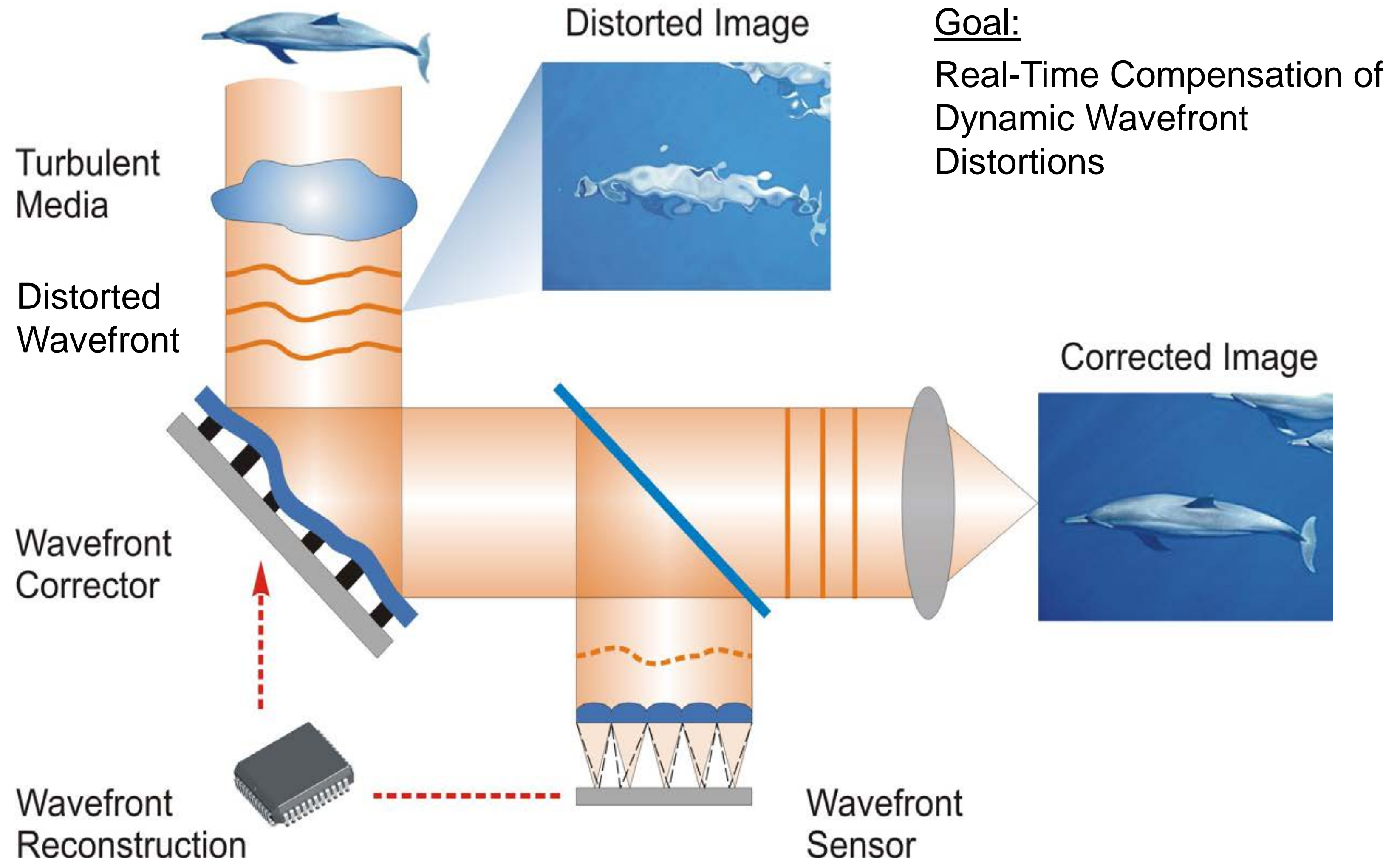


- MMA 2 defines region of illumination
- MMA1 restricts illumination angles
- Both are needed for effective light control

Experiment, POC
Institut Pasteur



Principle of Adaptive Optical Image Correction

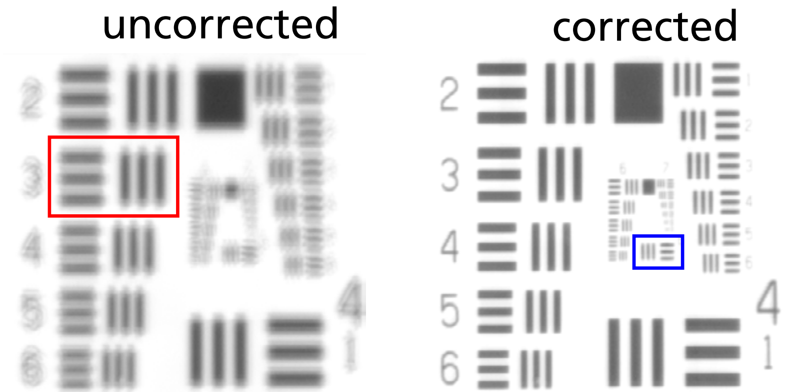


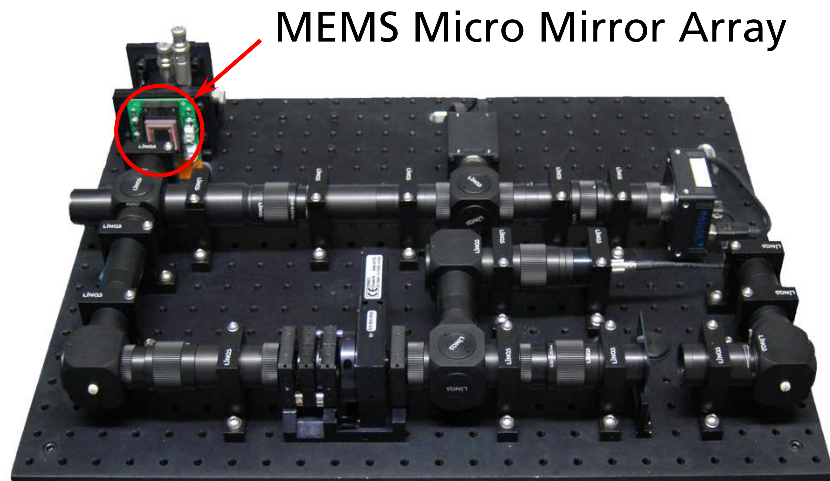
Goal:

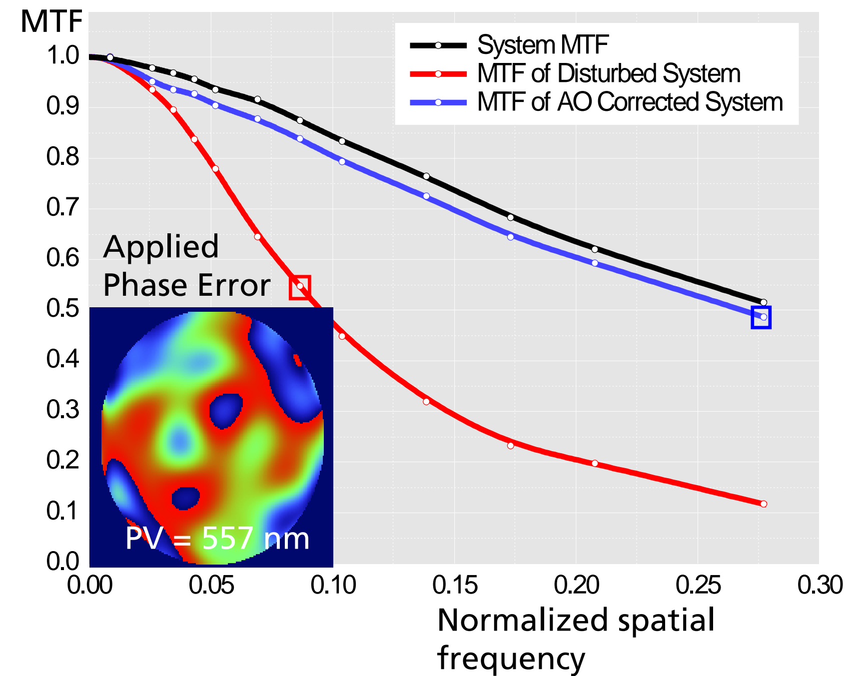
Real-Time Compensation of Dynamic Wavefront Distortions

AO Demonstration System

- Demonstration of AO image correction
  - extended objects (USAF test chart)
  - incoherent illumination
- Quantitative performance analysis by MTF measurements
- Phase errors introduced by phase plates
- Compact, portable setup footprint: 60 x 40 cm^2







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Summary

- Micro mirror arrays for advanced optical processing
  - High spatial resolution & speed
  - High spectral bandwidth (DUV to IR), polarisation insensitivity
  - Facilitate new applications + significant device miniaturization
- Device approach
  - Large-scale integrated micro mirror arrays – amplitude or phase effective
  - True analogue modulation capability
  - Support of complete chain: MEMS mirrors, CMOS circuitry, control interface
- Application examples
  - Optical Patterning
    - Sub-µ mask lithography
    - Laser Direct Imaging (LDI)
    - Laser marking/engraving
  - Adaptive optical phase control
  - Microscopy

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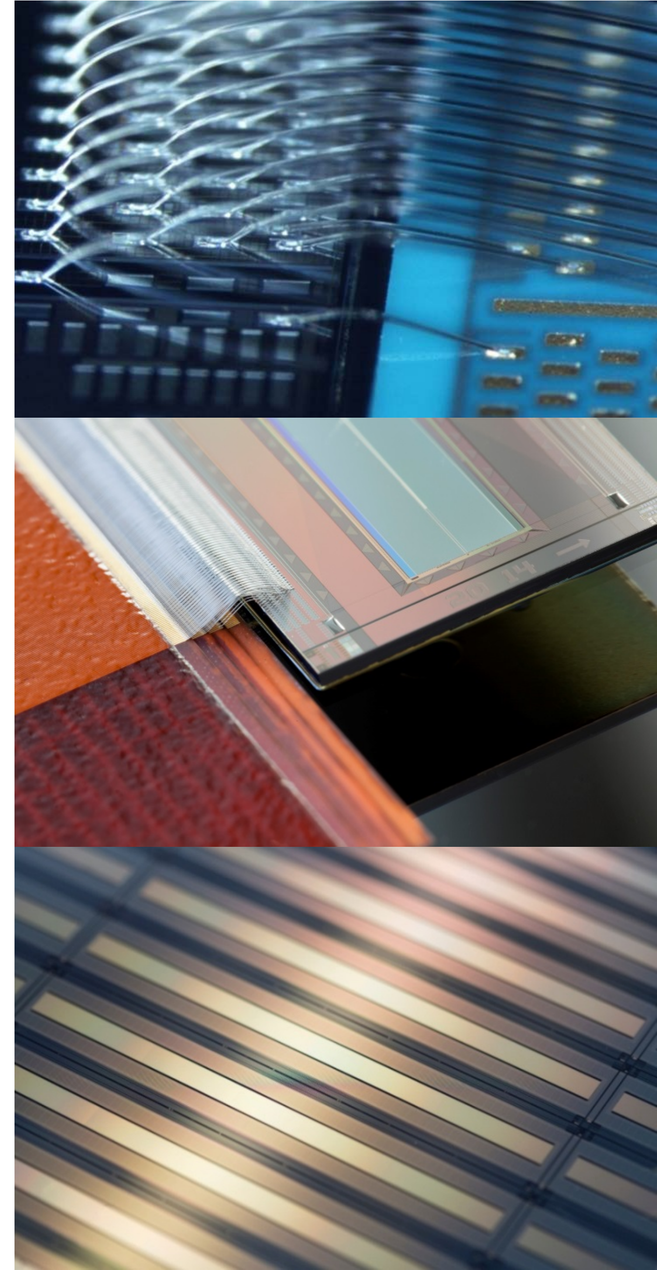
Acknowledgement

Jan Schmidt
Jörg Heber
Alexander Mai
and others from IPMS Business Unit SLM
IPMS engineering / fabrication teams

IPMS cooperation partners



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Thanks to

all of you for your attention

Prof. Moser, Prof. Quack, EPFL & swissphotonics for workshop organization