Micro-electro-mechanical deformable mirrors for Q-switched fiber laser systems

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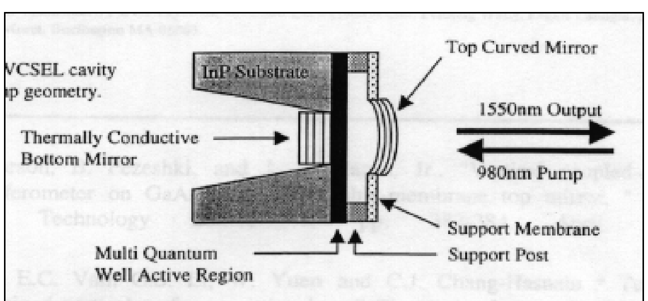
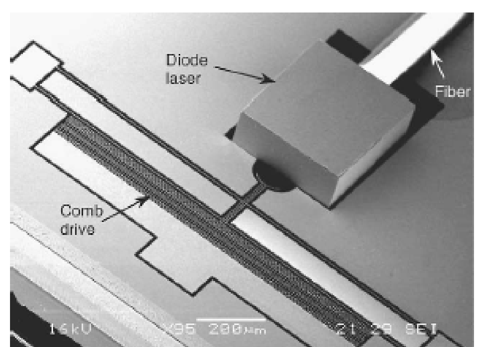
Optical MEMS

- Miniature structures fabricated using micro machining
  - provide mechanical, electrical + optical functions
  - integration, light, small size, low-cost fabrication
  - low insertion losses, small cross-talk…
- Main application areas
  - Optical communications
    - Switches and optical crossconnects (OXC)
    - Variable attenuators / shutters
    - tunable sources + filters, reflection modulator, spectral equalizer
  - Imaging
    - digital image processing (projection- DLP/DMD, printing…)
    - Micro-scanners (bar code reading, endoscopy…
  - Adaptive optics :(astronomy, ophthalmology, …)
  - Optoelectronics : fiber-chip connection, optoelectronic hybrid integration

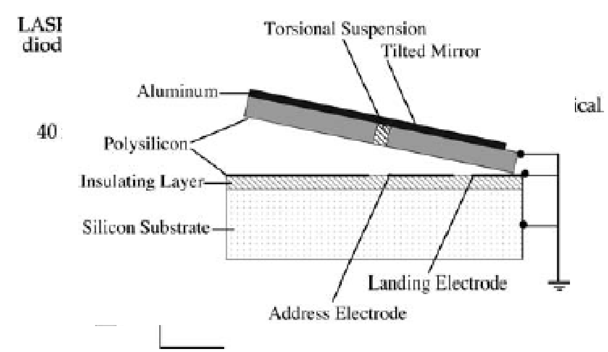
Tunable/ high power (micro)lasers

- along with optical switches they are key components in optical networks
- ideally, should be:
  - tunable over telecom frequencies (1530-1620 nm)
  - narrow emission spectrum
  - able to be locked on a certain frequency
- First demonstrators: Fabry-Perot interferometer, VCSELs with electrostatic actuation of the cavity mirror (Coretek, USA)





A.Q. Liu et al., Singapore



N.F. de Rooij et al., IMT Neuchatel, Switzerland

Q-switched (fiber) lasers

Q-switching regime:

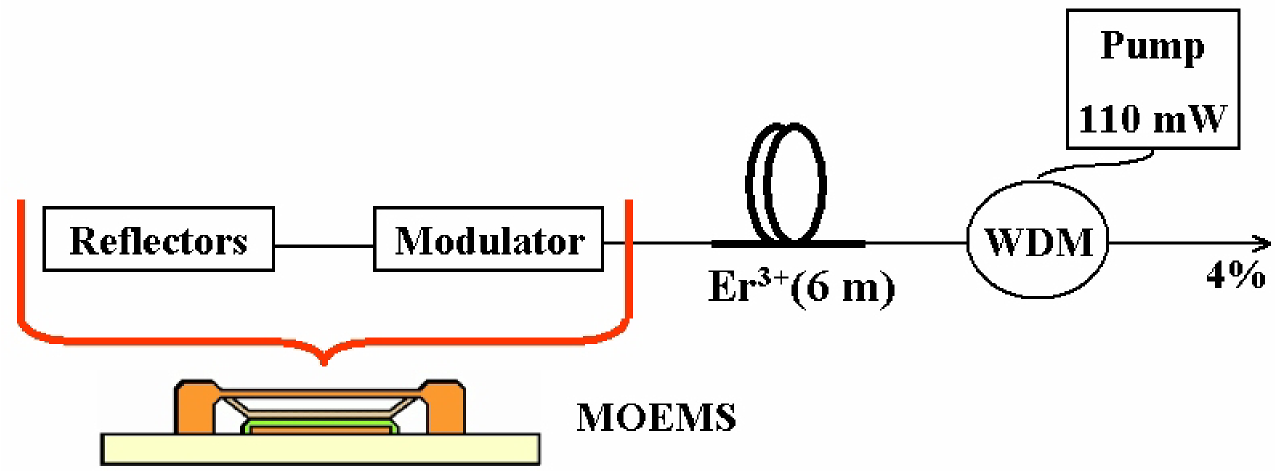
- rapid modulation of the Q-factor of the laser cavity
- generation of narrow, high-power pulses

Cavity losses modulation:

- Active modulators:
  - Electro- optic
  - Acousto- optic
  - Mechanical (shutters, choppers)
  - Piezoelectric or magnestriction modulation of Bragg mirrors
- Passive modulators (saturable absorbers Co^{2+}:ZnS, SESAMs…)

✘ Bulkiness – low integration, complicate design for a practical device
✘ Intracavity components – degradation of the laser beam, high losses
✘ low laser power levels operation
✘ lack of control of frequency and pulse width for the passive modulators

Optical MEMS-based Q-switching

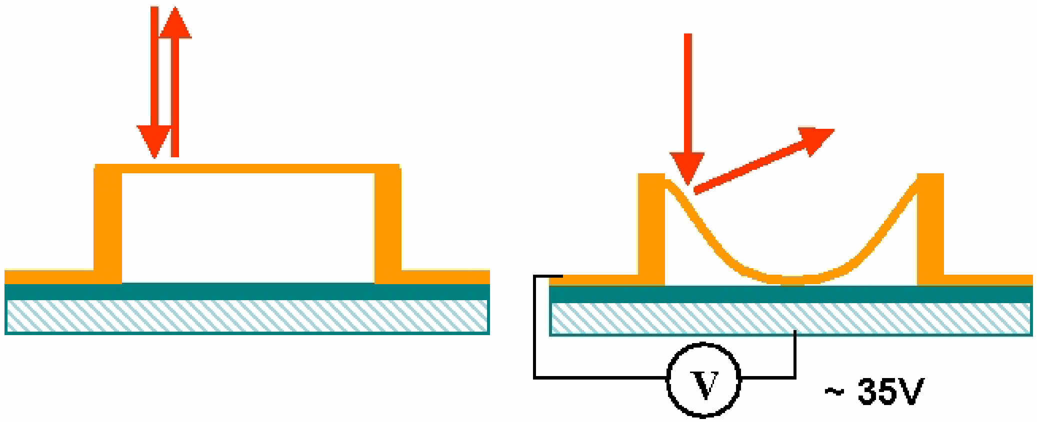


Electrostatically actuated membrane ≈ mirror with variable curvature:

- **external cavity mirror**
- **cavity losses modulator**

- **high integration potential**
- **high reflectivity, achromatic, polarization insensitive**
- **low-cost, batch, and simple fabrication process**

Q-factor modulation



off state (non-actuated)
-high Q factor cavity-

on state (actuated)
-low Q factor cavity-

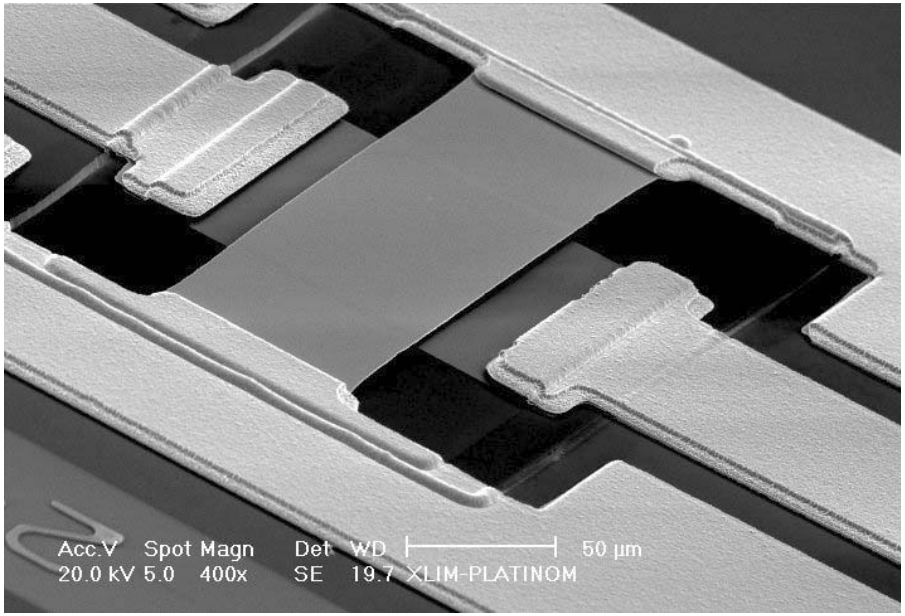
- 500 nm thick gold membrane
- thermally-grown SiO_2 (dielectric isolation)
- low-resistivity Si substrate (lower electrode)

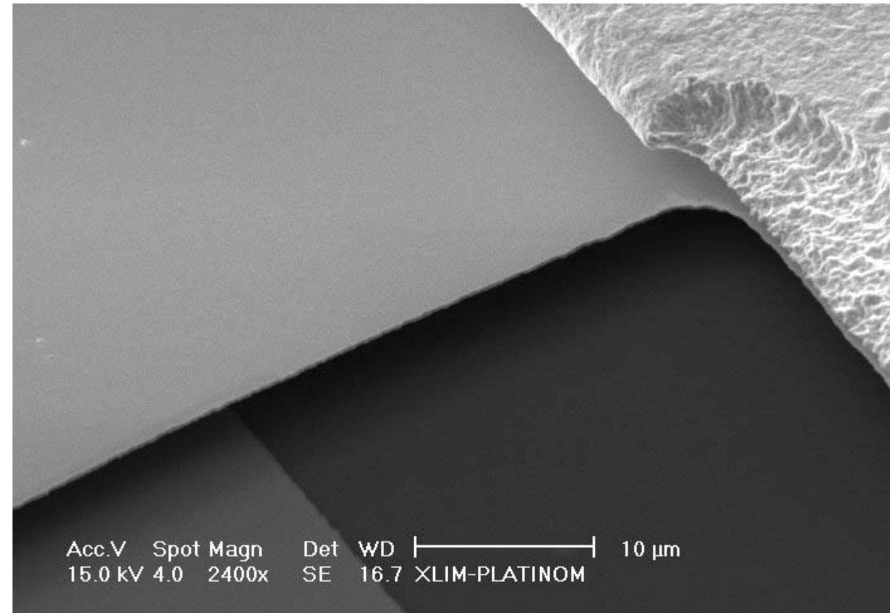
Fast Q-factor modulation ⇒ Q-switching

Key parameters:

- modulator speed ⇒ switching speed ⇒ mechanical resonant frequency (stiffness)
- reflectivity discrimination between the on- off-states during actuation

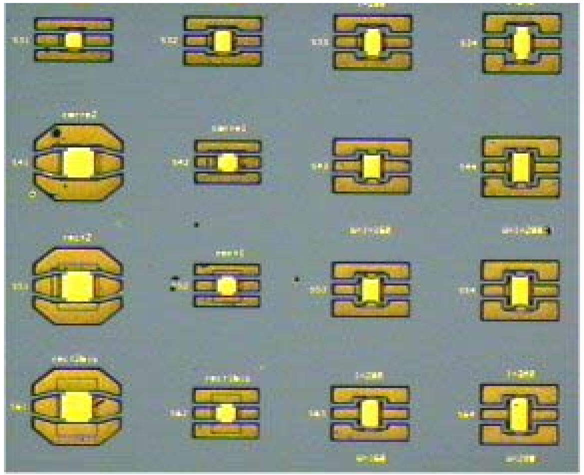
Optical MEMS parameters



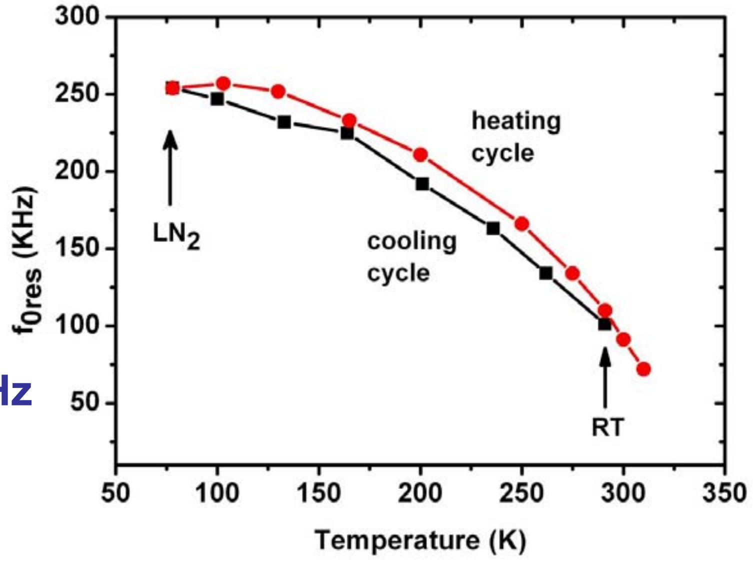


- **stiffness - spring constant, $k \cong 20 - 70$ N/m**
- **pull-in voltage, $V_{pull\text{-}in} \cong 15 - 35$ V**
- **mechanical resonant frequency, $F_{res} \cong 90 - 150$ kHz**
- **switching time, $t_s \cong 2 - 3$ µs**
- **low roughness (~ 2 nm rms)**

Mechanical resonant frequency

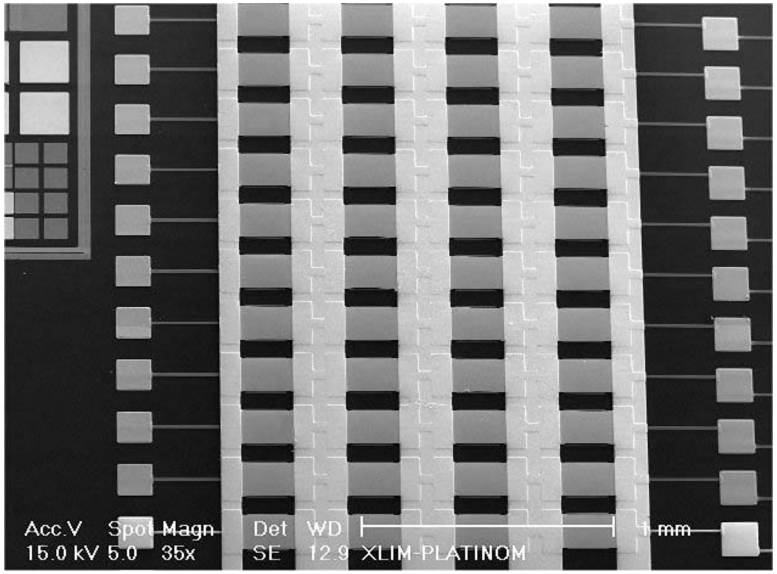


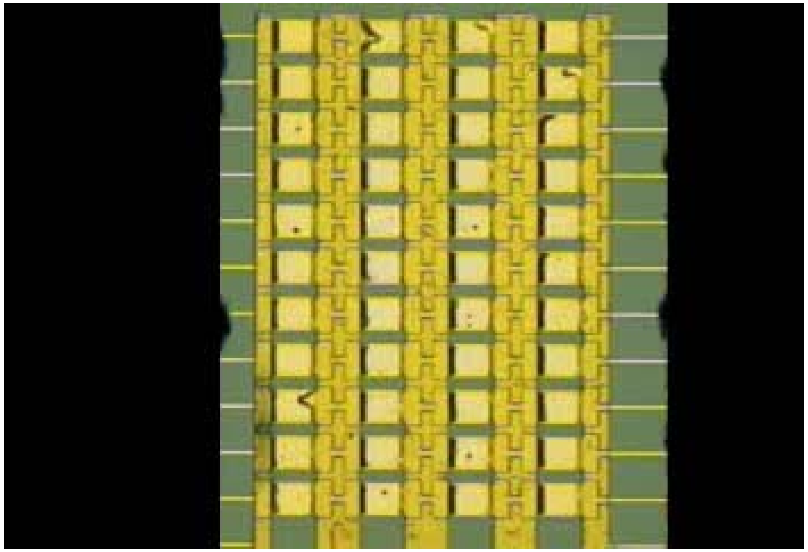
micro-mirrors with different dimensions
(240 x 160 mm^2 to 120 x 60 mm^2)



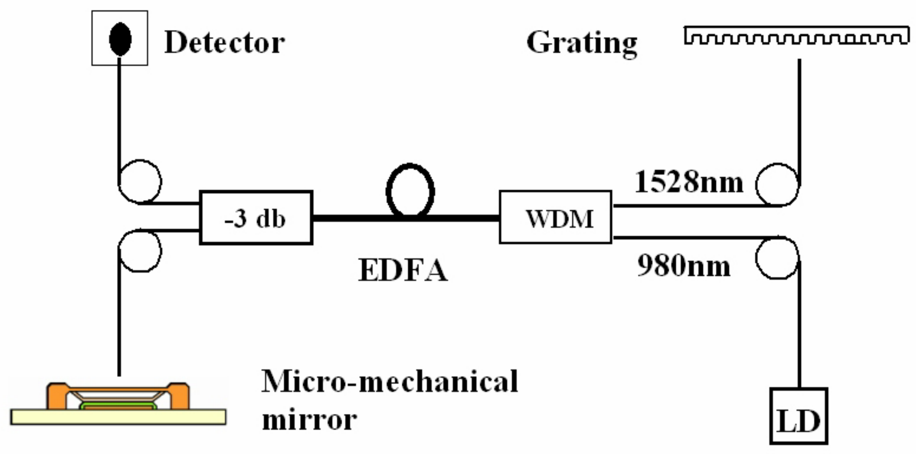
- mechanical resonant frequency, Fres ≅ 90 - 150 kHz
- depends on the structural material, dimensions, stress developed during fabrication process
- reproducible mechanical and electrical behaviour between LN2 temperature and 100°C

Micro-mirrors matrix - actuation



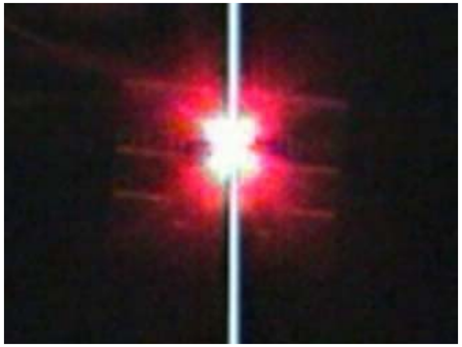


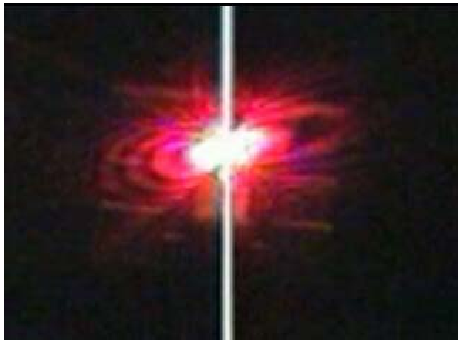
Experimental set-up



Er^{3+} fiber laser system :

- diode pumped (100 mW @ 980 nm)
- WDM 980/ 1500 nm

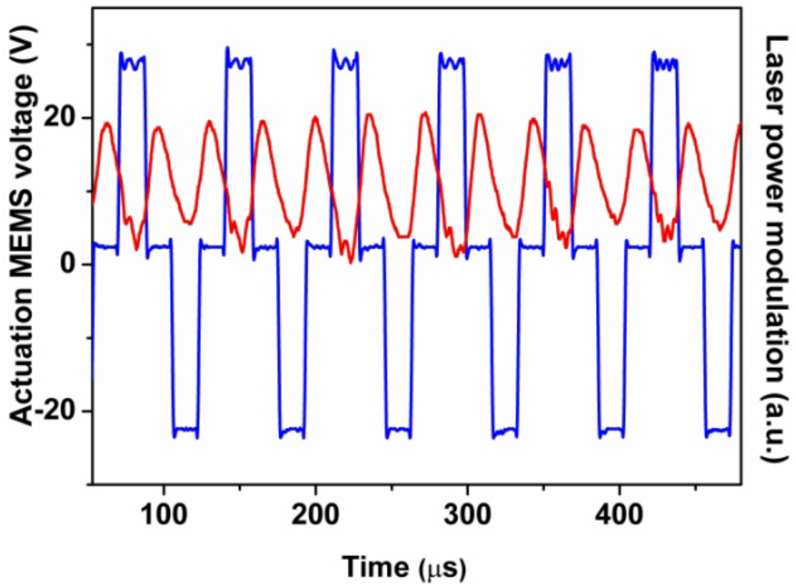


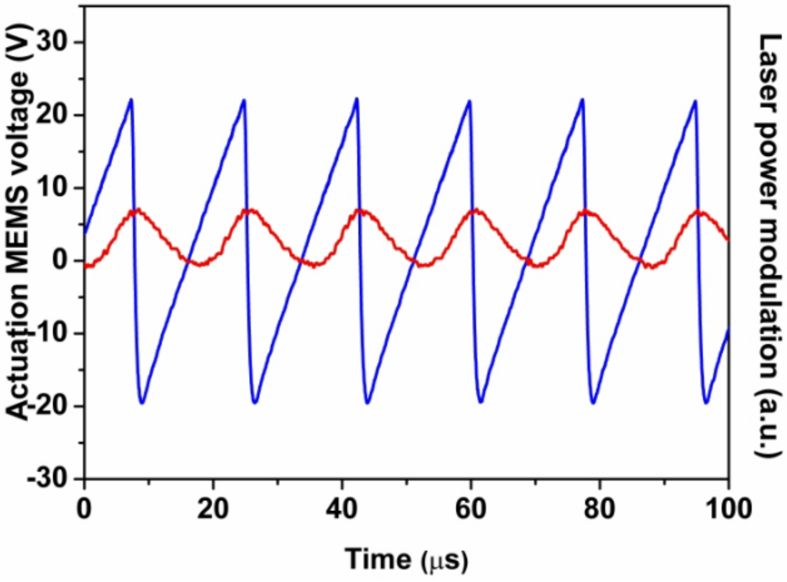


Micro-mirror :

- ~ 85- 90% reflectivity @ 1500 nm
- ~9° max deviation of a He-Ne laser beam during actuation
- withstands CW powers of around 1 W

Laser power modulation

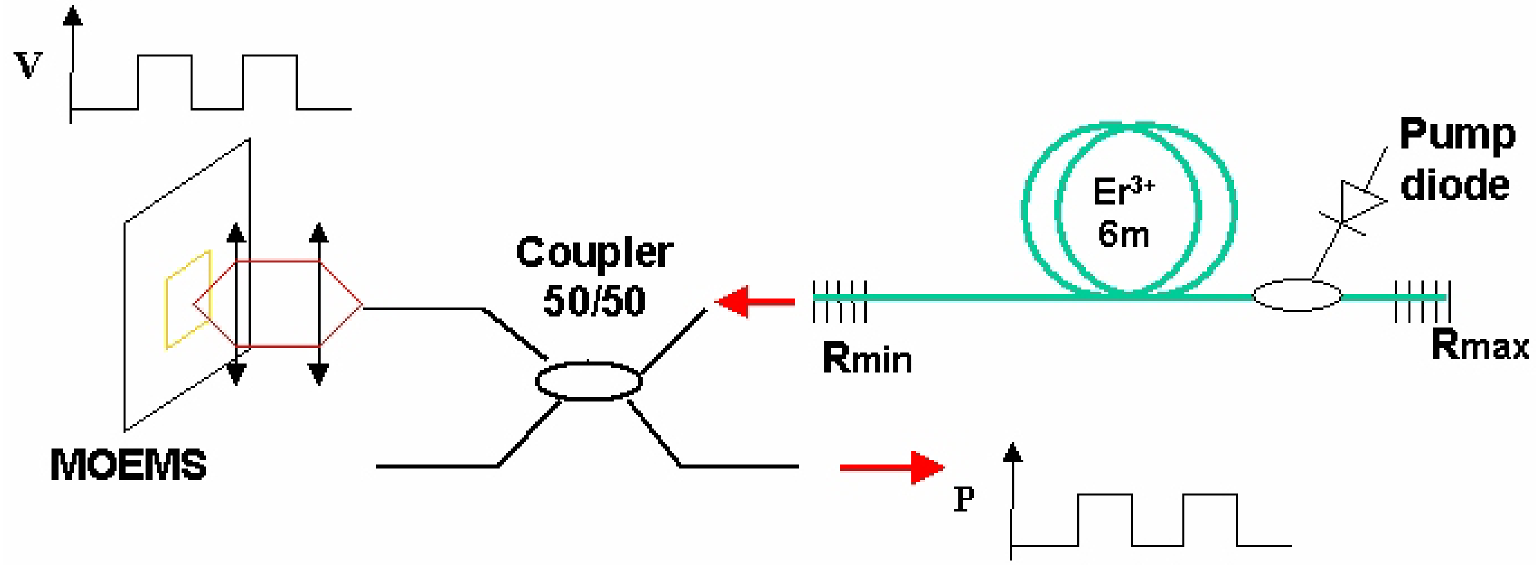


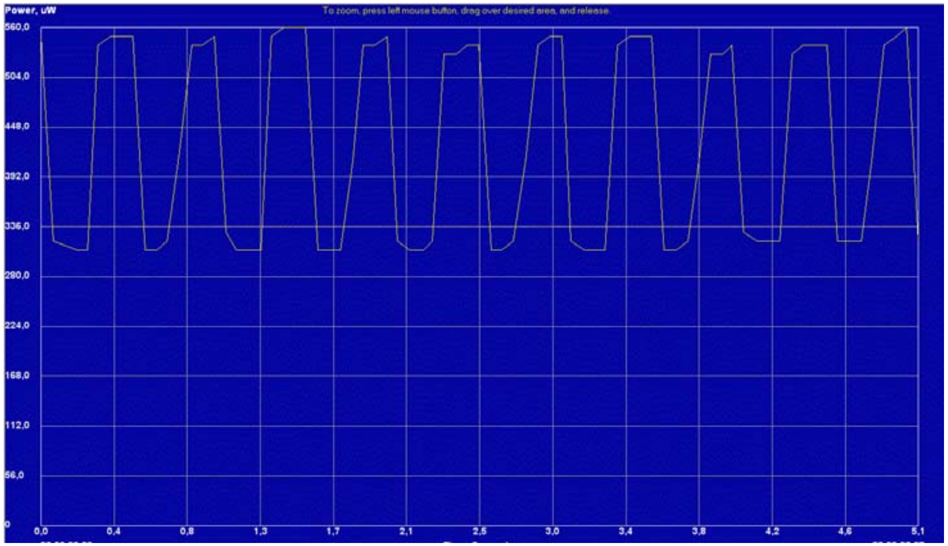


First output laser modulation:

- only modulation, no Q-switching
- "pulses" superposed over a continuum emission
- FWHM from ~ 20 µs for ramp waveform actuation @ 28 kHz down to ~ 10 µs for triangle- type waveform @ 57 kHz

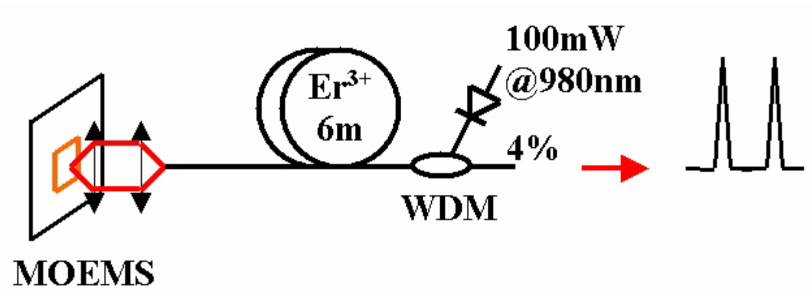
Optical MEMS reflectivity variation

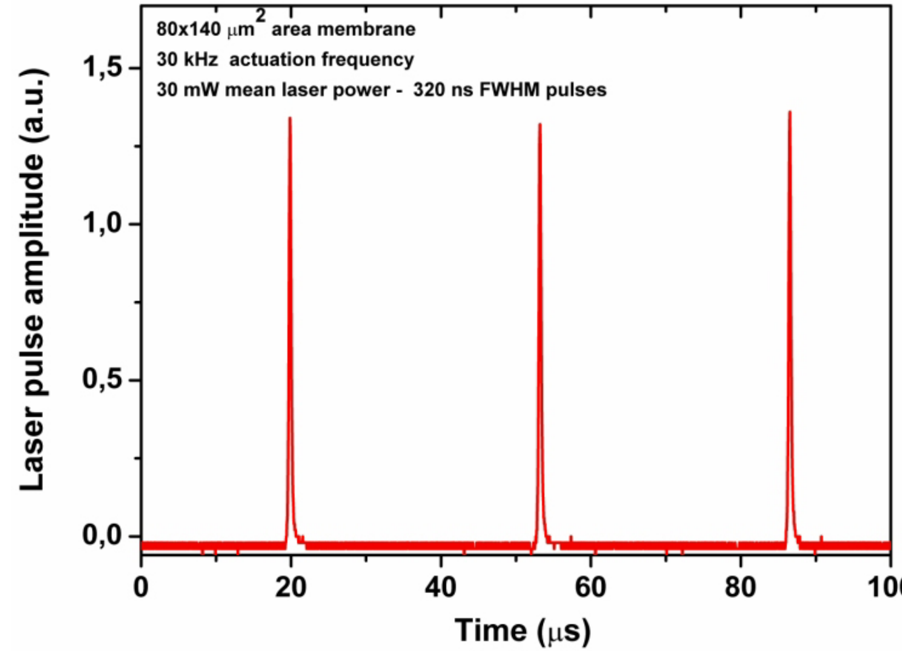


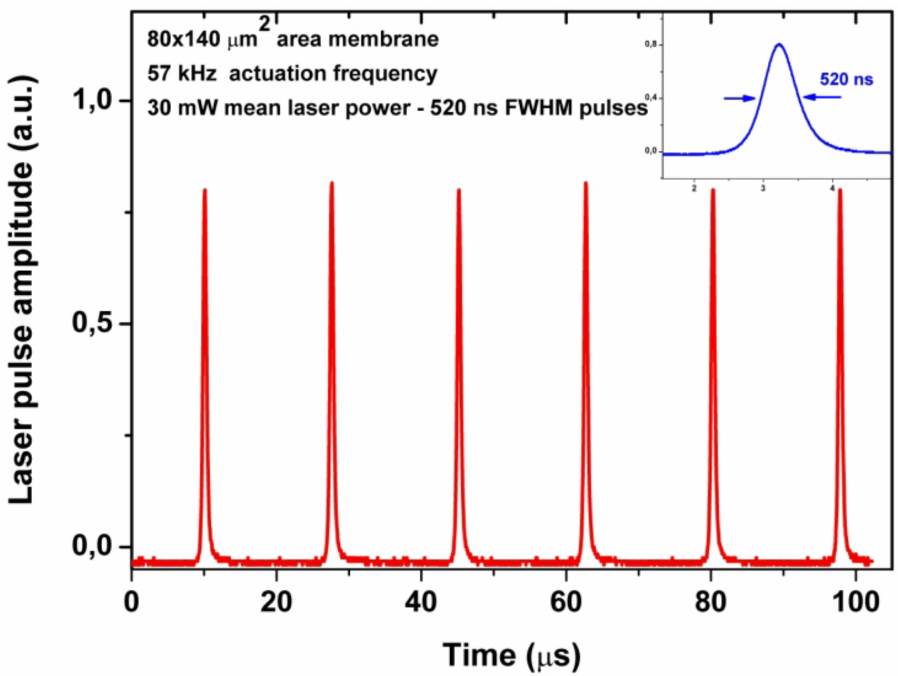


~45 % modulation

Fiber/ mirror alignment optimization

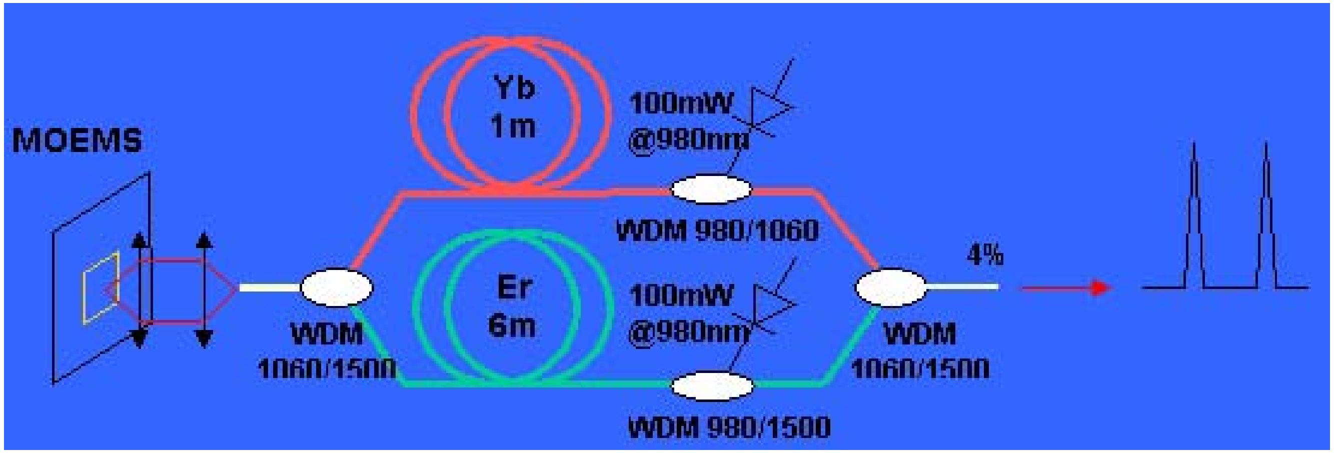


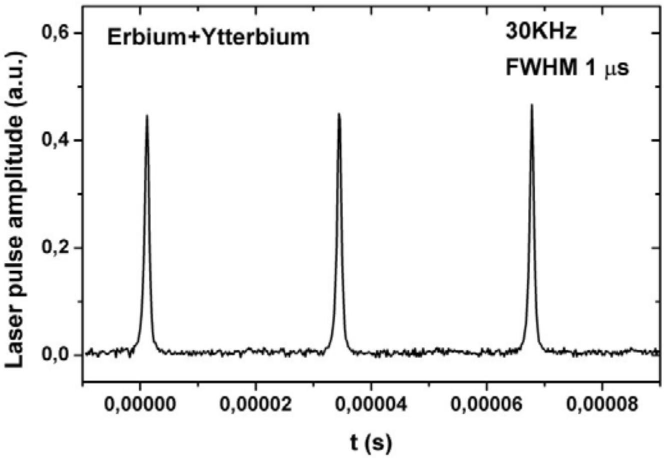


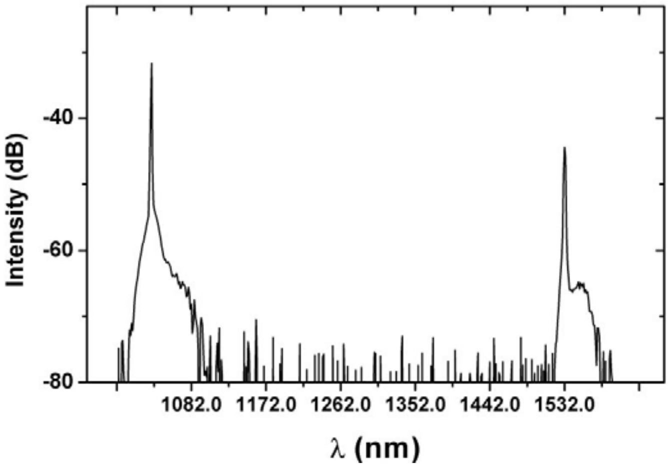


- attaining high-power train pulses
- FWHM down to 320 ns
- mean power ~ 30 mW
- peak powers of several Watts
- repetition rates: 20 to 120 KHz

Multi- wavelength fiber laser system







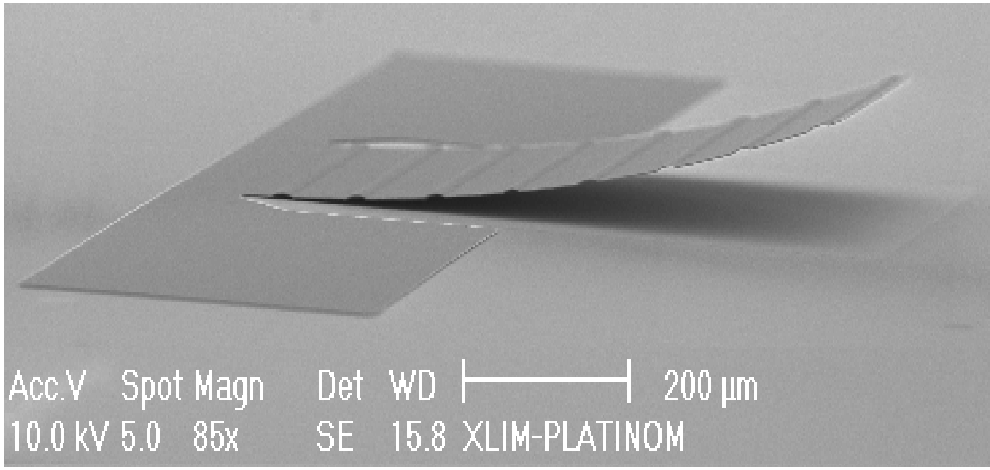
- Two-wavelength superposed train pulses

- Wavelength mixing + Coupling with non-linear crystals ⇒ emission of high power pulses with discrete wavelength emission (UV – IR)

On-going development

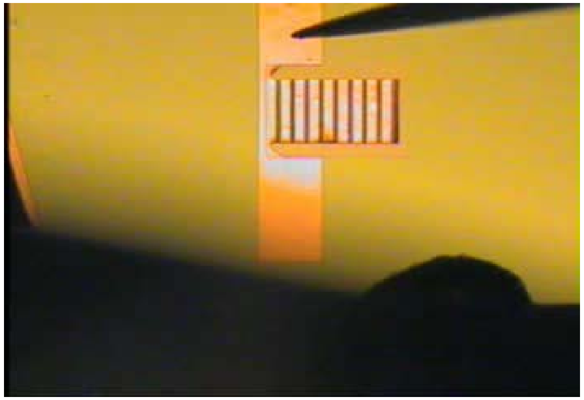
Design and integration of optical switching elements that:

- are faster
- present higher reflectivity discrimination states during actuation



Integration with solid-state micro-lasers

Different families of fiber lasers (Yb- or Er-Yb- doped) actuated independently or synchronous for wavelength mixing/ tuning applications



Conclusions

• Simple, low-cost technique to produce active Q-switching in a fiber laser system

• Repetition rate continuously tuned between 20 kHz and 120 kHz.

• High peak power (several W), narrow pulses (FWHM 320 ns - 1 μs)

• Integration with various types of laser amplifiers running at different wavelengths (synchronization, wavelength mixing)

• Various applications: communications, biotechnology etc.

• Packaging
• Reliability
• On-chip integration