On the use of ultrafast laser for permanent precision alignments and fine adjustments

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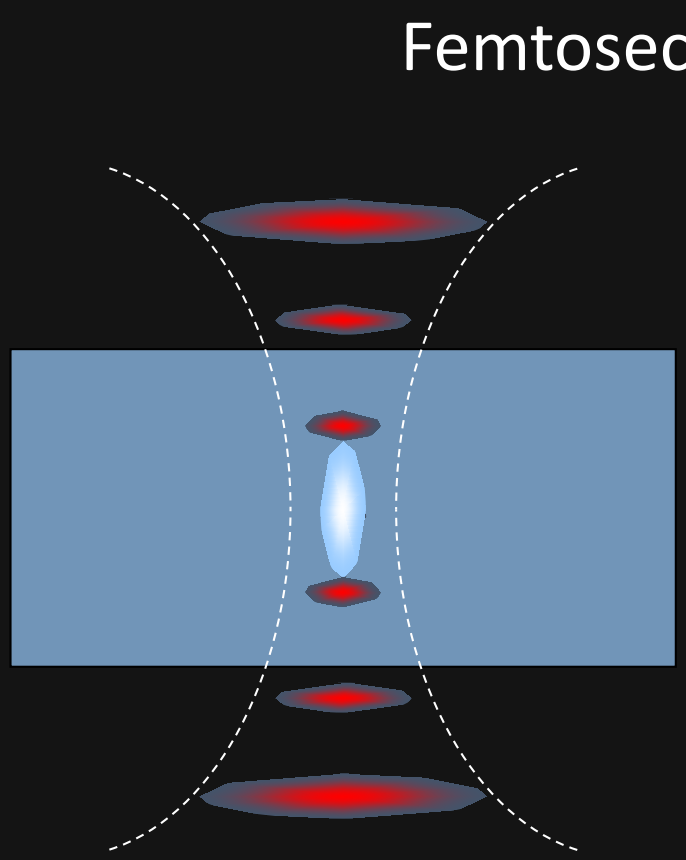
Packaging of optics: Issues and challenges…

- Sub-micron accuracy positioning requirements
- Manufacturing tolerances
- Assembly techniques
  - Post-weld shifts (Welding)
  - Glue (shrinkage)
- Robustness (shock, thermal expansion, etc.)
- Miniaturizing optical systems

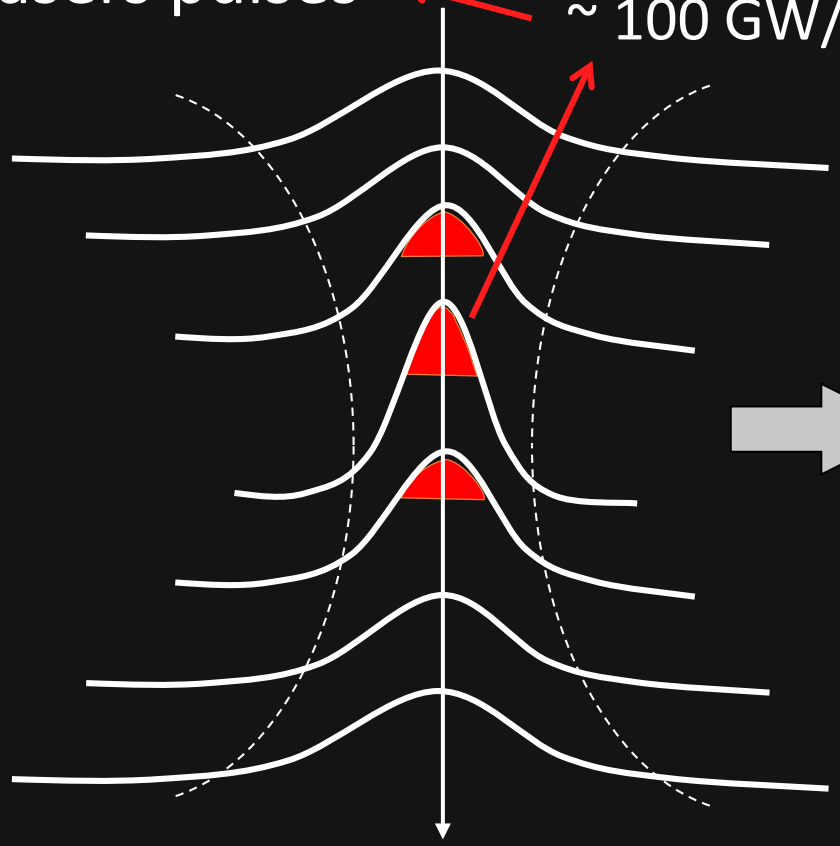
Can femtosecond lasers play a role?

Non-linear absorption opens up the 3D frontier



Femtosecond lasers pulses

~ 100 GW/mm^2

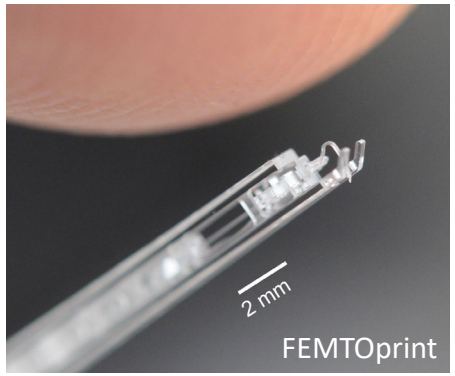


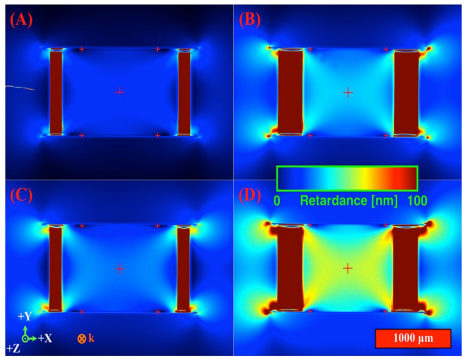
Energy is only absorbed at the focal volume

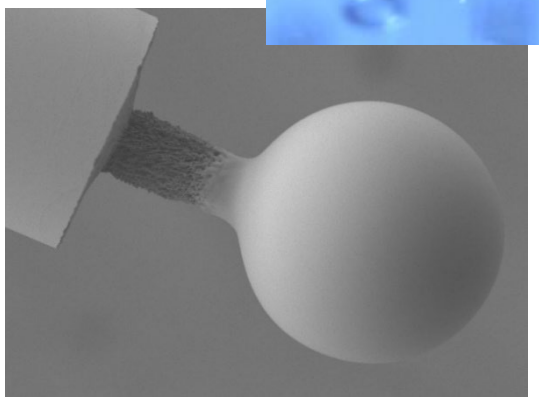
In a transparent material, energy can be absorbed in the volume

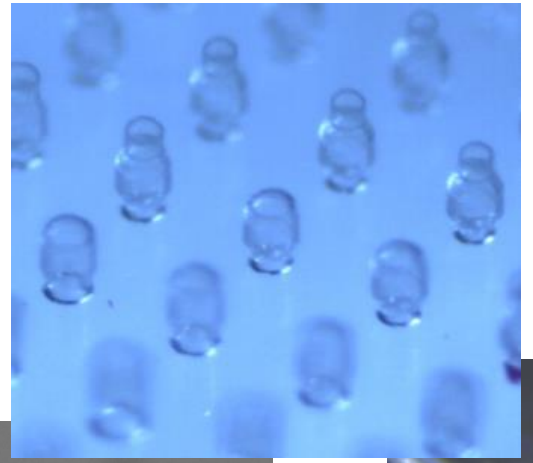
Key aspects of femtosecond laser processing

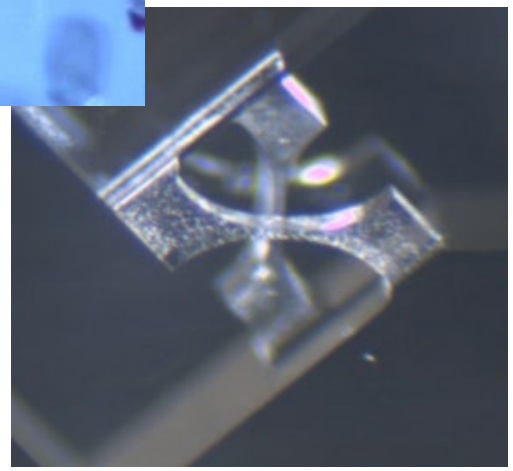
- Beyond diffraction limit: nanoscale resolution
- Ultra high-aspect ratio after etching (>1:300)
- Arbitrary 3D shapes
- Scalable
- Numerous applications in microengineering



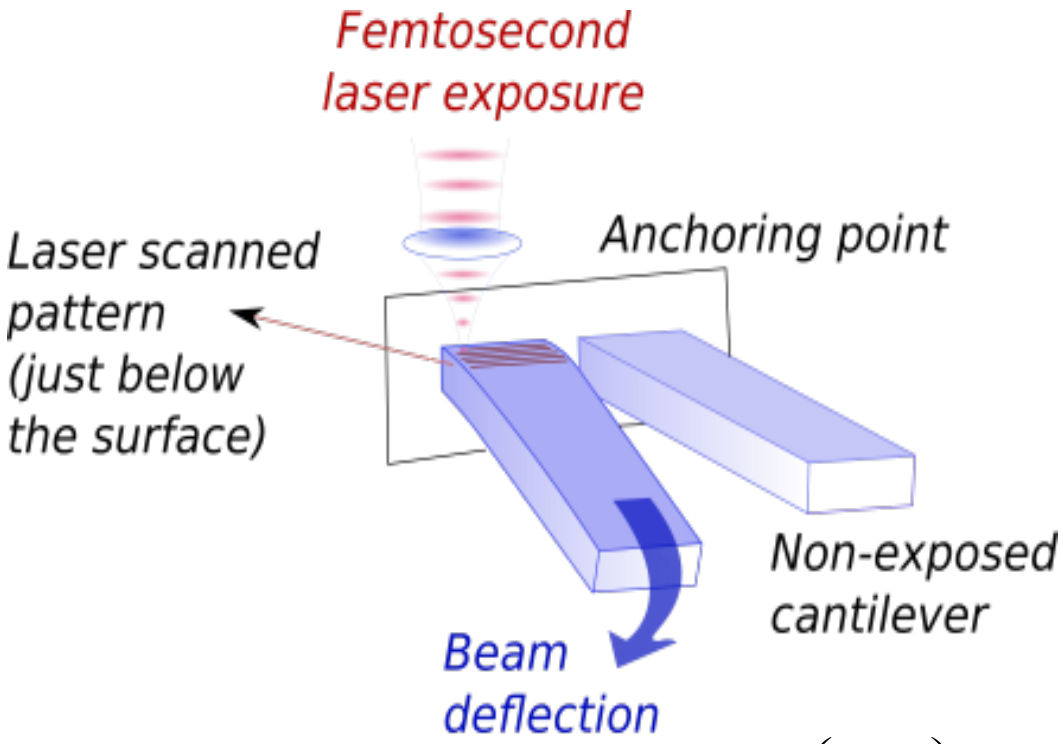


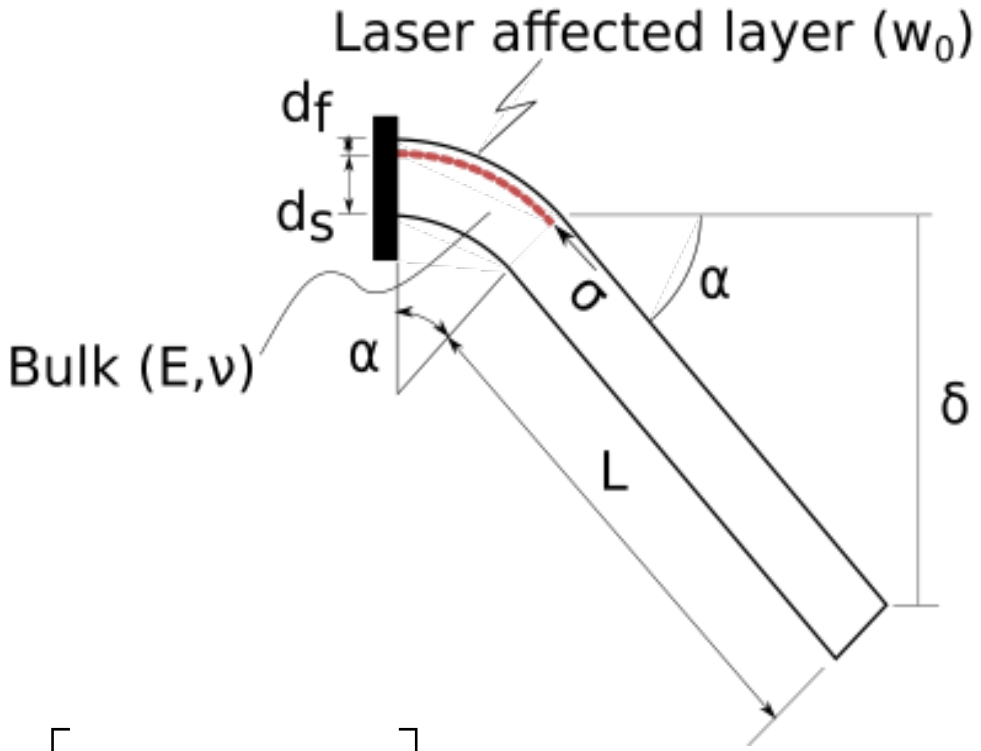






Laser induces stress and strain locally...

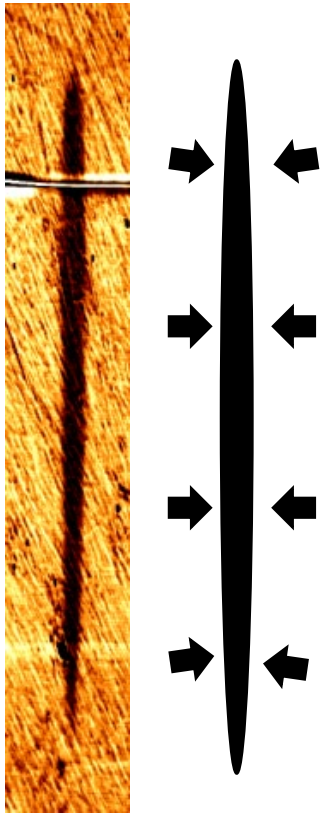




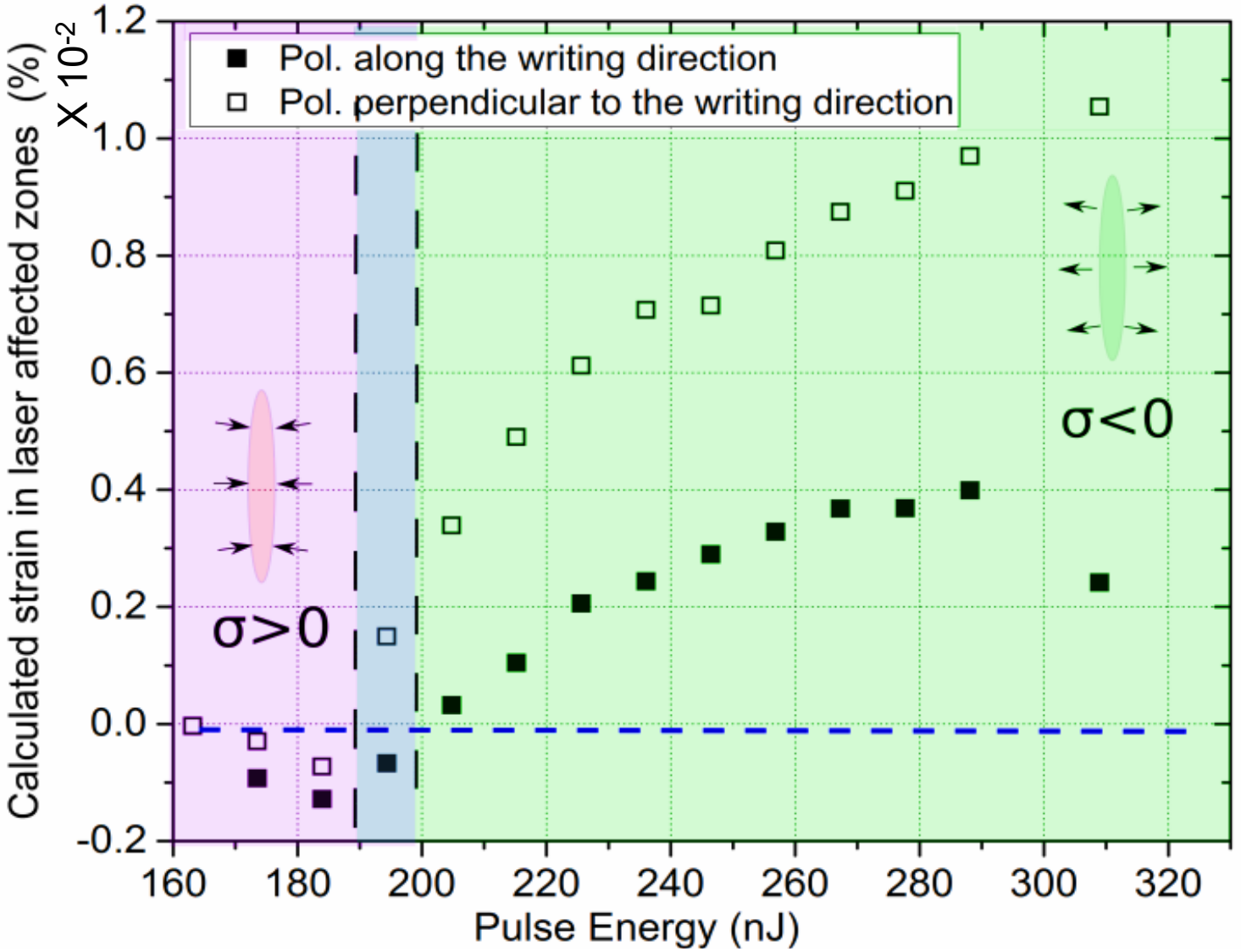
$$\varepsilon_{avg}(\delta) \approx \left(\frac{t_{sub}}{2w_0}\right)\frac{\delta}{L}, \quad \sigma_{xx}(\delta) \approx \left[\frac{Et_{sub}^2}{6w_0\left(1-\nu^2\right)t_{laz}}\right]\frac{\delta}{L}$$

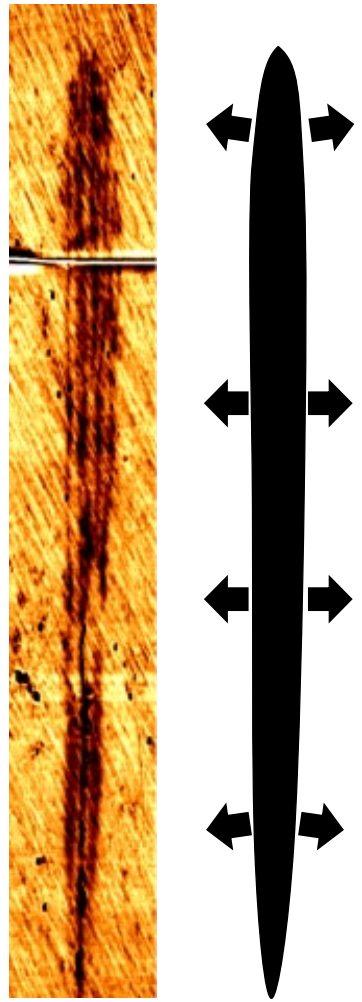
A. Champion, Y. Bellouard, Opt. Mater. Express **2**, 789–798 (2012)
Y. Bellouard, A. Champion, B. McMillen, S. Mukherjee, et al., Optica **3**, 1285 (2016).

Stress-state inversion due to pulse energy



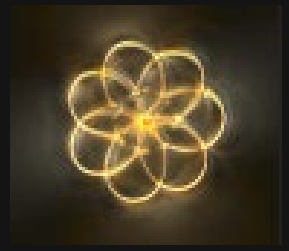
Regime I
‘Densification’





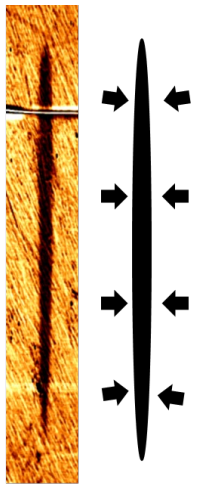
Regime II
‘Nanogratings’

Y. Bellouard, *et al.* Optica **3**, 1285 (2016)



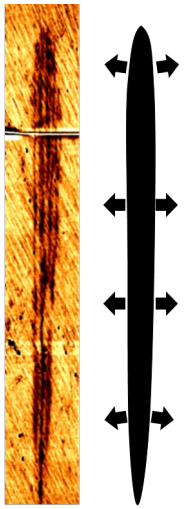
Illustrations: ultra-high accuracy packaging

Laser induced 3D localized strain + glass flexures...

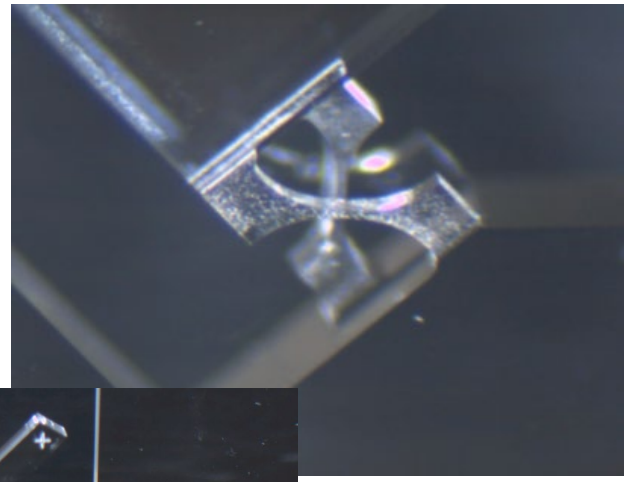


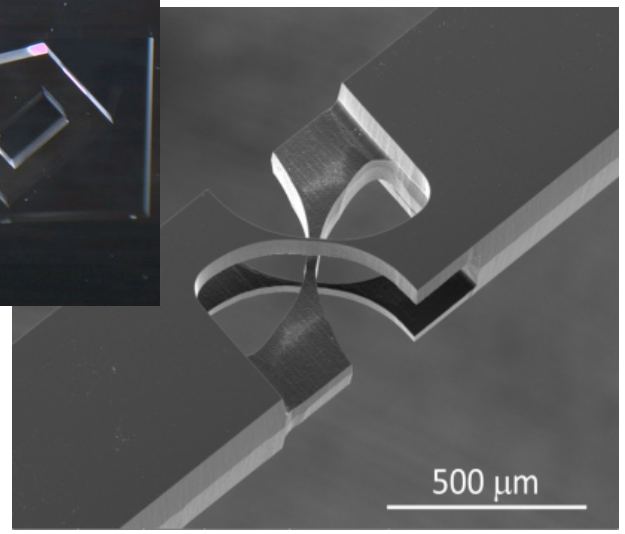
Regime I
'Densification'

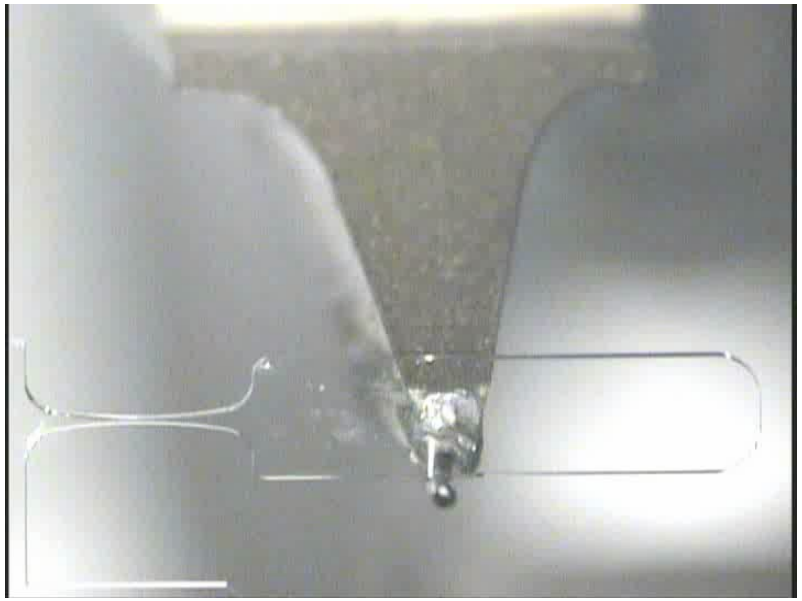
+



Regime II
'Nanogratings'

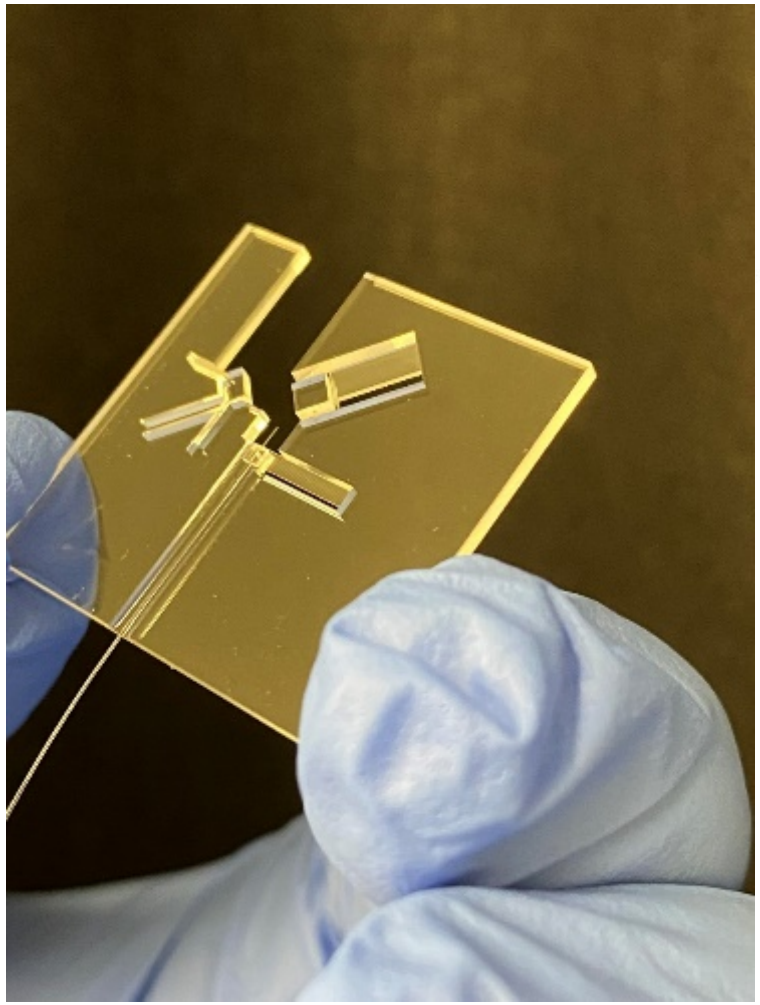


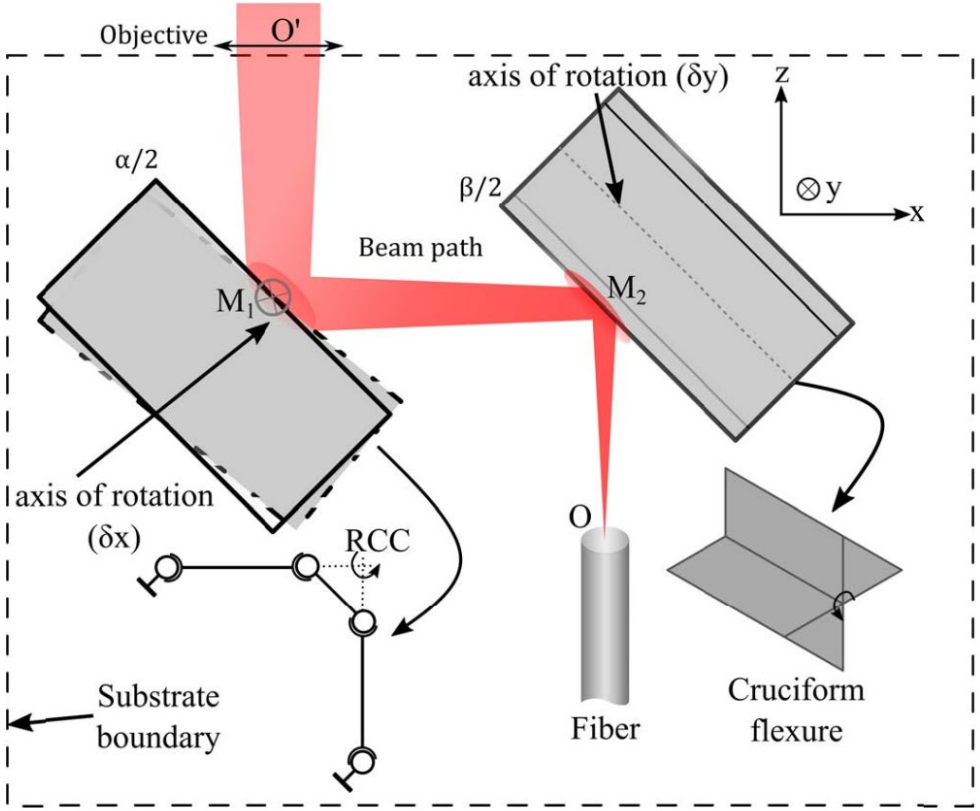


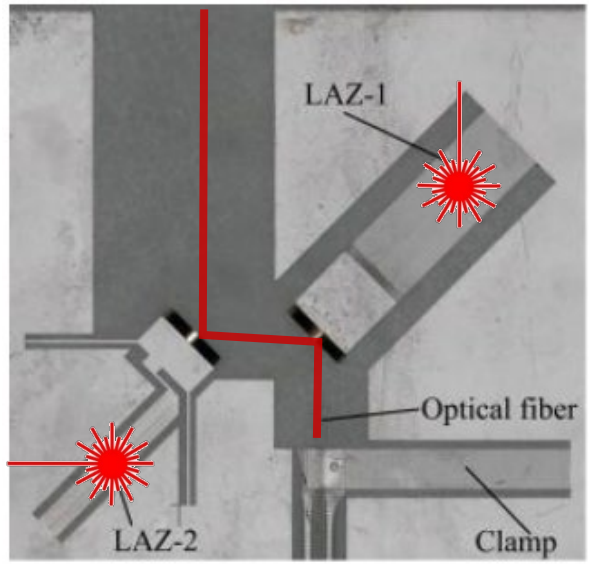


= ... non-contact, one time high precision adjustment mechanism.

Illustration: laser-to-fibre coupling



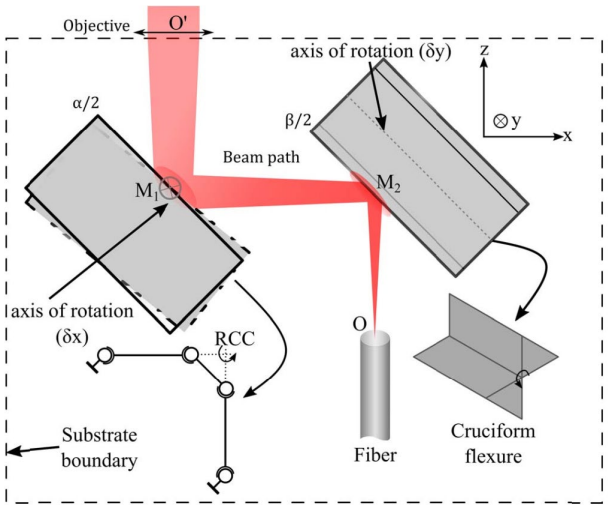


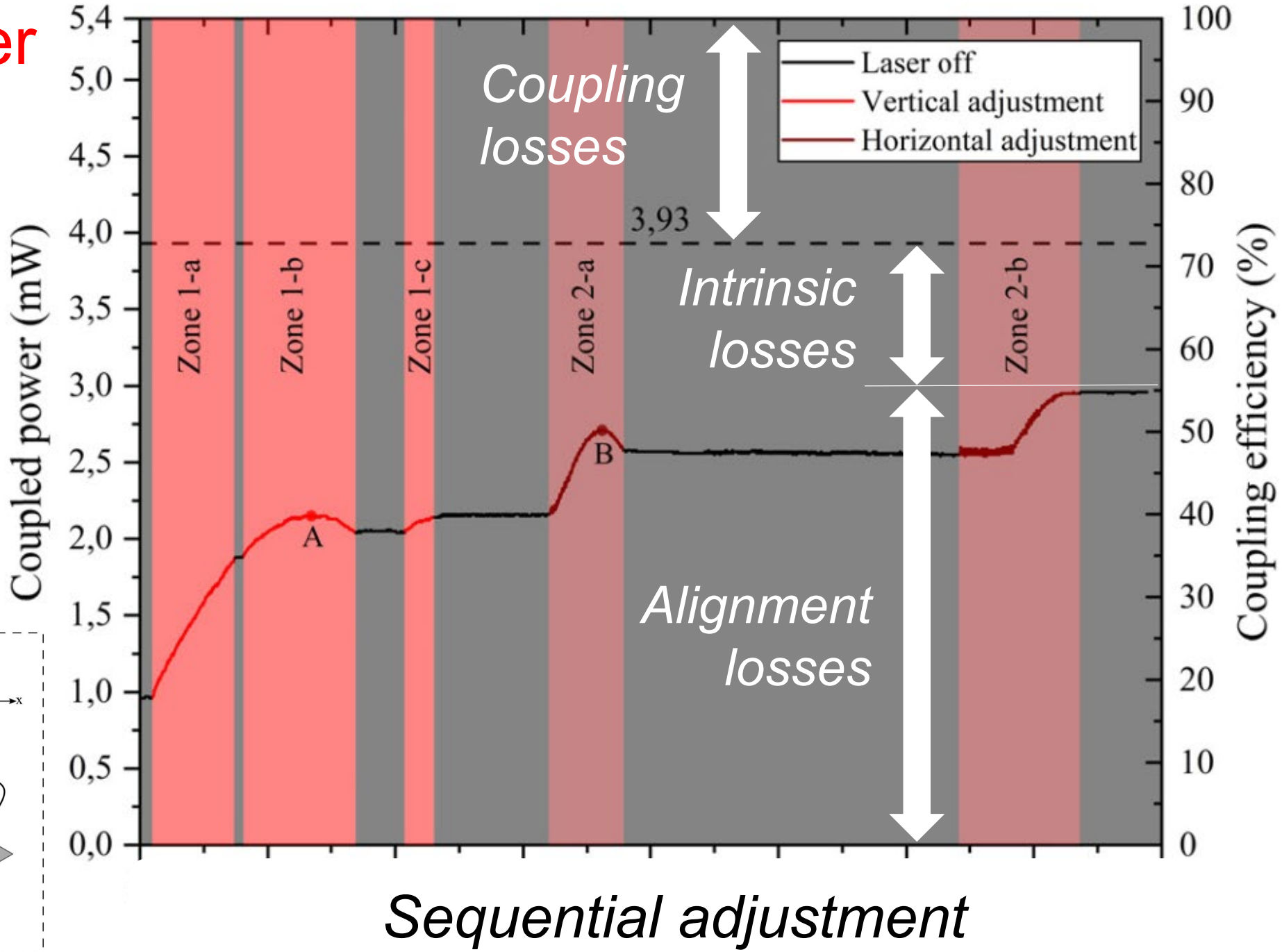


- Micro-rad alignment resolution
- Sub-nm displacement resolution
- Reach highest as possible coupling efficiency

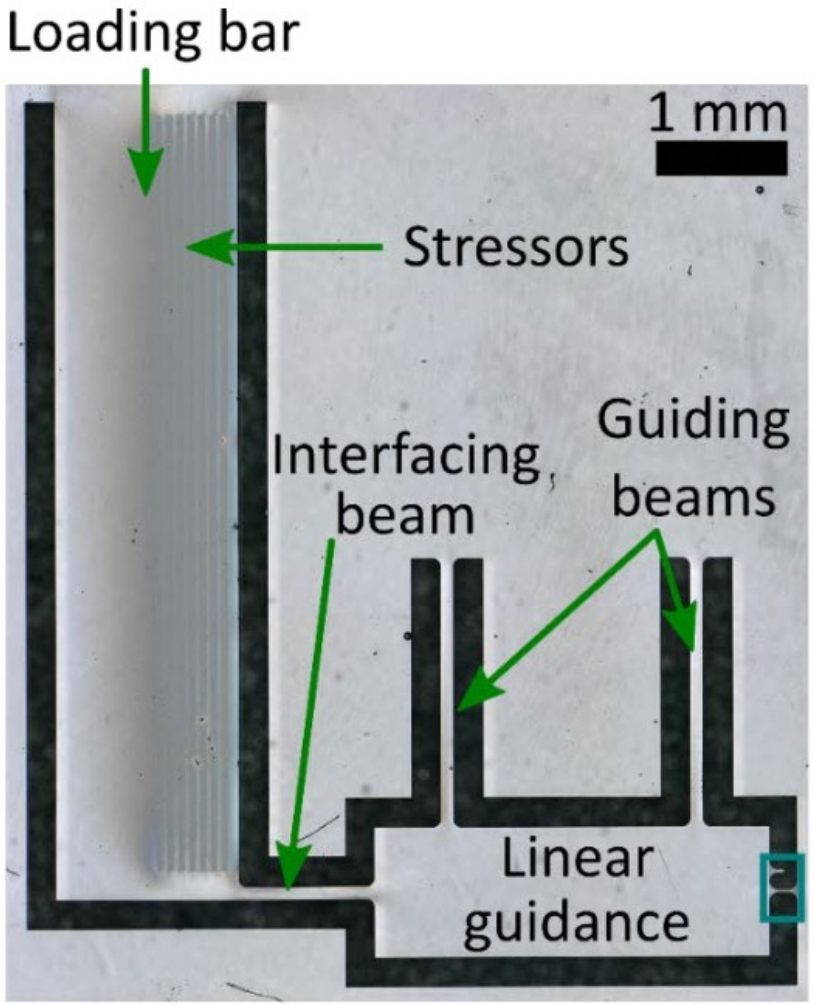
S. I. Nazir and Y. Bellouard, IEEE Trans. Compon., Packag. Manufact. Technol. (2021) http://dx.doi.org/10.1109/TCPMT.2021.3080513

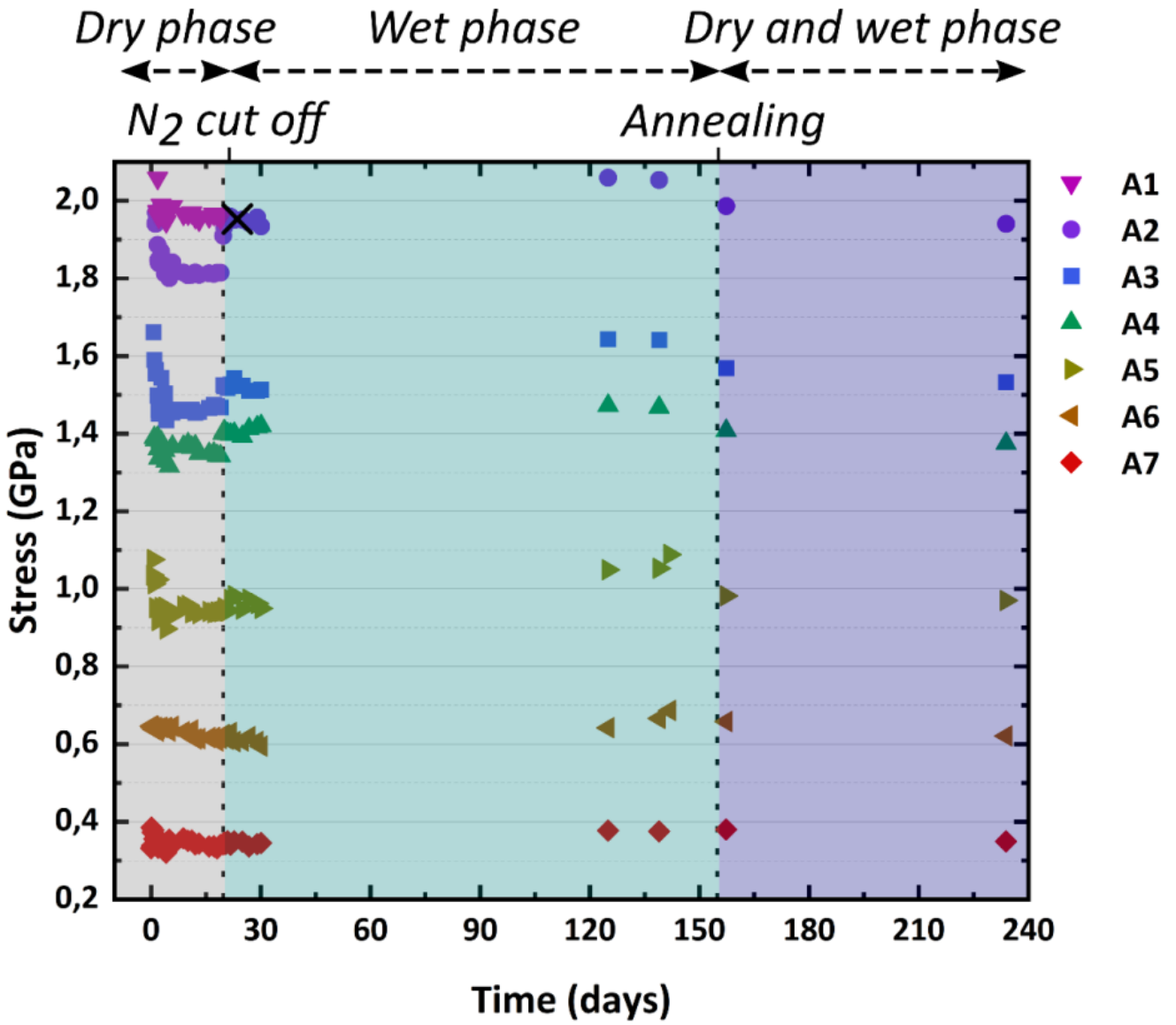
Laser-to-fiber coupling

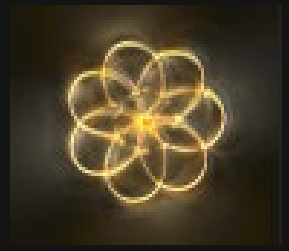




Long-term stability...

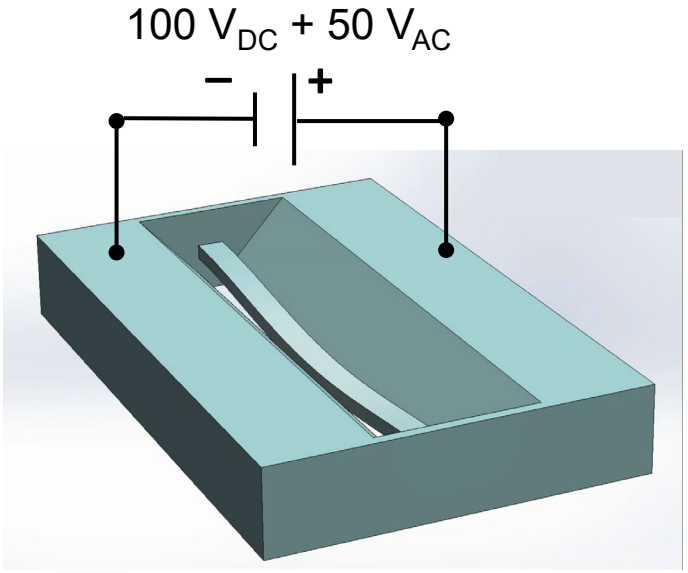


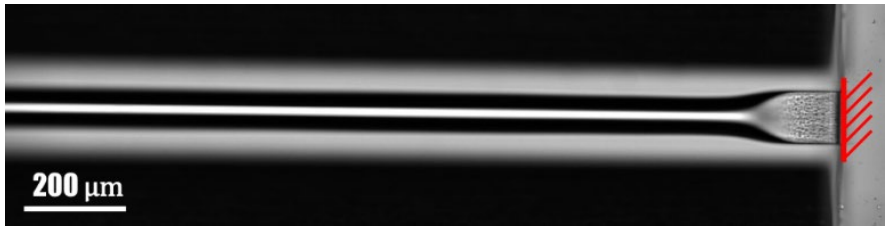


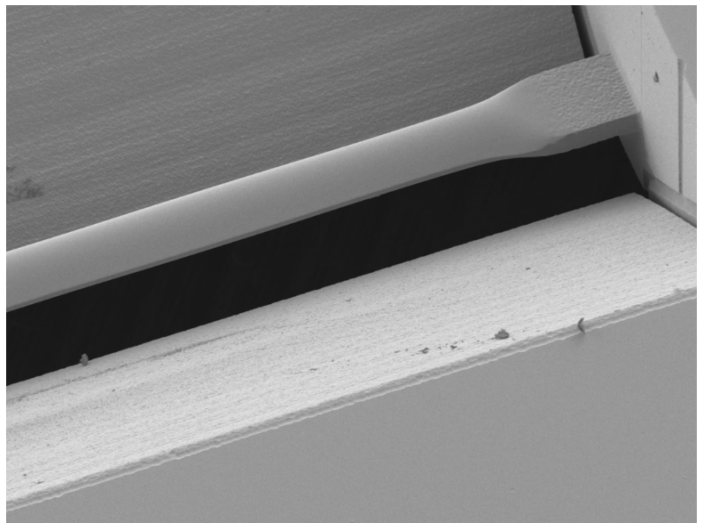


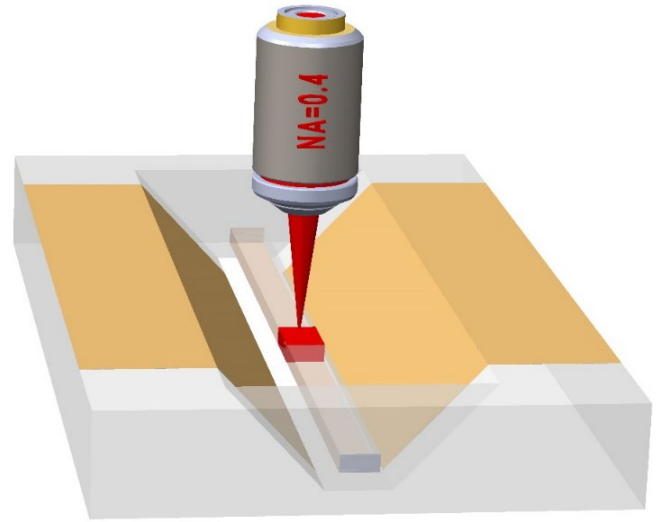
Beyond repositioning...

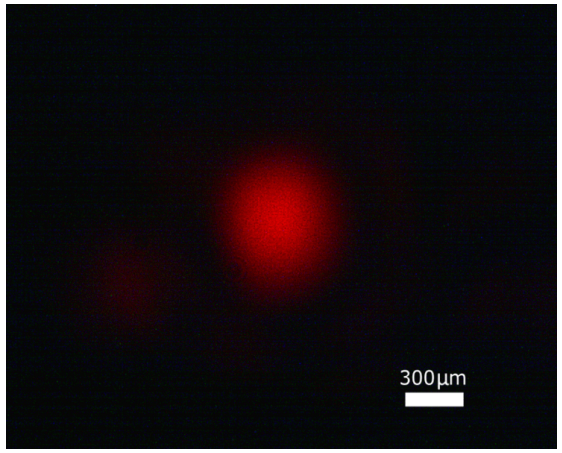
Tuning of *non-linear* optomechanical resonator











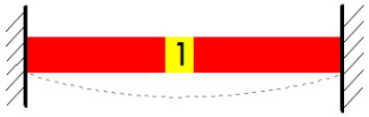
- Introduce a composite structure
  - modify beam curviness

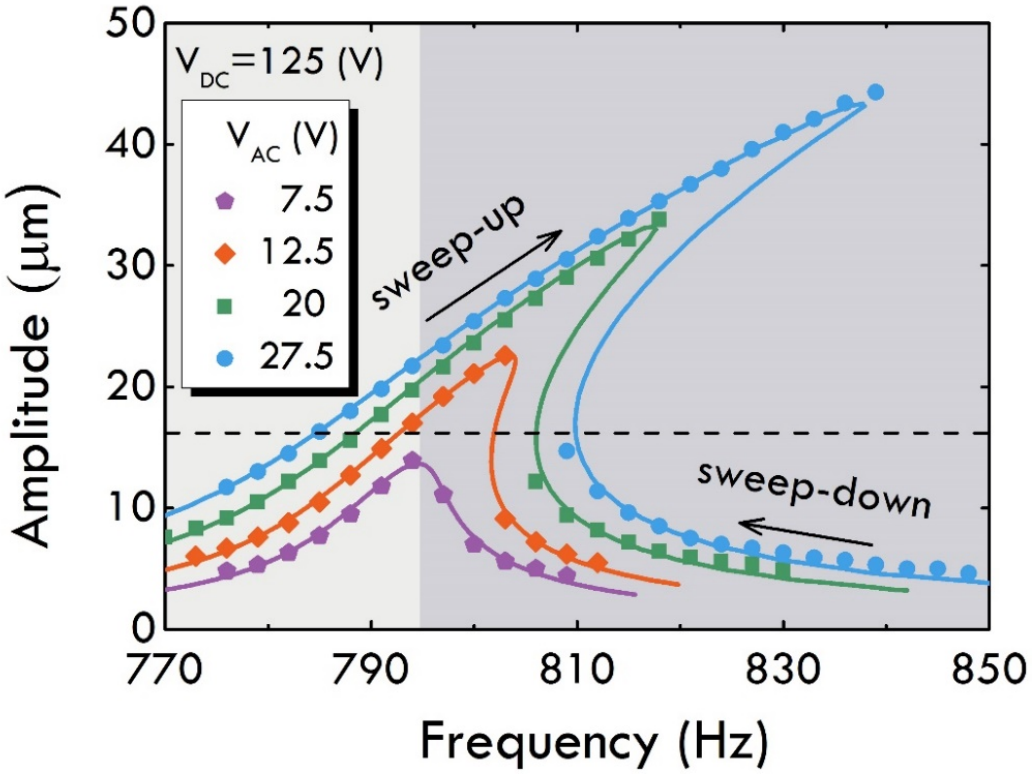
change nonlinear term k

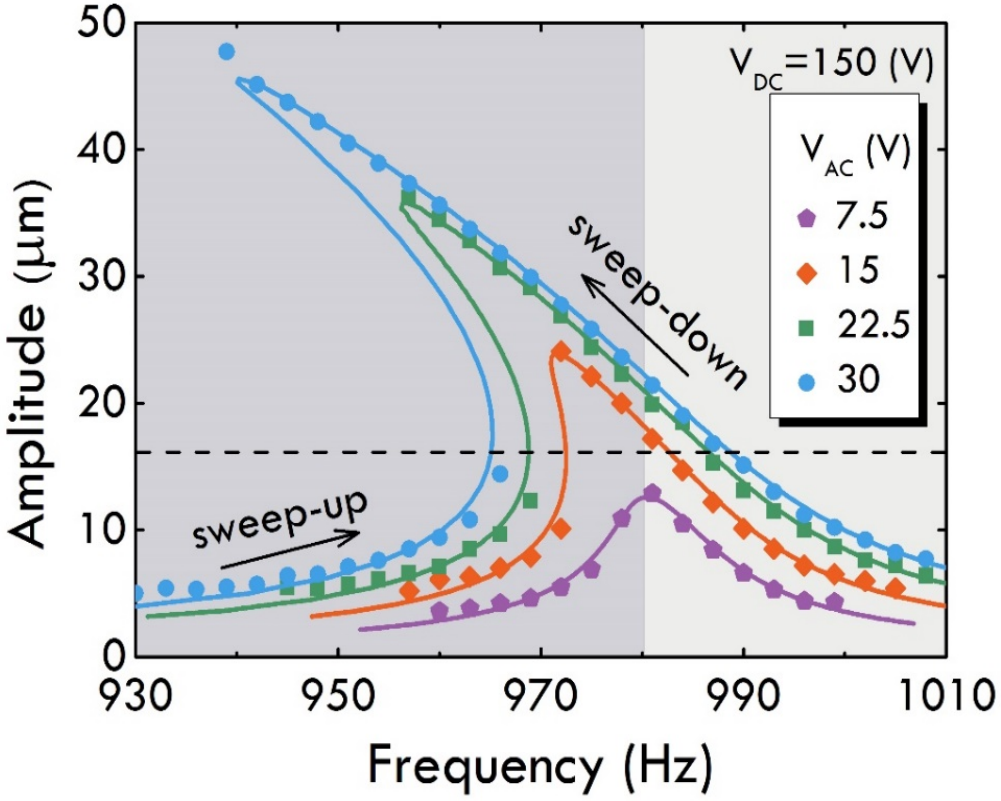
T. Yang, Y. Bellouard, Phys. Rev. Appl. **7**, 064002 (2017)

Tuning of non-linear optomechanical resonator

Laser local exposure

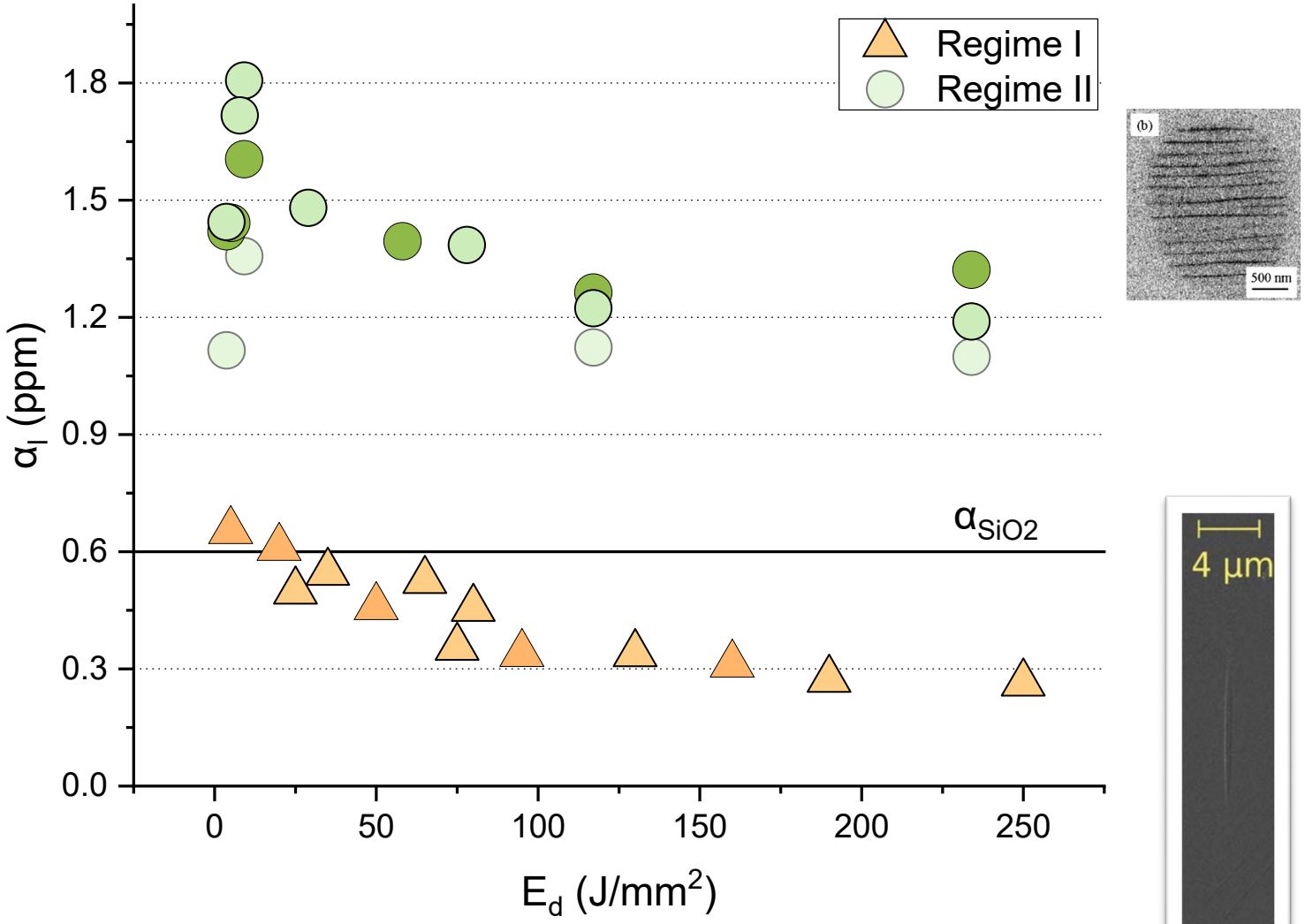






T. Yang, Y. Bellouard, Phys. Rev. Appl. **7**, 064002 (2017)

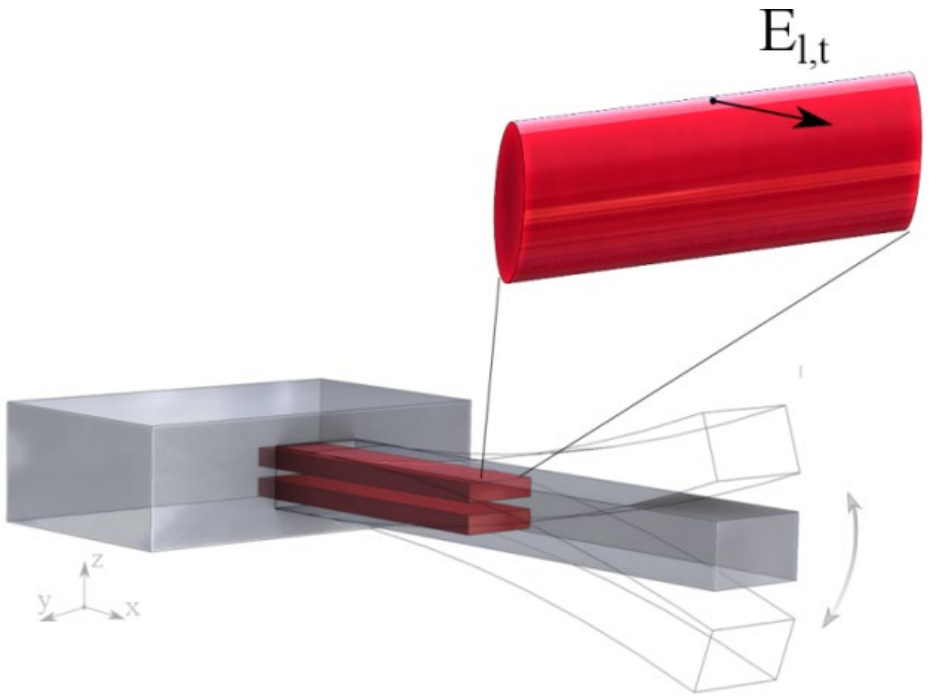
Tuning the coefficient of thermal expansion...

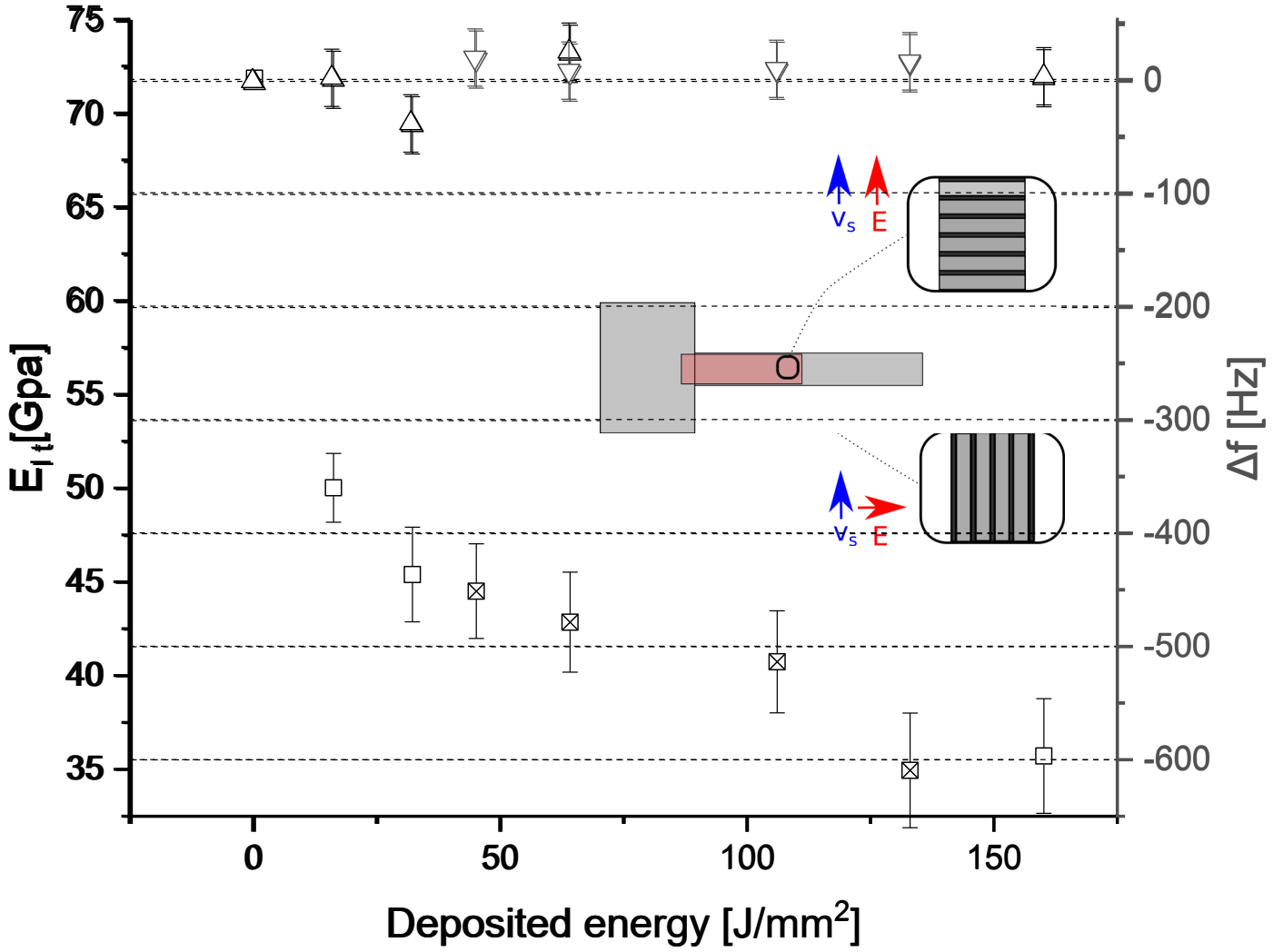


P. Vlugter, E. Block, and Y. Bellouard, Phys. Rev. Mat. **3**, (2019)

Young's modulus measurement

△ polarization= 0°
□ polarization= 90°

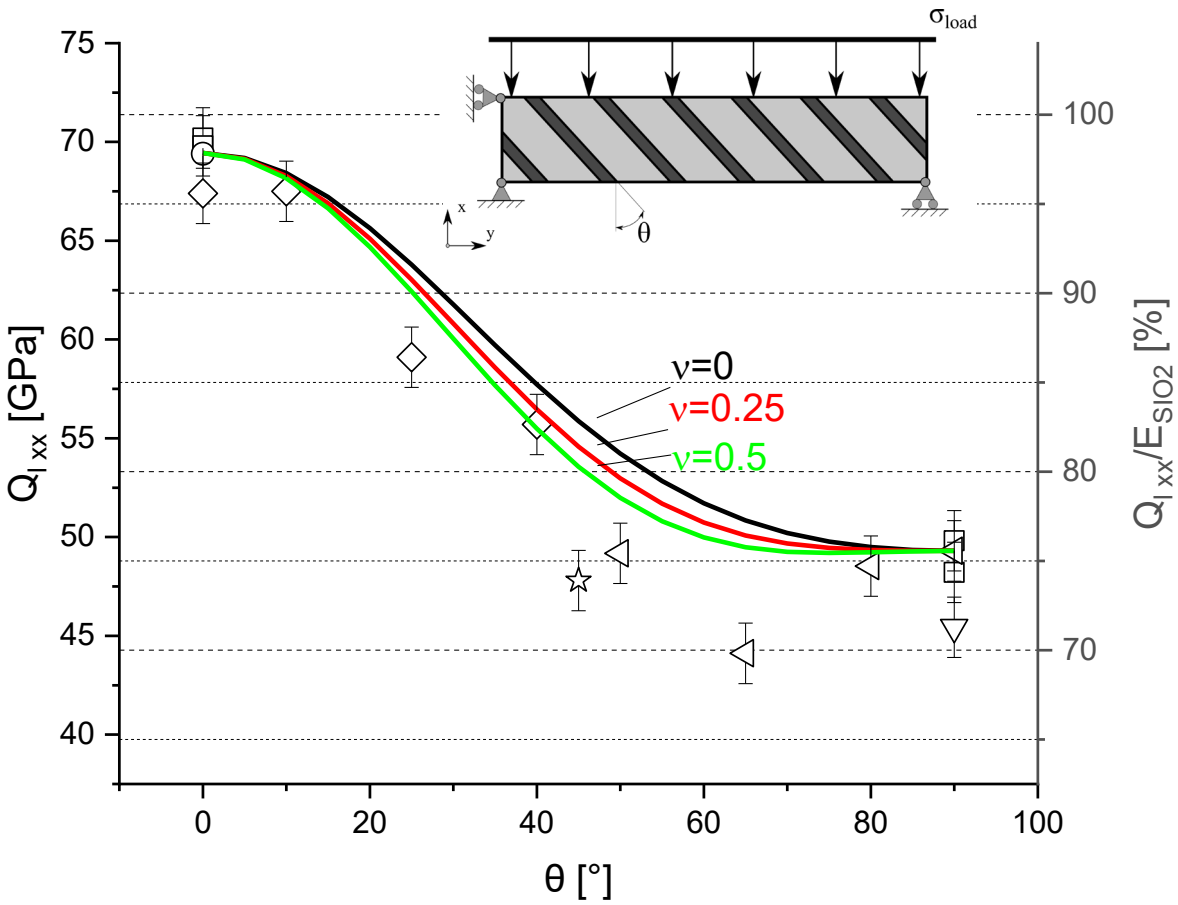




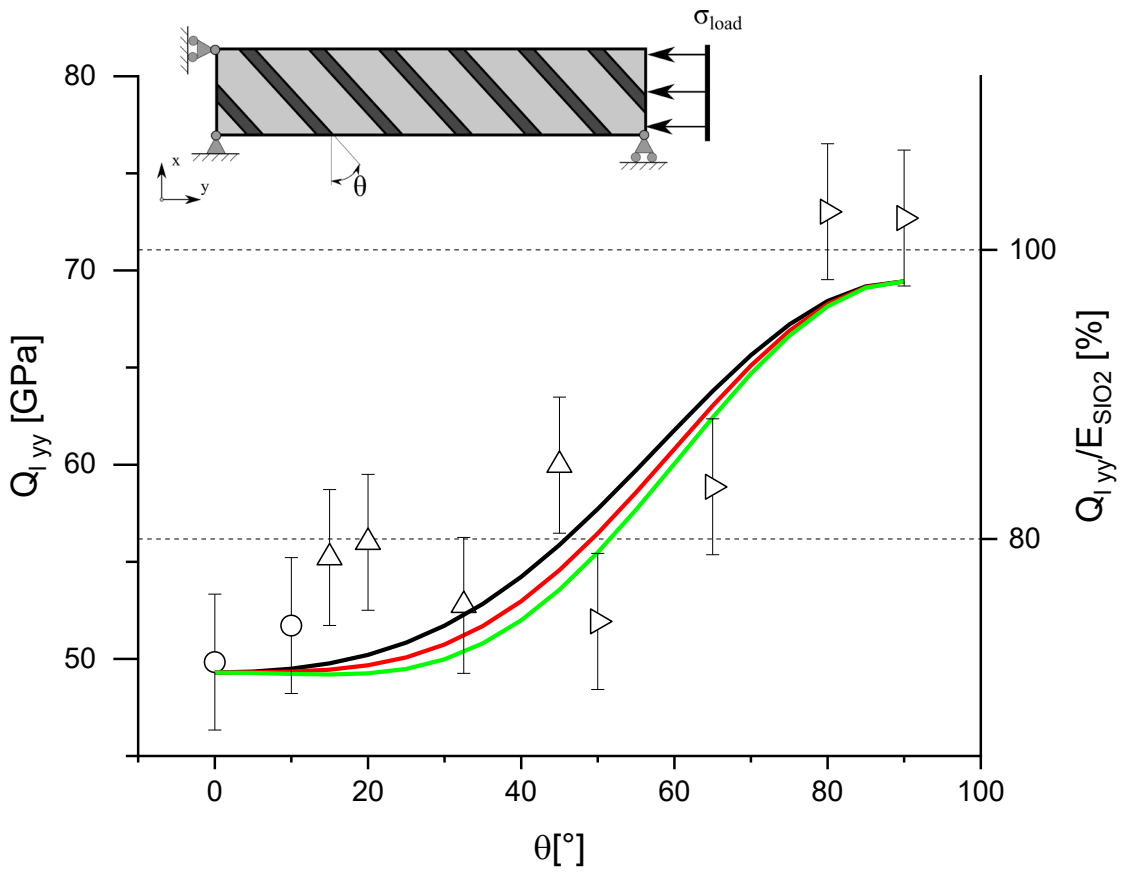
P. Vlugter and Y. Bellouard, Physical Review Materials **4**, 023607 (2020)

Tuning Young's modulus with laser patterns orientation

Transverse



Axial



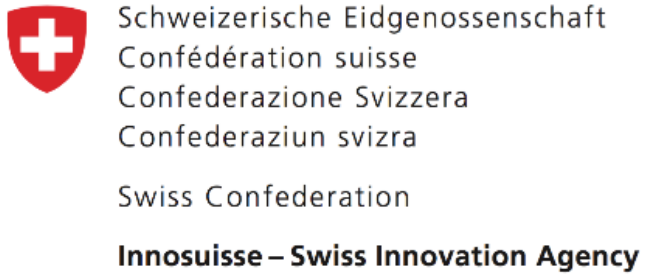
P. Vlugter and Y. Bellouard, Physical Review Materials **4**, 023607 (2020)

Femtosecond laser exposure offers...

- A *non-contact* method for nanometer resolution repositioning capabilities
- Tuning CTE / reduced for shorter pulses (<200fs) and increased in longer pulses (>200fs)
- Tuning the Young's modulus as a function of laser-written patterns
- 'Direct write composites' with tuned stiffness and thermomechanical properties

Thanks!

- Lab members who specifically contributed to this talk: Pieter Vlugter, Saood Nazir, Tao Yang
- FNS / SNF – Swiss National Science Foundation
- InnoSuisse
- European Research Council
- Sponsoring Richemont International




EPFL
Platform II
E-STOP
0.545 mm