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Development of MEMS micromirrors for intracavity laser control

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Motivation

- **Control the laser temporal behaviour using an intra-cavity Micro-Electro-Mechanical System (MEMS) micromirror**

- Work started as a collaboration between the Institute of Photonics (Dr. Burns) and the Centre for Microsystems and Photonics (Prof. Uttamchandani) - Now in house-investigations

- MEMS micromirrors initially used were primarily developed for other applications (simple laser scanning systems)

- Further development of more recent micromirrors tailored for intracavity laser use

Outline

- Description of the MEMS micromirrors used
    - Electrothermal
    - Electrostatic

- Temporal control of a Nd:YLF laser using an electrothermal MEMS mirror

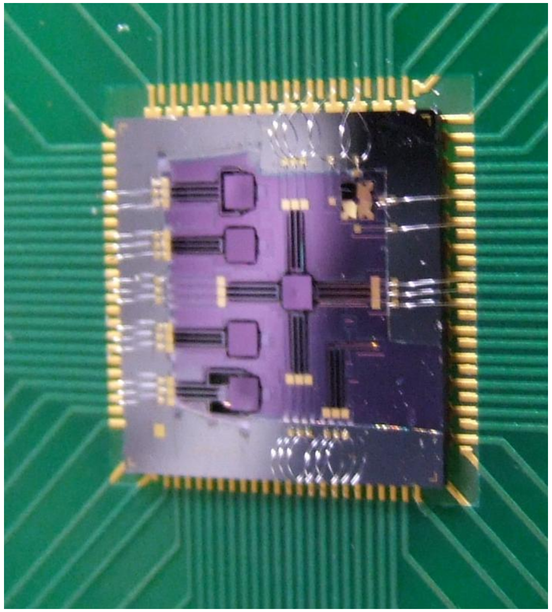
- Q-switch of a Nd:YLF laser using an electrostatic MEMS mirror

- Q-switch of a Nd:YAG laser using a more advanced electrostatic MEMS mirror

- Discussion

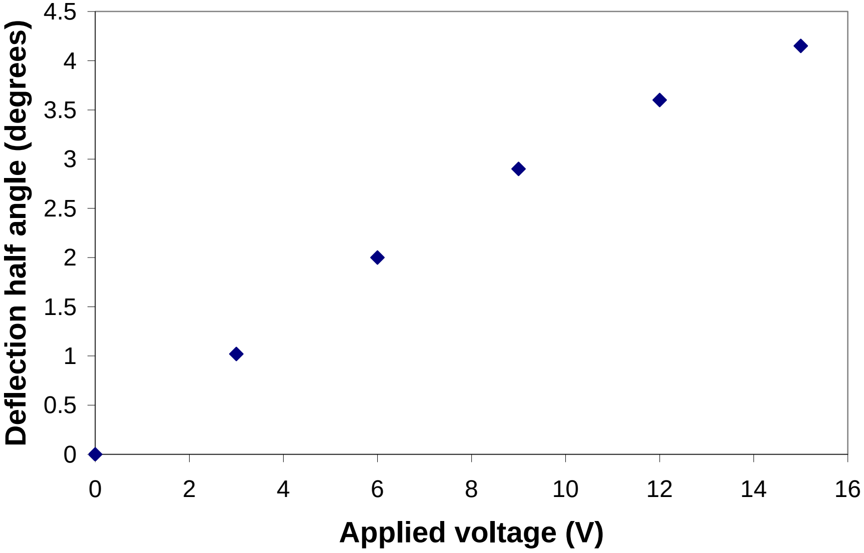
MEMS micromirrors

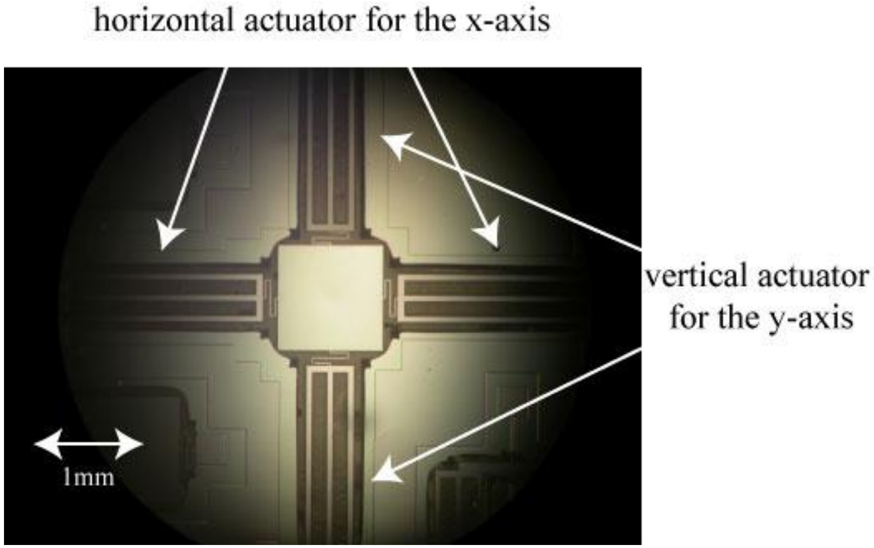
- Built using Silicon-On-Insulator foundry process at MEMSCAP Inc. (low cost technology)
- Scanning micro-mirrors with adjustable angular positioning on one or two dimensions according to the voltage applied
- Mirrored surface dimensions from 0.3 x 0.3mm to 3 x 3mm
- Potential for arrays of micromirrors
- Can be coated to ensure high reflectivity with
  - dielectric coatings (e.g. 8 pairs of SiO_2/Nb_2O_5 to ensure R>99% at λ=1064nm)
  - gold coated to reduce heat-induced surface curvature (R~87%)
- 2 types:
  - Based on electrothermal actuation
  - Based on electrostatic actuation

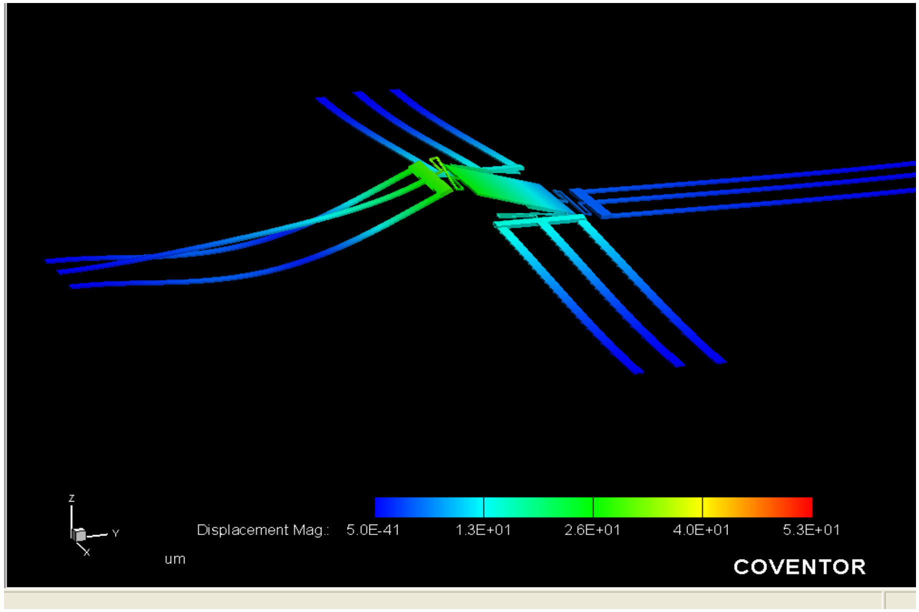


Electrothermal MEMS mirror

- ‘Miniature tip-tilt mirror’ where the angular position varies with the voltage applied
- Maximum half-angle deflection: 4.5º for 15V applied
- Has a DC response (the angular position can be kept constant over time)

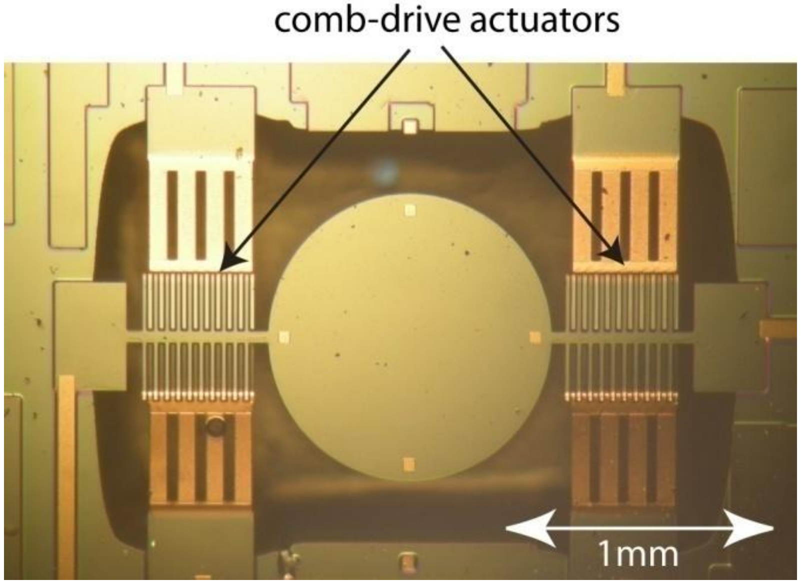






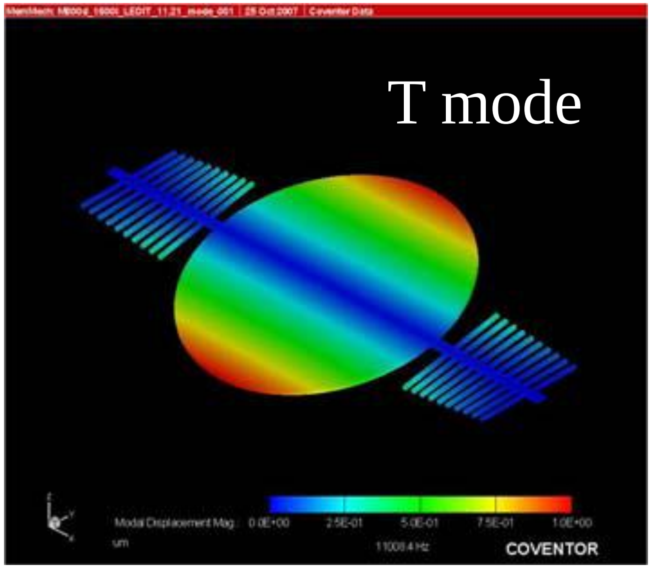
Electrostatic MEMS mirror

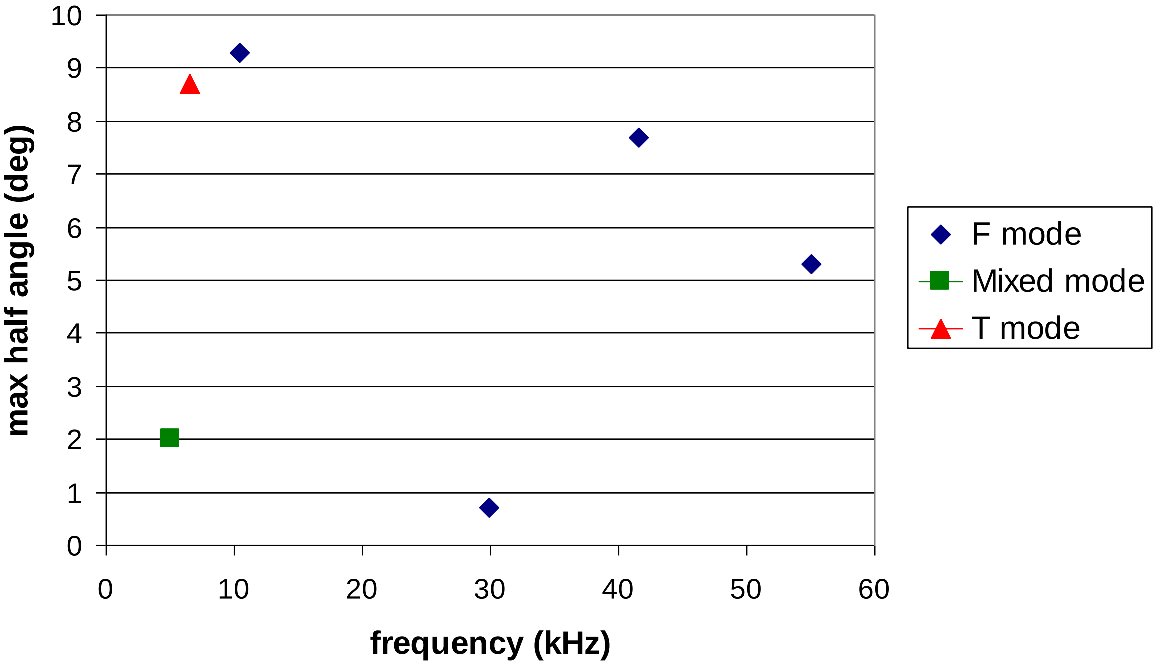
- Has no appreciable DC response: the angular position follows the frequency applied to the mirror (can range from 6 to 30kHz)
- This frequency applied must be reasonably close (+\- ~1%) to a natural resonance (or its harmonics) to maximise the deflection
- Thickness: 10μm
- Maximum half-angle deflection 10º for 200V applied

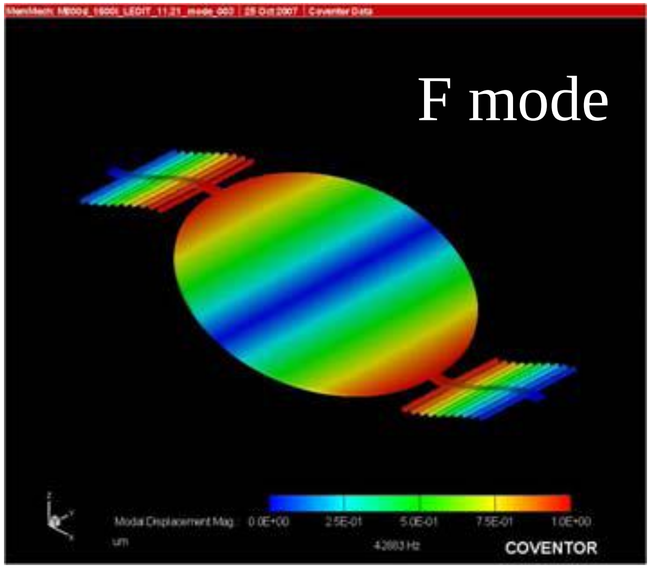


Electrostatic MEMS mirror

- Different resonating modes:
  - – torsional mode (T mode) (horizontal axis of rotation)
  - – flex mode (vertical axis of rotation)
  - – mixed mode

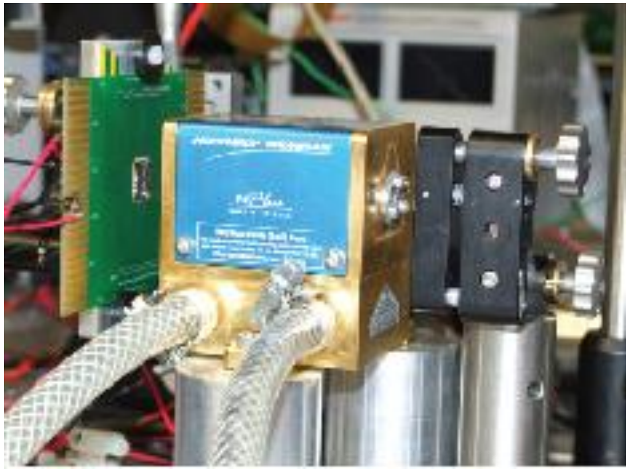


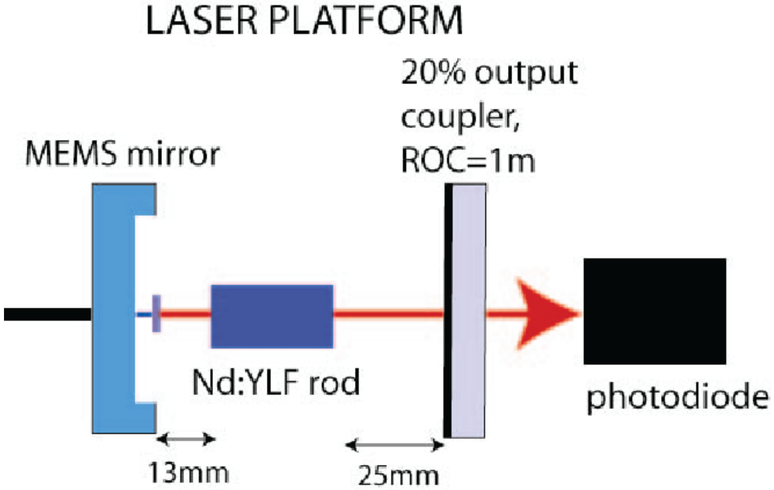




Temporal behaviour of a Nd:YLF laser using an intracavity electrothermal MEMS mirror

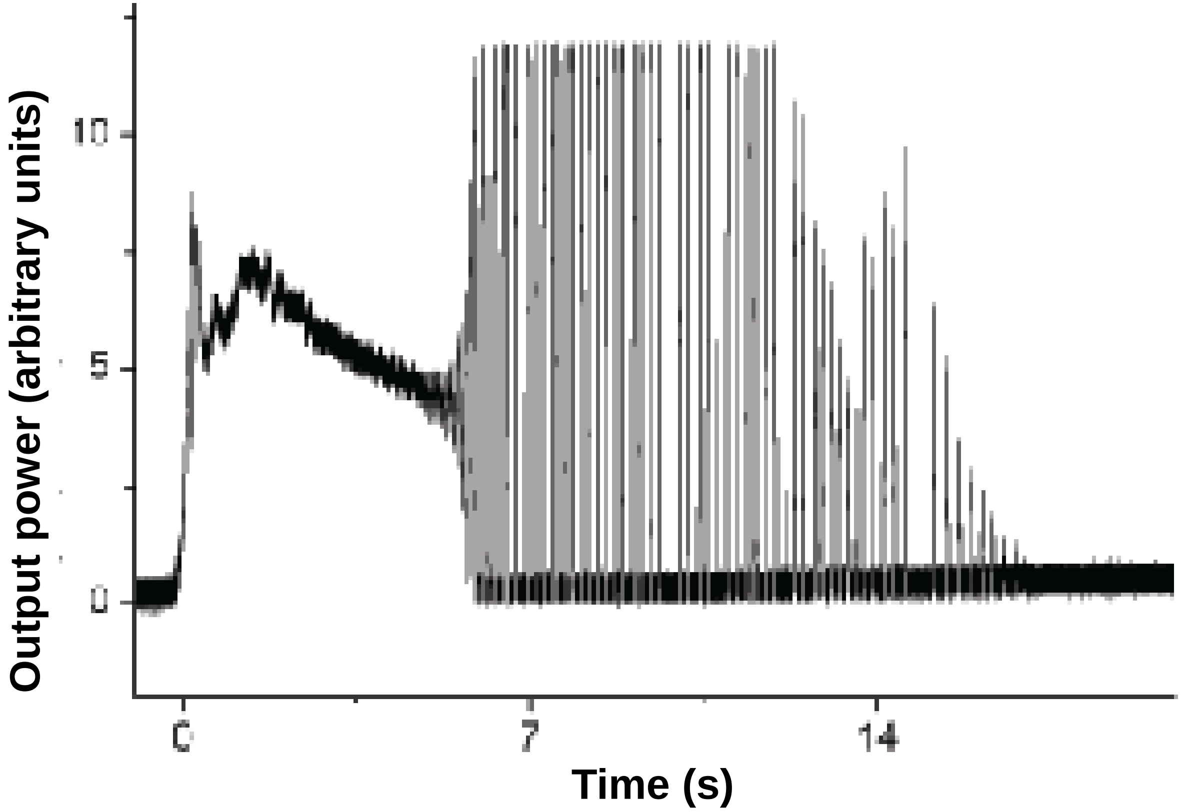
- 2-mirror Nd:YLF laser
- Stable CW operation with 200mW output power when pumped ~3W above threshold - the power density on the micro-mirror surface was calculated at 500W/cm^2
- However, fluctuation of the laser output power when the pump power is stronger.





Temporal behaviour of a Nd:YLF laser using an intracavity electro-thermal MEMS mirror

The pump power is linearly increased as a function of time



- CW operation until 18W (i.e. 500W/cm^2 of $P_{density}$ on the MEMS surface)
- Rapid modulation of the laser oscillation up until a certain pump power (25W) then laser oscillation terminates

Thermally-induced bistable behaviour

- The mirror surface is initially flat and laser can oscillate

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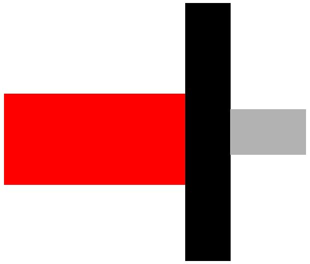
- The light not reflected by the dielectric coating is absorbed by the silicon



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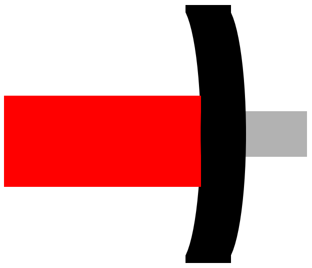

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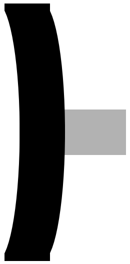

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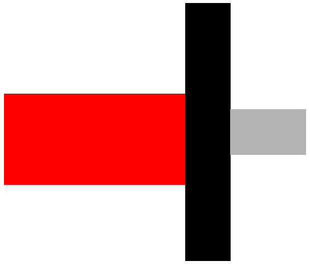

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- As a result, the MEMS mirror cools down, the bulge is reduced and the laser oscillates again – the process is repeated with a period typically of a few 100ms

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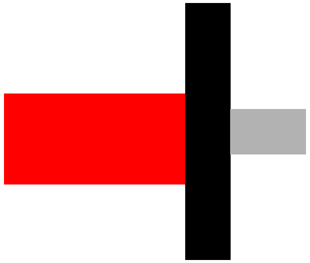

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In another laser cavity, the micromirror sustained 20kW/cm^2 without damage.

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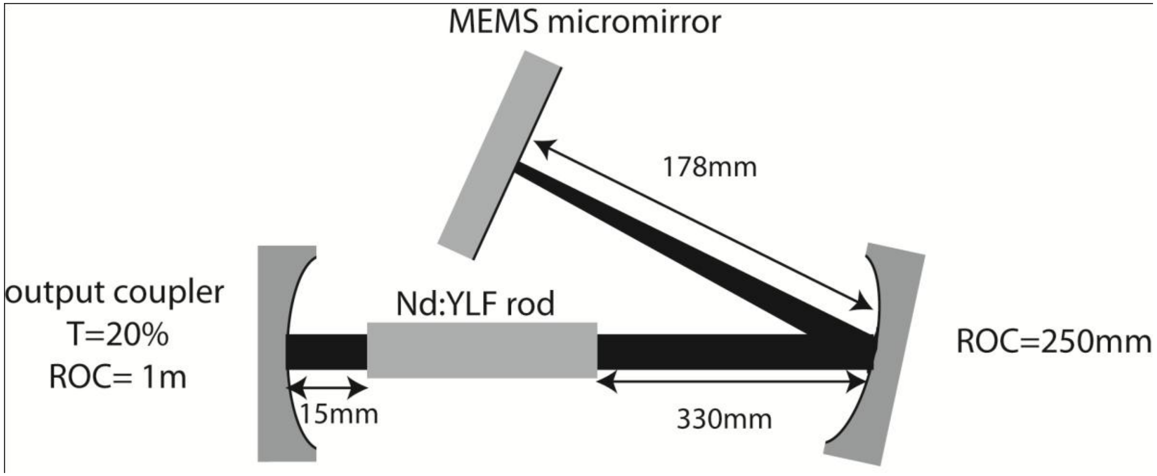
Q-switching of a Nd:YLF laser cavity

- 3-mirror laser cavity built around the side-pumped Nd:YLF pump module with an electro-static micromirror as an end-mirror (beam size~ 80μm)

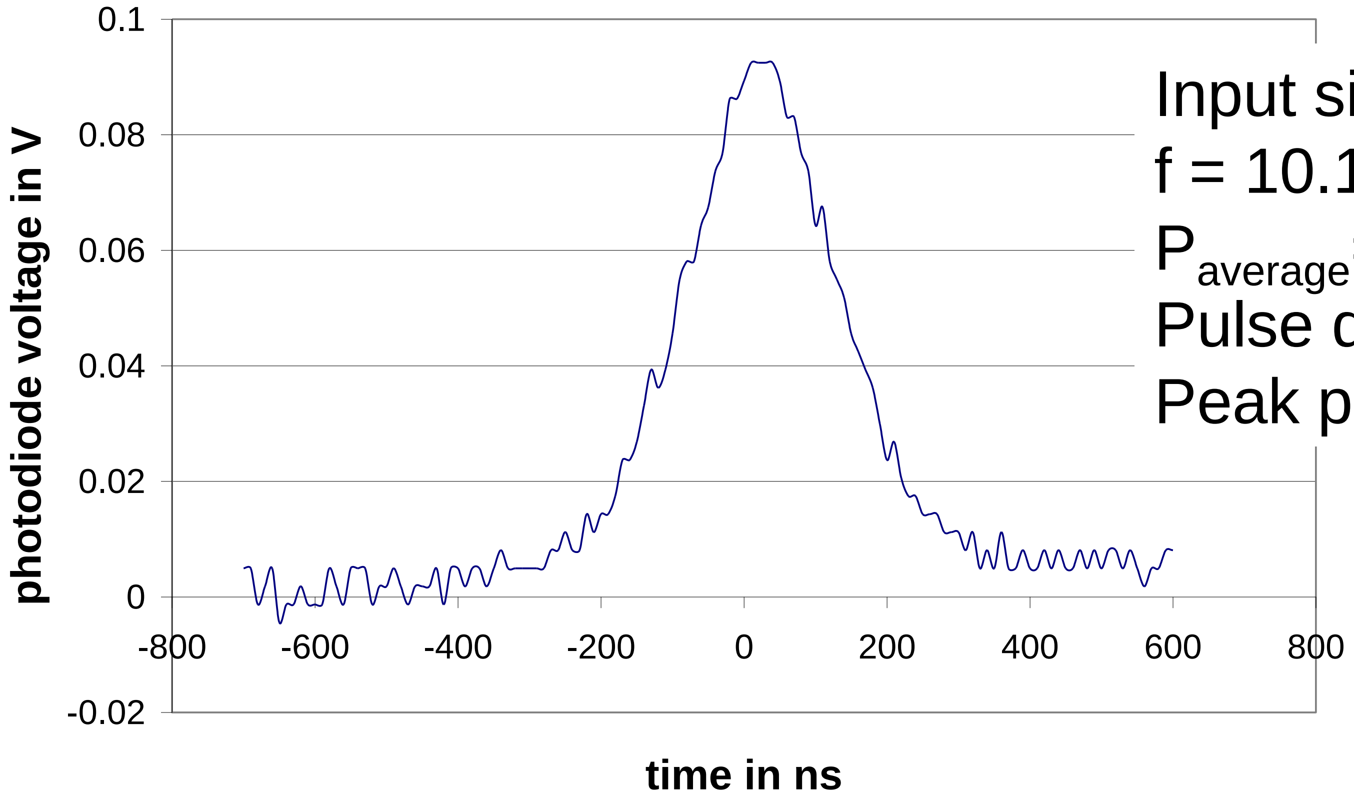


- At CW operation: P_{max}=300mW
- Voltage input: sinusoidal wave with
  - amplitude ranging from 0 to 200V
  - frequency varying from 5 to 40kHz

Lubeigt et al., Opt. Express **19**, pp. 2456-2465 (2011)

- At different pulse repetition frequency (ranging from 6kHz to 40kHz: 6, 10, 15, 30 and 40kHz) resulting pulse duration ranging from 220ns to 2μs

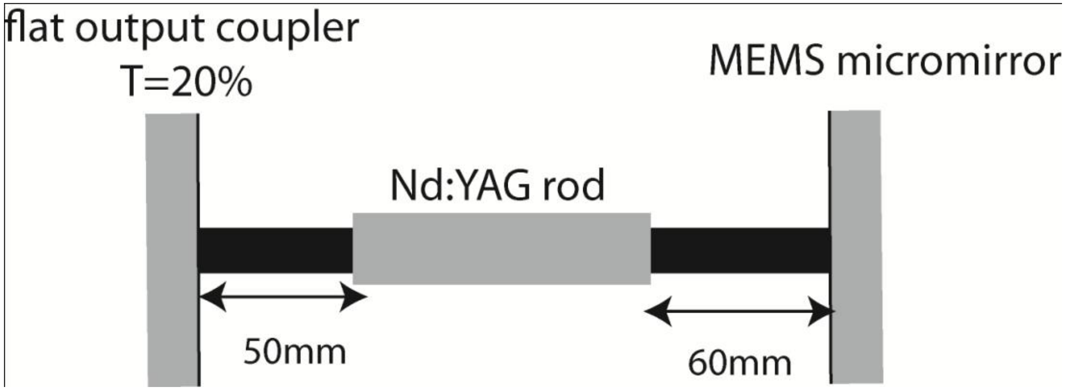
Q-switched Nd:YLF laser



Input signal: $V_{p\text{-}p}$=200V
f = 10.1kHz,
$P_{average}$=30mW
Pulse duration = 220ns
Peak power = 13.5W

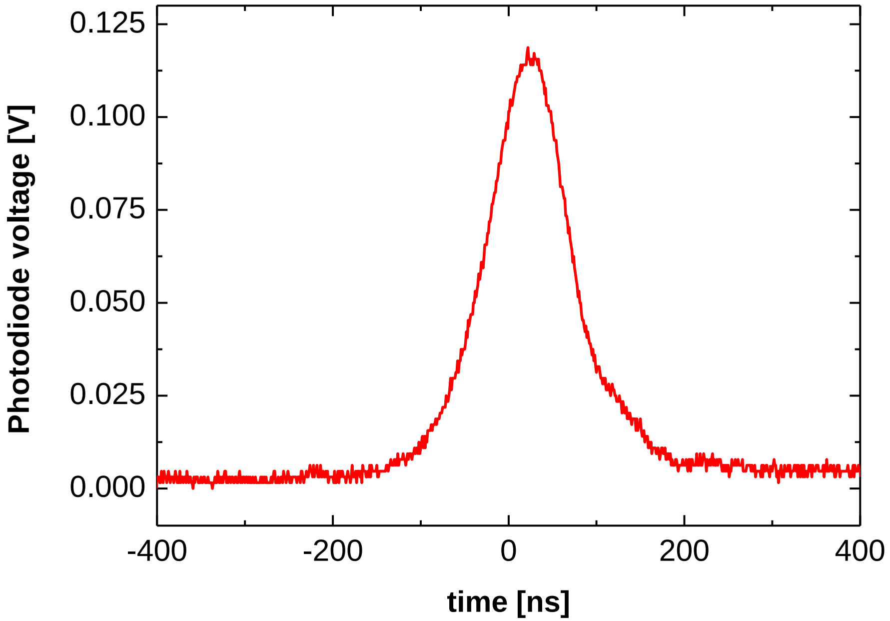
Nd:YAG laser with an intracavity electrostatic micromirror from the new generation

- 2-mirror laser cavity built around the side-pumped Nd:YAG pump module
  - with a gold-coated, 25µm thick, electrostatic micromirror as an end-mirror (beam radius~ 300µm)



- At CW operation: P_{max}=1.3W

MEMS Q-switched Nd:YAG laser



Input signal: square-wave V_{p-p}= 200V, f = 16.1kHz

(excitation at 1st harmonic of 8.05kHz mechanical movement frequency)

Laser output: $P_{average}$= 400mW, Pulse duration = 110ns, PRF = 8.05kHz

Nd:YAG laser with an intracavity electrostatic micromirror from the new generation

- 3-mirror laser cavity built around the side-pumped Nd:YAG pump module
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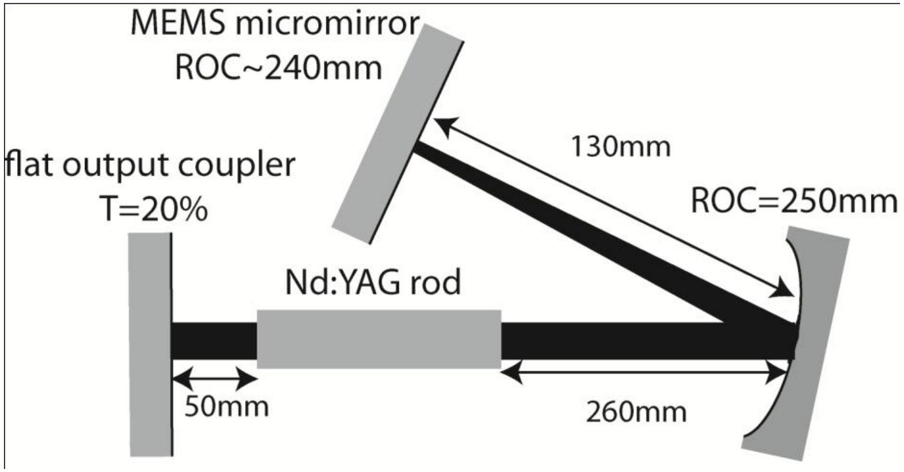
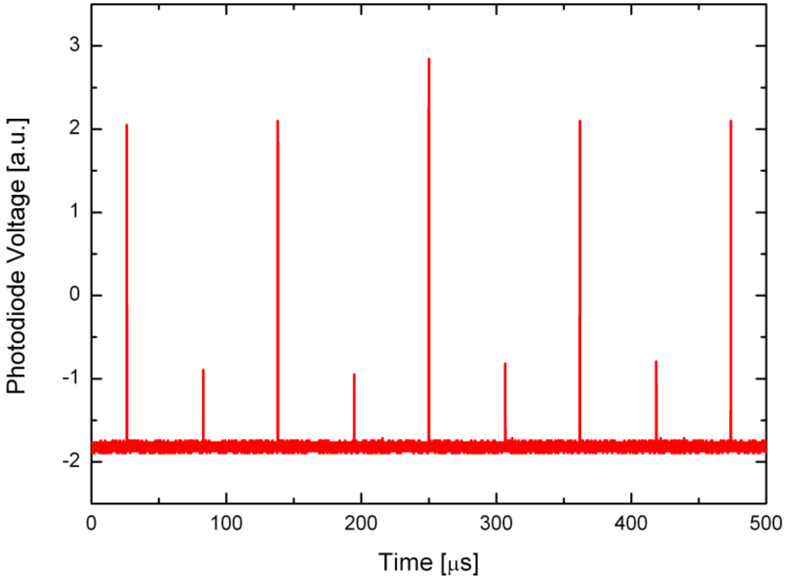
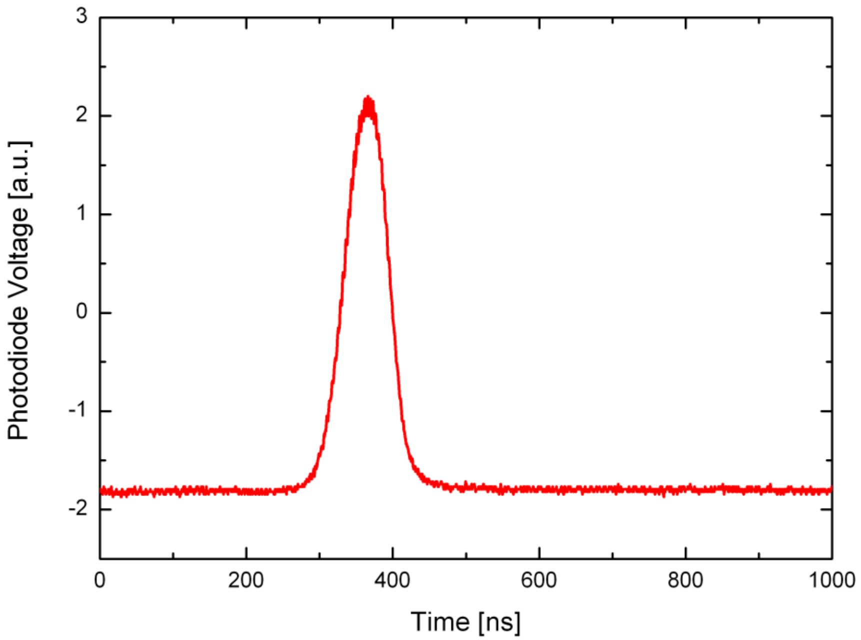




MEMS Q-switched Nd:YAG laser



Input signal: square-wave V_{p-p}= 200V, f = 17.9kHz

(excitation at 1st harmonic of 8.9kHz mechanical movement frequency)

Laser output: $P_{average}$= 30mW, Pulse duration = 70ns, PRF = 8.9kHz (between the large pulses)

The routes to power scaling

- Use a wavelength where silicon is transparent (>1.2μm).
  - No visible surface deformation with 200mW of CW incident power at λ=1.24μm

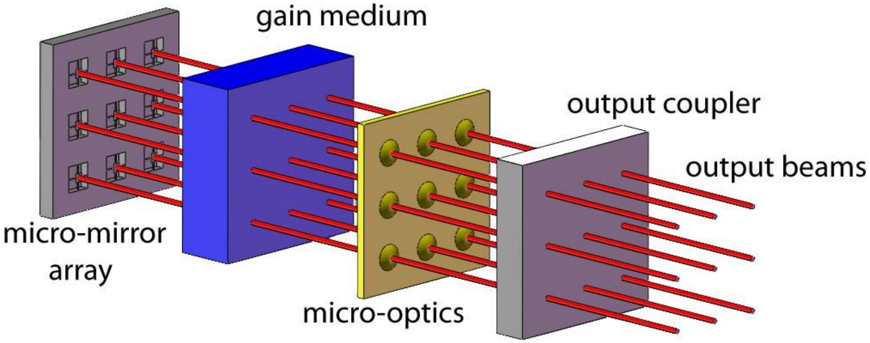
- Develop *athermal* MEMS mirrors
  - Designing be-spoke coatings to reduce the bimorph effect
    - Hybrid Au/dielectric coating (to reduce the difference in thermal expansion coefficient responsible for the deformation)
    - Same dielectric coatings on both faces of the silicon chip

Conclusions

- Successful temporal modulation of two Nd:based laser cavities using an intra-cavity MEMS mirror
  - Q-switched Nd:YLF laser: minimum pulse duration 220ns with P_{peak} =13.1 W
  - Q-switched Nd:YAG laser: minimum pulse duration 110ns with P_{peak} = 450W

- Output power limited by the heat-induced surface distortion of the MEMS mirror

- Potential for micromirrors array
  - Potential for pixellated lasers (i.e. lasers with multiple beam with independent control)



- Future work:
  - Use the MEMS in a laser cavity operating above 1.2μm
  - Developing athermal MEMS mirror

Acknowledgement

- People who contributed to this investigation:
  - IOP: David Burns, Andrew Kelly
  - CMP: Deepak Uttamchandani, Joao Gomes, Gordon Brown and Ralf Bauer
  - CUE: John Mackersie
  - Helia Photonics for the coatings

- Thanks for your attention!