Micro-Mirror-Arrays for Adaptive Optics in Space

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Werner Hupfer, EADS Astrium GmbH

Dr. Andreas Gehner, FhG-IPMS
Jan Liesener – ITO
Kotska Wallace – ESA-ESTEC

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- Project Organisation
- Background/Motivation
- Project Objective

Micro-Mirror-Arrays
- Characteristics and Parameters
- Wave-front Correction Principle
- FhG-IPMS MMA Technology

Bread-board Tests

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Introduction – Project Organization

ESA Contract Nr. 16632/02/NL/PA

EADS Astrium GmbH
Project Management, System Engineering, Technical Specifications, Simulation

FhG–IPMS (Fraunhofer Gesellschaft - Institut for Photonical Microsystems)
MMA Design and Manufacturing

ITO (University of Stuttgart, Institut for Technical Optics)
Fibre Coupling Concepts, Breadboard Design, Realization, Tests

Introduction – Background/Motivation

Large optical telescopes for space applications will require light-weighted, possibly segmented primary mirrors in order to reduce mass and cost.

But extreme light-weighting introduces wave-front errors caused by its floppiness mainly due to:

- print-through from mirror polishing
- mounting stress
- gravity release from transition to Zero-G
- asymmetric and periodical heating in Earth orbit
- discontinuities between segments

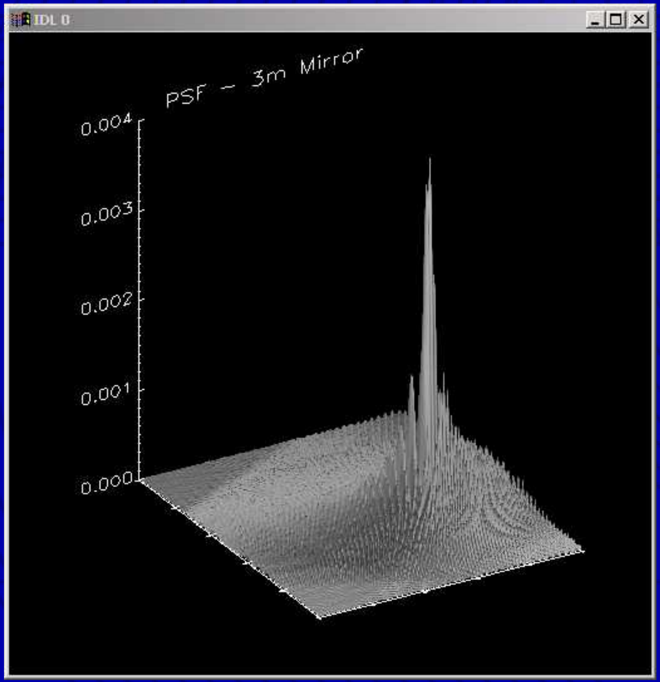
In order to produce diffraction limited performance
Wavefront Correction with Adaptive Optics (AO) is required!

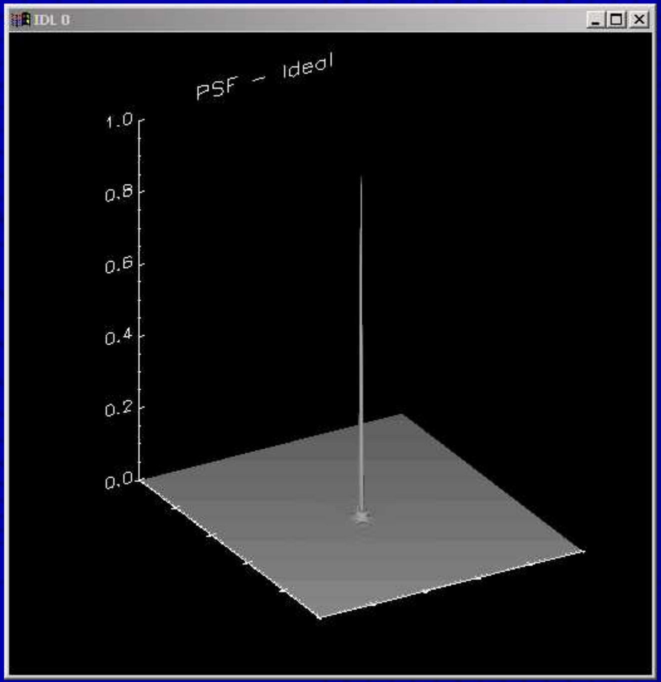
Introduction – Background/Motivation

Comparison of Star-Images:

Typical distortions of 3m light-weighted mirror

Corrected with AO



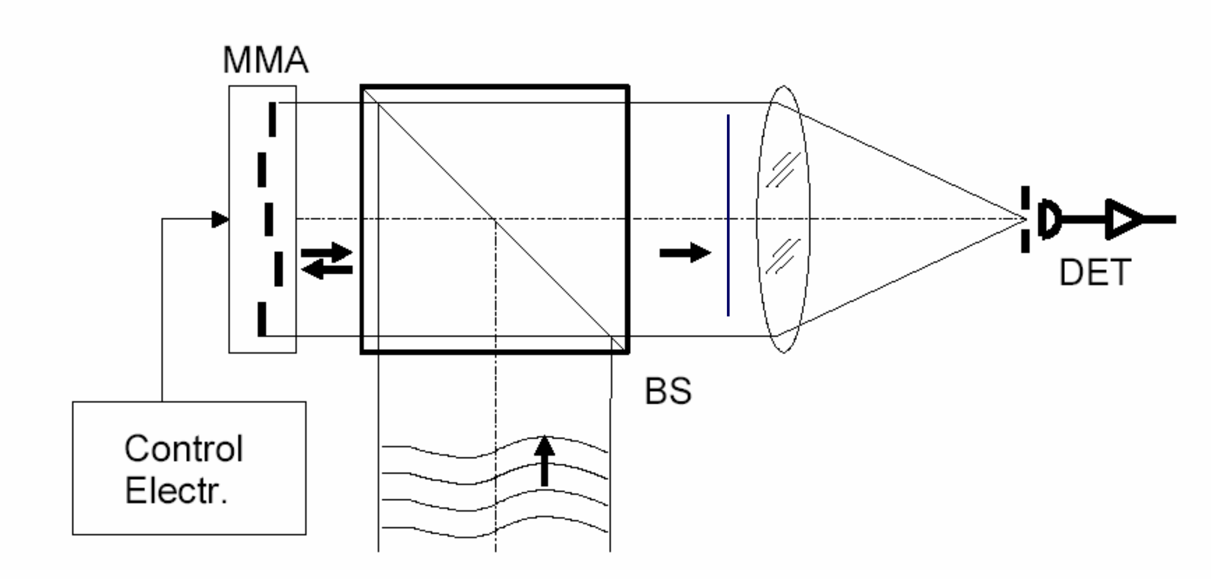


Energy is spread out over large area.
Peak is a fraction and not centred.

Introduction – Background/Motivation

Principle of Wave-front Correction:

Correction can be directly
- at main mirror
- or further down the optical chain, where beam size is smaller.



Correction-Device (MMA) has complementary 'shape' of incoming distorted wavefront. Wavefront reflected from MMA is almost flat.

Introduction – Project Objective

Demonstrate and analyse the wave-front correction capability of two types of Micro-Mirror-Arrays within an application:

- Coupling of a distorted free-space laser beam into a mono-mode optical fibre (Space application example: optical satellite communication)

Investigate various types of wave-front aberrations/distortions:

- typical wave-front errors of a light-weighted mirror
- positional misalignments of individual segments of a segmented mirror (step errors)

MMAs – Characteristics and Parameters

Why MMAs: MMAs are new promising and already commercially available wave-front correction devices based on MEMS technology. They provide high spatial resolution. The mirrors are individually addressable and have fast switching times.

Two types of MMAs were designed and manufactured by FhG-IPMS, then investigated and tested in a breadboard setup:

- Piston-Mirror MMA
- Tilt-Mirror MMA

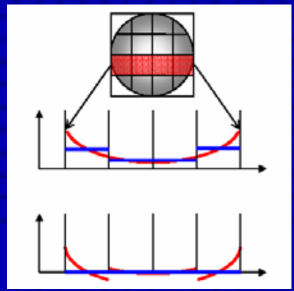
Number of Mirrors:	240 x 200
Mirror Pitch (Size):	40(35) x 40(35) µm 9.6 x 8 mm
Piston Mirror max. Stroke:	~ 400 nm (8 bit resolution)
Tilt Mirror Tilt Angle:	1° - used in binary operation

Wavefront Correction with MMAs

Principle:

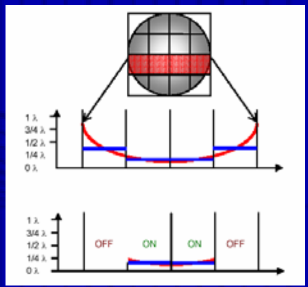
Piston mirror:

- Phase of distorted wave-front is measured and averaged over a local area (single mirror size) of the wave-front
- Corresponding MMA mirror height (modulo 2π) is set to this average phase value ➔ ‘flatened wavefront‘

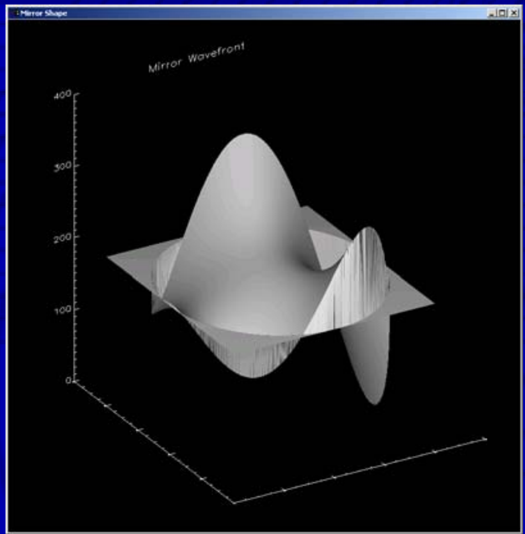


Tilt mirror:

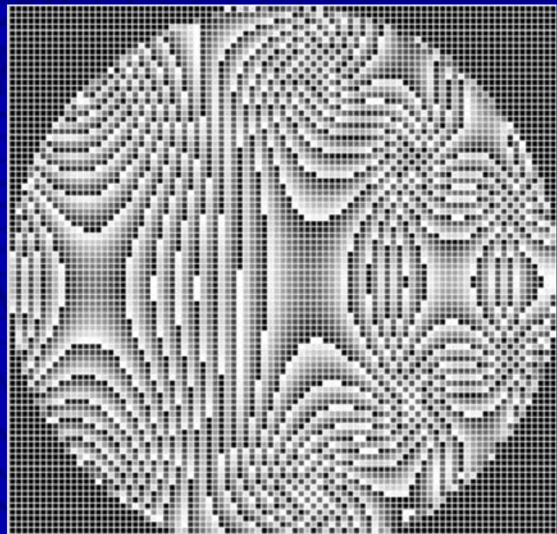
- Local phase measurement as for piston mirror
- Wave front sections which cause destructive interference are discarded ➔ mirror is turned OFF



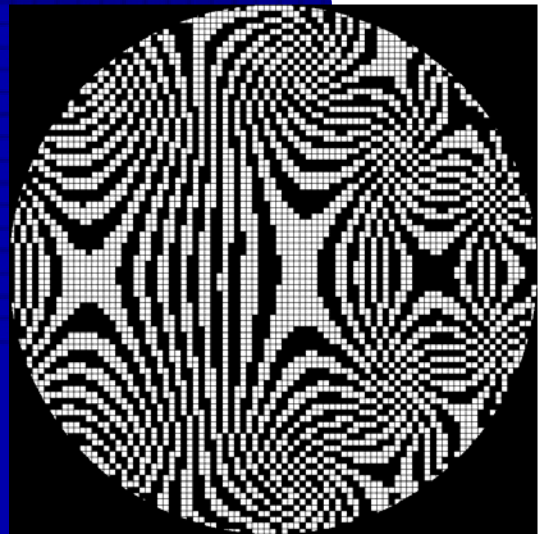
Wavefront Correction with MMAs



Wavefront
(height magnified)



Phase correction with Piston MMA (grey scale corresponds to height)



Phase correction with Tilt MMA (black = OFF, white = ON)

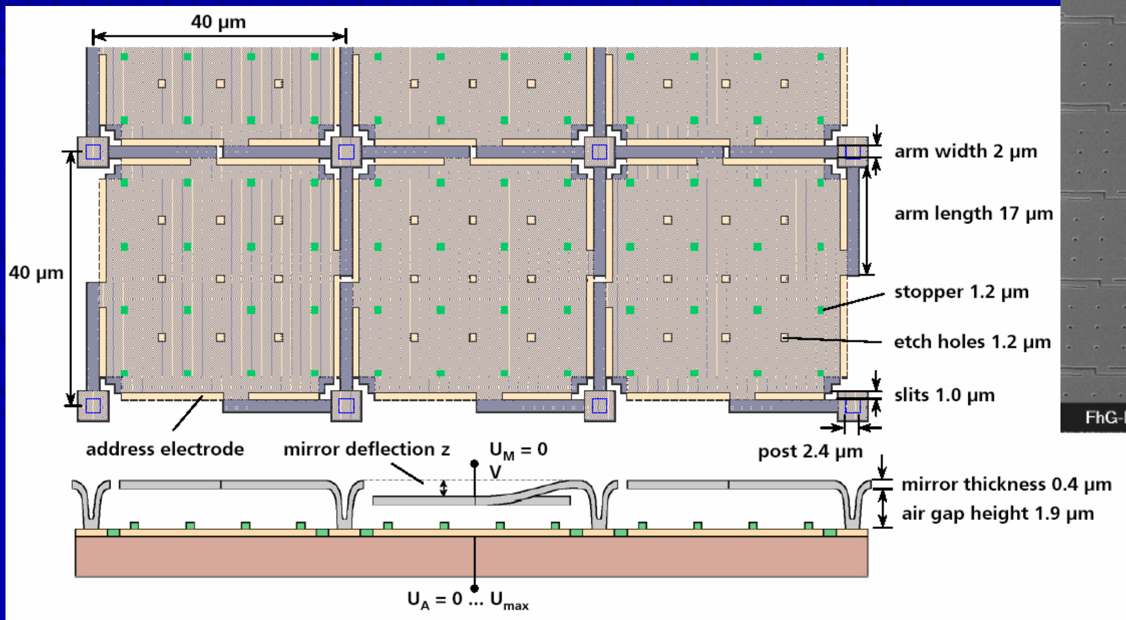
FhG-IPMS MMA Technology

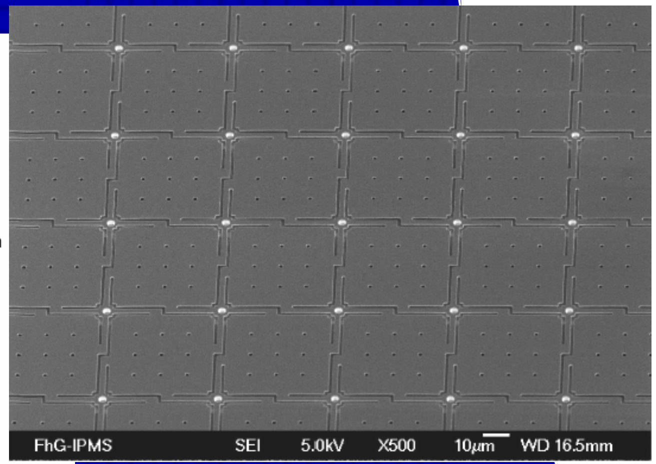
- Fully monolithic integrated approach of micro-mirrors together with an underlying CMOS address circuitry (standard semiconductor fabrication technology)
- Active CMOS address matrix, like DRAM. One switching transistor and storage capacitor per matrix cell. Analog voltage levels define electrostatic deflection for each individual mirror element.
- CMOS process with 19 lithographic layers, address voltage capability up to 30V for larger mirror deflections.
- Micro-mirrors are fabricated on top of the completed address circuitry within a fully CMOS-compatible process
- Surface-micromachining requires three additional layers. Mirror elements, suspension arms and support posts are deposited with aluminium alloy.
- Ceramic pin grid arrays (PGA) package covered by an anti-reflective optical window.

FhG-IPMS MMA Technology

Piston MMA:

Square plate is suspended by four cantilever beams over an air gap with an underlying address electrode. Upon electrical activation the mirror plate can be continuously deflected in a piston-like motion as a function of applied voltage providing a continuous phase shift for each pixel.

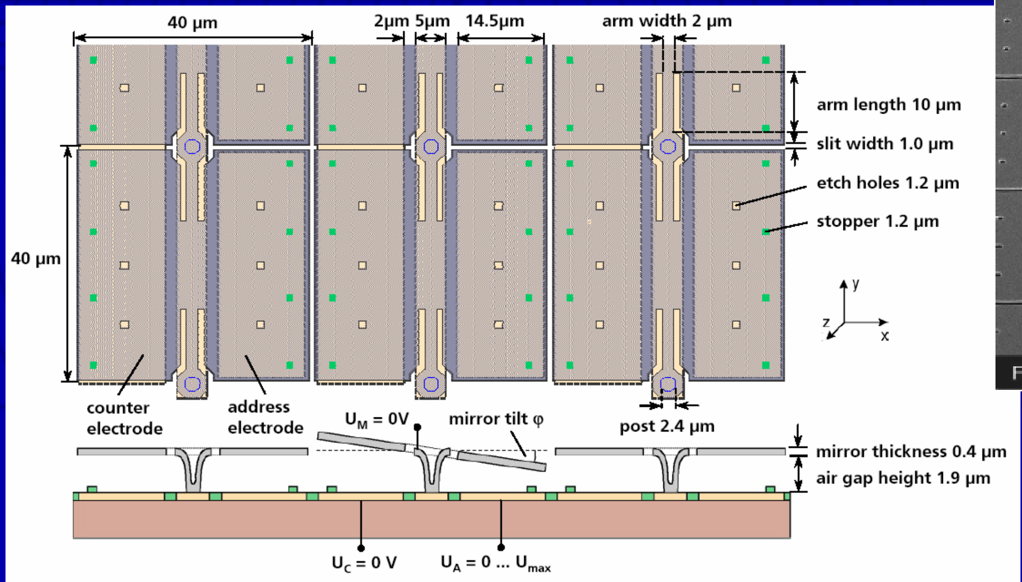


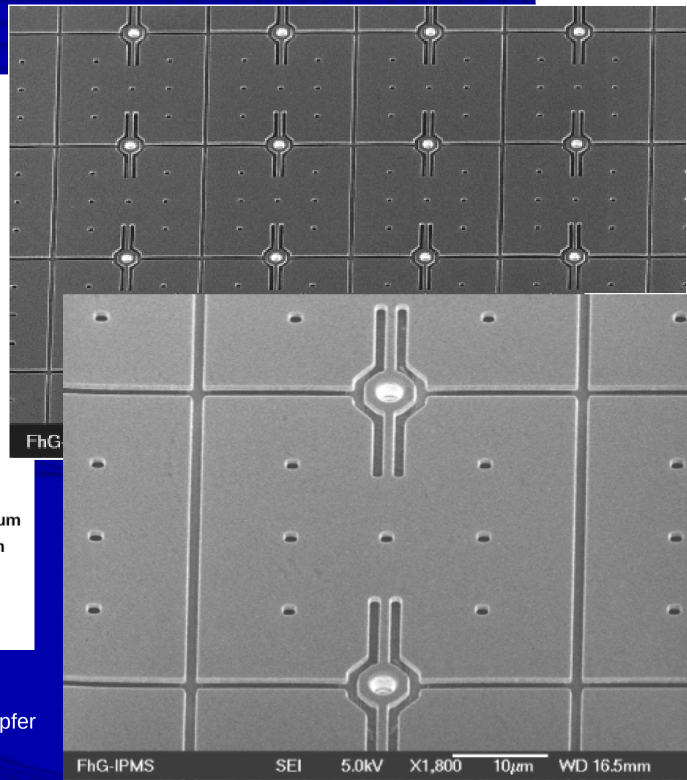


FhG-IPMS MMA Technology

Tilt MMA:

Mirror plate is suspended by two torsional arms along the pixel center axis with the underlying address electrode extending only on one side, on the opposite side is a counter-electrode common to all pixels. Applying a voltage causes the mirror to rotate.



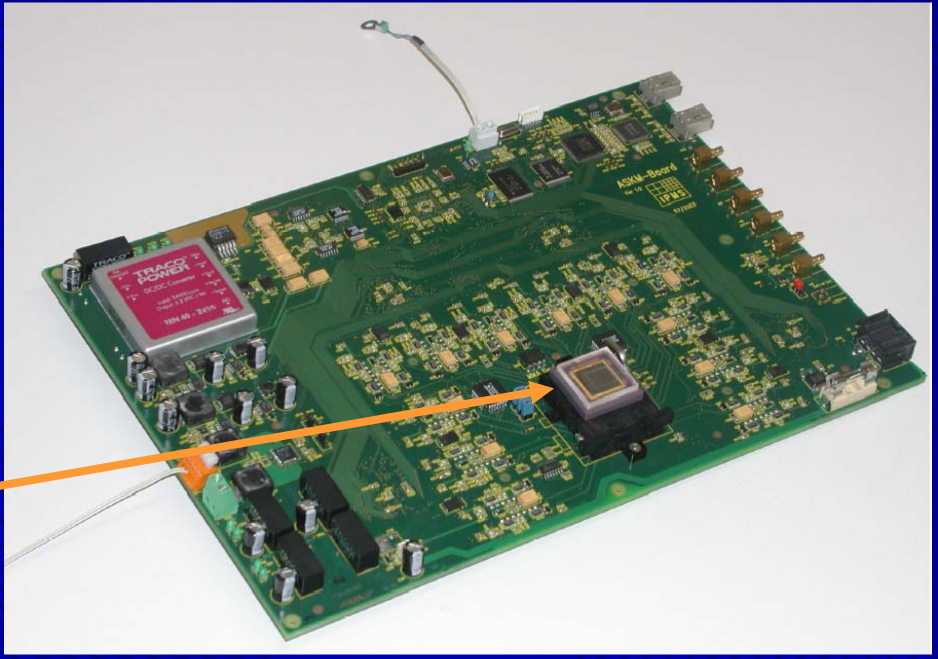


FhG-IPMS MMA Technology

Electronics and Software

Bread-board based on traditional electronics with
- IEEE 1394 (FireWire) I/F
- ActiveX programming environment + Stand-alone GUI

Reprogramming rate
- 5 kHz maximum
- 50 Hz in Bread-board



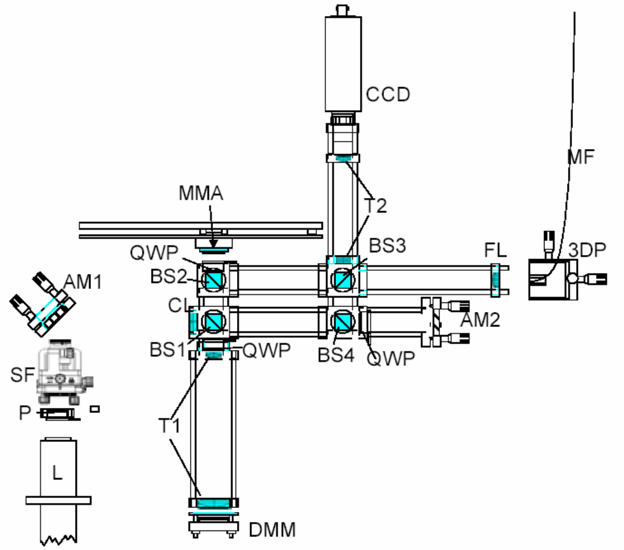
MMA

Bread-board Tests

Wave-front Correction Algorithms – 2 Methods

- Standard wave-front sensing (fast) with
  - Interferometry
  - Shack-Hartmann
- Stochastic method – (slow) does not require additional metrology!

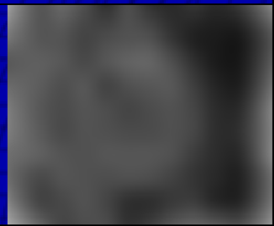
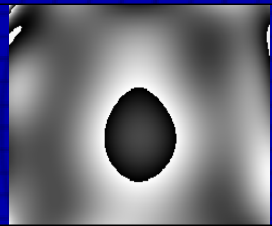
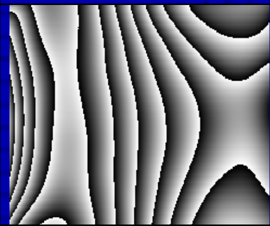
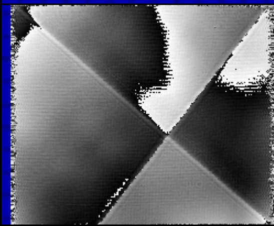
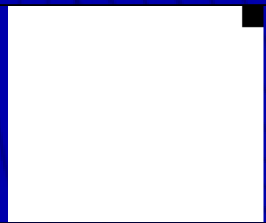
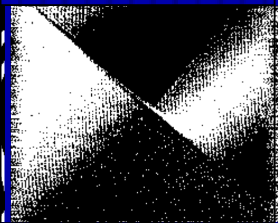
Membrane Mirror (DMM) is used for Wave-front Generation



- 3DP: xyz positioner
- AM: adjustable mirrors
- BS: beam splitters
- CCD: camera chip
- CL: collimation lens
- DMM: deformable membrane mirror
- FL: focussing lens
- L: laser
- MMA: micro mirror array
- MF: monomode fibre
- P: polariser
- SF: spatial filter
- T: telescopes (with 2 lenses)
- QWP: quarter wave plates

Results

Tests with 4 types of wave-front distortions:

	Measured wavefront errors (CWFE1, CWFE2, CWFE3, SWFE)			
Wavefront denomination	CWFE1	CWFE2	CWFE3	SWFE
Measurement with piston MMA (continuous)				
WFE (rms)	0.13 λ	0.25 λ	2.0 λ	0.17mm cover plate edges
WFE (PV)	0.7 λ	1.2 λ	7.9 λ	
Measurement with flip MMA (binary)				
	Achieved coupling efficiency with piston MMA			
With correction	63%	49%	40%	42%
Without correction	51%	1.4%	0.27%	8.1%
	Achieved coupling efficiency with flip MMA			
With correction	35%	8.1%	4.2%	7.9%
Without correction	34%	4%	0.15%	1.0%

Max. coupling efficiency: Piston MMA = 65.5% Tilt MMA = 40.5%

Conclusion

Both MMA devices can be used for wave-front correction in an Adaptive Optics System.

Tilt mirror has low efficiency and the performance is strongly wave-front error depended

Prefered Choice: Piston MMA

- delivers the heighest Coupling Efficiency
- corrects wave-front errors with high spatial frequency and even discontinuities.
- corrects 'flat' wave-front errors due to it's high resolution (2 nm)