Volume variation after femtosecond laser exposure in fused silica in two regimes

Department of Mechanical Engineering

Technische Universiteit Eindhoven University of Technology

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A. Champion, Y. Bellouard

Eindhoven University of Technology

Introduction

Femtosecond lasers can be used for producing integrated microsystems in fused silica. The laser is not used for ablating materials but rather for modifying their structure.

Problem statement

Femtosecond laser exposure of fused silica below the ablation threshold leads to two types of modifications: homogeneous modifications and self-organized nano-scale gratings [1-3].

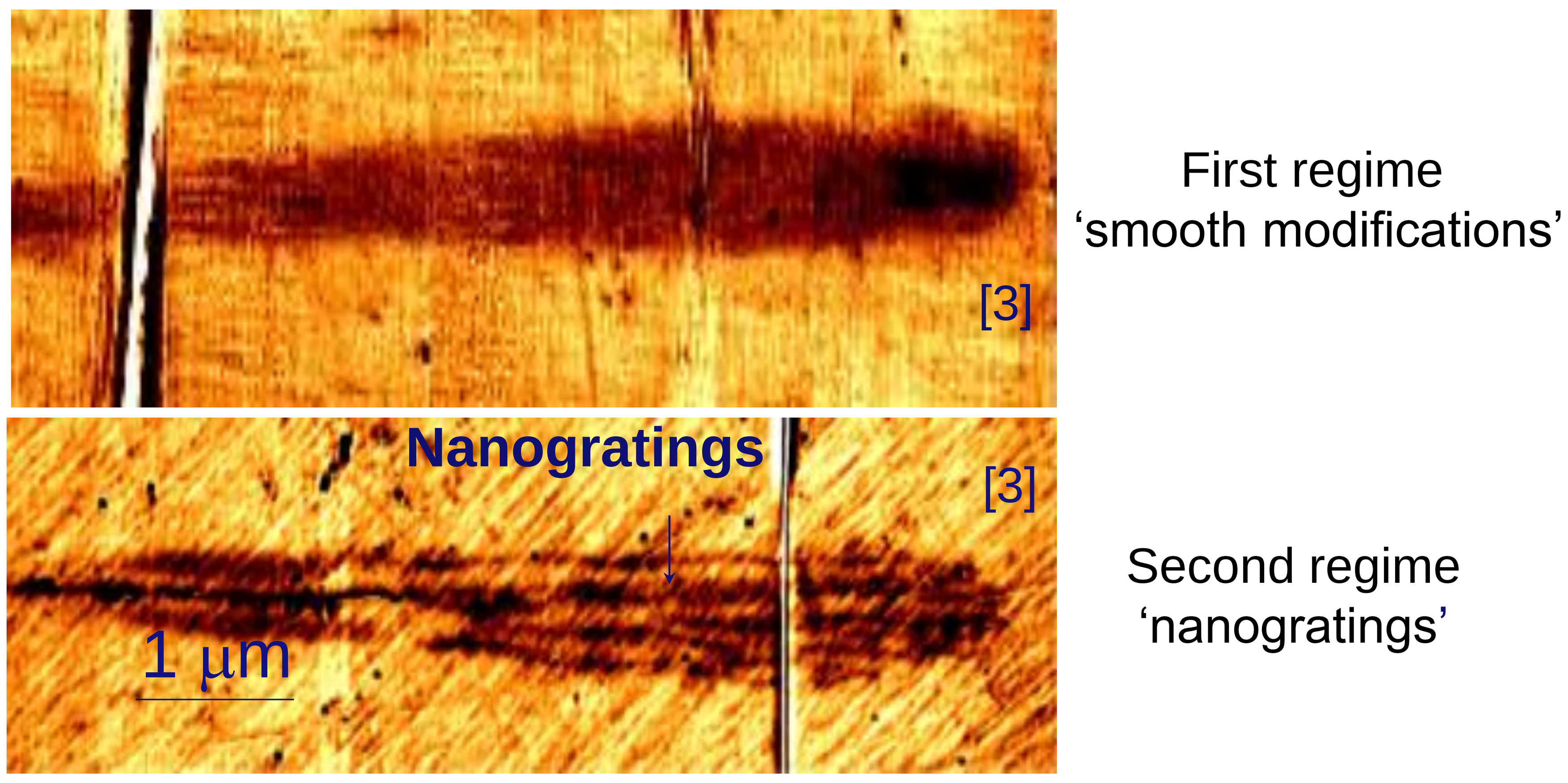

Figure 1: Atomic Force Microscope (SThM) image of transverse cut showing morphologies of laser affected zones.

In this research, we investigate volume variations associated with femtosecond laser exposure in fused silica.

Measurement method working principle

Fused silica cantilevers are used to measure volume changes resulting from partial femtosecond laser irradiations by monitoring their deflections (see Figure 2).

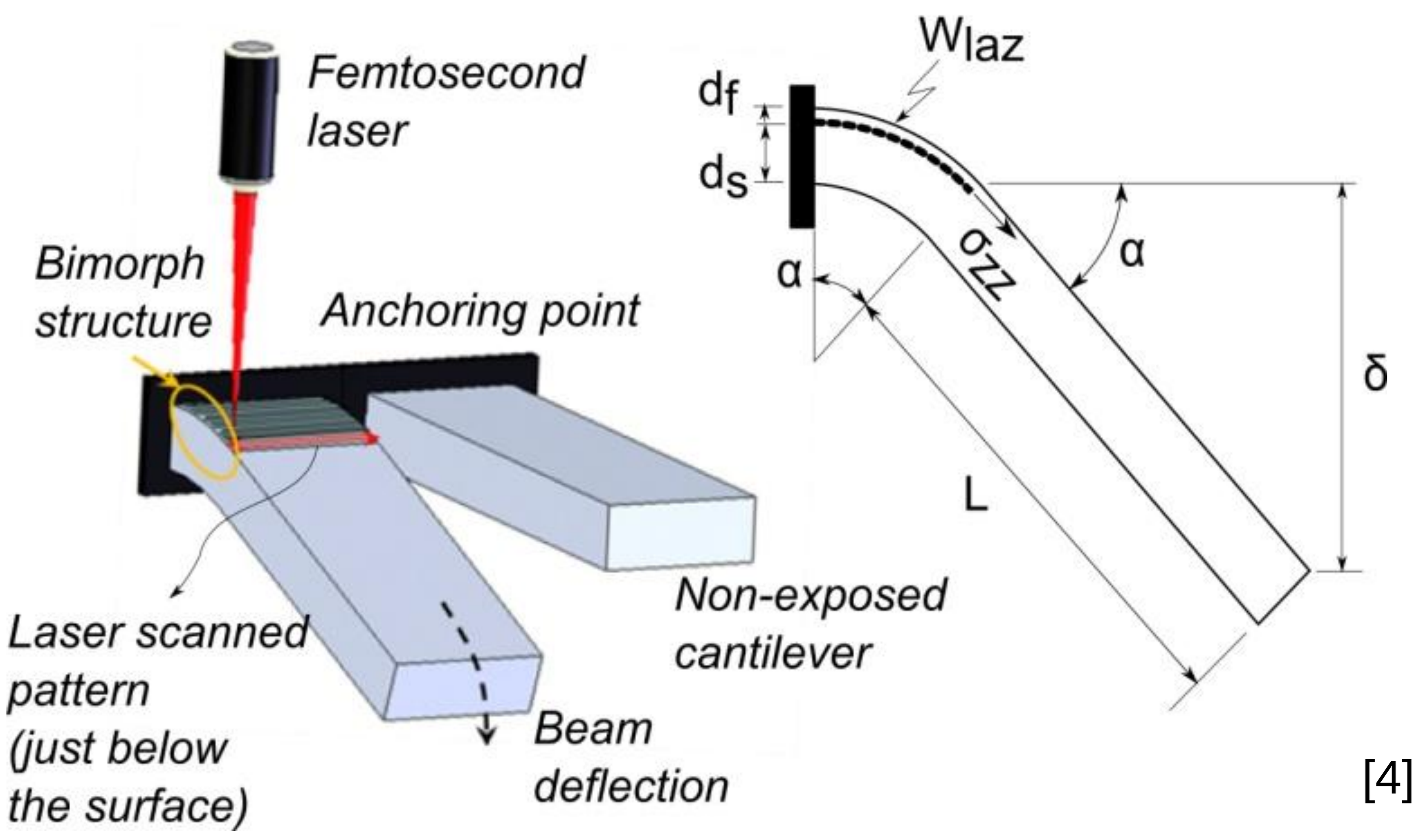

Figure 2: Measurement method principle: local volume variations induced by laser exposure on a top layer of a cantilever causes the cantilever to bend.

From the measured deflections, we calculate the volume expansion resulting from laser exposure and, using Stoney equation as a first approximation, we estimate the stress in the laser affected zone.

$$\varepsilon(\delta) \simeq \left(\frac{d_s}{2w_{laz}}\right)\frac{\delta}{L} \quad , \quad \sigma_{zz}(\delta) \simeq \left[\frac{E_s d_s^2}{6w_{laz}\left(1-\nu^2\right)d_f}\right]\frac{\delta}{L}$$

Experimental details and results

A femtosecond laser providing 160 fs pulse duration at 100 kHz is used to expose the cantilever's bases. Pulse energies span from 180 nJ to 300 nJ. Constant writing speed (10 mm/s) are used. An example of a set of cantilevers is shown Figure 3.

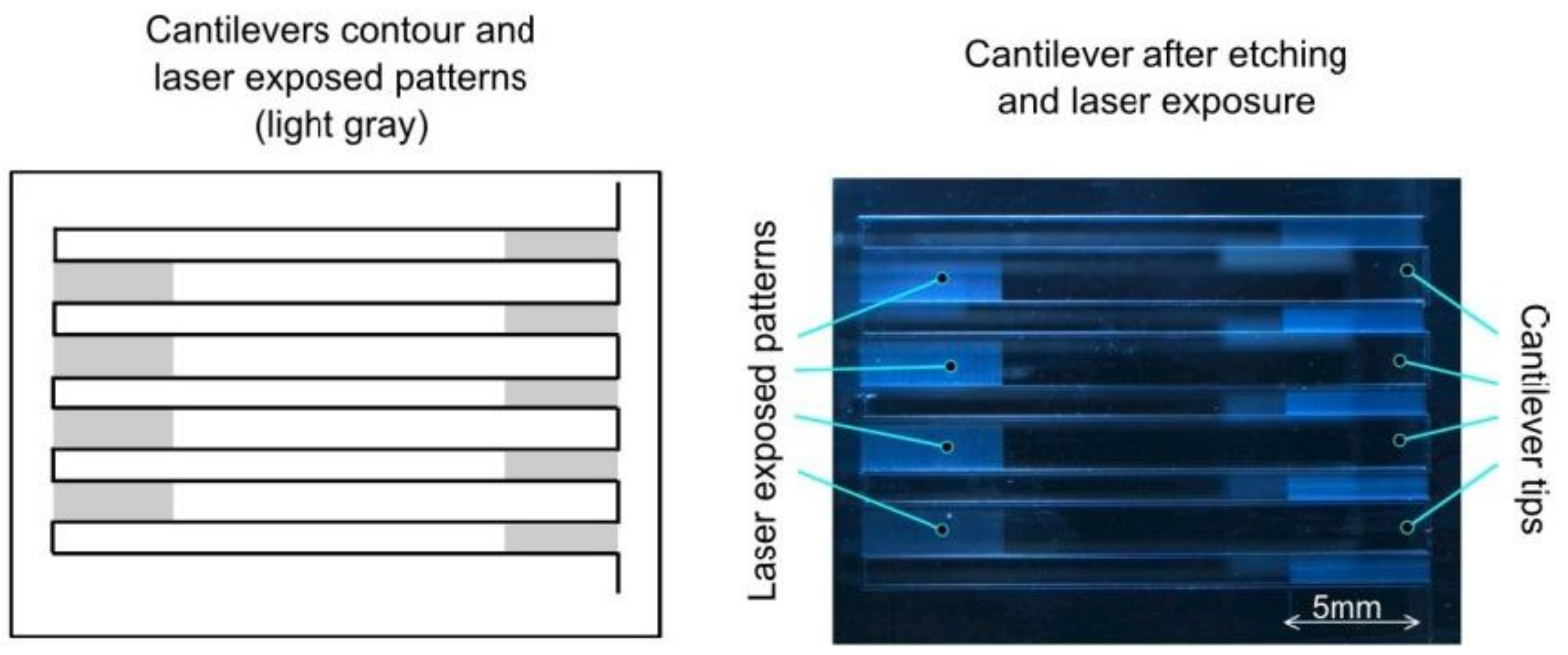

Figure 3: Fused silica cantilever schematics and optical micro-scope image after exposure.

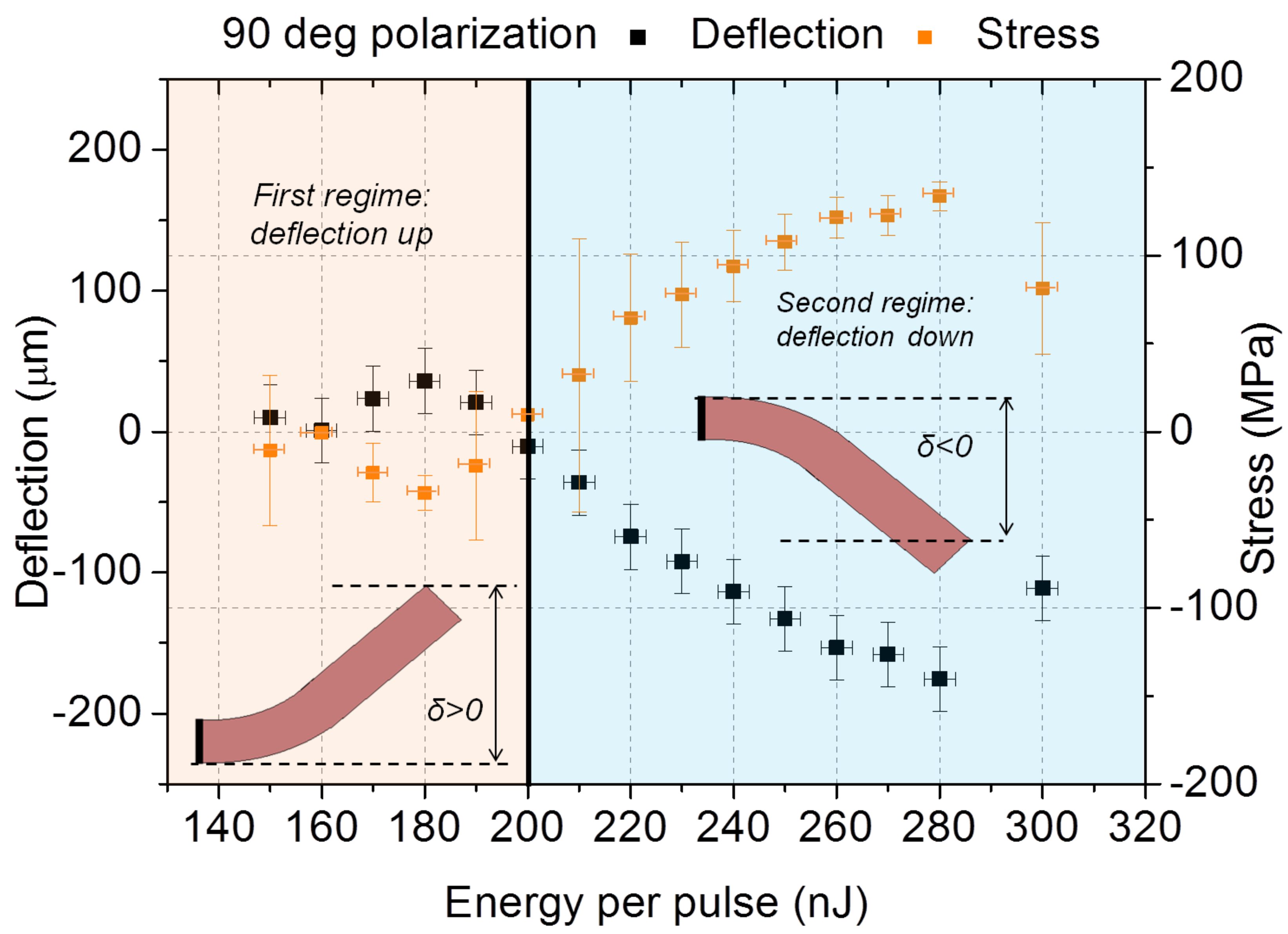

Figure 4: Measure deflections and calculated stress levels as a function of pulse energy.

Interestingly, we observe opposite behaviors between both laser exposure regimes. A densification in the low-energy regime and a volume expansion at higher pulse energies.

Conclusion

Femtosecond laser exposure with pulses shorter than 200 fs induces densification at low pulse energies and a volume expansion at higher levels. These observations are important for identifying the exposure parameters where increased refractive index and integrated optics can be achieved.

References

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