Hybrid Microfabricated Mirrors for Space Applications

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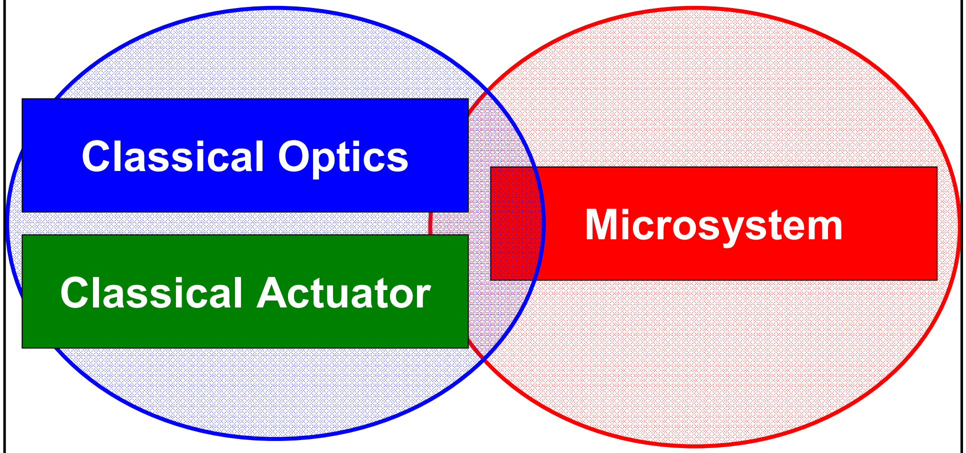
Motivation

- 60 mW GaAlAs laser transmitter
- Photodiode detector, with a 25 cm telescope aperture
- Weight: 160 kg

Artemis satellite, ESA
Oiptical / Laser link for inter-satellite communication

Hybrid ??? … Micromirror

- **What is *hybrid* … ??**



Hybrid ??? … Micromirror

- **What is *hybrid* … ??**

Classical Optics

Microsystem

Classical Actuator

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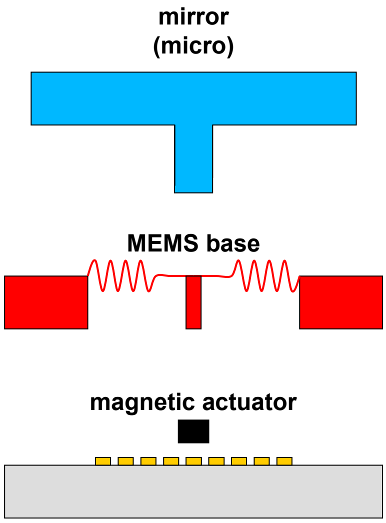

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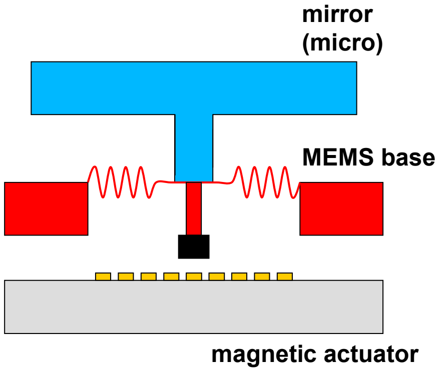
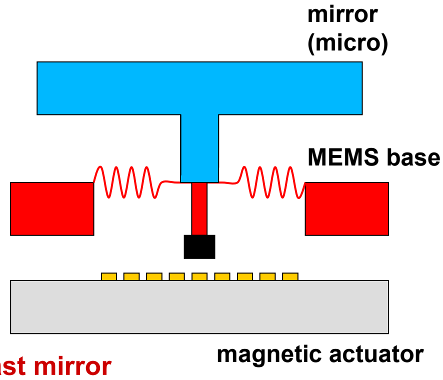


Why Hybrid? Advantages?

- **Mirror**
  - **Very flat**
  - **Optimized coatings**
- **MEMS Base**
  - **High thermal heat conductance**
  - **Very flexible**
  - **Very reliable**
- **Magnetic Actuator**
  - **High force → stiffer springs → fast mirror**
  - **Very linear, no snap-in**



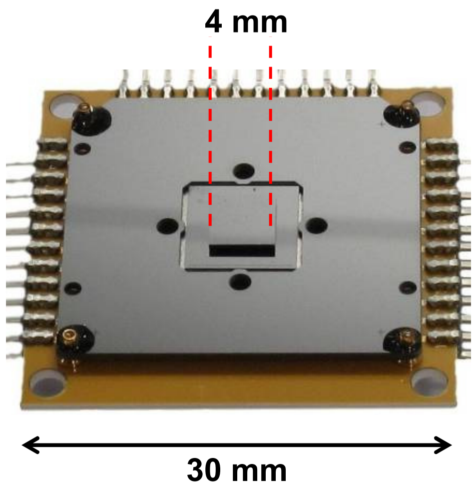
Fabricated Hybrid Micromirror

- **Three main components**

Classical Optics

Microsystem

Classical Actuator



Fabricated Hybrid Micromirror

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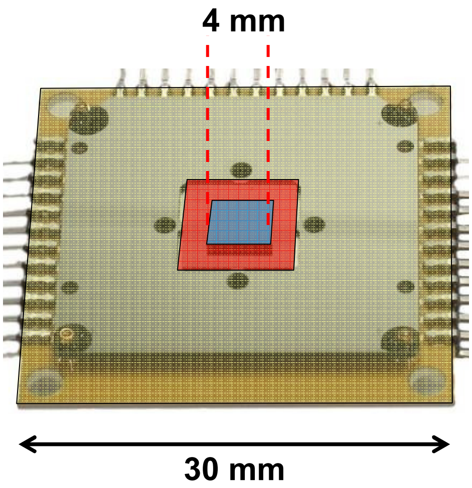
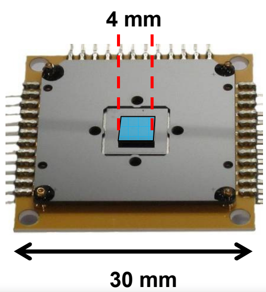
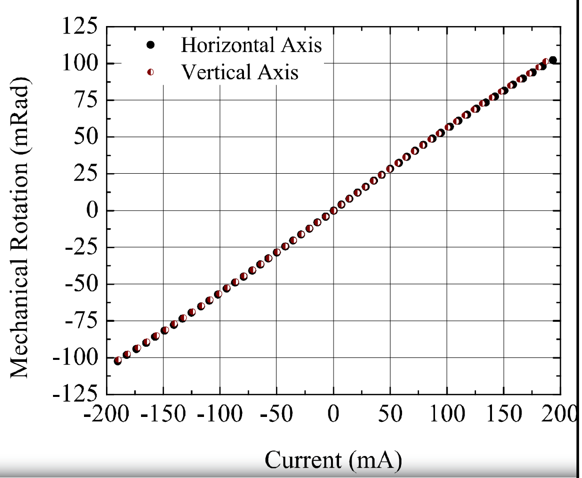


Hybrid Magnetic Mirror

- Well performing hybrid system ....
  - Mirror size: 4x4 mm²
  - Tilt angle: ±10°
  - Resonance freq. ~100Hz
  - Thermal load: ~1 kW/m²
    (not optical load)

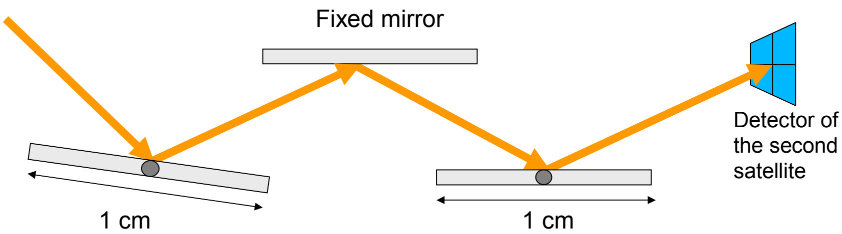




Motivation

- **Applications**
  - **Intersat. Communication**
  - **LIDAR**
  - **…**
- **ESA Requirements**
  - **Large Mirror: 1 cm**
  - **Fast: > 1 kHz**
  - **Precise**
  - **Shock resistant**
  - **…**

Concept

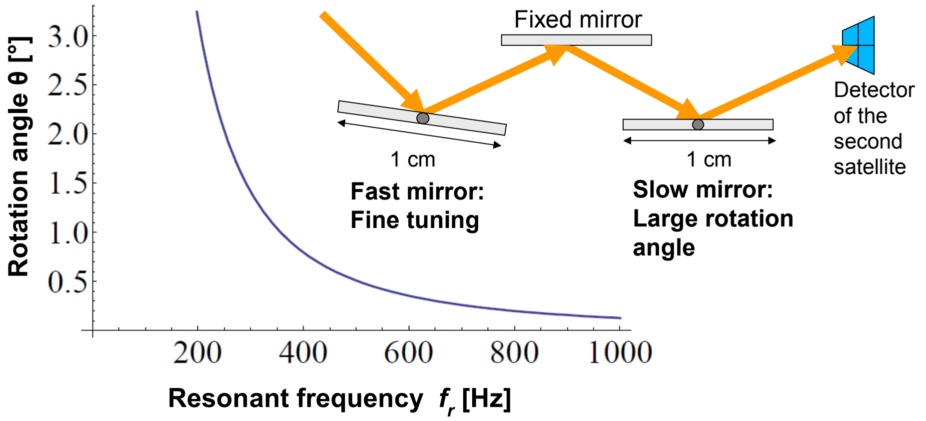


Fast mirror
Electrostatically actuated
f_r = 1 kHz
θ_{mech}= ±0.2° mechanical

Slow mirror
Magnetically actuated
f_r = 150 Hz
θ_{mech}=±3.5° mechanical

- **Two mirrors that work synchronously to find and accurately fix the laser beam on the detector**

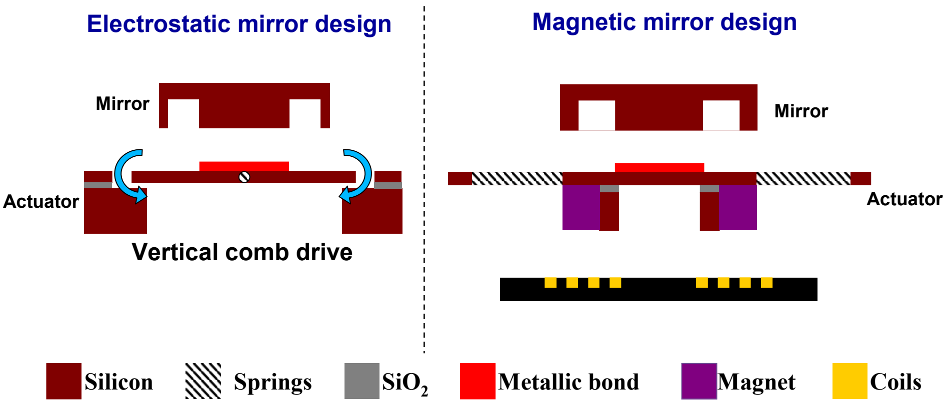
Why two mirrors?



- Resonant frequency is inversely related to angular displacement at any fixed force value

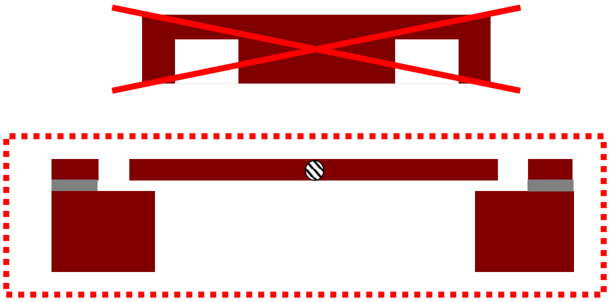
Design schematics

2 SOI wafers for each actuator



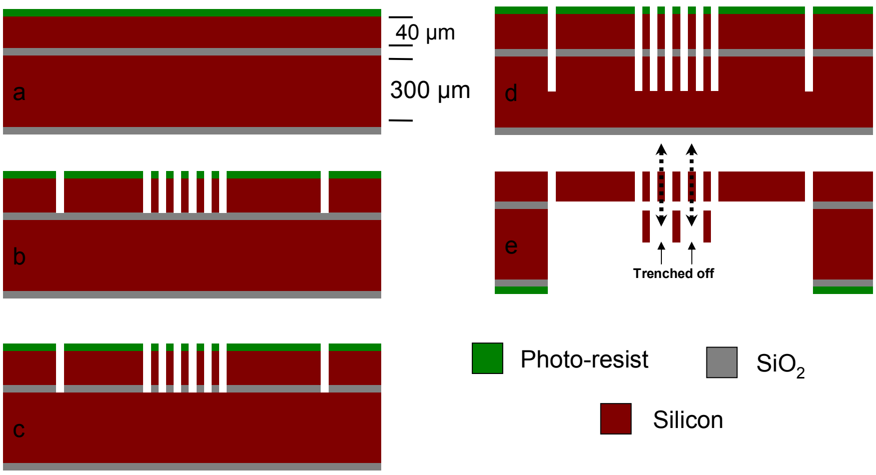
- Actuation platform and mirror fabricated out of 2 SOI wafers that are bonded together

Electrostatic test device



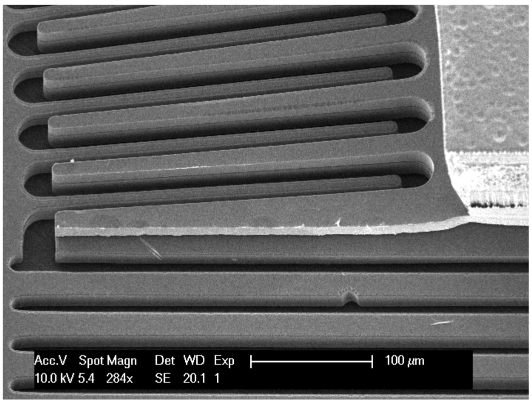
- Test device to evaluate micro-fabrication feasibility

Process flow of electrostatic test structure

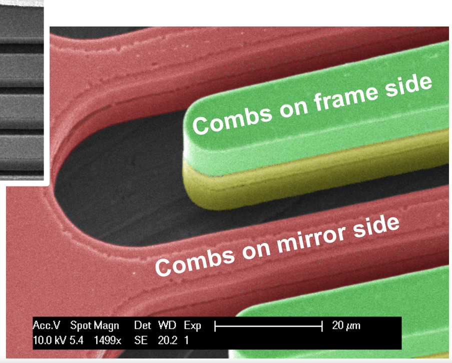


- Process flow to create a vertical comb actuator with completely self-aligned combs

Micro-fabrication results



back side of the electrostatic test structure



The height difference between the red and green parts permits the vertical movement

Resonant frequency of the test structure

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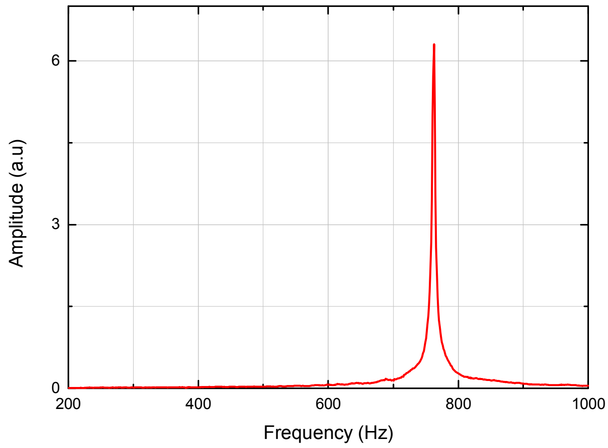


Q factor in air:

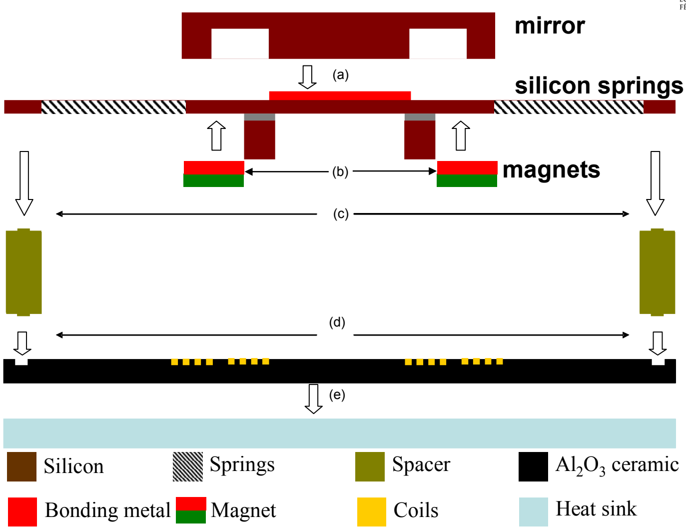
Q ≈ 20

first actuation mode: piston movement

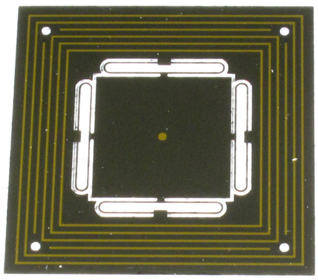
f = 760Hz

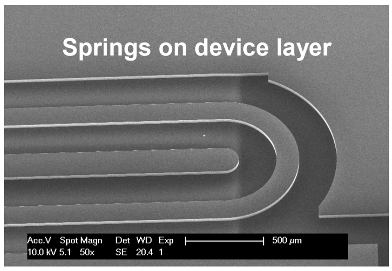
IMT – INSTITUT DE MICROTECHNIQUE – NEUCHÂTEL
MNT 2010 – ESA/ESTEC
Wilfried Noell, Dara Bayat
esa

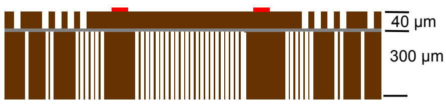
Magnetic mirror



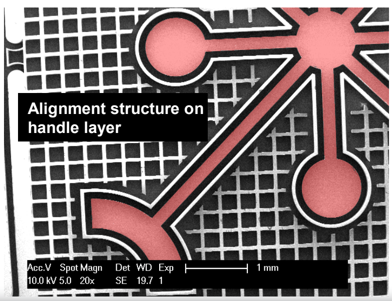
Actuation platform fabrication





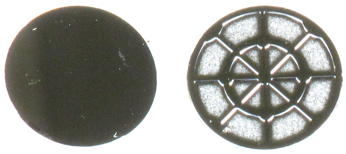


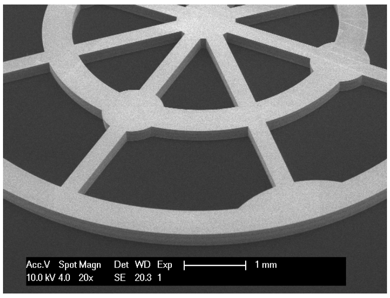
- Springs formed on SOI front side
- Alignment structures formed on SOI back side

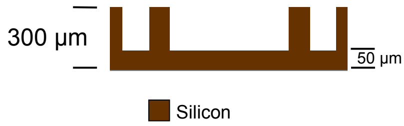


Mirror fabrication

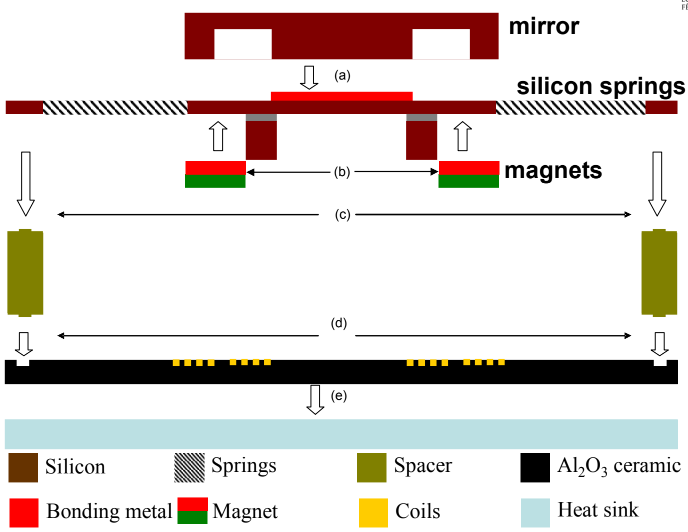
- **Handle layer of SOI wafer**
- **Hollowed out to reduce weight**





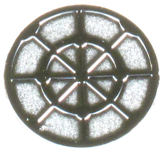


Eutectic bonding

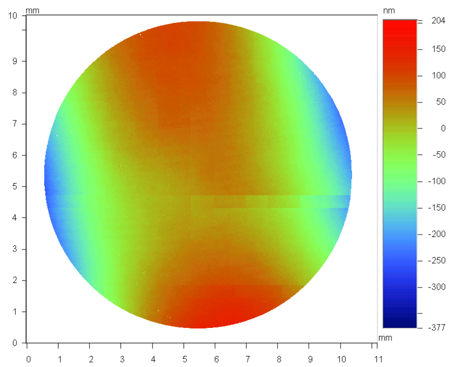


Mirror flatness vs. bonding profile

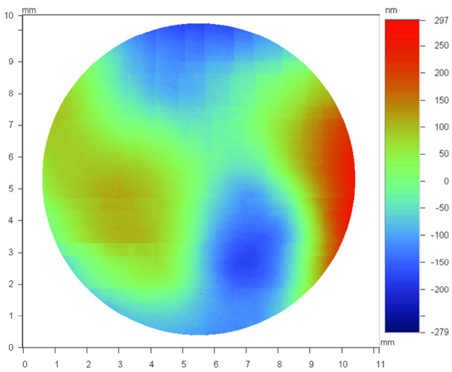
Mirror glued on the actuation platform at the center



Eutectic bonding with 5 bonding circles

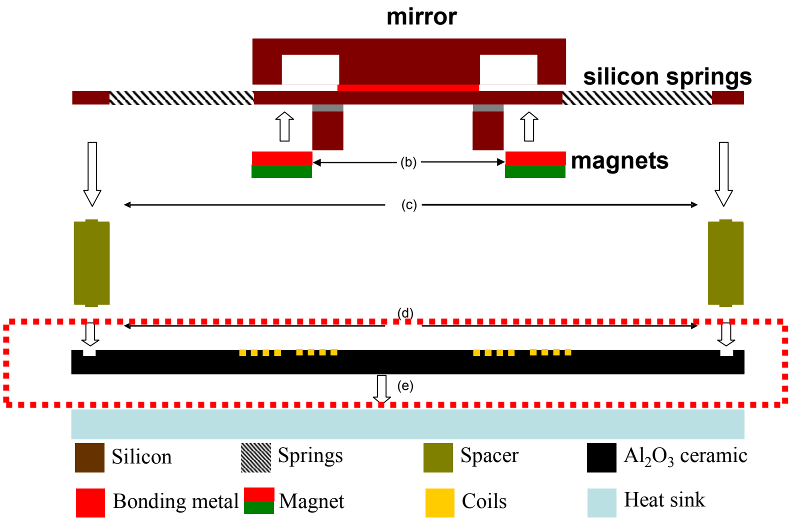


Rq = 81 nm

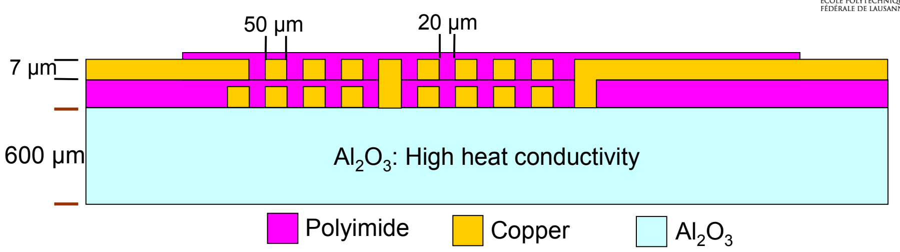


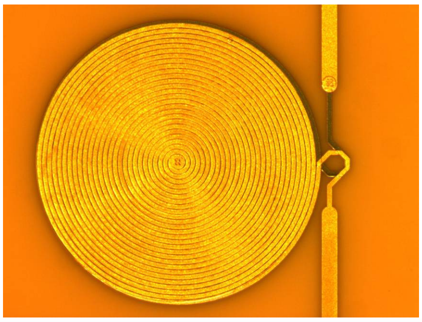
Rq =91 nm

Micro-fabricated coils



Micro-fabricated Coils





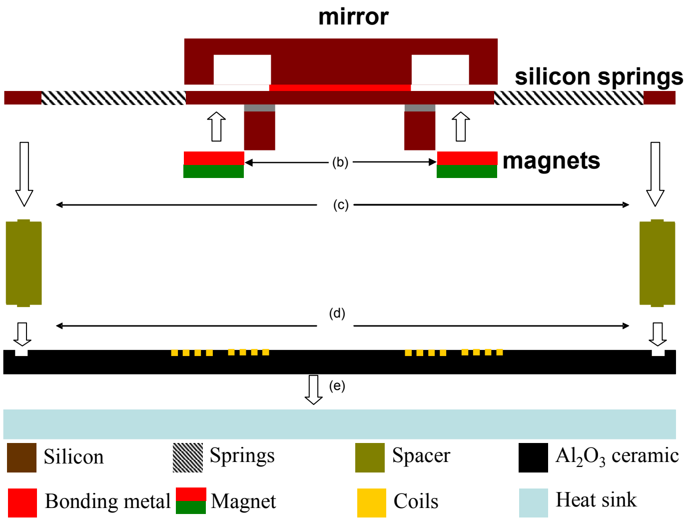
Injected current:

***I* = 500 mA**

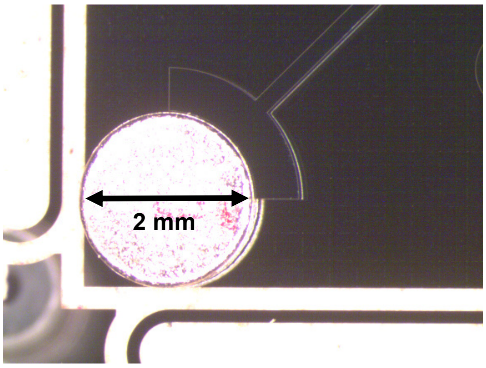
***J* = 1.4 X 10^9 [A/m^2]**

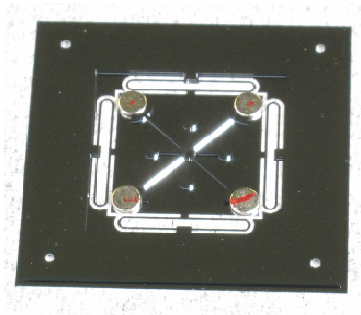
- Electroplated coils
- Fabricated by Hightec MC AG, Switzerland

Assembly



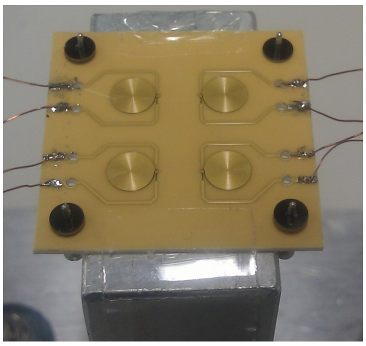
Magnet assembly

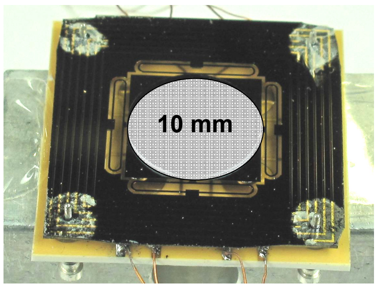




- Magnets are manually glued on the four corners
- Glue: Cyanolite compound (super glue)
  - Very low viscosity
  - Creates a very thin adhesion layer

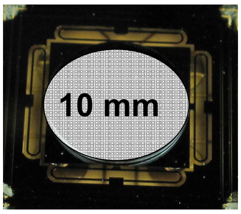
Coil-mirror assembly

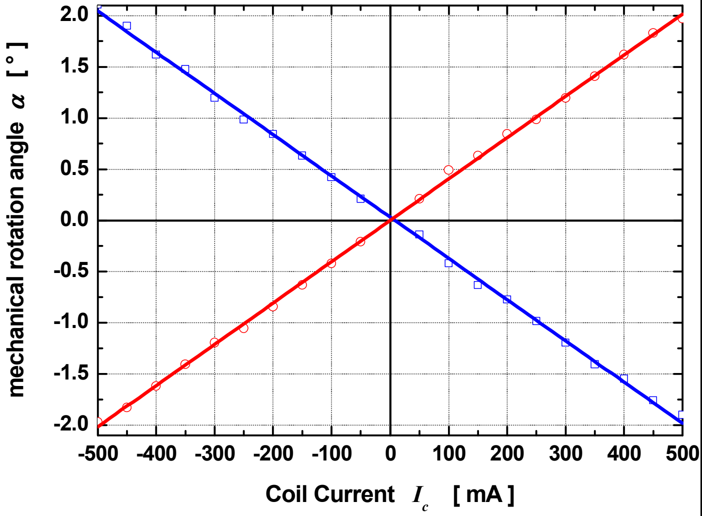




- The coils sit on an aluminum heat sink
- 4 pins are put in the four holes on the corners
- 4 silicon spacers (650 µm thick) are put on the pins

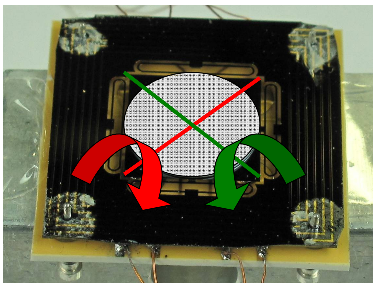
Tilt angle measurements

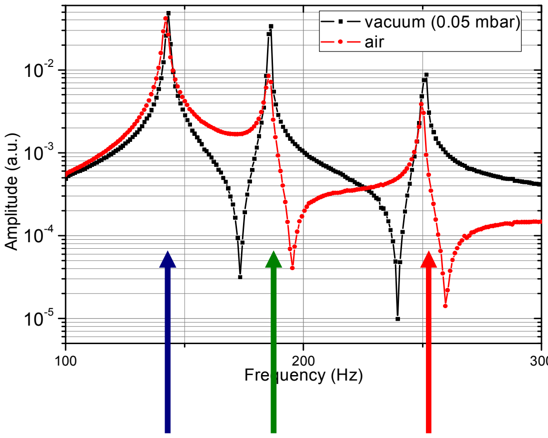




- **Symmetrical in the X and Y Axes**

Frequency response





- First mode:
  - Piston
  - $Q_{vacuum} = 71$
  - $Q_{air} = 45$
- Second & third modes:
  - Rotation along diagonals

Conclusion

- Concept of two tip-tilt mirrors for space applications were shown
- Micro-fabrication of an electrostatically actuated test structure was shown
- Micro-fabrication and preliminary results of an magnetically actuated mirror was shown

Future steps:

- Micro-fabrication of the electrostatic mirror
- Complete wafer level bonding of the magnetic structures
- Overcome the current and heat limits

Acknowledgment

EPFL

SAMLAB

CSEM

Division C / Microfabrication facility

ESTEC

European Space Agency

!!! Thank you for your attention !!!