Micromachining optical waveguides using a femtosecond laser oscillator

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Alan Jamison
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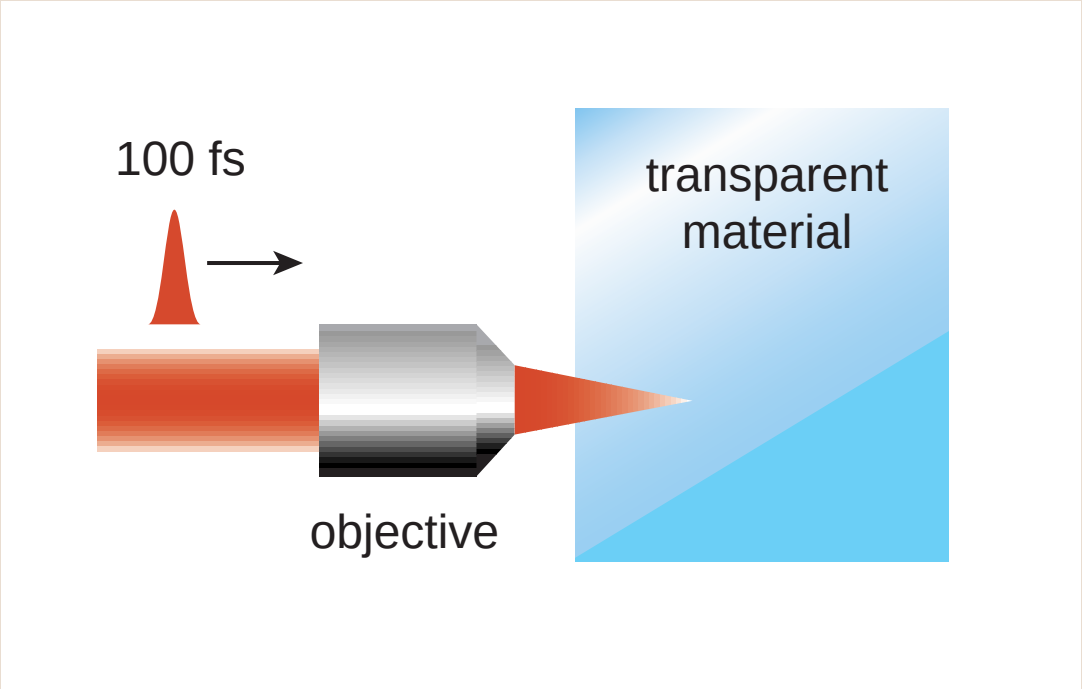
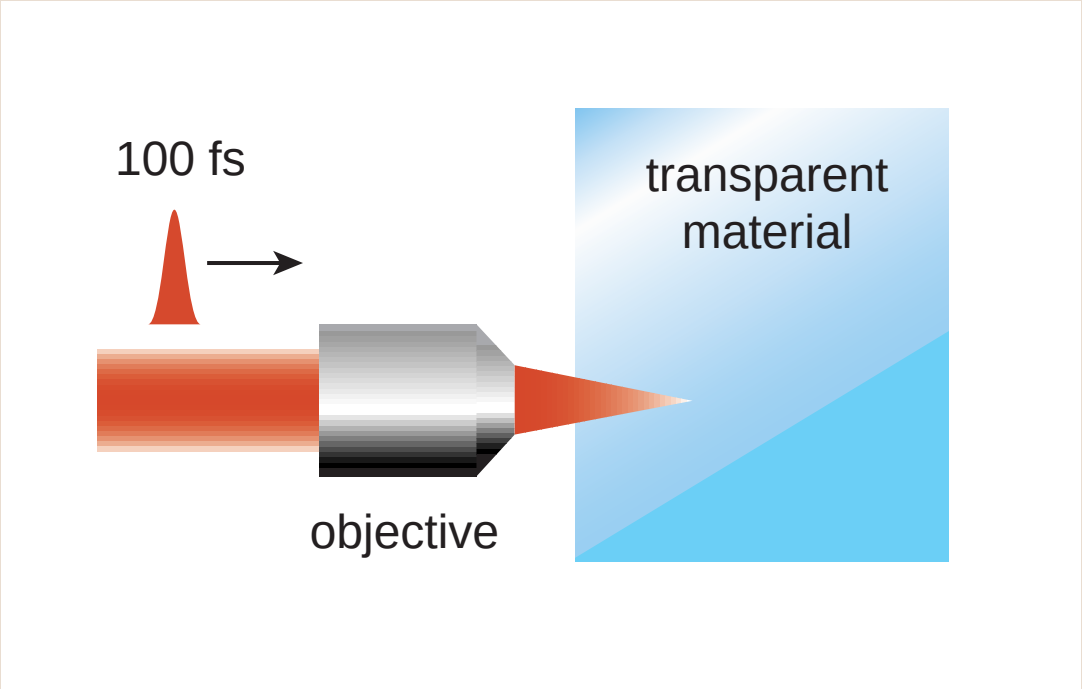
OSA Annual Meeting
October, 2000

Harvard University
Department of Physics

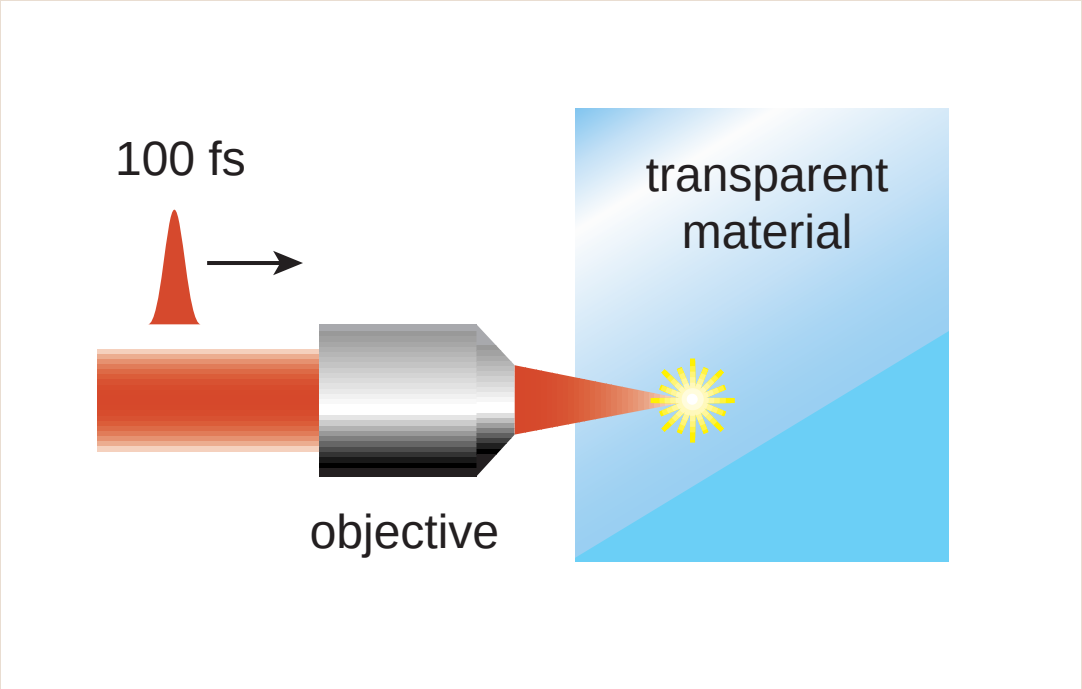
focus laser beam inside material



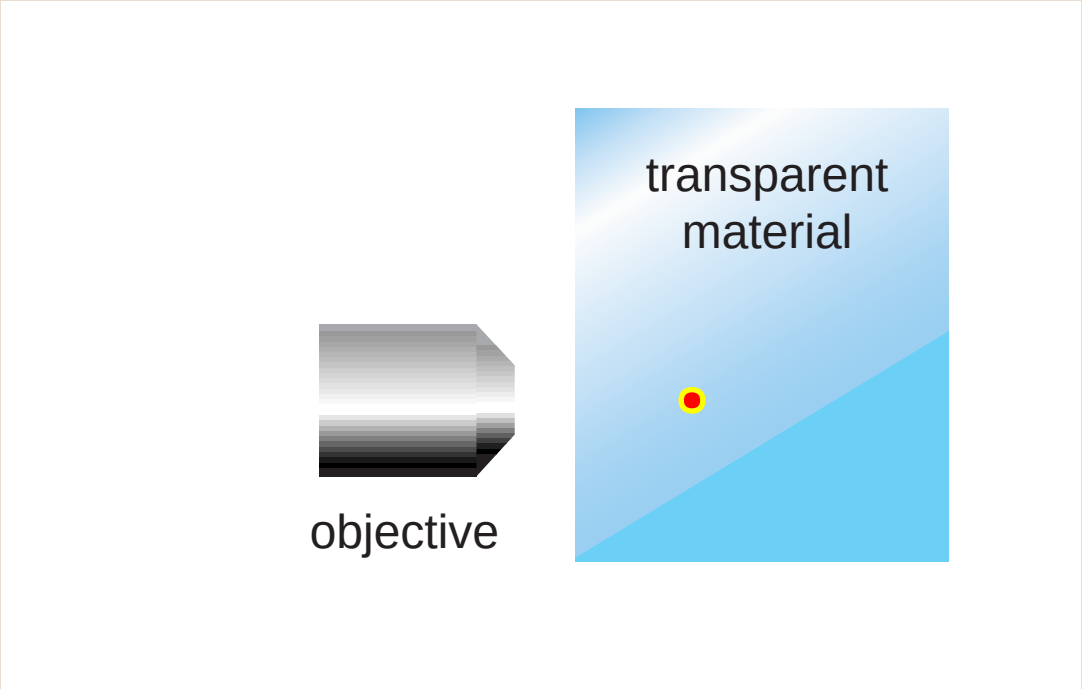
high intensity at focus



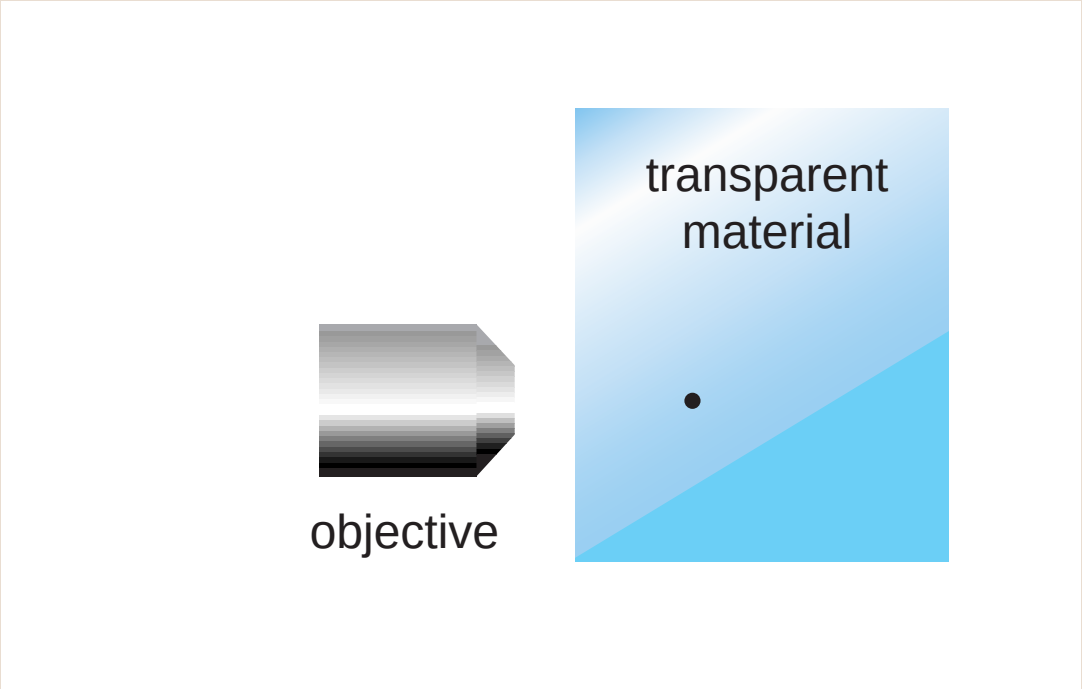
causes nonlinear ionization



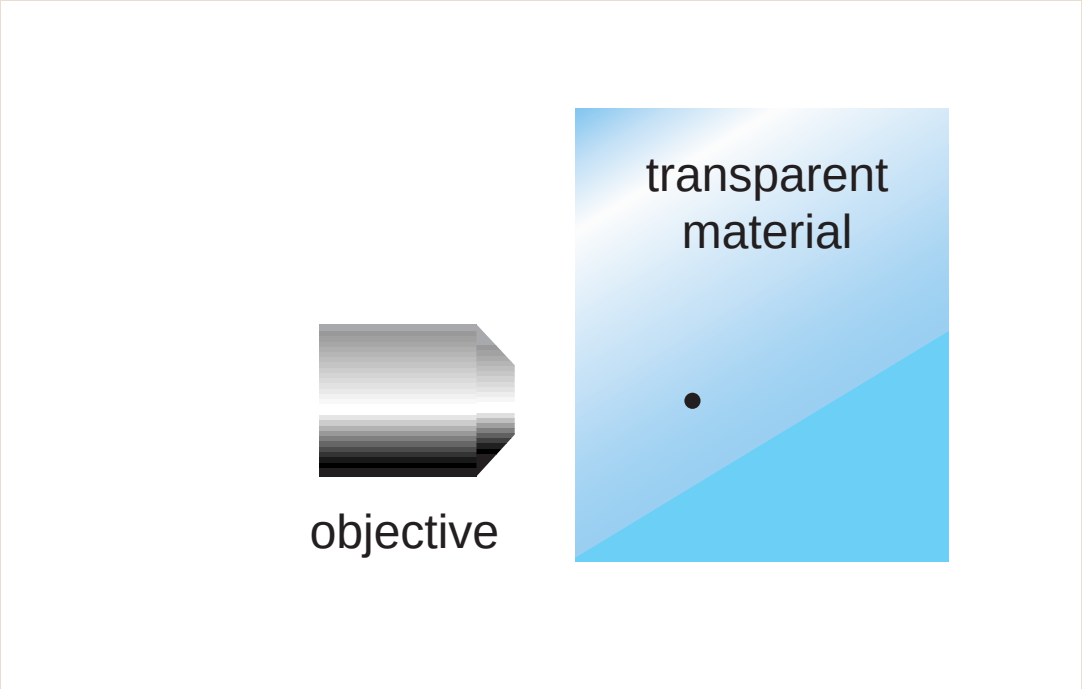
energy is deposited in the focal volume



producing microscopic bulk damage

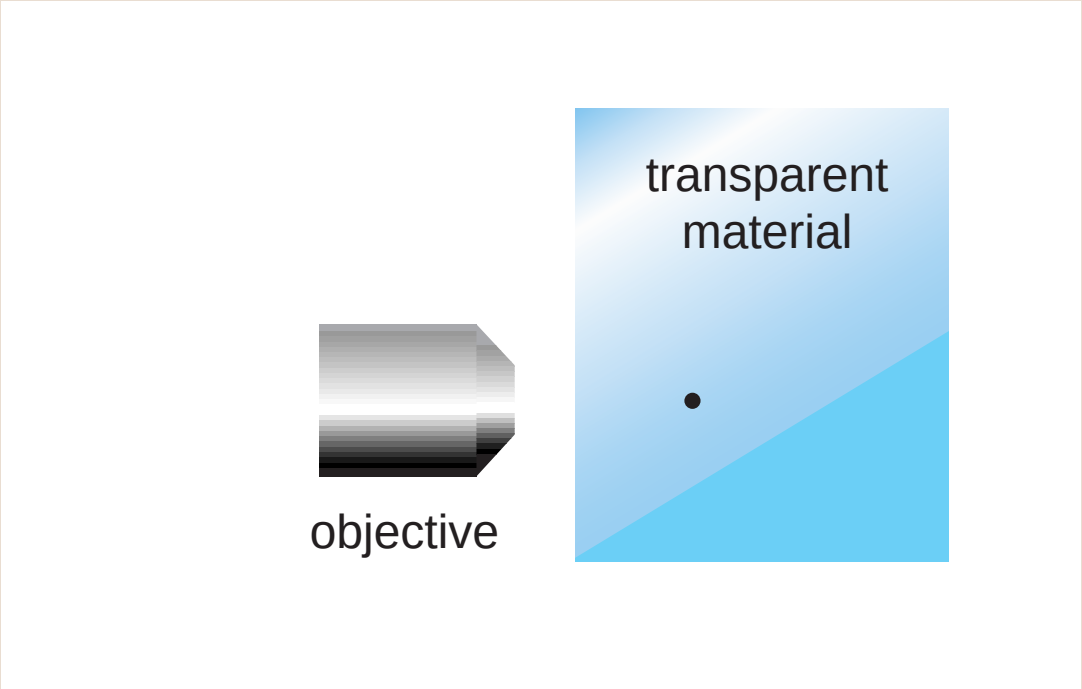


producing microscopic bulk damage



with only tens of nanojoules!

producing microscopic bulk damage

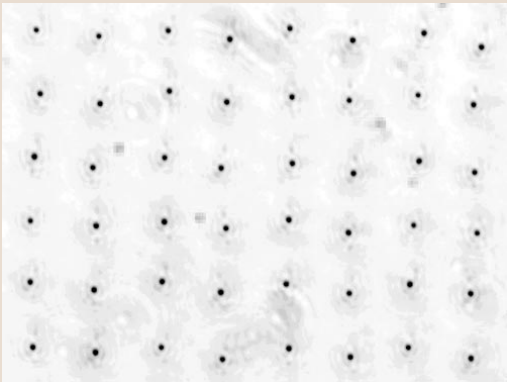


with only tens of nanojoules!

why bulk?

why bulk?

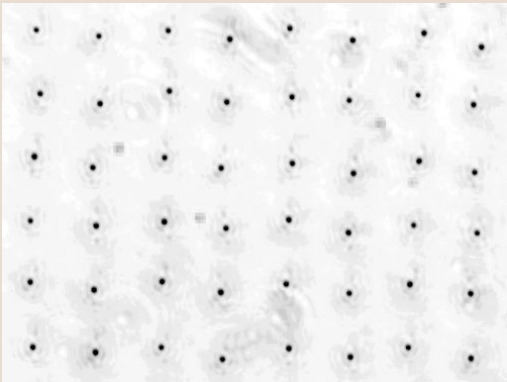
three-dimensional micromachining



INTRODUCTION

why bulk?

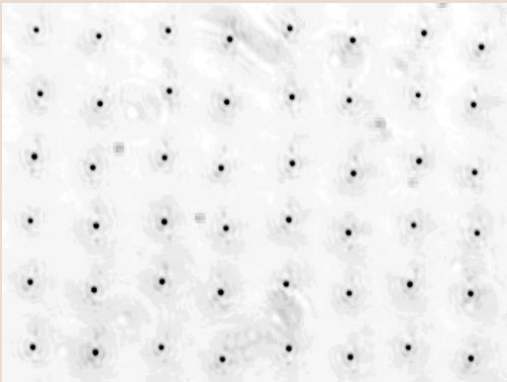
three-dimensional micromachining



why nanojoules?

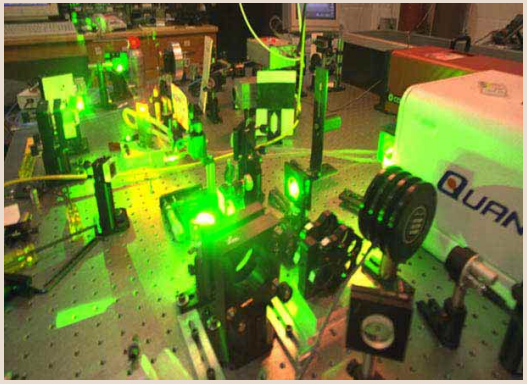
why bulk?

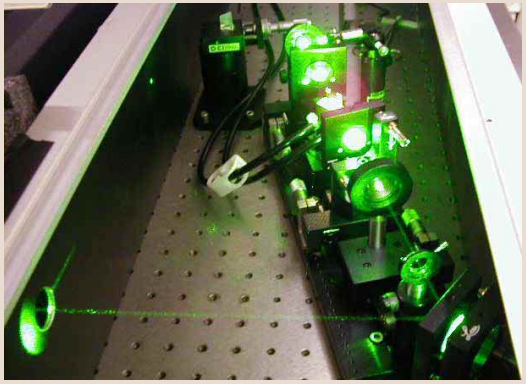
three-dimensional micromachining



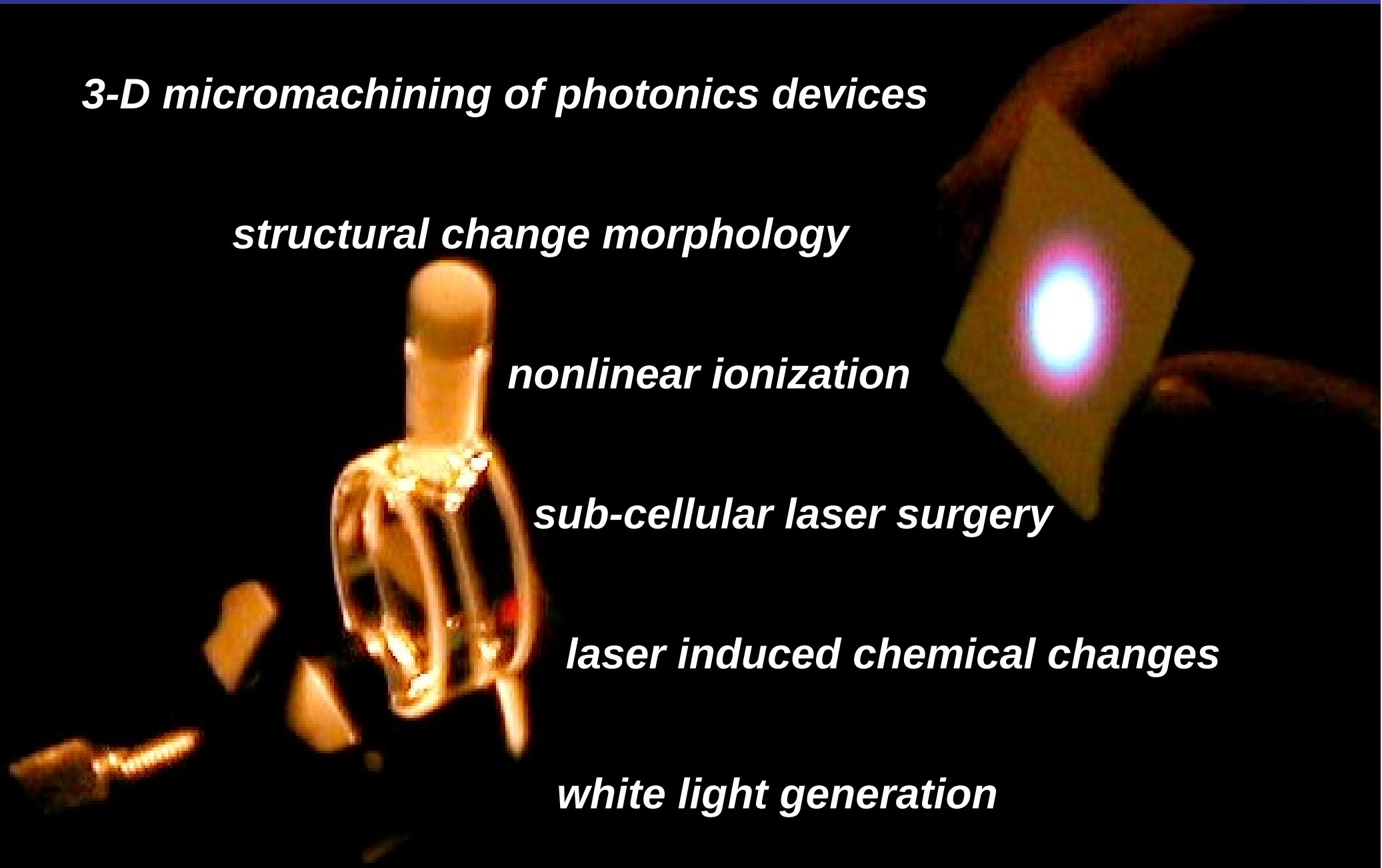
why nanojoules?

non-amplified micromachining





INTRODUCTION



3-D micromachining of photonics devices

structural change morphology

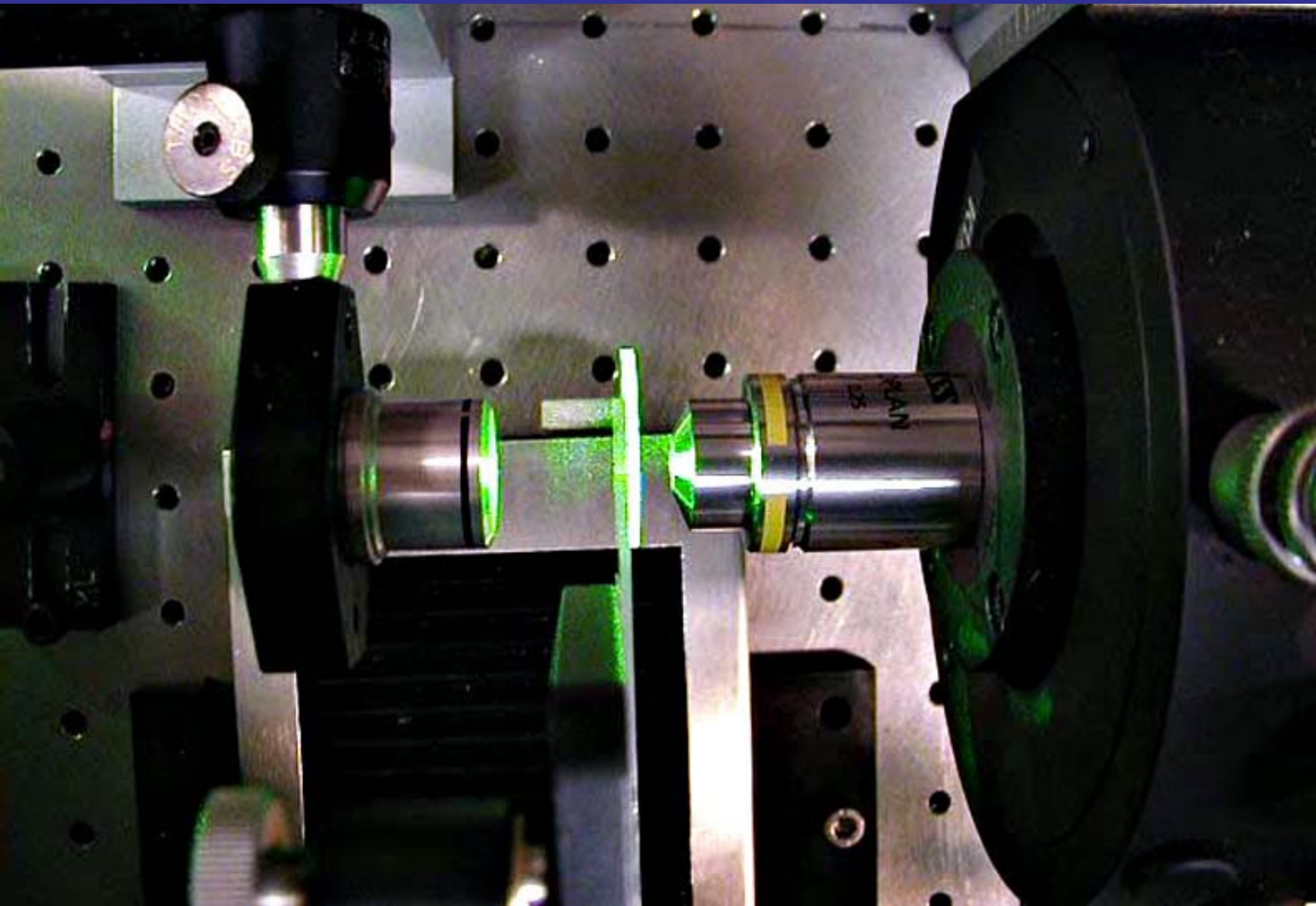
nonlinear ionization

sub-cellular laser surgery

laser induced chemical changes

white light generation

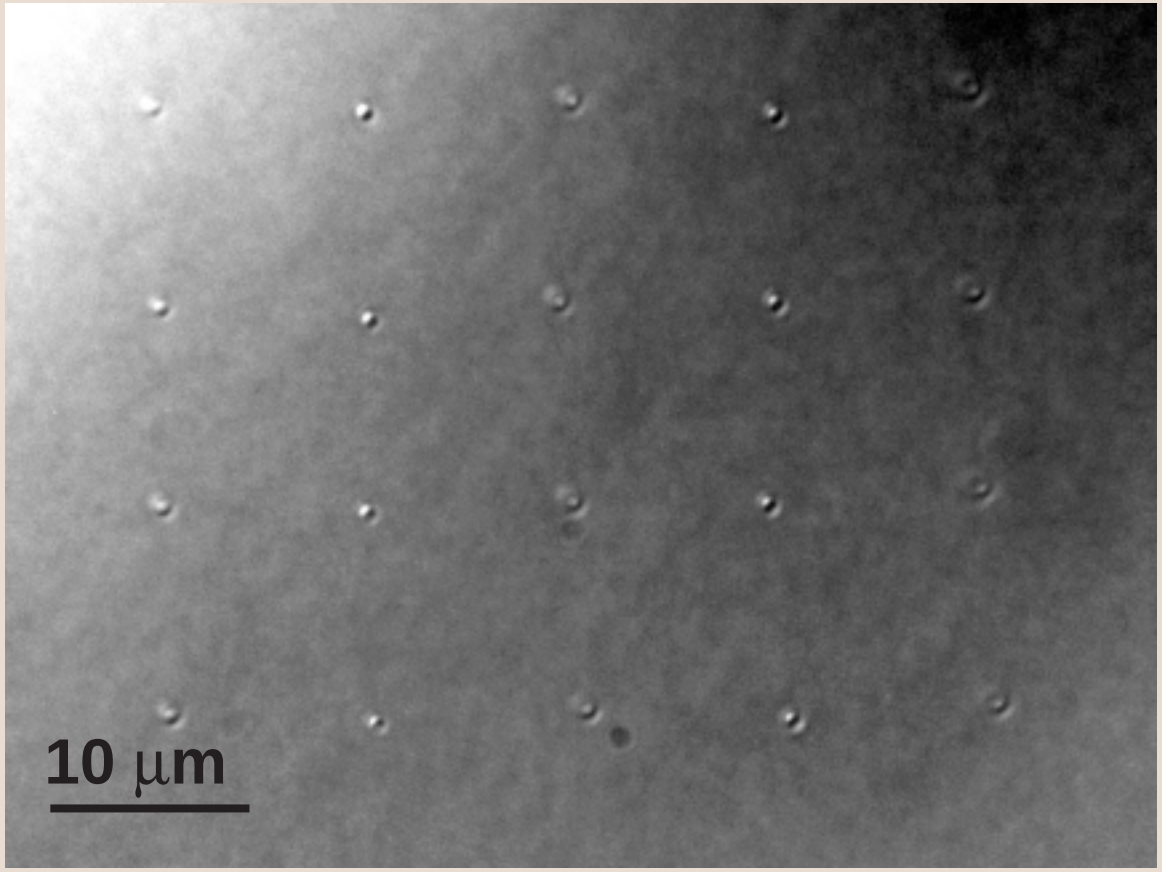
OUTLINE



OUTLINE

- Morphology
- Oscillator micromachining
- Applications

MORPHOLOGY

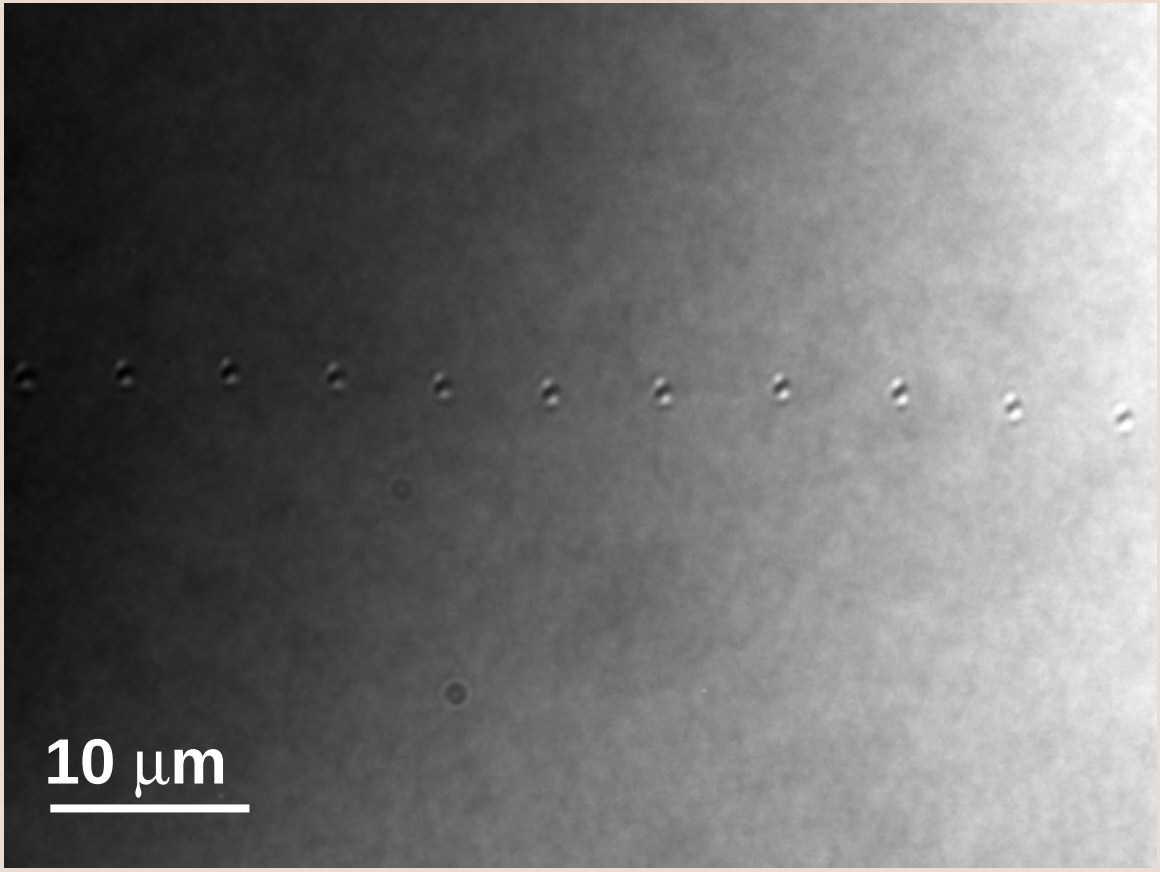


10 nJ
100 fs
1.4 NA
Corning 0211

$\otimes k$

top view

MORPHOLOGY

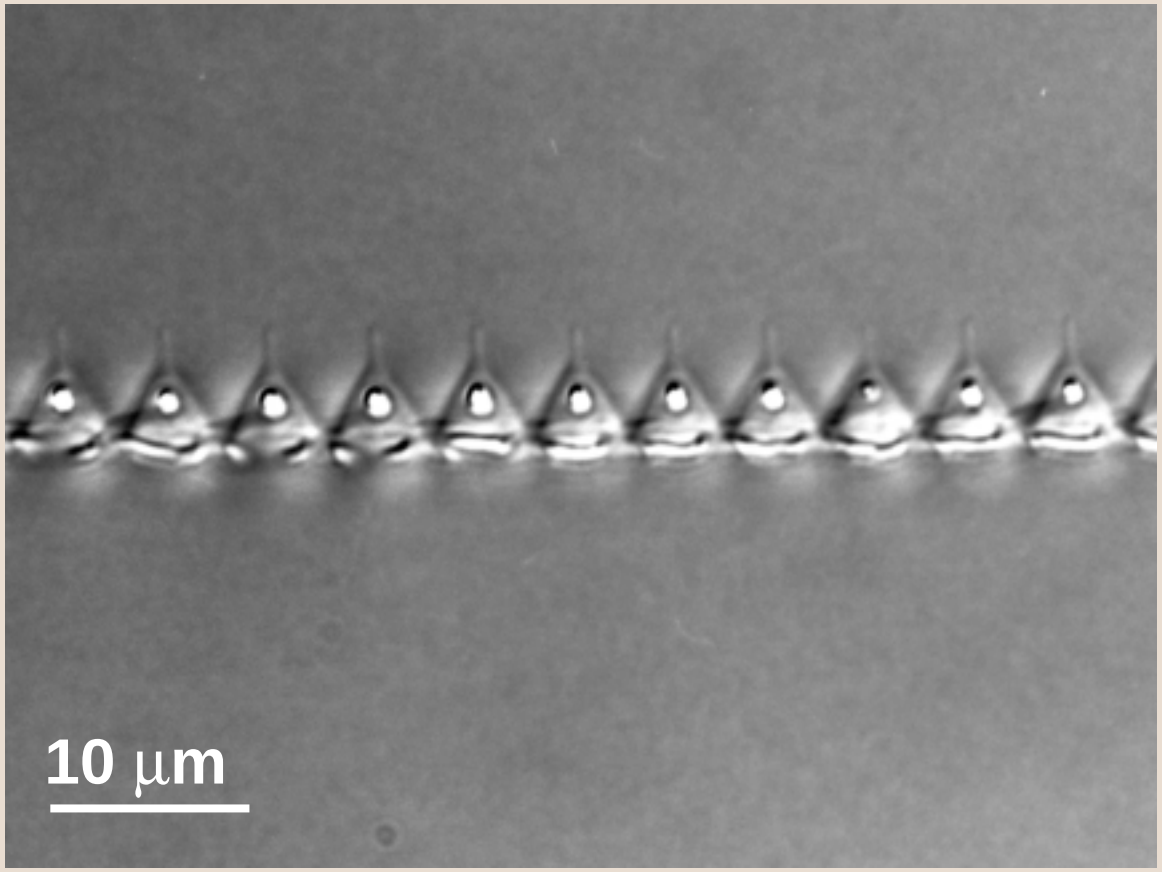


15 nJ
100 fs
1.4 NA
Corning 0211

k

side view

MORPHOLOGY

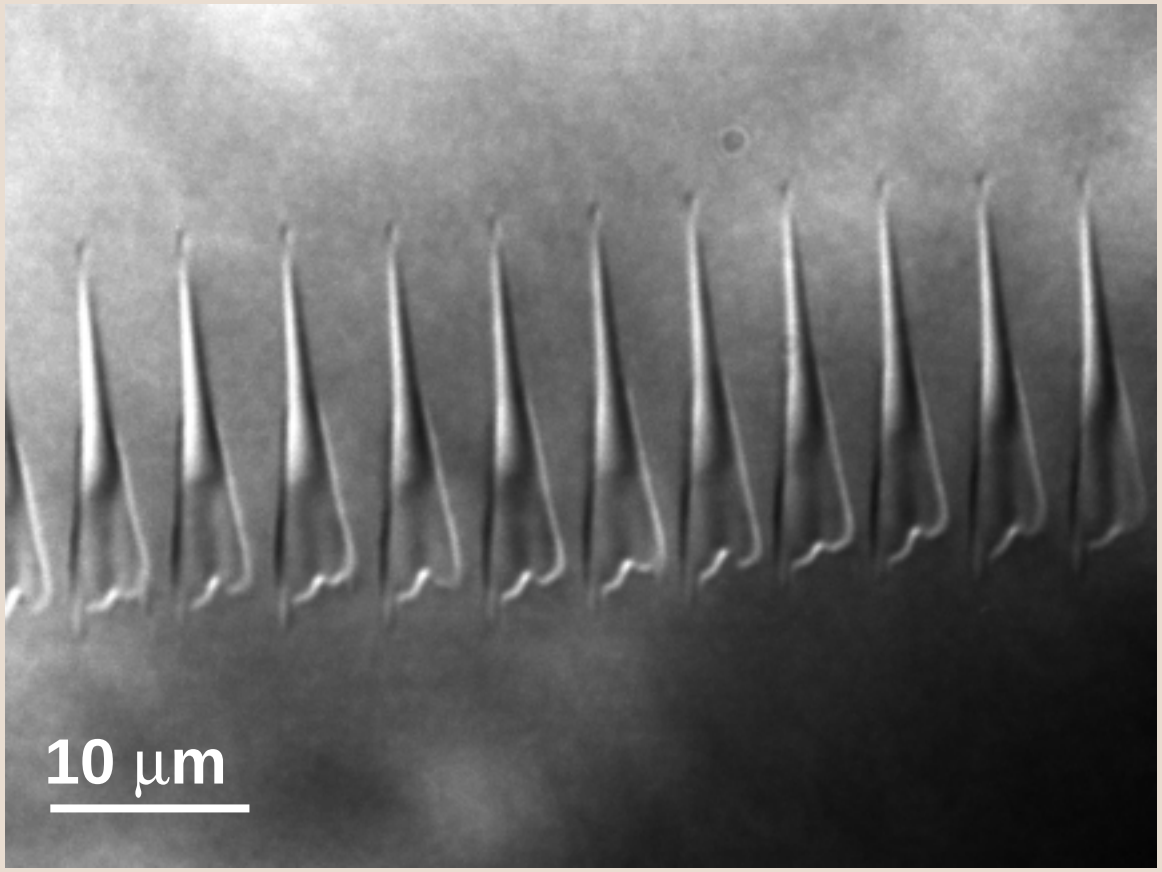


500 nJ
100 fs
1.4 NA
Corning 0211

k

higher pulse energy

MORPHOLOGY

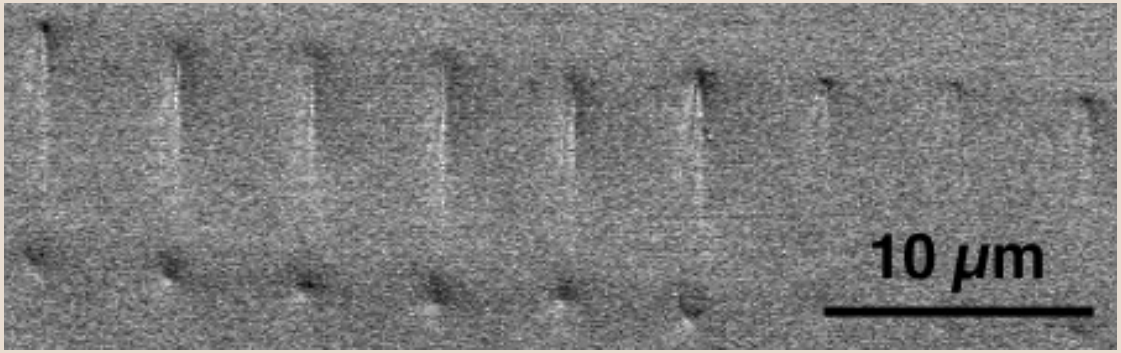


500 nJ
100 fs
0.45 NA
Corning 0211

k

slower focusing

MORPHOLOGY



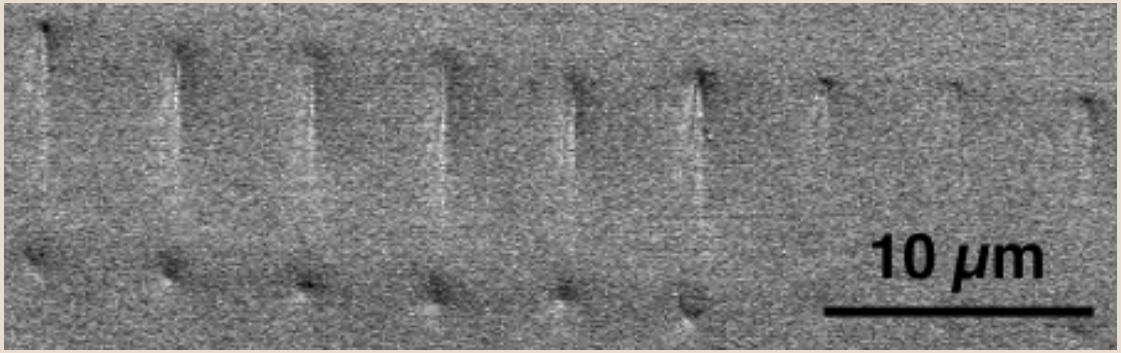
140 nJ

100 fs
800 nm
0.45 NA
Corning 0211

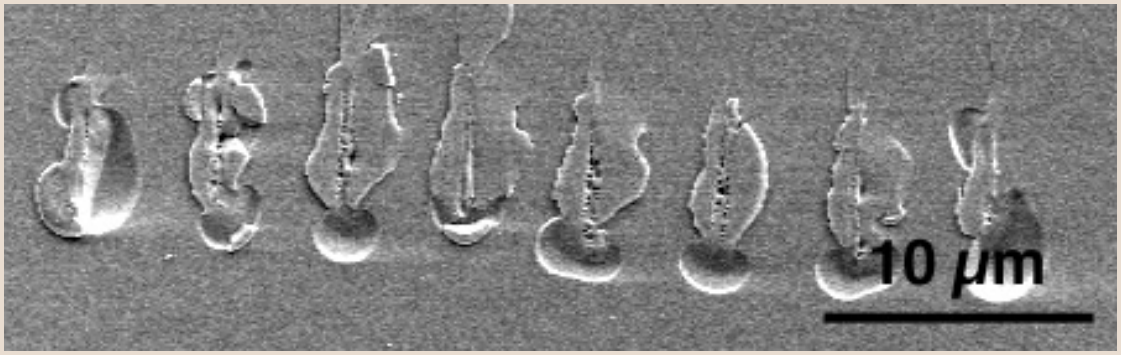
k

side view SEM

MORPHOLOGY



140 nJ



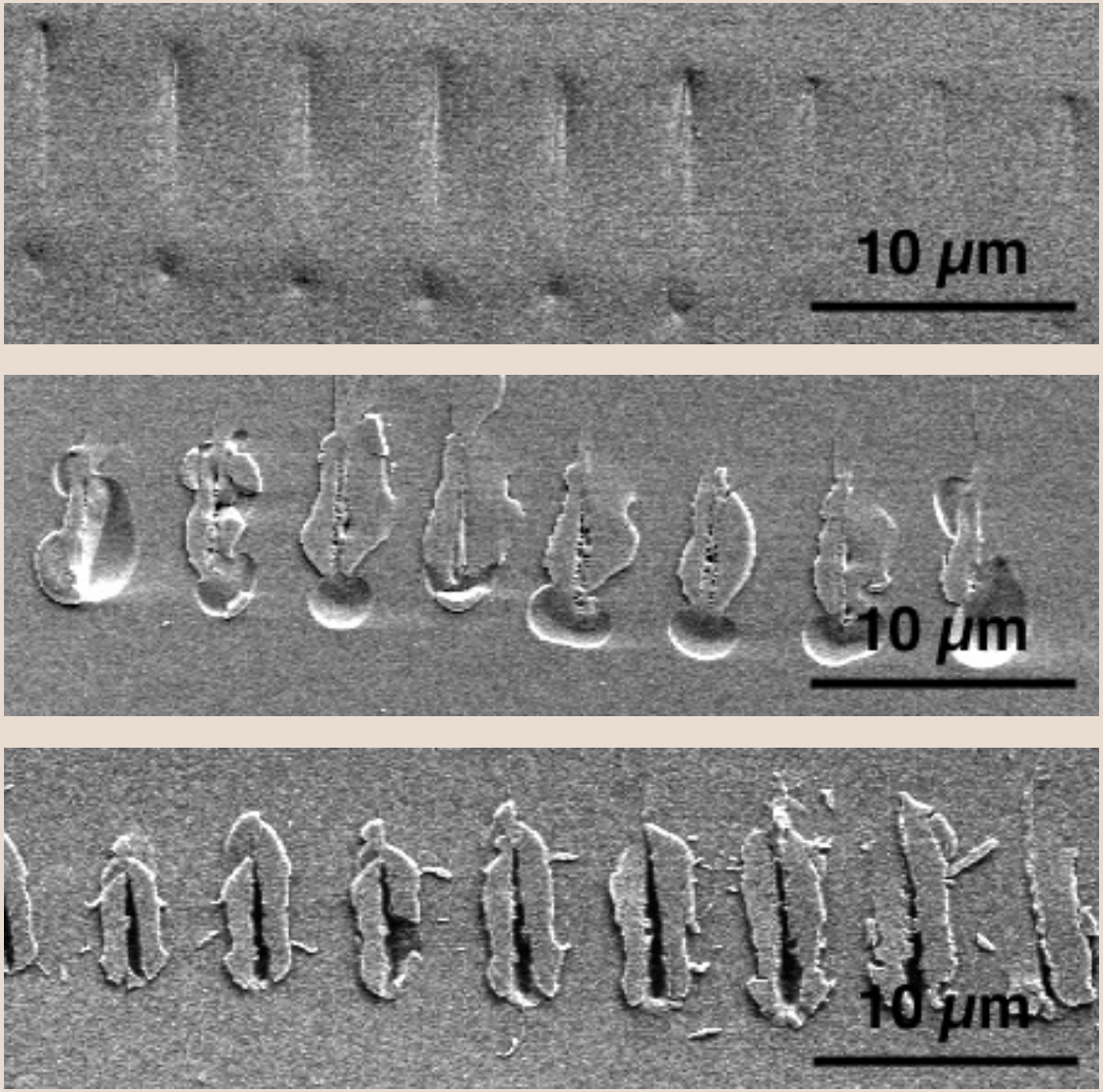
250 nJ

100 fs
800 nm
0.45 NA
Corning 0211

k

side view SEM

MORPHOLOGY



140 nJ

250 nJ

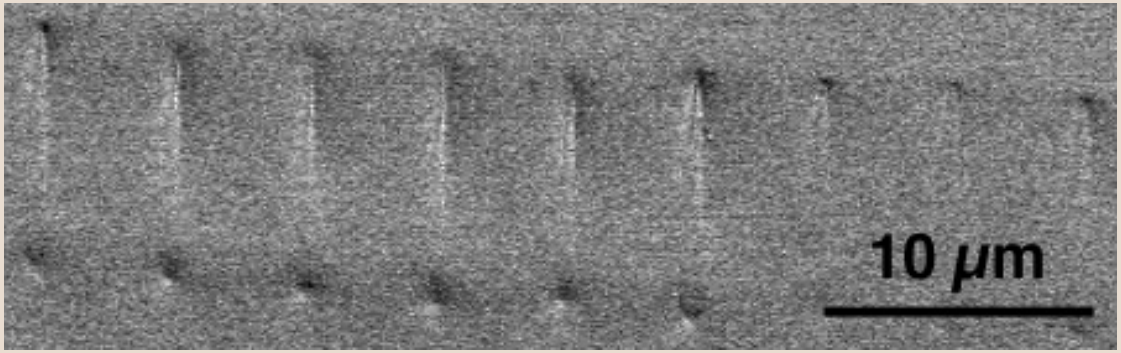
540 nJ

k

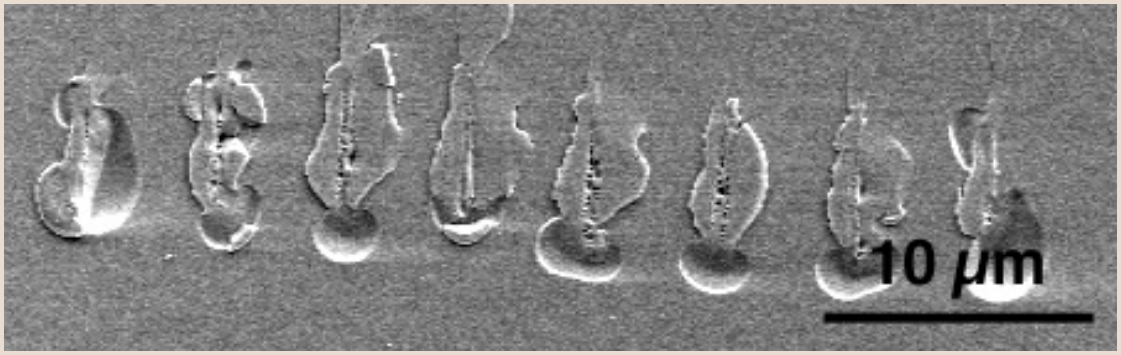
100 fs
800 nm
0.45 NA
Corning 0211

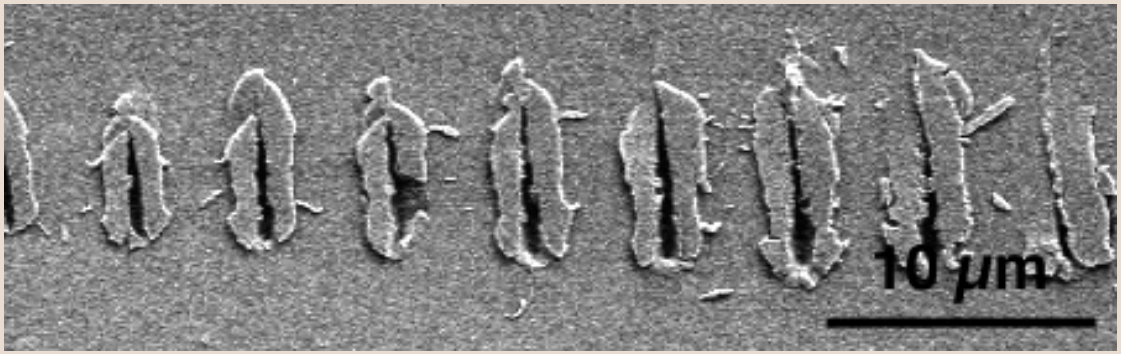
side view SEM

MORPHOLOGY



thermal mechanism





explosive mechanism

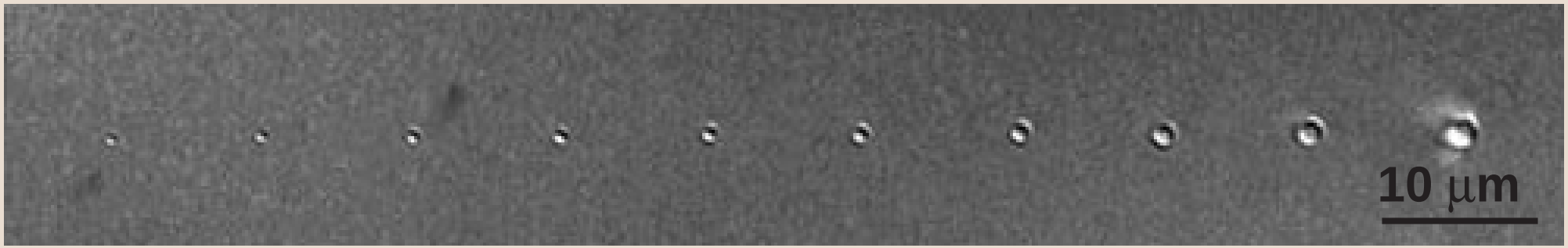
100 fs
800 nm
0.45 NA
Corning 0211

side view SEM

MORPHOLOGY

vary laser energy

6.6 nJ 13 nJ 33 nJ 66 nJ



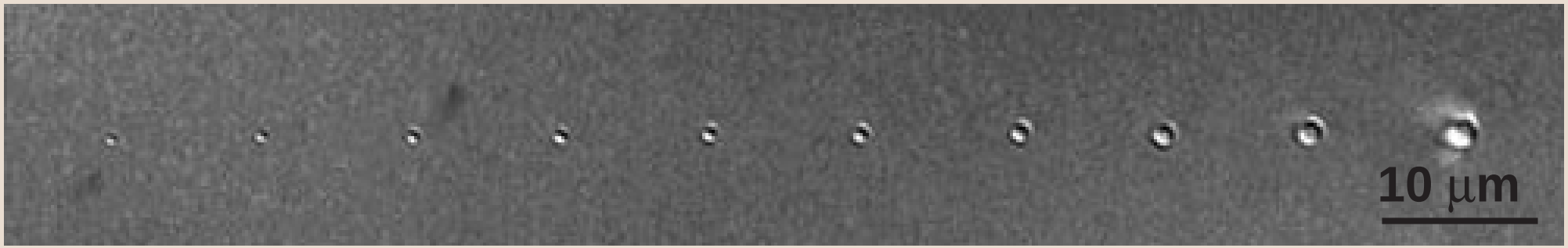
100 fs
1.4 NA
Corning 0211

$\otimes k$

MORPHOLOGY

vary laser energy

6.6 nJ 13 nJ 33 nJ 66 nJ

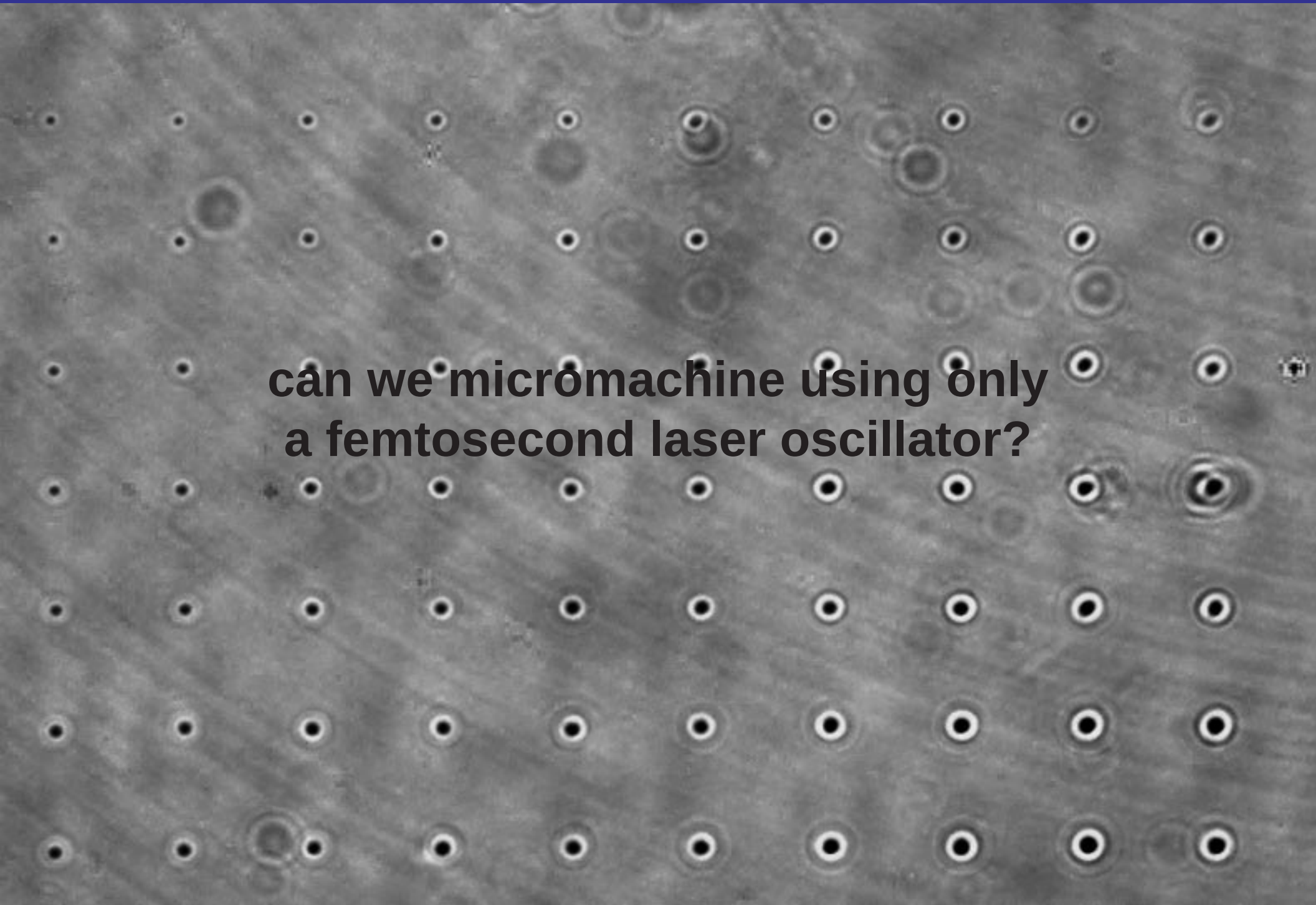


100 fs
1.4 NA
Corning 0211

$\otimes^{k}$

do we need amplified lasers to micromachine?

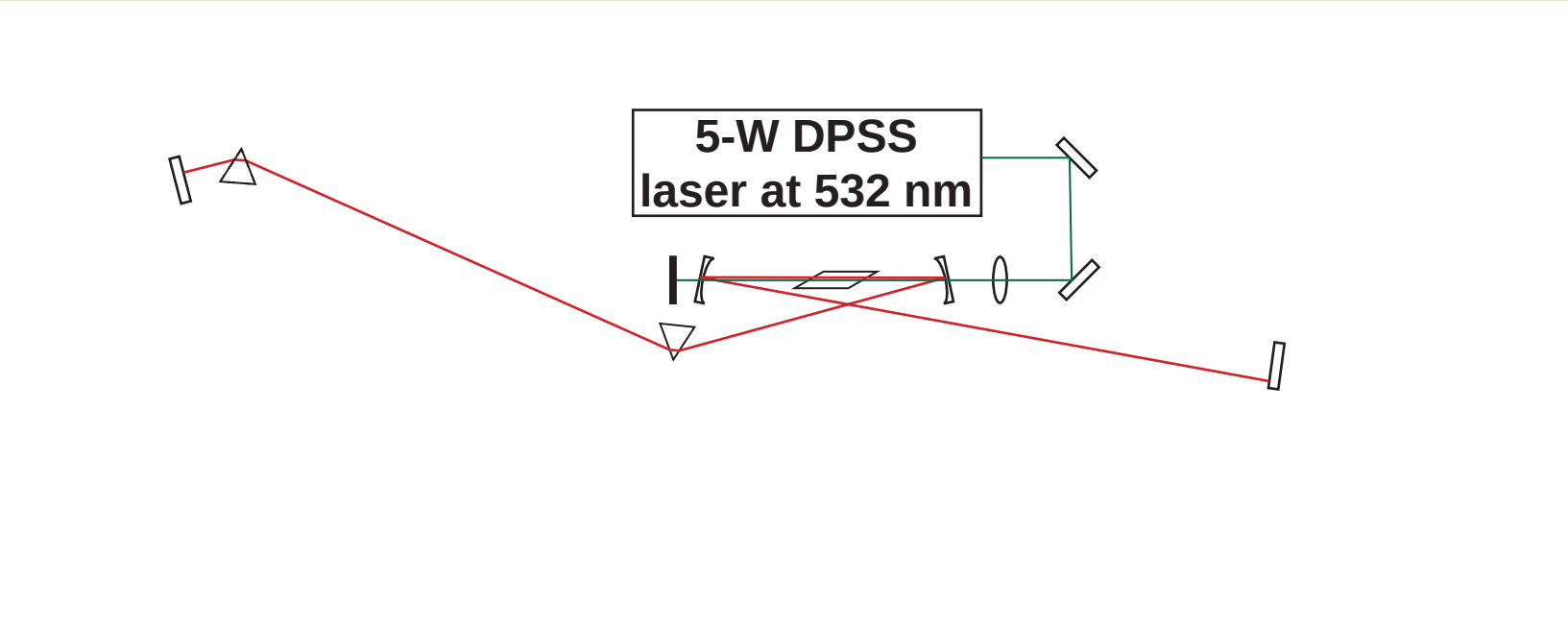
OSCILLATOR MICROMACHINING



can we micromachine using only a femtosecond laser oscillator?

OSCILLATOR MICROMACHINING

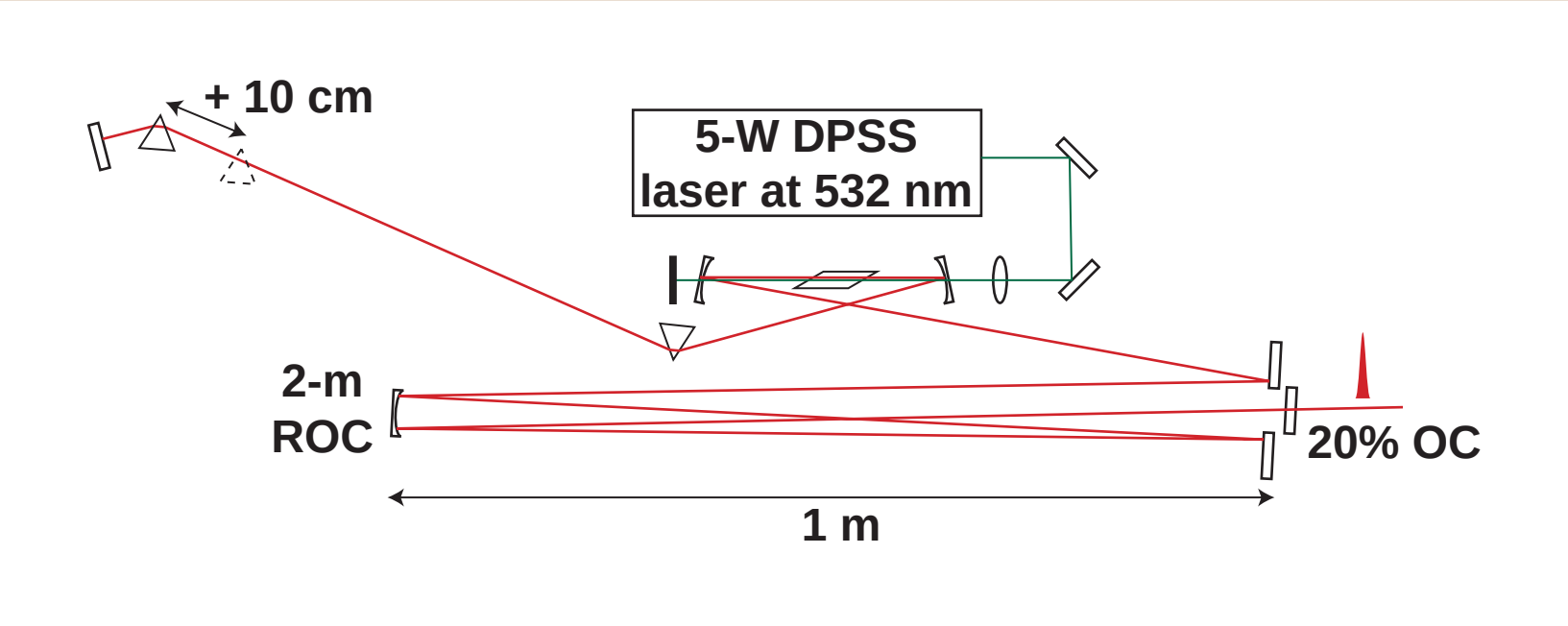
to deliver 5 nJ to the sample



after losses in the objective and prism compressor...

OSCILLATOR MICROMACHINING

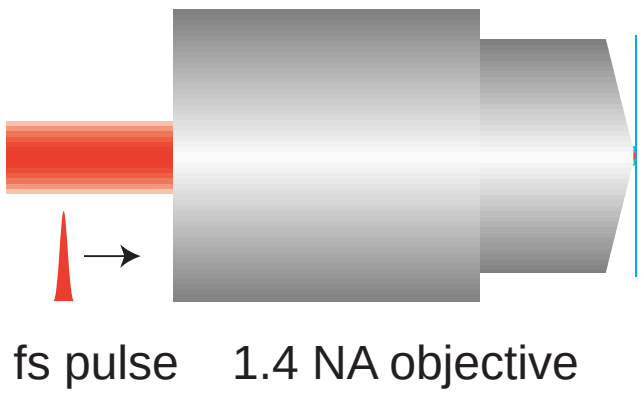
... extend cavity of standard Ti:Sapph oscillator



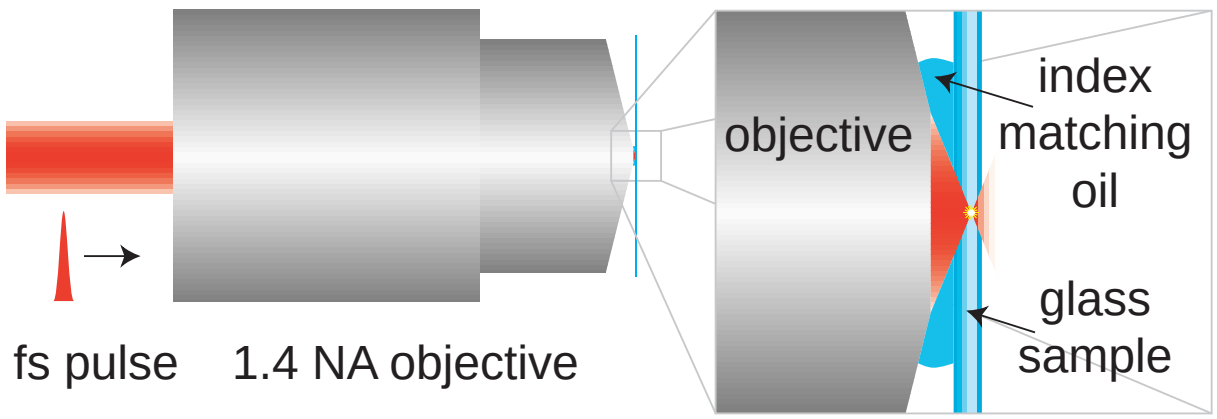
laser specs: 20 nJ, 25 MHz, 20 fs

Ref: A.R. Libertun, et.al., CLEO 1999; S.H. Cho, et. al., CLEO 1999.

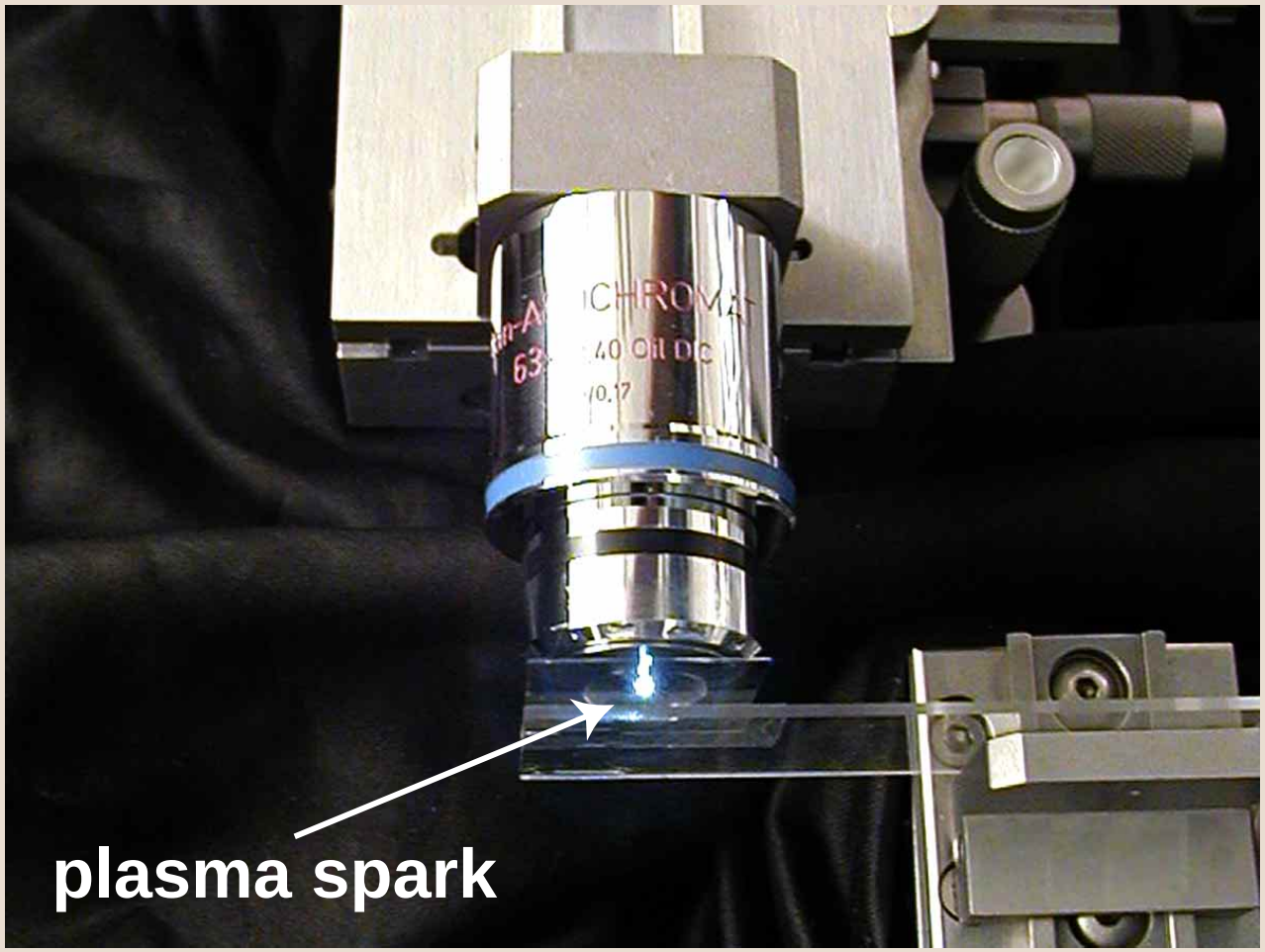
scale model of 1.4 NA focusing geometry



scale model of 1.4 NA focusing geometry

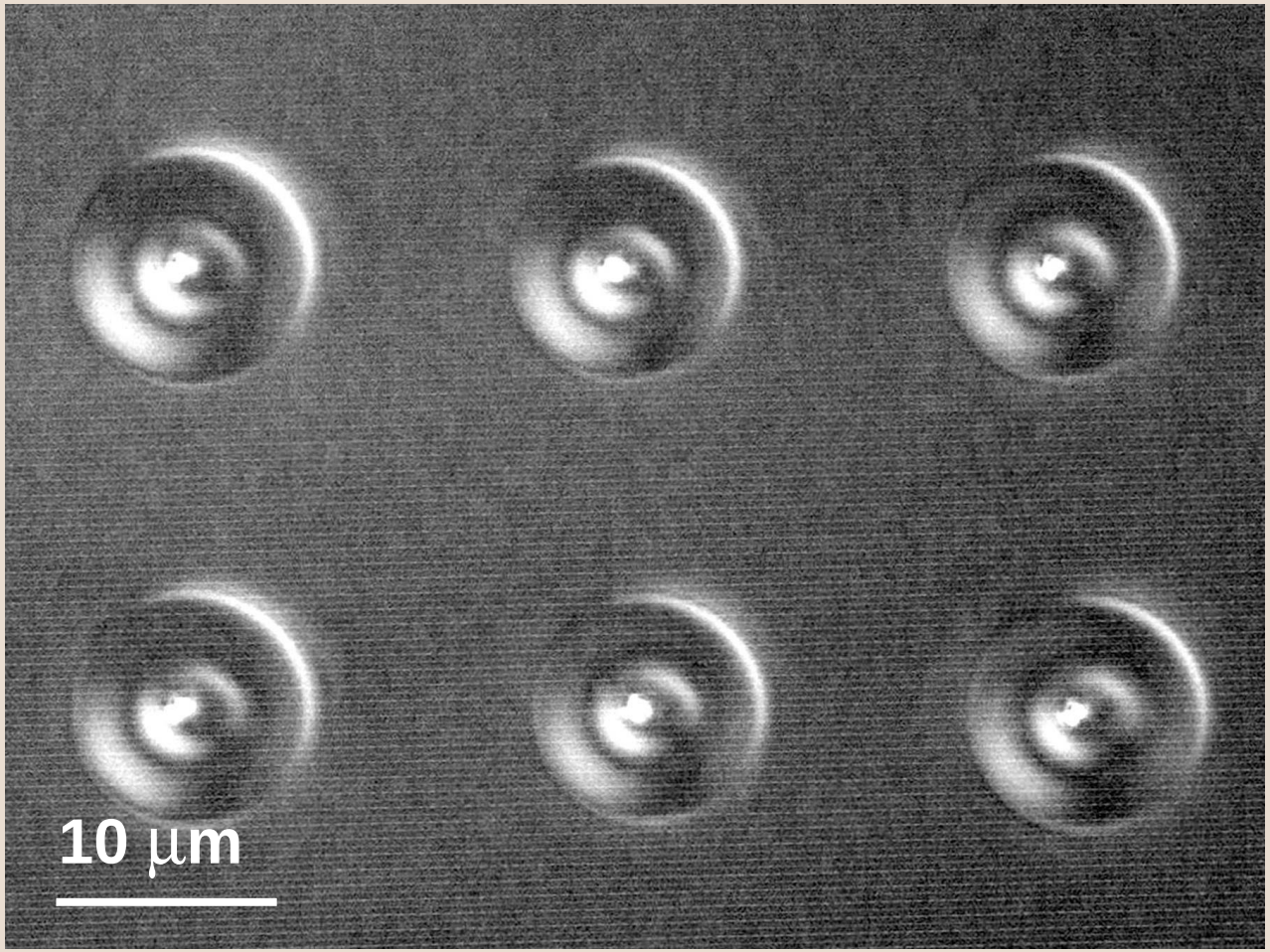


actual 1.4 NA focusing geometry



OSCILLATOR MICROMACHINING

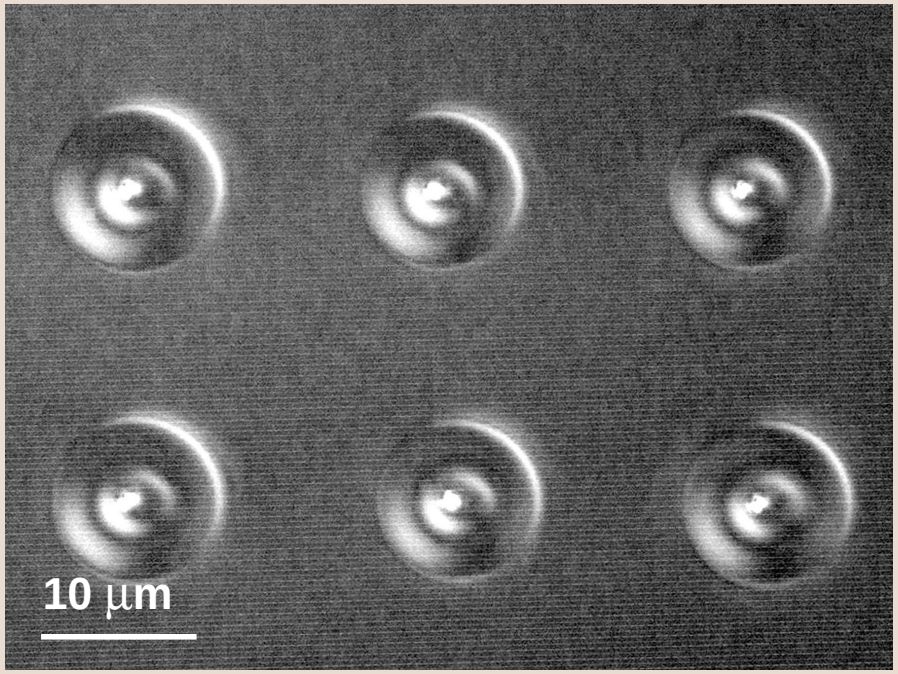
structures made with 25-MHz oscillator: 5 nJ; 25,000 shots

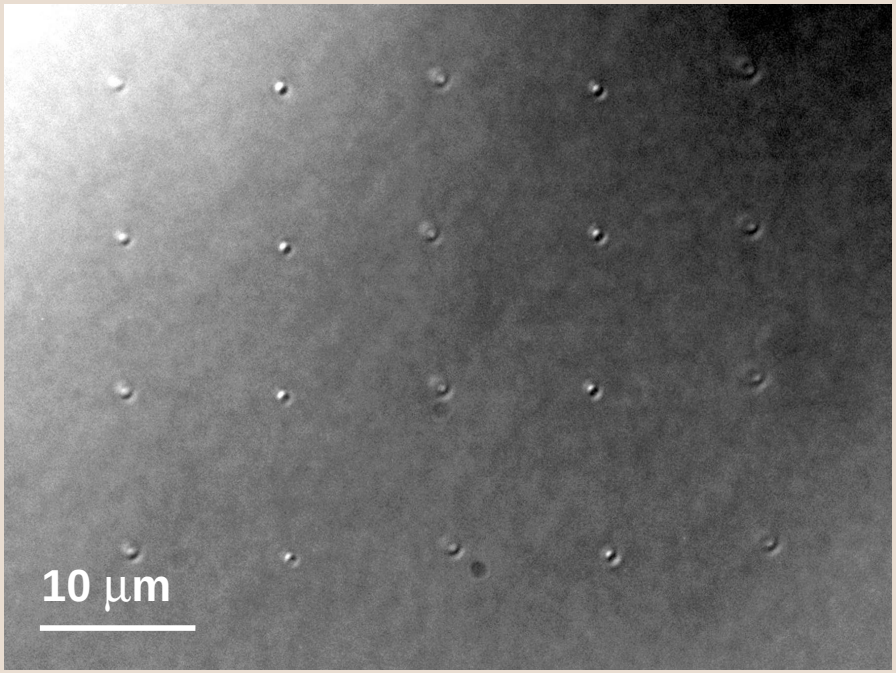


< 100 fs
800 nm
1.4 NA
Corning 0211

OSCILLATOR MICROMACHINING

5 nJ; 25,000 shots

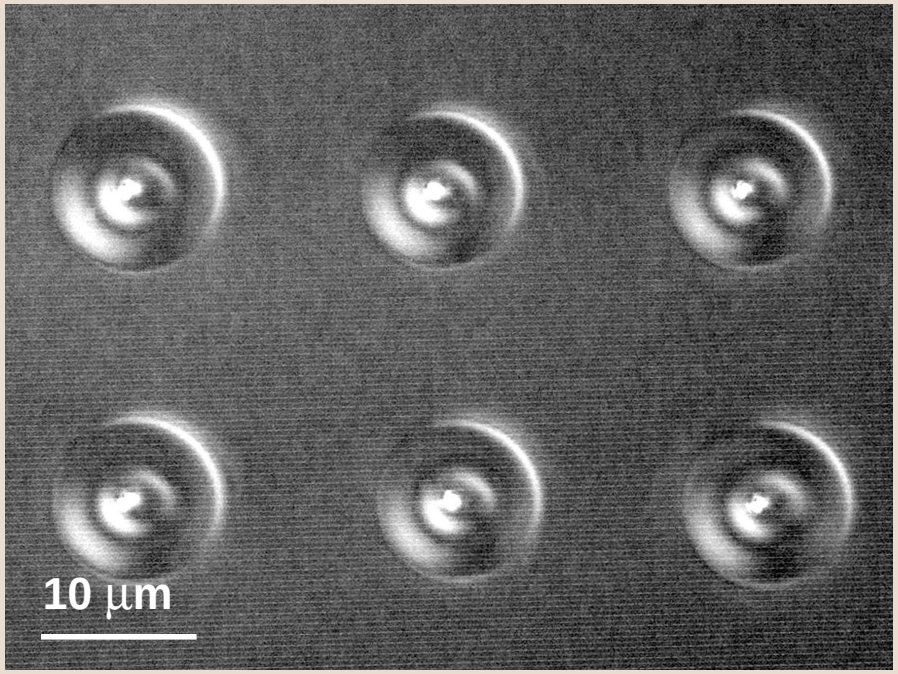




10 nJ; single shot

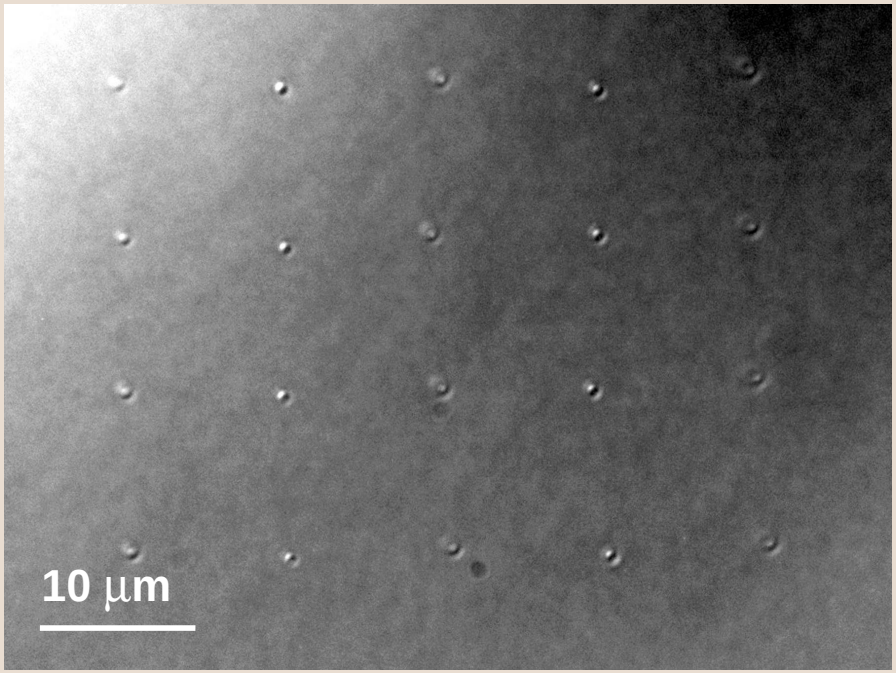
OSCILLATOR MICROMACHINING

5 nJ; 25,000 shots



cumulative heating by successive pulses melts the glass

explosive or small-scale melting mechanism

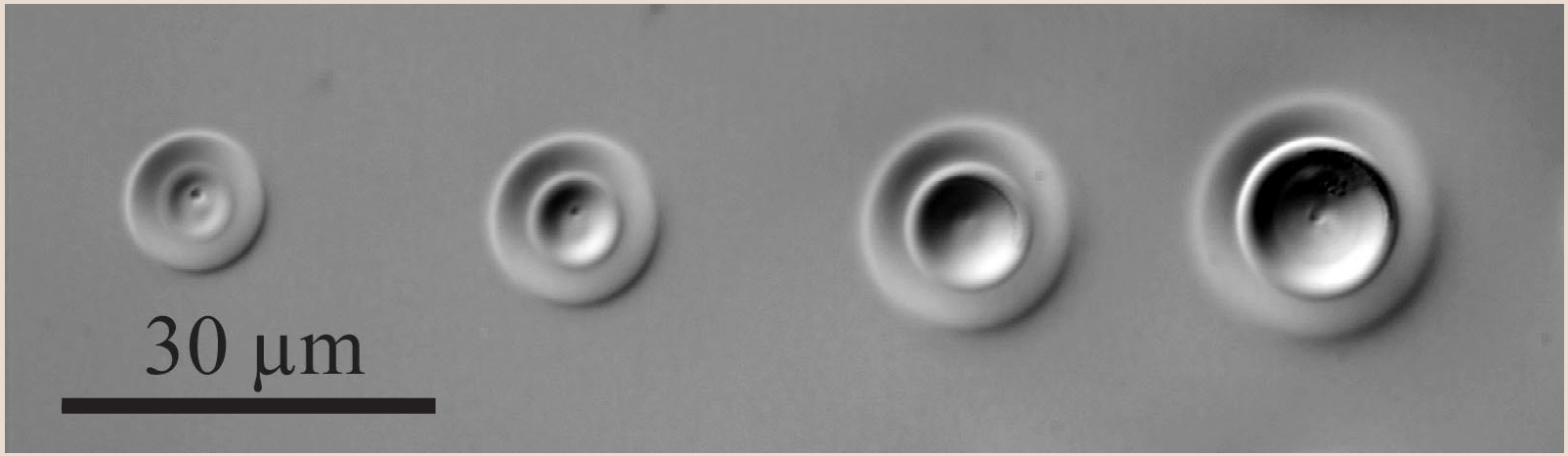


10 nJ; single shot

OSCILLATOR MICROMACHINING

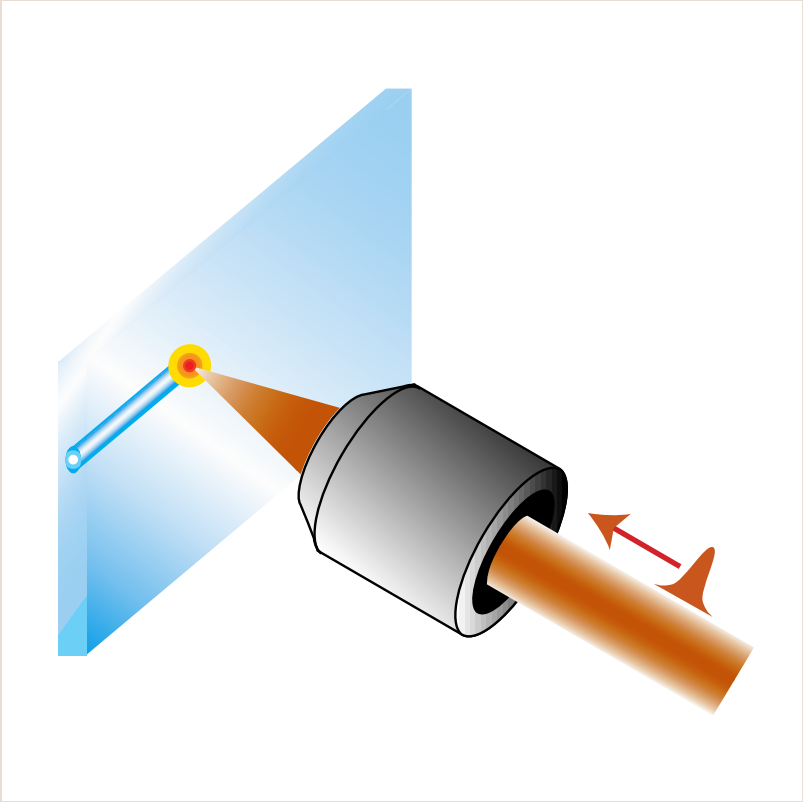
number of laser shots

2.5×10^4 2.5×10^5 2.5×10^6 2.5×10^7



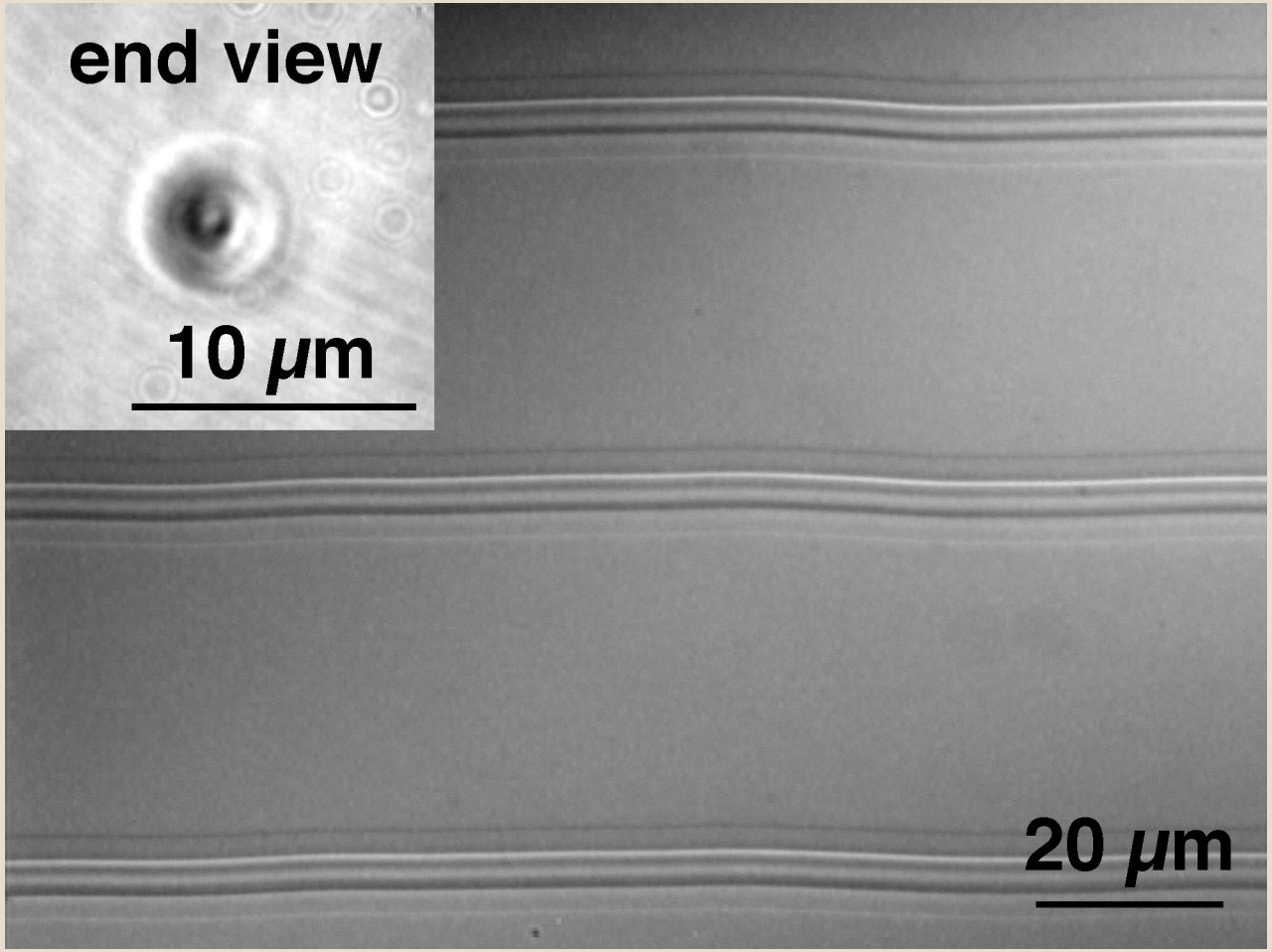
more shots melt larger volumes

how can we use femtosecond thermal micromachining?



write waveguides!

waveguide morphology: 20 mm/s machining speed



waveguide mode analysis

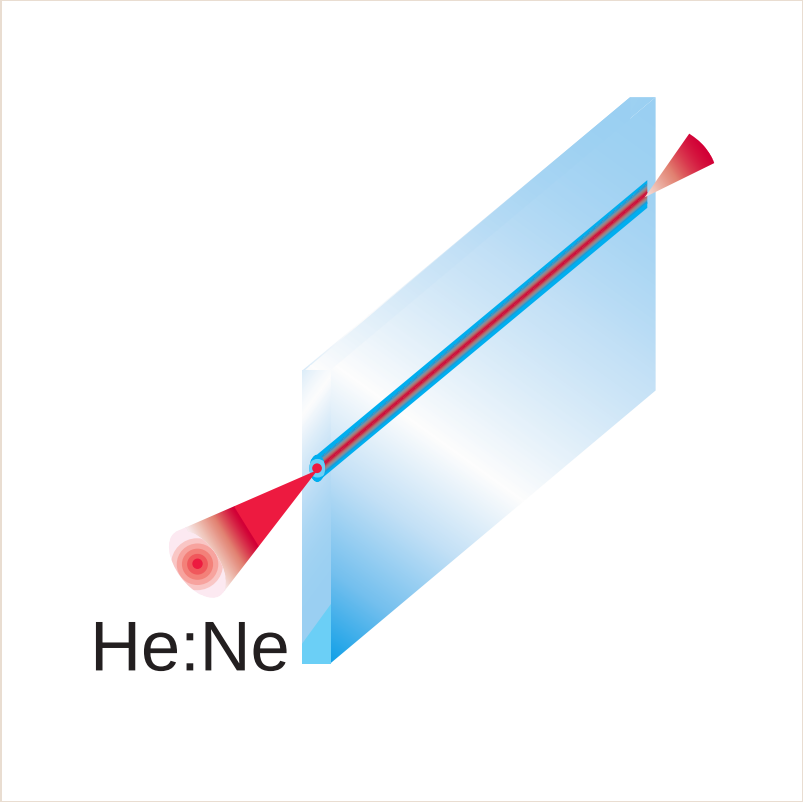
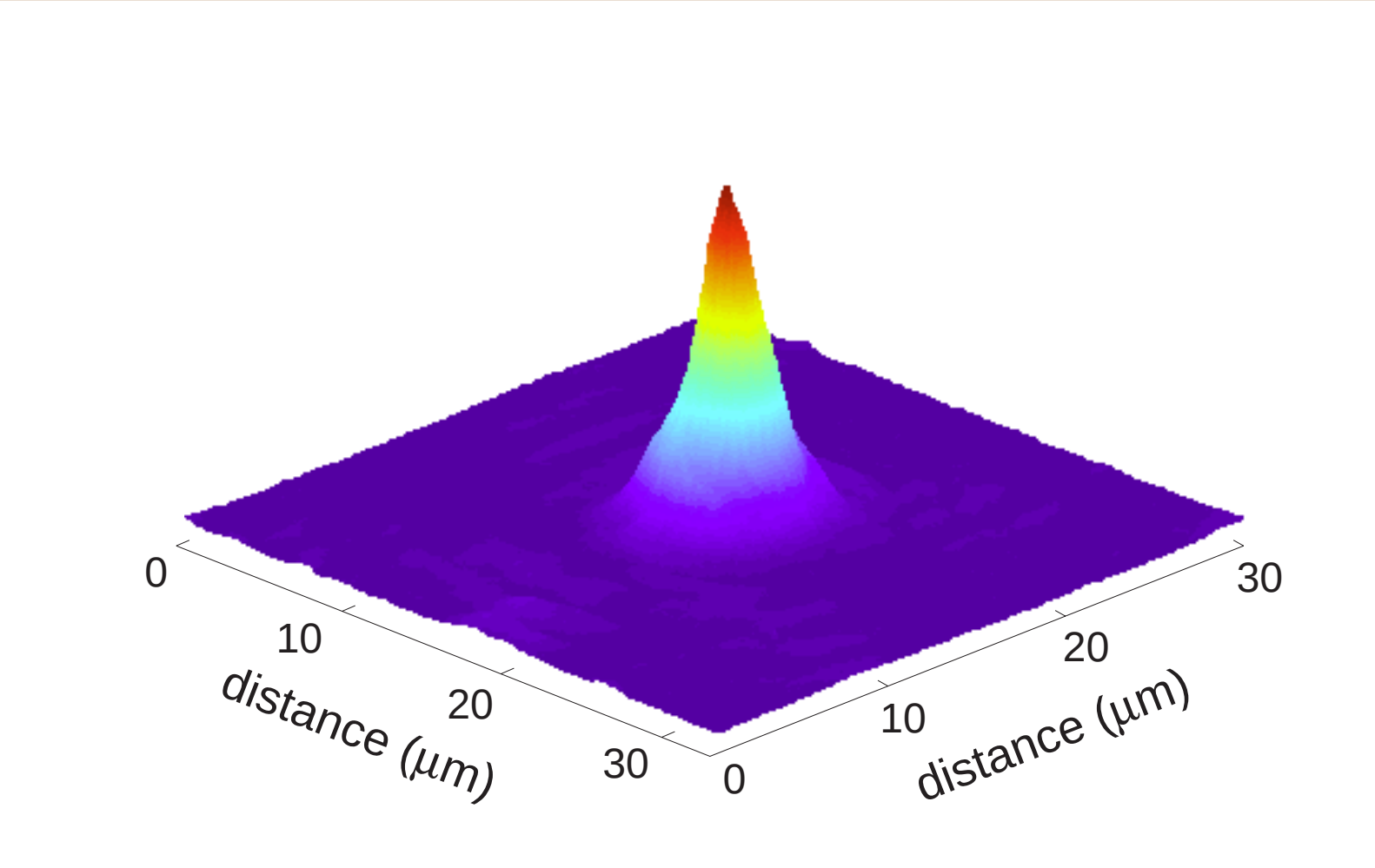
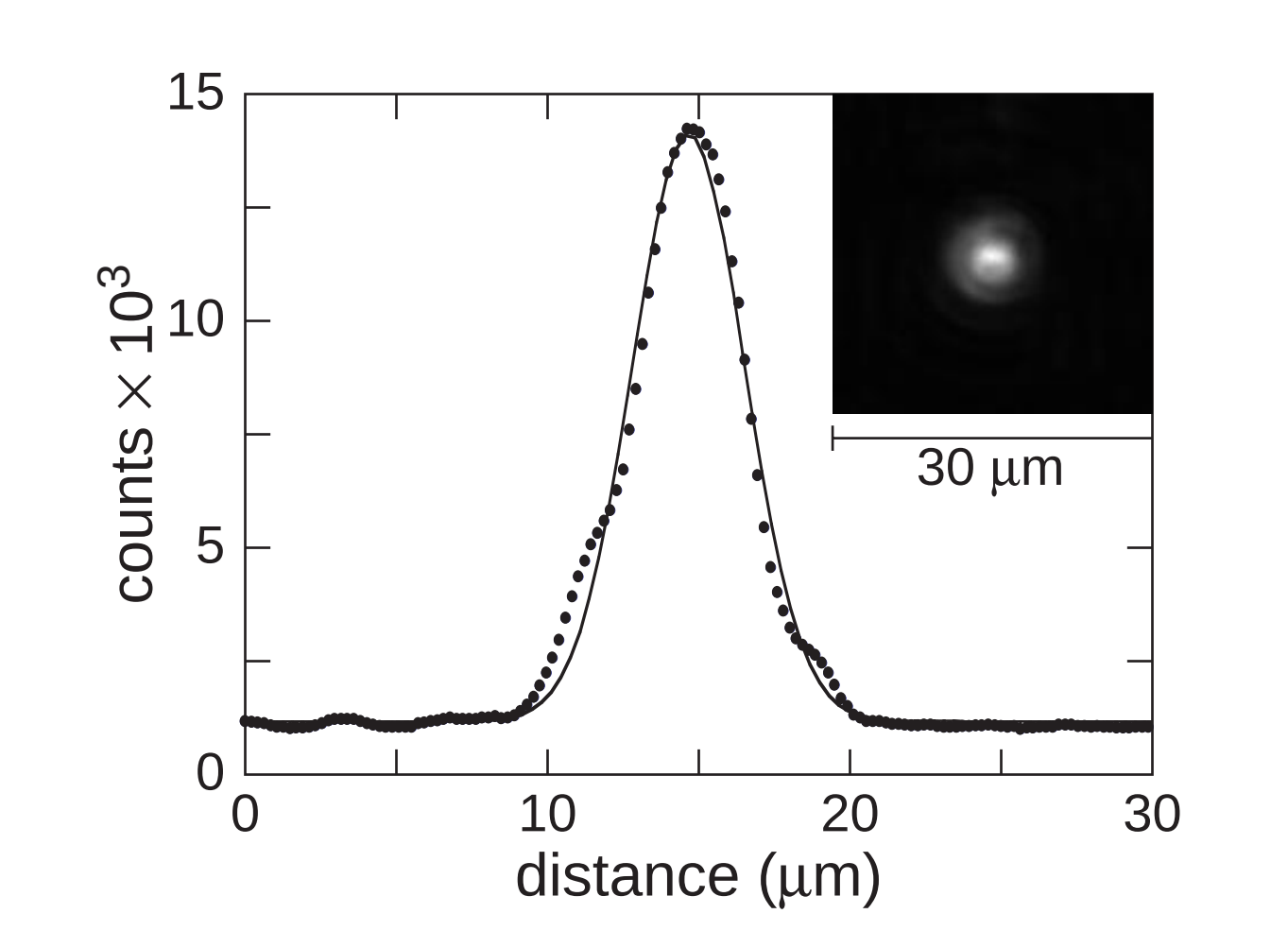


image of near field mode



APPLICATIONS



line-out of near field waveguide mode for 633 nm

Morphology

- Conneting morphology to mechanisms

morphologies and mechanisms

	low energy	high energy
single shot	sub-µm Δn small melt	sub-µm voids explosive
multiple shot high rep. rate	µm-sized Δn cumulative melting	???

SUMMARY

Morphology

- Conneting morphology to damage mechanisms
- Need work on ionization mechanisms

SUMMARY

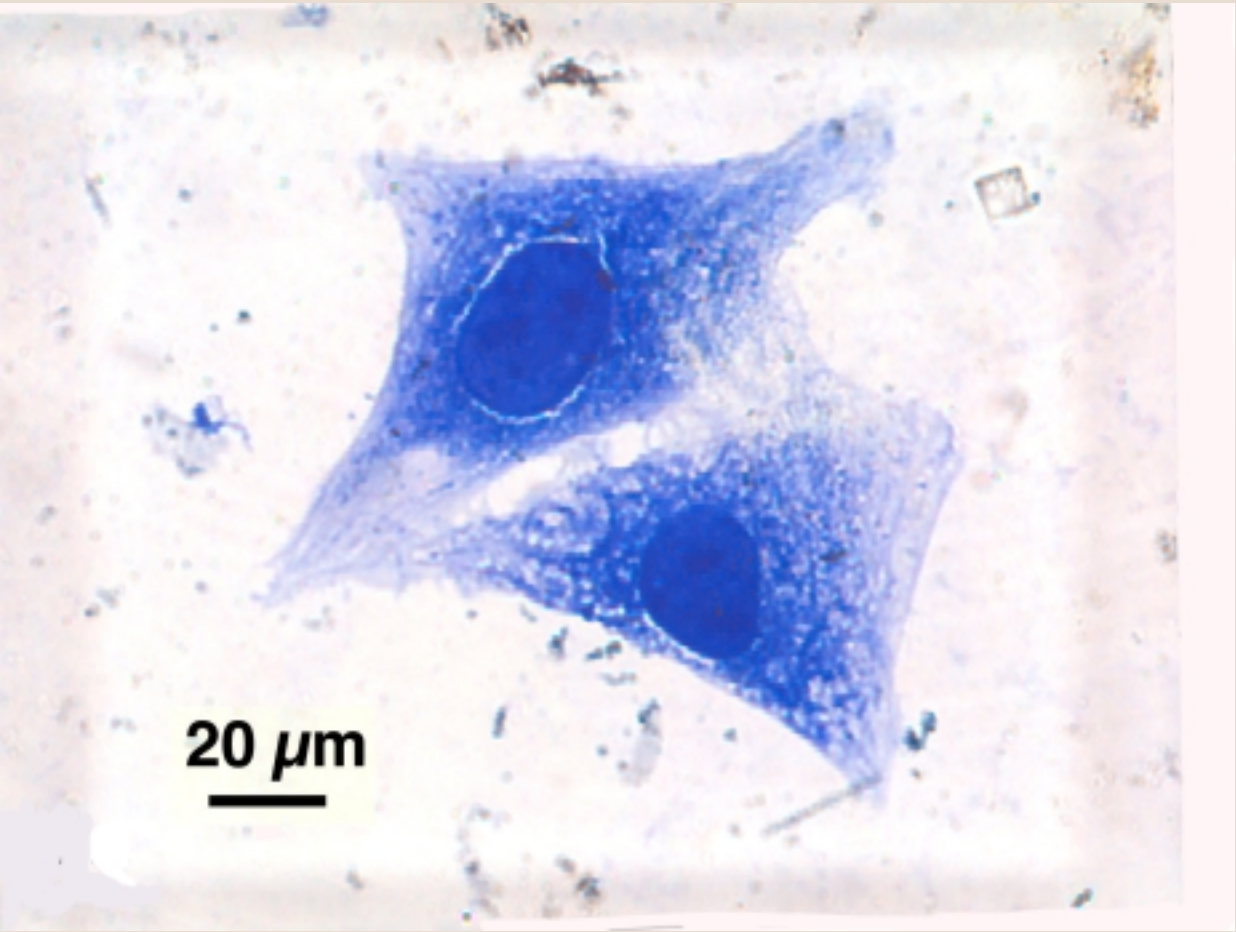
Morphology

- Conneting morphology to damage mechanisms
- Need work on ionization mechanisms

Oscillator-only micromachining

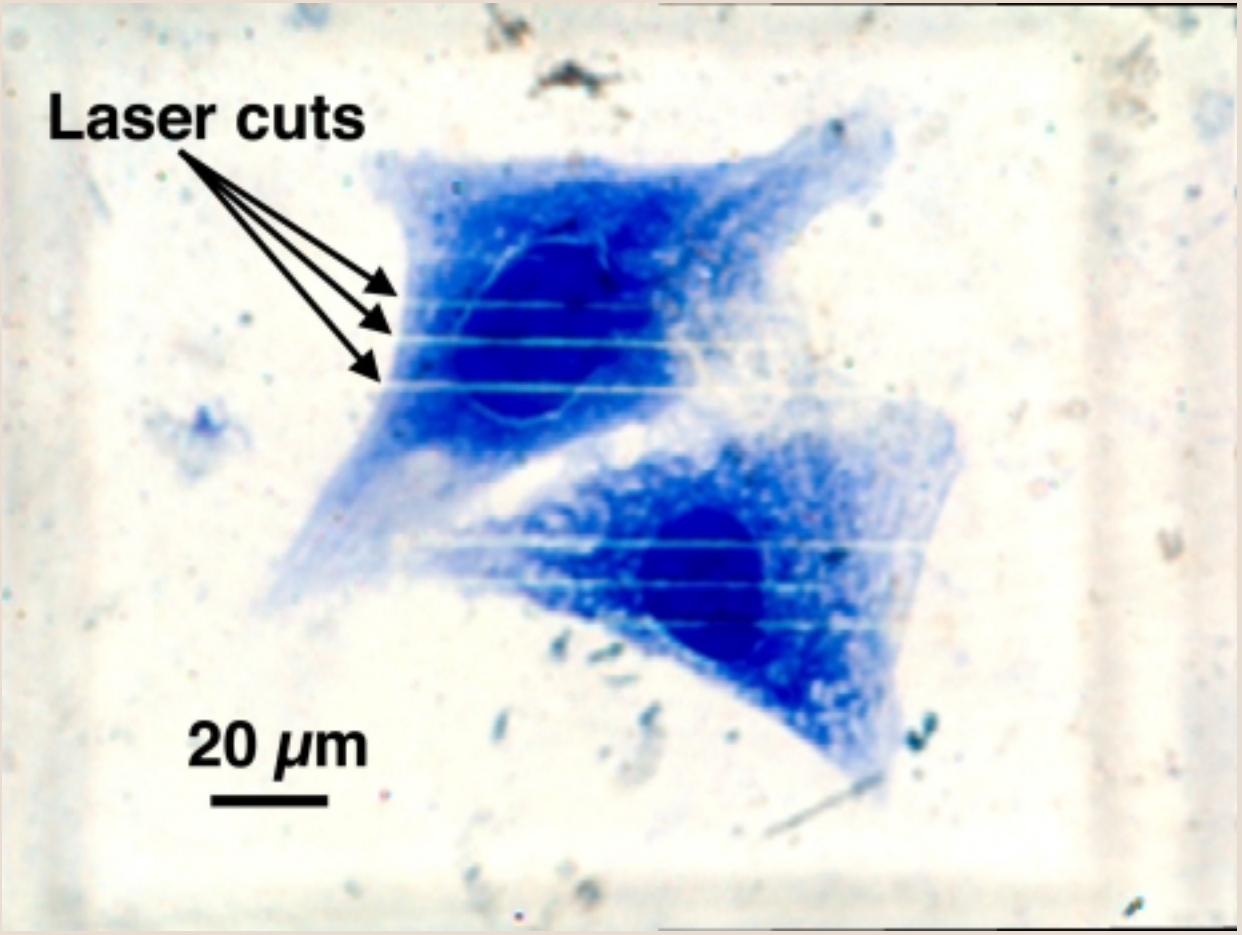
- Combining thermal and single-shot micromachining, we hope to create a variety of photonic structures using only a femtosecond laser oscillator.

BIOLOGICAL RESEARCH



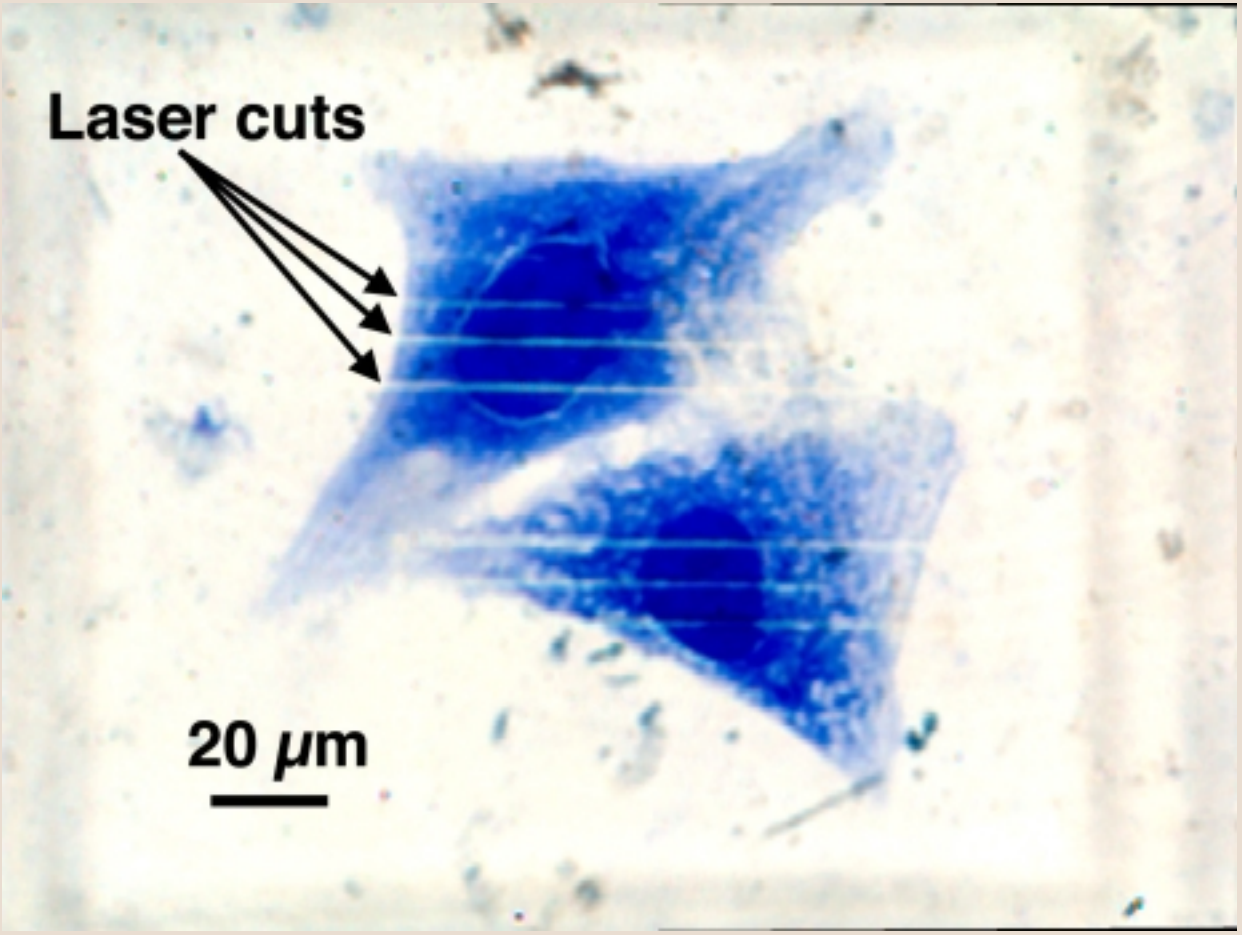
bovine epithelial cells

BIOLOGICAL RESEARCH



after irradiation with 10-nJ pulses

BIOLOGICAL RESEARCH



sub-cellular surgical precision!

ACKNOWLEGEMENTS

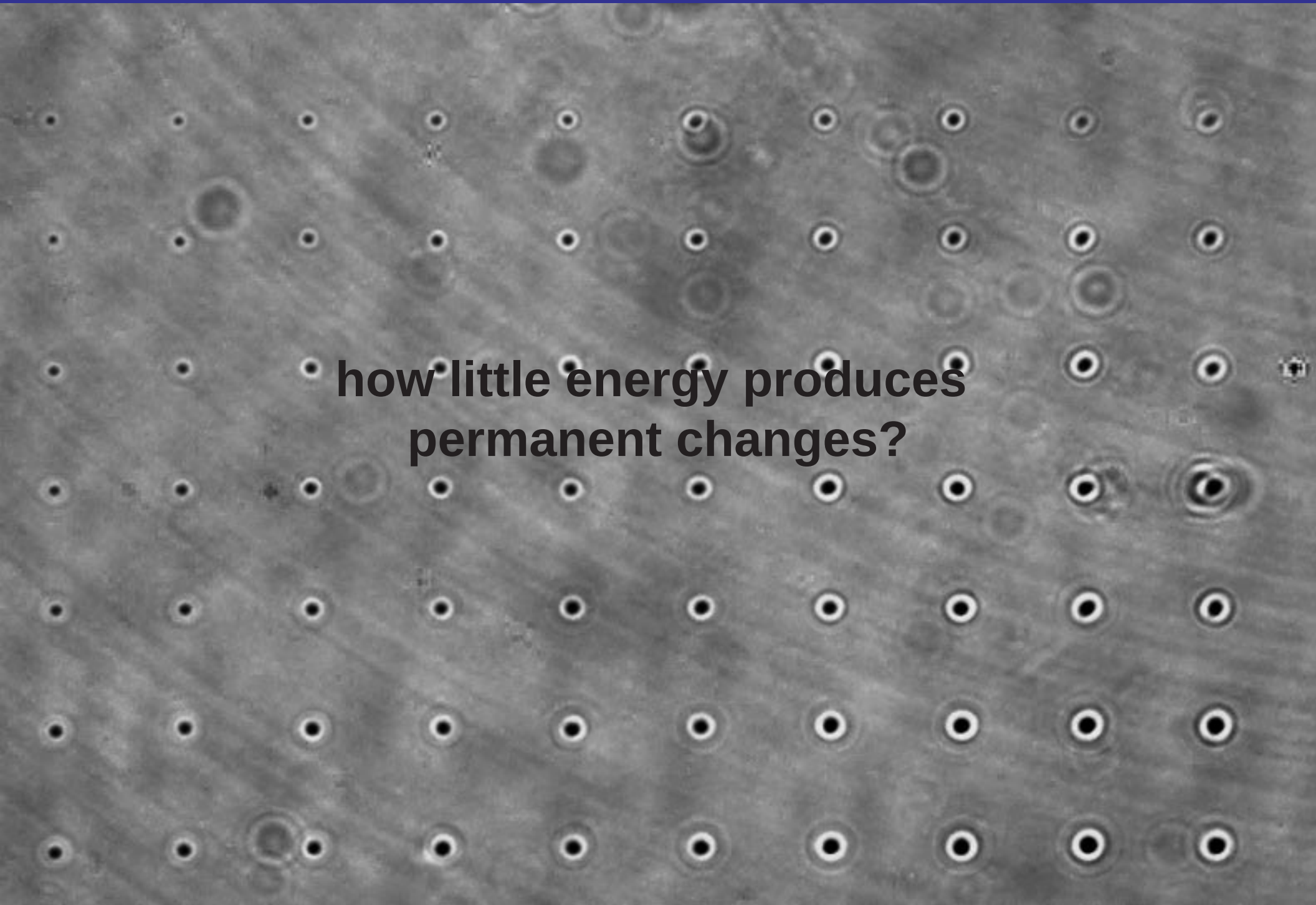
W. Leight and N. Shen
Prof. N. Bloembergen

National Science Foundation

For a copy of this talk and additional information, see:

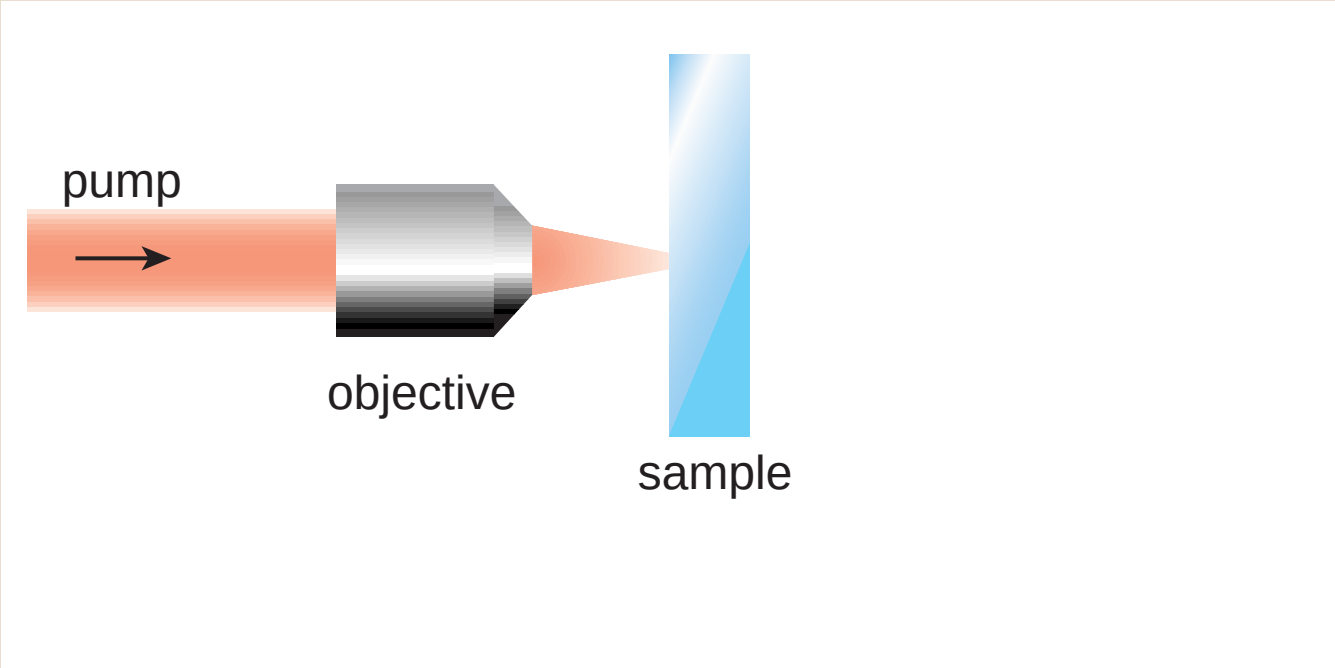
http://mazur-www.harvard.edu/

THRESHOLDS

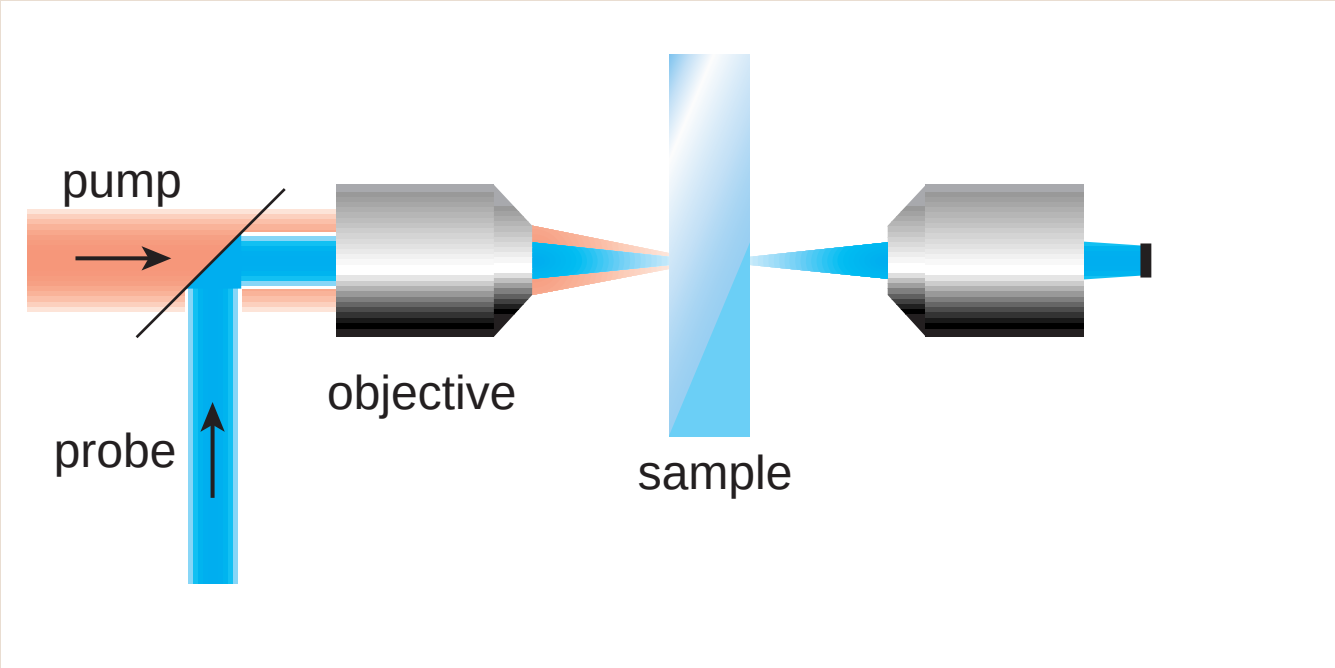


how little energy produces permanent changes?

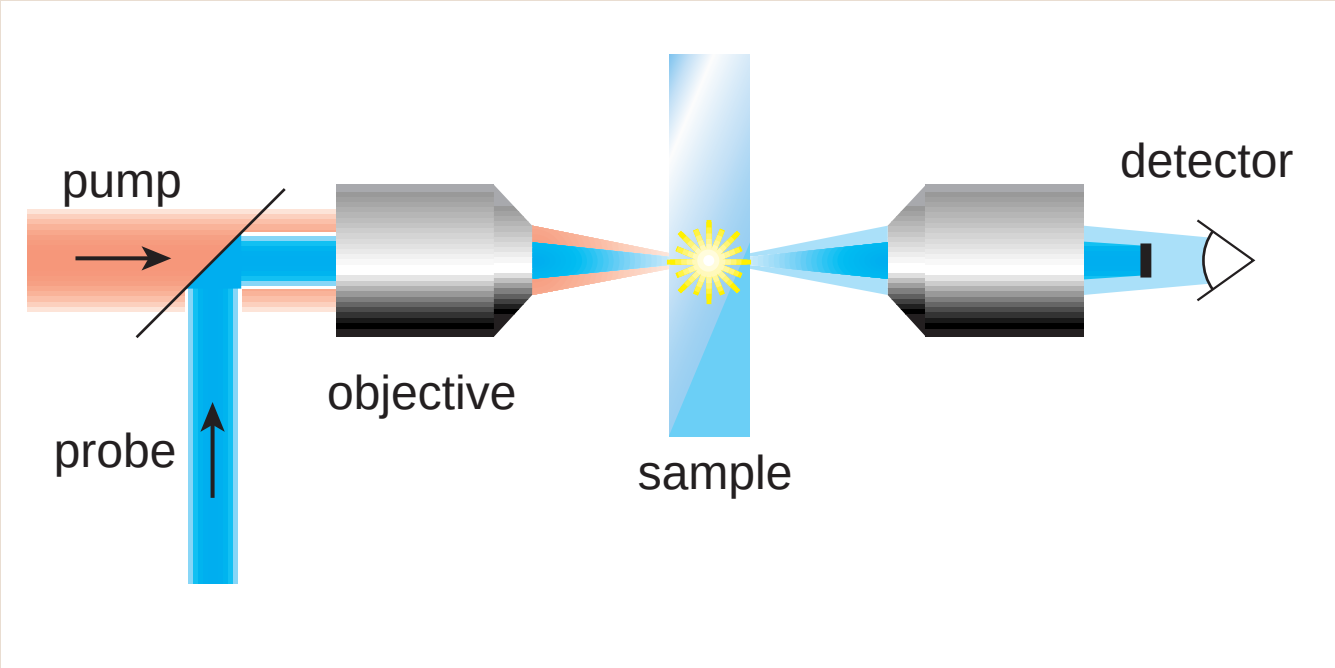
pump sample with femtosecond pulse



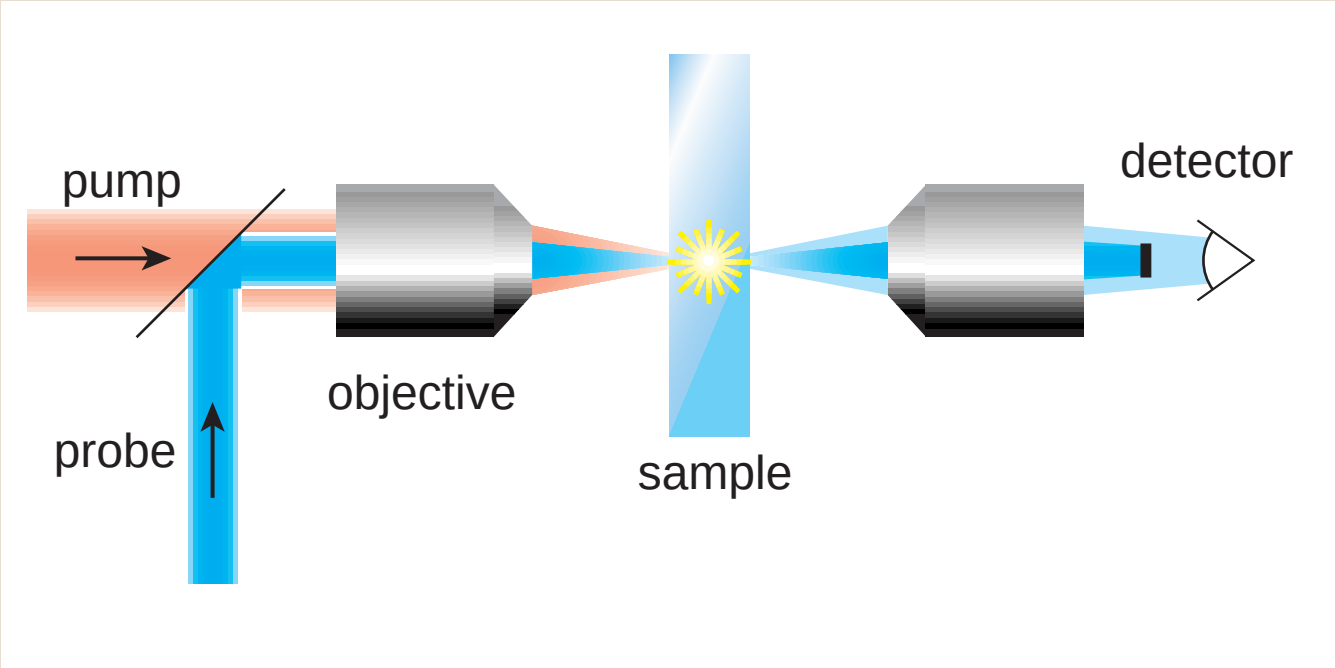
block probe beam



detect light scattered by damage

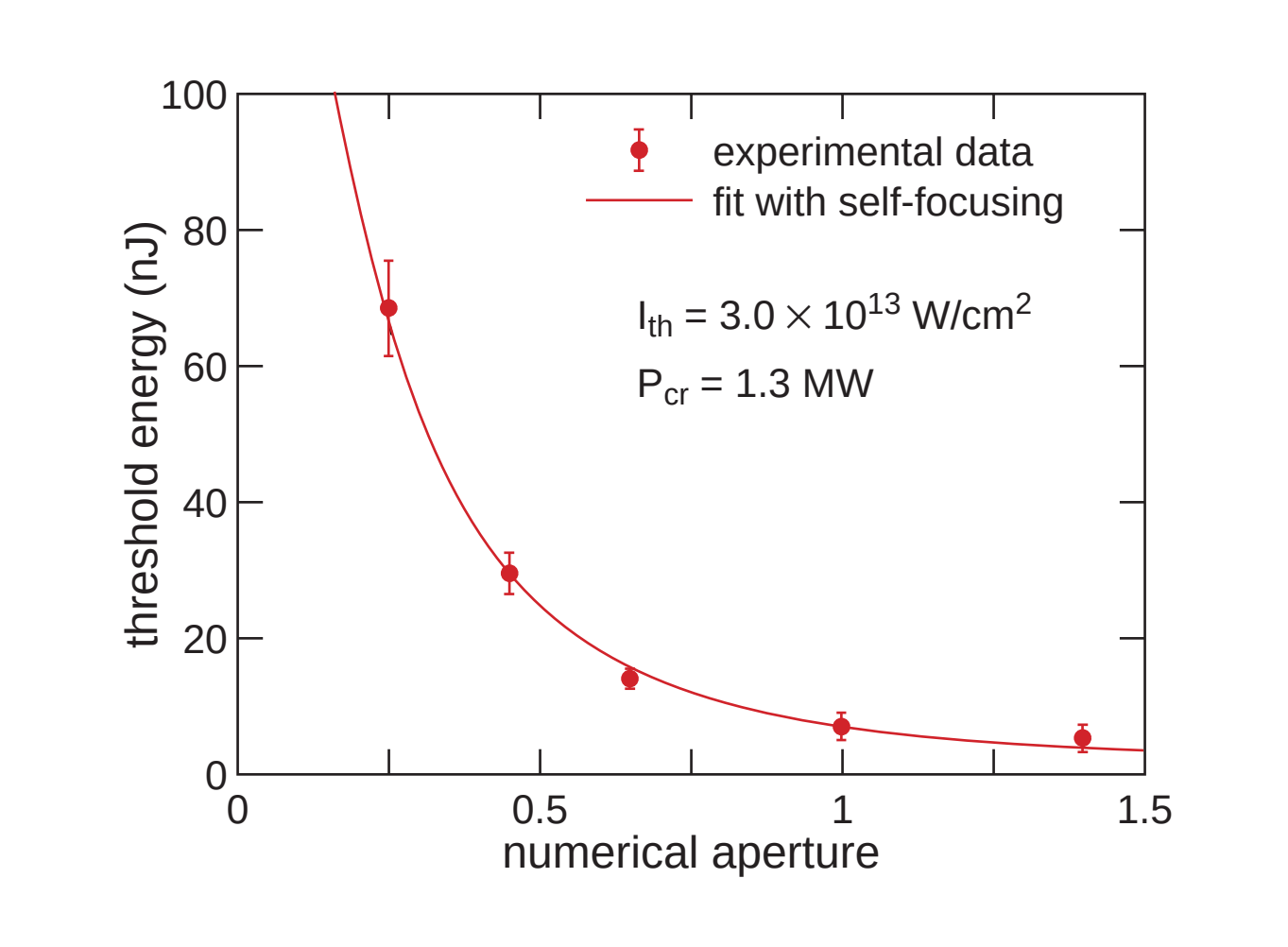


THRESHOLDS



vary NA, material, pump wavelength

THRESHOLDS



energy threshold vs. NA for 100-fs pulses in Corning 0211