Specifications and technology developments for next generation of High Order Deformable Mirrors at Cilas

"DMs: key technology or critical technology?"

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Topics

- Introduction
- Deformable mirrors specifications and piezo array techno
- Requirements for development of DMs
- Qualification of DMs
- Preliminary roadmap for development
- Combined technologies
- Conclusion

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Introduction / principles

Future astronomical instrumentation will require high-density / high-order DMs

Need for high reliability / high homogeneity / long lifetime for large number of actuators: several thousands

Significant step

Tracks to follow for risks mitigation:
- Effort on standardization
- Effort on reliability and yield
- Industrial production of actuators (precision of tools)
- Accuracy of control during fabrication

Qualification:
- Operational performances
- Lifetime evaluation

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Deformable mirrors specifications and piezo array technology

Deformable Mirrors specifications

Parameter	Required value (TBC)	Potential of Cilas piezo array technology
Number of useful actuators	1 000 to 10 000	Several thousands
Clear aperture	200 to 500 mm Circular or elliptical shape	> 500 mm diameter (with same technology) - circular or elliptical aperture
Actuator spacing	1 to 10 mm	Standard spacing values are: 3.5 mm, **5 mm**, 7 mm, 10 mm, 14 mm…
Stroke (mechanical)	≥ 10 µm PV after flattening	Standard stroke ≥ 10 µm PV for 5 mm spacing
Mechanical coupling	20 to 30%	20 to 30% (according to the need in order to obtain the best fitting error)
Inter-actuator stroke (mechanical)	≥ 2 µm	30 to 40% of the max stroke PV (according to mechanical coupling value)
Optical quality (once the mirror flattened)	< 30 nm rms WFE (goal < 20 nm rms WFE)	< 20 nm rms WFE (polishing done at the end of manufacturing)
Control frequency	1 to 5 kHz	Actuator longitudinal frequency in 10 to 20 kHz range, thanks to materials stiffness - global dynamical behavior to be studied
Linearity & hysteresis	< 1 to 10% according to open or close loop operation	< 5% (for full stroke), thanks to piezo material
Dissipated power	As low as possible	Very low at mirror level, thanks to capacitive principle
Operating temperature	-30 C to 25 C	Very low temperature dependence, thanks to materials choice

→ Cilas piezo array technology can fit next DMs requirements

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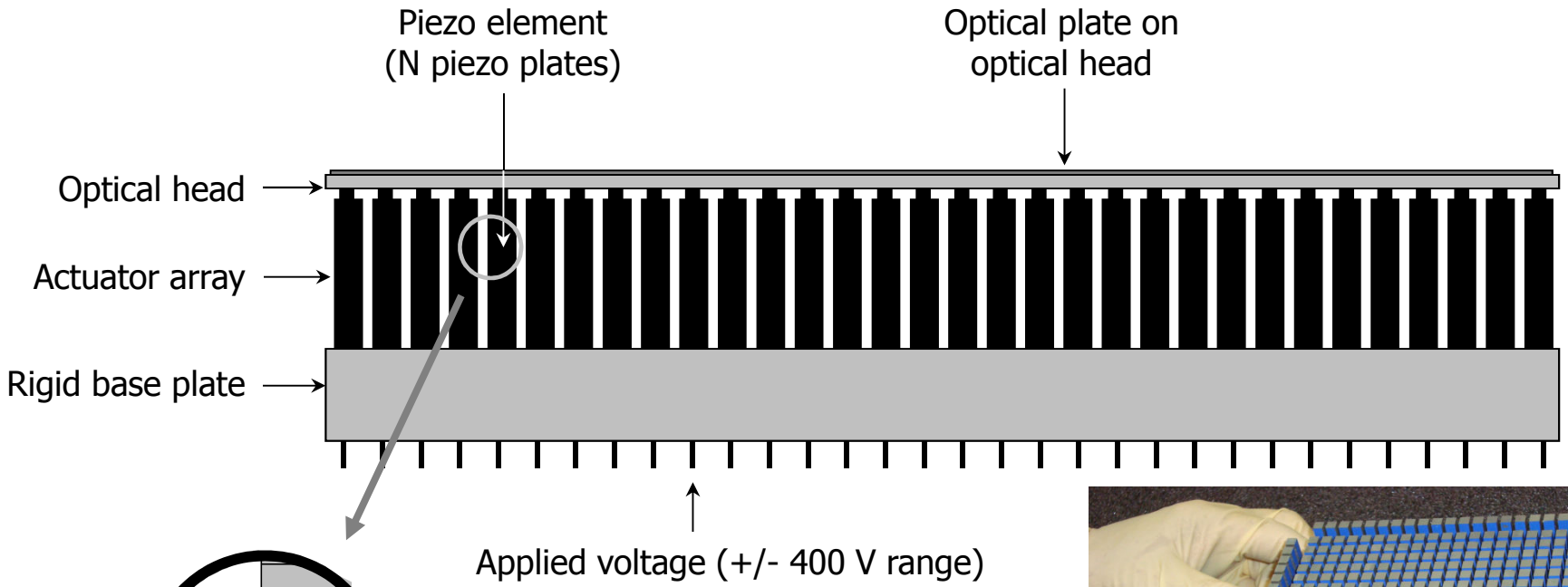
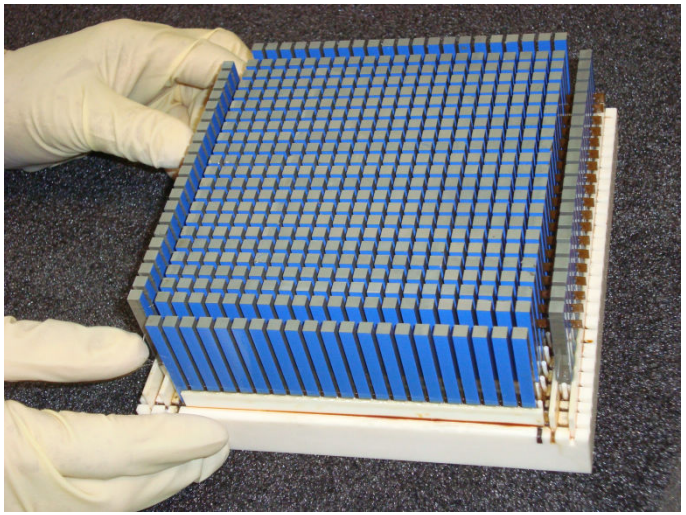
Piezo Stack Array Mirror (SAM) concept

piezo direct effect



Maximum stroke of an actuator: δ **= N d33 V**
N: number of piezo plates
d33: piezo coefficient (µm/V)
V: applied voltage (V)

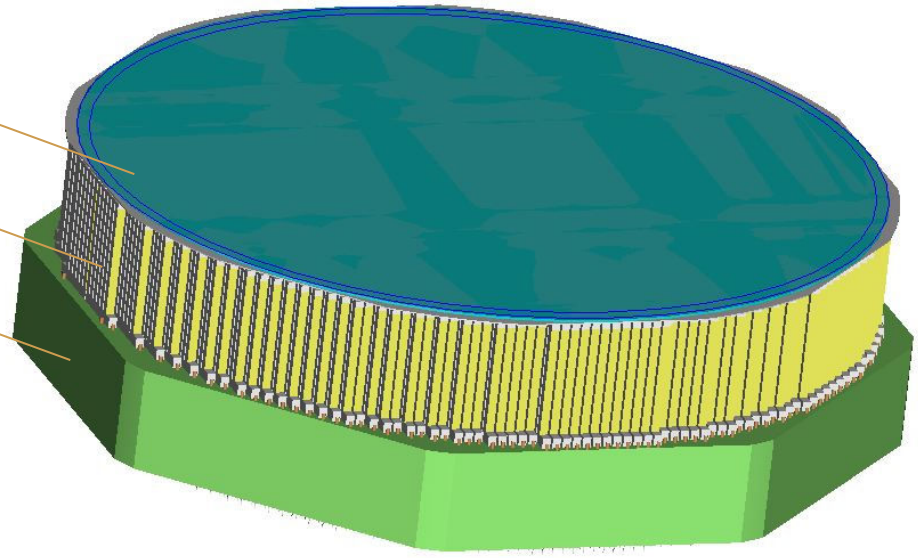


General design of DMs

Deformable optical plate

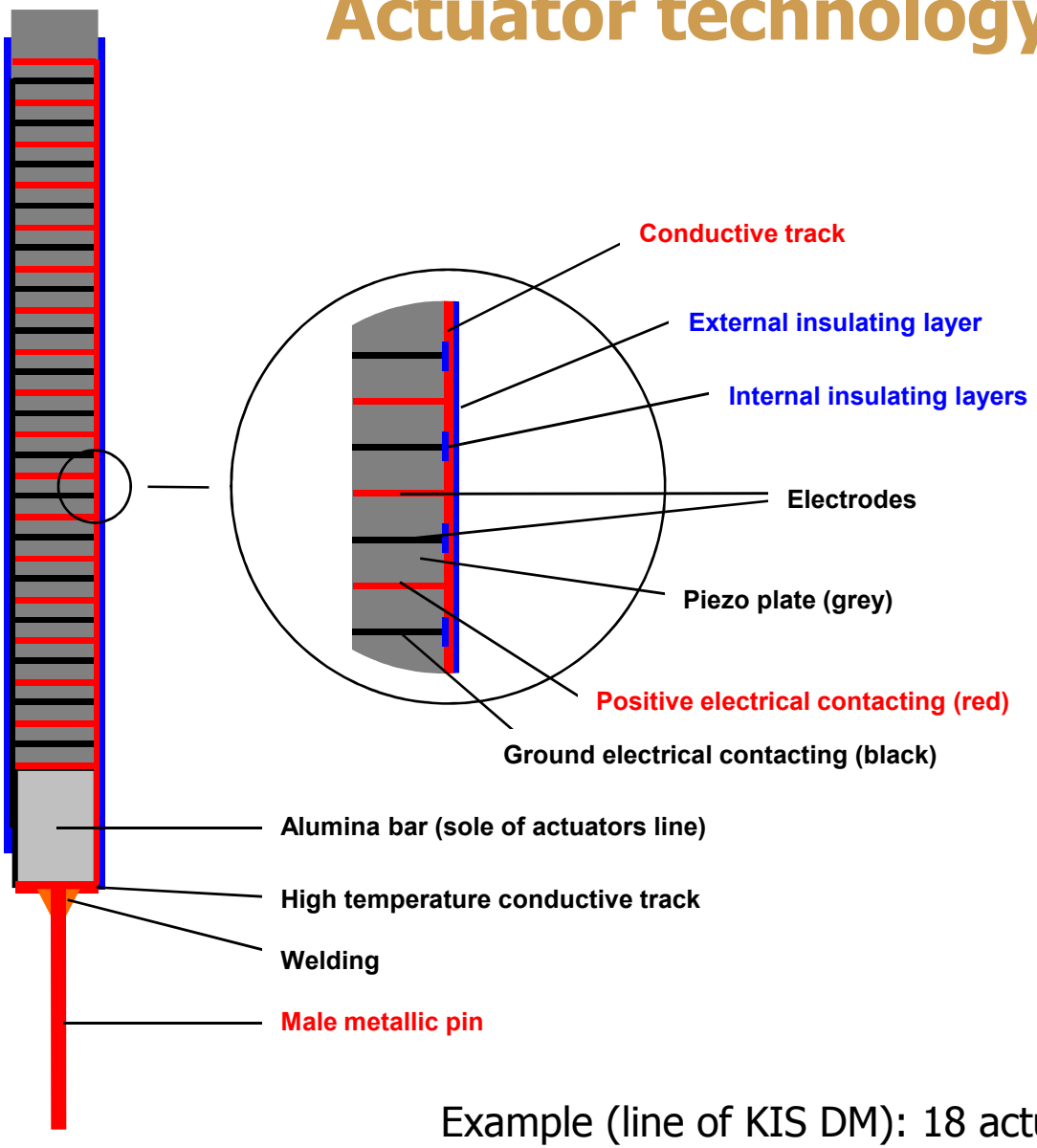
Actuator array (assembly of actuator lines)

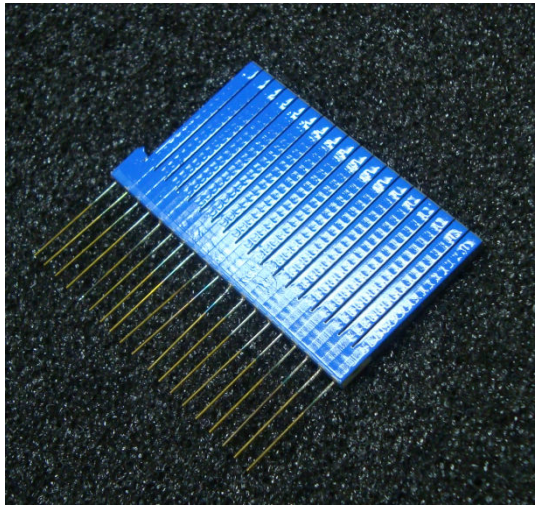
Rigid base plate



Example (design for TMT): ~ 4500 actuators, 5 mm spacing, Ø ~ 400 mm

Actuator technology





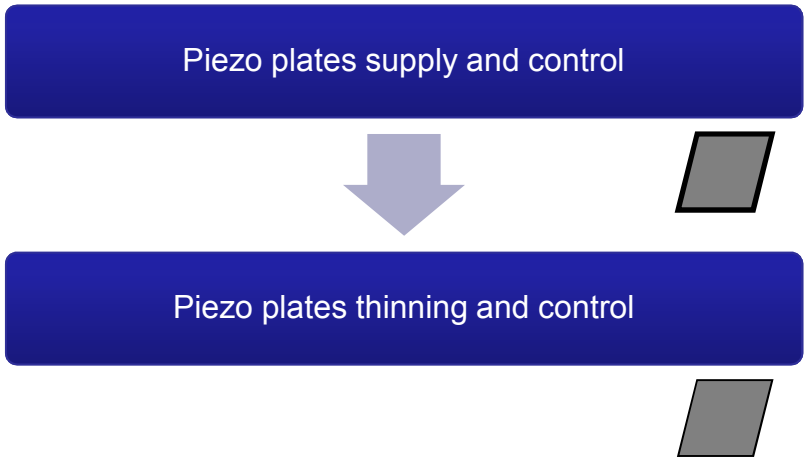
Example (line of KIS DM): 18 actuator line, ~ 3.5 mm spacing

Requirements for development

SAM manufacturing flowchart:
Phase 1: Materials preparation

Piezo plates supply and control

SAM manufacturing flowchart:
Phase 1: Materials preparation



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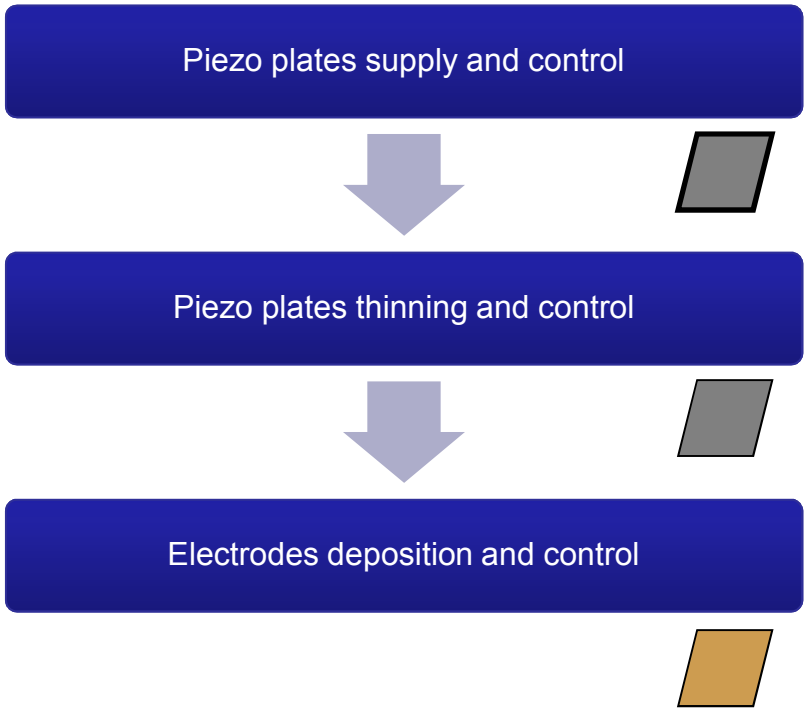

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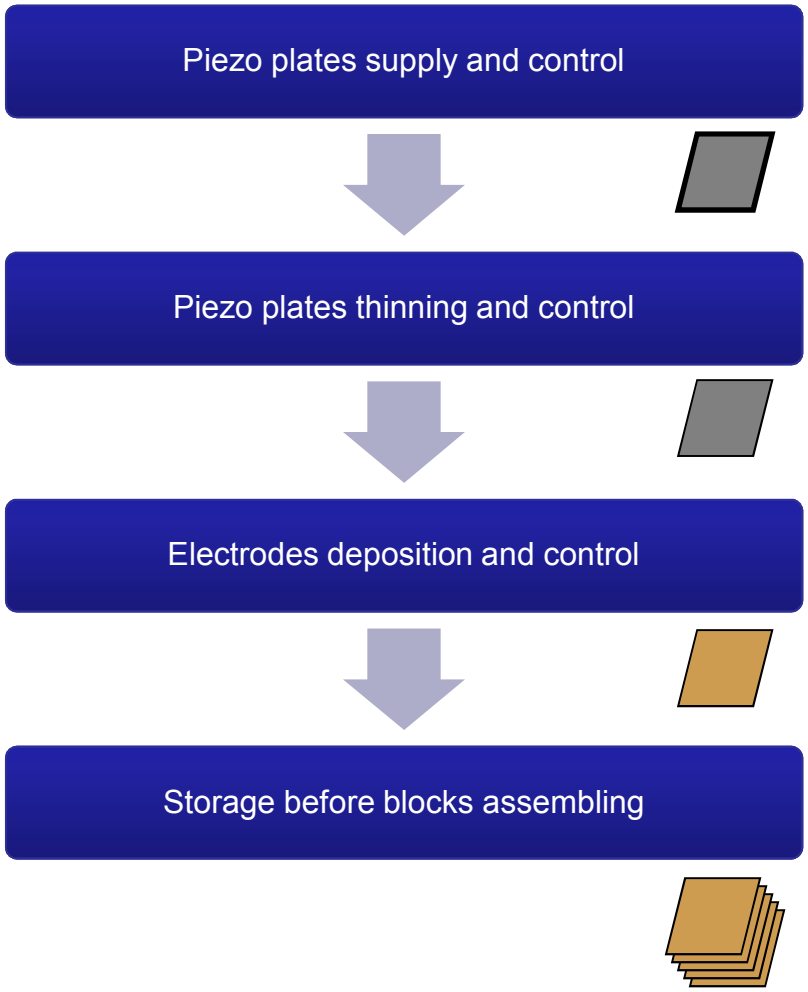

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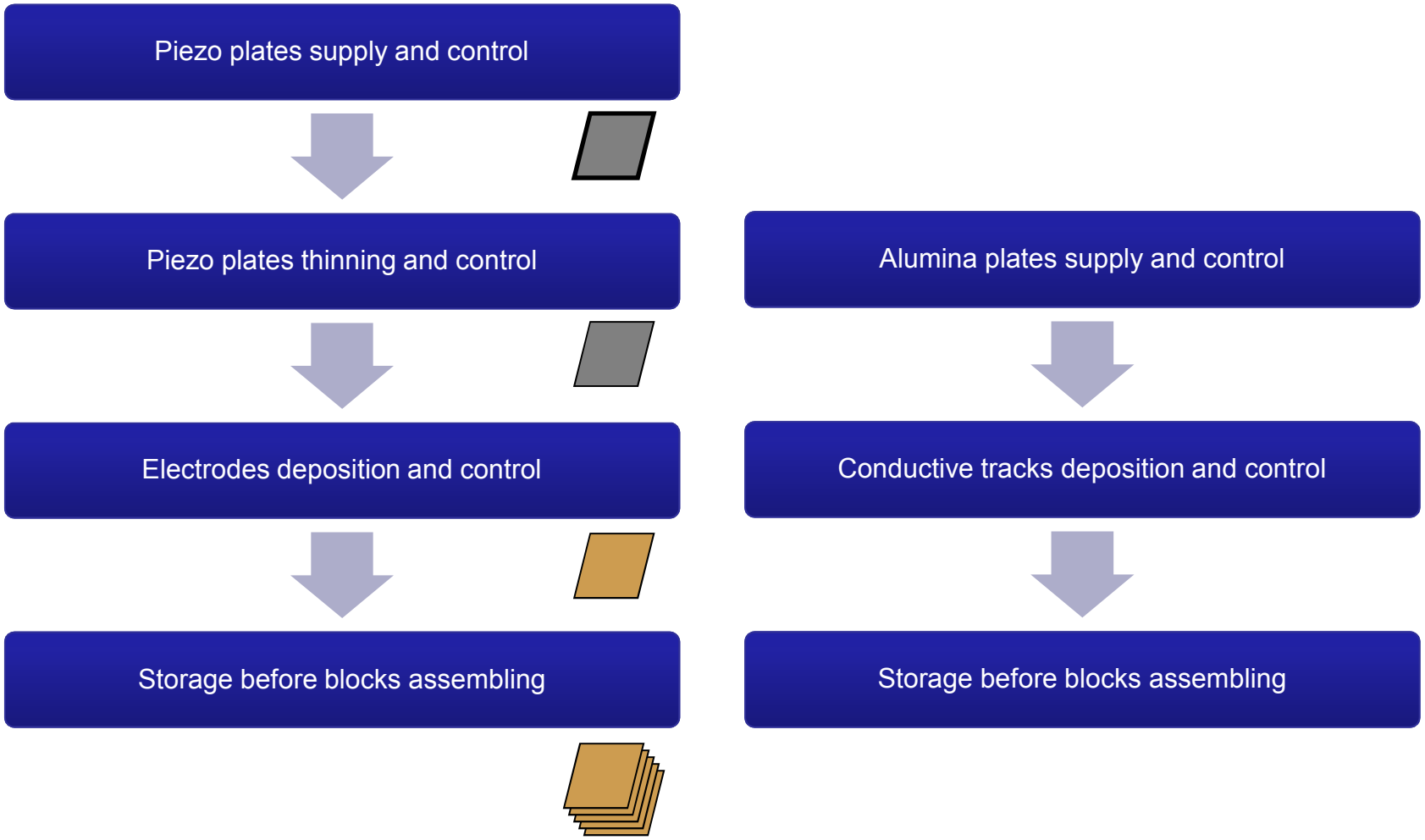

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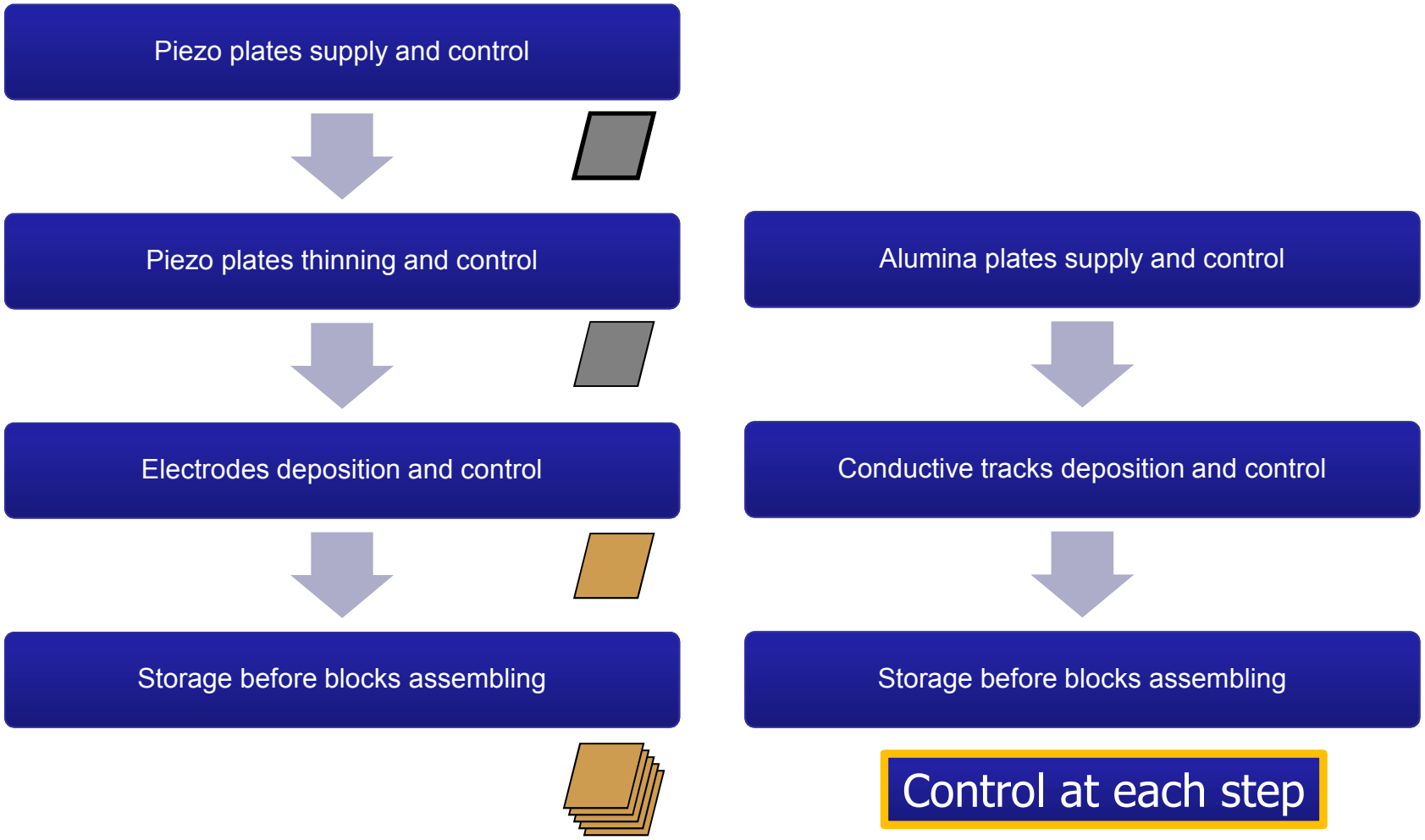
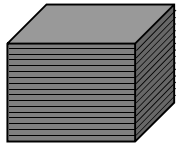


SAM manufacturing flowchart:
Phase 2: Lines of actuators manufacturing

Block manufacturing: piezo + alumina assembling, bonding, curing & control



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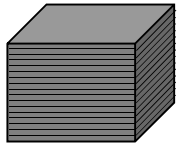
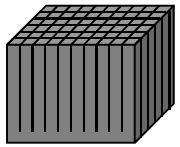


Block sawing in lines of actuators and control



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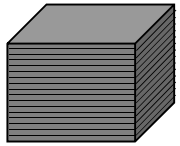

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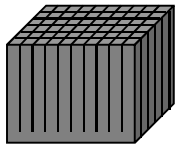
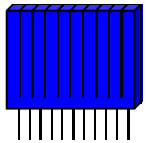


Electrical insulation and contacting
(internal insulating layers, conductive tracks, pins welding and external varnish), control



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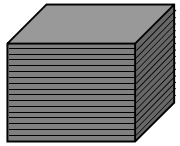

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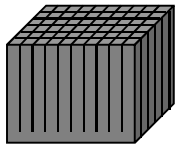

Dedicated tools and control at each step

Electrical insulation and contacting
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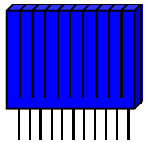

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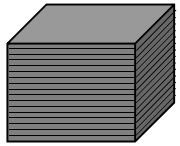

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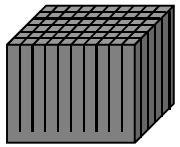

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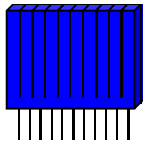
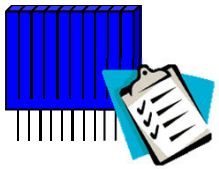


Electrical test and qualification of lines of actuators, sorting



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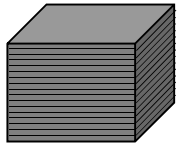

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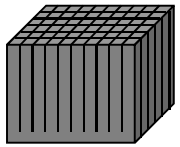

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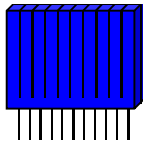

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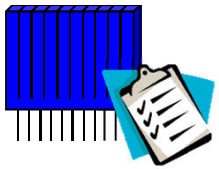

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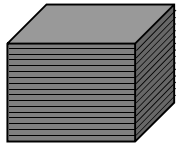

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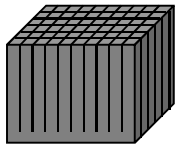

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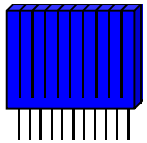

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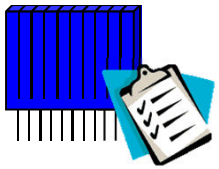
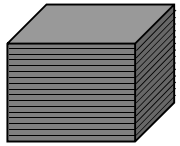


Storage of actuator lines before DM manufacturing

SAM manufacturing flowchart:
Phase 2: Lines of actuators manufacturing

Block manufacturing: piezo + alumina assembling, bonding, curing & control



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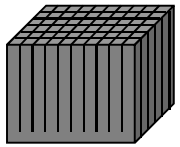

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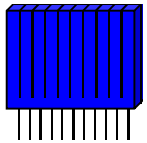

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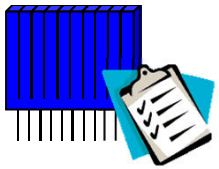

Storage of actuator lines before DM manufacturing

Qualified lines on the shelves, can be used for any DM

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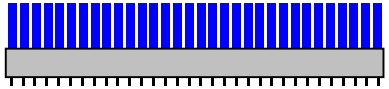
SAM manufacturing flowchart:
Phase 3: DM manufacturing

Actuator lines bonding on baseplate to obtain actuator array and control

↓

Tooling of actuator array / Preparation of optical head



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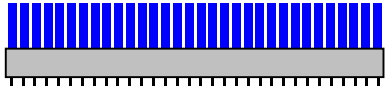
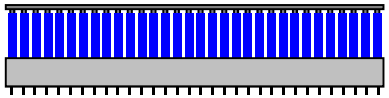


Tooling of actuator array / Preparation of optical head

Bonding of optical head (metal part) against actuator array and control



Preparation and bonding of optical plate against optical head

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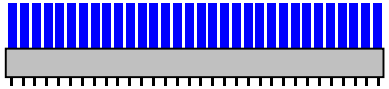
Phase 3: DM manufacturing

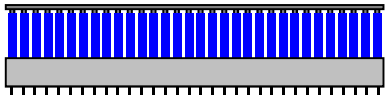
Actuator lines bonding on baseplate to obtain actuator array and control



Tooling of actuator array / Preparation of optical head

Manufacturing process to validate with breadboards

Bonding of optical head (metal part) against actuator array and control



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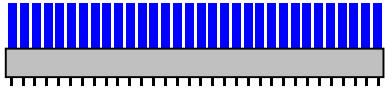

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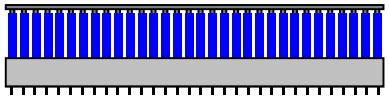
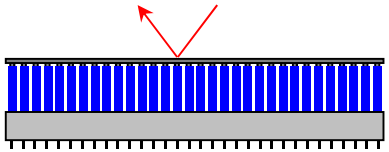


Preparation and bonding of optical plate against optical head

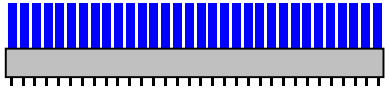
Thinning and polishing of optical surface and optical control (shape at rest, stroke)



Coating of optical surface and optical control

SAM manufacturing flowchart:
Phase 3: DM manufacturing

Actuator lines bonding on baseplate to obtain actuator array and control



Tooling of actuator array / Preparation of optical head

Manufacturing process to validate with breadboards

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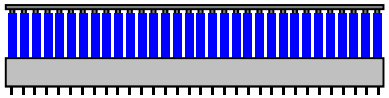
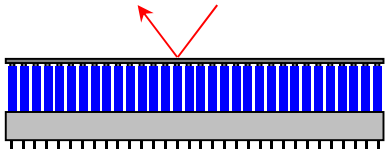


Preparation and bonding of optical plate against optical head

Thinning and polishing of optical surface and optical control (shape at rest, stroke)

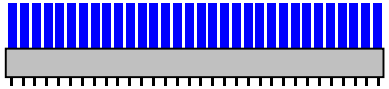
Optical quality is obtained at this step



Coating of optical surface and optical control

SAM manufacturing flowchart:
Phase 3: DM manufacturing

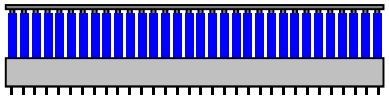
Actuator lines bonding on baseplate to obtain actuator array and control



Tooling of actuator array / Preparation of optical head

Manufacturing process to validate with breadboards

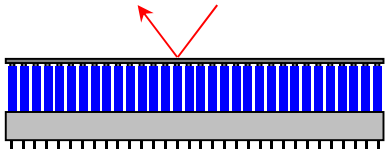
Bonding of optical head (metal part) against actuator array and control



Preparation and bonding of optical plate against optical head

Thinning and polishing of optical surface and optical control (shape at rest, stroke)

Optical quality is obtained at this step



Coating of optical surface and optical control

DM final integration (electrical and mechanical) and qualification

SAM manufacturing flowchart:
Phase 3: DM manufacturing

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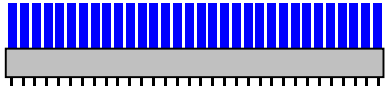

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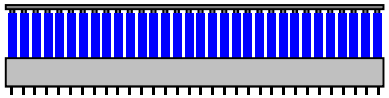

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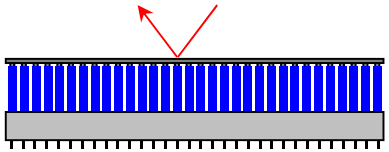
Thinning and polishing of optical surface and optical control (shape at rest, stroke)

Optical quality is obtained at this step



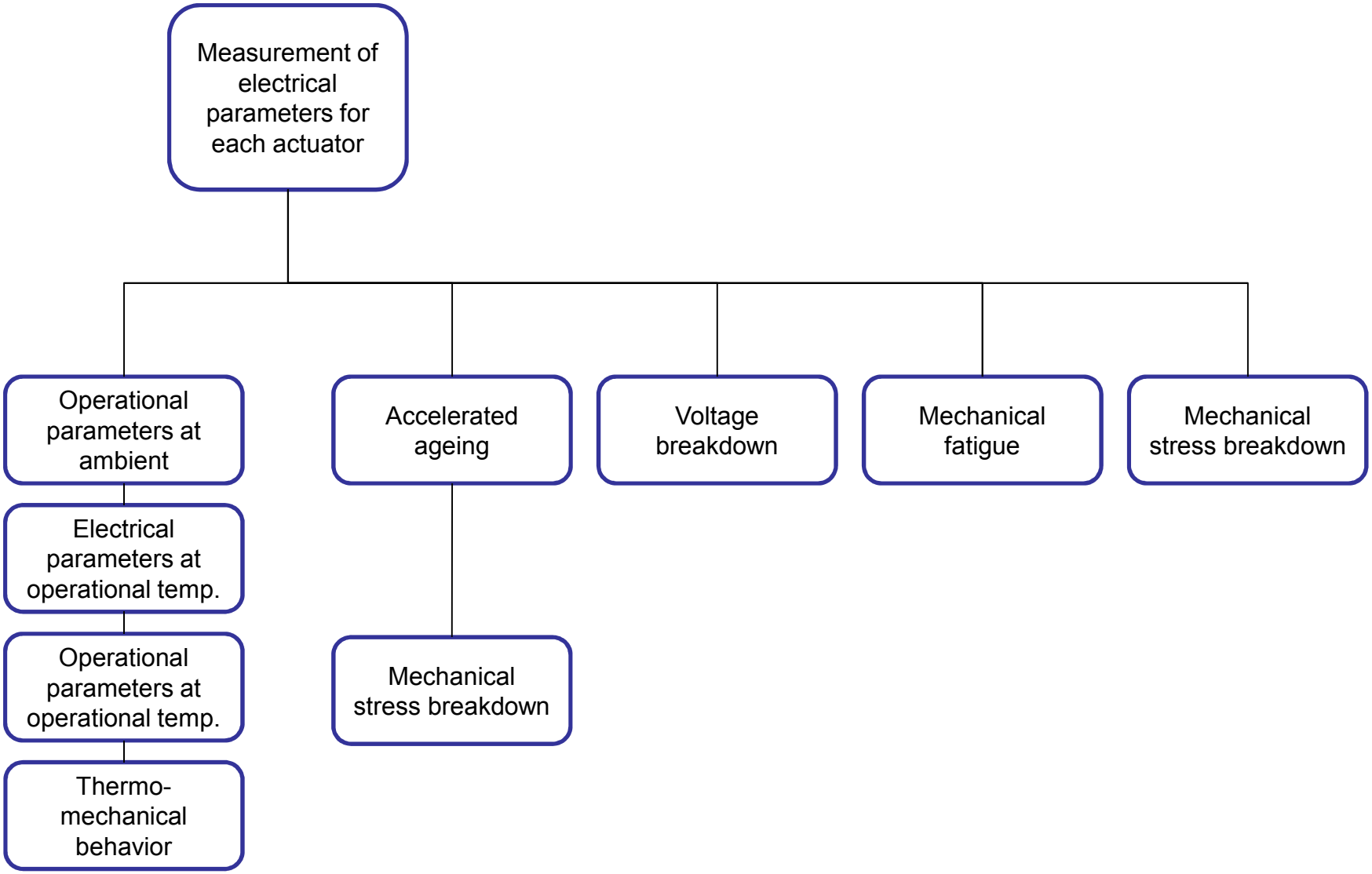
Coating of optical surface and optical control

DM final integration (electrical and mechanical) and qualification

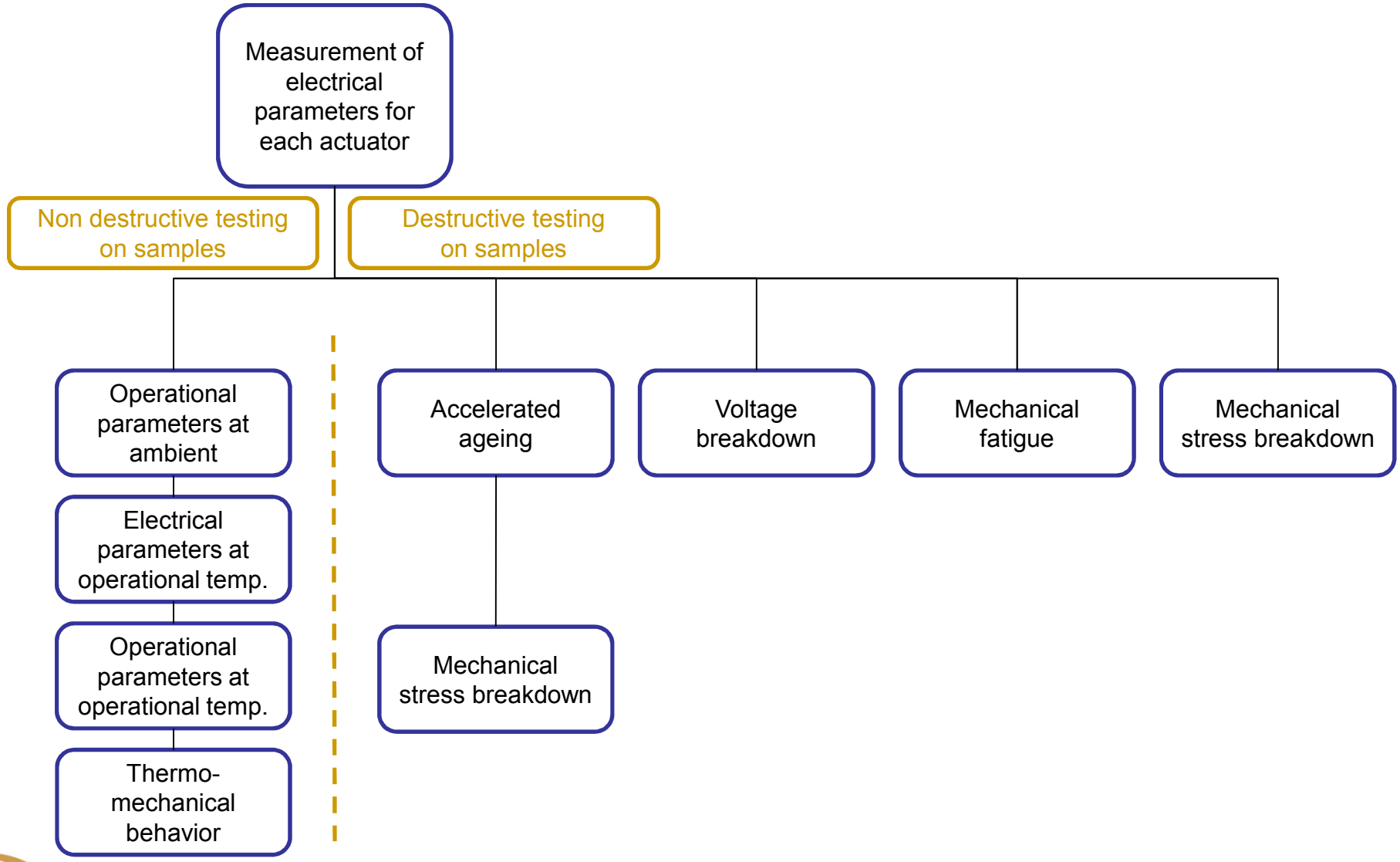
See presentation of qualification hereafter

Qualification

Qualification of actuator lines

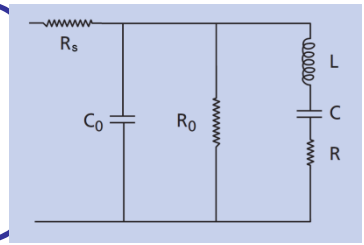


Qualification of actuator lines



Qualification of actuator lines

Measurement of electrical parameters for each actuator



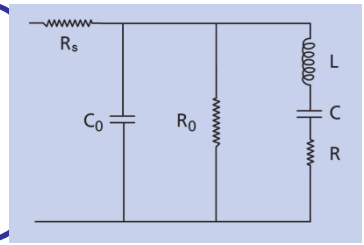
Non destructive testing on samples

Destructive testing on samples

- Operational parameters at ambient
  - Electrical parameters at operational temp.
    - Operational parameters at operational temp.
      - Thermo-mechanical behavior
- Accelerated ageing
  - Mechanical stress breakdown
- Voltage breakdown
- Mechanical fatigue
- Mechanical stress breakdown

Qualification of actuator lines

Measurement of electrical parameters for each actuator



Non destructive testing on samples

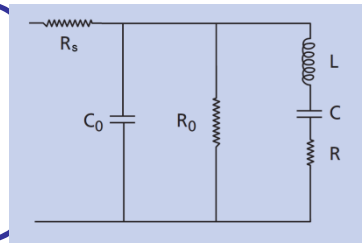
Destructive testing on samples

- Operational parameters at ambient
- Electrical parameters at operational temp.
- Operational parameters at operational temp.
- Thermo-mechanical behavior

- Accelerated ageing
  - 85C, 85% HR, 400V
  - Duration without failure > 50 hours
  - Mechanical stress breakdown
- Voltage breakdown
- Mechanical fatigue
- Mechanical stress breakdown

Qualification of actuator lines

Measurement of electrical parameters for each actuator



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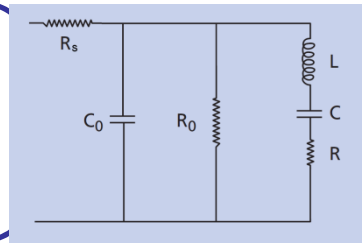
- Voltage breakdown
  - Breakdown voltage > 2*400V + 1000V = 1800V
- Mechanical fatigue
- Mechanical stress breakdown

Qualification of actuator lines

Measurement of electrical parameters for each actuator



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Destructive testing on samples

- Accelerated ageing
  - 85C, 85% HR, 400V
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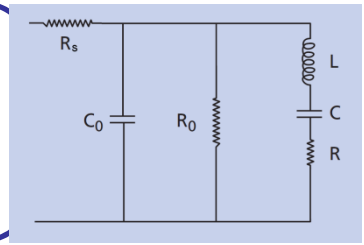
  - Mechanical stress breakdown
- Voltage breakdown
  - Breakdown voltage > 2*400V + 1000V = 1800V
- Mechanical fatigue
  - Actuator driven at resonance frequency
  - Duration without failure > TBD hours
- Mechanical stress breakdown

Qualification of actuator lines

Measurement of electrical parameters for each actuator



Non destructive testing on samples

- Operational parameters at ambient
- Electrical parameters at operational temp.
- Operational parameters at operational temp.
- Thermo-mechanical behavior

Destructive testing on samples

- **Accelerated ageing**
  - 85C, 85% HR, 400V
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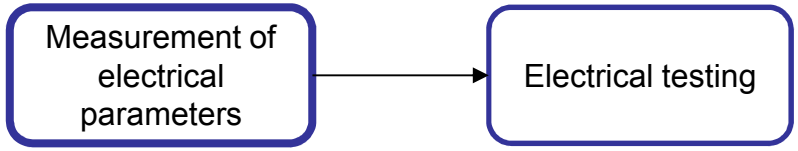
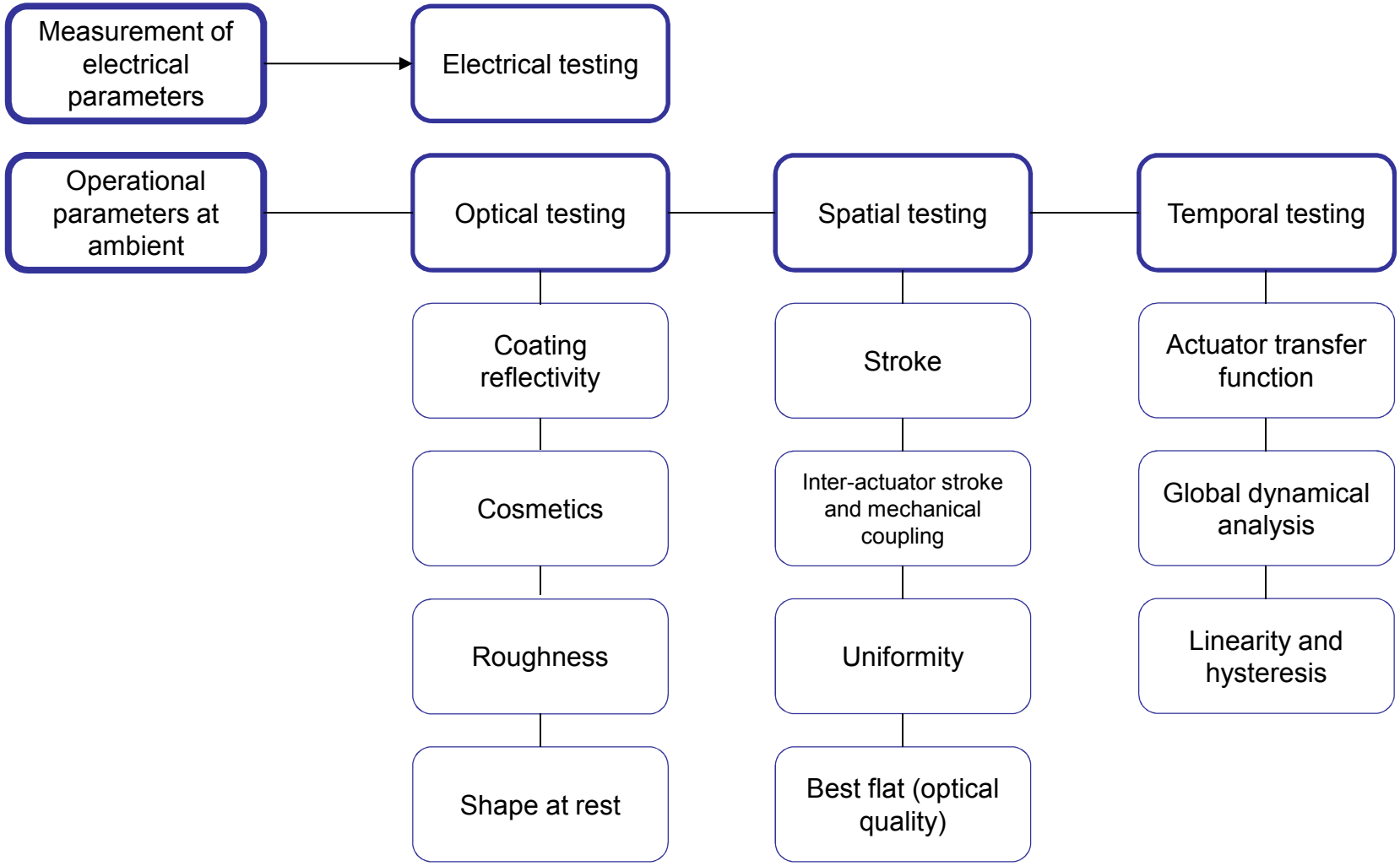
- **Voltage breakdown**
  - Breakdown voltage > 2*400V + 1000V = 1800V
- **Mechanical fatigue**
  - Actuator driven at resonance frequency
  - Duration without failure > TBD hours
- **Mechanical stress breakdown**
  - Breakdown stress > TBD MPa

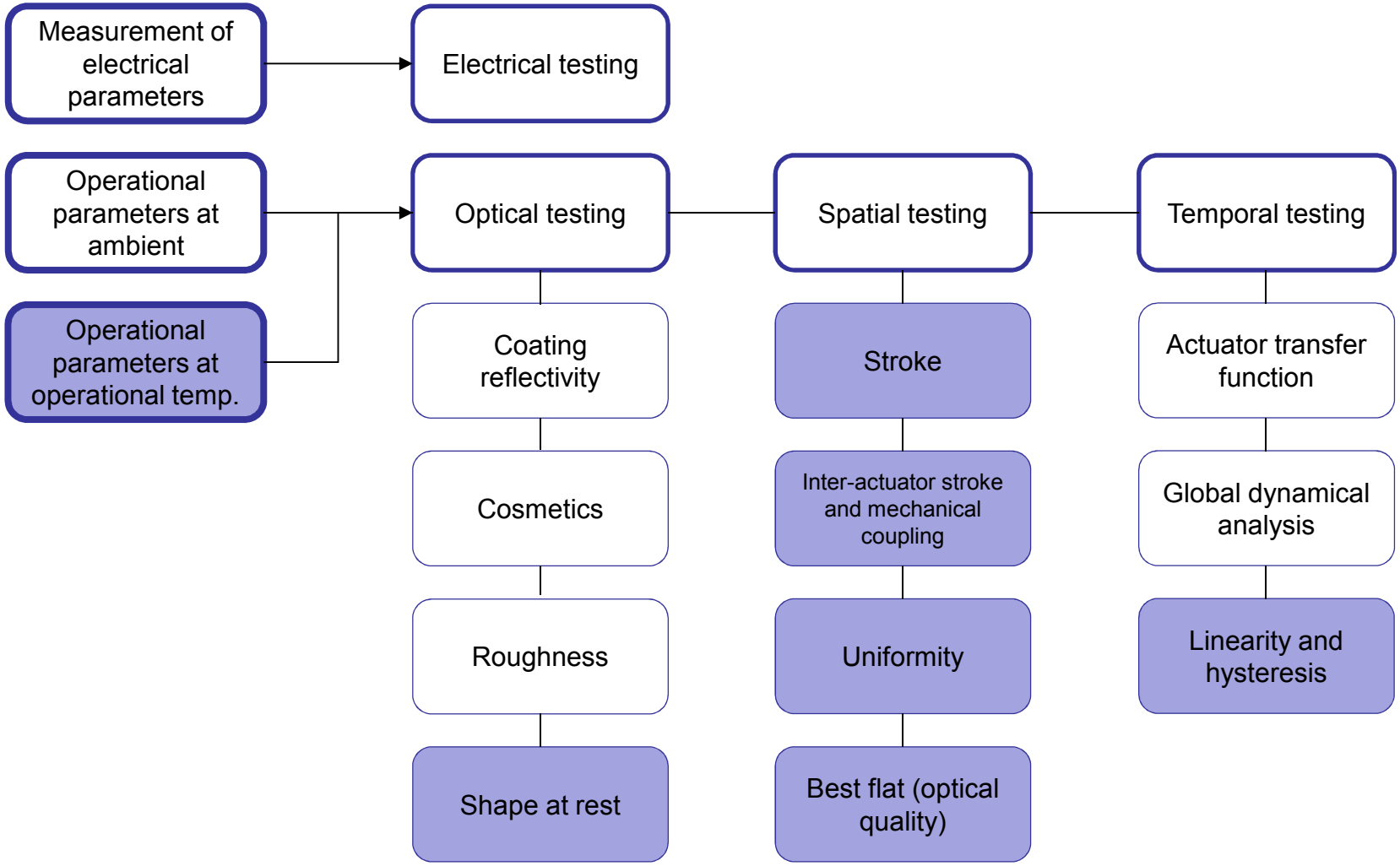
Qualification of DM



Qualification of DM



Qualification of DM



Preliminary roadmap for development

Main phases

A) Risks and opportunities analysis
Design and FEM/FEA

B) Actuator lines sawing and contacting optimization
Process qualification of actuator lines manufacturing
- Manufacturing files and tools
- Control tools

Actuator lines qualification

C) Large DMs processes qualification (using breadboards) for:
- Manufacturing files and tools
- Assembling
- Polishing
- Coating

DMs qualification

Combined technologies

- Tip-Tilt Mount (TTM)
- Deformable Mirrors Drive Electronics (DMDE)

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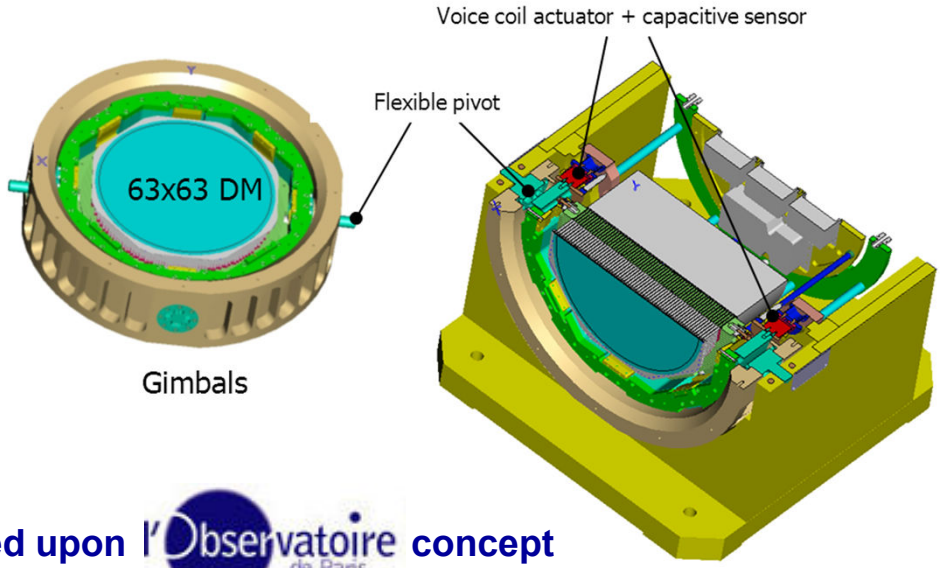
Tip-Tilt Mount (TTM)

- Angular stroke: 500 µrad PV
- Angular stroke @ 20 Hz: > 25 µrad PV
- Bandwidth: 100 Hz
- Noise: < 40 nrad rms
- Operating temperature: 20 and -35C



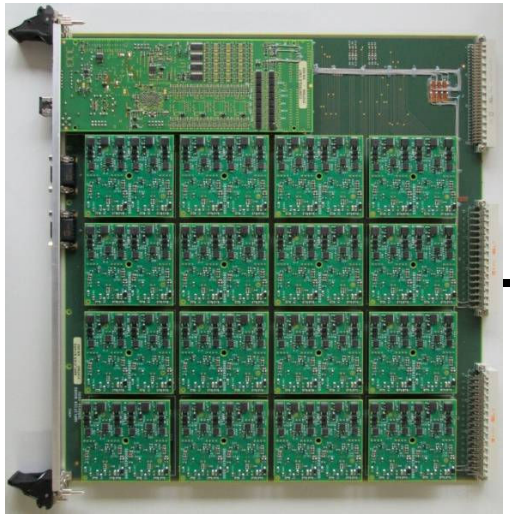
Assembly with dummy 32kg DM manufactured for TMT

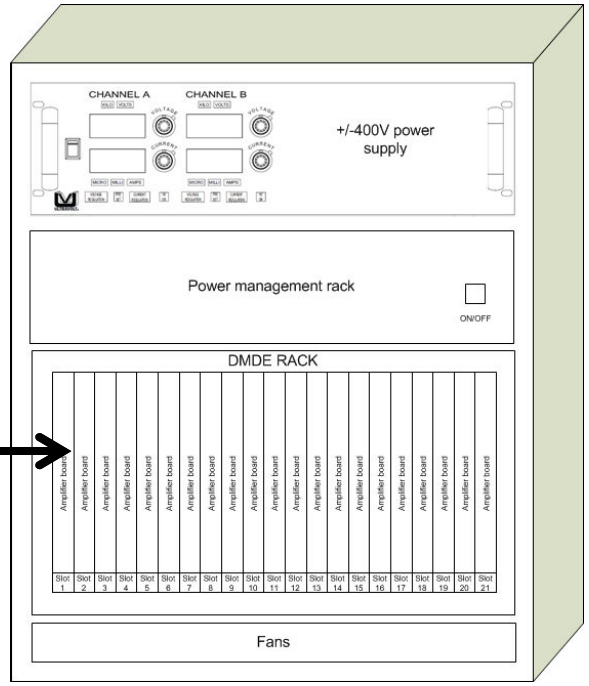
Based upon l'Observatoire de Paris concept

Deformable Mirrors Drive Electronics (DMDE)

- High speed data link: sFPDP
- Housekeeping link: RS485
- 64 HV channels per amplifier board
- 21 amplifier boards per driver (1344 HV channels)
- 8 drivers can be used simultaneously (10 752 HV channels)
- Bandwidth: 2 to 10 kHz (for 22 to 5 nF load)
- Drive voltage: +/-400 V
- Max slew rate: 100 V/ms
- Max latency: 40 µs

Amplifier board with 16x4 HV channels





Conclusion

- Cilas technology can meet the required specifications for future astronomical instrumentation (high-density / high-order DMs)

- Large HODMs showing high reliability / high homogeneity / long lifetime require strong efforts:
  - Thorough technological studies
  - Standardization
  - Industrial production of actuators with dedicated tools
  - Safe processes for assembling and integration
  - Accuracy of control during fabrication
  - Exhaustive qualification

*"… After a few years of preparation, the VLT construction went on the right path, with a **solid methodology inspired by space developments**."*

Catherine Cesarsky – The Messenger – ESO – Dec. 2012

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