Microscopic bulk damage in dielectric materials using nanojoule femtosecond laser pulses

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Andre Brodeur
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CLEO
May, 1999

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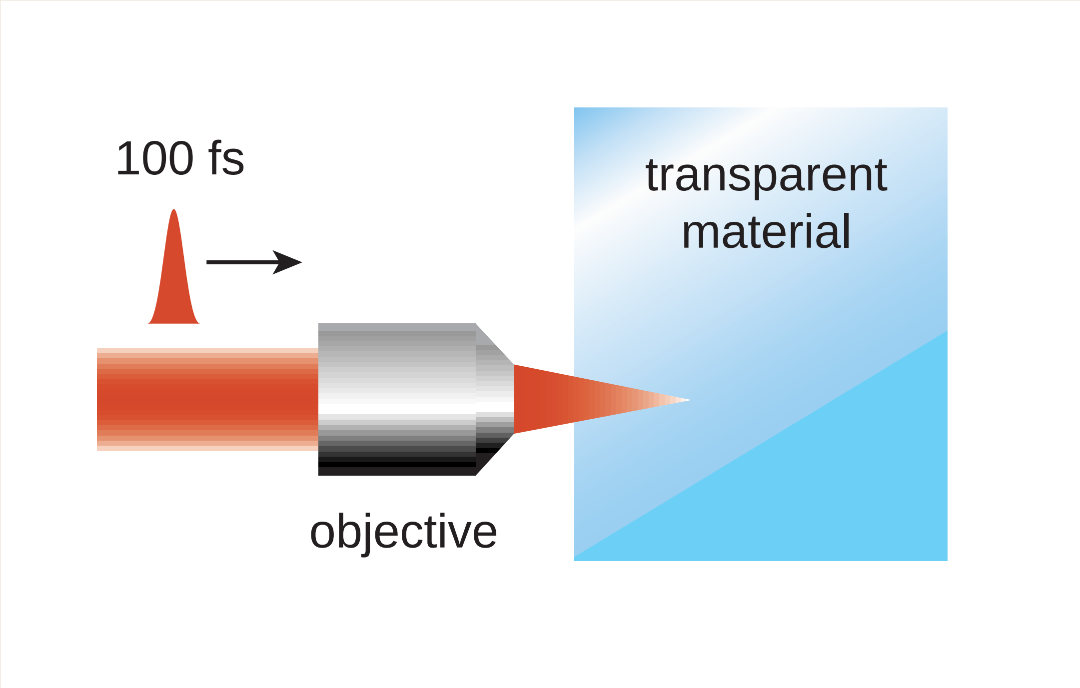
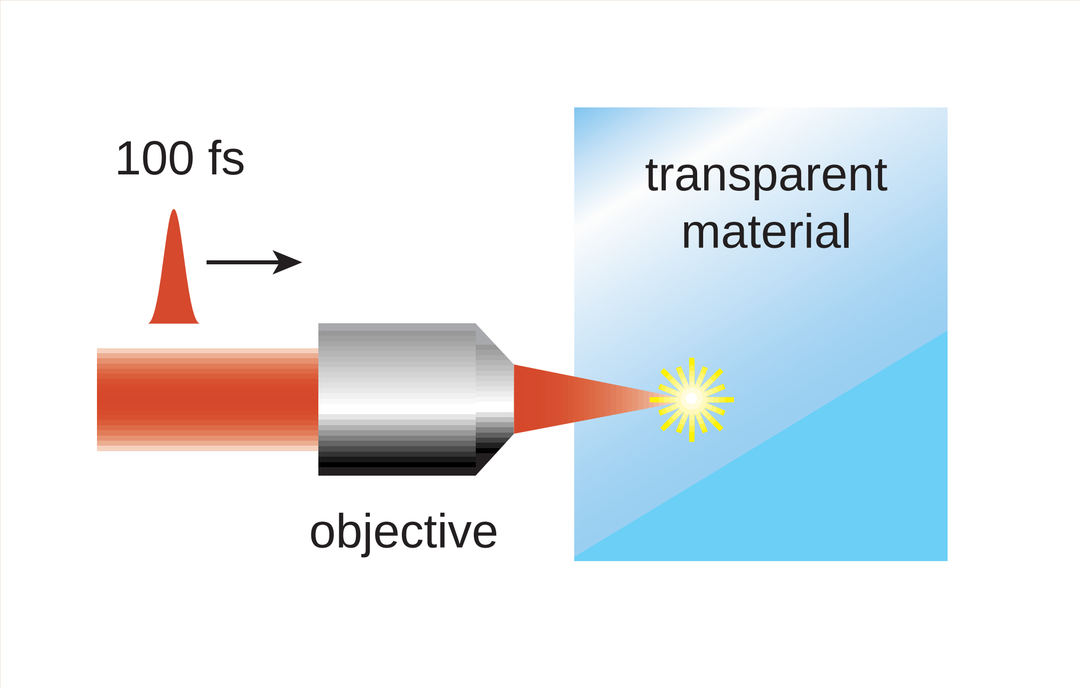
Department of Physics

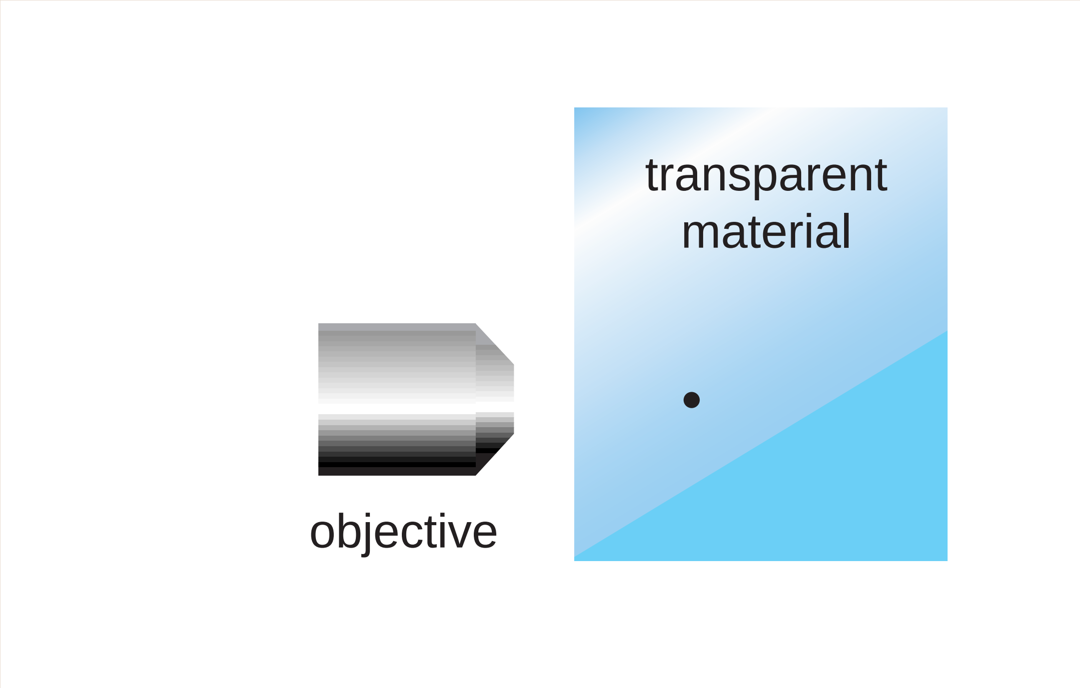
high intensity at focus



causes nonlinear ionization



producing microscopic bulk damage



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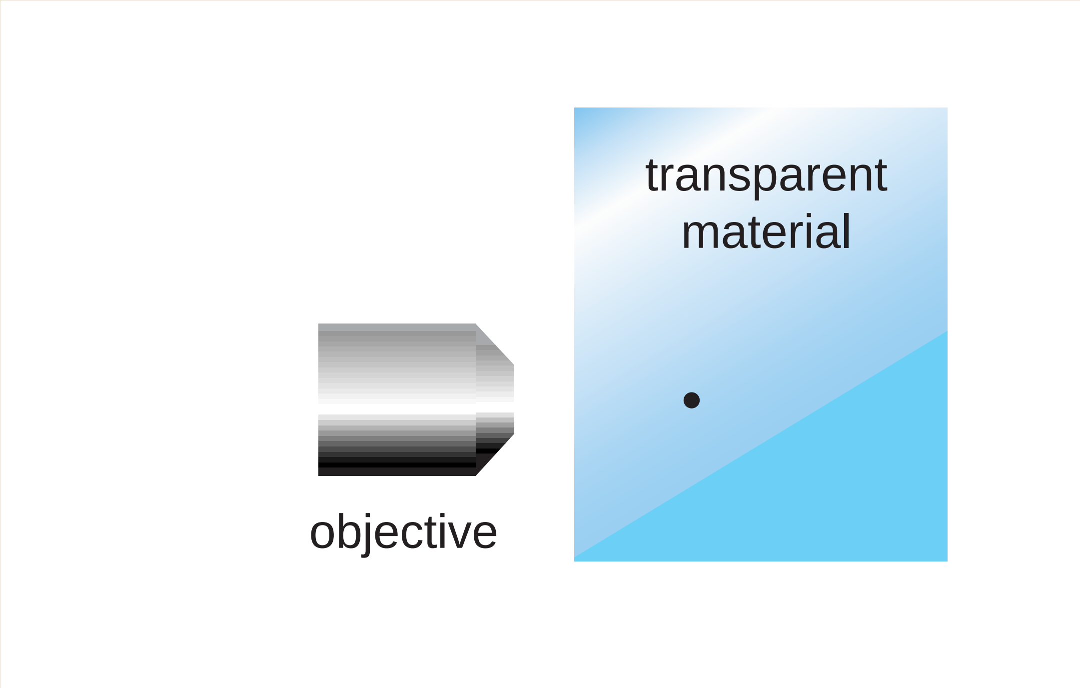
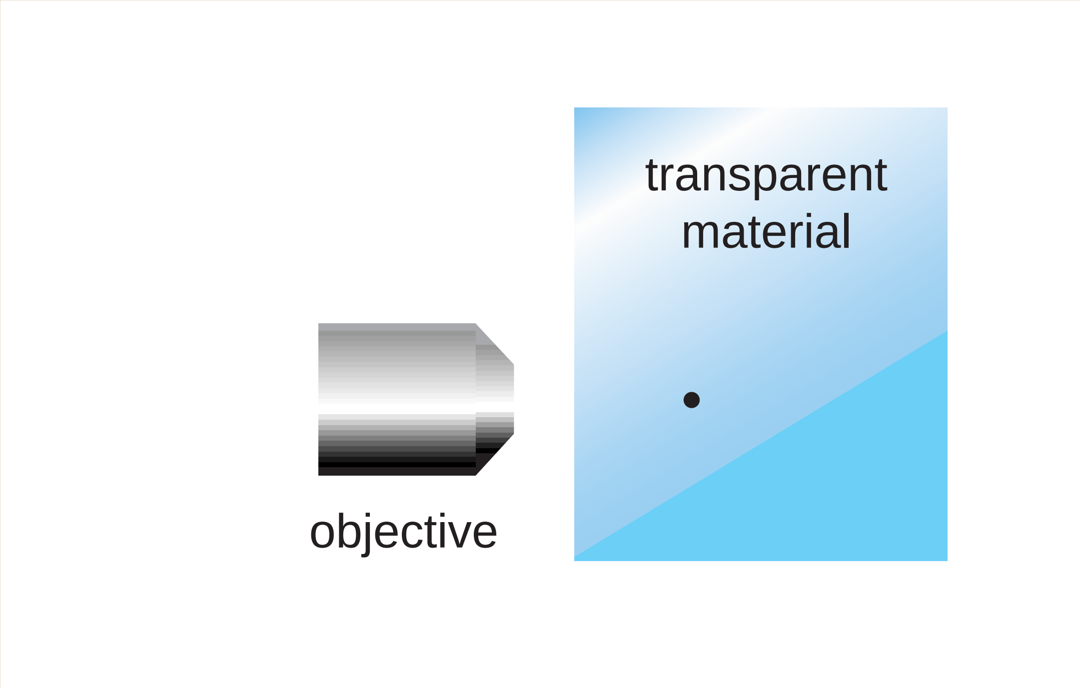


with only tens of nanojoules!

producing microscopic bulk damage



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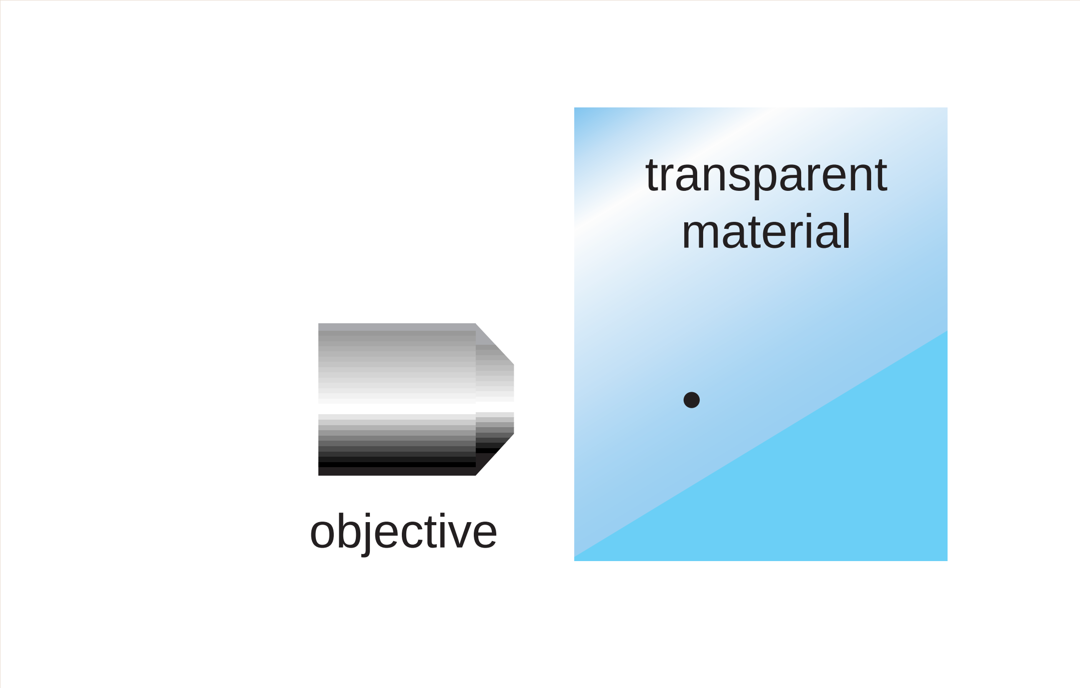

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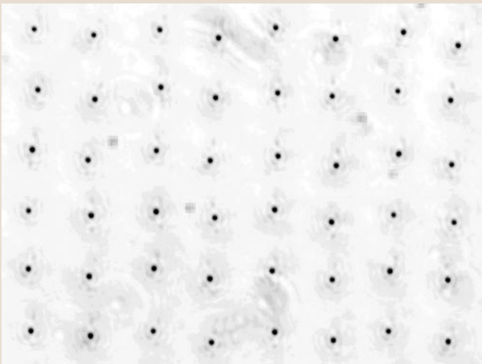
why bulk?

why bulk?

three-dimensional micromachining



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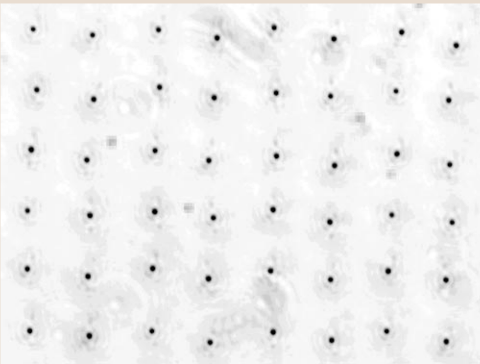
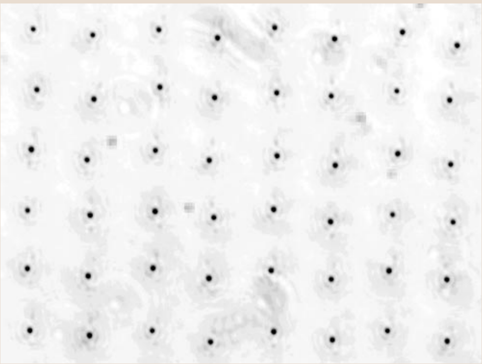


fundamental physics governing material damage

why **bulk**?

three-dimensional micromachining



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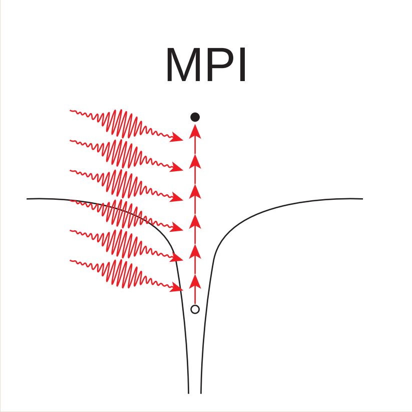

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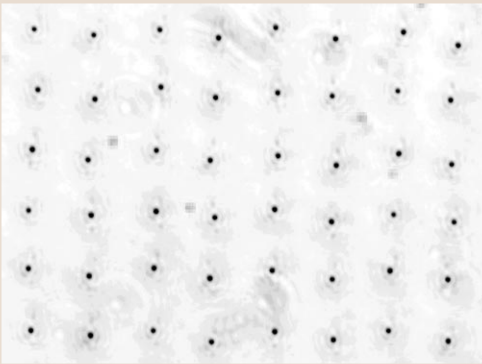
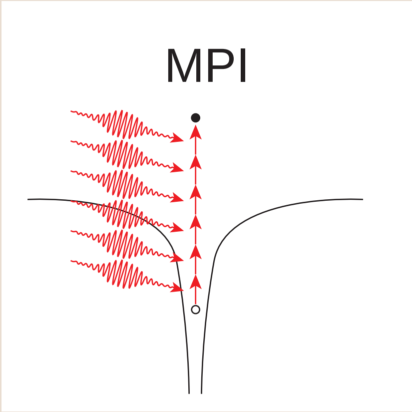
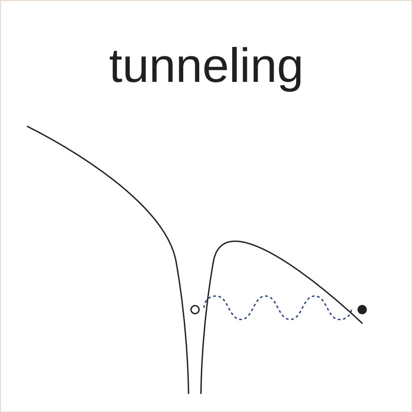


fundamental physics governing material damage





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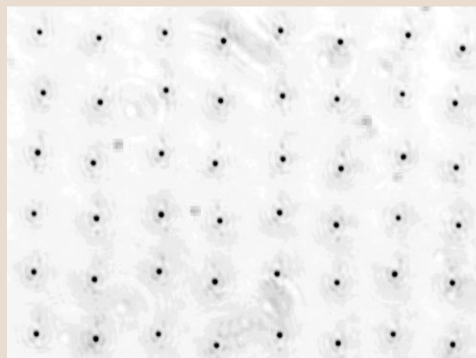

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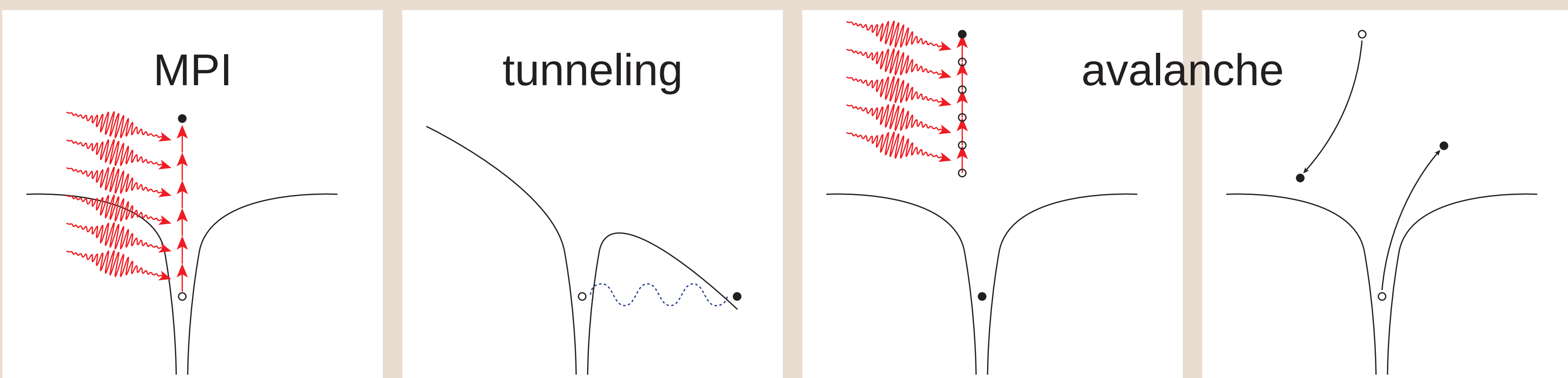

why nanojoules?

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non-amplified micromachining

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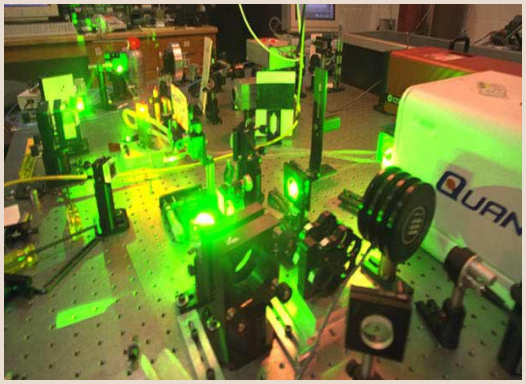
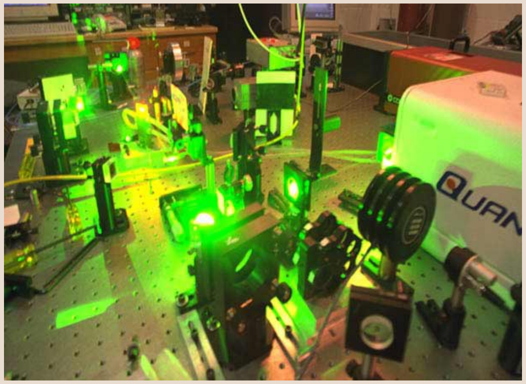
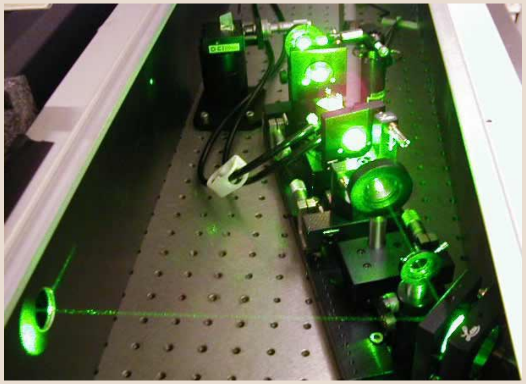


INTRODUCTION

why nanojoules?

non-amplified micromachining





INTRODUCTION

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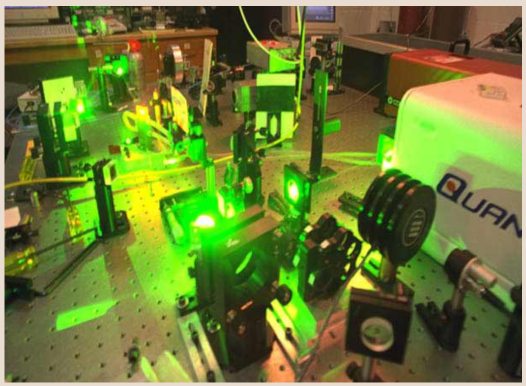
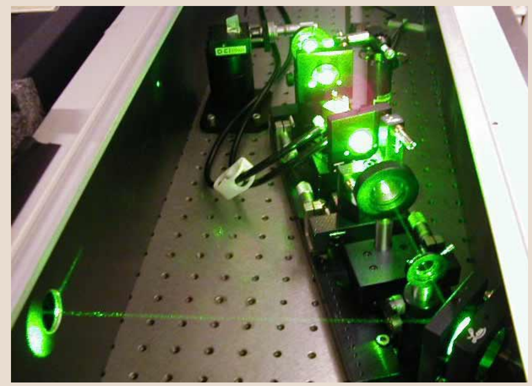
non-amplified micromachining





minimal self-focusing

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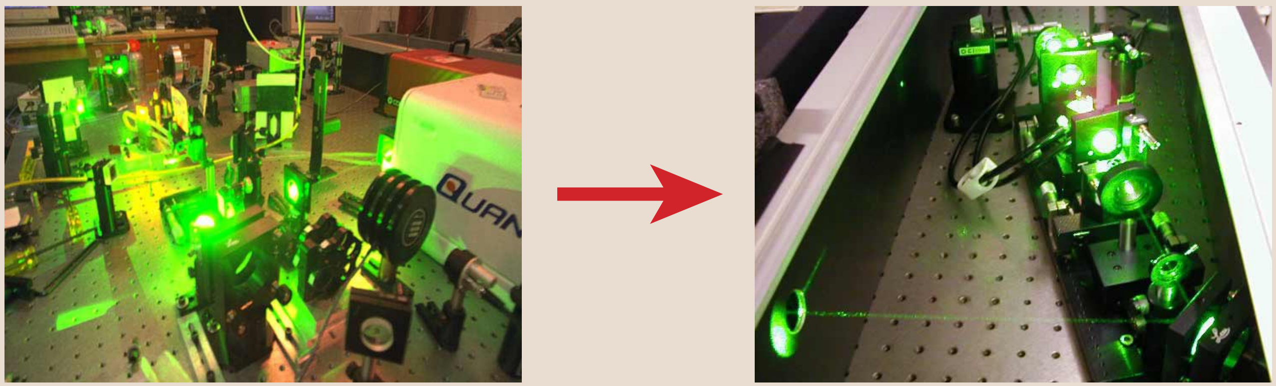

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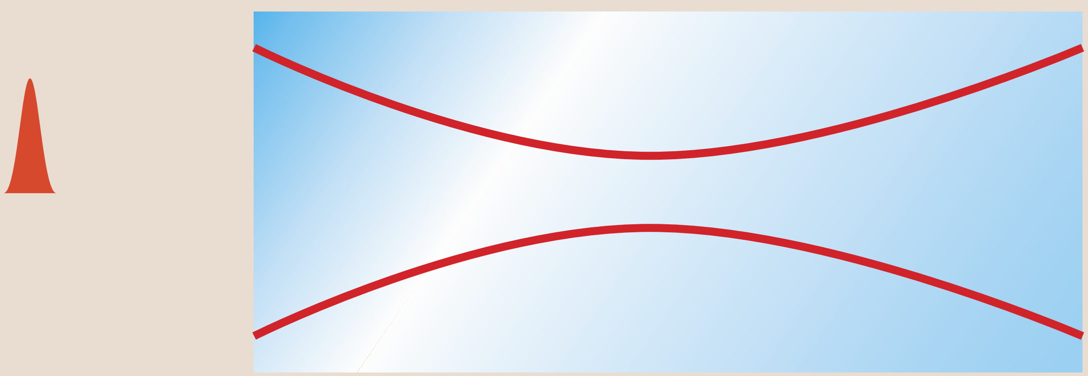

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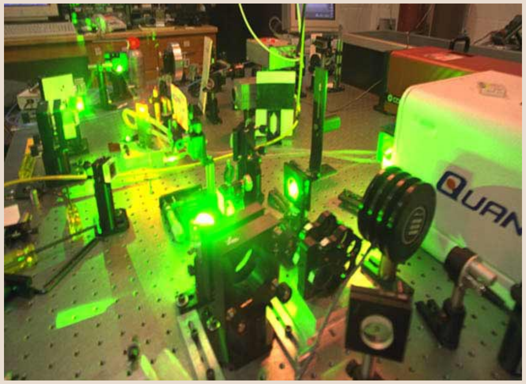

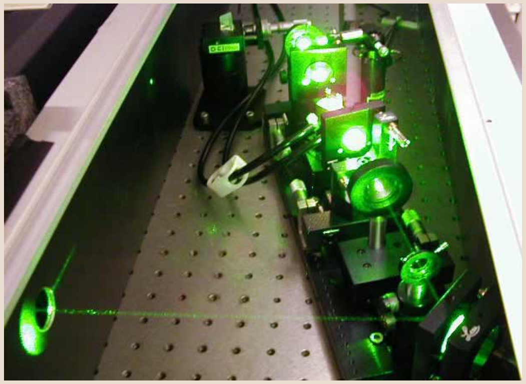

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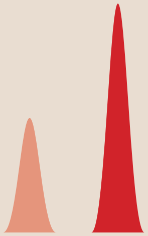
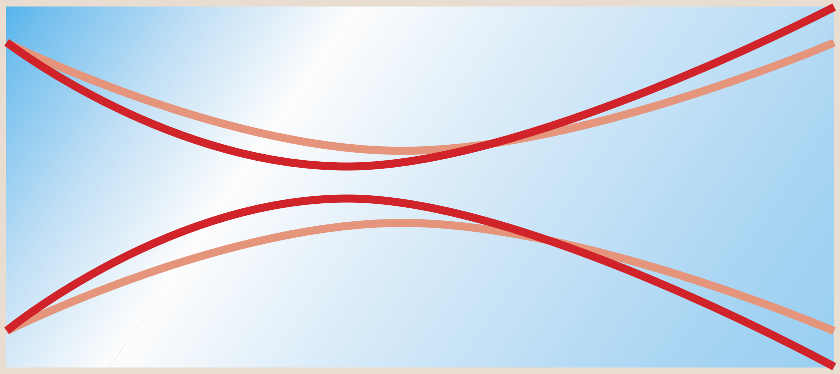
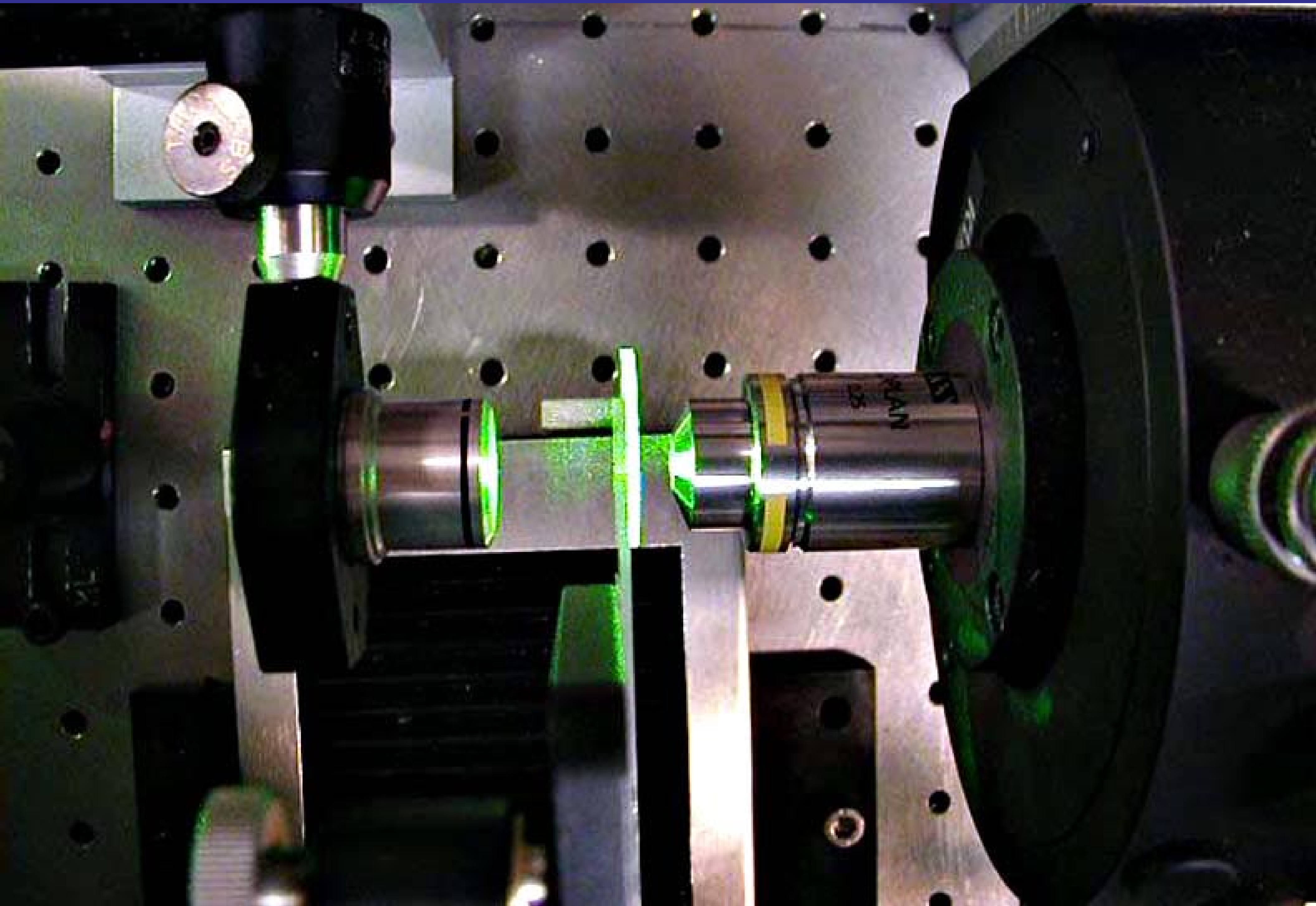


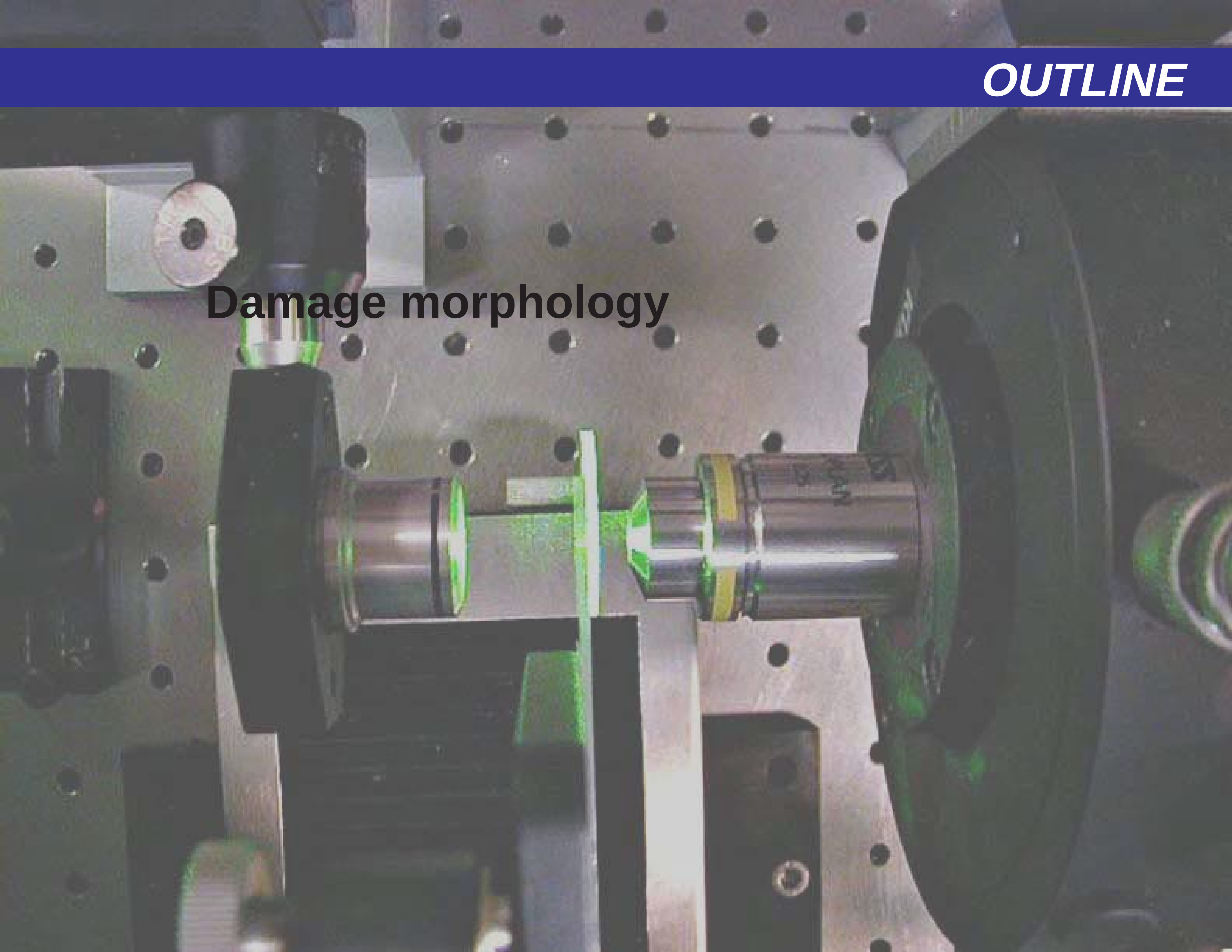


OUTLINE

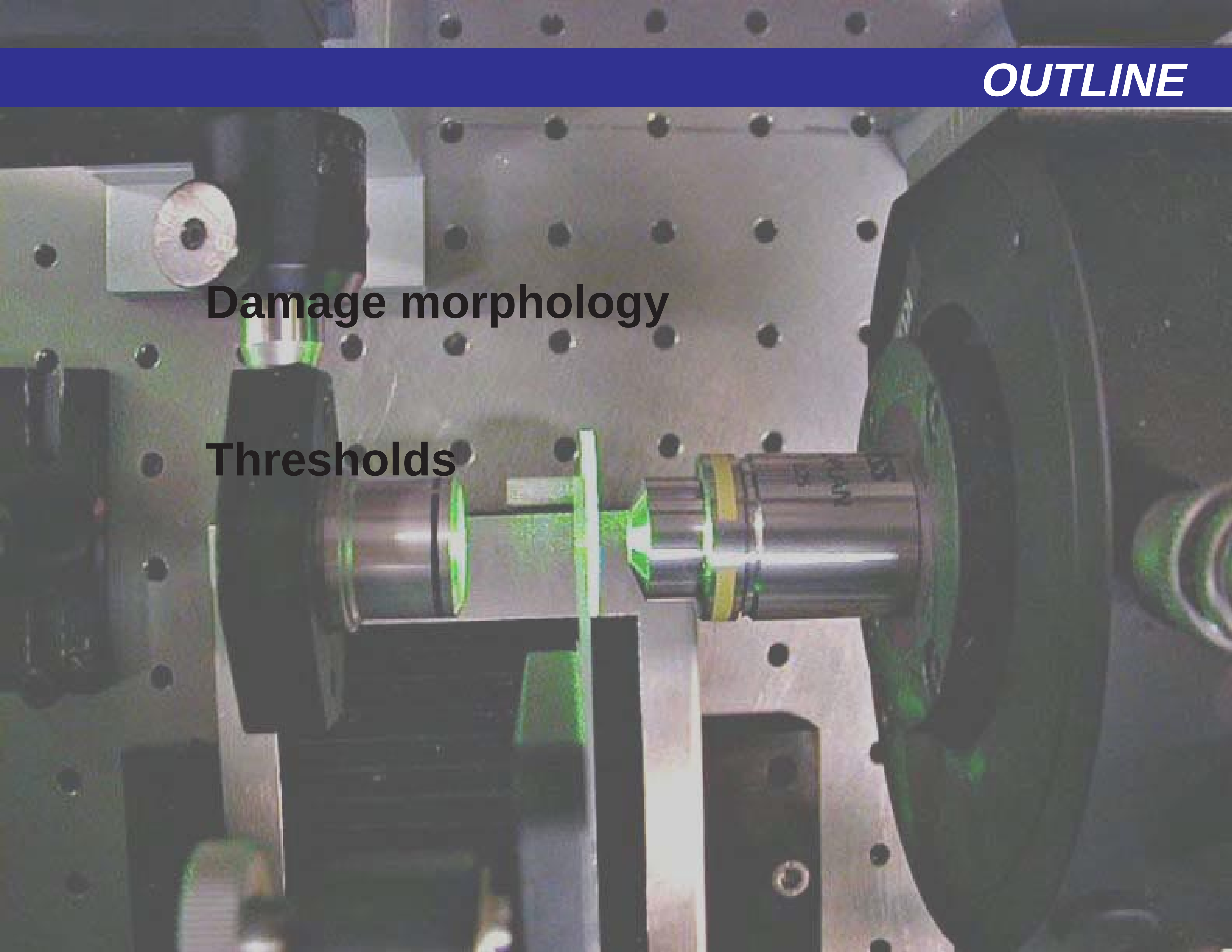


OUTLINE

Damage morphology



OUTLINE



Damage morphology

Thresholds

OUTLINE

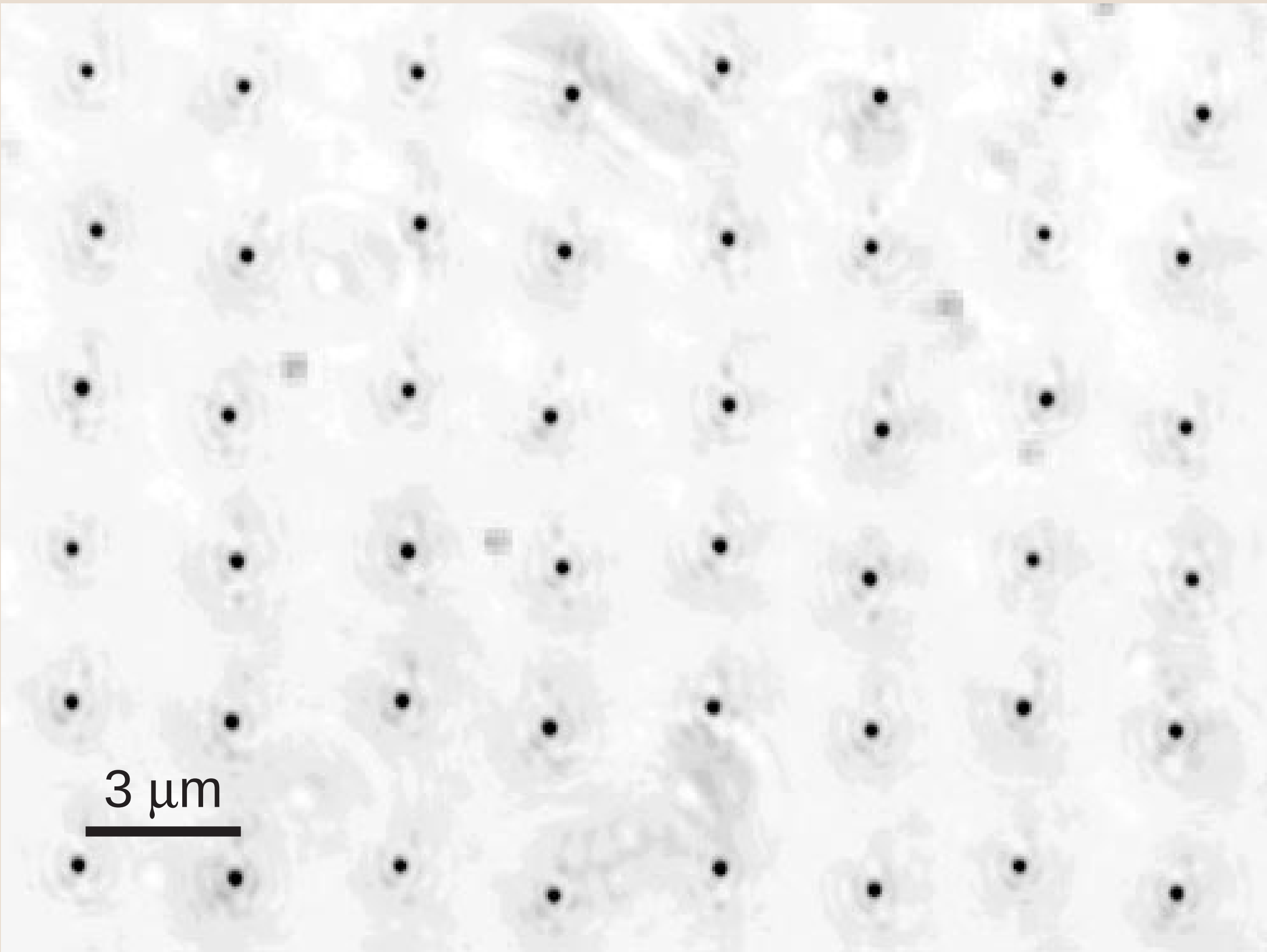
Damage morphology

Thresholds

Ionization mechanisms

DAMAGE MORPHOLOGY

40 nJ
100 fs
800 nm
0.65 NA
Corning 0211



top view

DAMAGE MORPHOLOGY

40 nJ
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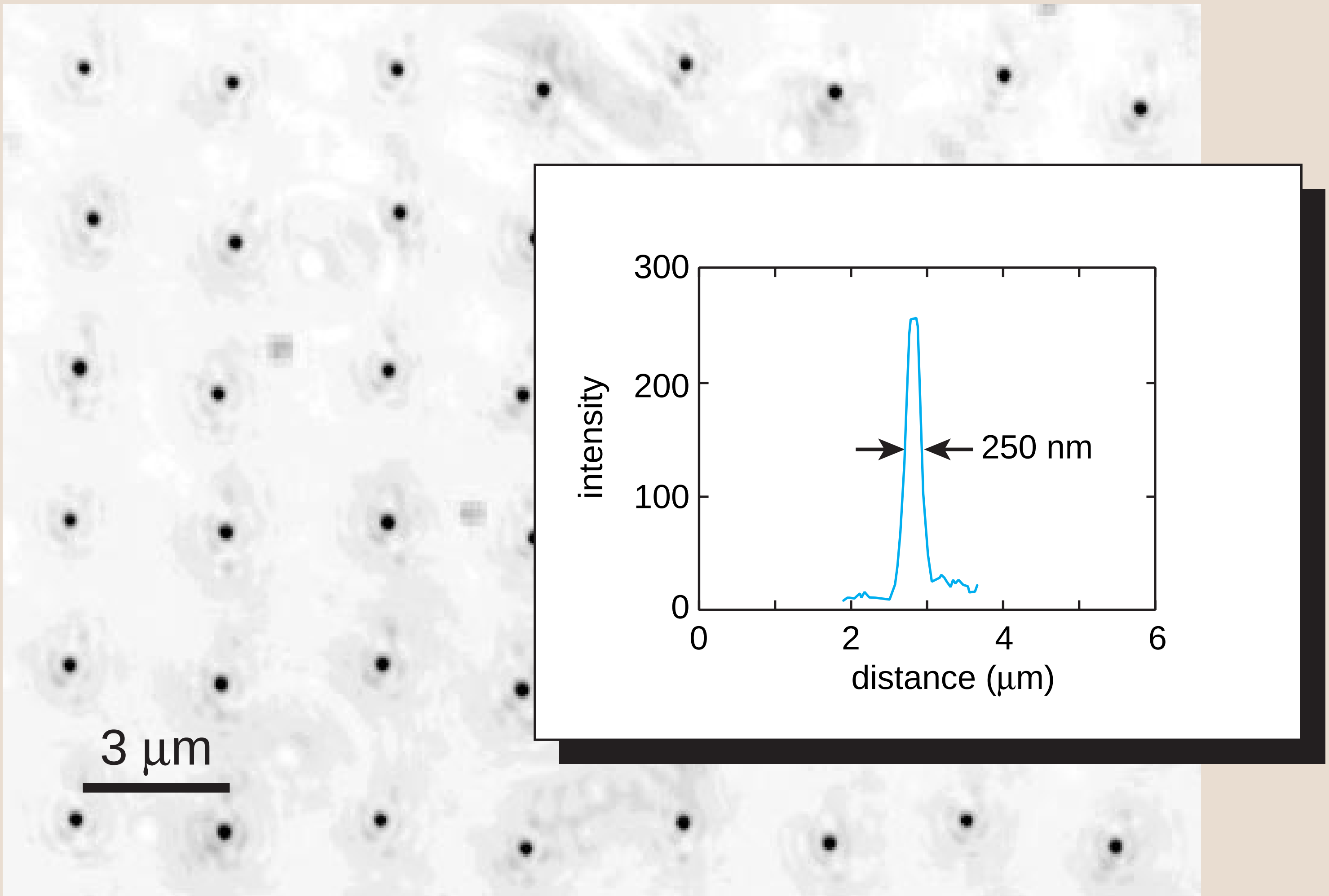


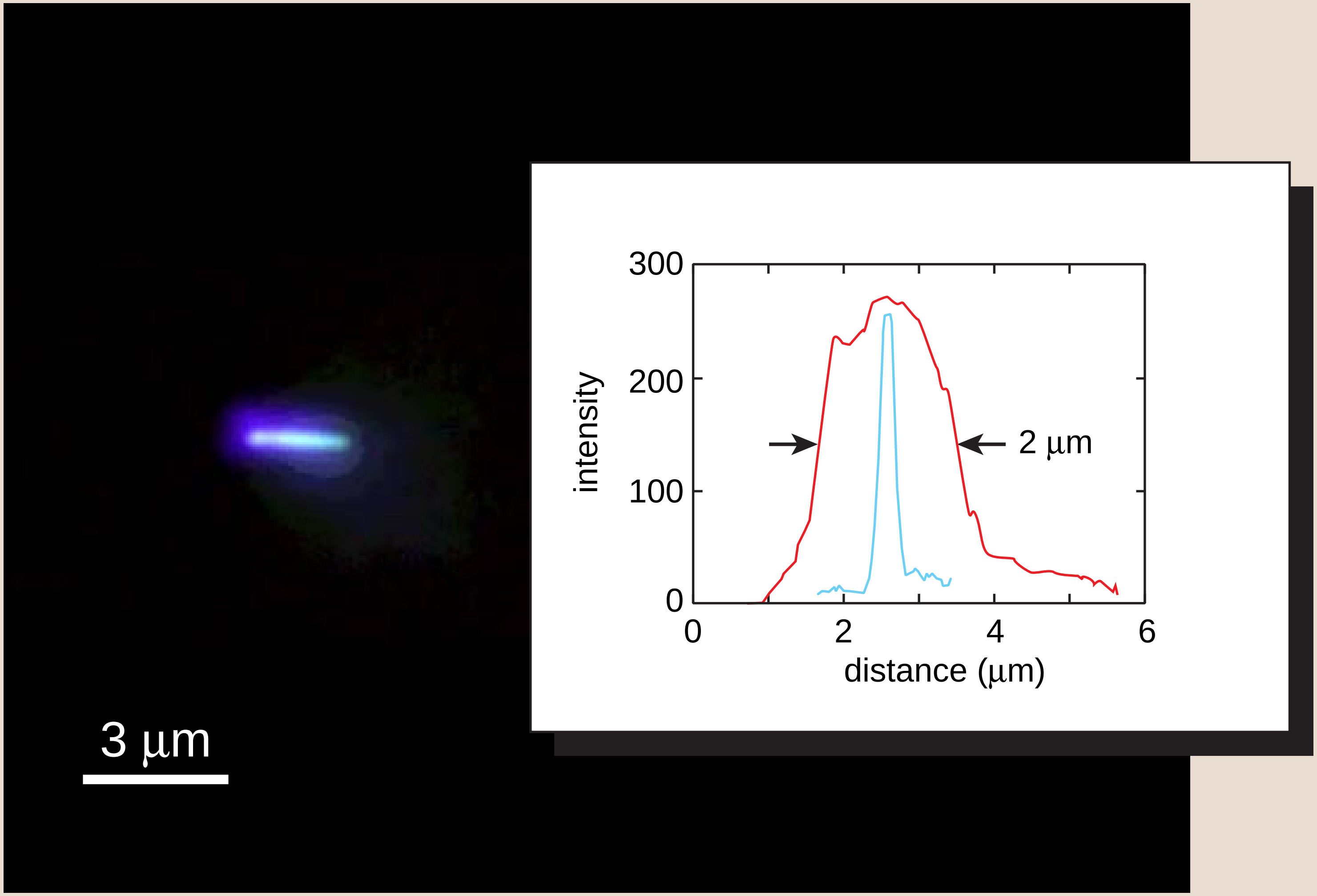
top view

DAMAGE MORPHOLOGY

40 nJ
100 fs
800 nm
0.65 NA
Corning 0211

side view

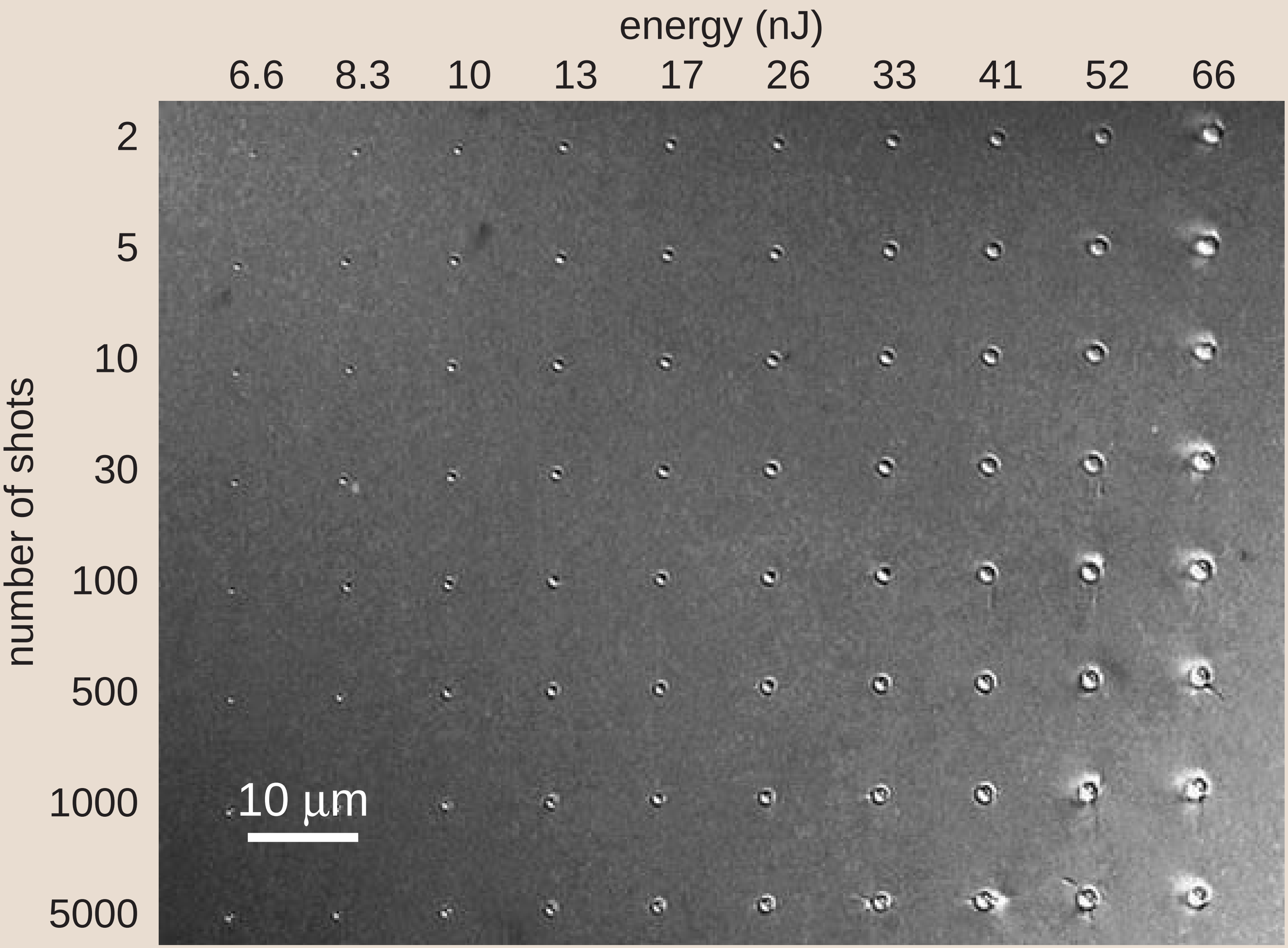
DAMAGE MORPHOLOGY



40 nJ
100 fs
800 nm
0.65 NA
Corning 0211

side view

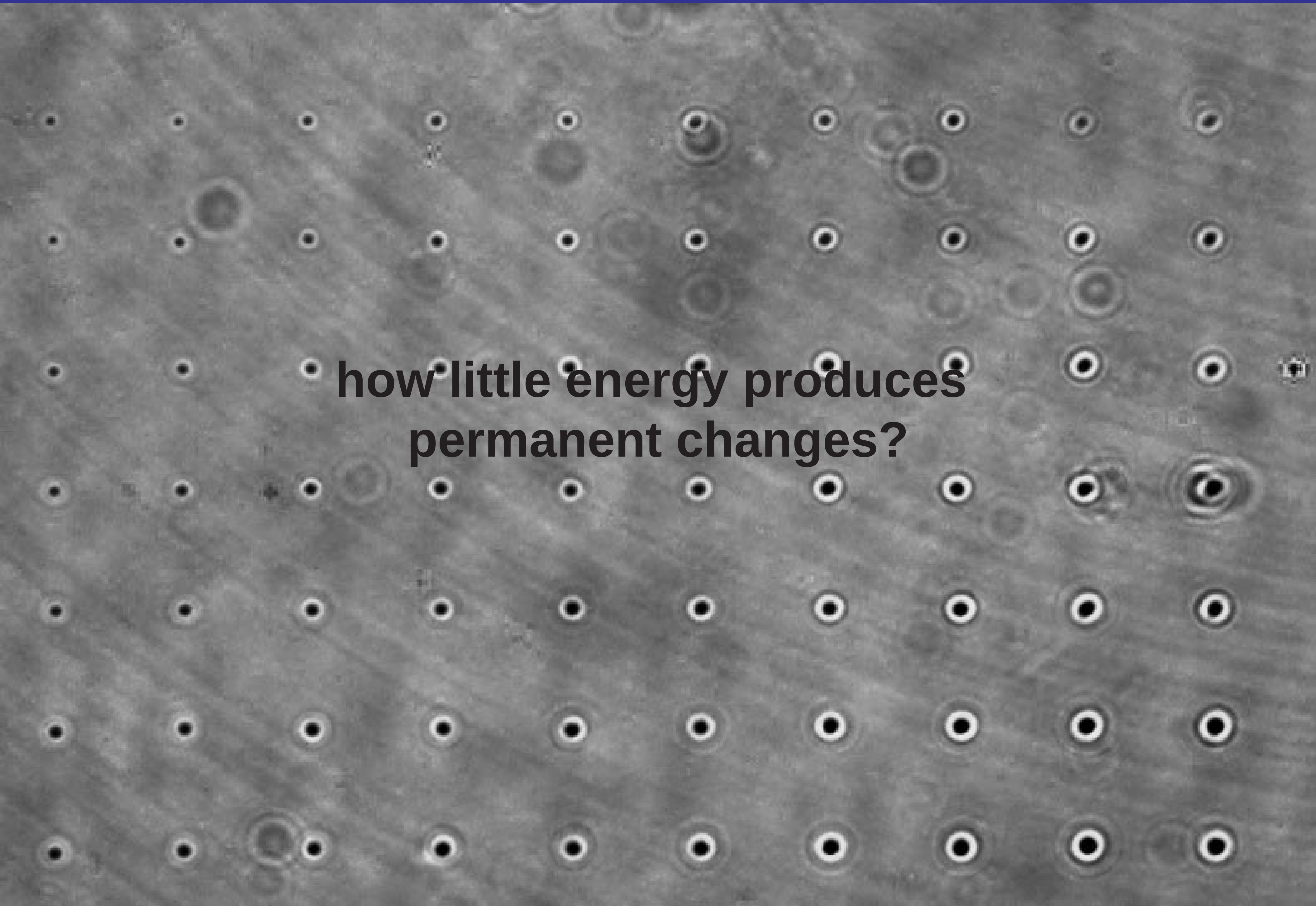
DAMAGE MORPHOLOGY



100 fs
800 nm
1.4 NA
Corning 0211

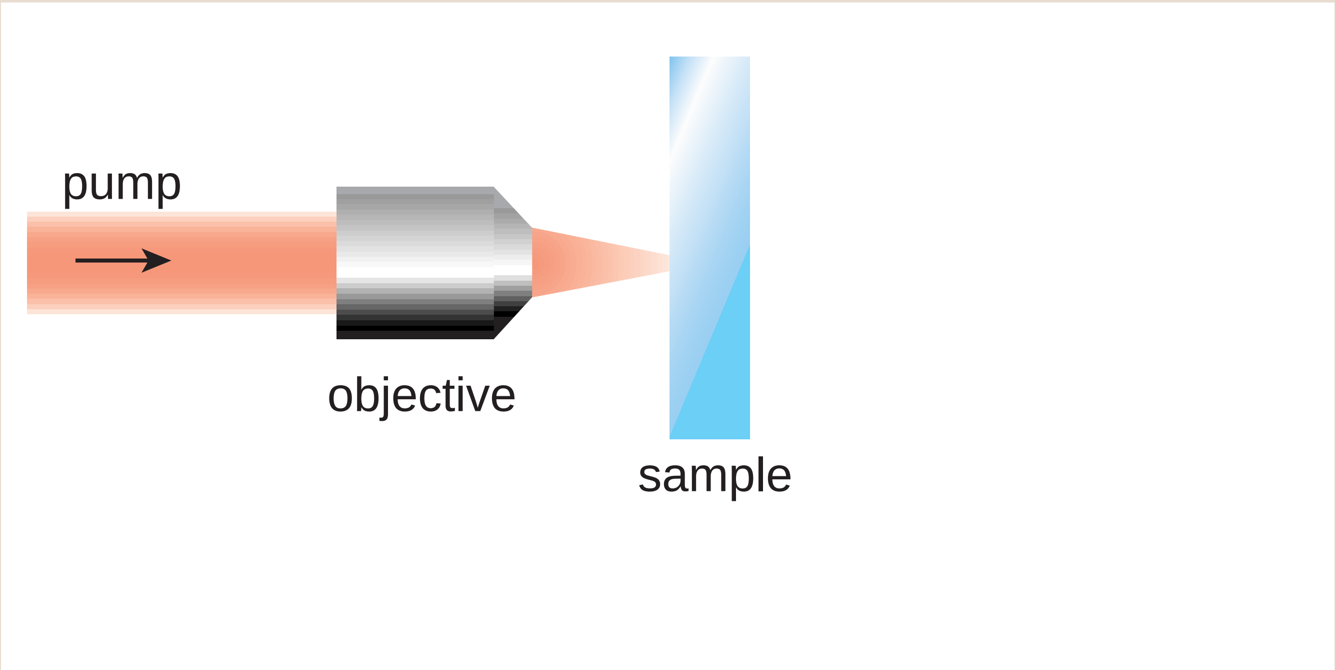
shot number and energy dependence

THRESHOLDS

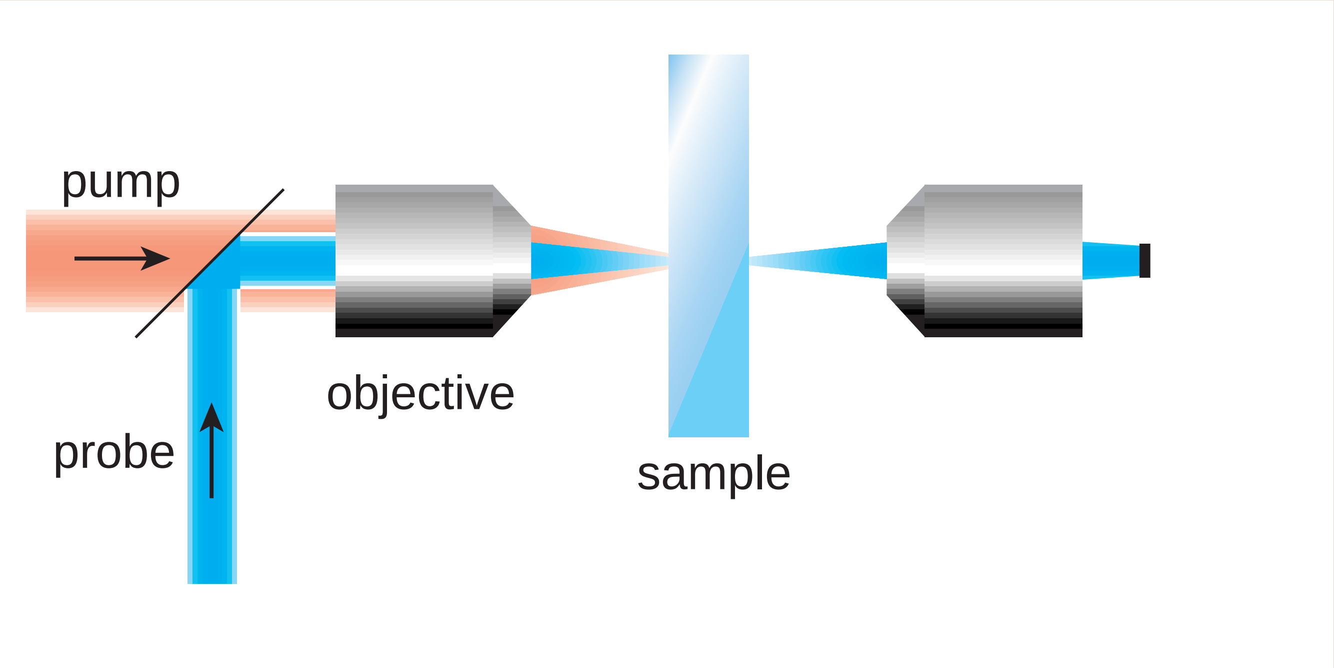


how little energy produces permanent changes?

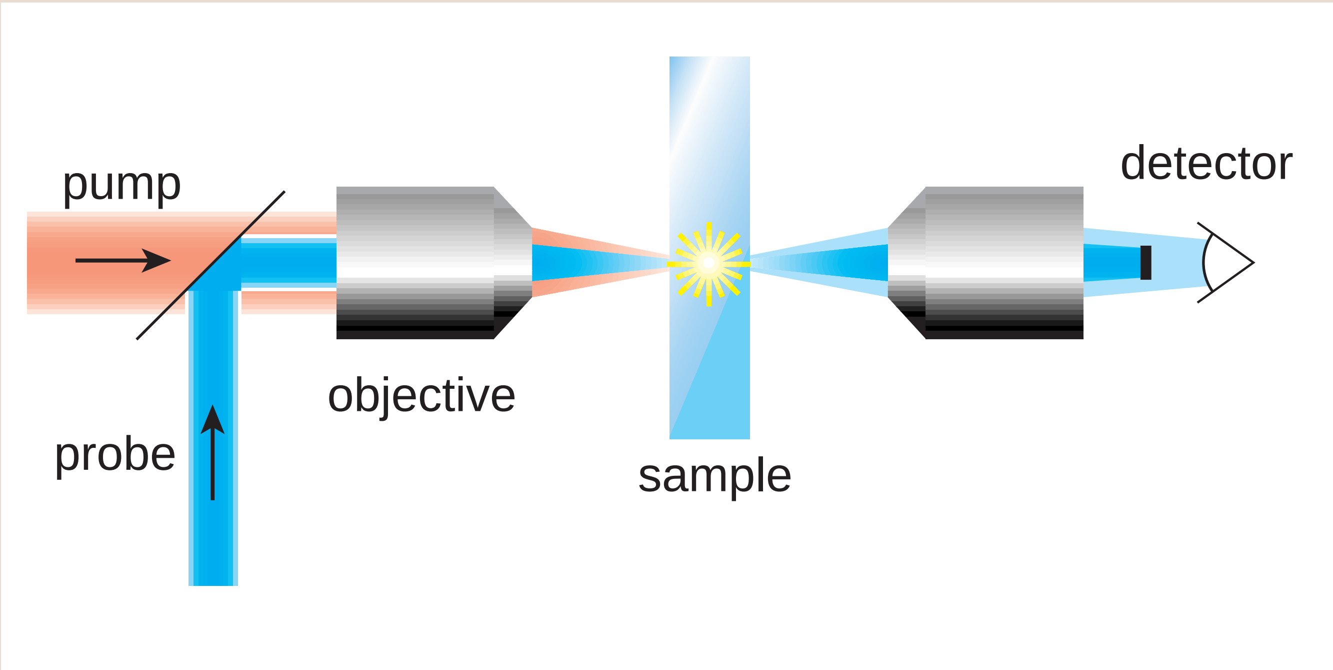
pump sample with femtosecond pulse

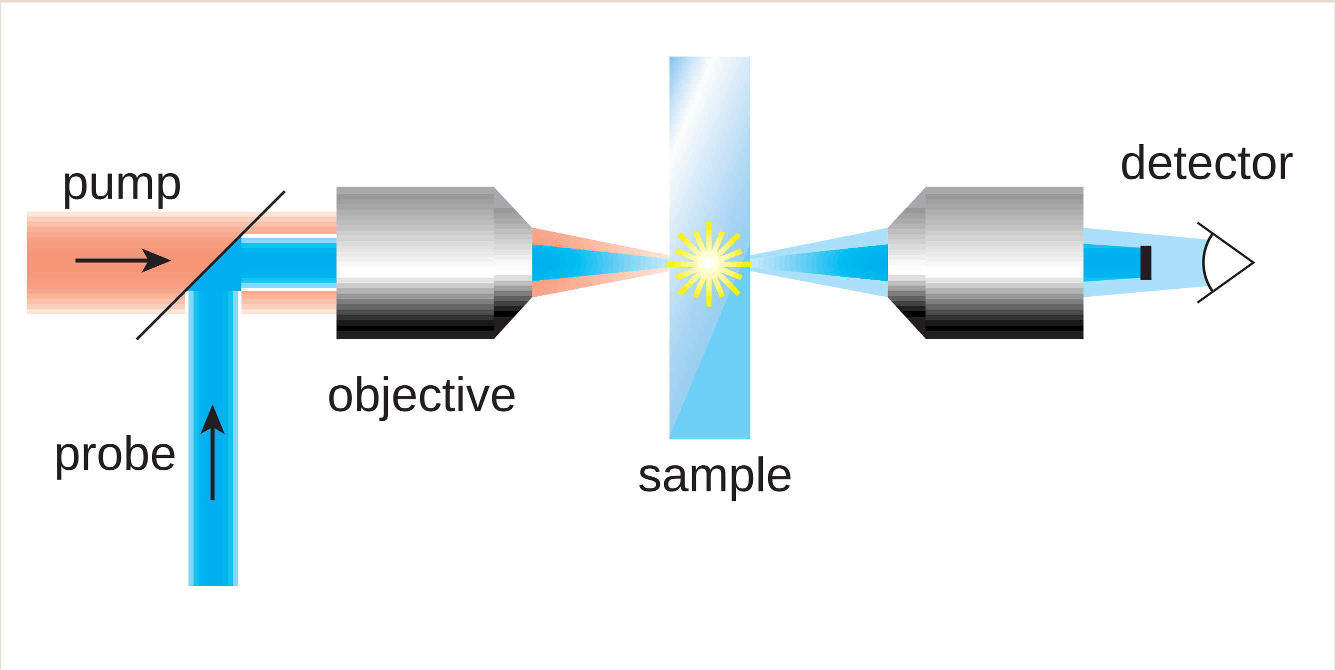


block probe beam



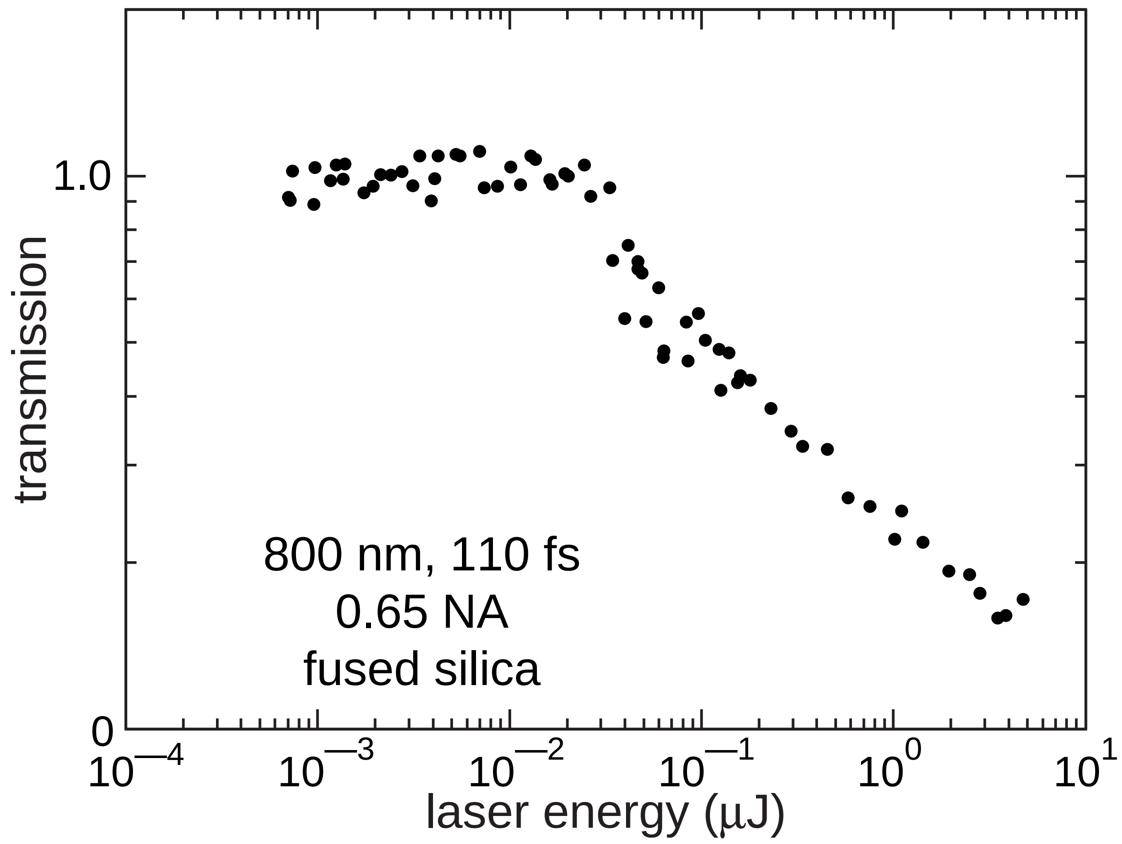
detect light scattered by damage



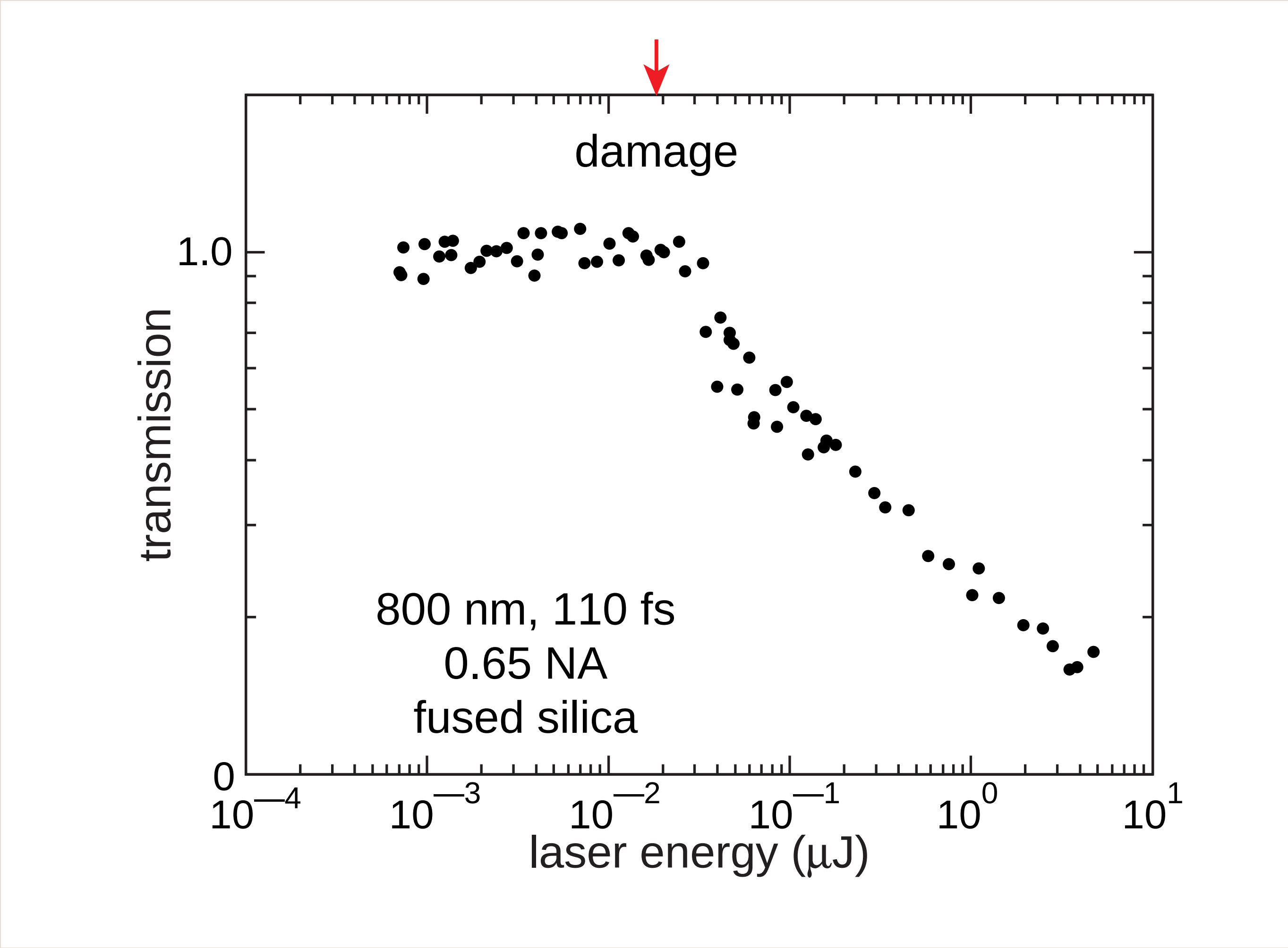


vary NA, material, pump wavelength

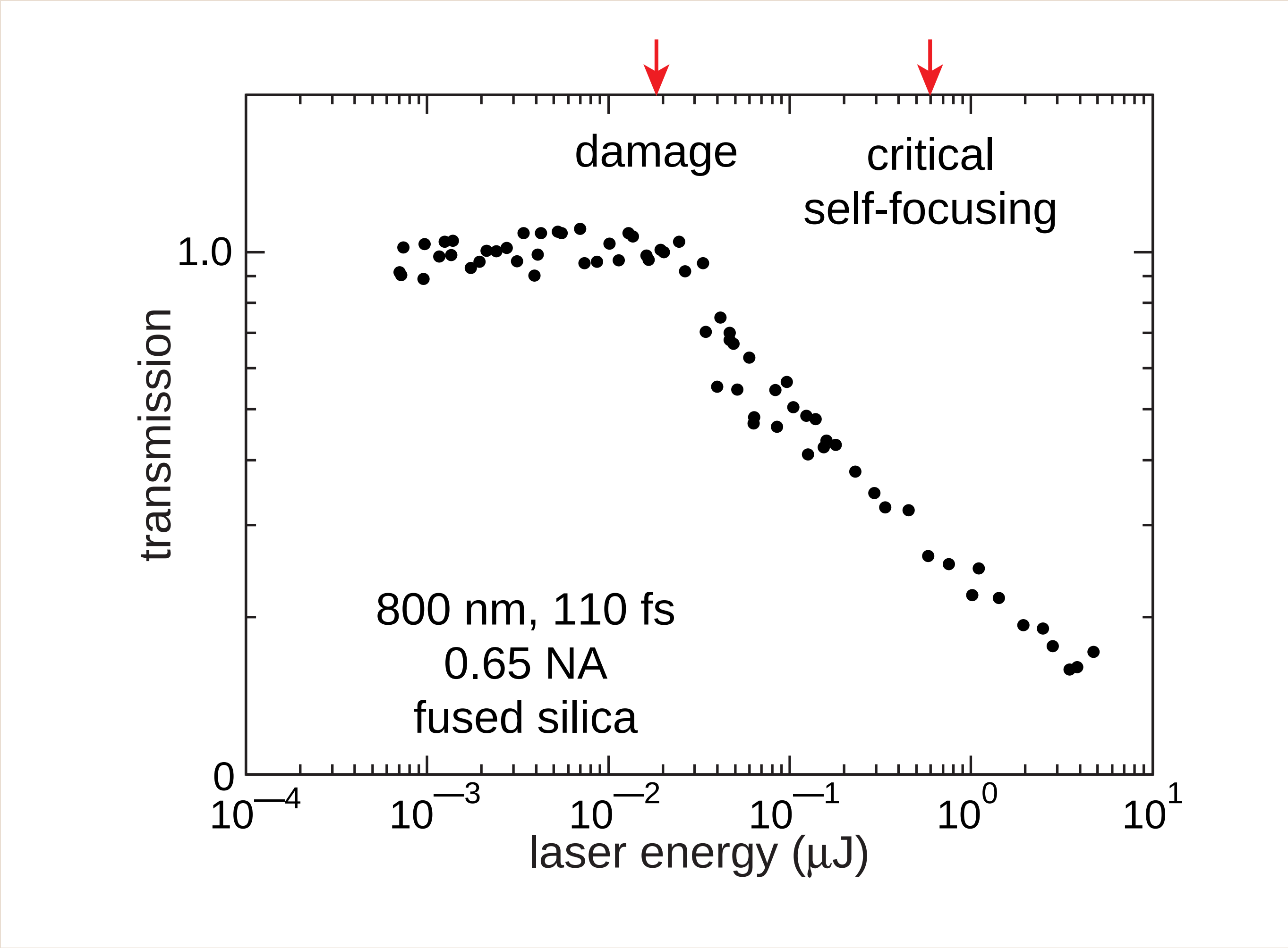
transmission of laser pulse as a function of energy



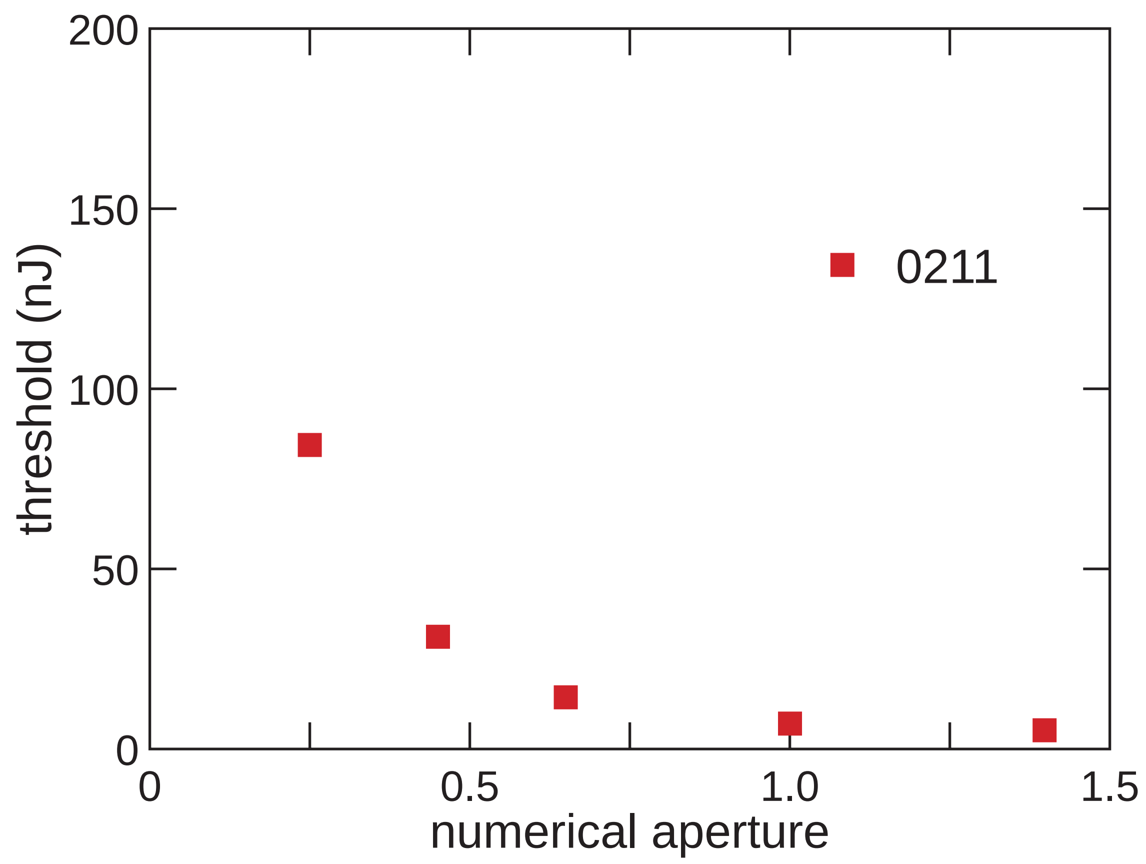
damage threshold corresponds to kink in transmission



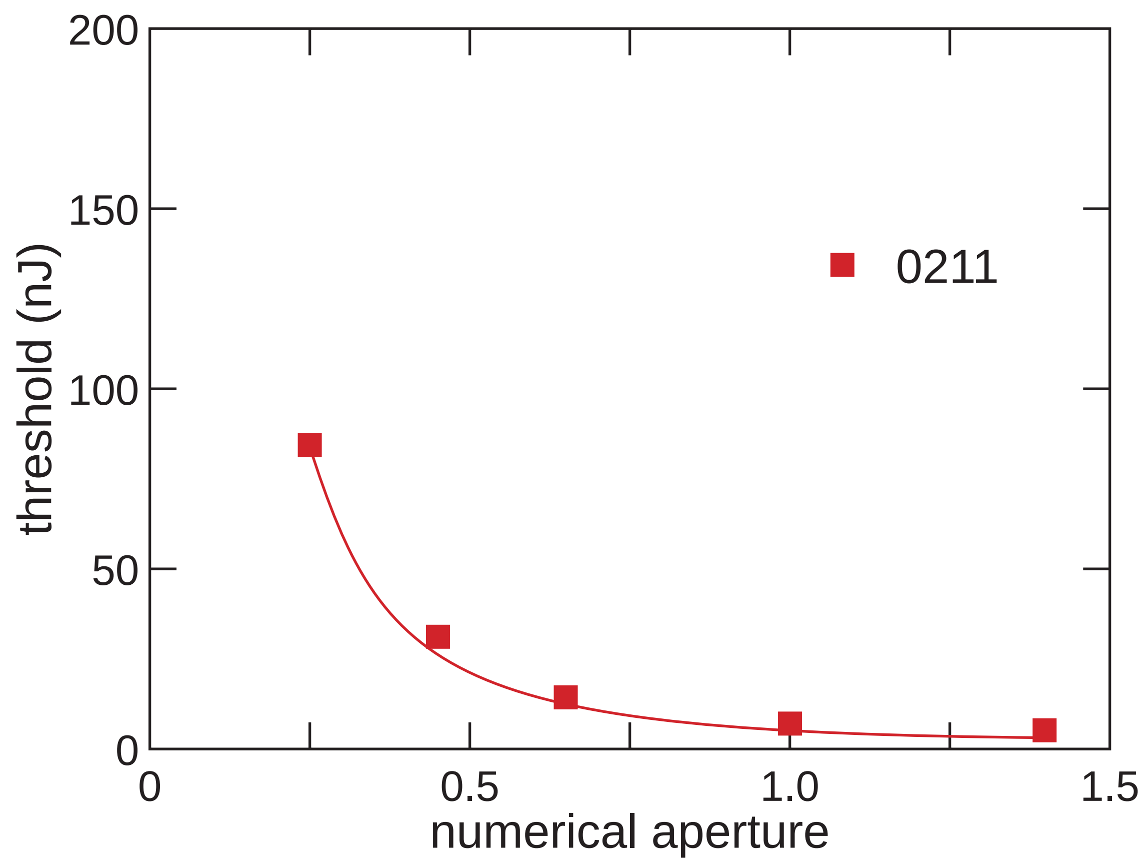
self-focusing threshold much higher



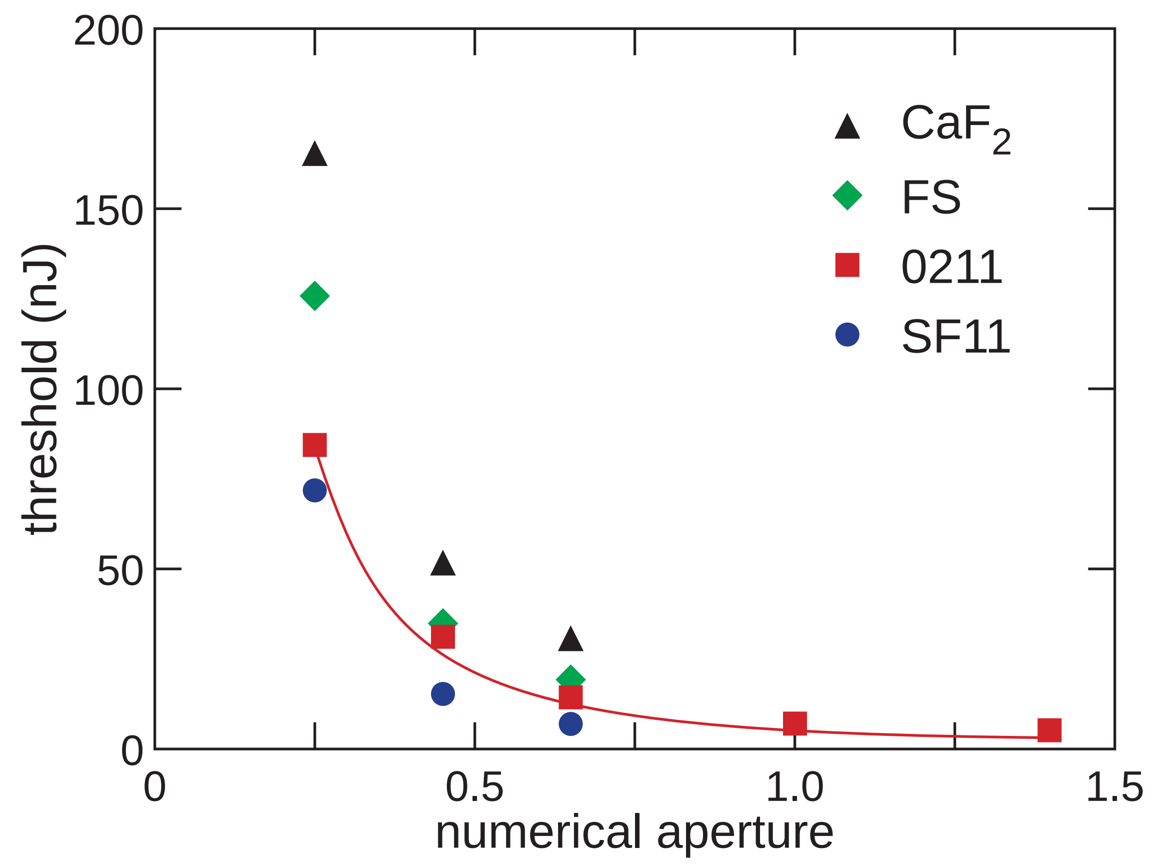
threshold at several numerical apertures



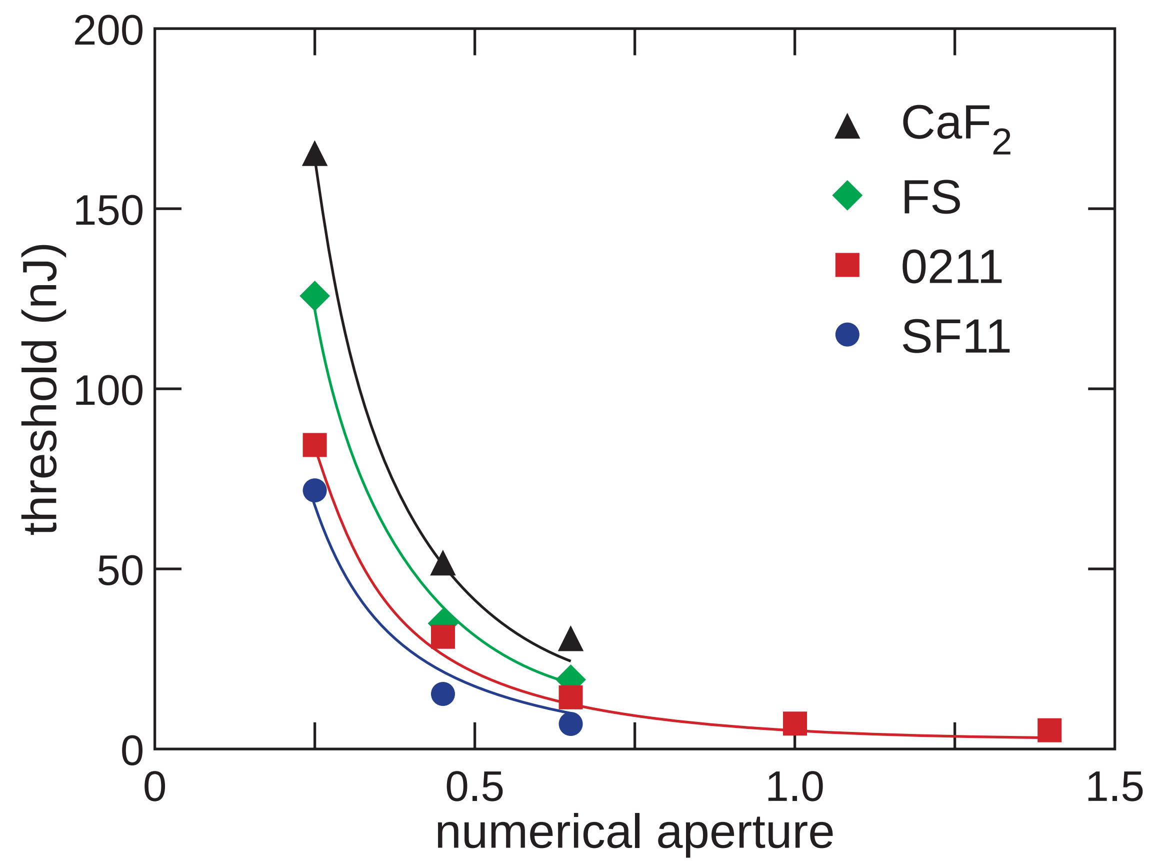
fit gives intensity: $I_0 = 2.5 \times 10^{13}$ W/cm^2



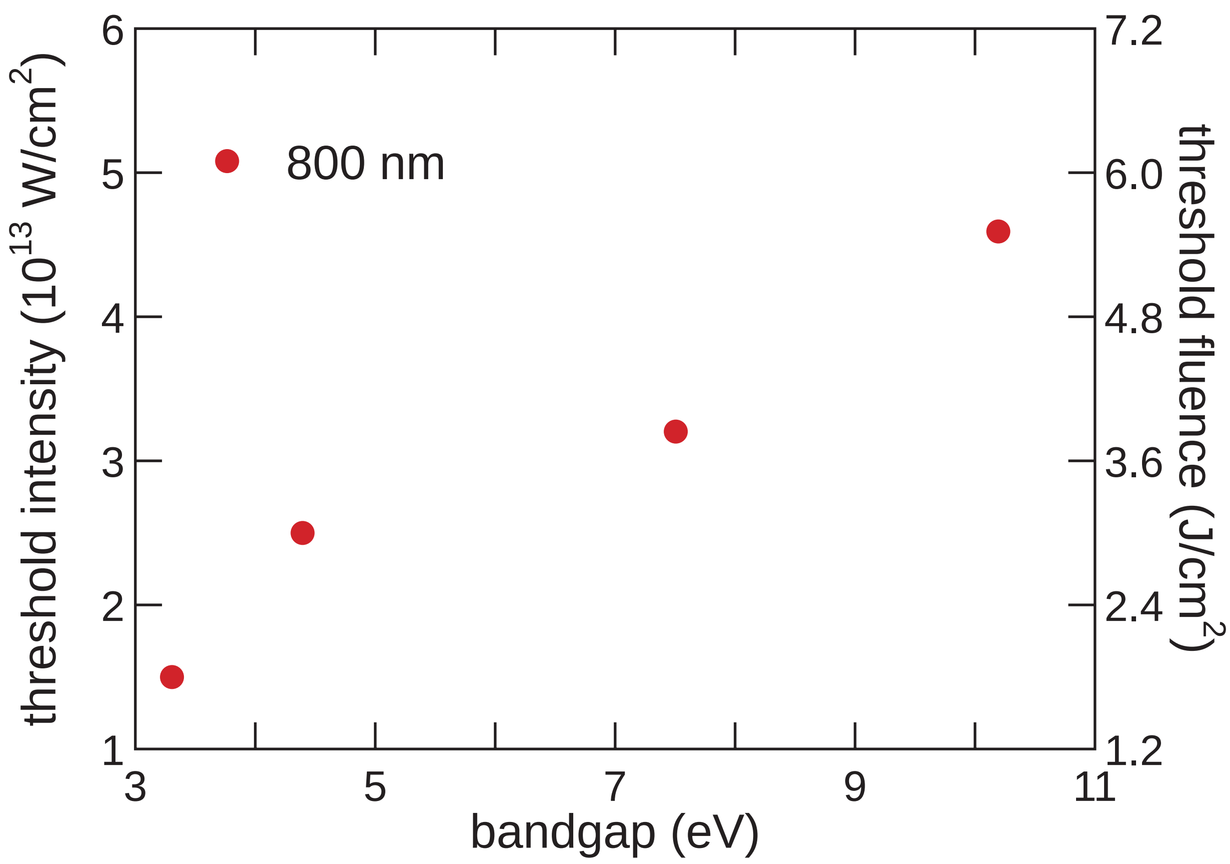
other materials



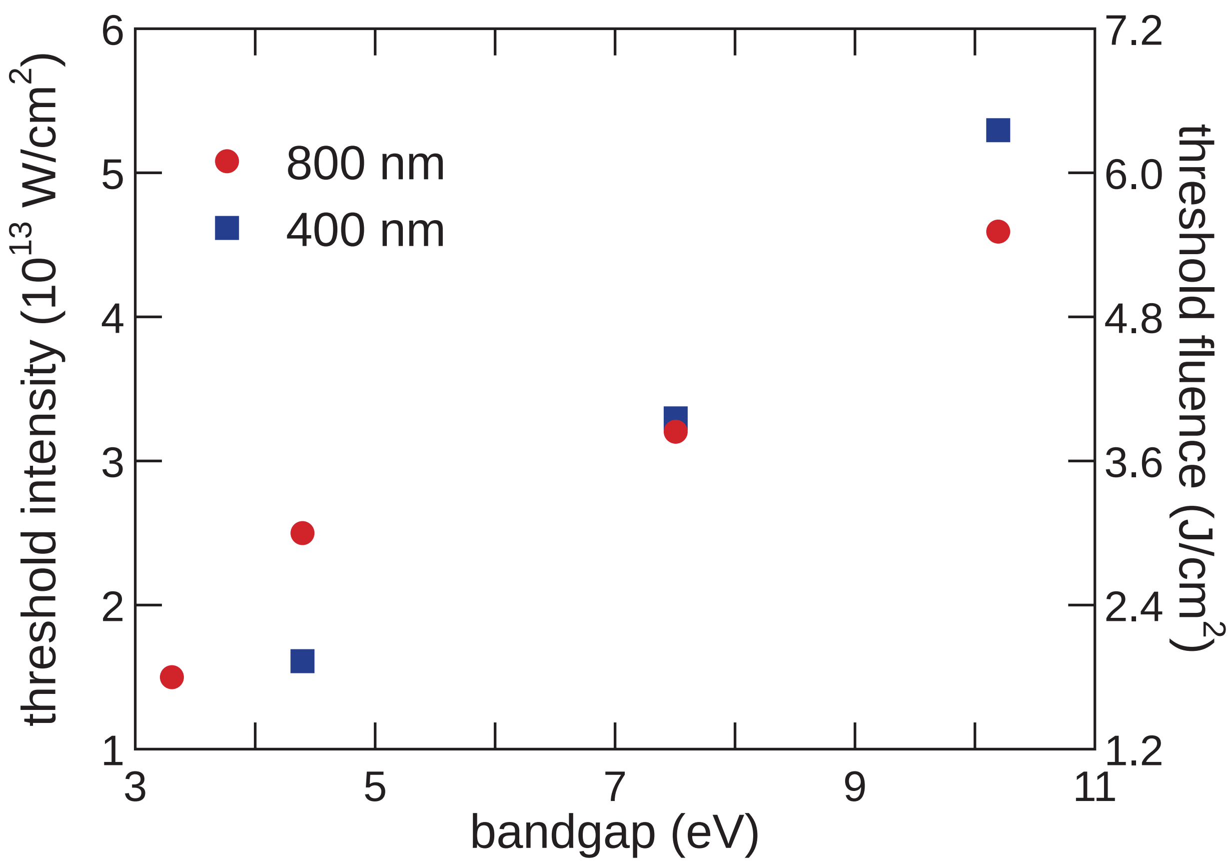
threshold intensity for various materials



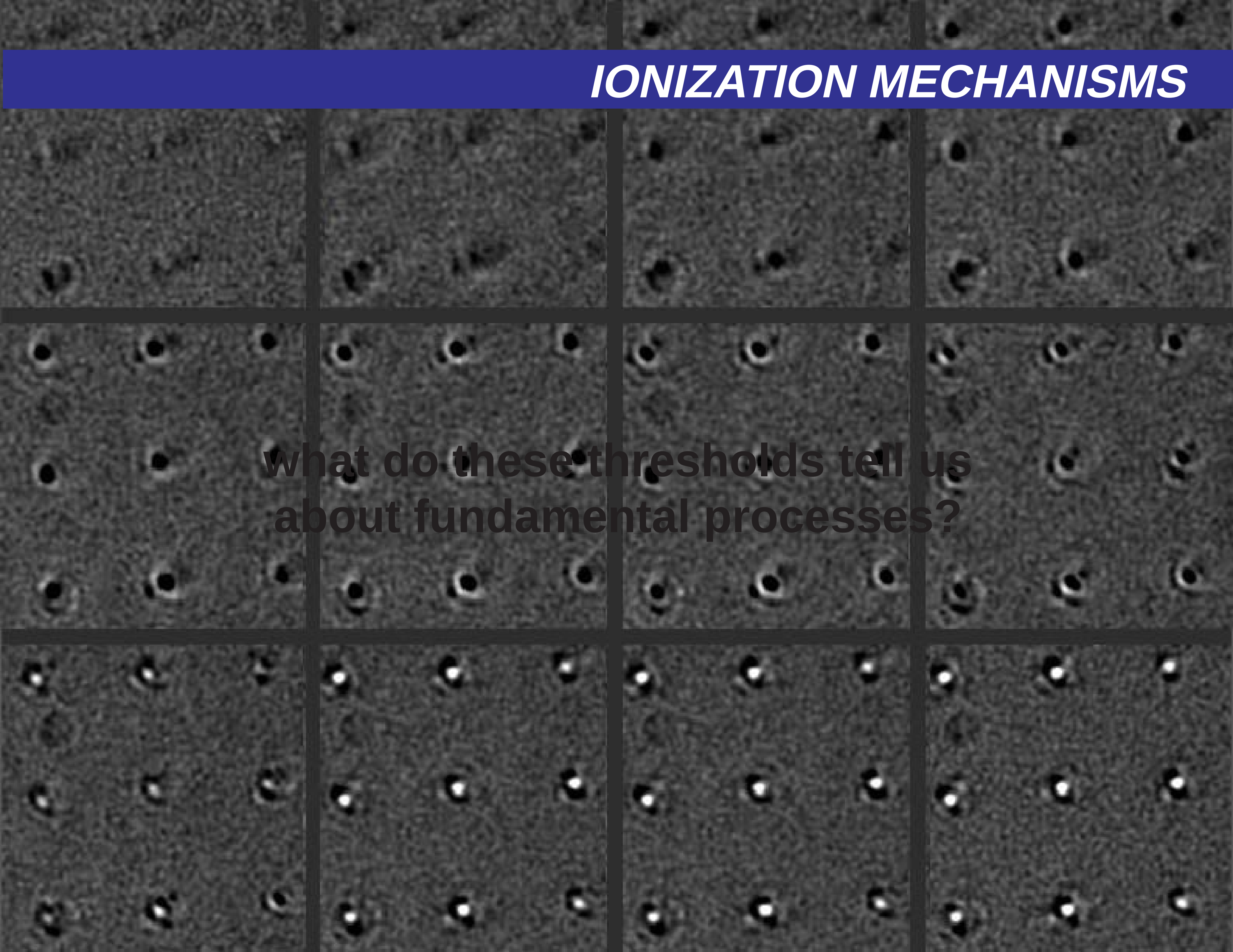
bandgap dependence of threshold intensity



repeat experiment for frequency-doubled pulses

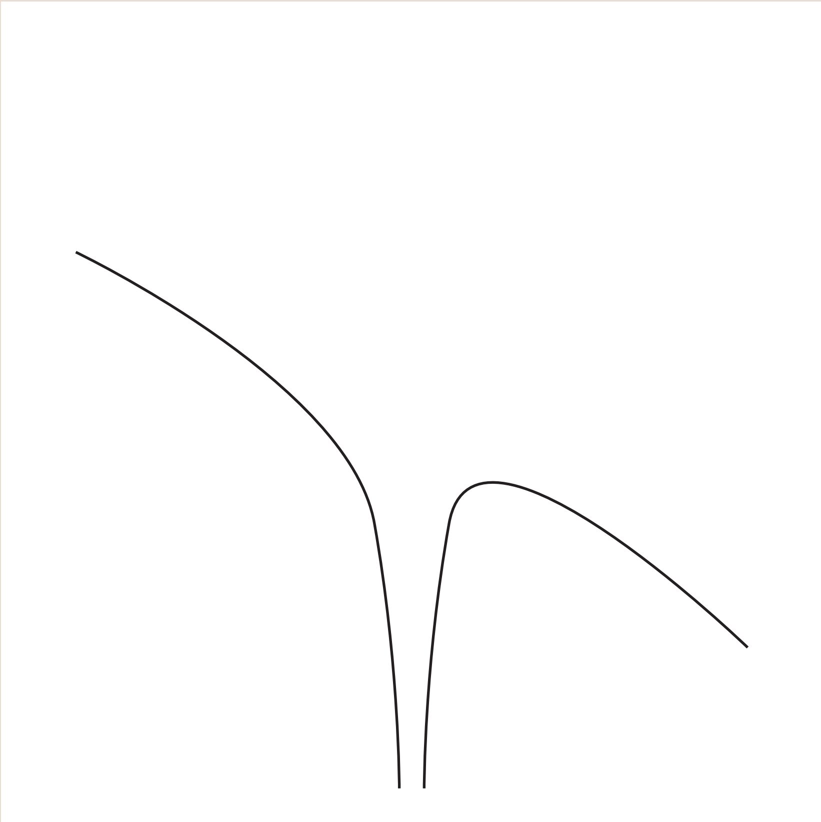


IONIZATION MECHANISMS



what do these thresholds tell us about fundamental processes?

Keldysh parameter



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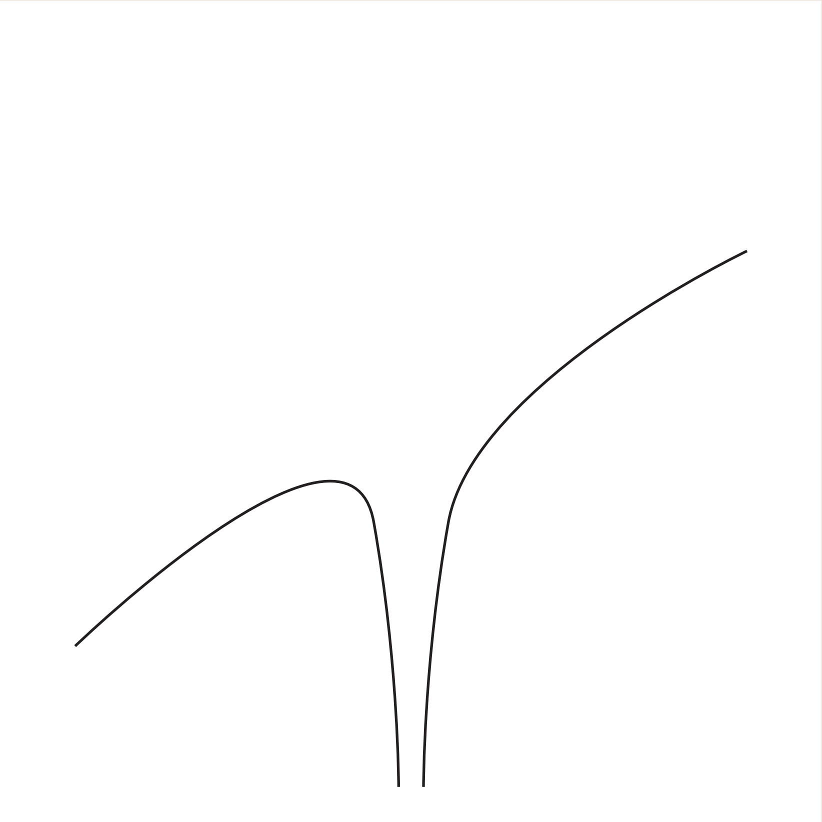

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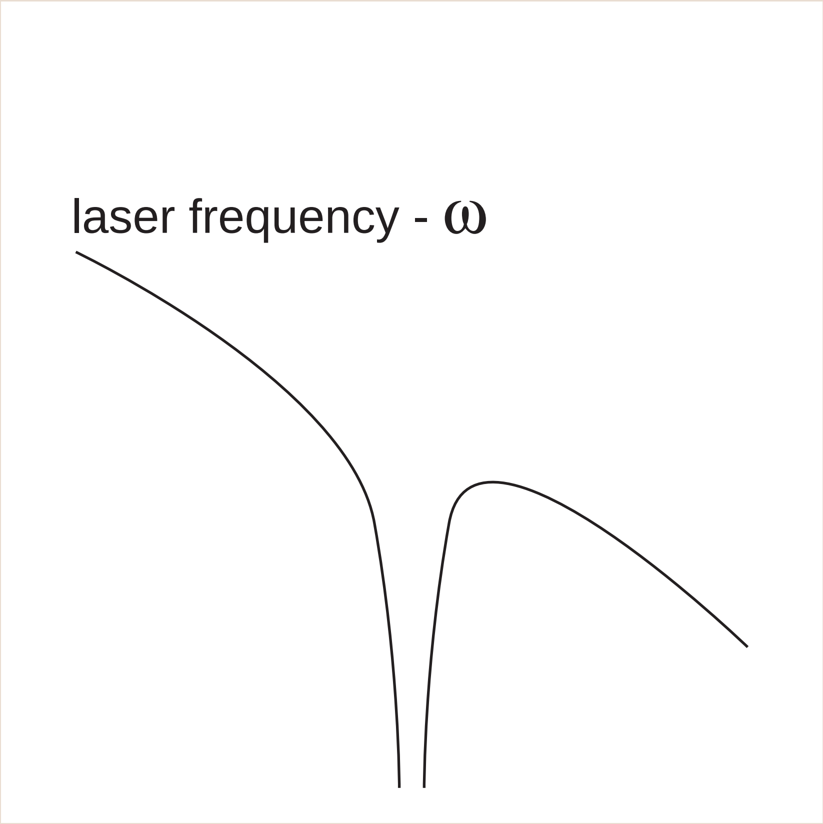
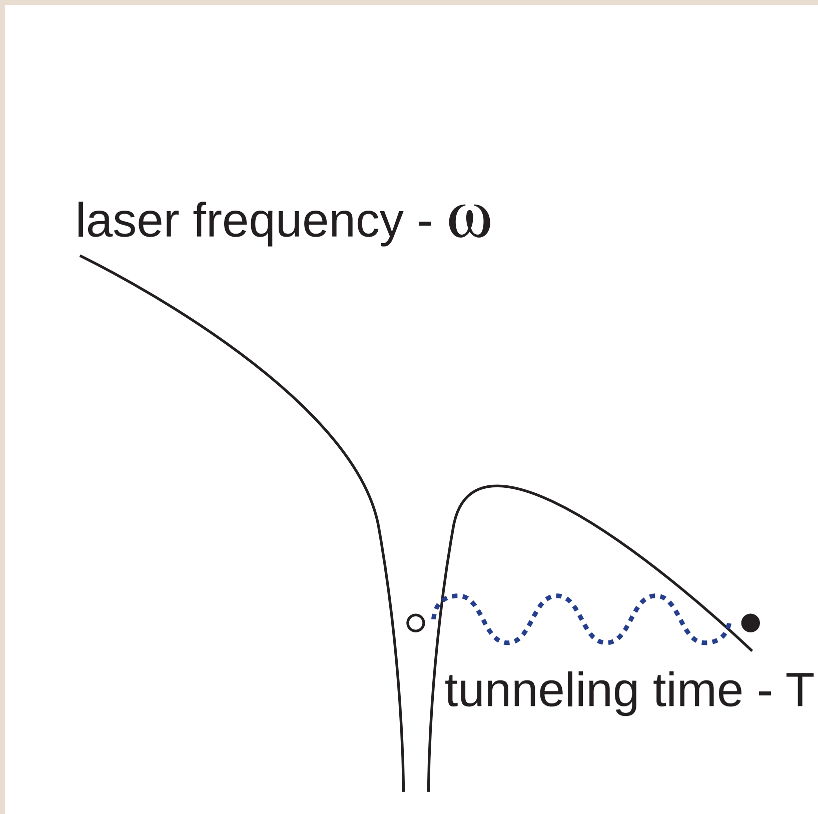


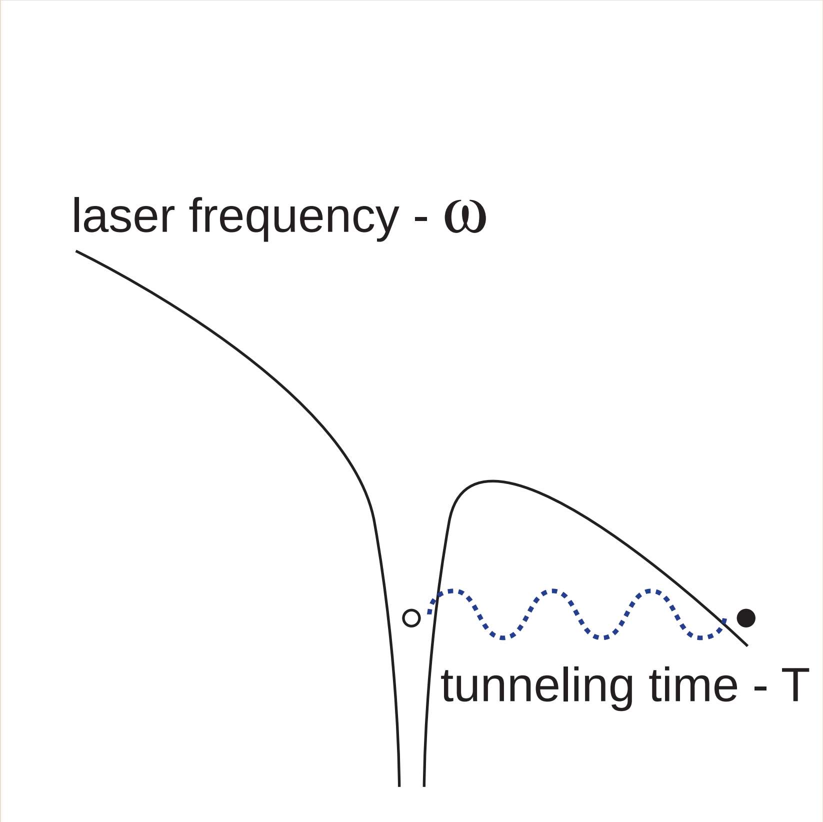
Keldysh parameter



Keldysh parameter

$\gamma = (\omega\ T) / 2^{1/2}$

$\gamma > 1.5$ MPI
$\gamma < 1.5$ tunneling

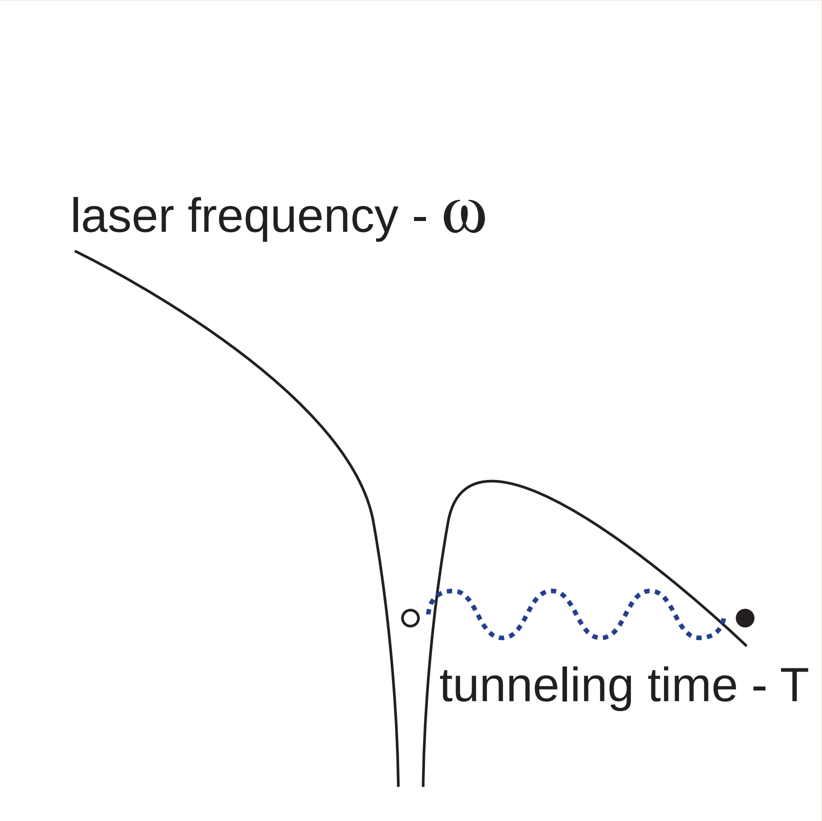


Keldysh parameter

$$\gamma = (\omega^2\ m\ c\ n\ \varepsilon_0\ E_g\ /\ e^2\ I)^{1/2}$$

$\gamma > 1.5$ MPI

$\gamma < 1.5$ tunneling



Keldysh parameter

$$\gamma = (\omega^2 \, m \, c \, n \, \varepsilon_0 \, E_g \, / \, e^2 \, I)^{1/2}$$

$\gamma > 1.5$ MPI
$\gamma < 1.5$ tunneling

material	γ (800 nm)
CaF_2	1.2
FS	1.2
0211	1.1
SF11	1.3

Keldysh parameter

$$\gamma = (\omega^2 \, m \, c \, n \, \varepsilon_0 \, E_g / e^2 \, I)^{1/2}$$

$\gamma > 1.5$ MPI
$\gamma < 1.5$ tunneling

material	γ (800 nm)	γ (400 nm)
CaF_2	1.2	2.1
FS	1.2	2.4
0211	1.1	2.6
SF11	1.3	

Keldysh parameter

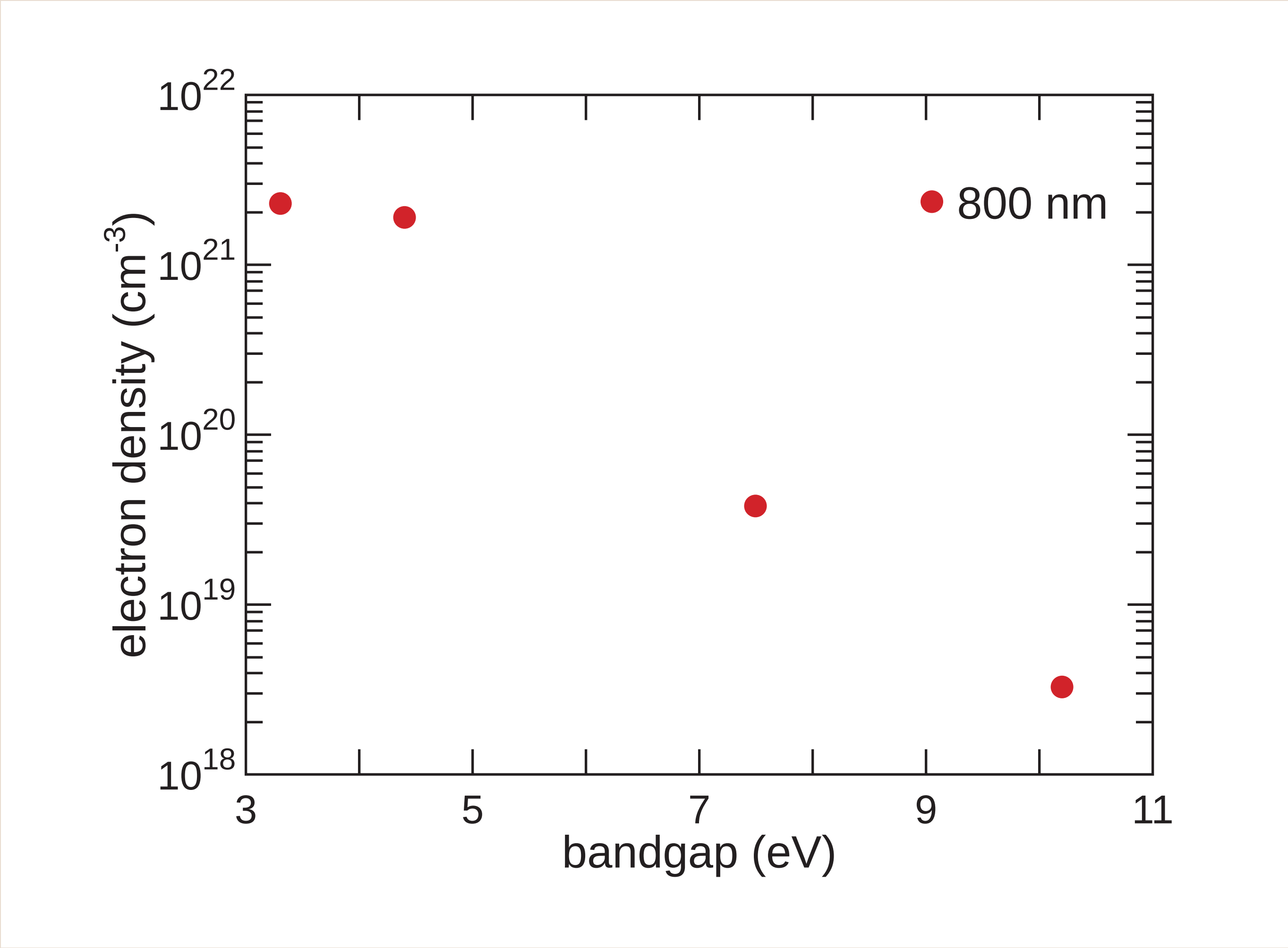
$$\gamma = (\omega^2 m\, c\, n\, \varepsilon_0\, E_g / e^2 I)^{1/2}$$

$\gamma > 1.5$ MPI
$\gamma < 1.5$ tunneling

material	γ (800 nm)	γ (400 nm)
CaF_2	1.2	2.1
FS	1.2	2.4
0211	1.1	2.6
SF11	1.3	

tunneling at 800 nm, MPI at 400 nm

calculate electron density produced by MPI and tunneling



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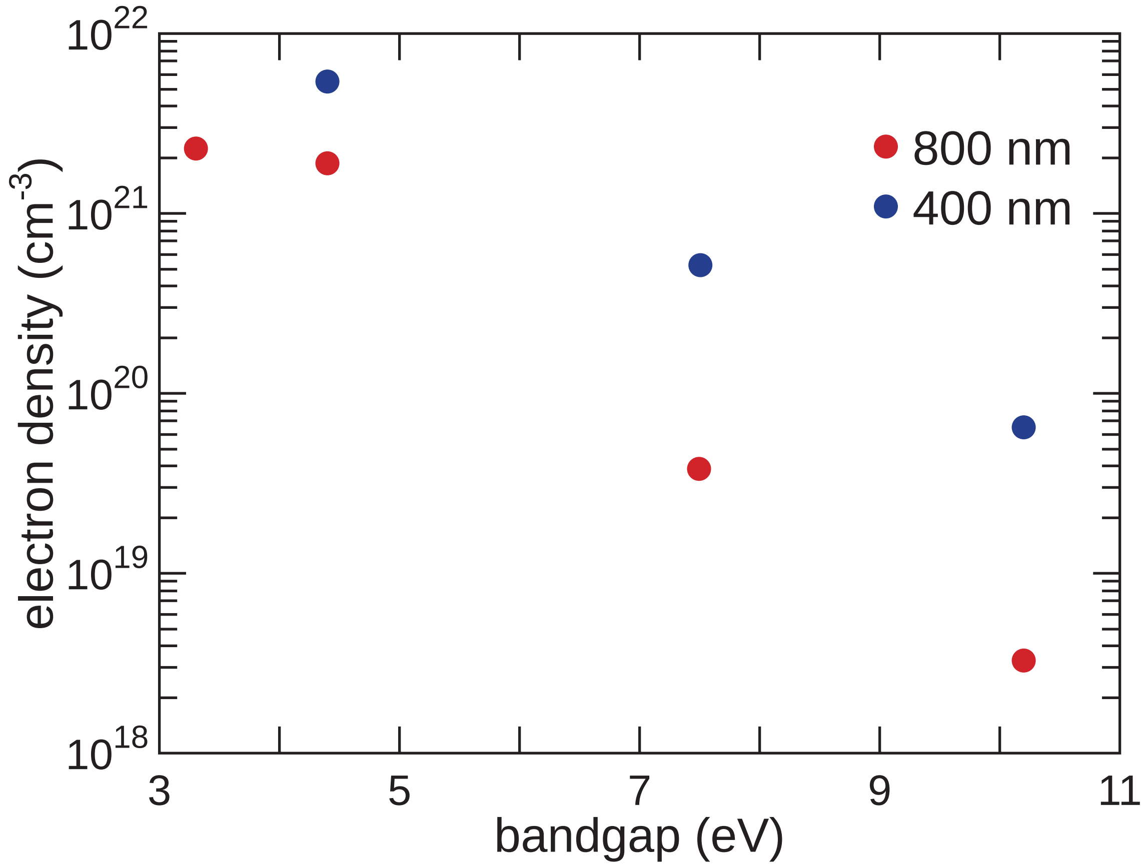
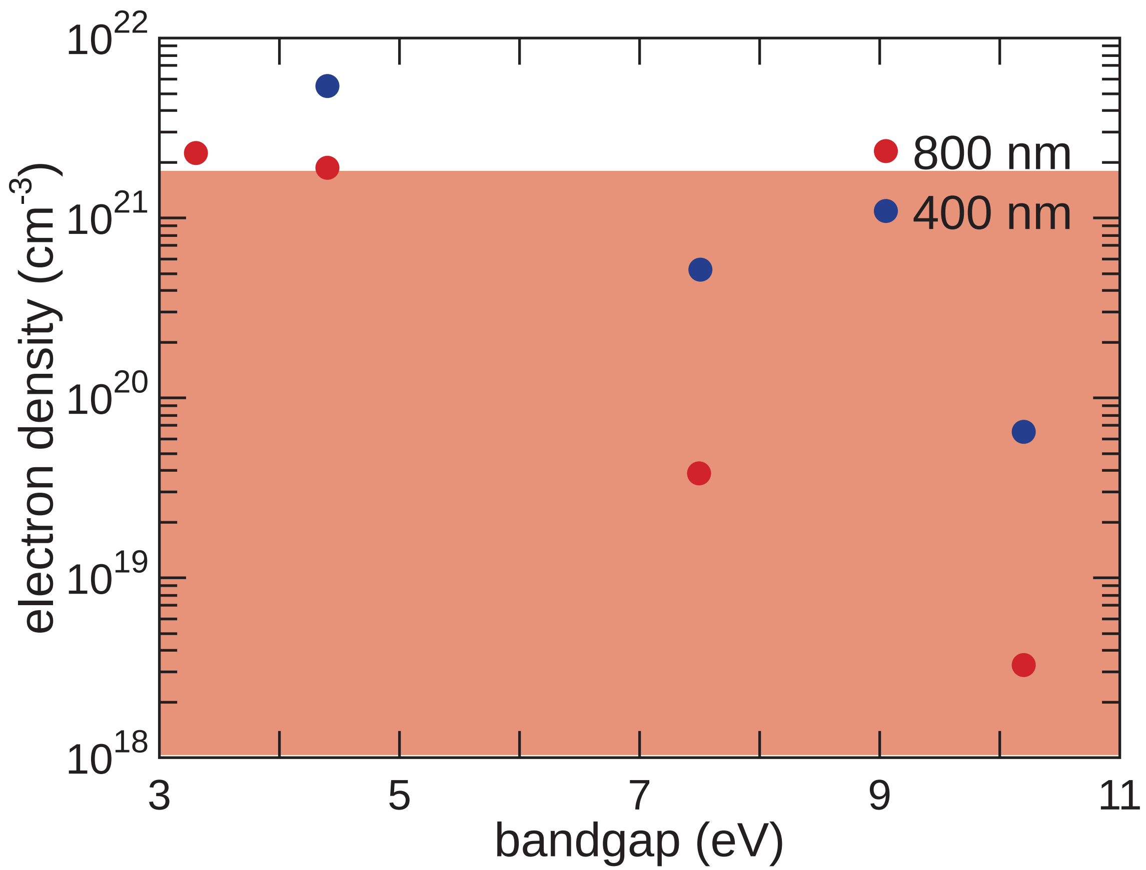
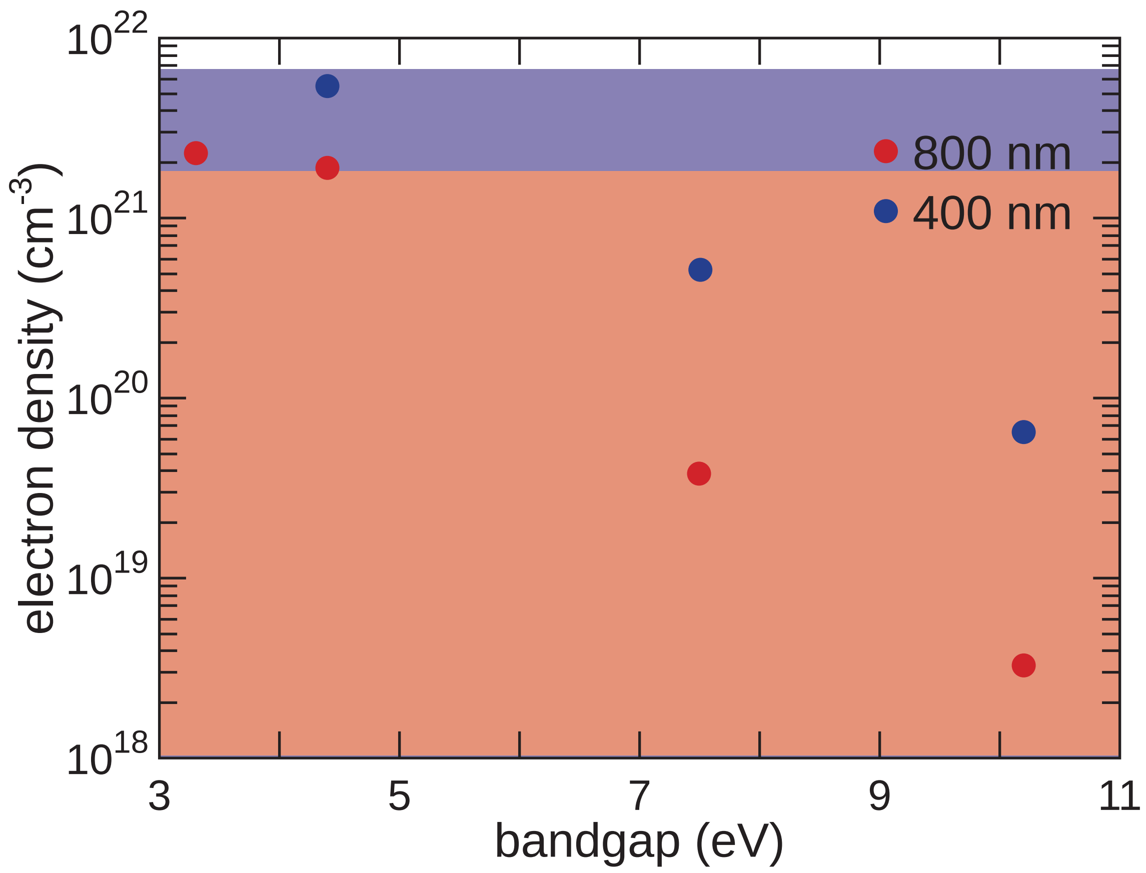


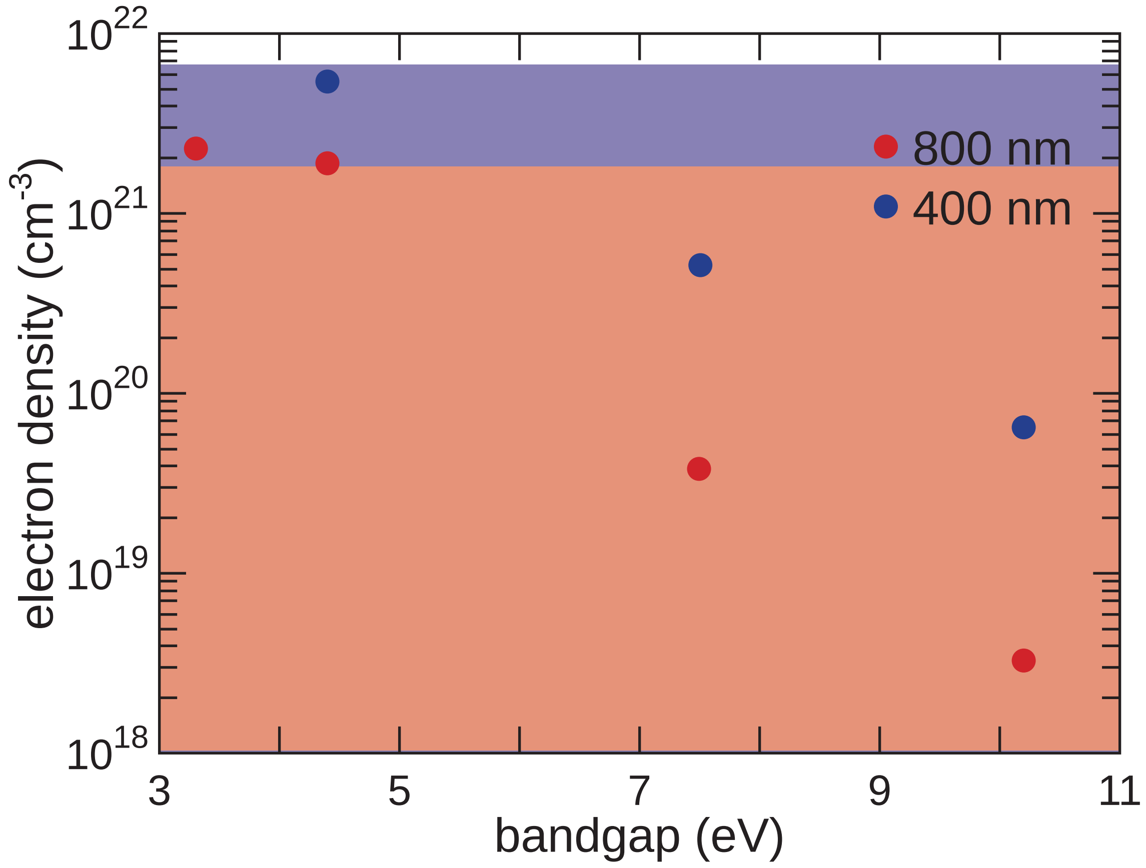
800 nm critical density



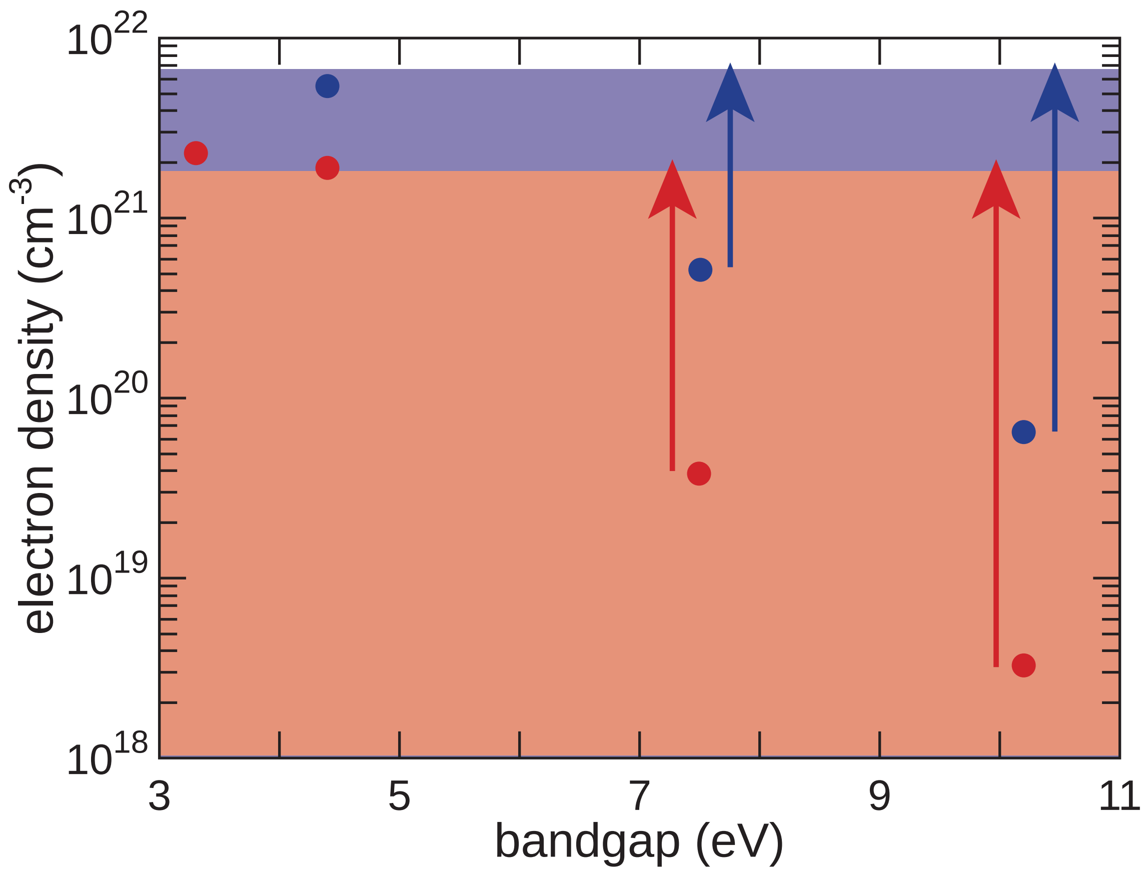
400 nm critical density



tunneling or MPI sufficent at low gap



avalanche required at large gap



CONCLUSIONS

Material damage with less than 10 nJ

Bandgap and wavelength dependence of damage threshold

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Material damage with less than 10 nJ

- oscillator-only micromachining

Bandgap and wavelength dependence of damage threshold

CONCLUSIONS

Material damage with less than 10 nJ

- oscillator-only micromachining

Bandgap and wavelength dependence of damage threshold

- extend wavelength studies

ACKNOWLEGEMENTS

W. Leight
N. Nishimura
Prof. N. Bloembergen
Carl Zeiss, Inc.

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

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