

micro and nanoelectronics  
microsystem  
ambient Intelligence  
image chain  
biology and health



2007

# *Review of deformable mirrors developed at LETI- MINATEC*

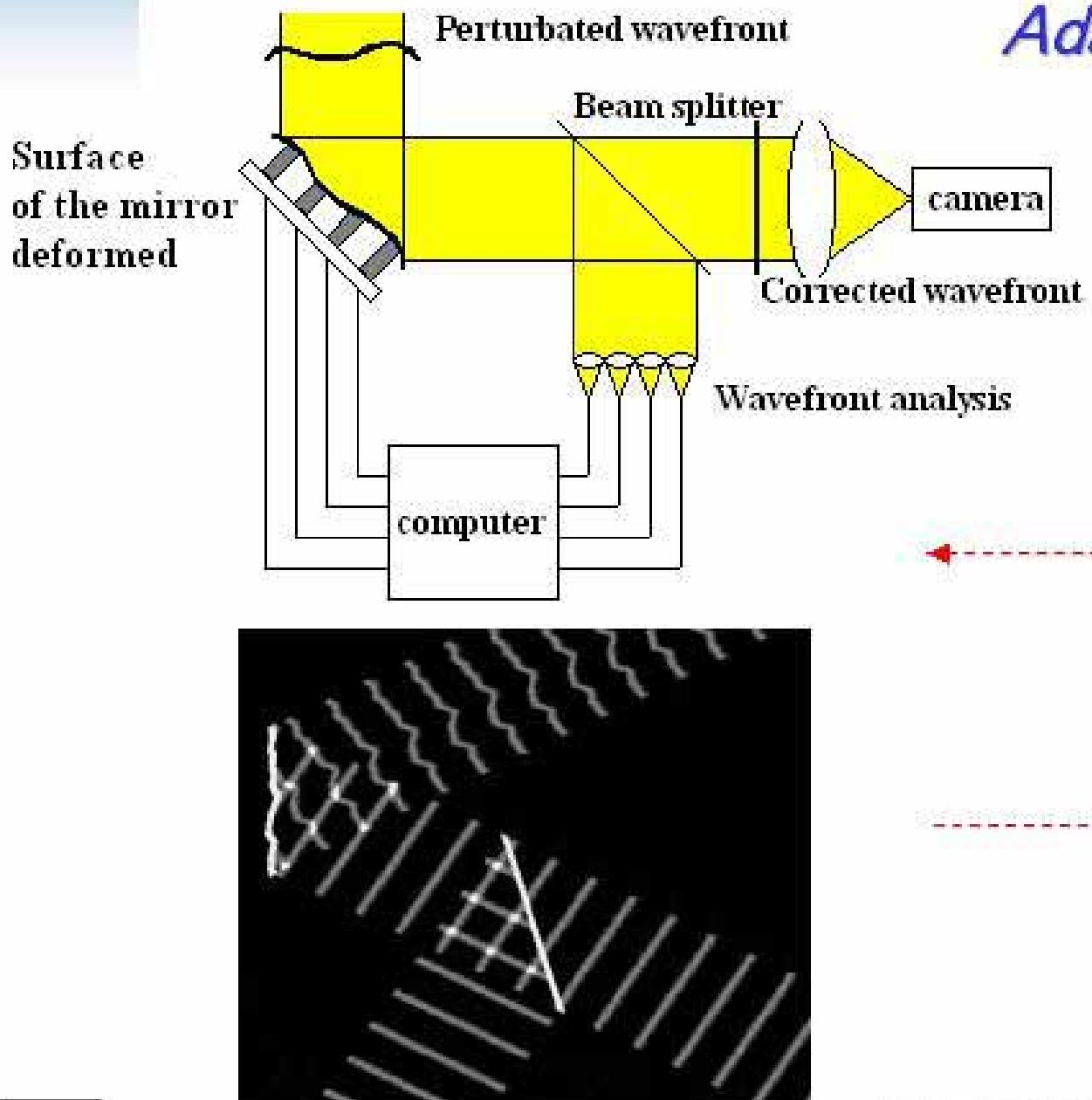
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Divoux, M.H. Vaudaine and P. Robert

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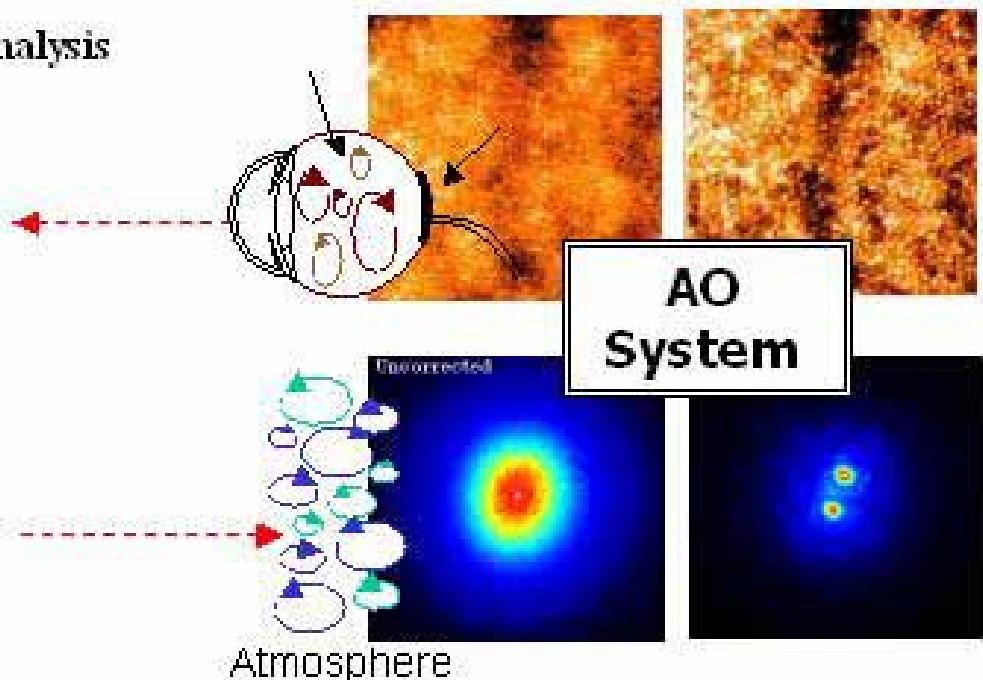
- Introduction to deformable mirrors (DM)
- DM for Astrophysics and Ophthalmology
- DM for optical data storage
- DM for optical Scanner
- Conclusion

# Leti 2007 (1) Deformable mirrors for wave front controlling



## Adaptive Optics loop (AO)

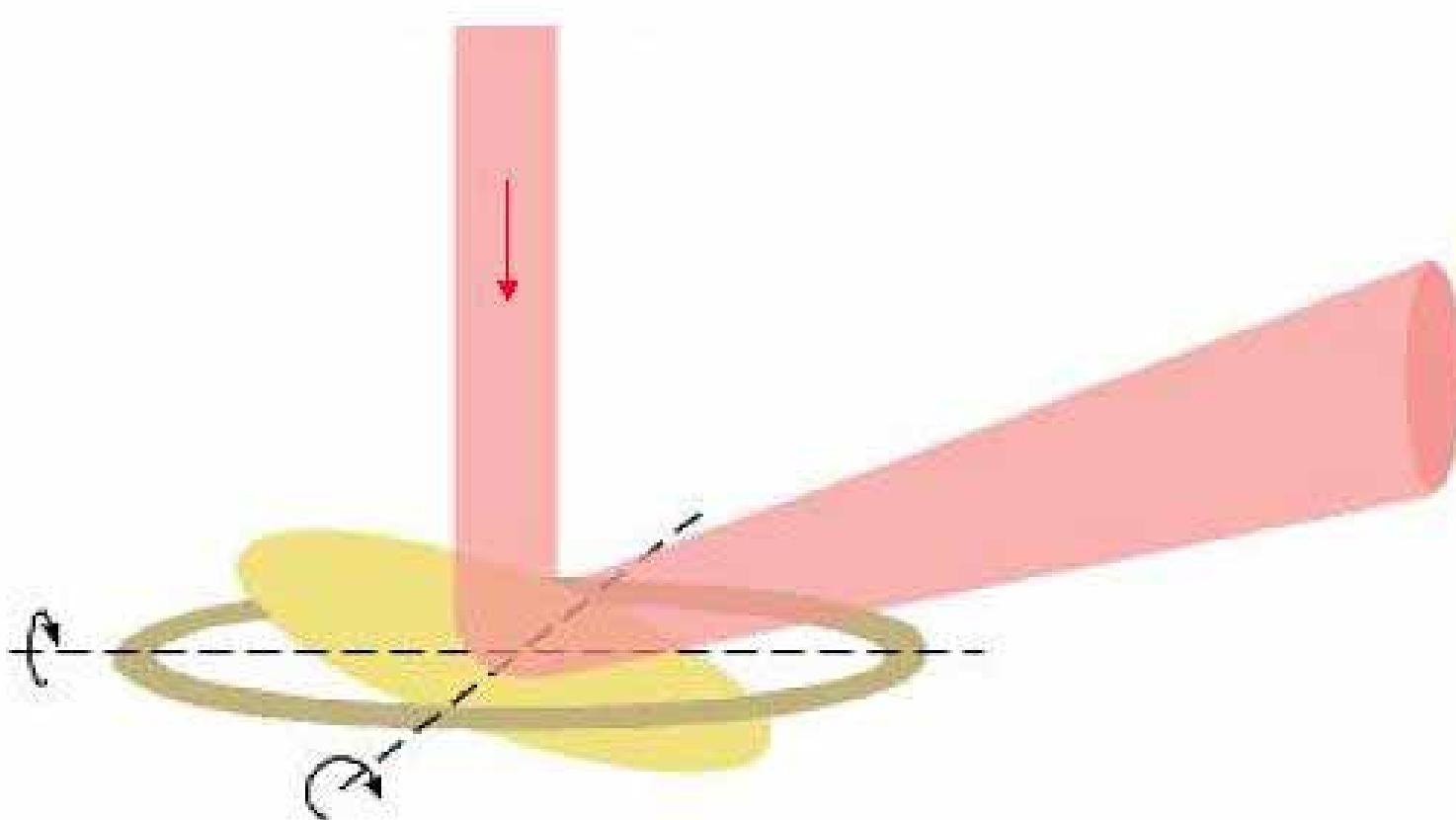
## Ophthalmology



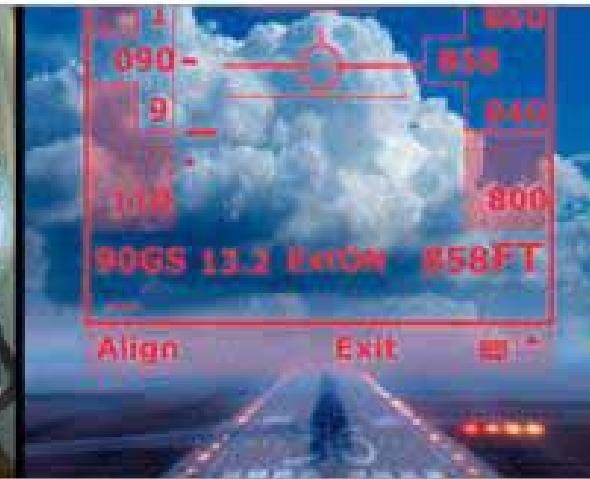
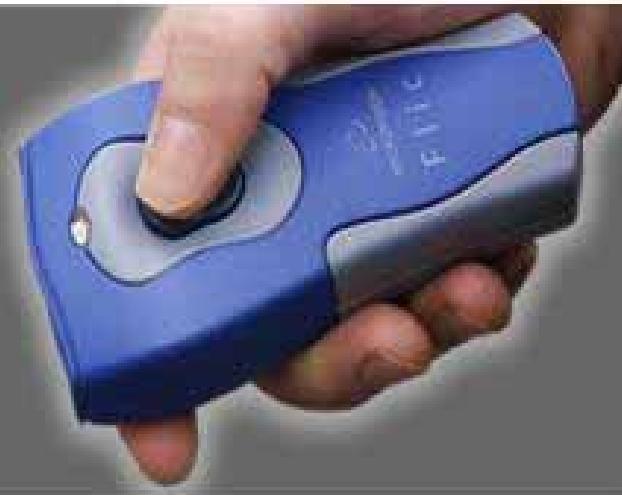
## Astrophysics

## (2) DM for optical scanners

*Change the directory of light (2 axes)*



## (2) DM for optical scanner



Barcodes reader

Micro-displays



Projectors for mobile devices



Imaging in surgery

- Requirements:

- Deformable Mirrors need Continuous membranes and Large Global and Inter-actuator Strokes (total deflexion +/- 5µm, Deflexion between 2 actuators ~ 2 µm at voltage < 200 V)

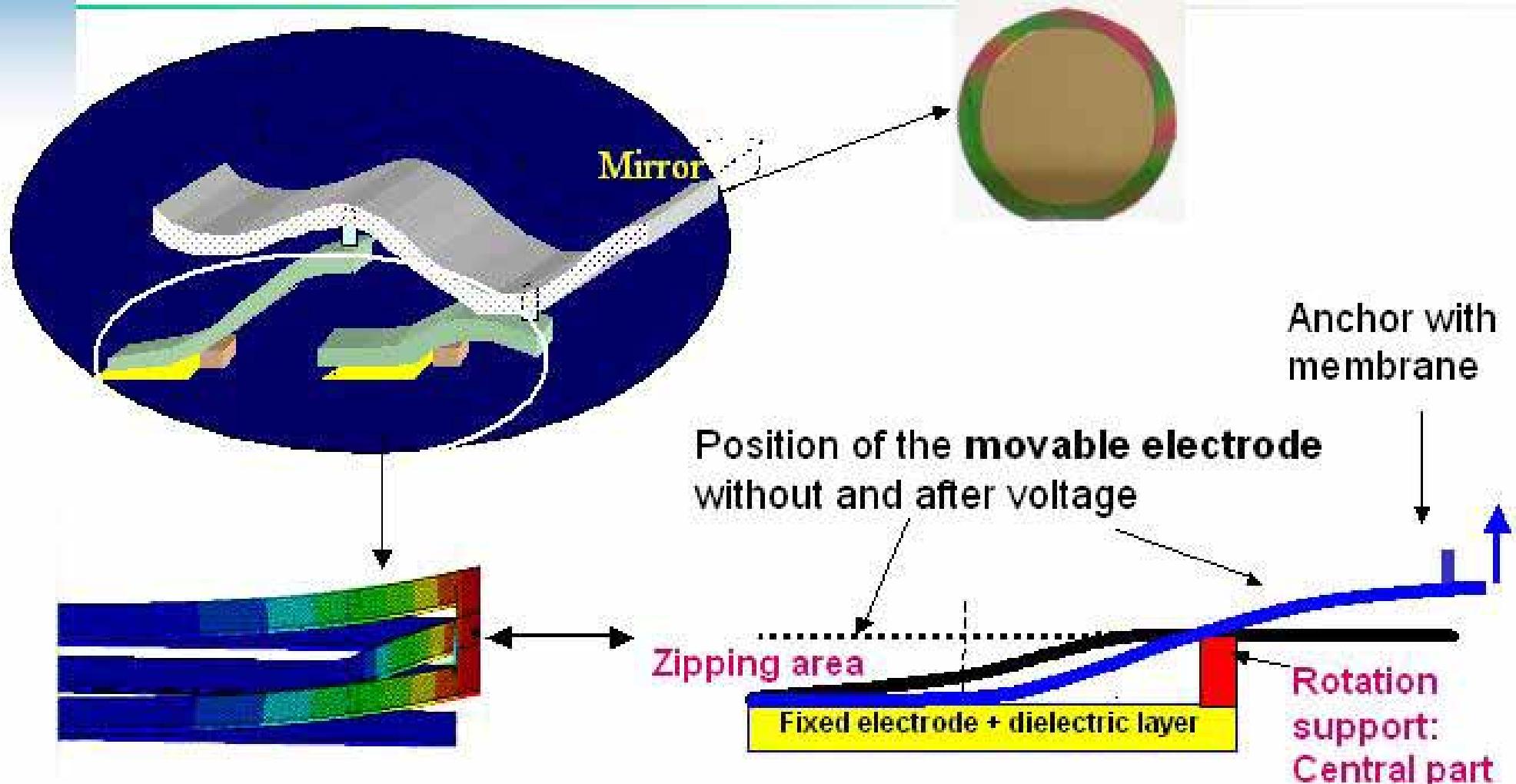
- Advantageous of continuous mirrors:

- Better optical performances compared to segmented mirrors
  - Electrostatic Actuators display low power consumption and good fabrication compatibility

- A new type of Zipping Actuator developed:

- Reduces the required initial electrostatic gap
  - Operates as a lever, pushing or pulling the reflective membrane

# Description of the new zipping actuator



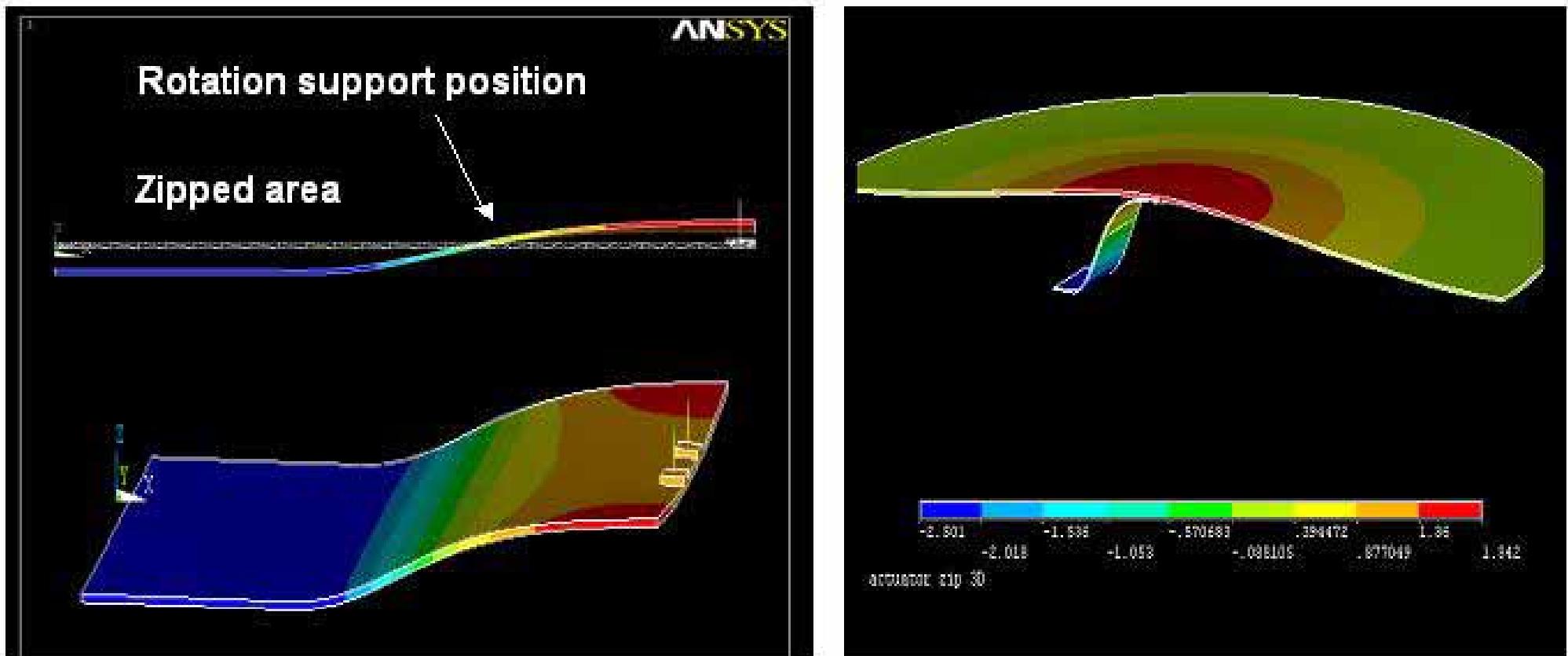
## Bi-directional electrostatic actuator

To summarize:

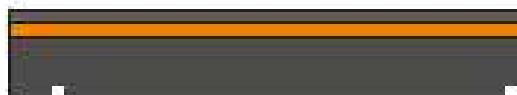
- **V** applied under the central arm, the lever **Pushes** the mirror
- **V** applied under the two external arms, the lever **Pulls down** the mirror

## Static simulation performed by Finite Element Method using ANSYS software

- One actuator in "PUSHING" mode has been simulated
- Contact between actuator and dielectric layer is supposed to present a high tangential stiffness: to avoid sliding
- Contact between actuator and rotation support is supposed to be a straight Line



**Simulations provide optimized parameters for the actuator:  
thickness, width, height of the rotation support ...**

*Fabrication of mirror: Process flow**Membrane Part*

SOI wafer



**Actuators anchor** are patterned on silica layer



Poly-silicon (2 $\mu$ m) **actuators** are deposited and structured



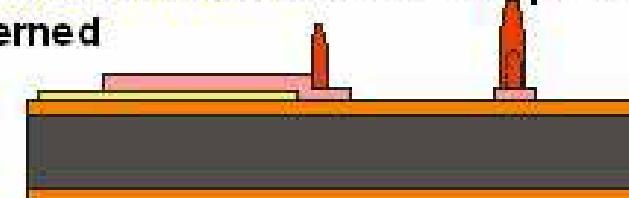
Silicon mirror is dry etched



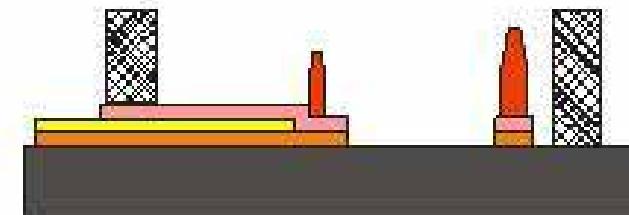
**Actuators** are released

*Electrode Part*

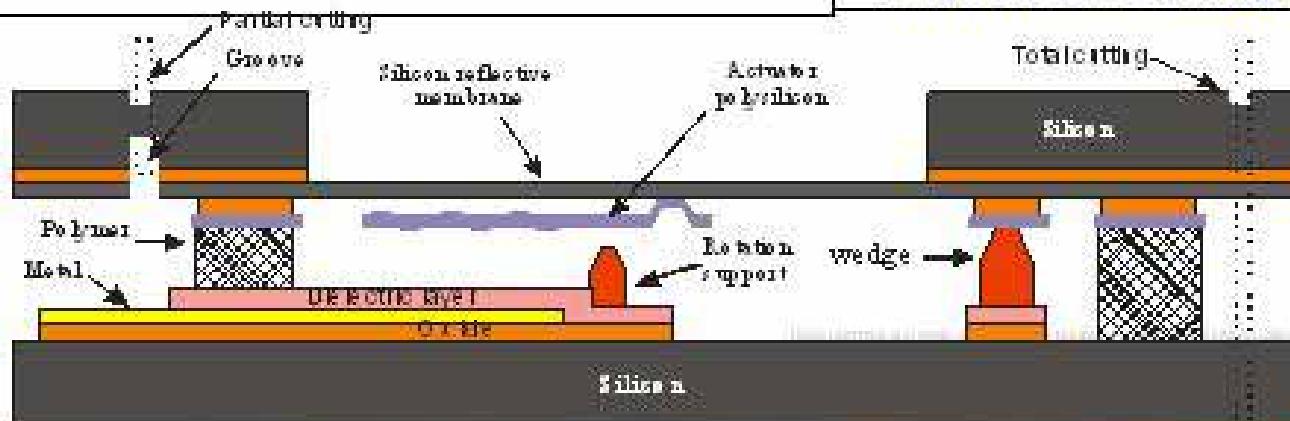
Silica (2  $\mu$ m) is grown on silicon substrate  
**Metallic conductors** are then deposited and patterned



**Rotation support and Spacers:** 2.5  $\mu$ m (silica) are deposited and patterned over dielectric layer

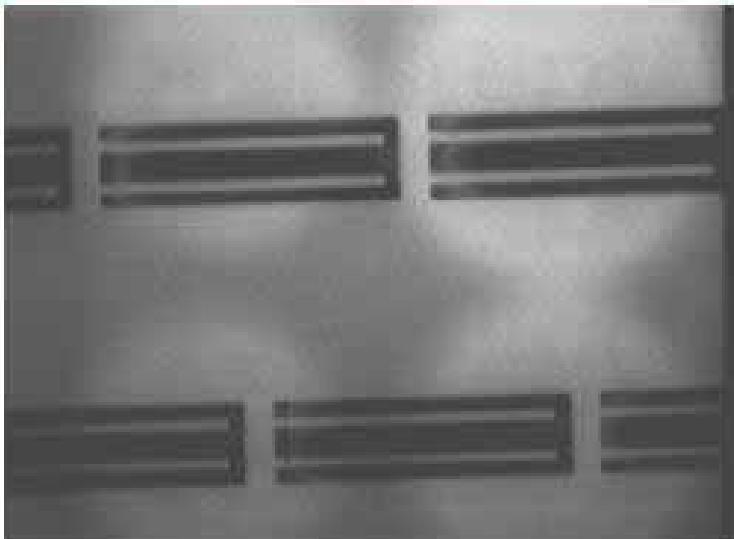


**Polymer for bonding** is deposited and patterned

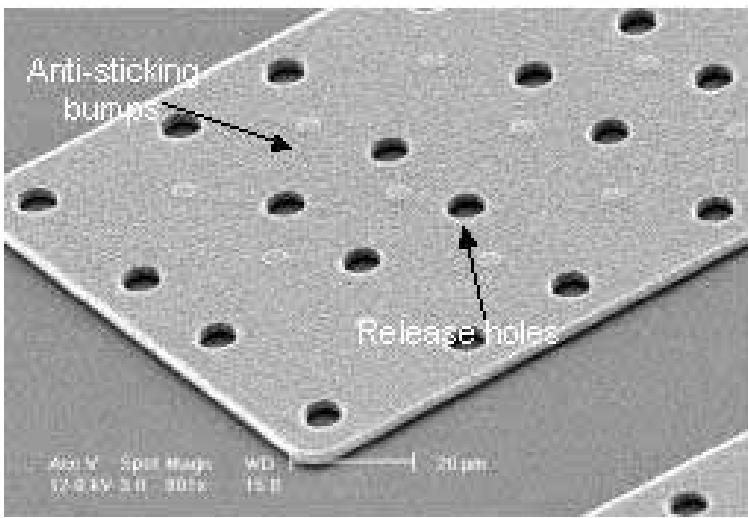


**Final mirror after bonding**

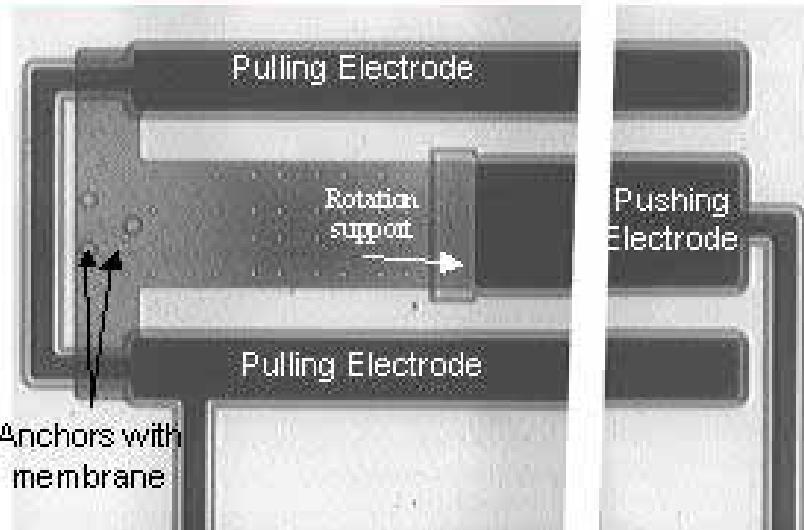
# *Views of the Device*



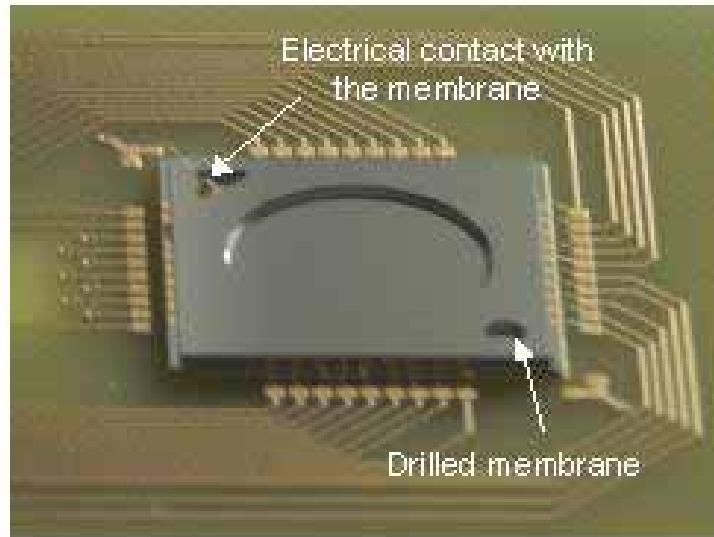
1- Actuators after Release: No Stress



2 - SEM image of one Actuator



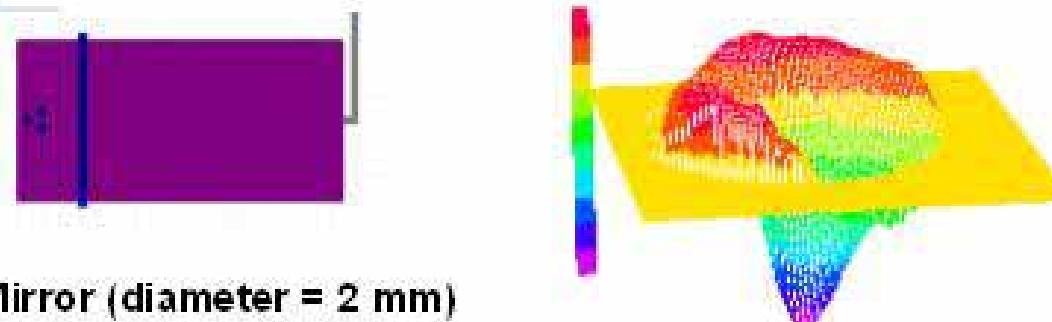
3- IR image after bonding



4- Deformable Mirror with 19 actuators  
Device on the Print Circuit Board

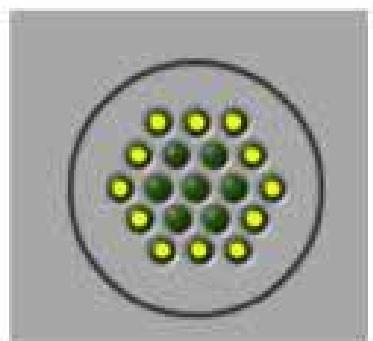
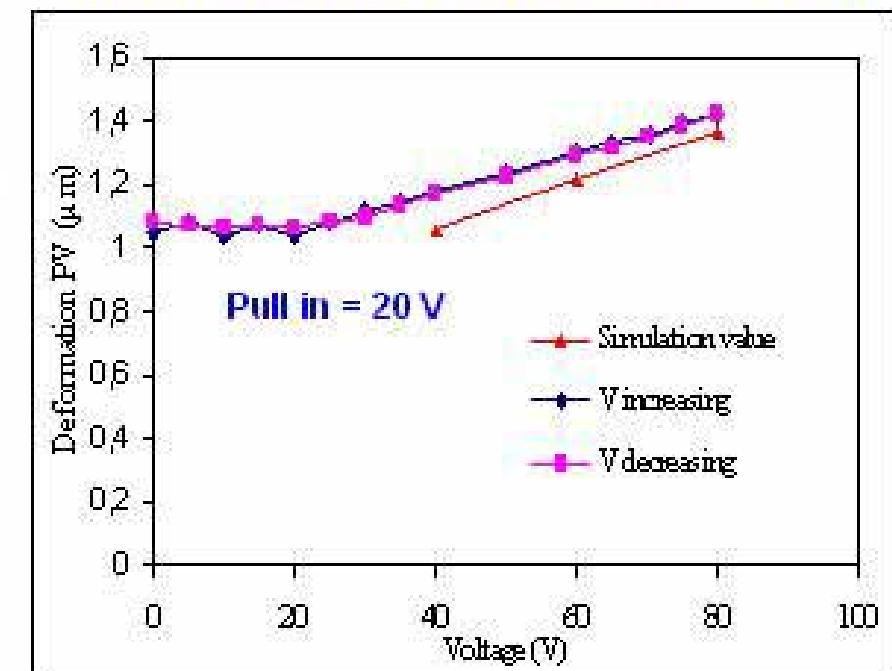
# Optical Characterization of devices

- Optical wave front measurements realized with **Shack-Hartmann Wave Front Sensor**



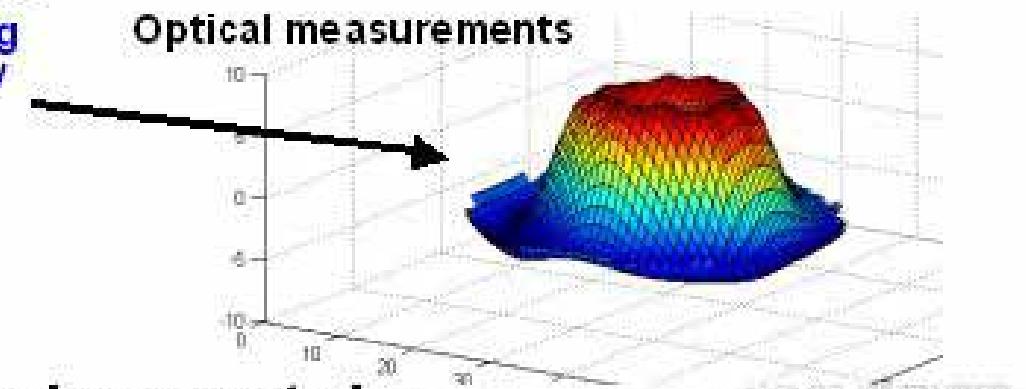
**Relative optical deformation = 0.8  $\mu\text{m}$  at 80 V**

- Linear Deformation of Membrane
- V cycle → No hysteresis => No charges trapped



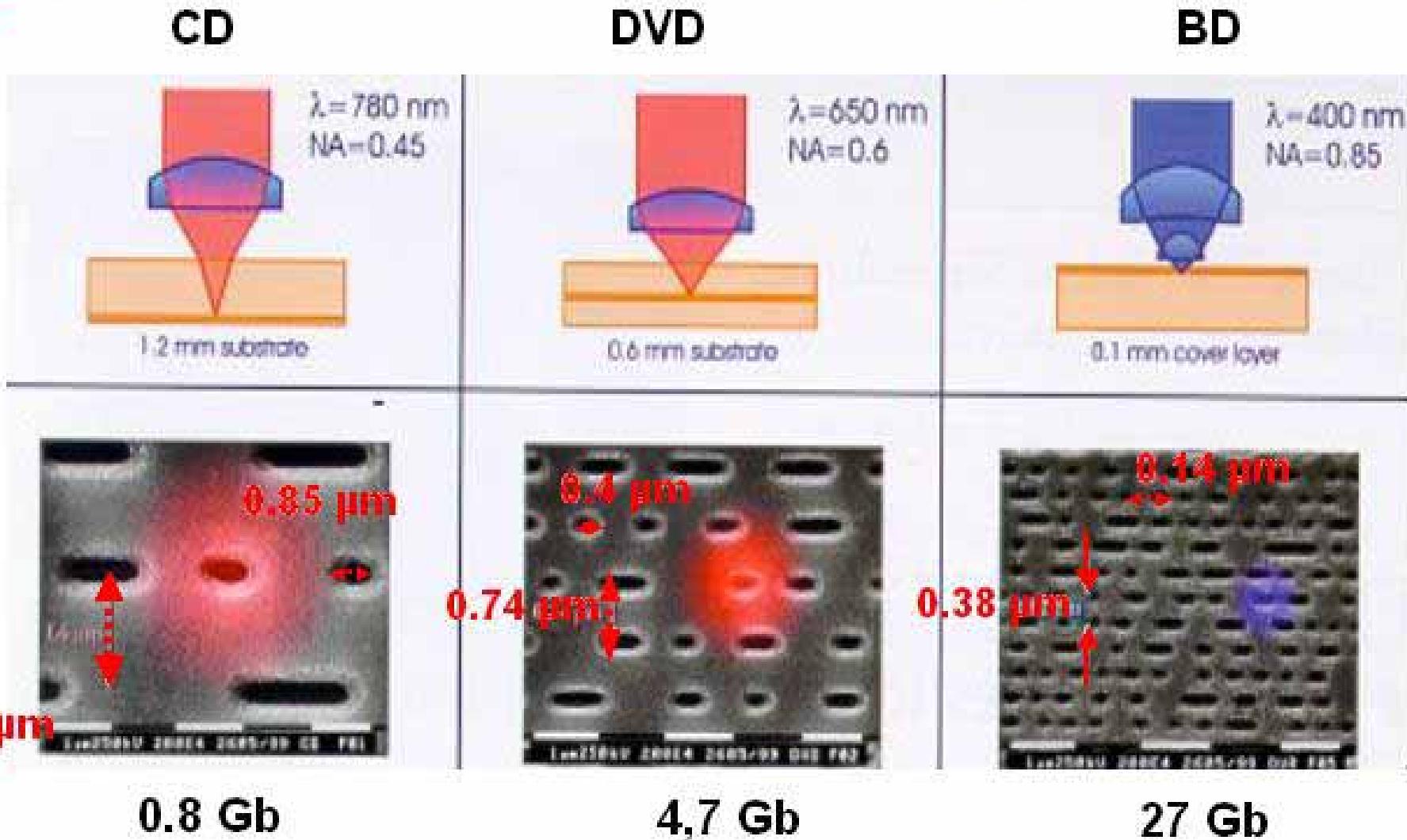
- Optical wavefront deformation obtained from a deformable mirror with 19 actuators: only 12 pulling electrodes are actuated with 60V
- Mechanical displacement of about 4.5  $\mu\text{m}$  (half of the chart values) is measured

**PV ( $\mu\text{m}$ ) Mechanical Deformation membrane vs Voltage**



**Complex wave front deformations can be corrected**

# DM for Optical data storage application

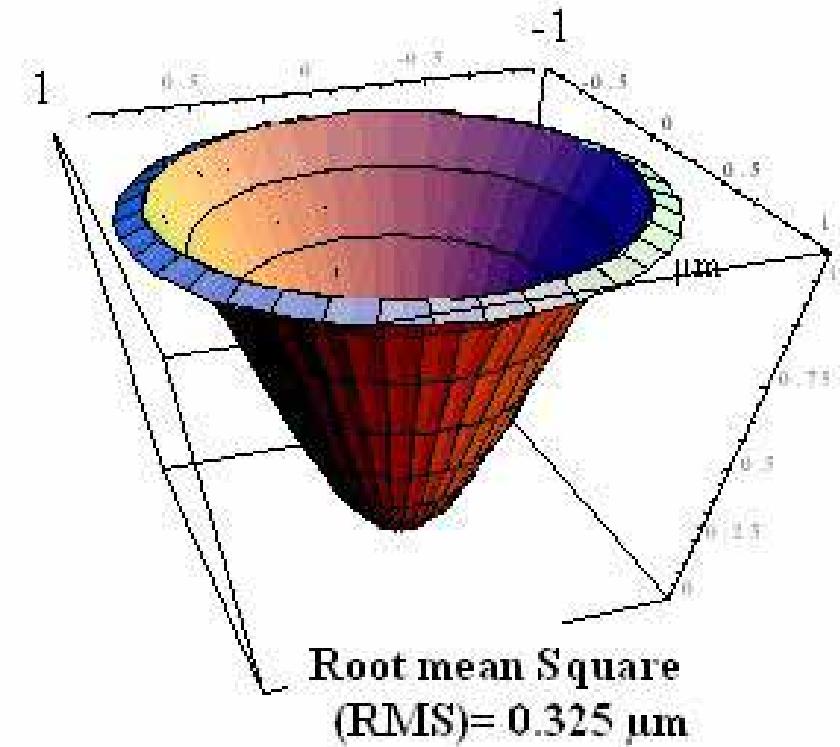
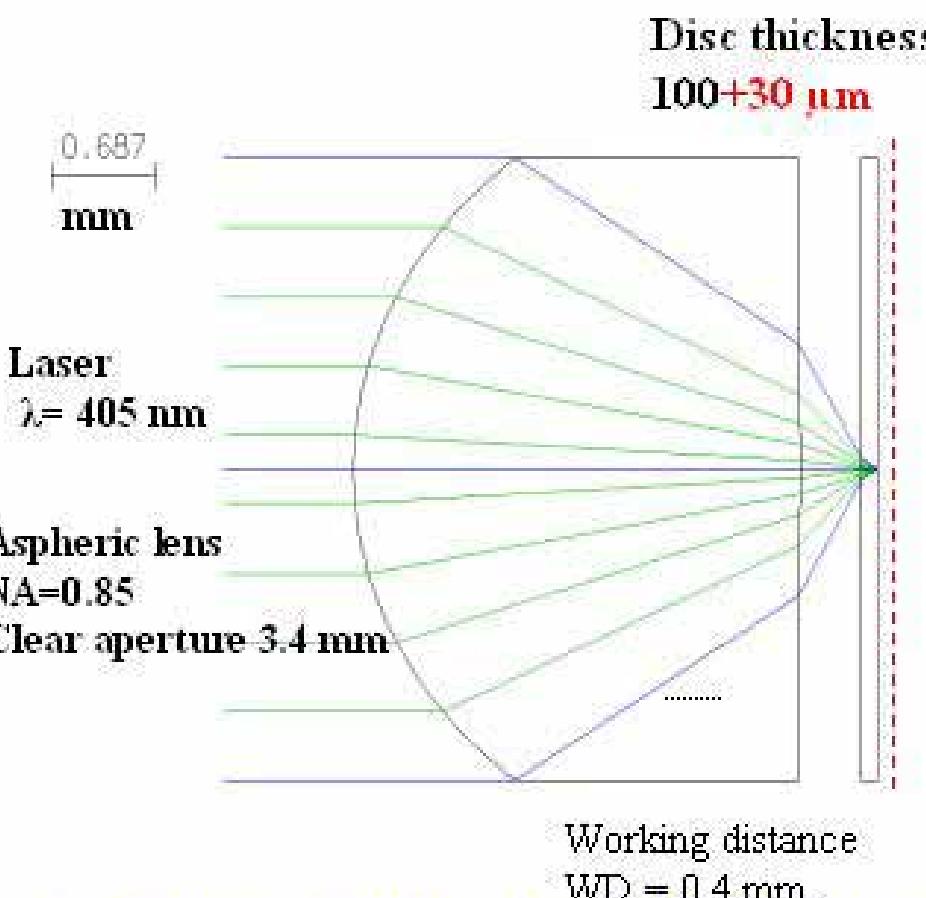


Storage density has to be increased,  $\lambda \downarrow$ ,  $\text{NA} \nearrow$ , using multi-layers

$$\text{Spherical Aberration} \approx \alpha \cdot \Delta t \cdot \text{NA}^4$$

# Aberrations to correct

Using Blue Ray Discs optical parameters aberration induced by the change of writing layers separated by  $30 \mu\text{m}$ , equivalent to a disc thickness defect of  $30 \mu\text{m}$  was calculated,



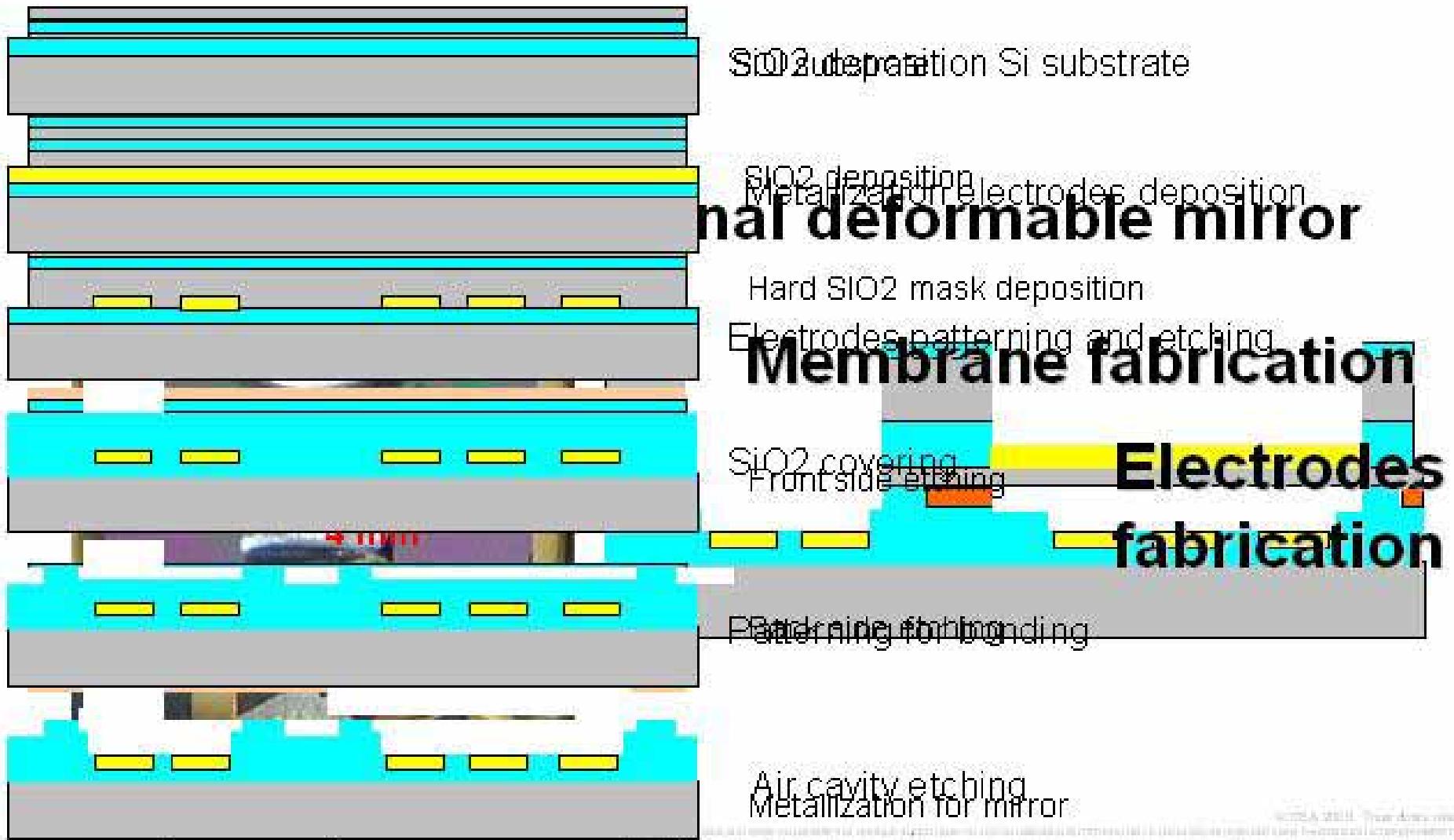
Optical wave front deformation  
Peak to valley (P-V) =  $1.05 \mu\text{m}$

Spot size on disc =  $4.7 \mu\text{m}$   
compared to  $0.290 \mu\text{m}$  needed !

# Mirror fabrication

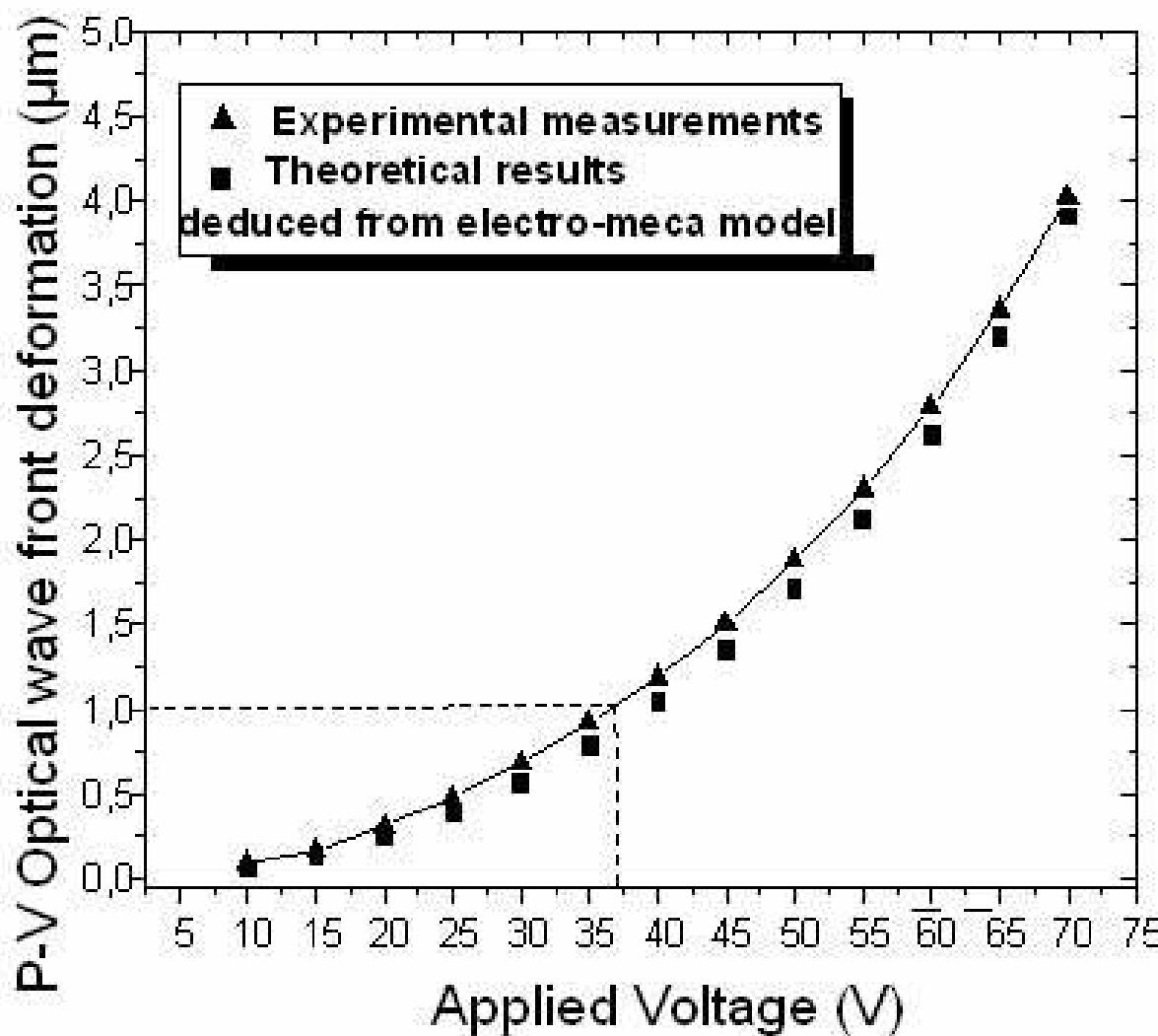
To cope with mass-production of optical drives, standard silicon micromachining technology was used to realize a deformable mirror with a basic conception with electrostatic actuation (3 concentric electrodes)

Two components: membrane and electrodes



# Mirror characterization

PV optical wave front deformation with the 3 concentric electrodes under the same voltage was measured

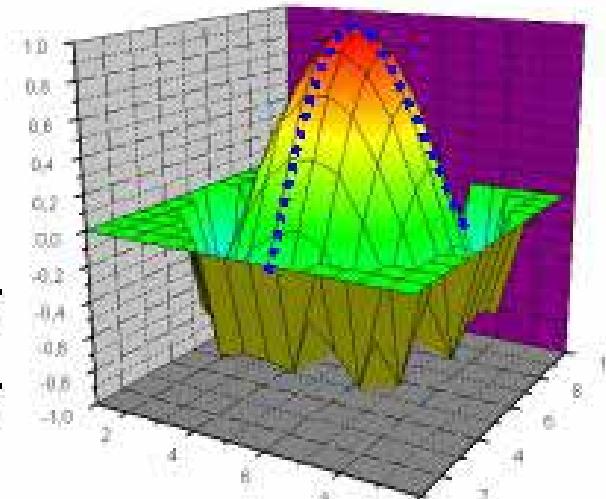
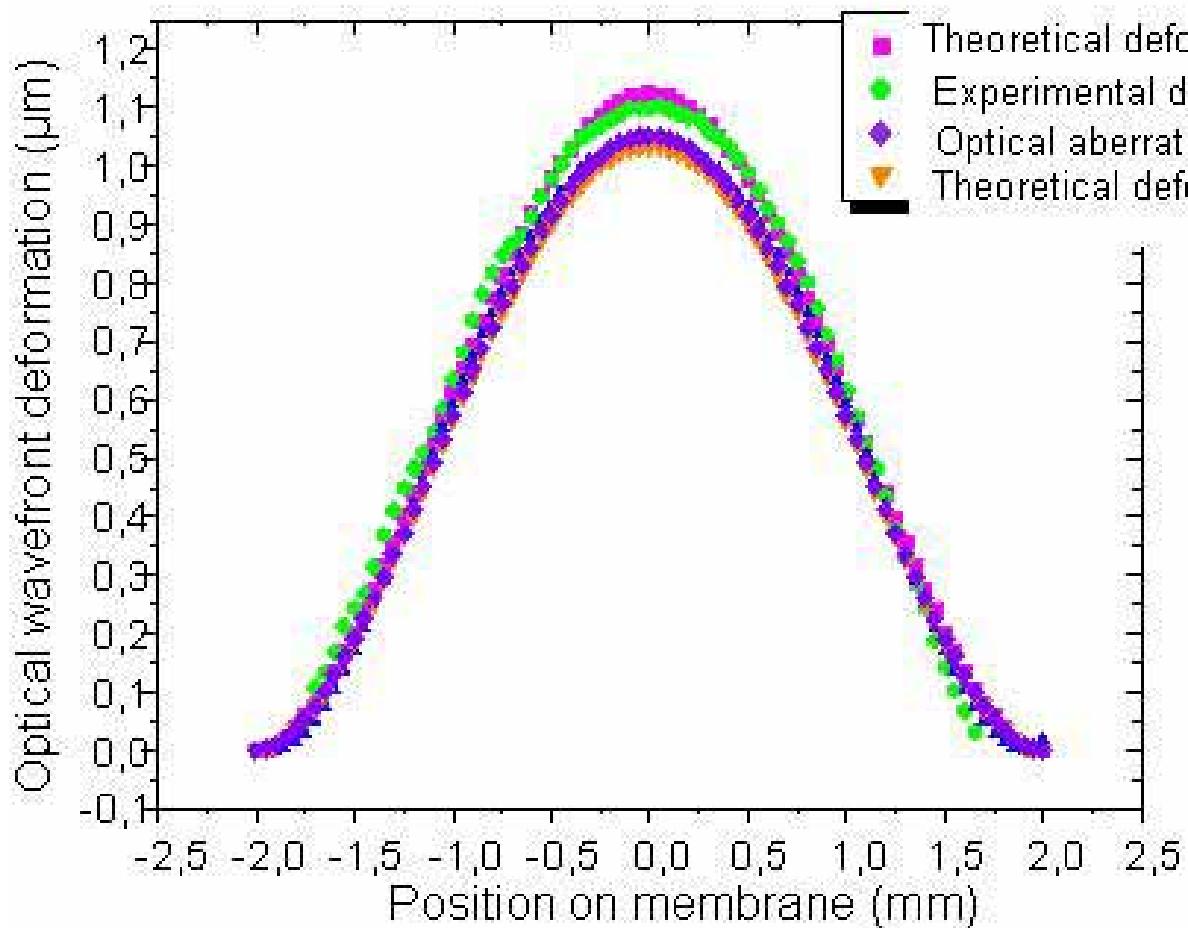


- Measurements fit very well with theoretical predictions
- Optical deformation as important as 4.5 μm can be reached with applied voltage lower than 75 V.
- Only 37 V for a 0.5 μm membrane displacement (specification to correct aberrations)

This makes the demonstrator easy to integrate in a final optical drive.

# Shape of Wave front deformation analysis

The 3 concentric electrodes under the same voltage



(1) electromechanical modeling and experimental measurements fit very well for 40 V

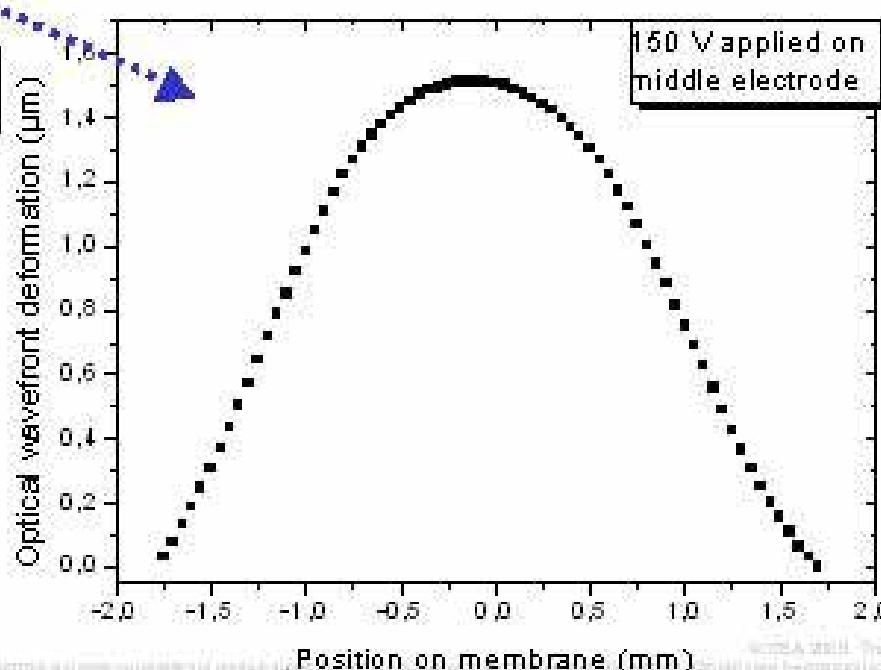
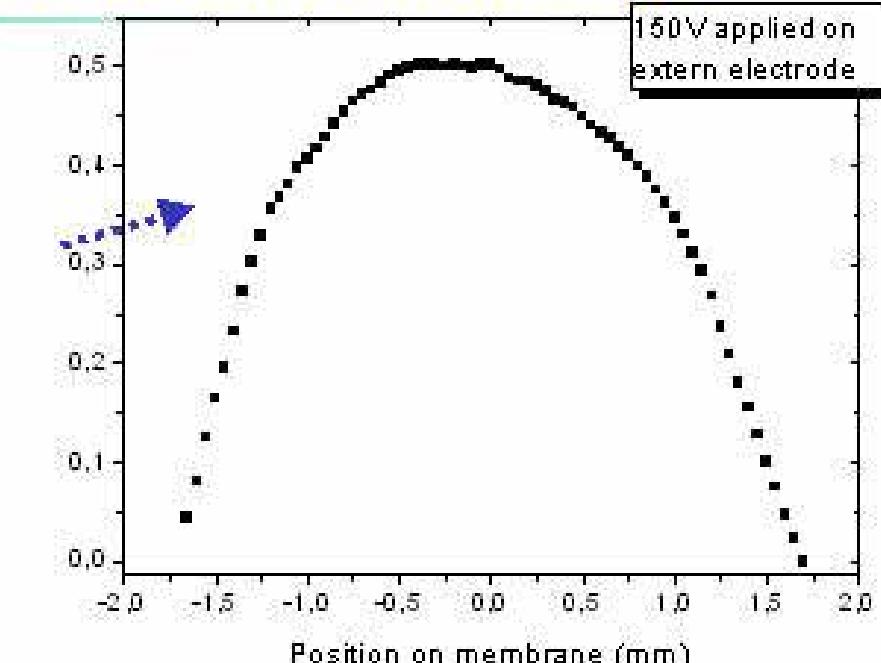
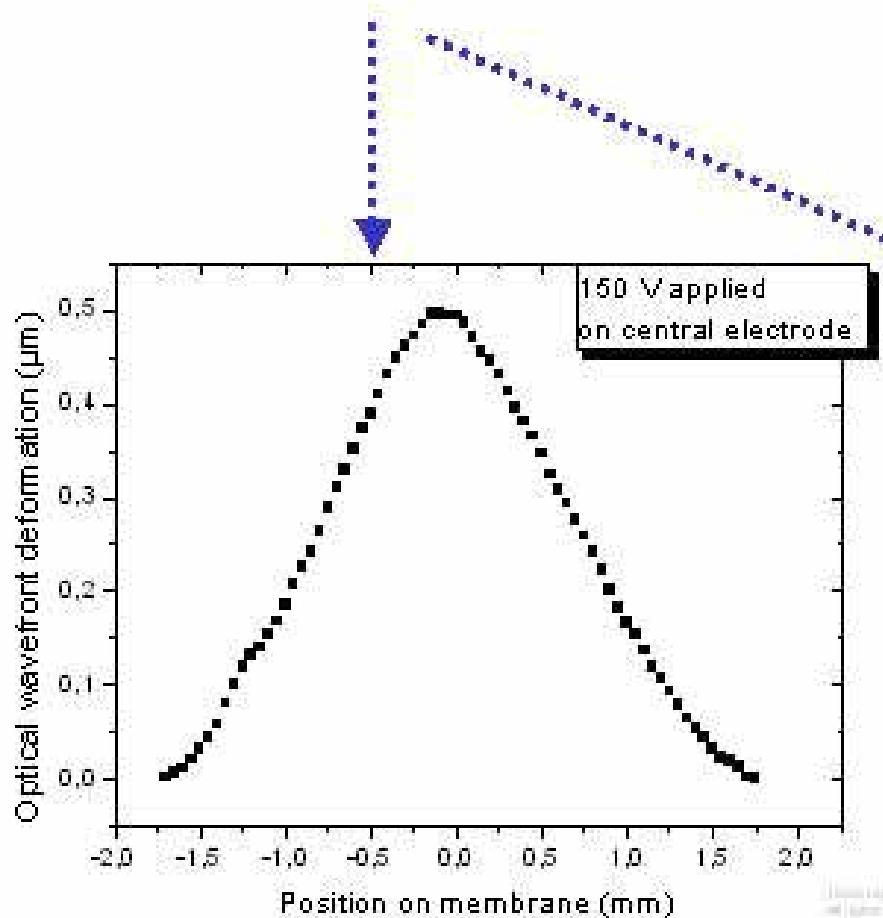
Validation of model

(2) Aberration to correct totally fits with theoretical deformation calculated with 38.8 V

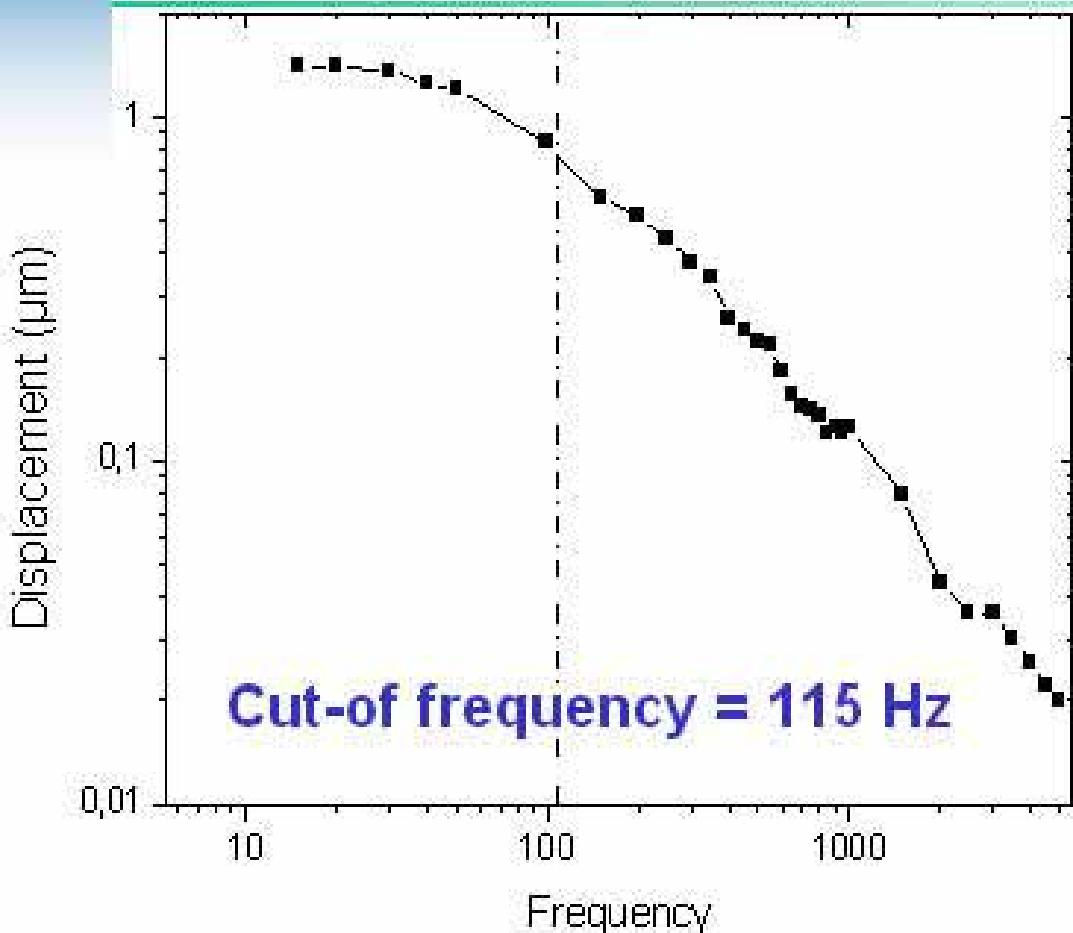
Demonstrate the potential of this deformable mirror for next optical drives

# Wave front deformation control

The membrane deformation shape can be accurately controlled by choosing the driving electrode



# Dynamic behavior under operation

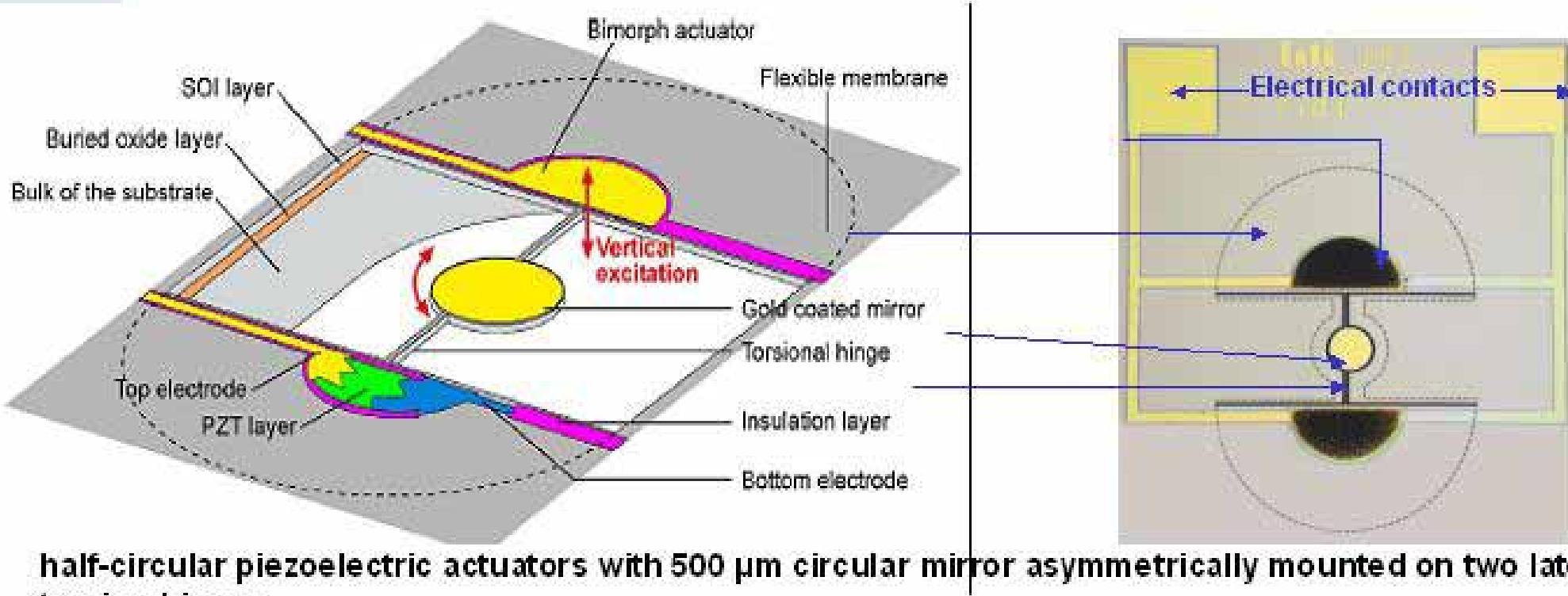


No frequencies of resonance observed, due to air damping

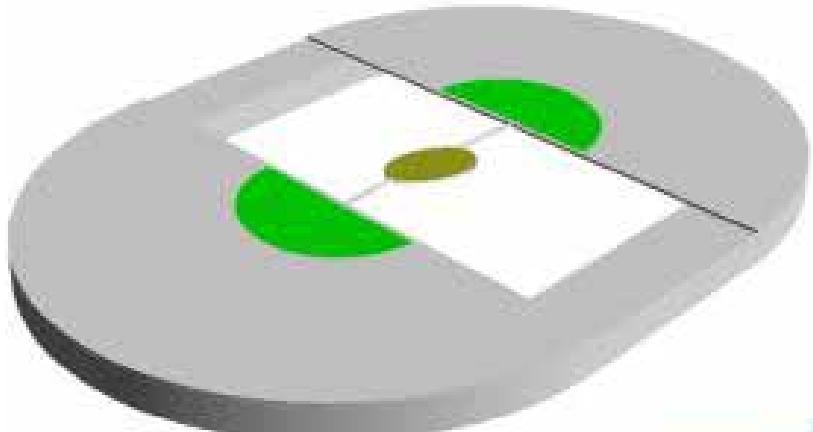
A cheap deformable mirror based on a simple design, realized in standard semiconductor technology to correct spherical aberration in optical drives for data storage has been demonstrated. Results of opto-mechanical characterizations of prototype fit with drive specifications.

# DM for optical scanner

## Micro-mirrors with piezoelectric bimorph actuators

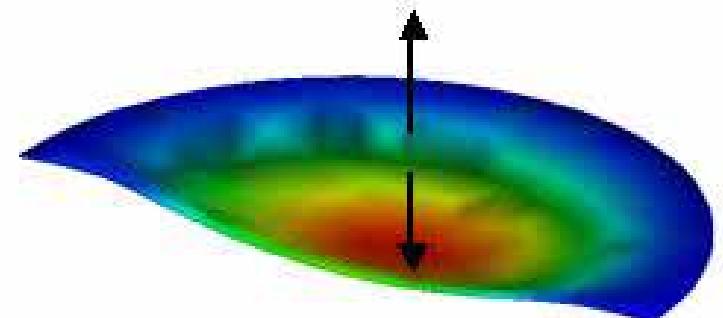


half-circular piezoelectric actuators with 500 µm circular mirror asymmetrically mounted on two lateral torsion hinges



The center of mass of the mirror is 50 µm off axis of torsion arms, by this way the vertical translation excitation is converted into a rotational oscillatory movement of the mirror

Applying voltage on bimorph actuator



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## SOI Substrate

- 20  $\mu\text{m}$  Si thickness

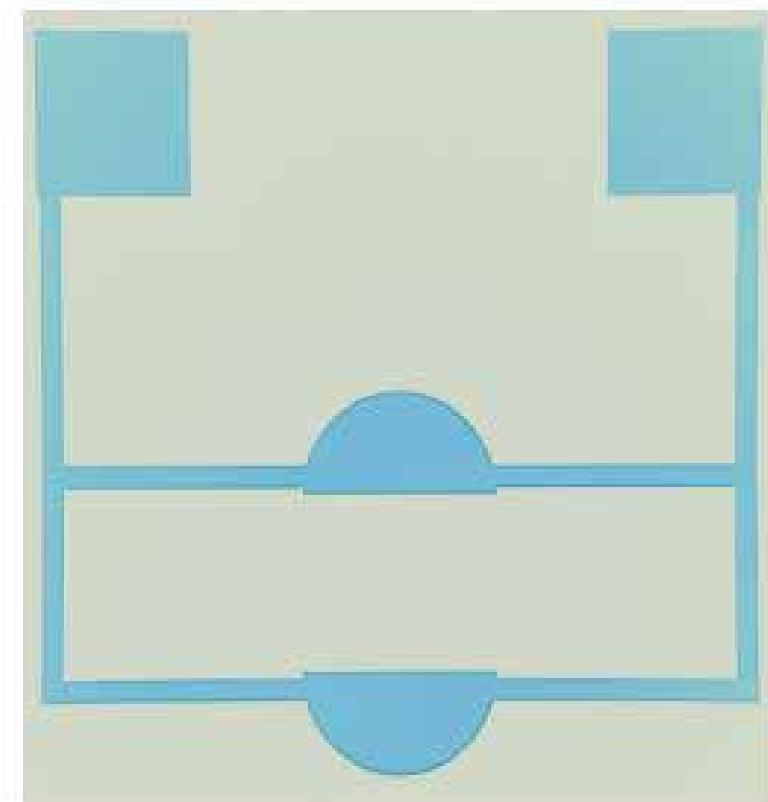


- Silicon
- Silica

## Oxidation



- Silicon
- Silica

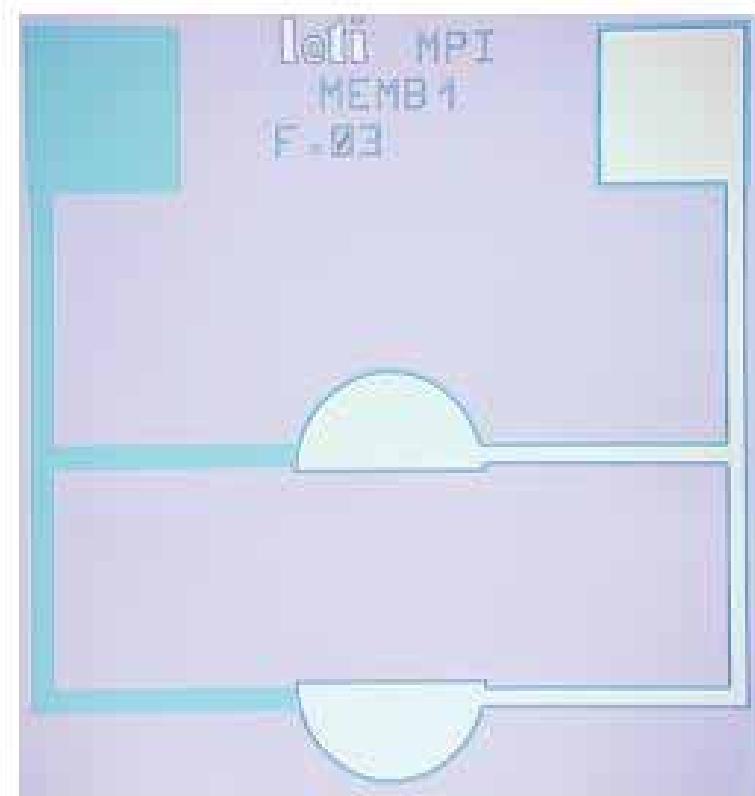


# Fabrication of the DM

Lower electrode deposited and structured

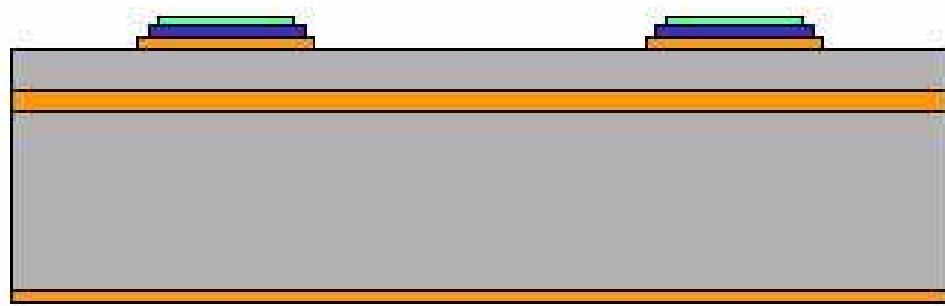


- Silicon
- Lower electrode (Ti/Pt)
- Silica

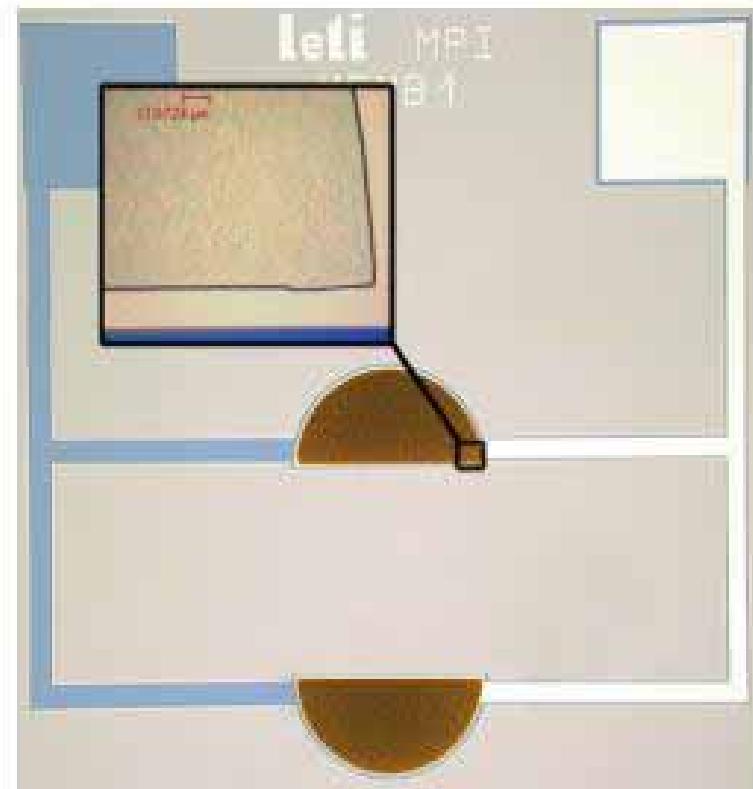


# Fabrication of the DM

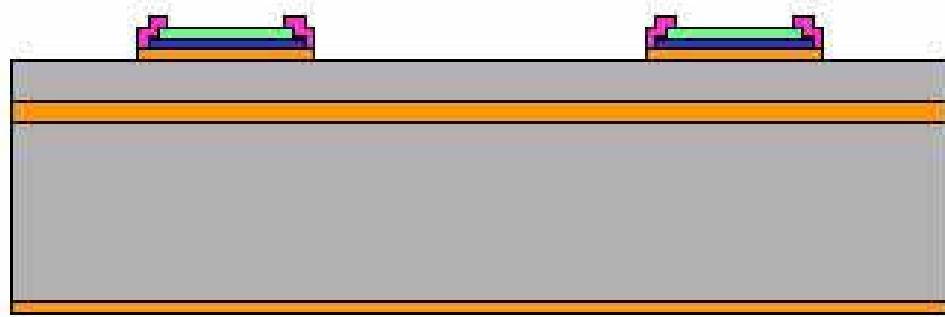
Piezoelectric PZT deposited and structured



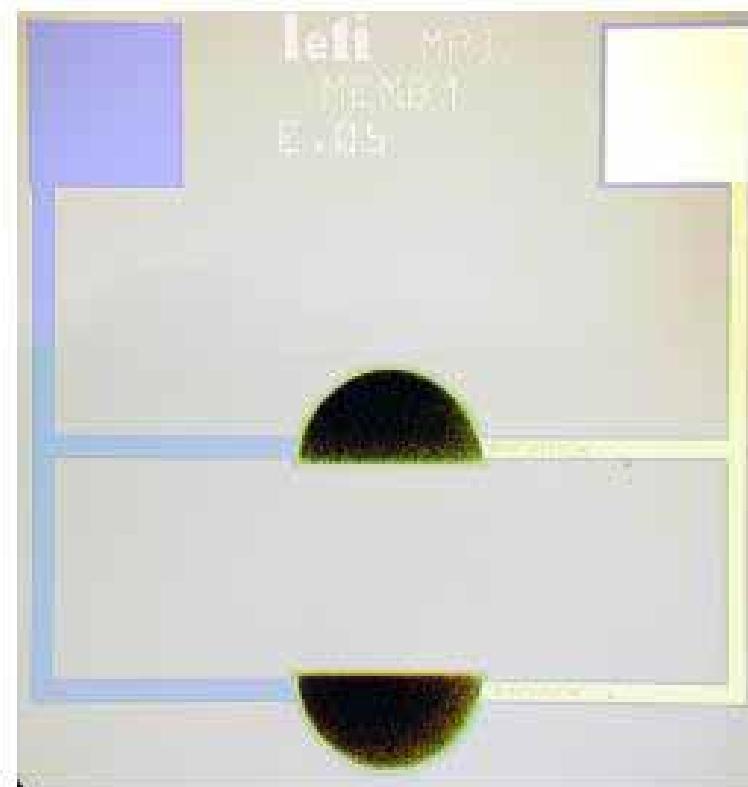
- Silicon
- Lower electrode (Ti/Pt)
- Silica
- PZT



## Inter-electrodes insulating layer deposited

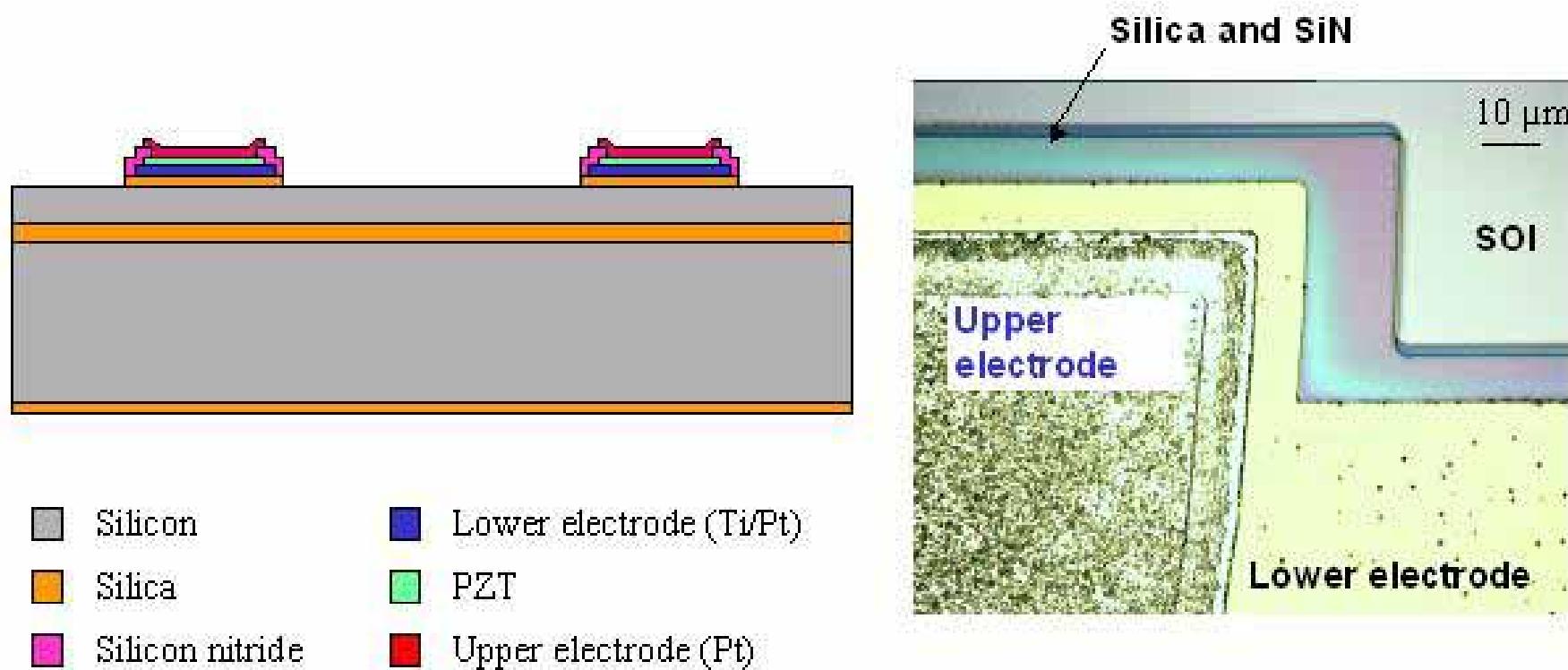


- |                   |                           |
|-------------------|---------------------------|
| ■ Silicon         | ■ Lower electrode (Ti/Pt) |
| ■ Silica          | ■ PZT                     |
| ■ Silicon nitride |                           |



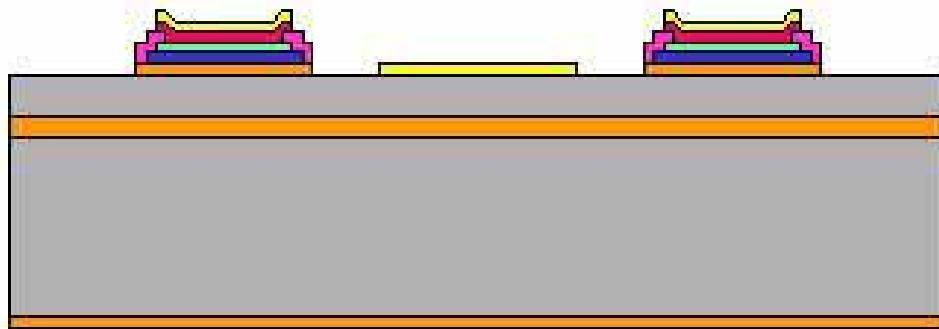
# Fabrication of the DM

The Upper electrode deposited and structured

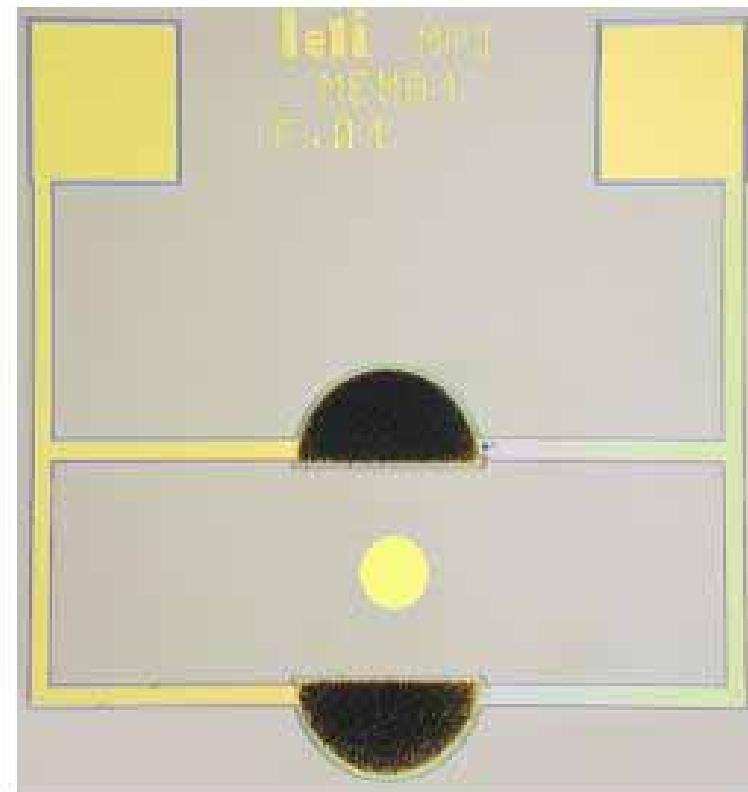


# Fabrication of the DM

Reflective coating on mirror and electrical tracks deposited

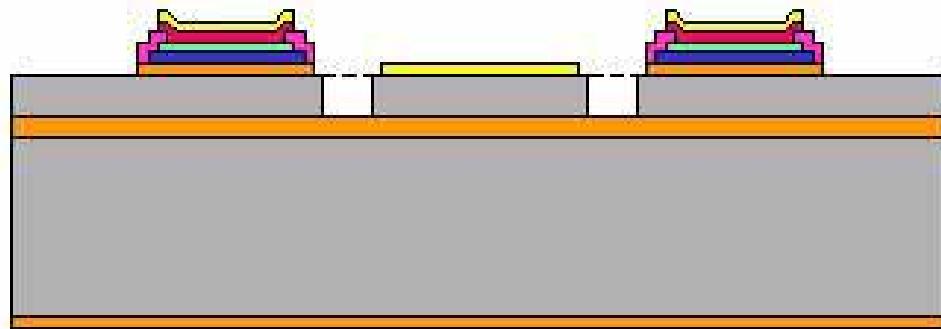


- |  |                           |
|--|---------------------------|
| ■ Silicon  | ■ Lower electrode (Ti/Pt) |
| ■ Silica   | ■ PZT                     |
| ■ Silicon nitride                                    | ■ Upper electrode (Pt)    |
| ■ Electrical tracks and<br>reflective mirror (Ti/Au) |                           |

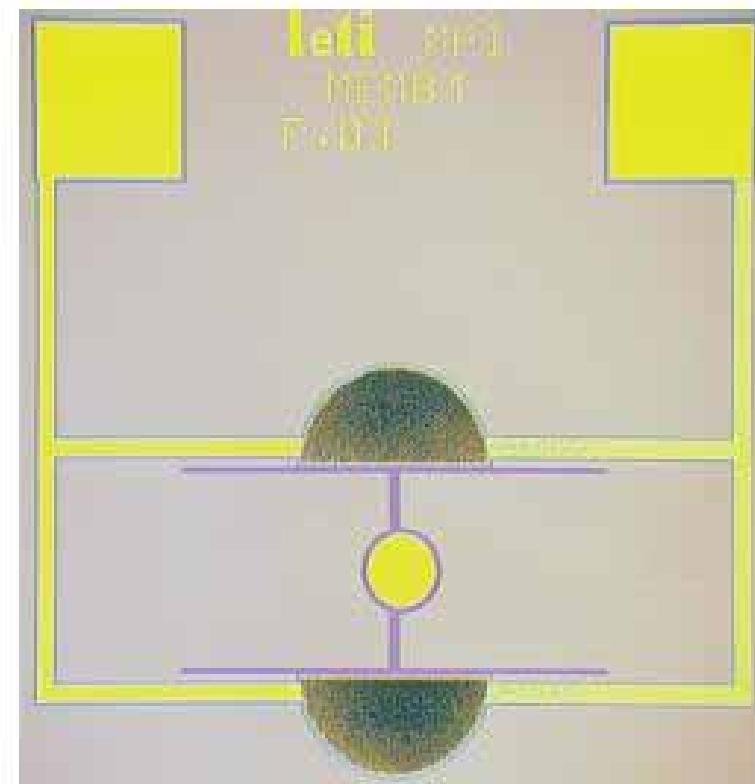


# Fabrication of the DM

Mechanical parts: tensional hinges and mirror are structured on SOI

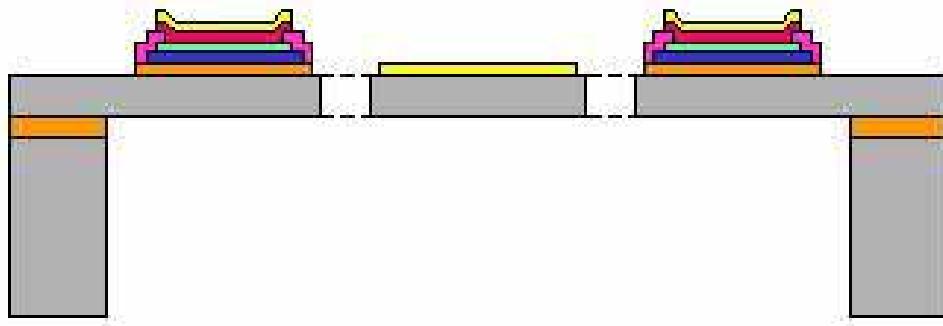


- Silicon
- Lower electrode (Ti/Pt)
- Silica
- PZT
- Silicon nitride
- Upper electrode (Pt)
- Electrical tracks and reflective mirror (Ti/Au)

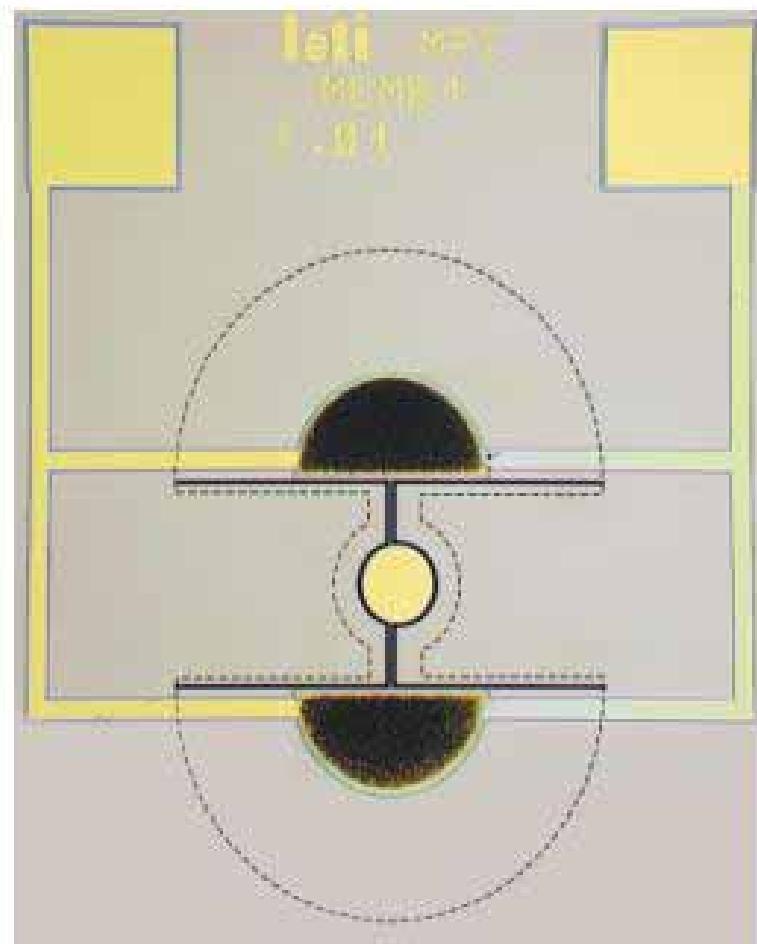


# Fabrication of the DM

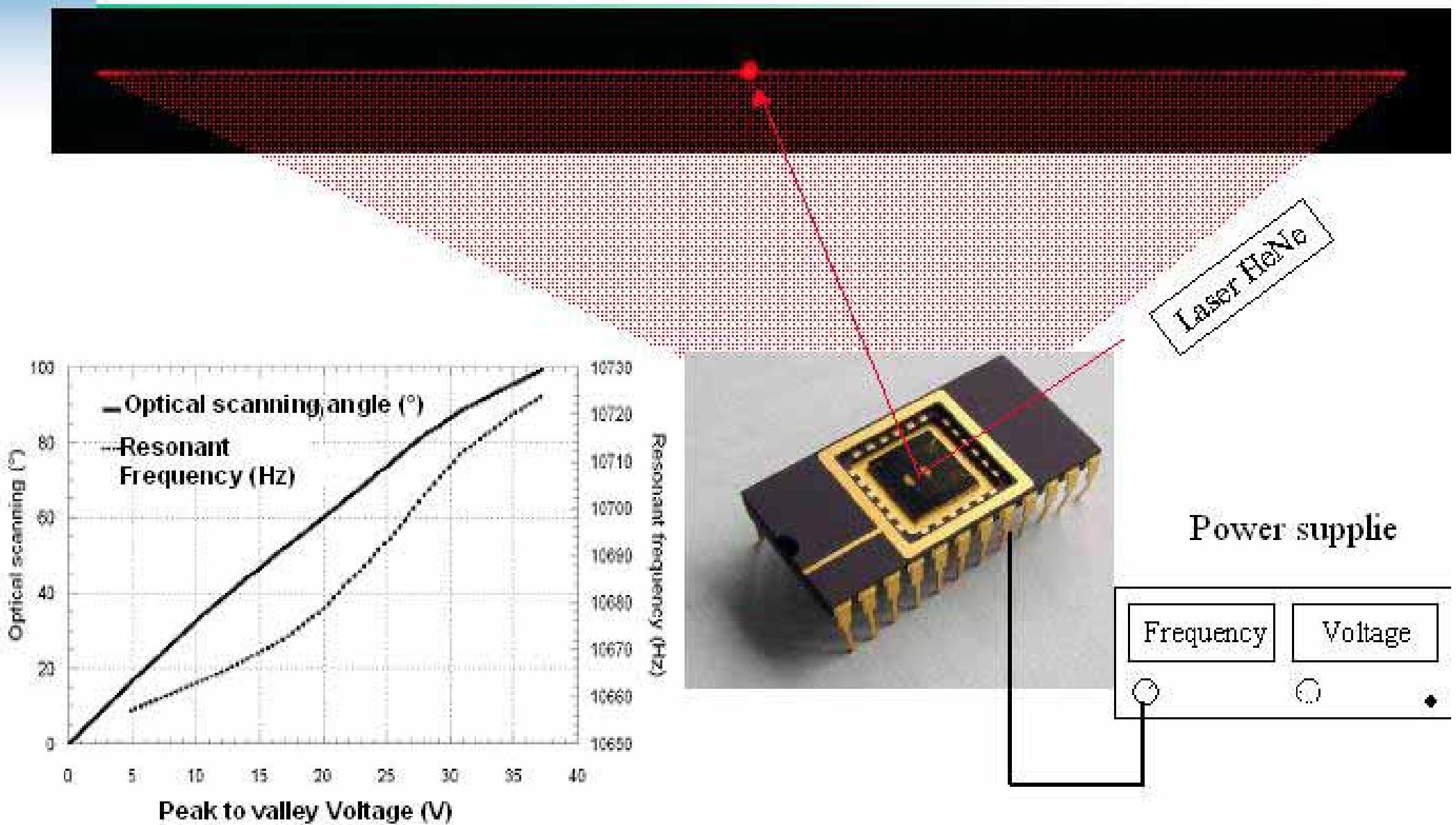
## Final process step: Mechanical structures releasing



- Silicon
- Lower electrode (Ti/Pt)
- Silica
- PZT
- Silicon nitride
- Upper electrode (Pt)
- Electrical tracks and reflective mirror (Ti/Au)



# Characterization of the DM



**Very promising result: Optical scanning amplitude 99.1° for 37.2 Vpp at 10.6 KHz**

- ✓ Three deformable working mirrors realized at CEA-LETI for different applications were presented:
  - Astrophysics, ophthalmology,
  - Data storage
  - Optical scanning for displays
- ✓ The current transfer of MEMS foundry from 4 to 8 inches substrate at LETI should enhance MOEMS technological fabrication and therefore improve devices specifications.
- ✓ LETI is now ready to develop special MEMS or MOEMS for displays applications.



MICRO AND NANOTECHNOLOGY  MICROELECTRONICS 

Thank you for your attention!