Deformable Mirrors Technologies at CILAS

Jean-Christophe SINQUIN
sinquin@cilas.com
Topics

- Deformable Mirrors for Astronomy
- Deformable Mirrors for Laser Applications
Deformable Mirrors for Astronomy

• Piezo array
  • SAM (Stack Array Mirror) technology
  • Large DM technology
  • Mini DM technology

• Piezo Bimorph

• Tip/Tilt Mount
SAM concept (direct effect)

\[ \delta = N \cdot d_{33} \cdot V \]

- Base plate
- Actuator array
- Piezo element (N plates)
- Optical plate

Applied voltage (V)

Optical plate with concave (or convex) shape
SAM for Gemini MCAO: DM4.5

Delivered in April 2006

Optical head

Actuator array

Optical plate

Base plate

106 mm dia. - 22x22 array - 416 actuators - Spacing: 5 mm x 5 mm

Goes with DM0:
293 actuators 5 mm spacing
& DM9:
208 actuators 10 mm spacing
**SAM for ESO VLT: HODM SPHERE**

Delivered in November 2007

180 mm dia. - 41x41 array - 1377 actuators - Spacing: 4.5 mm x 4.514 mm
SAM for NSO ATST: Cooled M9 DM

200 mm dia. - 41x41 array - 1385 actuators - Spacing: 5 mm x 5 mm

Preliminary design done in April 2007
SAM for TMT NFIRAOS: DM0

Preliminary design done in June 2007

300 mm dia. - 63x63 array - 3125 actuators - Spacing: 5 mm x 5.127 mm

Will be mounted on a Tip/Tilt Stage

Operating temp.: -35°C
SAM for TMT NFIRAOS: DM1

Conceptual design done in 2006

360 mm dia. - 73x73 array - \( \approx \) 4200 actuators - Spacing: 5 mm x 5 mm

Flattened subscale mirror @ -35°C: < 15 nm rms

Operating temp.: -35°C
# SAM main common characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pupil diameter:</td>
<td>up to 500 mm diameter</td>
</tr>
<tr>
<td>Actuator spacing:</td>
<td>from ≈ 4 to some tens of mm</td>
</tr>
<tr>
<td>Stroke:</td>
<td>see hereafter</td>
</tr>
<tr>
<td>Interactuator stroke:</td>
<td>large, thanks to actuator strength - around 30 to 40% of the stroke PV according to the mechanical coupling</td>
</tr>
<tr>
<td>Actuator bandwidth:</td>
<td>well within usual correction needs, thanks to parts stiffness - see hereafter</td>
</tr>
<tr>
<td>Optical quality:</td>
<td>high since the polishing is done at the end of the manufacturing process 20 nm rms wavefront error obtained once the mirror is flattened</td>
</tr>
<tr>
<td>Hysteresis:</td>
<td>≈ 5% (for full stroke)</td>
</tr>
<tr>
<td>Dissipated power:</td>
<td>negligible at mirror level, thanks to capacitive principle</td>
</tr>
<tr>
<td>Temperature dependence:</td>
<td>very low, thanks to materials choice - tested quasi-constant behavior from -35°C to 30°C</td>
</tr>
<tr>
<td>Mechanical compatibility:</td>
<td>very good since the structure is very stiff and the optical plate thick (&gt; 1 mm for 5 mm spacing)</td>
</tr>
</tbody>
</table>
SAM temporal behavior

Actuator behavior

First natural frequency of an actuator:

\[ f_r = 0.25 \frac{l^{-1}}{(E/\rho)^{1/2}} \]

- \( l \): actuator length (mm)
- \( E \): Young modulus of the piezo material (N/m2)
- \( \rho \): density of the piezo material (kg/m3)

For SAM this frequency is situated in the 15-20 kHz region, which is consistent with usual temporal needs.

Example: ESO SPHERE Mirror measurement
SAM spatial behavior

**Maximum stroke**

- $\pm 5.0 \, \mu m$ for $\pm 400 \, V$
- $\Rightarrow \pm 4.5 \, \mu m$ (after flattening)

**Interactuator stroke**

- $3.0 \, \mu m$ for $\pm 400 \, V$

Example: ESO SPHERE Mirror measurements
SAM spatial behavior

High order correction

Example: ESO SPHERE Mirror measurements on a $\phi$ 150 mm pupil
SAM spatial behavior

Stroke vs. spacing

µm PV vs. mm

ESO
NAOS
TMT
DM
ESO
SPHERE
Gemini
MCAO

This document is the property of CILAS and may not be reproduced without authorization.
Toward Large DMs (ASMs)

Stroke vs. spacing
Large DM for E-ELT: M4AM

Optical plate

Base plate

Actuator array

≈ 2.5 m dia. - ≈ 8600 actuators - Spacing: 24.5 mm

Early concept proposed to ESO in June 2007

Conceptual design, prototyping & preliminary design
November 2007 - April 2010

Mechanical positioning
SiC base plate
Using SiC for optics
High level spec. analysis
Assistance for concept
Large DM spatial behavior

Maximum mechanical stroke:
\[ \delta = N \times d_{33} \times V \]

- **N**: number of piezo plates constituting the stack
- **d_{33}**: direct piezo coefficient (m/V)
- **V**: applied voltage (V)

For:
- **N = 250**
- **d_{33} = 300E-12 m/V**

\[ \Rightarrow \delta_{\text{max}} = \pm 30 \mu m \text{ (60 } \mu \text{m PV) for } \pm 400 \text{ V} \]

**Tradeoffs between:**
- needed strokes
- needed mechanical coupling
- stresses in the plate
Large DM dynamical behavior

Actuator natural frequency

\[ fr = 0.25 l^{-1}(E/\rho)^{1/2} \]

\( l \): actuator length,
\( E \): Young modulus of the PZT material
\( \rho \): density of the PZT material

For:
\( l \approx 250 \text{ mm} \)
\( E = 6.0\text{E}10 \text{ N/m}^2 \)
\( \rho = 7550 \text{ kg/m}^3 \)
\[ \rightarrow fr \approx 2.8 \text{ kHz} \]

Goal: natural frequencies of M4AM high enough to avoid effect on the closed-loop correction features of M4AU
Toward Mini DMs

Stroke vs. spacing

μm PV

Mini DM (mDM)
mDM concept (transverse effect)

\[ \delta = d_{31} V L / h \]
Mini DM prototyping

Under manufacturing for LAOG/ESO
Design review passed in November 2007

50x50 actuator array sawing test

49 mm dia. - 50x50 array - ≈ 1900 actuators - Spacing: 1 mm x 1 mm
Mini DM spatial behavior

Maximum stroke

± 1.3 (goal 1.5) µm for ± 400 V

Interactuator stroke

1.0 (goal 1.2) µm for ± 400 V

Example: early result on a mockup

100 V on 1 actuator
“Mini”! DM goal characteristics

- **Pupil diameter:** 200 mm diameter
- **Actuator spacing:** 1 mm
- **Number of actuators:** ≈ 30,000
- **Stroke:** 3 µm
- **Interactuator stroke:** 1.2 µm
- **Actuator resonance freq.:** > 30 kHz
- **High order WFE:** 20 nm rms
- **Hysteresis:** ≈ 5% (for full stroke)
BIMorph concept (transverse effect)

Pupil diameter: up to 100 mm diameter
Optical quality: 20 nm rms wavefront error obtained once the mirror is flattened
Temperature dependence: very low, thanks to symmetrical architecture
Temporal behavior: curvature resonance frequency > 700 Hz
BIM188 for Subaru Telescope

Delivered in July 2005

130 mm dia. - 94 mm aperture - 188 electrodes - ± 12 m curv. radius (± 90 µm stroke)
**Tip/Tilt Mount** *(Gimbals concept)*

**Architecture:** simple

**Stroke:** large

**Resolution:** high

**Mechanical spec.:**
- two independent and perpendicular axes with very low cross-talk
- rotation axes well defined
- soft interaction with chassis
- weak spurious modes

Concept coming from Observatoire de Paris
Tip/Tilt Stage Proto for TMT

Design review passed in October 2007

32 kg DM mass - 40 Hz bandwidth @ -3dB - 500 µrad PV stroke
Deformable Mirrors for Laser Applications

- Piezo Monomorph
- Force actuators DM
**MONOmorph concept** (transverse effect)

- **Pupil diameter:** up to 200 mm diameter
- **Optical quality:** < 10 nm rms wavefront error obtained once the mirror is flattened (see hereafter)
- **Temperature dependence:** compensated by DM stroke
- **Temporal behavior:** curvature resonance frequency > 700 Hz
MONO36 for LOA

MONO36 under test @ Imagine Optics

Former Bimorph architecture

New Monomorph architecture

Filtered shape at rest

110 mm dia. - 60 mm aperture - 36 electrodes - 3.4 nm rms wavefront once filtered
MONO61 for University of Osaka

110 mm dia. - 75 mm aperture - 61 electrodes - 4 nm rms wavefront once flattened

FAT in November 2007
MONOMorph spatial behavior

Curvature correction

20 µm wavefront for 200 V max
-> residual error: 9 nm rms wavefront

Astigmatism correction

20 µm wavefront for 200 V max
-> residual error: 8 nm rms wavefront

Example: MONO61 measurements
MONOmorph laser energy level

Enhanced protected silver coating

Dielectric coating

Under study

Estimation based upon test results
Force Actuators DM for LMJ

Polished BK7 optical plate (446x426x9 mm³)

39 Force actuators (not shown)

3 Knee joints

Base plate

Actuator ISP System
Force Actuators DM main characteristics

Architecture: Large size, scalability and simple design

Correction: Adapted correction stroke (10 µm range)

Stability: Excellent open loop stability (0.2 µrad rms/hour)

Optical quality: High quality optical surface (1.4 µrad rms mechanical)

Energy level: > 10 kJ/pulse @ 1053 nm (ns range)
... and thank you