Two-Axis MEMS Mirror For Precise Beam Steering Without Feedback

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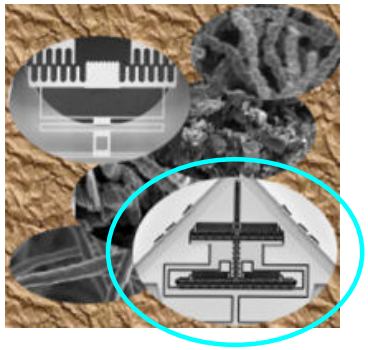
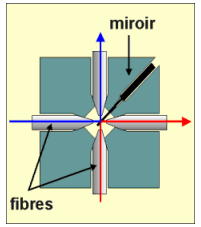
Microoptical switches for future telecommunication payloads without feedback



2x2 optical switch (OXC)

- ON/OFF switch
- → inherently no feedback required



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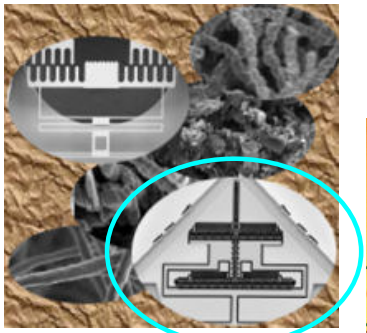

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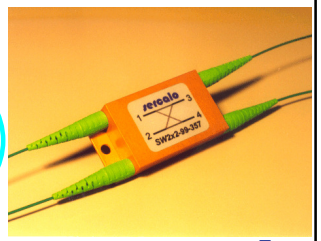

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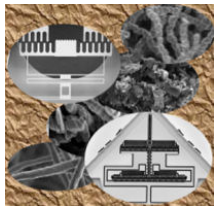

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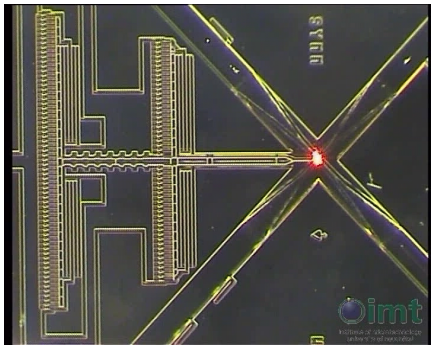

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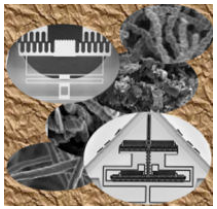
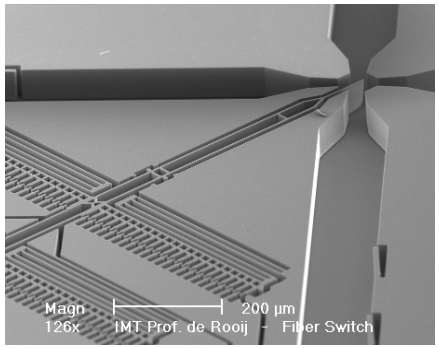




2x2 optical switch (OXC)

- ON/OFF switch

→ inherently no feedback required

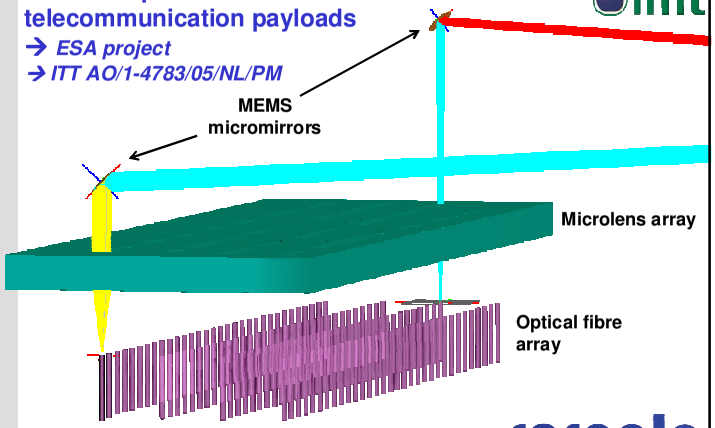
Future Telecommunication Payloads Need …

- … NEW FEATURES
  - Wavelength selective switching
  - High data rates
  - …
- … MID to HIGH PORT COUNTS
  - OPTICAL cross connects (OXC) → reconfigurable
- … to replace ELECTRICAL components …
  - with MICROOPTICAL and MEMS components

→ Less weight
→ High signal isolation
→ High reliability (no stiction, no friction, less drift over time, …)

3D Microoptical switches for future telecommunication payloads

→ *ESA project*
→ *ITT AO/1-4783/05/NL/PM*



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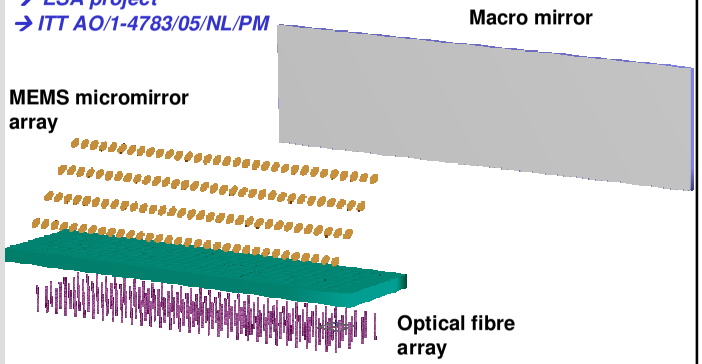
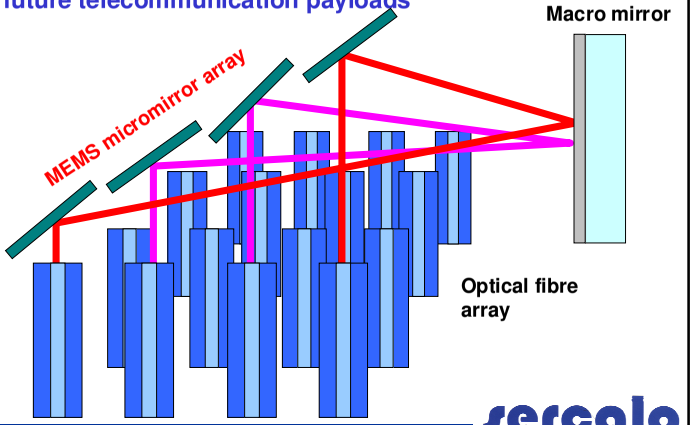


3D Microoptical MEMS switches for future telecommunication payloads

imt



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2-axis micromirror without feedback
6th ESA Round Table on Micro/Nano Technologies for Space 8.-12. Oct. 2007

3D Microoptical switches for future telecommunication payloads

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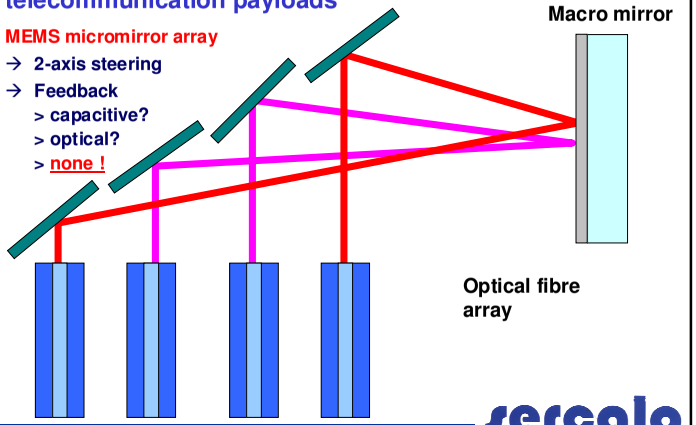

MEMS micromirror array
- → 2-axis steering
- → Feedback
  - > capacitive?
  - > optical?
  - > none !

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Competence in fiberoptic MEMS
Wilfried Noell (UniNE-IMT) / Peter Herbst (sercalo)

2-axis micromirror without feedback
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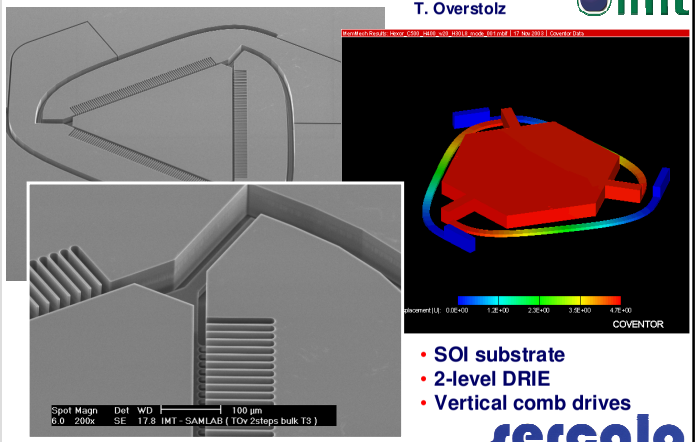
IMT & CSEM Micromirror

PhD Thesis
T. Overstolz

imt



- SOI substrate
- 2-level DRIE
- Vertical comb drives

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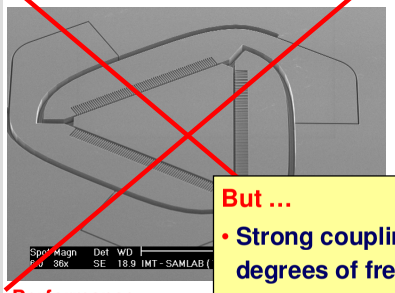
IMT & CSEM Micromirror

imt



Technology & Design:
- SOI substrate
- 2-level DRIE (delayed etch)
- Integrated vertical comb-drive actuators

But …
- Strong coupling between different degrees of freedom
- Feedback required

→ Complex control unit → more weight
→ Need to tap light → signal loss

Performance
- Optically flat
- Large stroke: ~20 µ
- Small tilt angles
  → ideal for laser/filter cavity tuning

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2-axis MEMS Mirrors Stability Issues

Micro-mirror position can change due to:

1) Electrostatic charging near the electrodes
2) Electrostatic crosstalk from neighbour electrodes or circuit paths
3) Mechanical stress in the mirror membrane changes the mirror position (e.g. due temperature change)
4) Mechanical flexion or plastic deformation of the metal on the tilting beams (hysteresis)
5) Mechanical interaction of pre-stressed membranes (bi-stable positions)

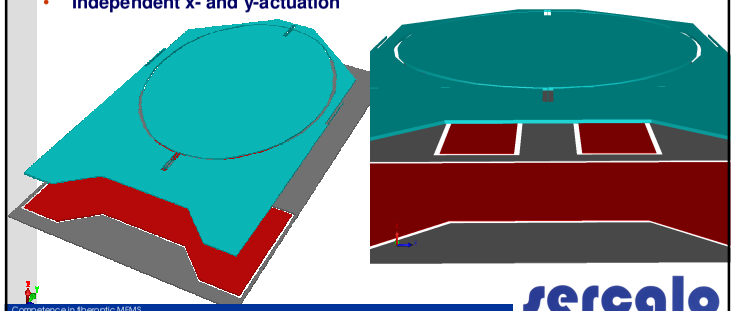
Novel Mirror Design Was Required...

Mirror design that comprises ...

- Stress compensation
  → mirror flatness
  → no buckling
- Independent x- and y-actuation

Mirror design that comprises ...

→ NO feedback
→ "easy" calibration
→ "simple" look-up table



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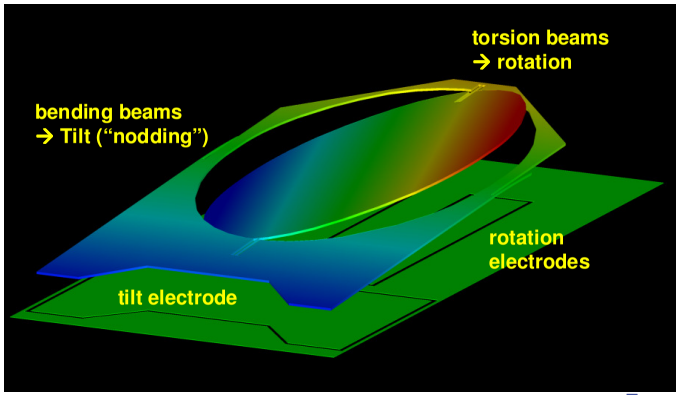

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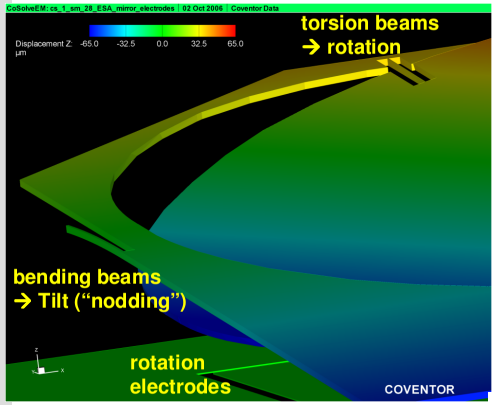
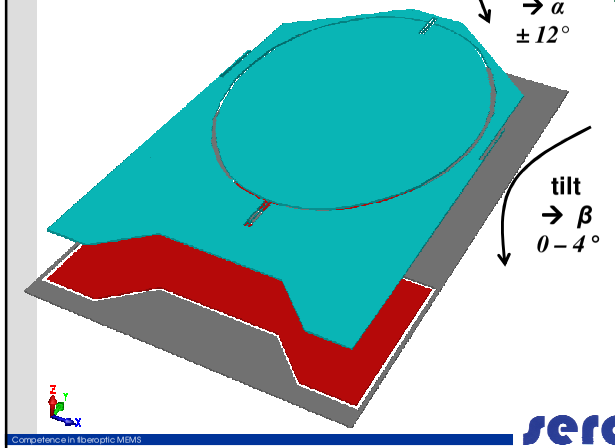


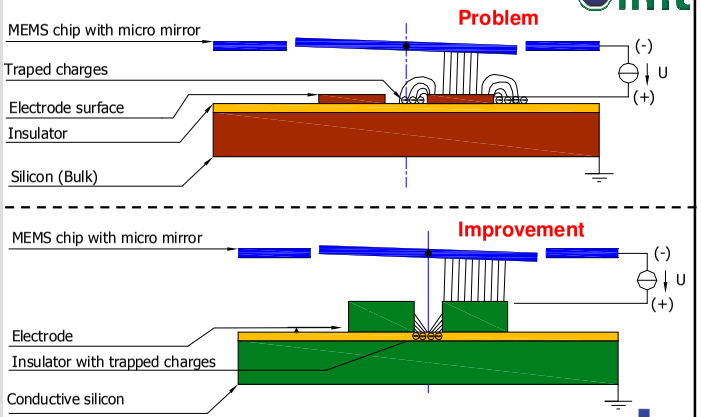
FEM Simulations

- no mechanical coupling between tilt and rotation

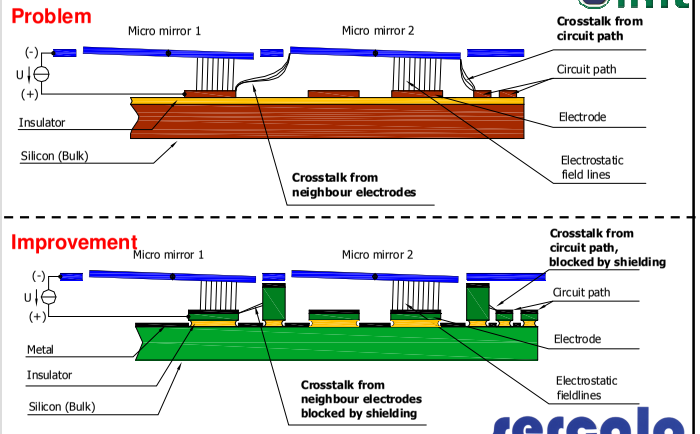
Angular Positioning Range



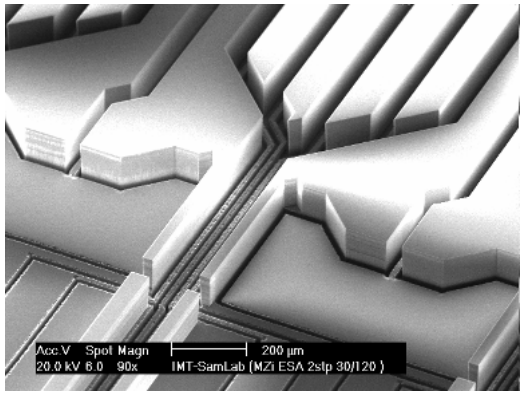
Charging and Shielding



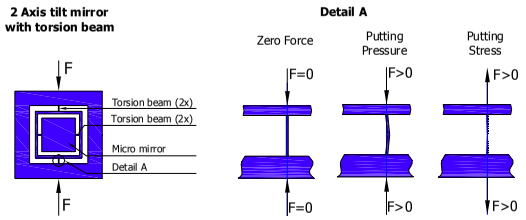
Electrostatic Cross Talk



Electrode-Chip / Shielding Side Walls

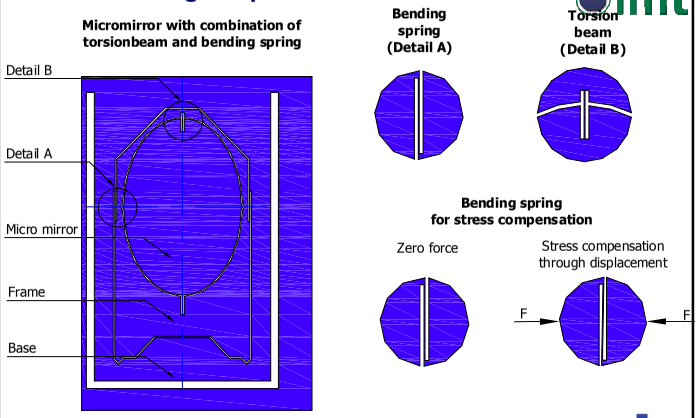


3) Mechanical Stress in the Mirror Membrane

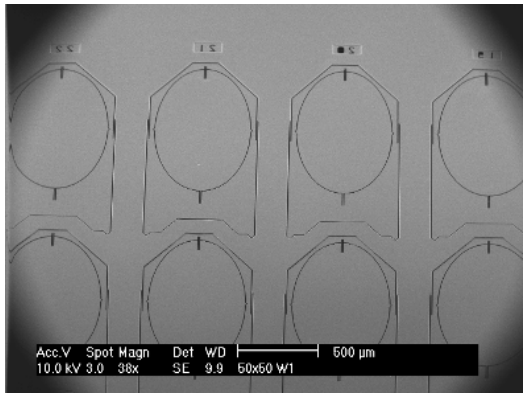


- Pressure and Tension changes the resonance frequency of the mirror
- Torsion beam for both axis (or meander shape) needs generally more space
  → not practical for high fill factor

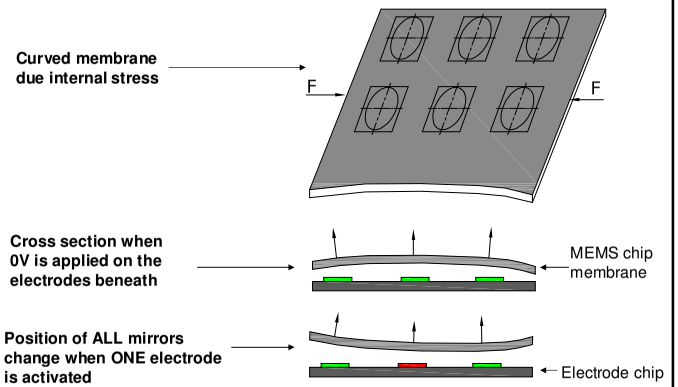
Stress Reducing Suspensions



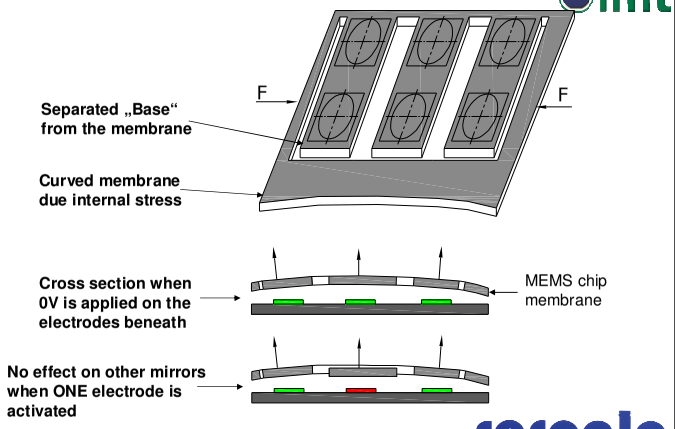
Micromirror Array



Issue: Membrane/Frame Deformation



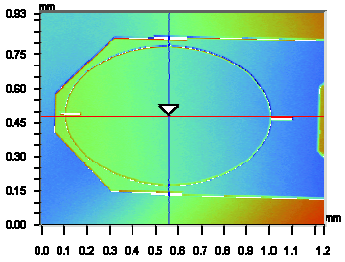
Mirrors Decoupled From Supporting Frame

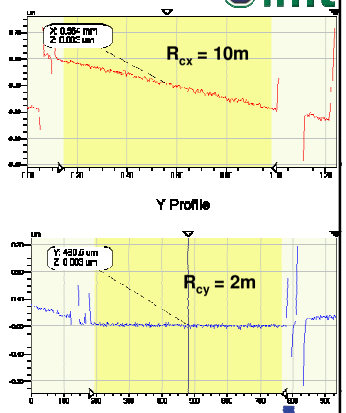


Mirror Decoupled from Membrane

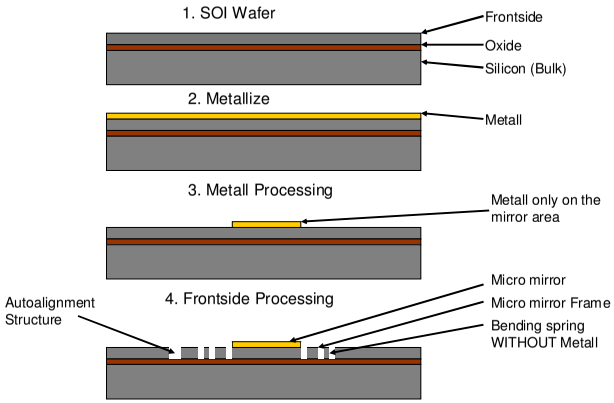
Wyko Measurements

- Membrane bent
- Mirror flat !!!
- Low R_c

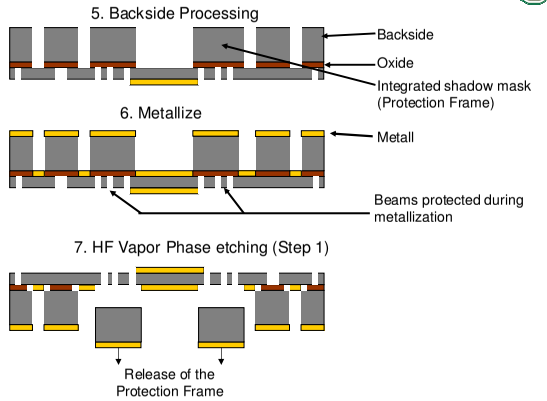




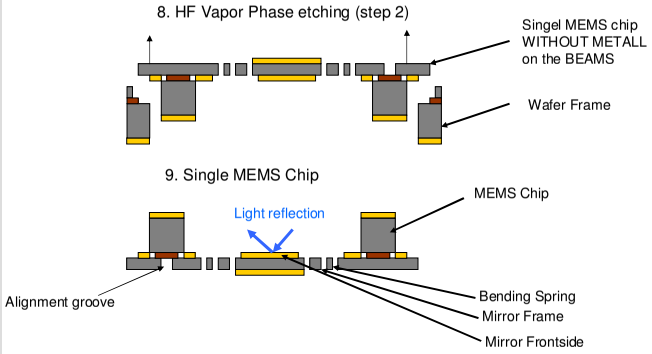
Fabrication: Mirror Chip / Frontside



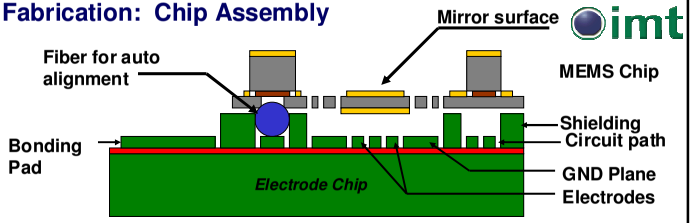
Fabrication: Mirror Chip / Backside

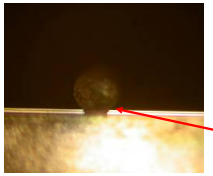


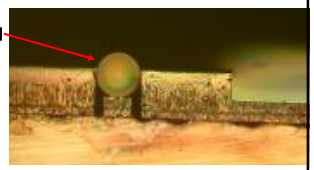
Fabrication: Mirror Chip / HF-VPE-Release



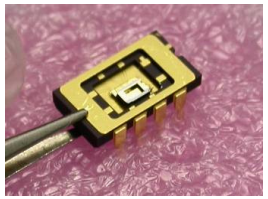
Fabrication: Chip Assembly



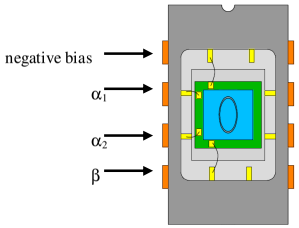




Applications: Single Mirror



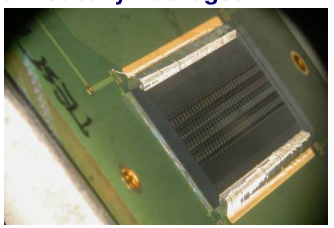
Single tilt mirror in DIL 8 housing



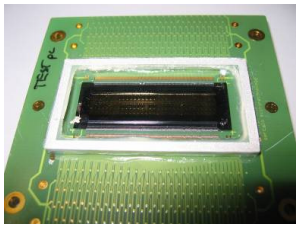
PIN Layout of tilt mirror

- Mirror size 900 x 600 µm (elliptic)
- Alpha angle +/- 4° (mechanical)
- Beta angle +1° (mechanical)
- Resonance Frequency ~300 Hz
- Using bias to keep actuation voltage accessible for comercial electronics
- Driving Voltage 0-40V
- Near critical damping

Applications: 4x32 Mirror Array Hermetically Packaged



Wire bonded 4x32 Electrode array

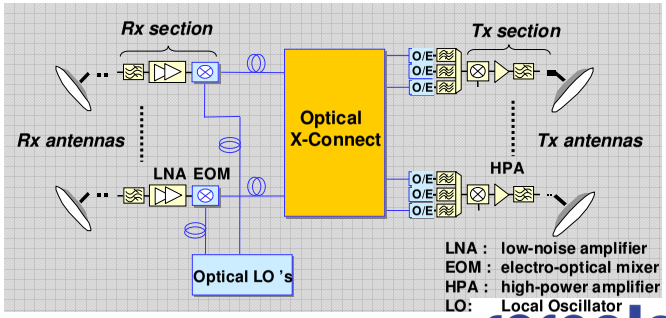


NON hermetic package 4x32 tilt mirror array

- Drift less micro mirror array of 4x32
- 384 Electrodes with driving voltage from 0 to 300V
- Tilt angle alpha +/- 12° (mechanically)
- Tilt angle beta + 2.5° (mechanically)
- PCB size 63x63 mm with 4x100 Pin connector on the backside
- Continuous tilting possible

Applications: Large-Scale Optical Cross Connect

- Satellite telecom payload with flexible beam-to-beam connectivity
  - optical generation & distribution of high-frequency LO's (> 10 GHz)
  - optical frequency mixing and down-conversion, e.g. from Ka (30GHz) to C (4GHz)
  - optical cross-connection of µ-wave signals through MOEMS switches

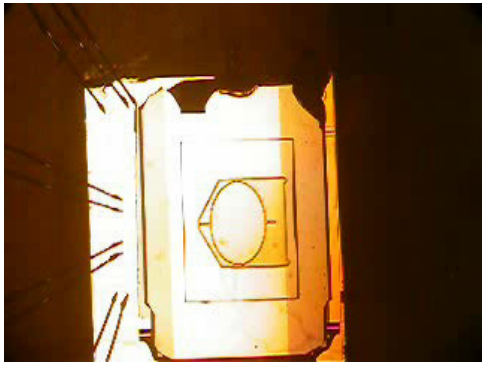


Other Applications

- Fully reconfigurable optical cross connect
- Displays
- Endoscopy
- Wavelength selective switch

Conclusion

- ✓ The motivation for the development of a potential drift free 2 axis tilt mirror are
  - Less components necessary -> more reliable
  - Less weight and size -> important for satellite integration
  - No light through the switch necessary for maintaining the mirror position
  - Opening new potential features
- ✓ We explained the sources of drift and the design solutions to avoid drift phenomena
  - No metal on the beam due integrated shadow mask
  - Temperature stress compensation with torsion beam – bending spring combination
  - Elimination of mechanical crosstalk (bi-stable membrane) by introducing a „base" which separates the mirror from the rest of the array membrane
  - Special design of the electrode with shielding and high electrodes to avoid electrical crosstalk and drift due charging effects
- ✓ We gave some ideas for applications



Thank You!