Oscillator-only micromachining of transparent materials

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Photonics West
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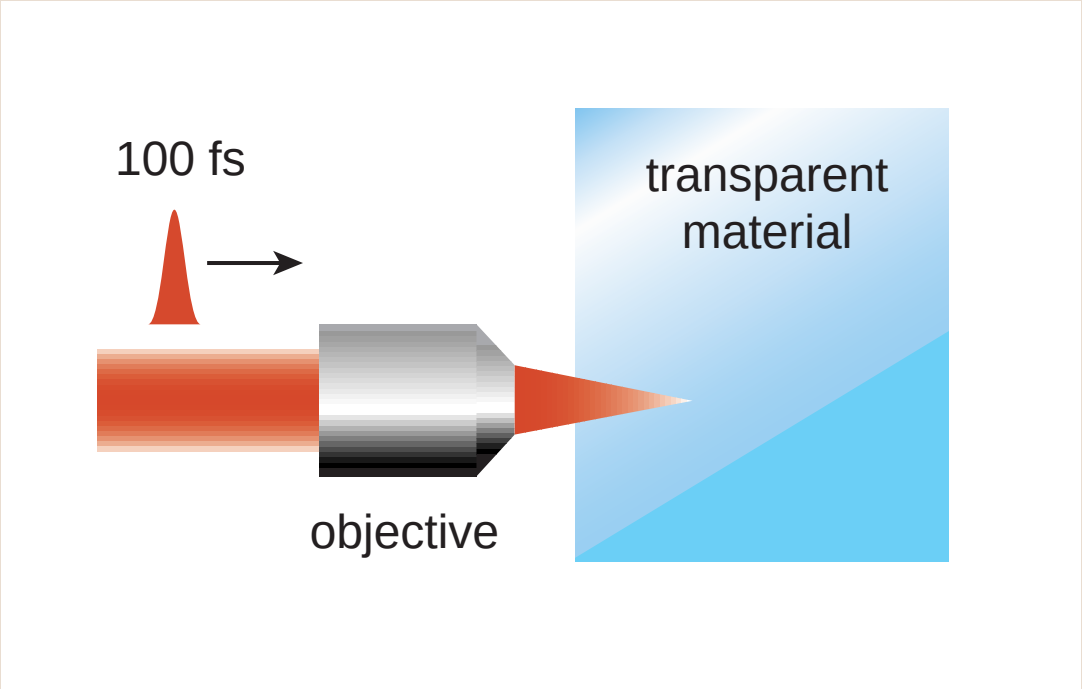
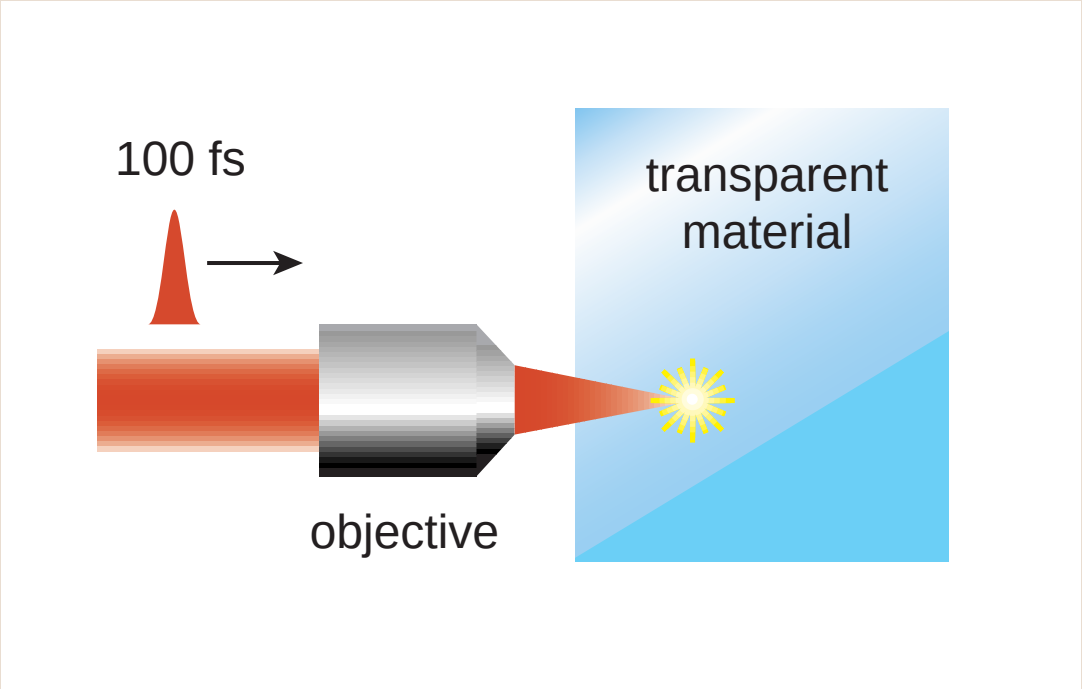
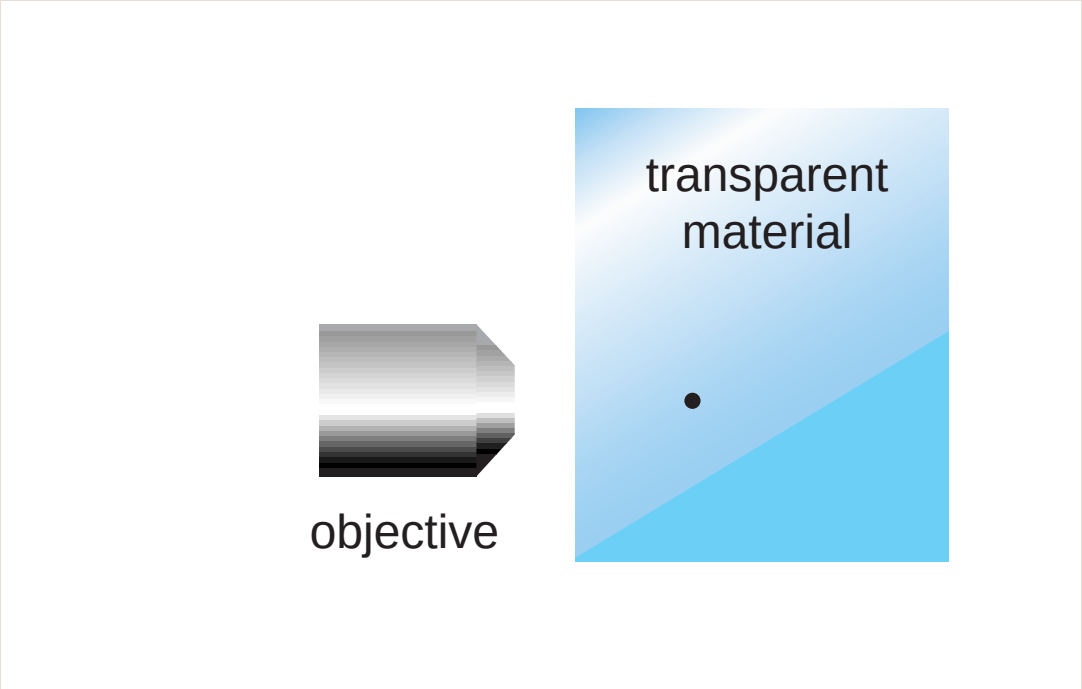
high intensity at focus



causes nonlinear ionization



producing microscopic bulk damage



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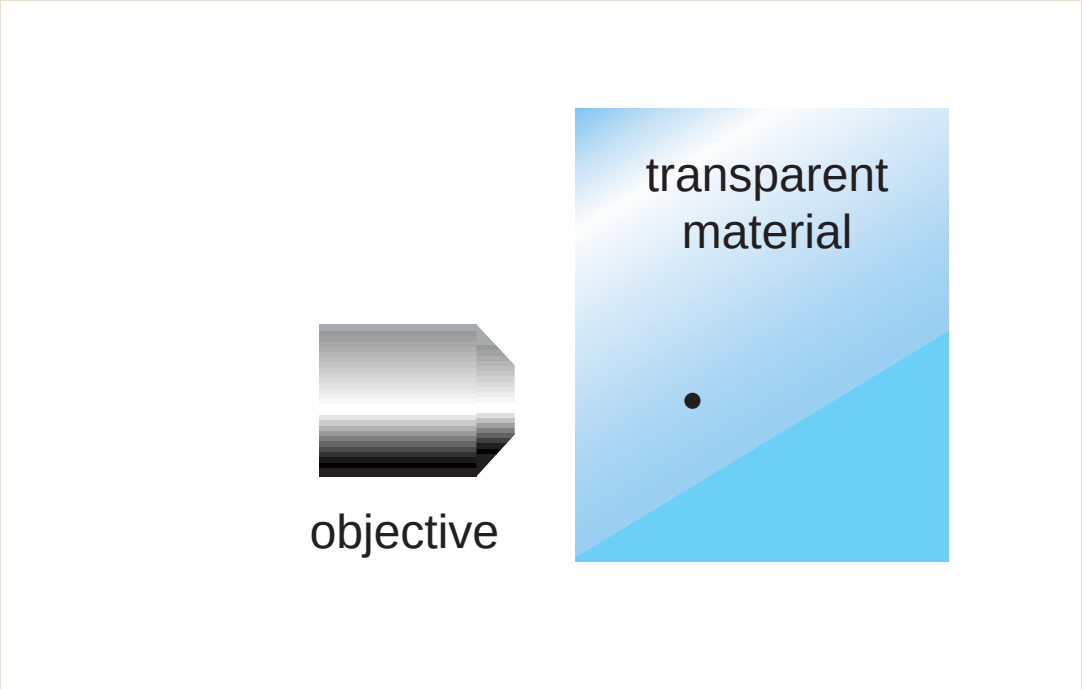
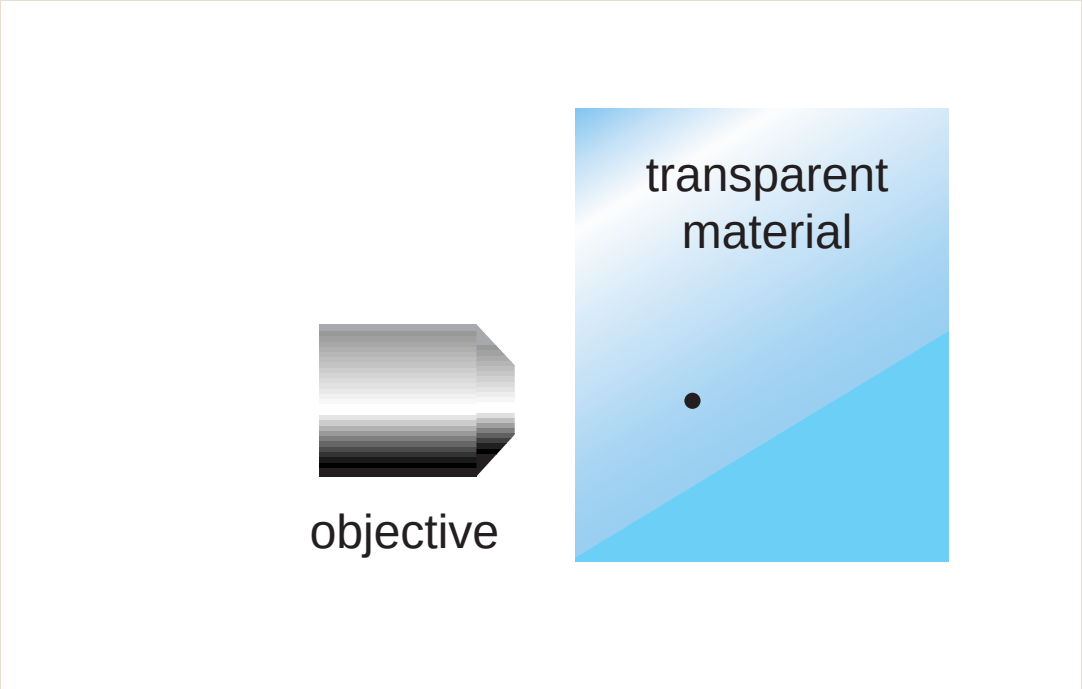


with only tens of nanojoules!

producing microscopic bulk damage

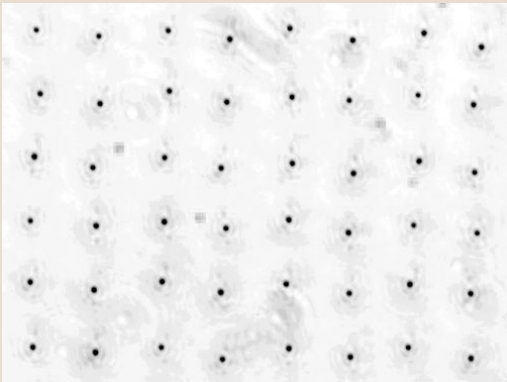


with only tens of nanojoules!

why bulk?

why bulk?

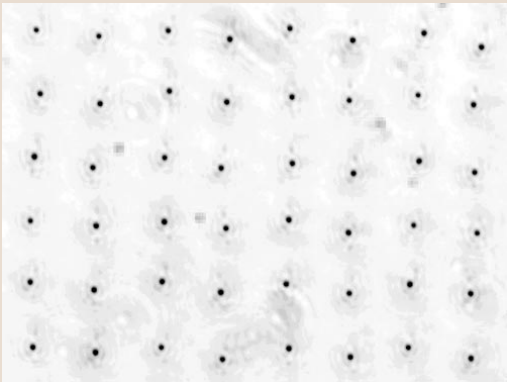
three-dimensional micromachining



INTRODUCTION

why bulk?

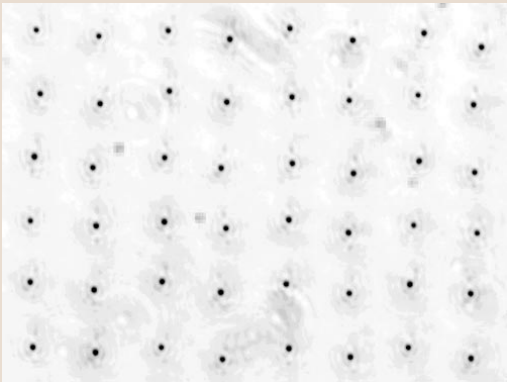
three-dimensional micromachining



why nanojoules?

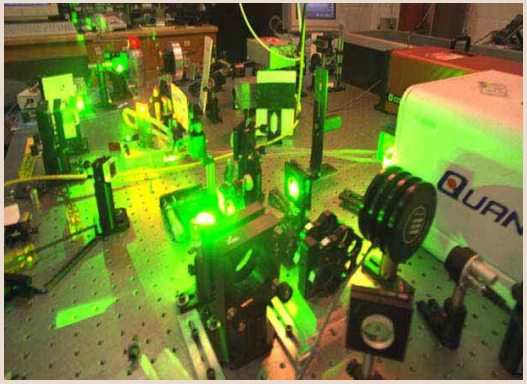
why bulk?

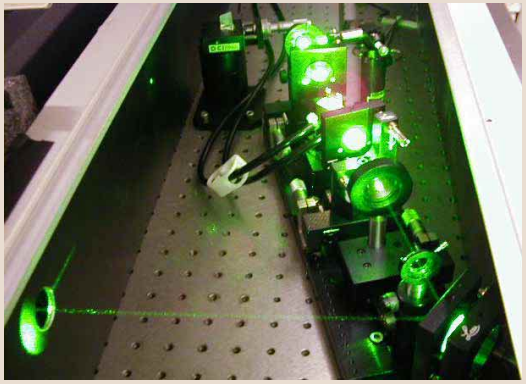
three-dimensional micromachining



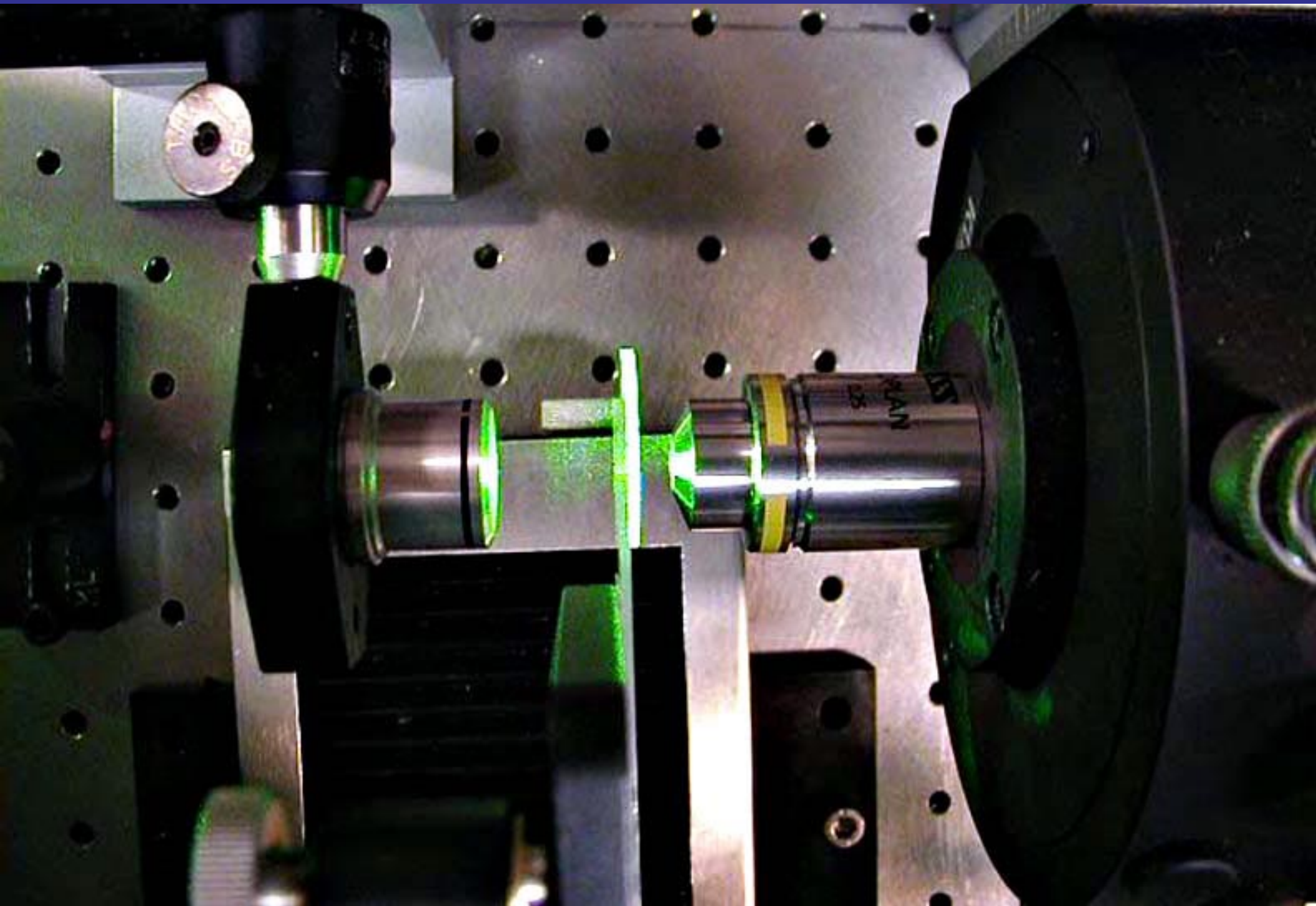
why nanojoules?

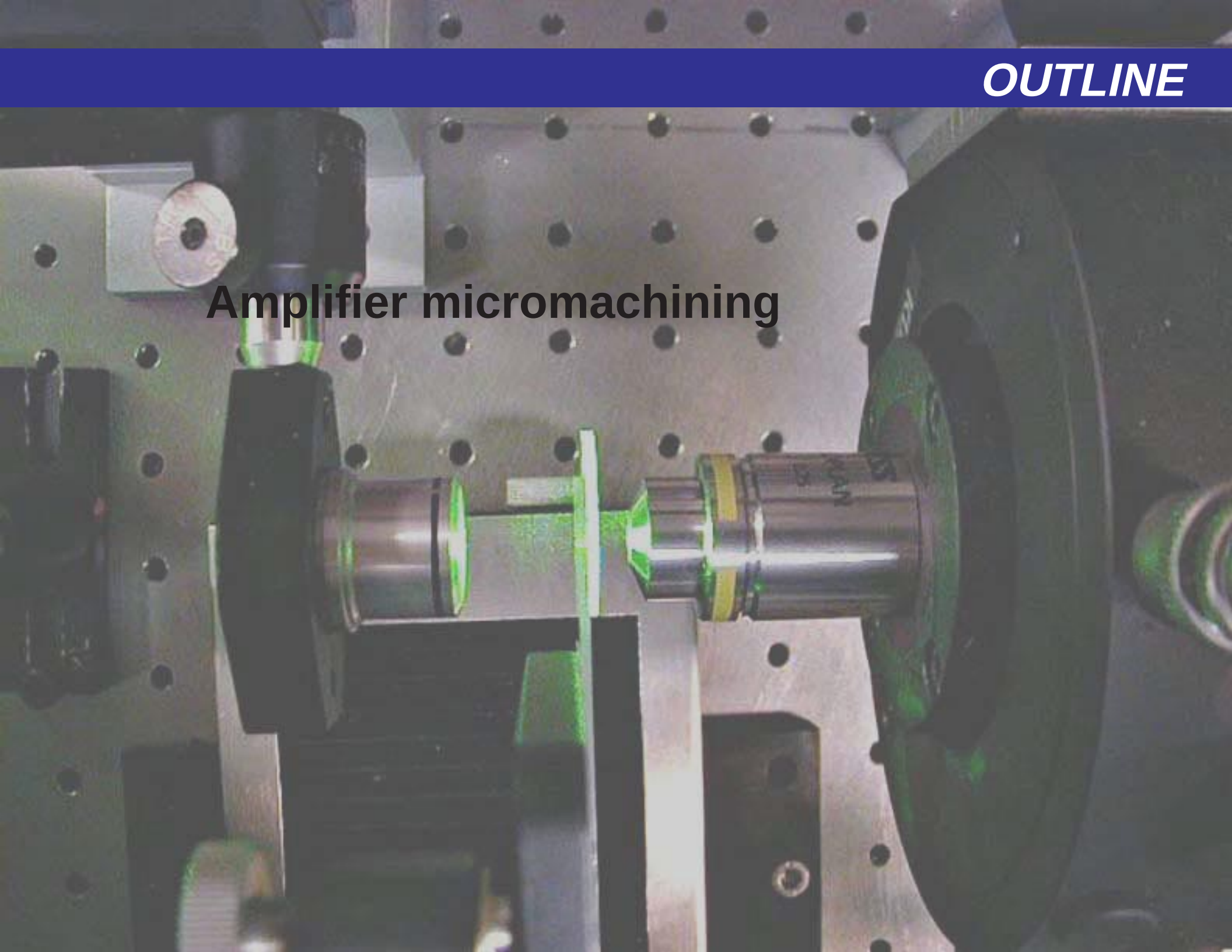
non-amplified micromachining





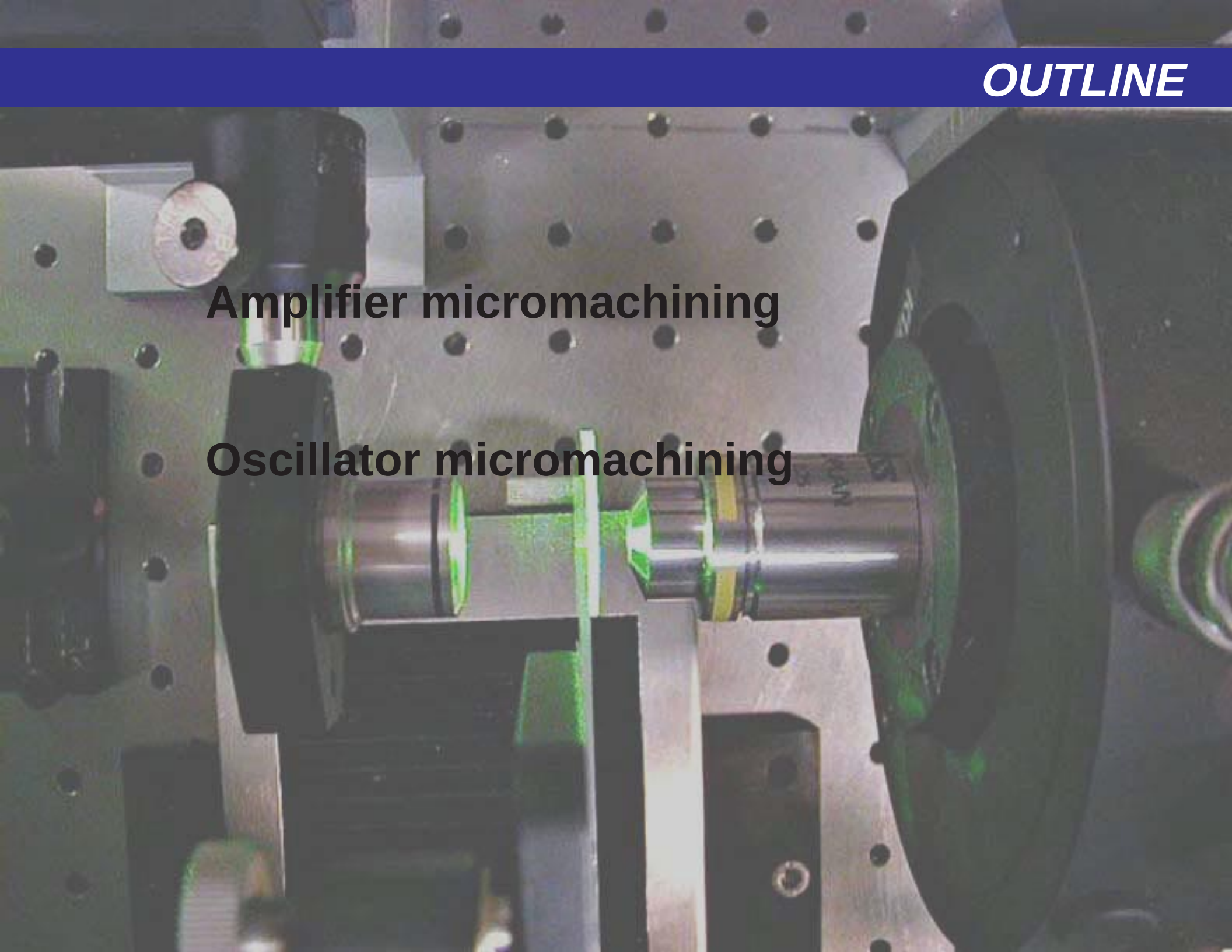
OUTLINE





Amplifier micromachining

OUTLINE



Amplifier micromachining

Oscillator micromachining

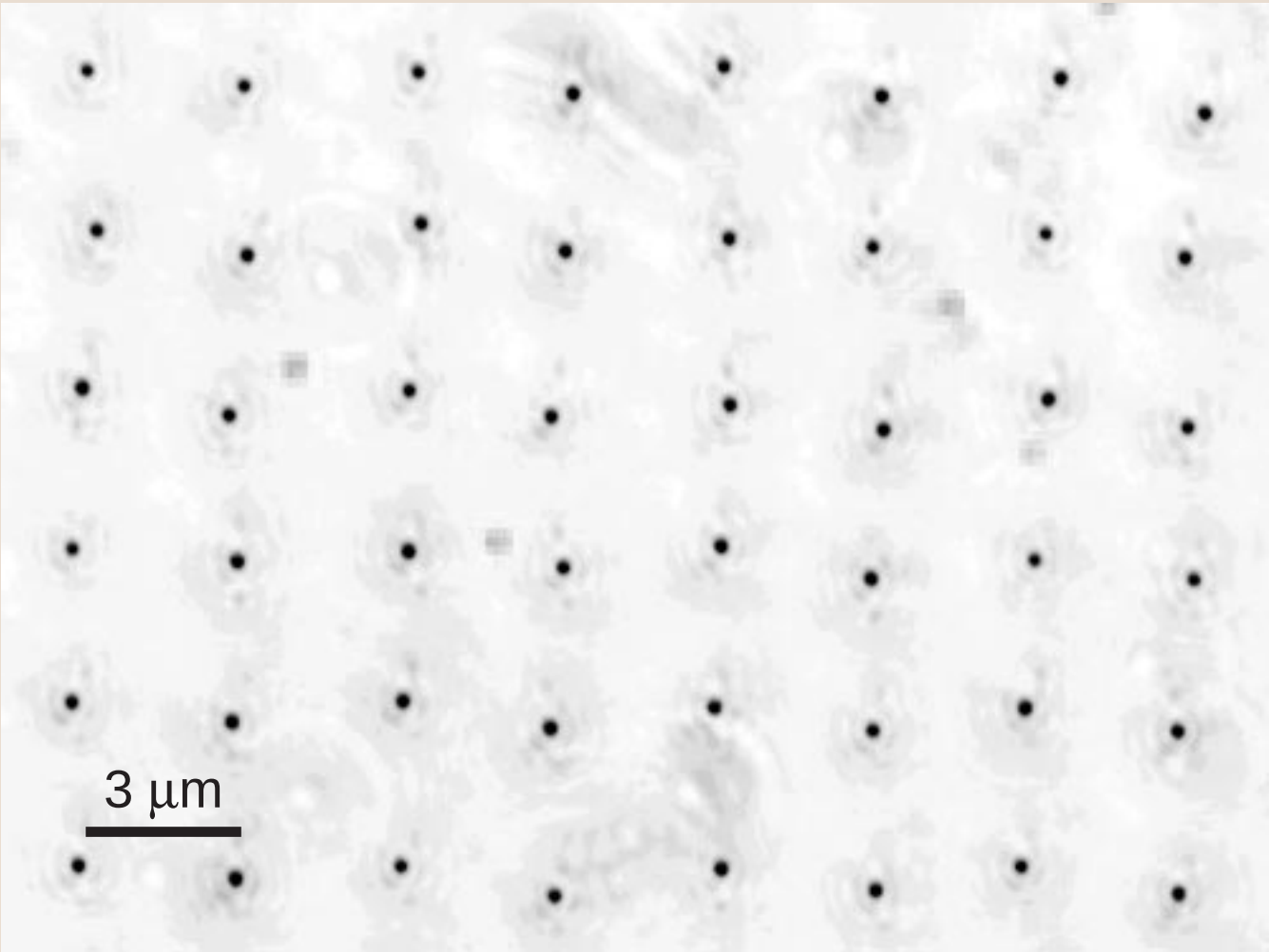
OUTLINE

Amplifier micromachining

Oscillator micromachining

Summary

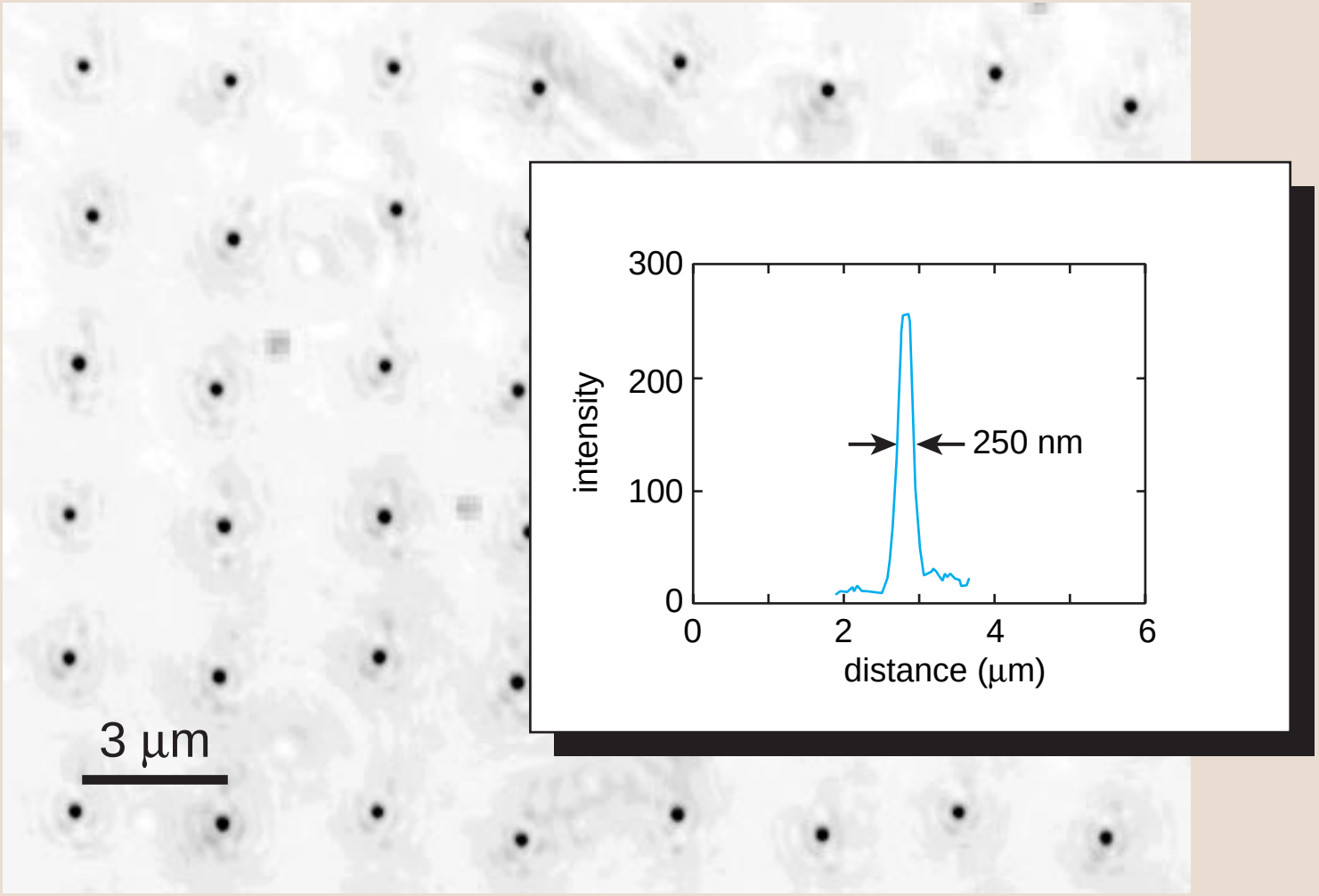
AMPLIFIER MICROMACHINING



40 nJ
100 fs
800 nm
0.65 NA
Corning 0211

top view

AMPLIFIER MICROMACHINING



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Corning 0211

top view

AMPLIFIER MICROMACHINING

40 nJ
100 fs
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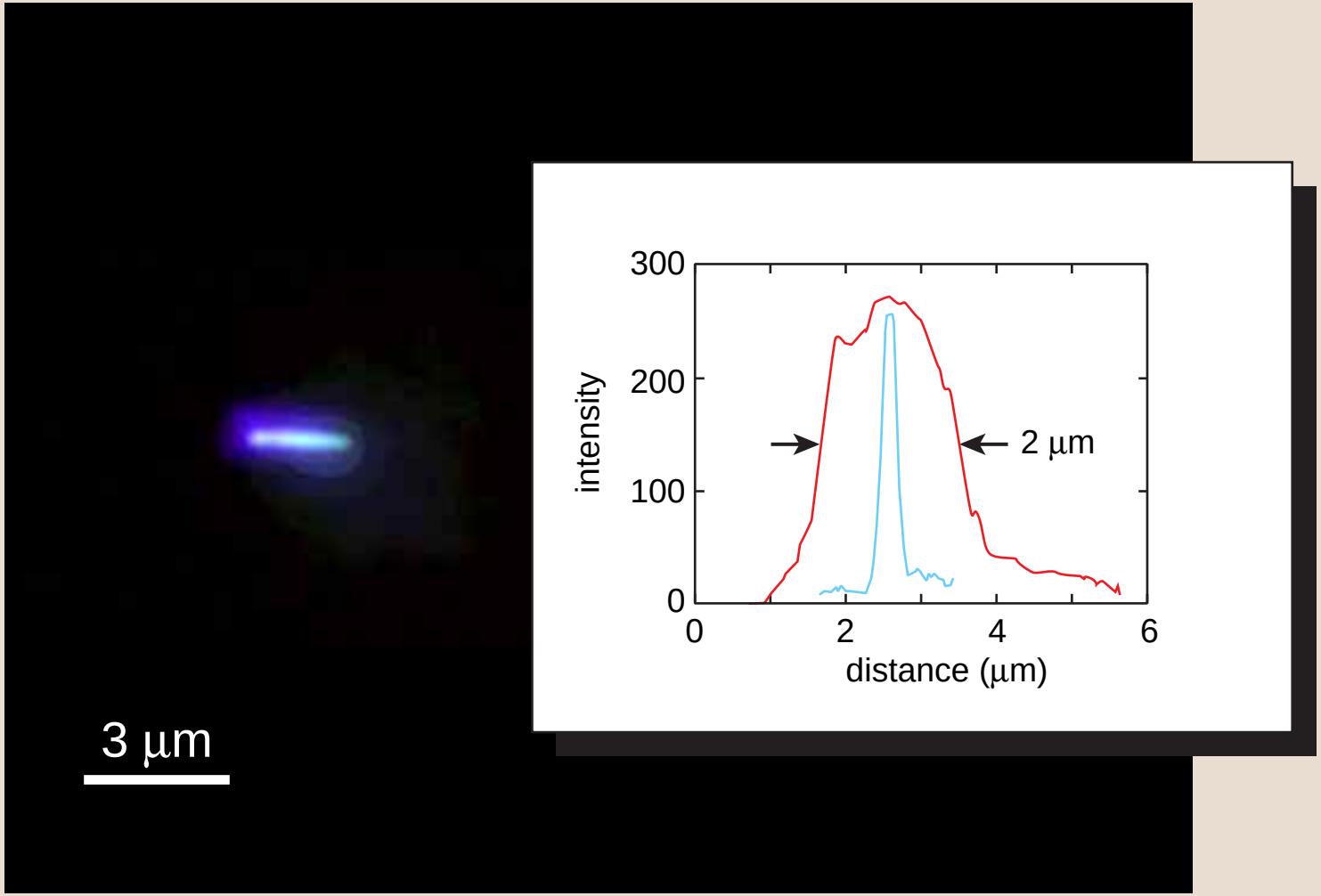
Corning 0211

side view

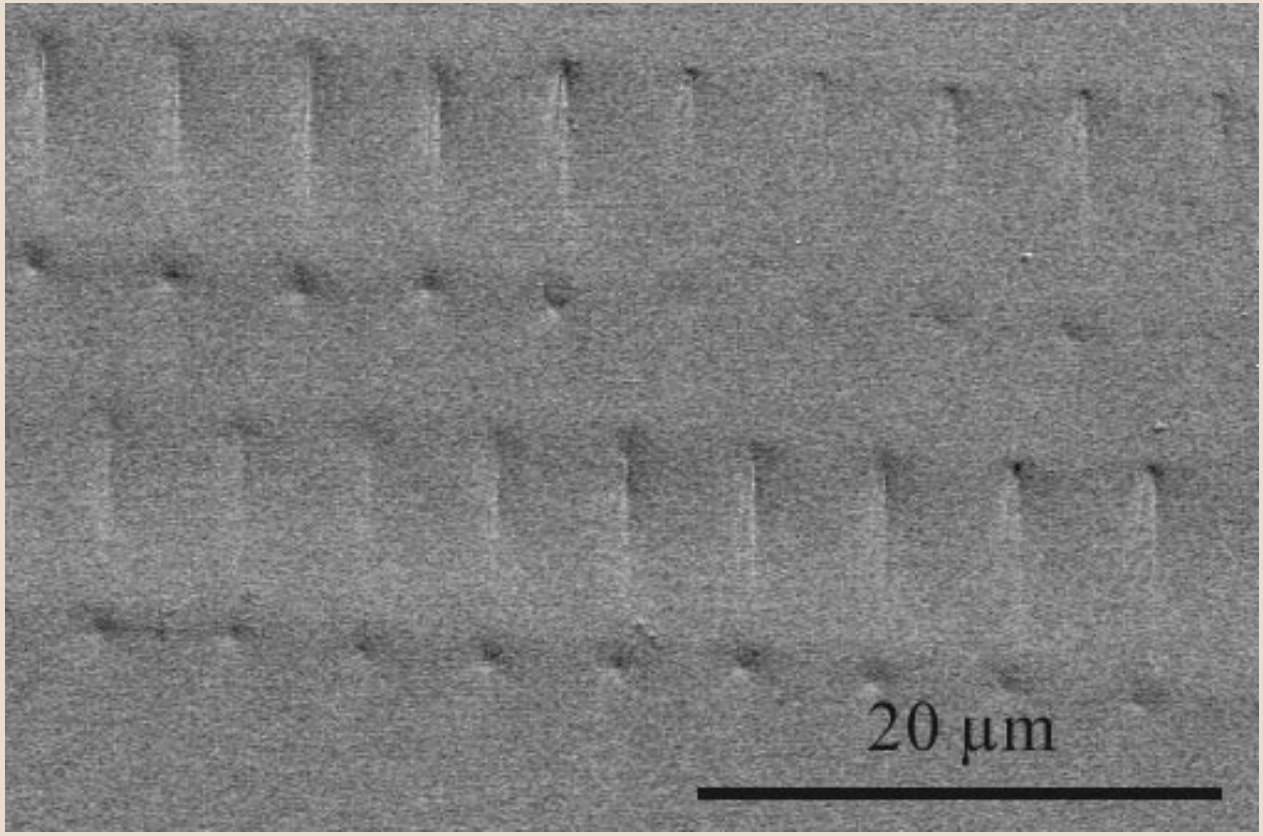
AMPLIFIER MICROMACHINING



40 nJ
100 fs
800 nm
0.65 NA
Corning 0211

side view

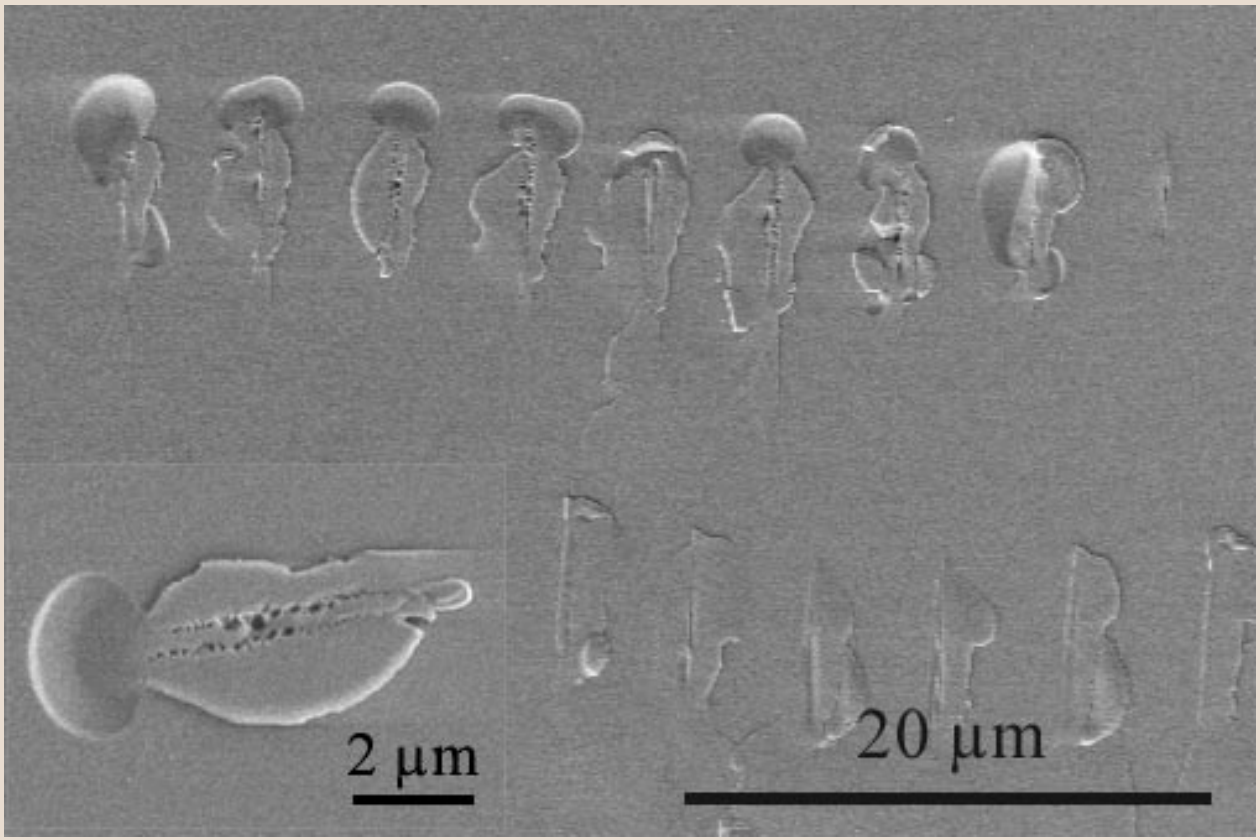
AMPLIFIER MICROMACHINING



100 fs
800 nm
0.45 NA
Corning 0211

side view SEM, 140 nJ

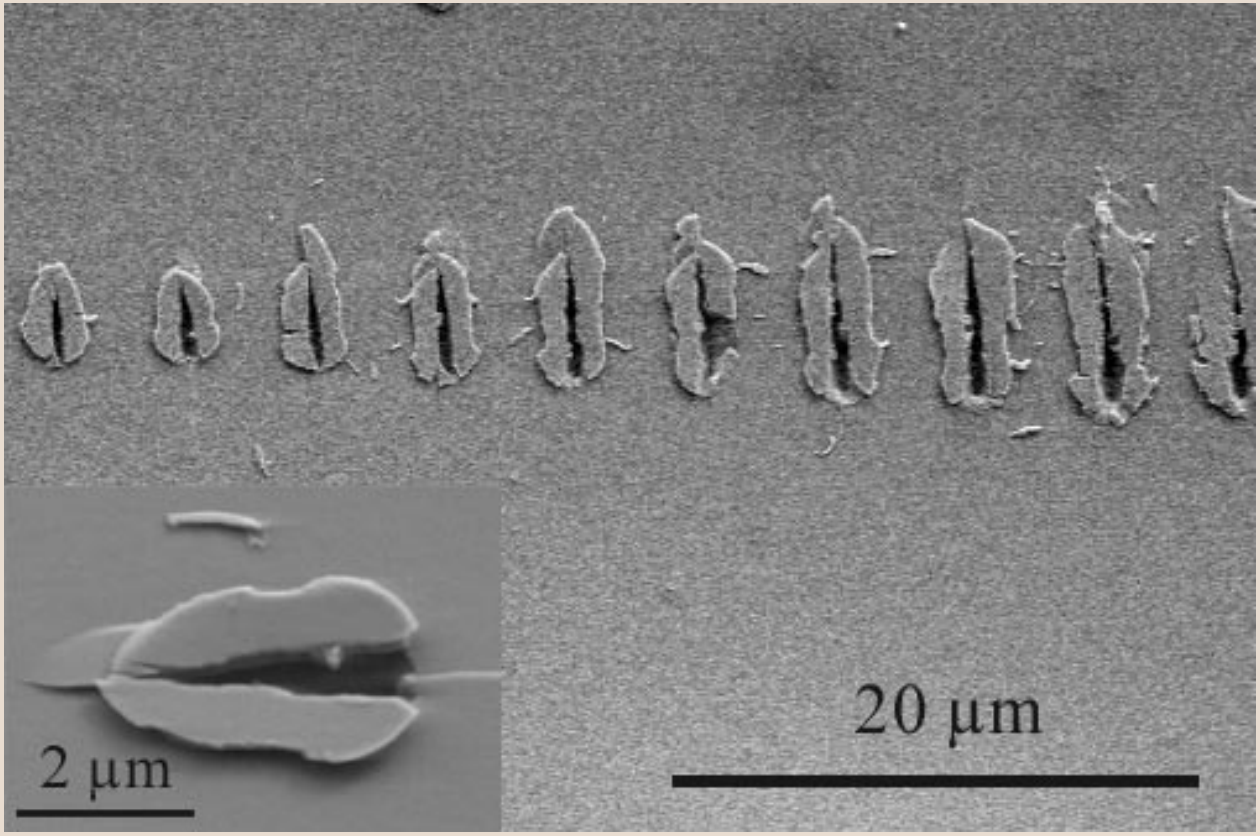
AMPLIFIER MICROMACHINING



100 fs
800 nm
0.45 NA
Corning 0211

side view SEM, 250 nJ

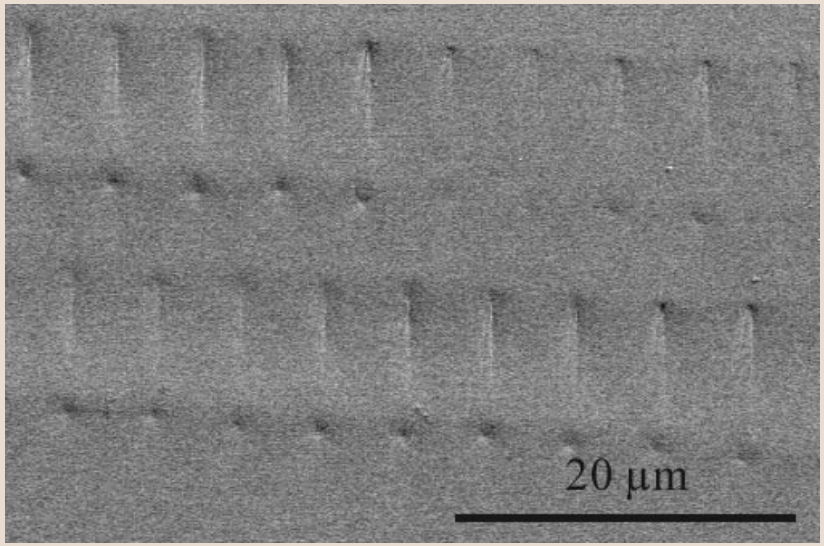
AMPLIFIER MICROMACHINING



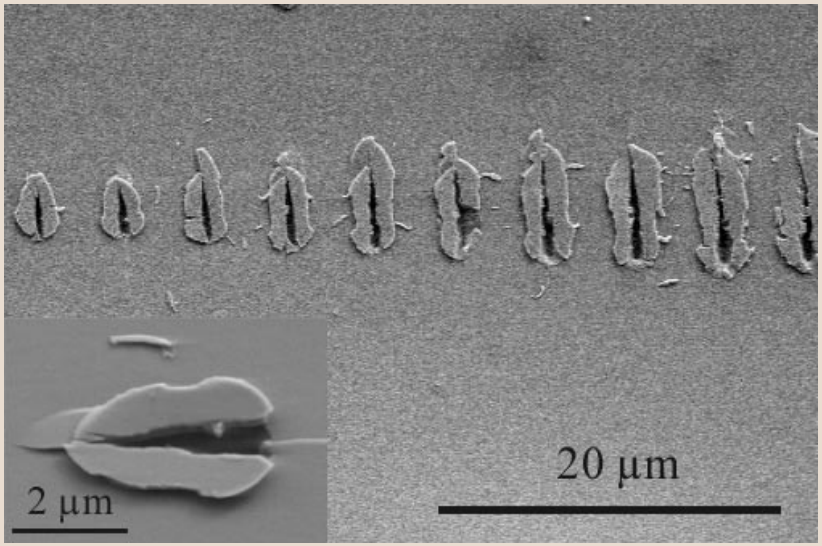
100 fs
800 nm
0.45 NA
Corning 0211

side view SEM, 540 nJ

AMPLIFIER MICROMACHINING



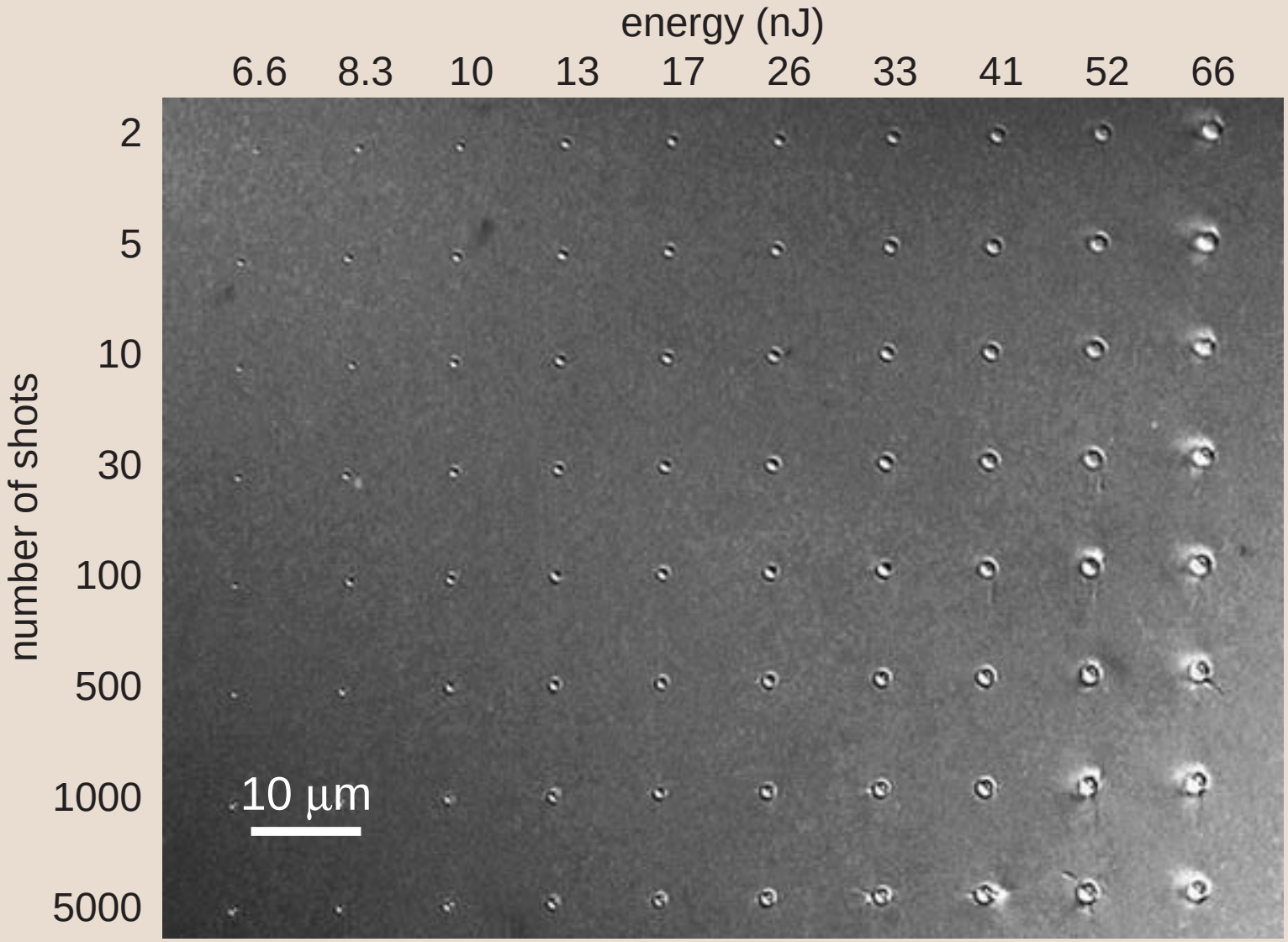
thermal mechanism



explosive mechanism

transition in damage mechanism and morphology

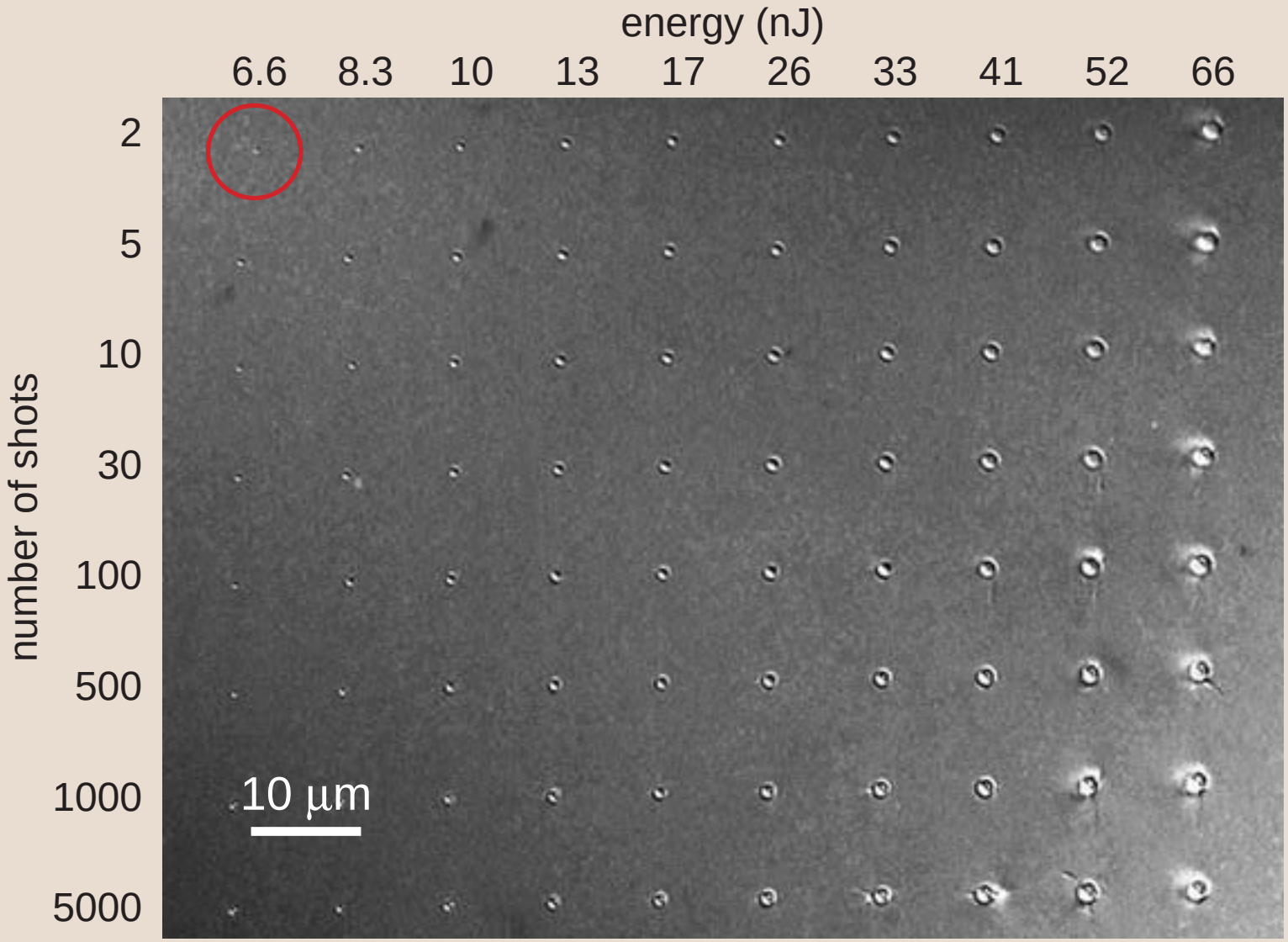
AMPLIFIER MICROMACHINING



100 fs
800 nm
1.4 NA
Corning 0211

shot number and energy dependence at 1 kHz

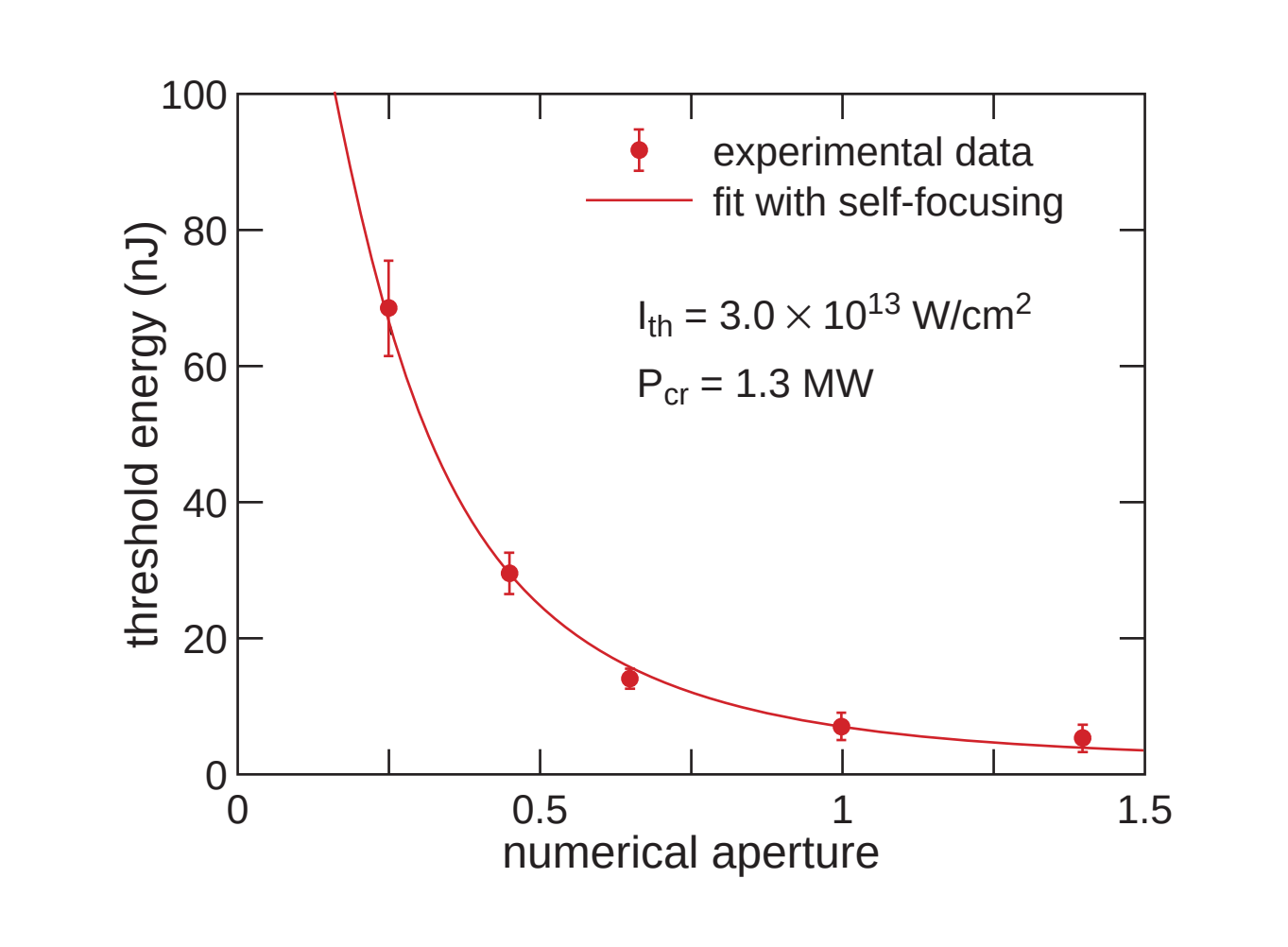
AMPLIFIER MICROMACHINING



100 fs
800 nm
1.4 NA
Corning 0211

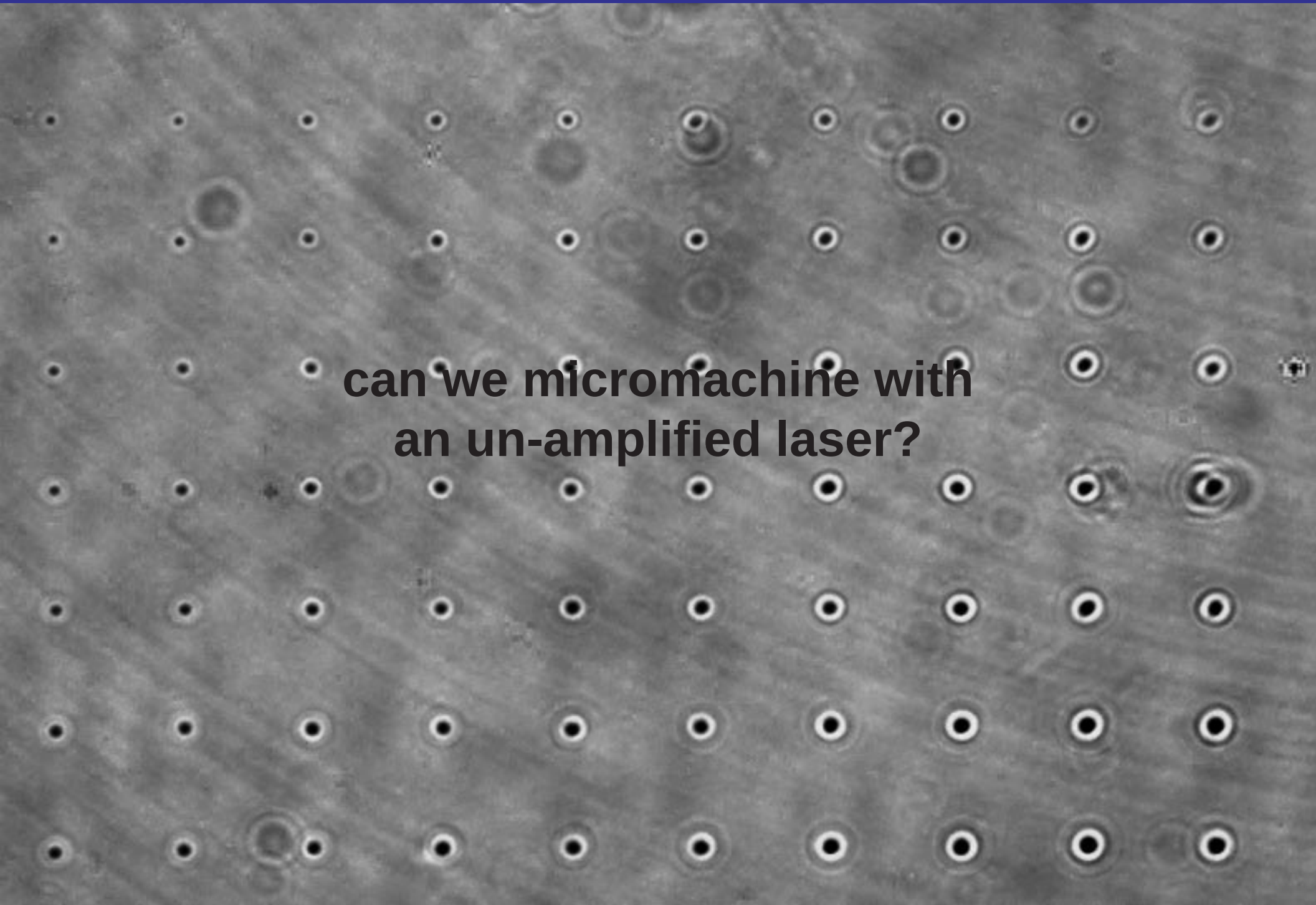
only 6.6 nJ; can we use only an oscillator?

AMPLIFIED MICROMACHINING



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

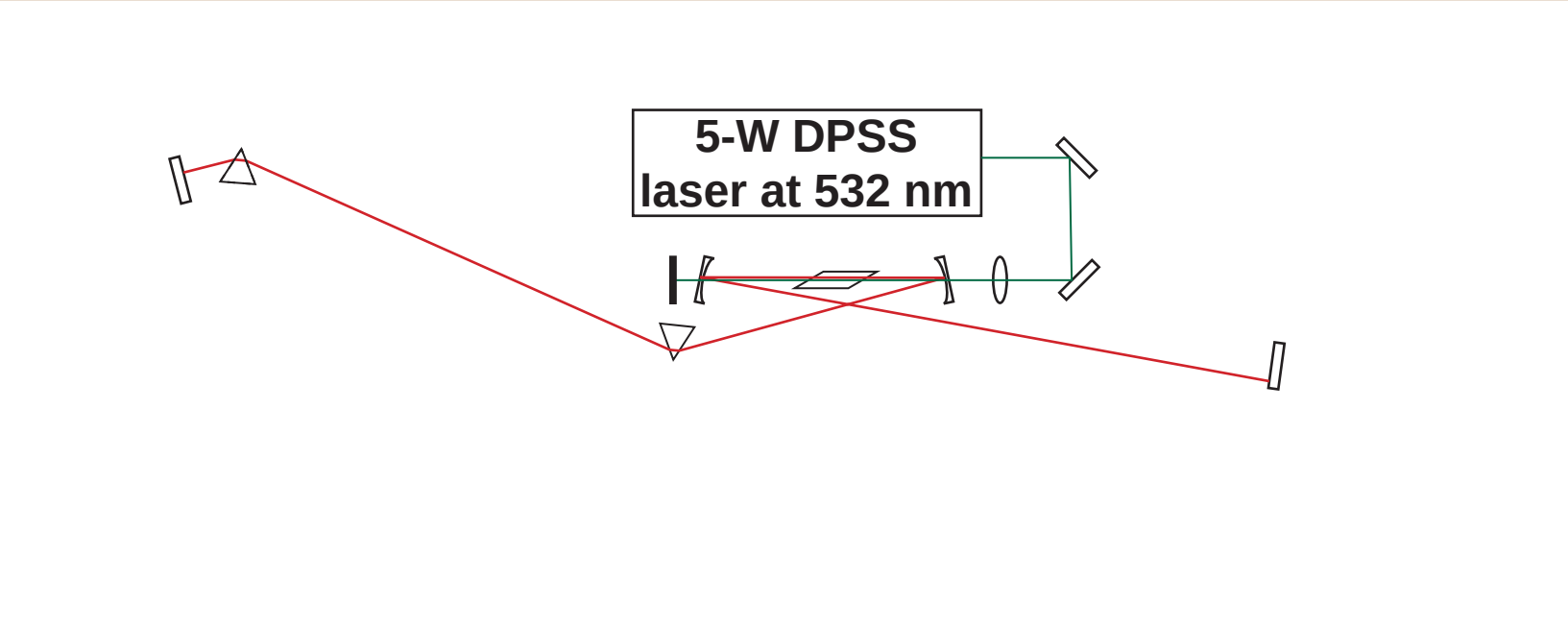
OSCILLATOR MICROMACHINING



can we micromachine with an un-amplified laser?

OSCILLATOR MICROMACHINING

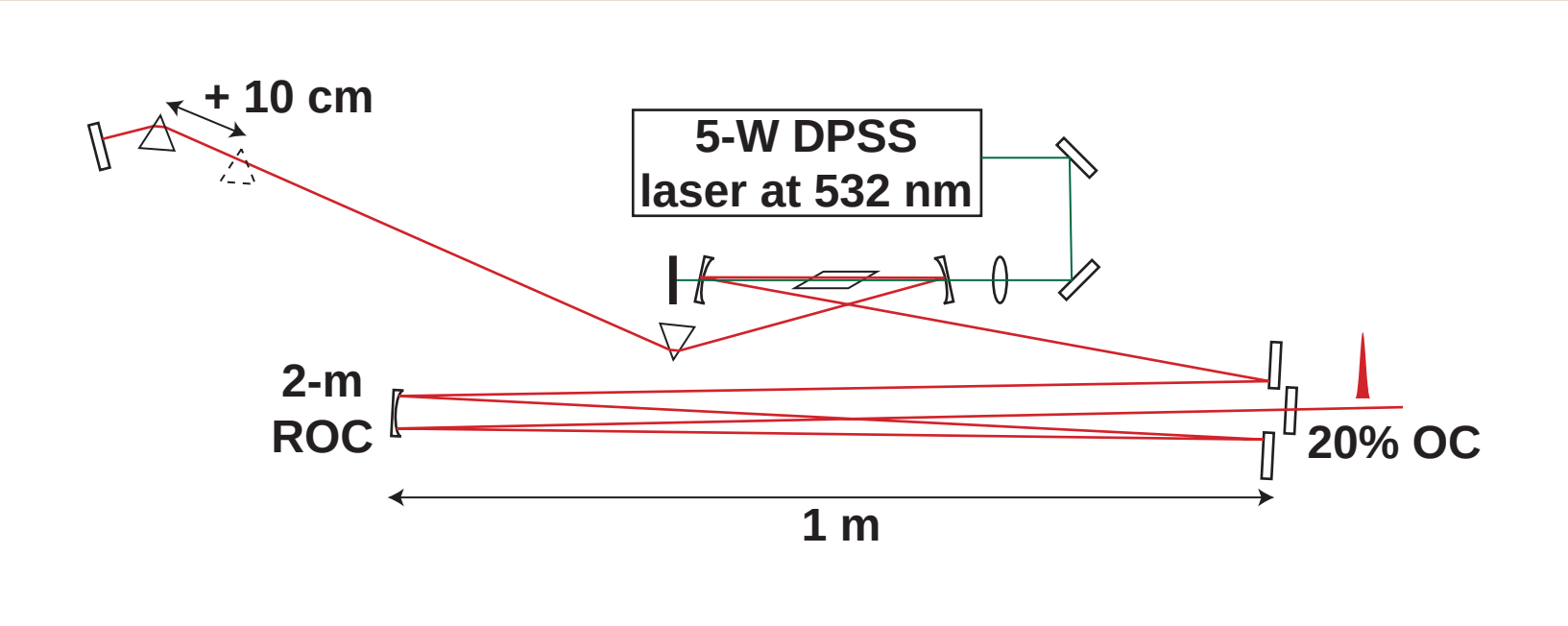
to deliver 5 nJ to the sample



after losses in the objective and prism compressor...

OSCILLATOR MICROMACHINING

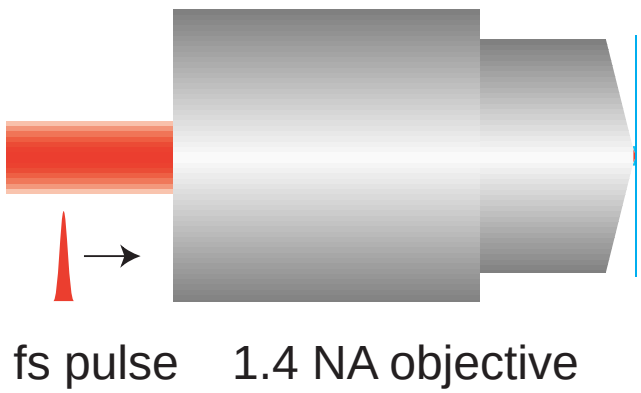
... extend cavity of standard Ti:Sapph oscillator



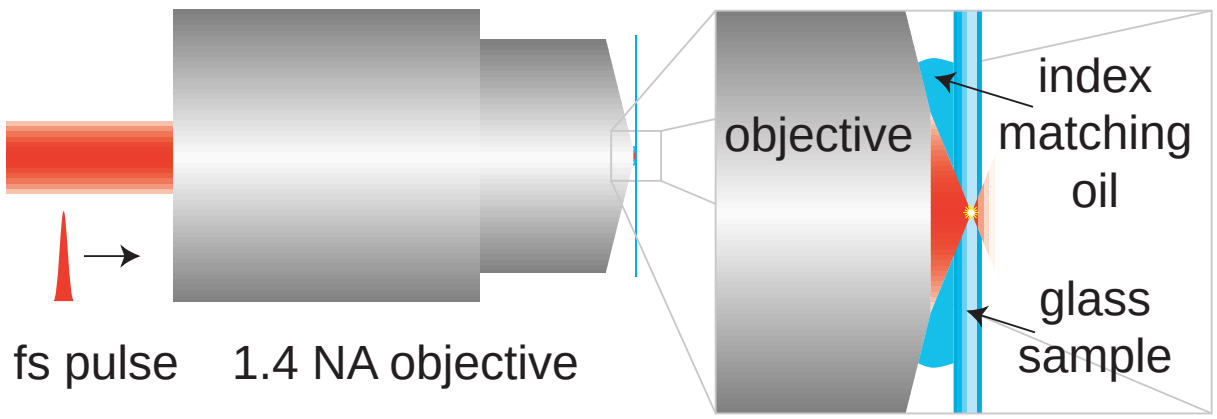
laser specs: 20 nJ, 25 MHz, 20 fs

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

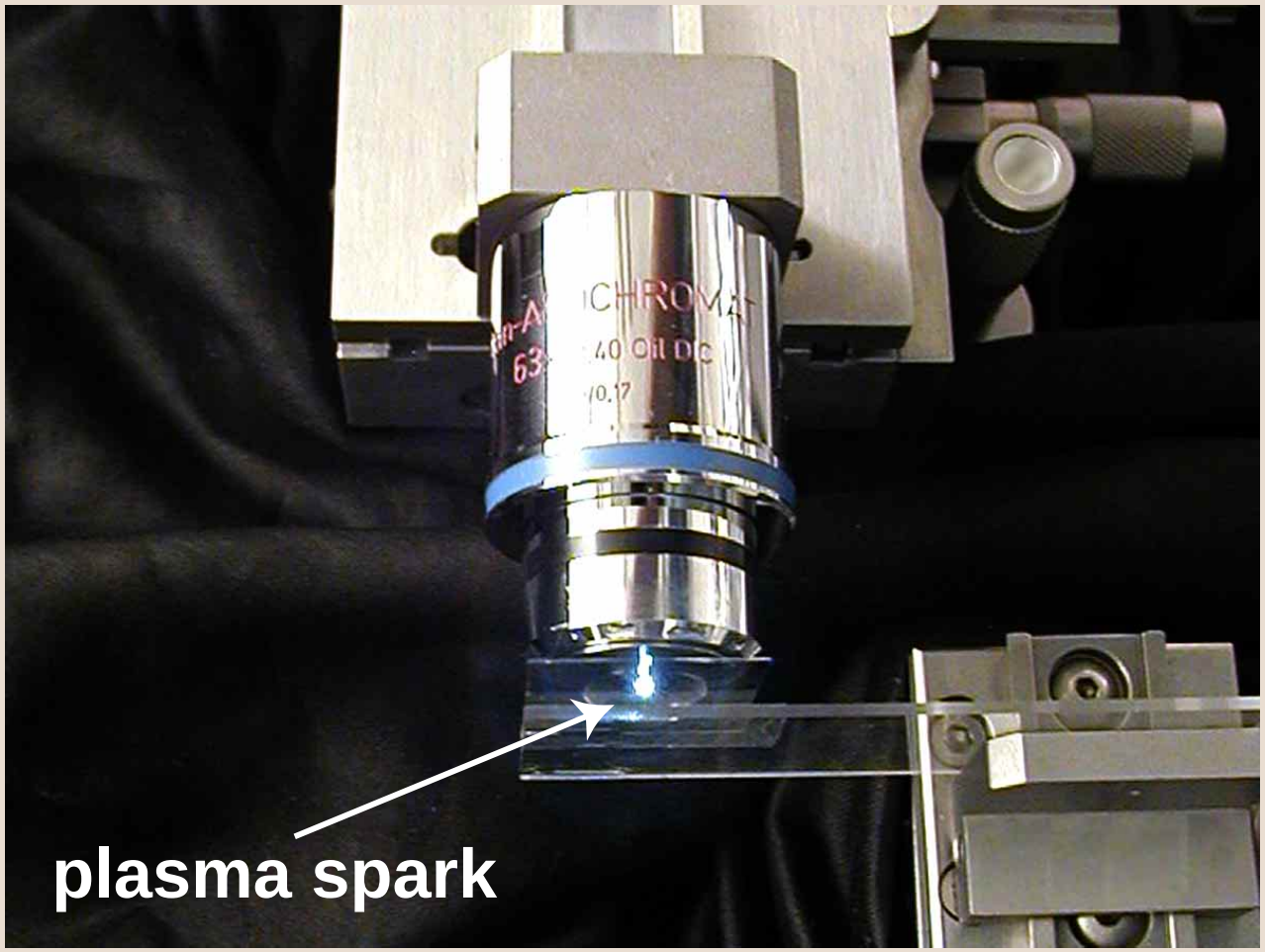
scale model of 1.4 NA focusing geometry



scale model of 1.4 NA focusing geometry

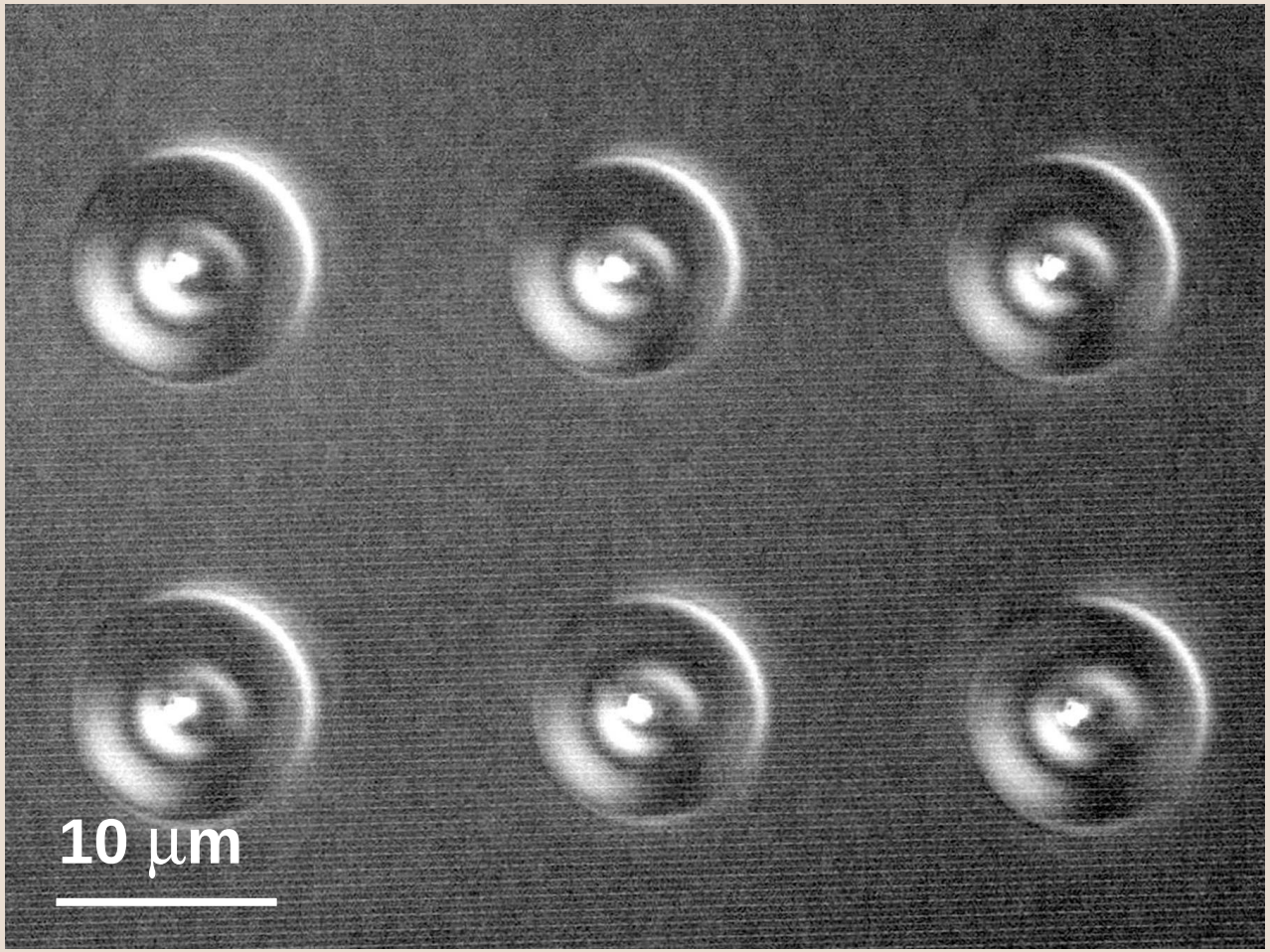


actual 1.4 NA focusing geometry



OSCILLATOR MICROMACHINING

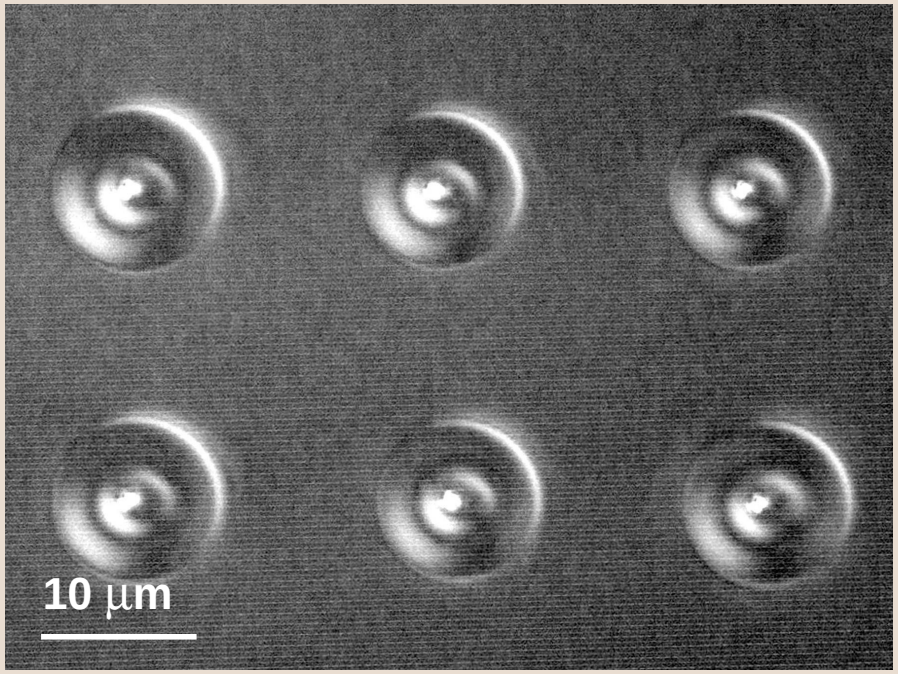
damage made with 25-MHz oscillator: 5 nJ; 25,000 shots



< 100 fs
800 nm
1.4 NA
Corning 0211

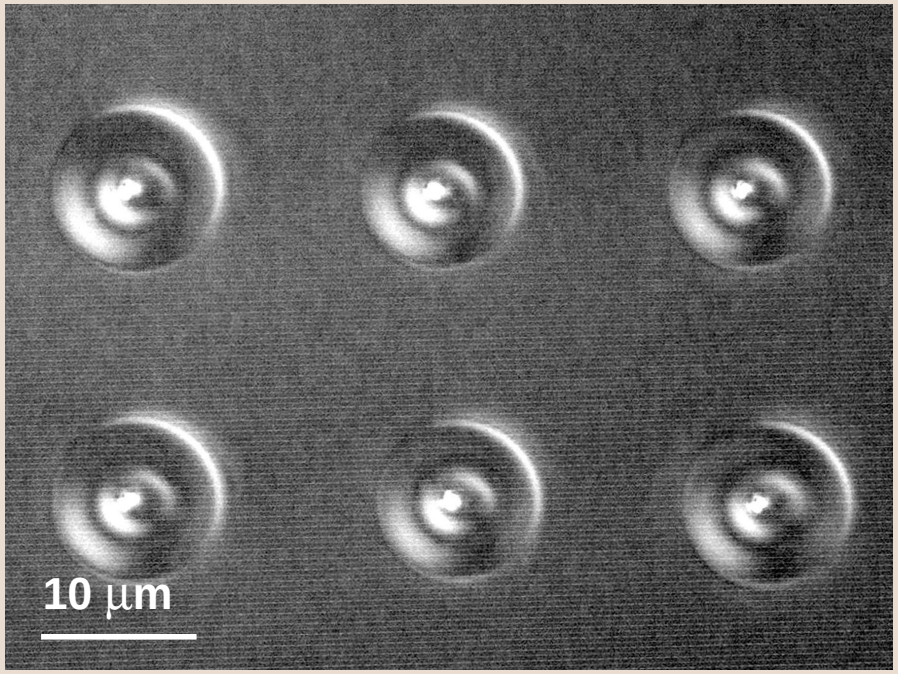
OSCILLATOR MICROMACHINING

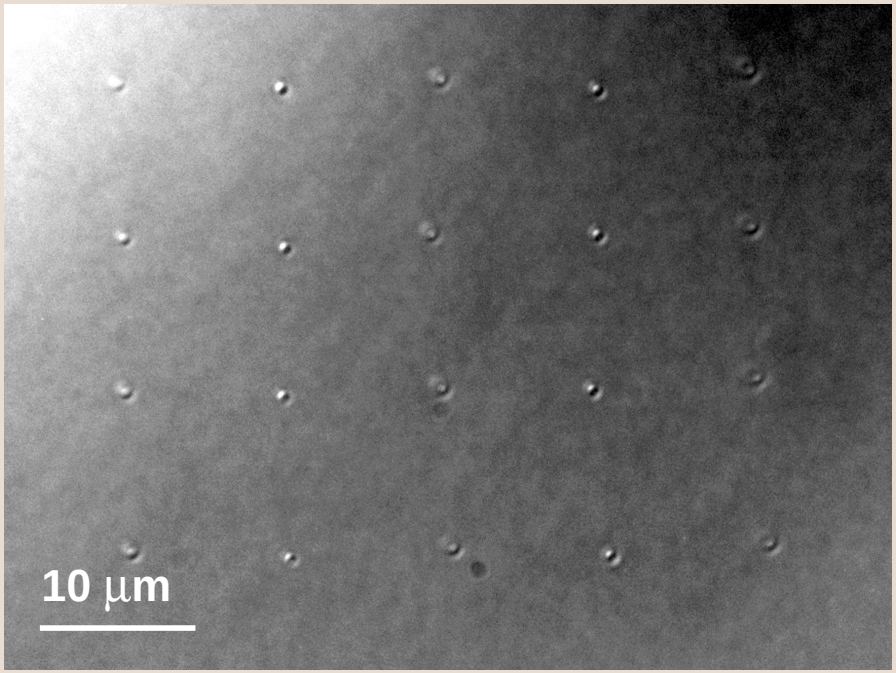
5 nJ; 25,000 shots



OSCILLATOR MICROMACHINING

5 nJ; 25,000 shots

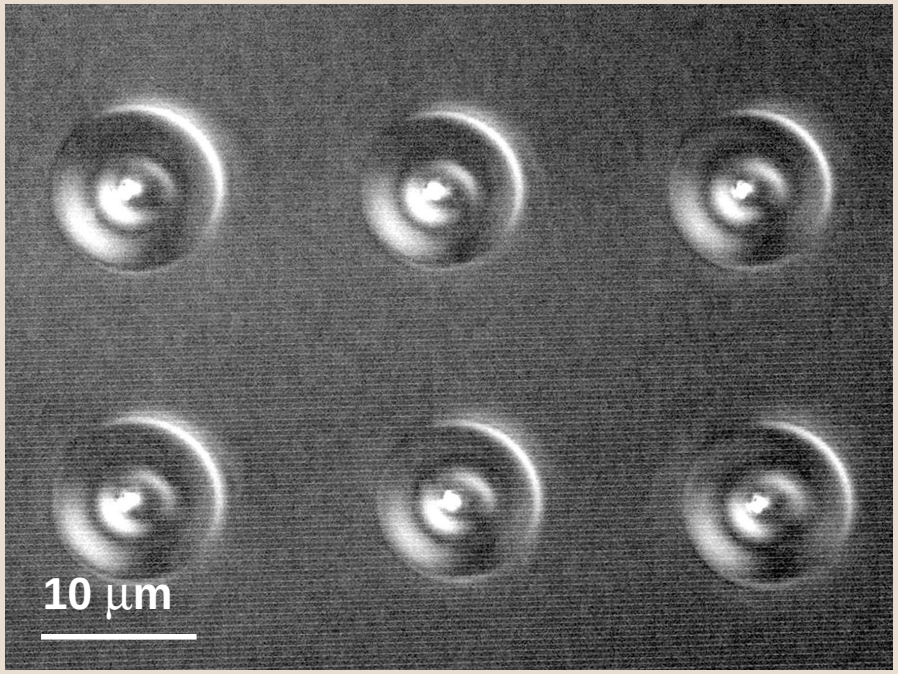




10 nJ; single shot

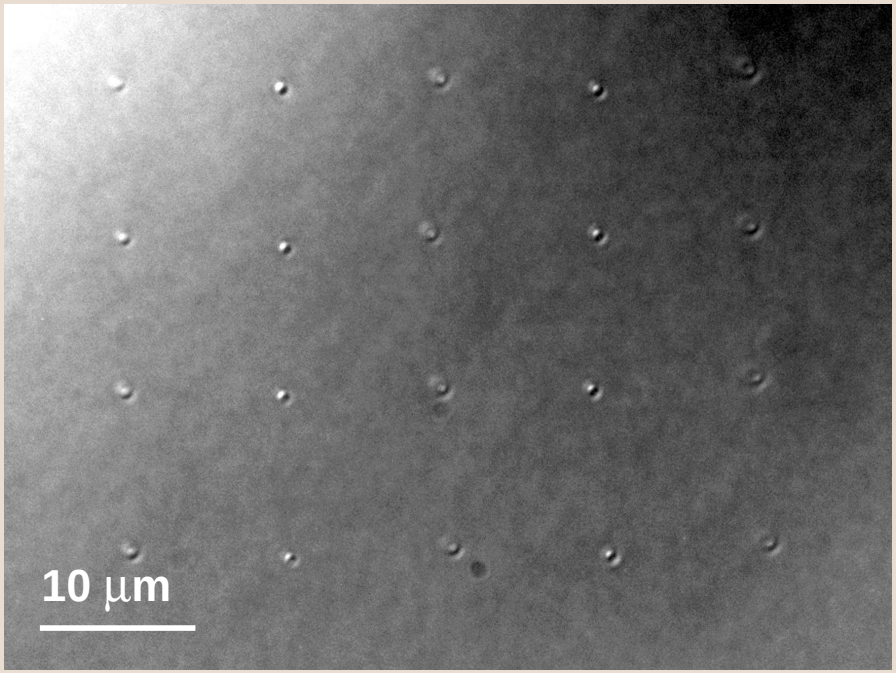
OSCILLATOR MICROMACHINING

5 nJ; 25,000 shots



cumulative heating by successive pulses melts the glass

explosive or small-scale melting mechanism

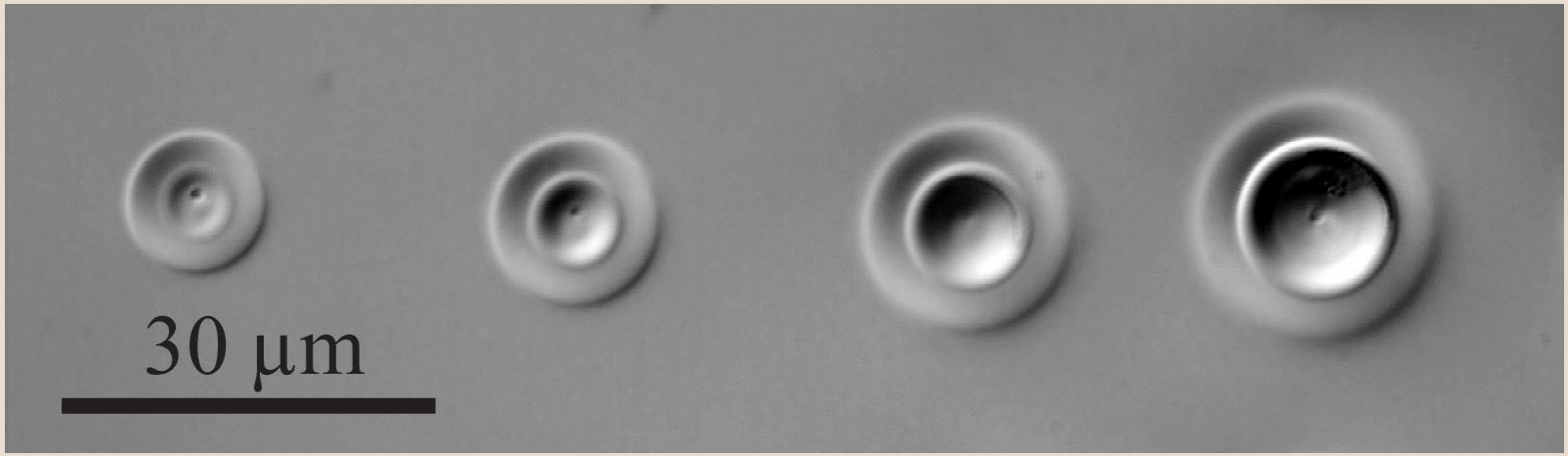


10 nJ; single shot

OSCILLATOR MICROMACHINING

number of laser shots

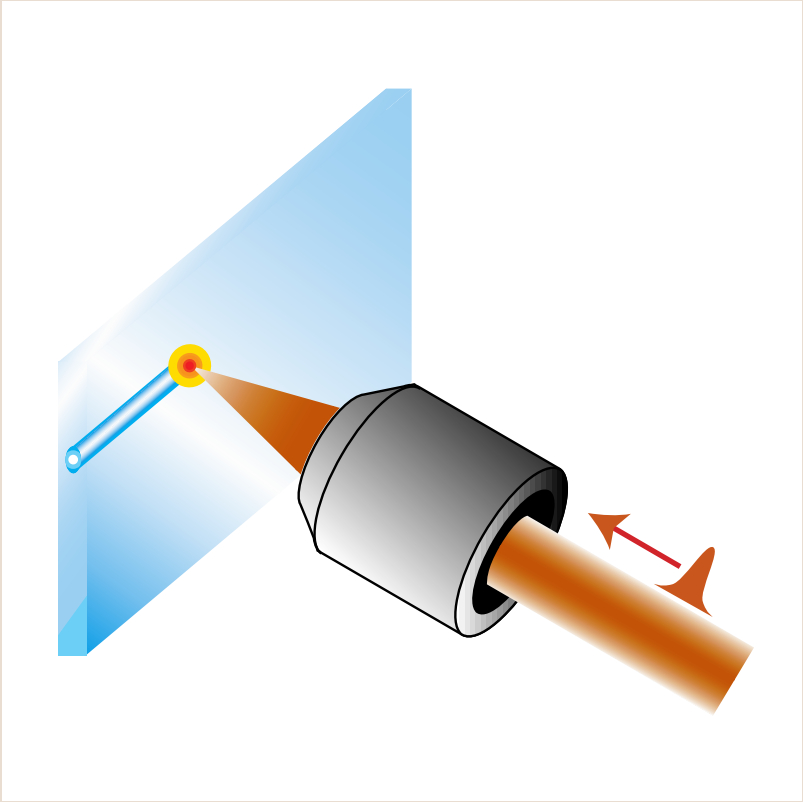
2.5×10^4 2.5×10^5 2.5×10^6 2.5×10^7



more shots melt larger volumes

OSCILLATOR MICROMACHINING

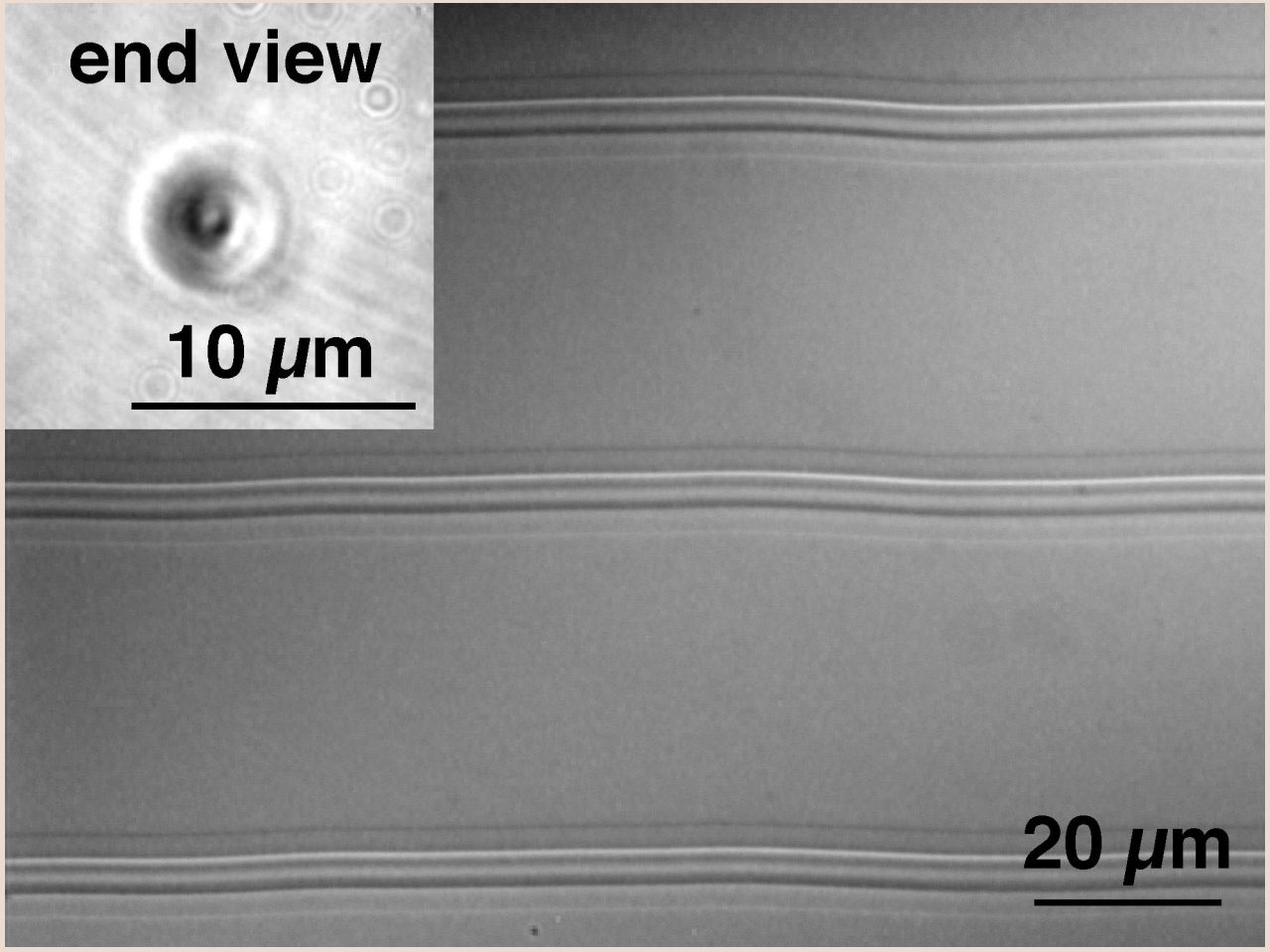
how can we use this new femtosecond thermal micromachining?



write waveguides!

OSCILLATOR MICROMACHINING

waveguide morphology: 20 mm/s machining speed



OSCILLATOR MICROMACHINING

waveguide mode analysis

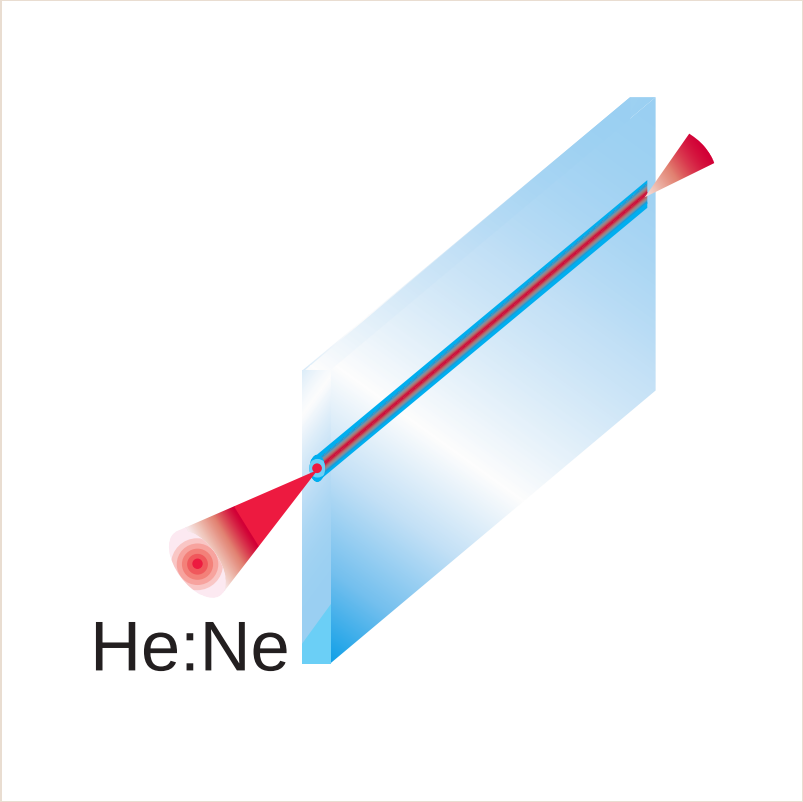
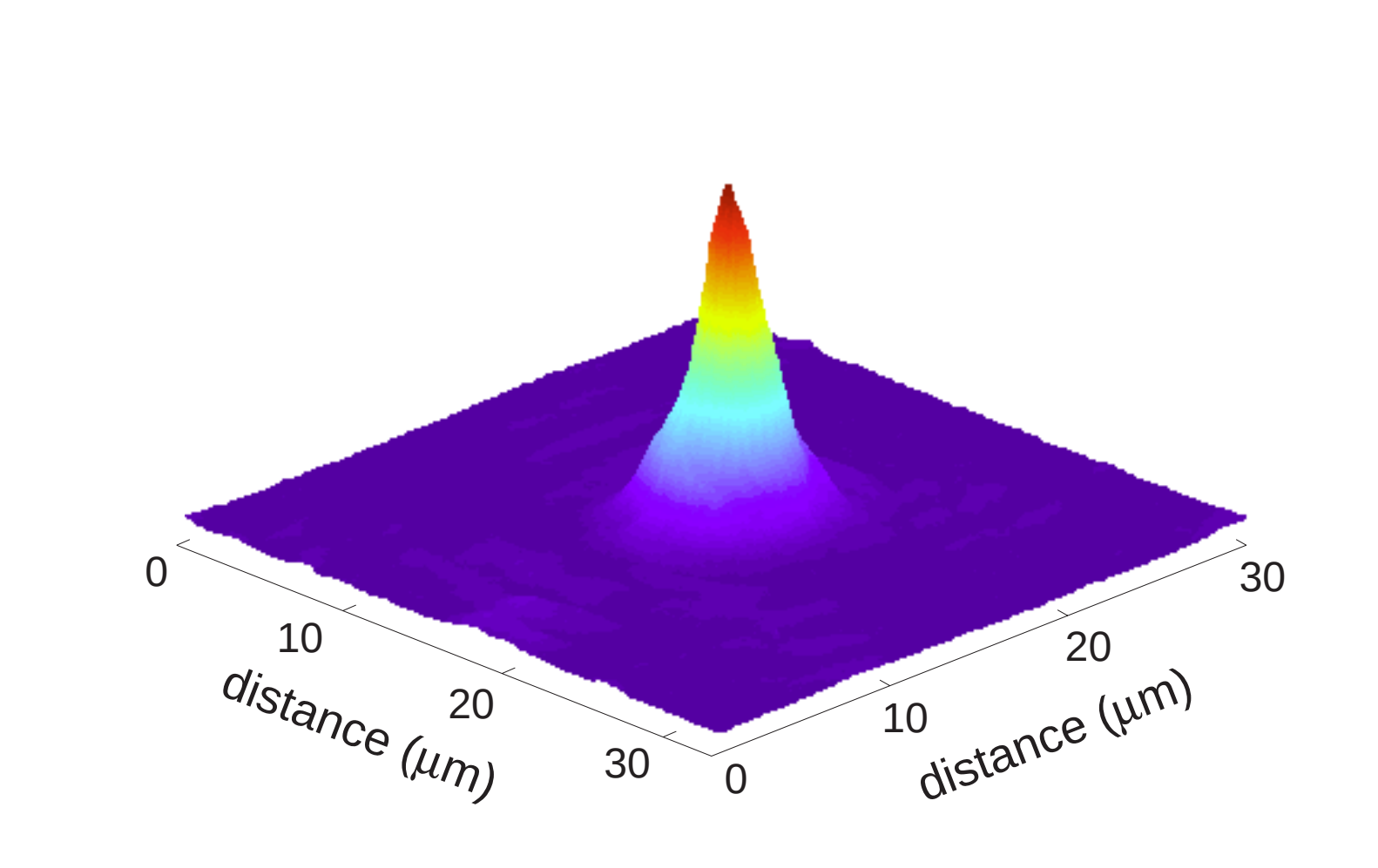
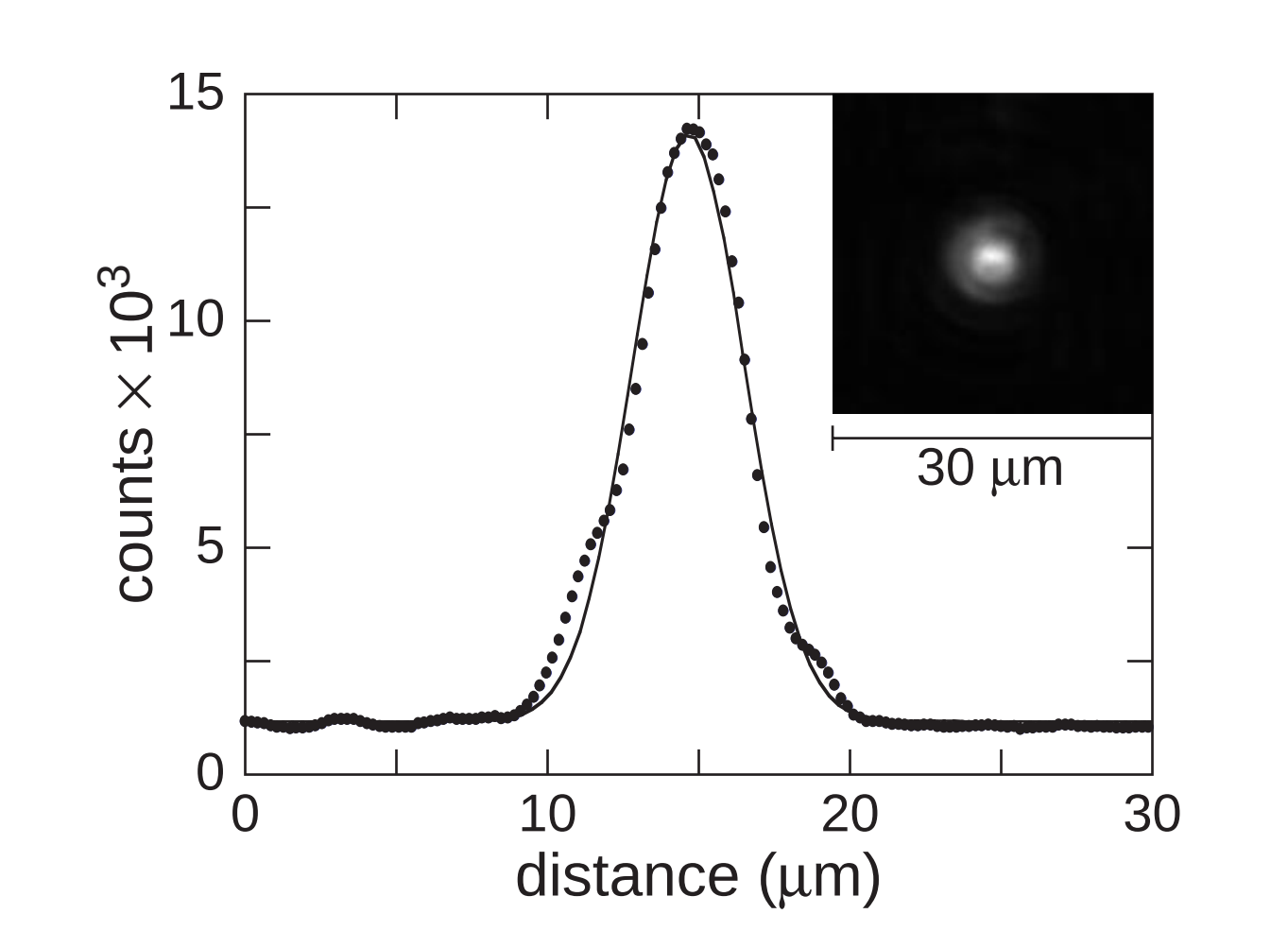


image of near field mode



OSCILLATOR MICROMACHINING



line-out of near field waveguide mode for 633 nm

damage morphologies and mechanisms

	low energy	high energy
single shot	sub- m Δn small melt	sub- m voids explosive
multiple shot slow rep. rate	larger Δn accumulated melt	high contrast voids cumulative drilling
multiple shot high rep. rate	m-sized Δn cumulative melting	CAN’T AFFORD! $$$$

SUMMARY

Damage morphology

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

Oscillator only machining

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

ACKNOWLEGEMENTS

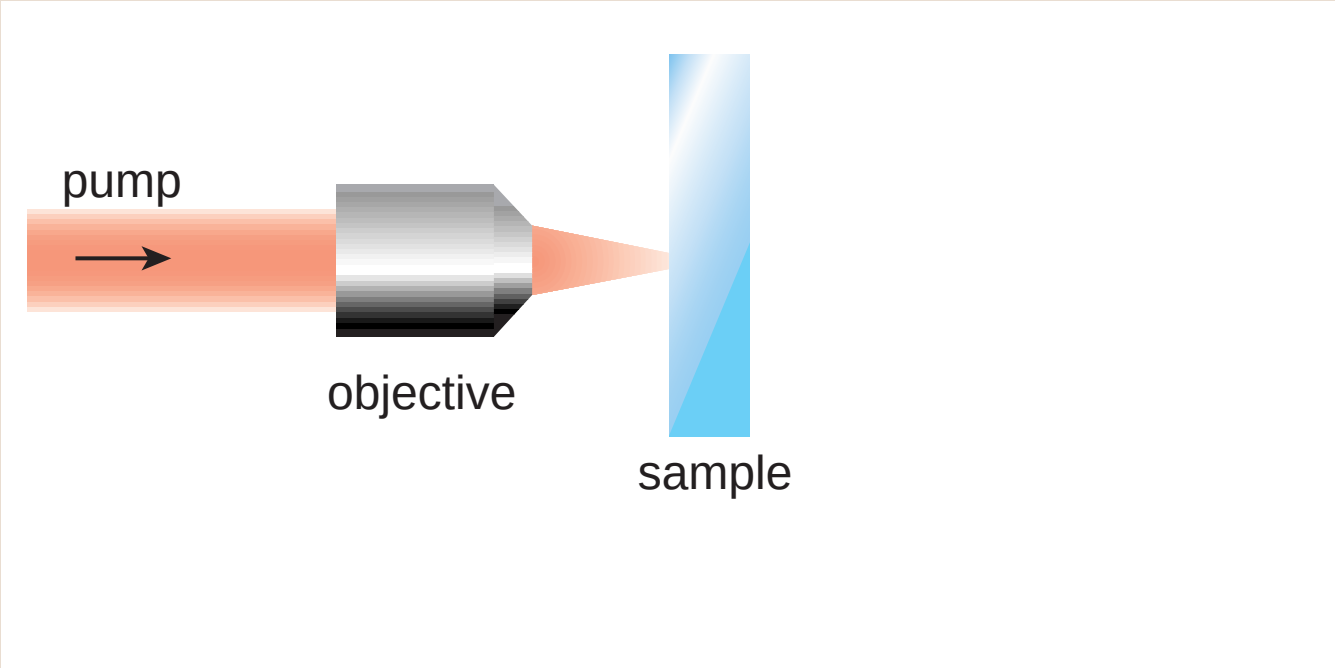
W. Leight
Prof. N. Bloembergen

National Science Foundation

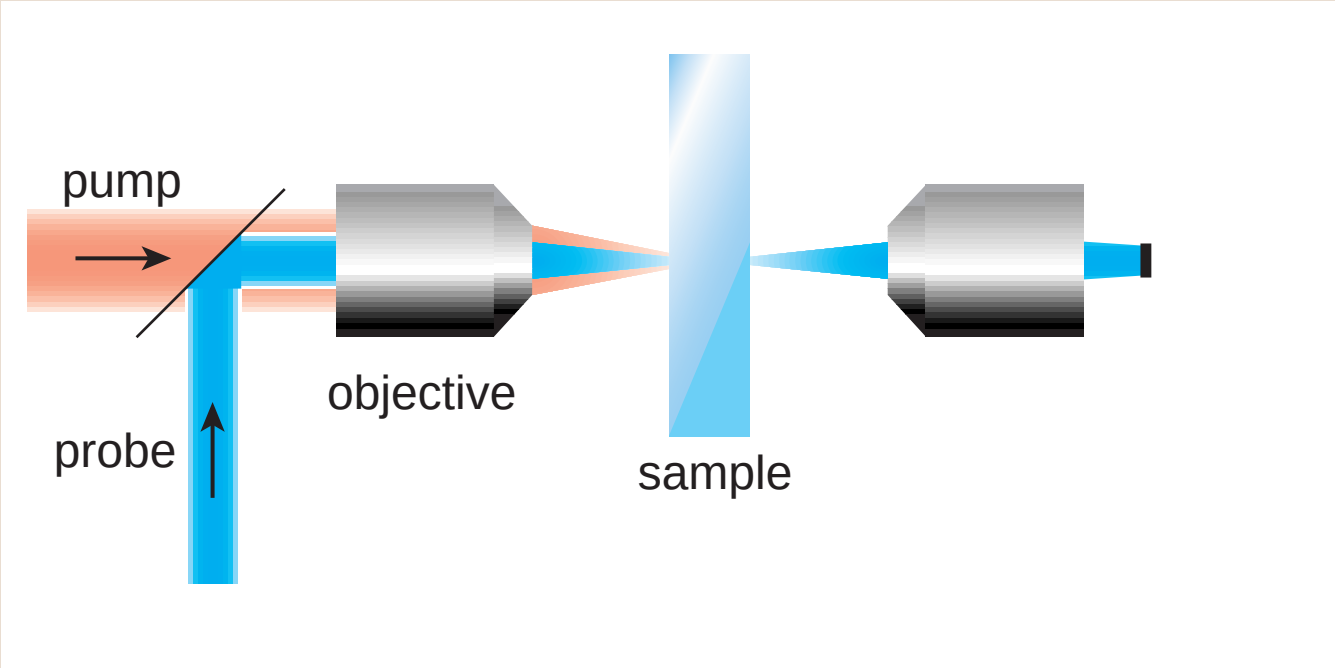
For a copy of this talk and additional information, see:

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

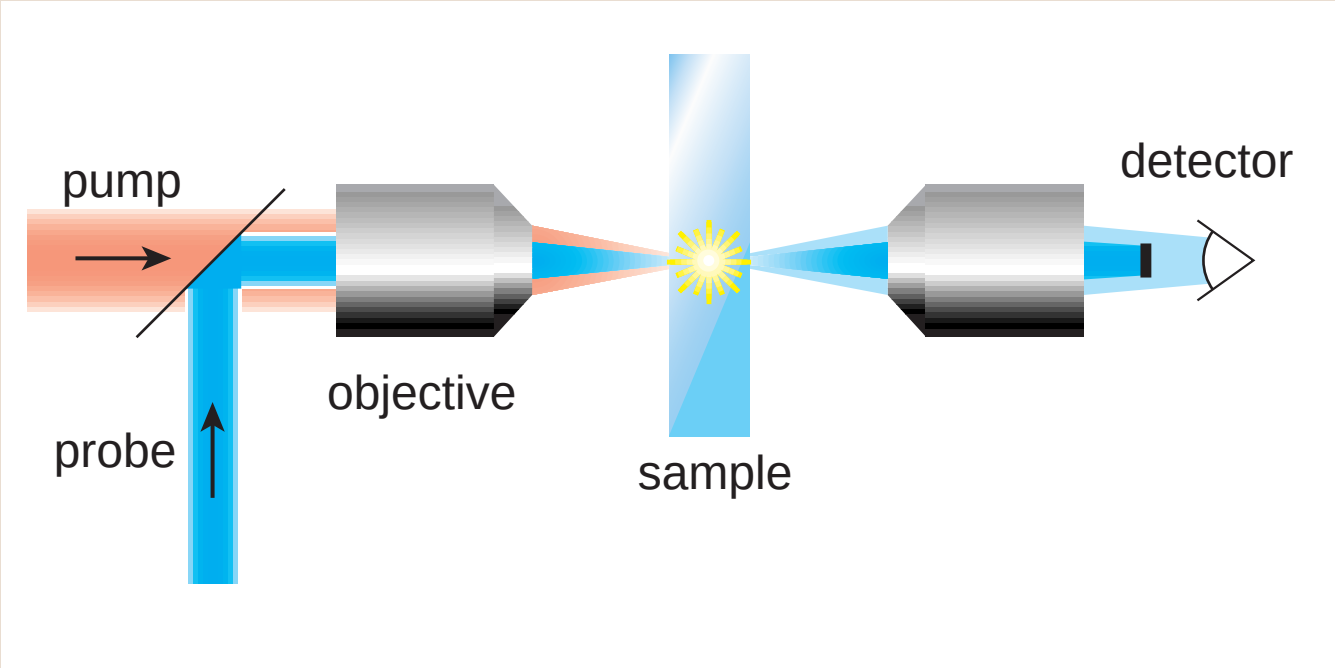
pump sample with femtosecond pulse



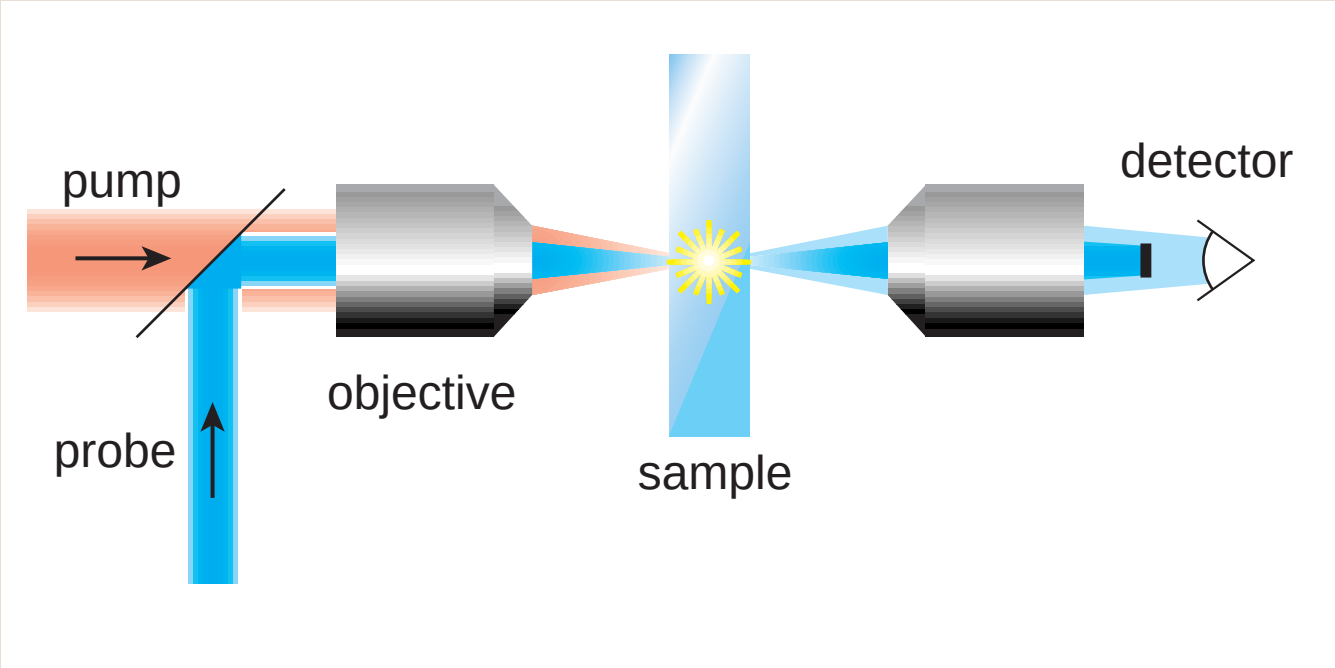
block probe beam



detect light scattered by damage



THRESHOLDS



vary NA, material, pump wavelength