Lasers in Manufacturing, LIM 2007, Munich ICM International Congress Centre Munich
Messegelände An der Poin, D-81823 München 18 – 22 June 2007

Micro-processing of Glass with Femtosecond Laser Pulses

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[1]Osaka University,
[2] National Institute of Advanced Industrial Science and Technology

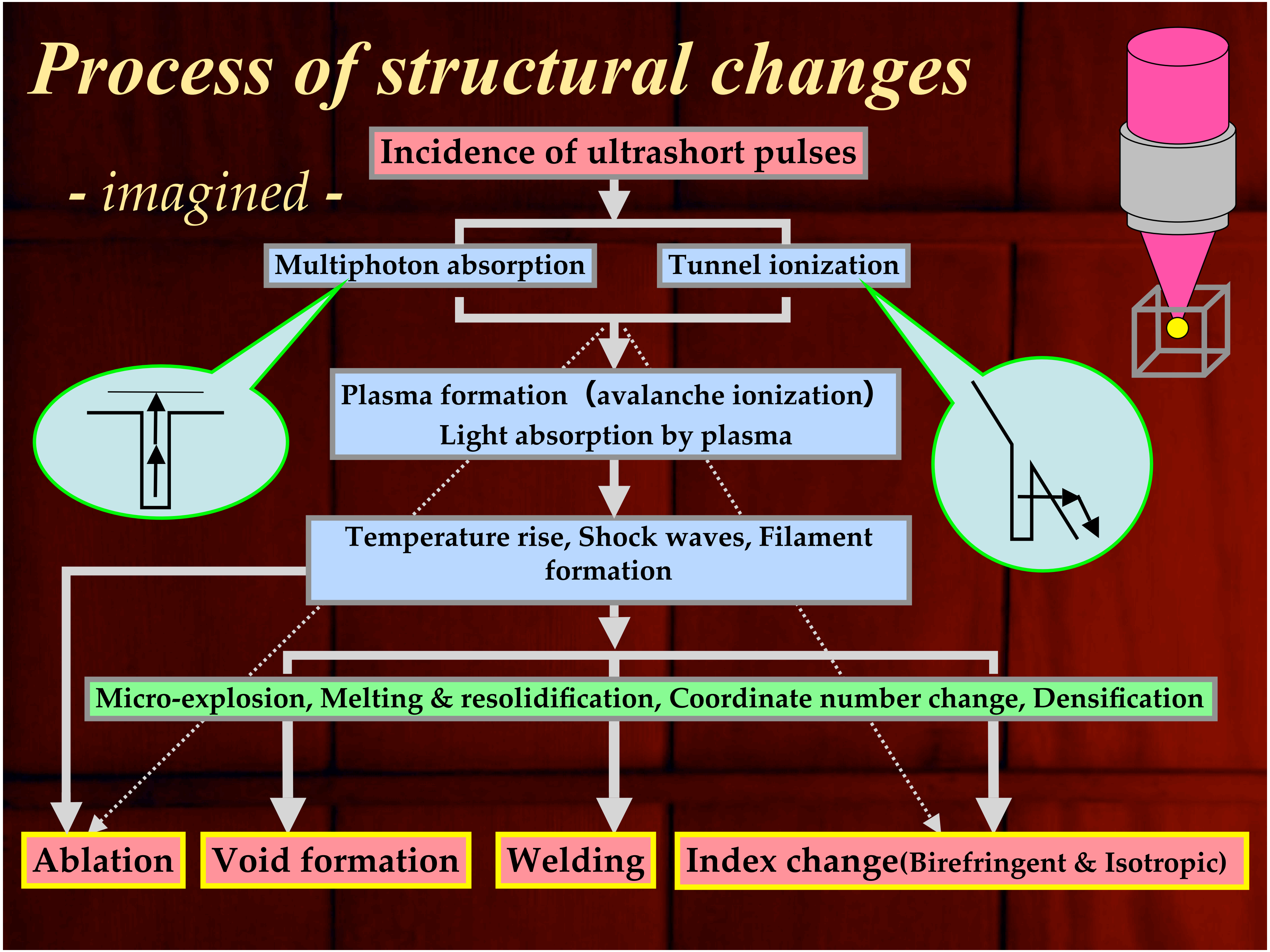
Outline

- Introduction to laser micro-processing

-Fabrication of optical devices
with filaments

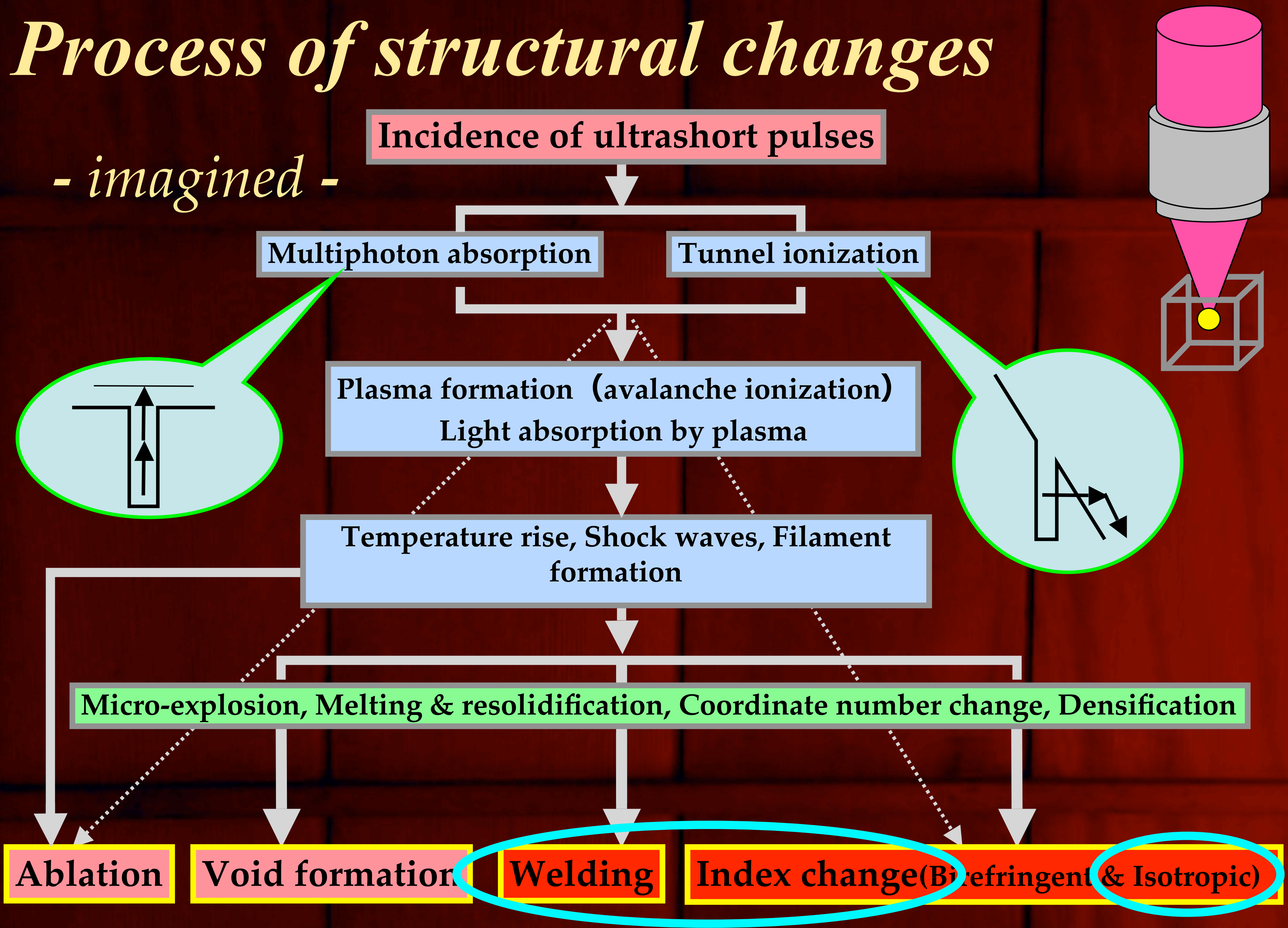
- Ultra-fast laser micro-welding of glass
with filaments

- Ultra-fast laser micro-welding of
heterogeneous materials


Process of structural changes
- imagined -
Incidence of ultrashort pulses
Multiphoton absorption
Tunnel ionization
Plasma formation (avalanche ionization)
Light absorption by plasma
Temperature rise, Shock waves, Filament formation
Micro-explosion, Melting & resolidification, Coordinate number change, Densification
Ablation
Void formation
Welding
Index change(Birefringent & Isotropic)

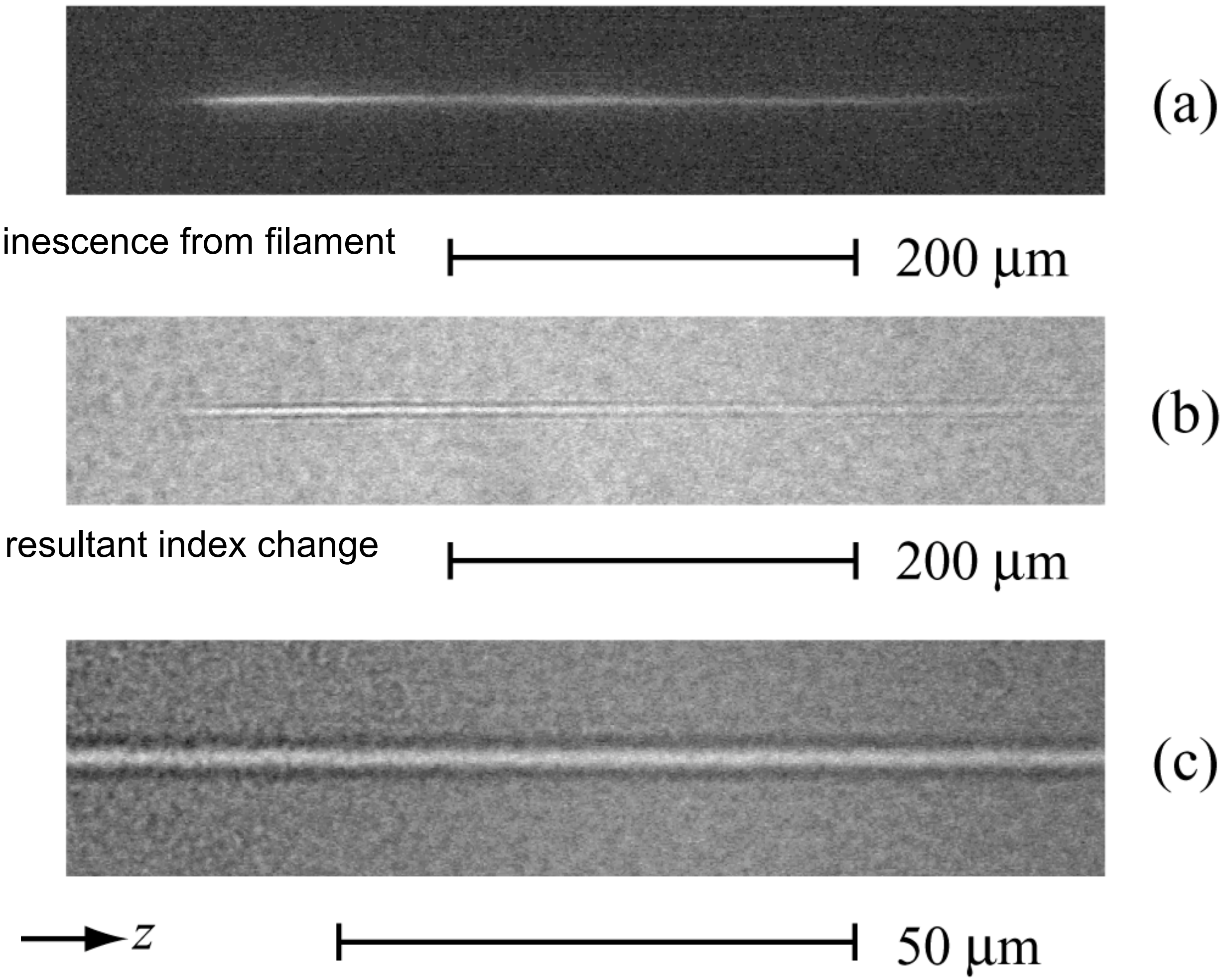
Process of structural changes

- imagined -



Filamentation

- balancing between self-focusing and defocusing by plasma -



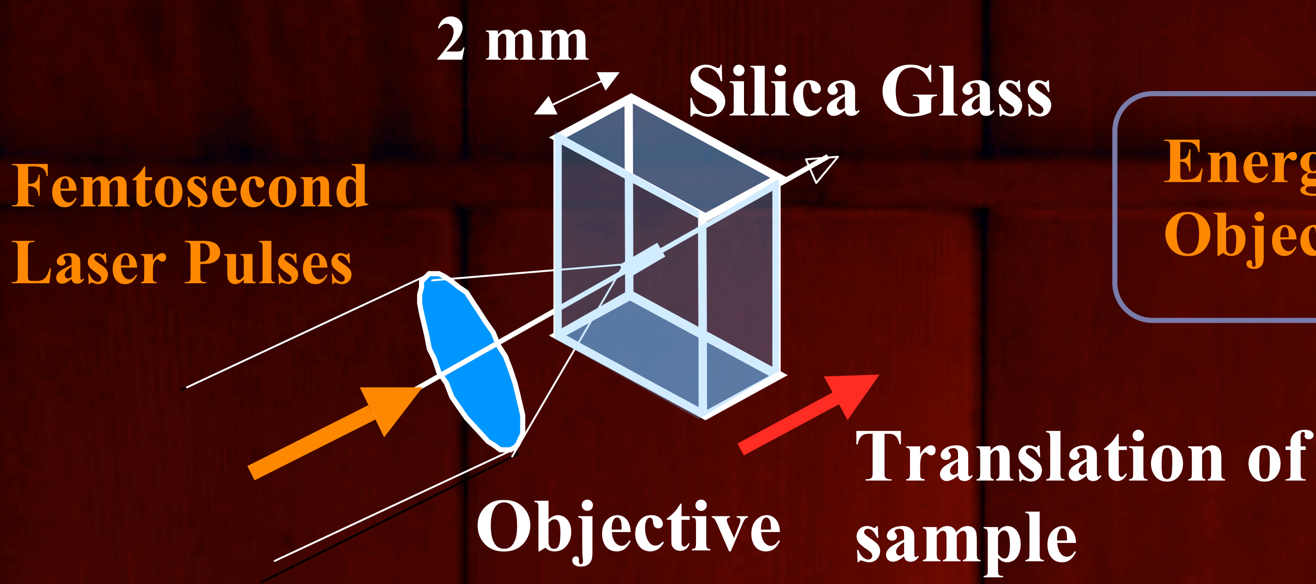
Scattering or luminescence from filament

Micrograph of the resultant index change

Magnified micrograph

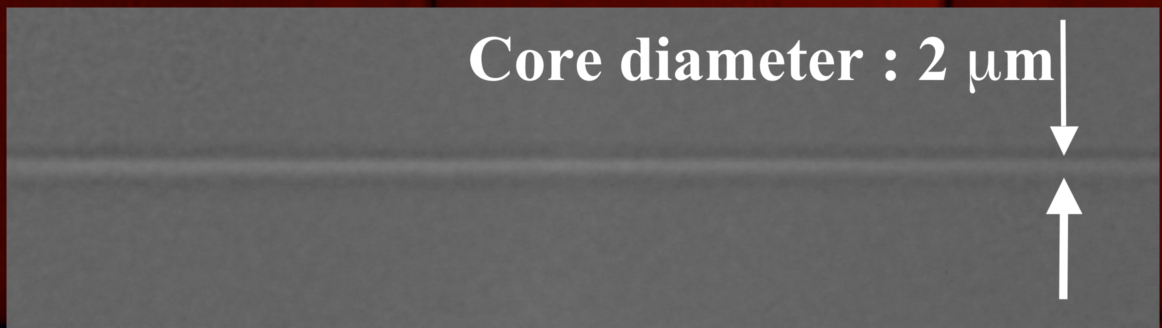
- *Fabrication of optical devices with filaments*

Fabrication of Waveguide



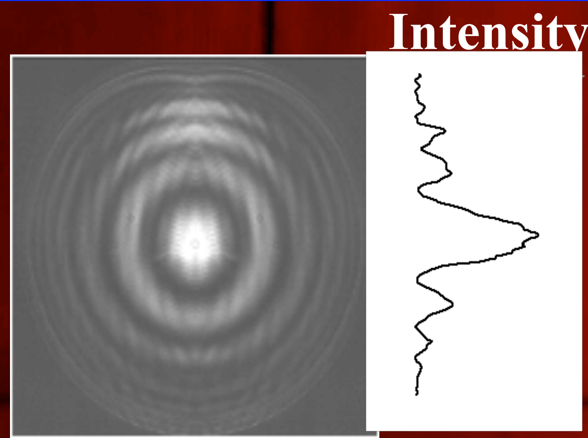
Energy : 0.73 μJ / pulse
Objective : NA = 0.1

Waveguide



Total length 2mm

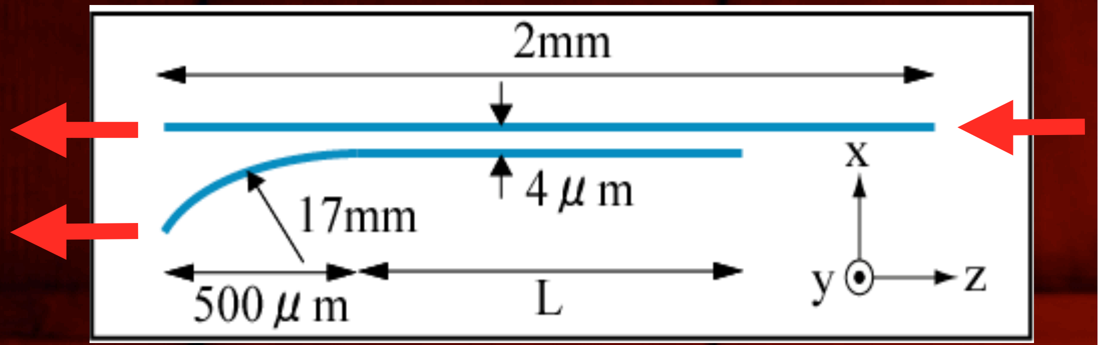
$\Delta n_z = 0.4 \times 10^{-2}$ $\Delta n_{x,y} = 0.6 \times 10^{-2}$

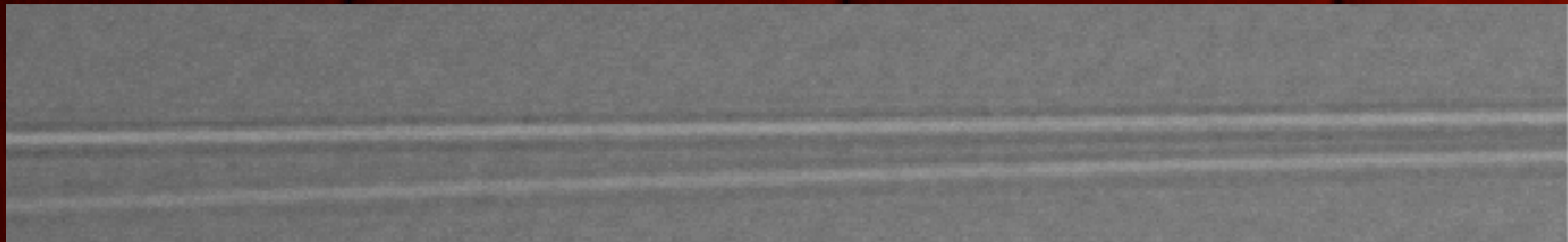


Far-field Pattern

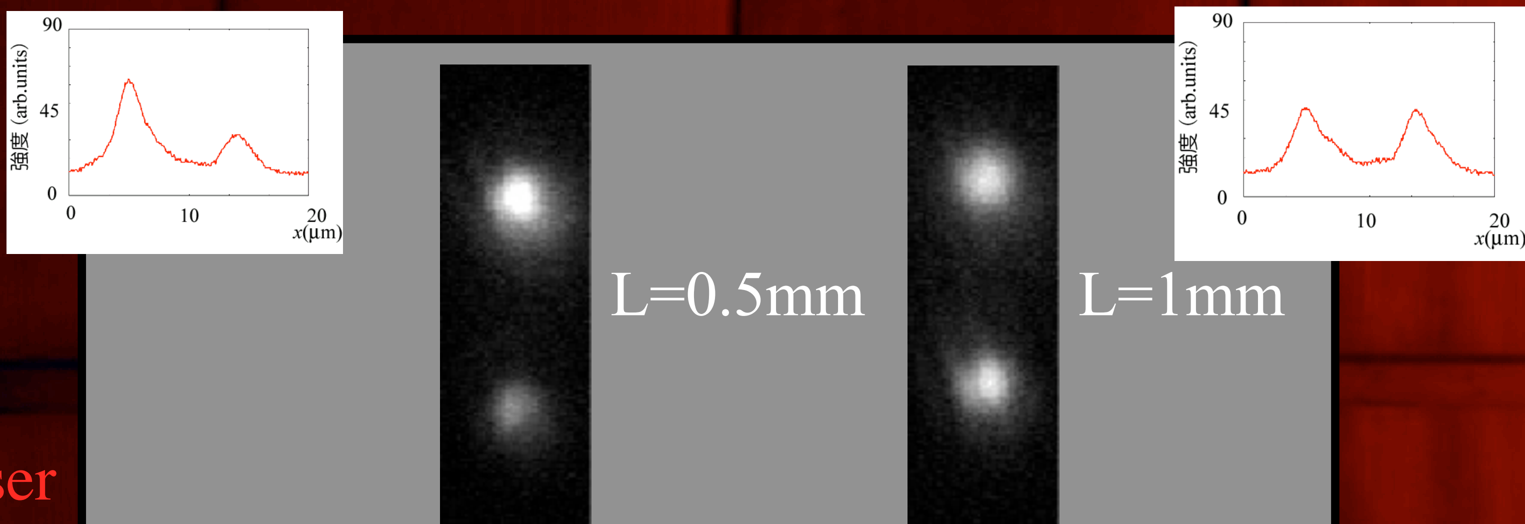
(Wavelength: 633 nm)

2-D Directional Coupler





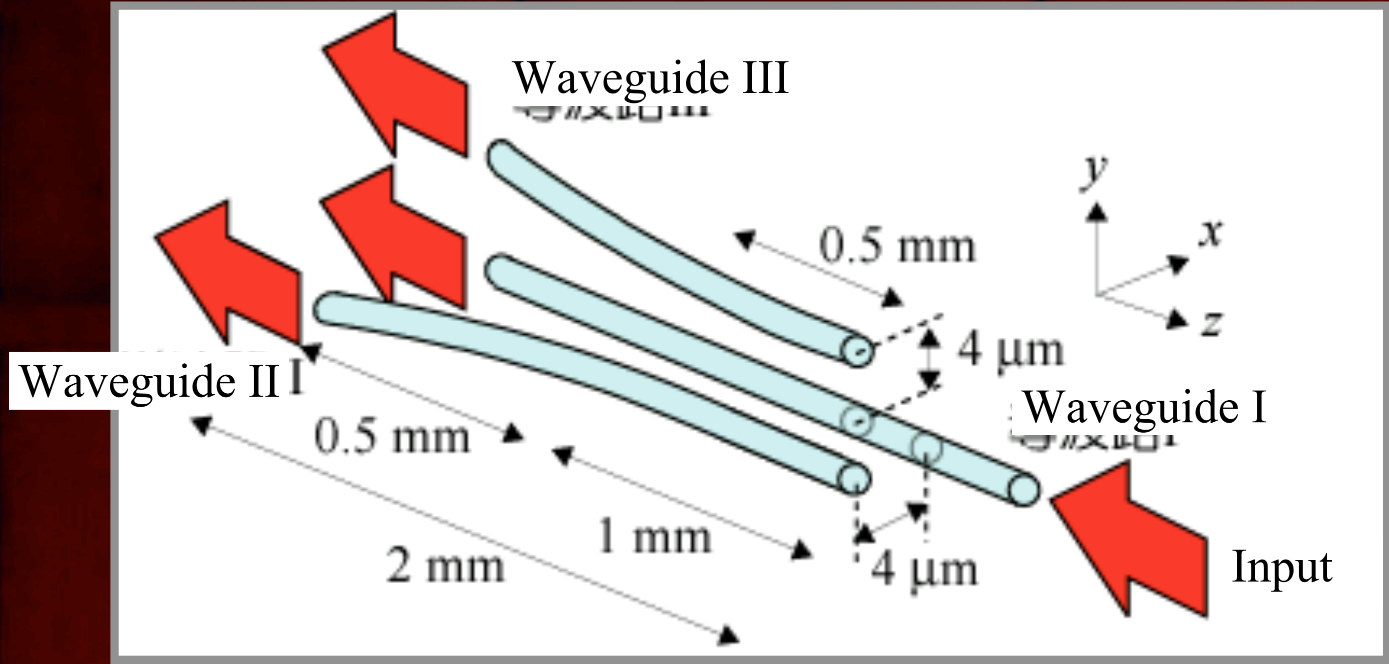
Microscope image of directional coupler



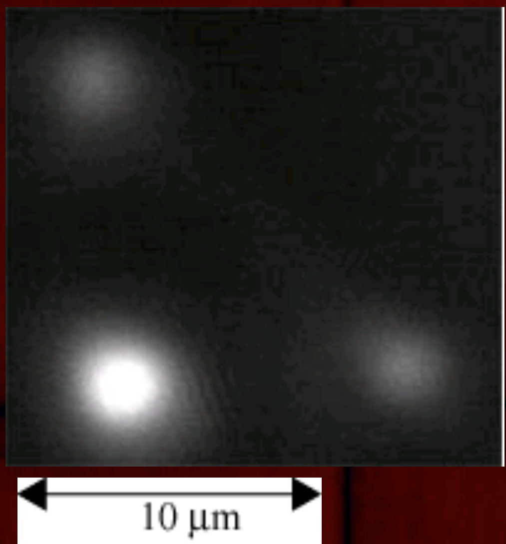
Near field pattern at end face of glass block

He-Ne laser
633 nm

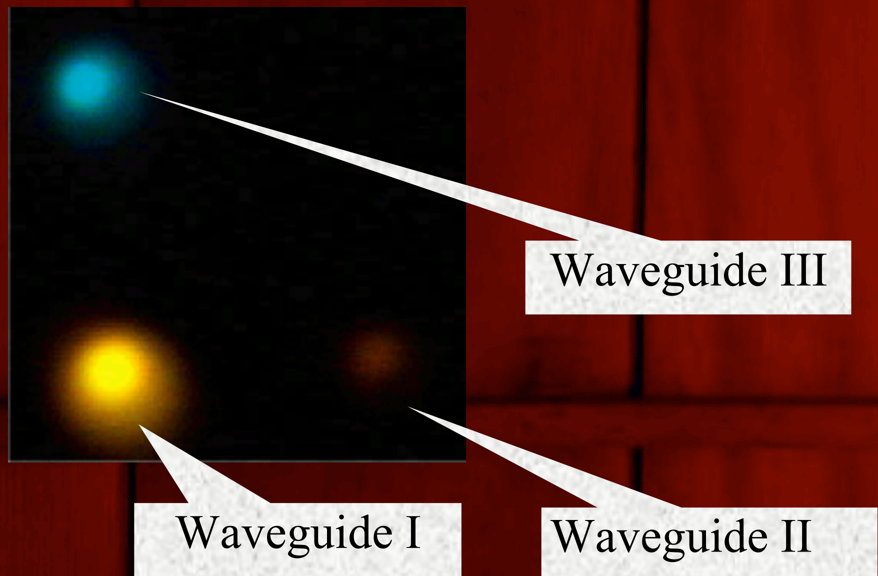
3-D Coupler



Input light：632.8 nm



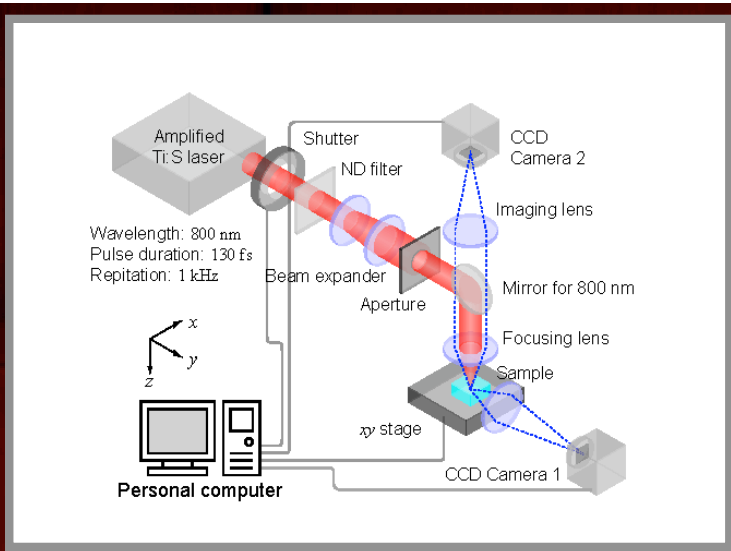
Input light：White light

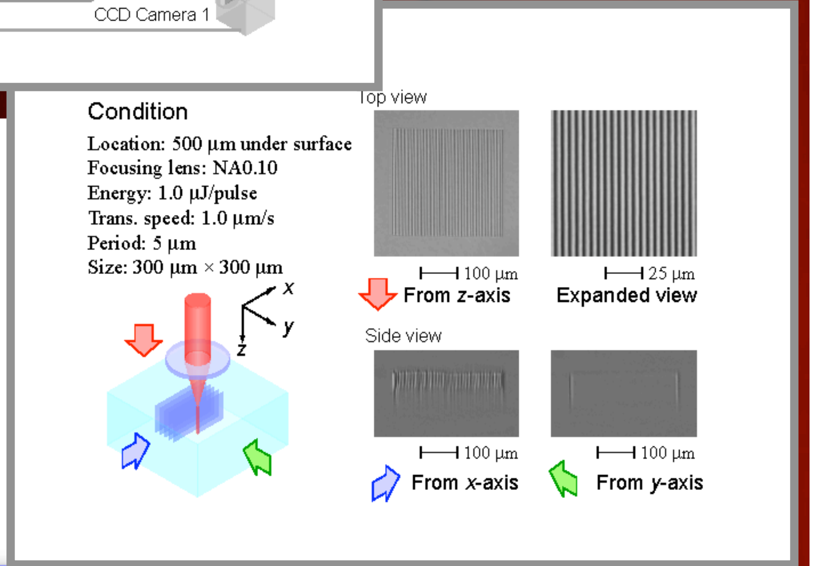


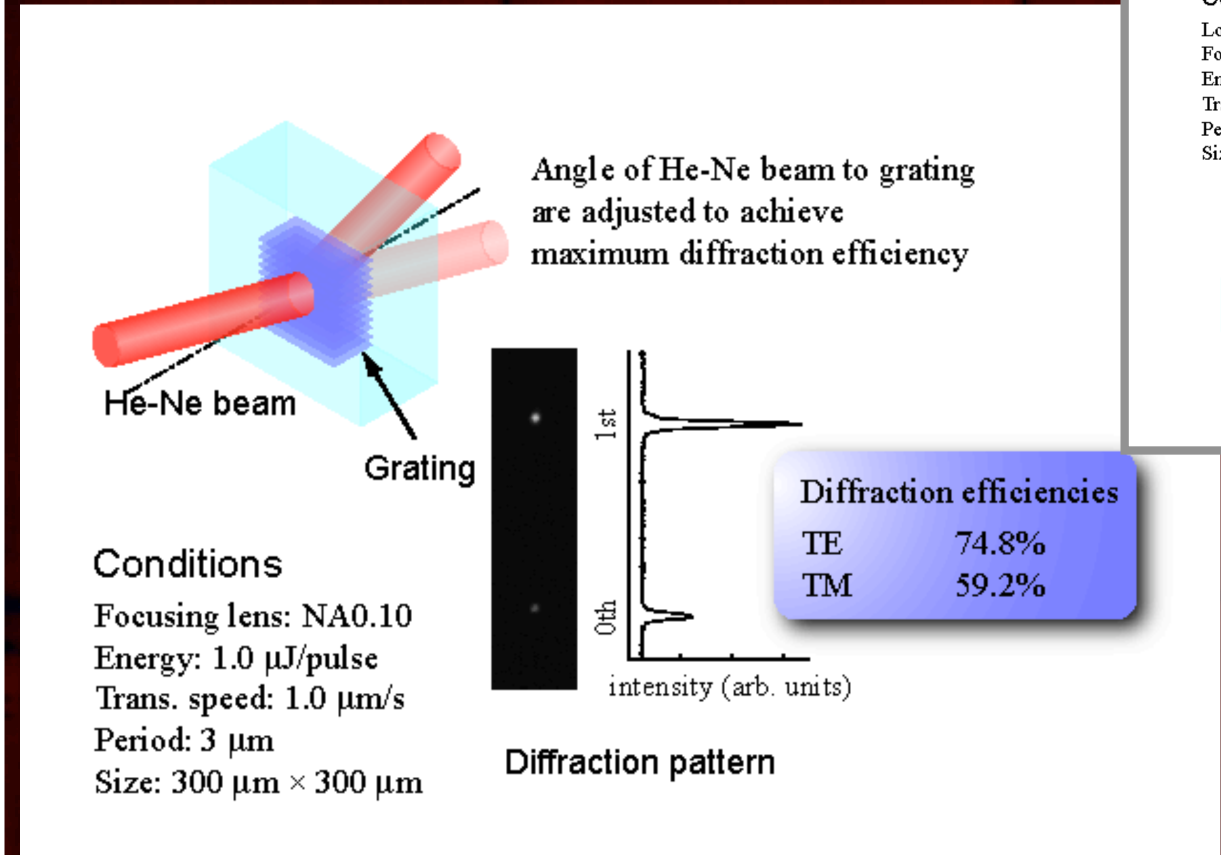
W.Watanabe, et al, Opt. Lett. Vol. 28, No. 24, 491-2493 (2003).

Fabrication of Bragg grating

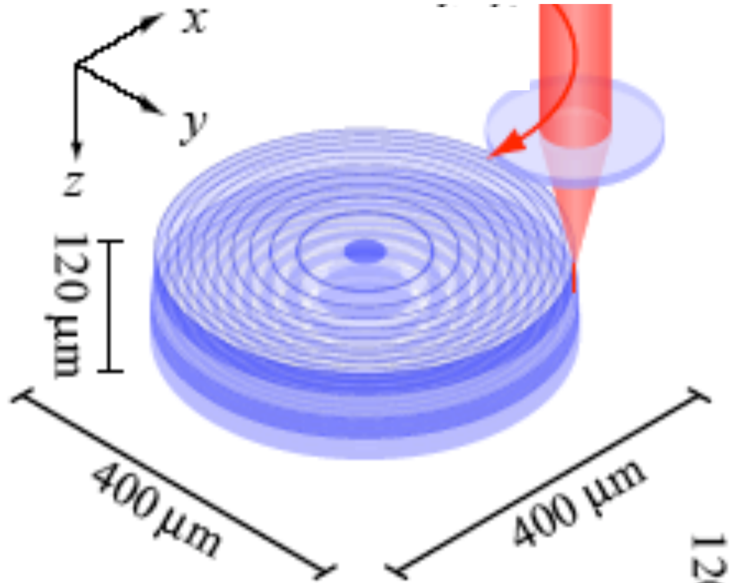
K. Yamada et al, Jpn. J. Appl. Phys., Vol. 42, Part 1, No. 11, 6916(2003).

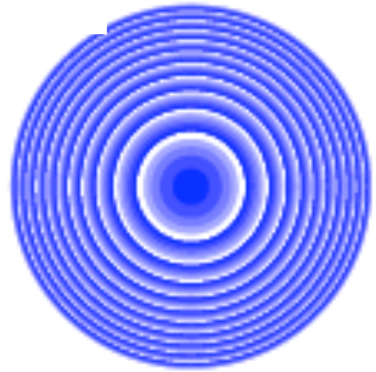


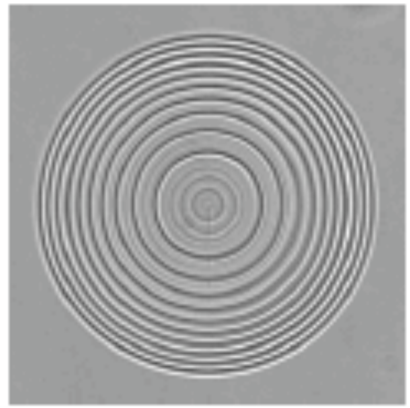


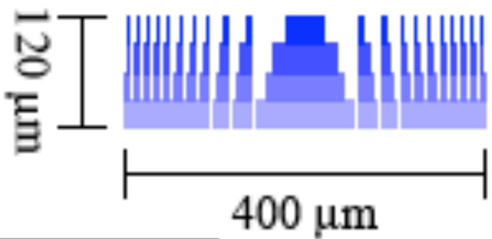


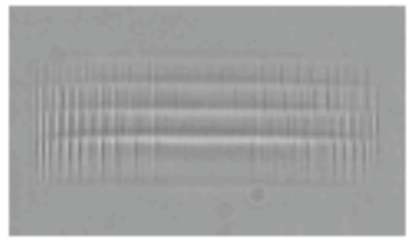
Multi-Level Phase Zone Plate Lens





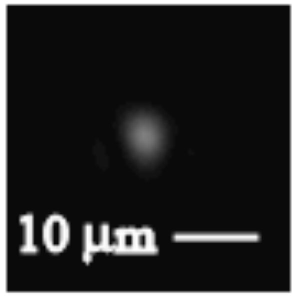






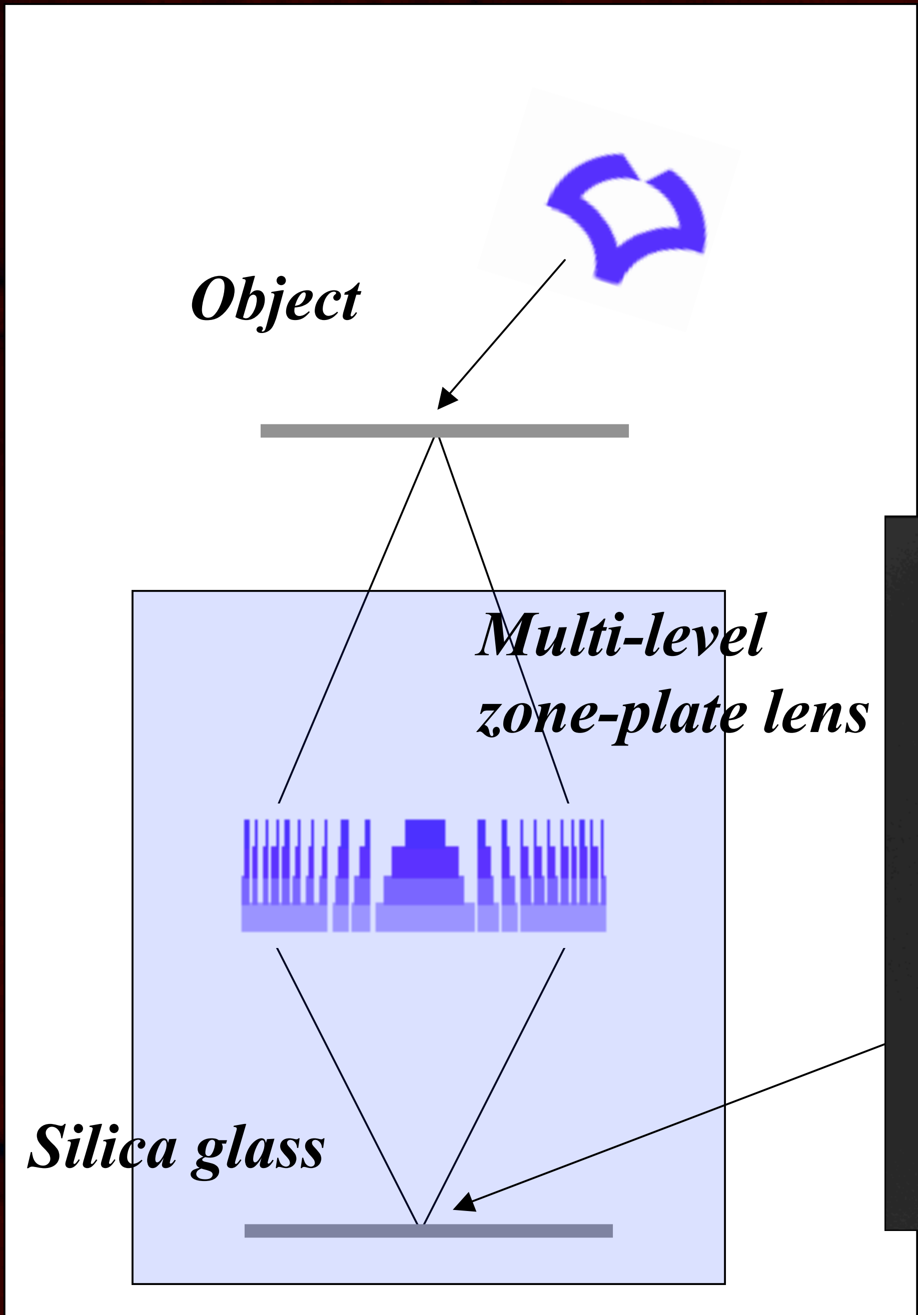
Beam
Energy
Wavelength
Focal Length
Thickness
Layers

NA 0.30
0.8 µJ/pulse
5 µm/s
632.8 nm
3 mm
30 µm
4 layers



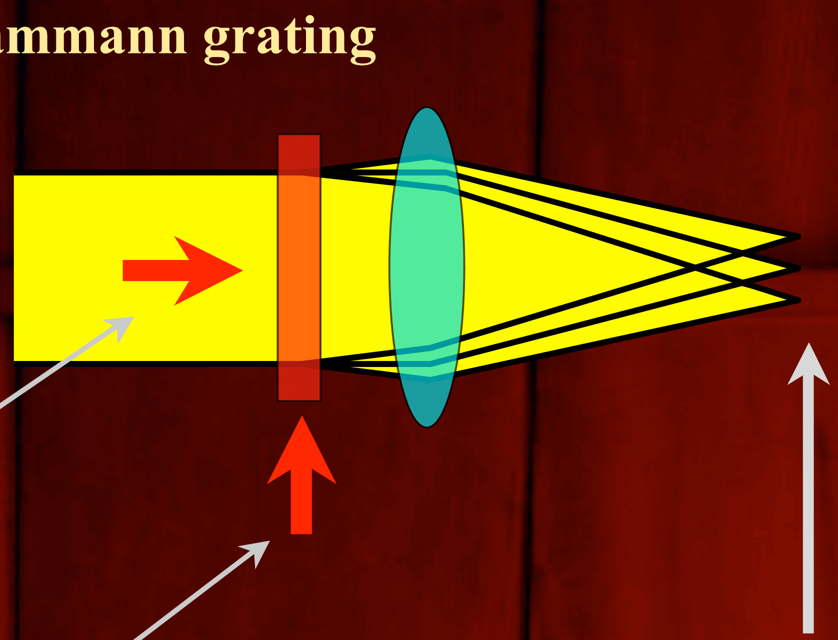
Diffraction. eff.	28.1 %
Focal Spot Size	7.3 µm

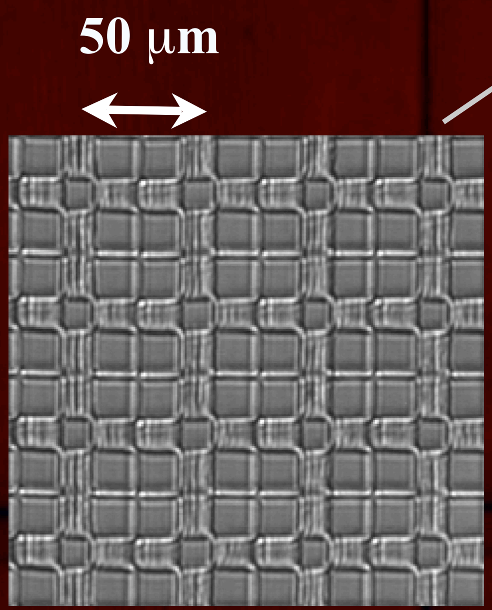
Image formed by zone-plate lens in silica glass

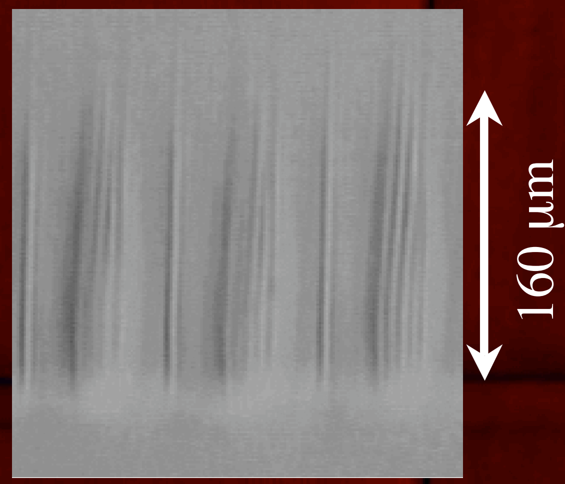


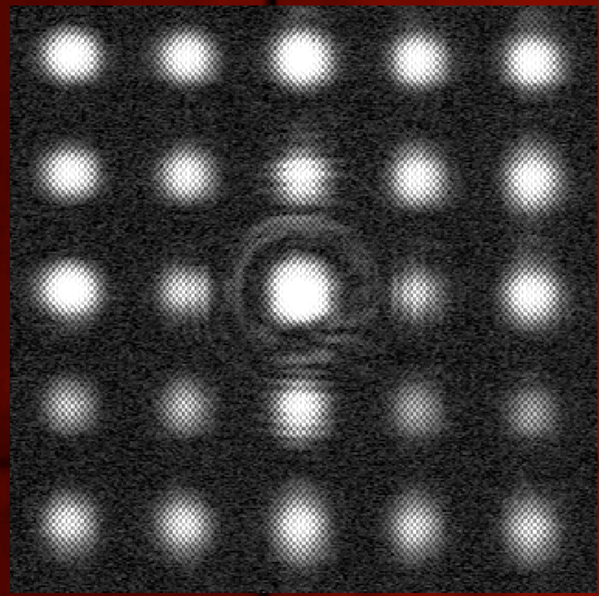
K. Yamada et al, Opt. Lett., Vol. 29, No. 16, 1846-1848 (2004) .

Fabrication of Dammann grating









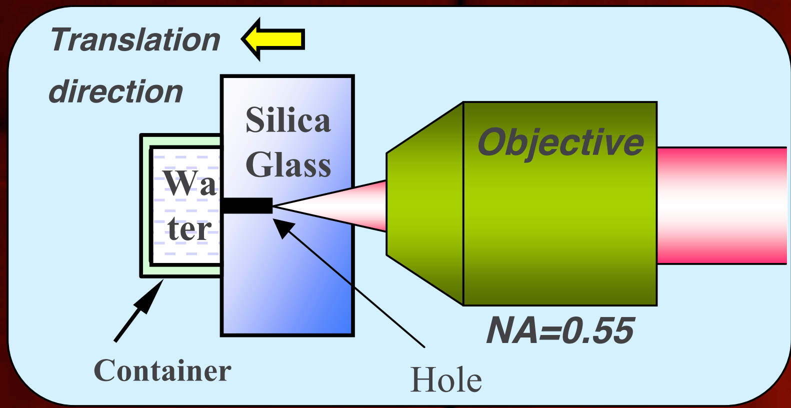
Yudong Li *et al*, Jpn. J. Appl. Phys., Vol. 44, No. 7A, 5014-5016 (2005).

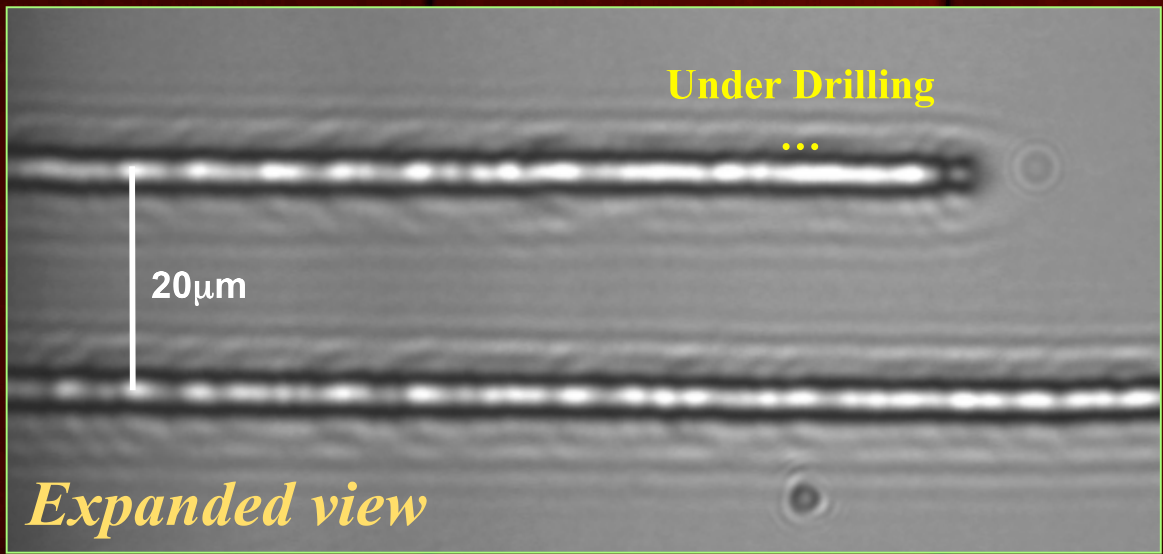
Drilling micro holes

Incident Power : 1 mW (1µJ/pulse)

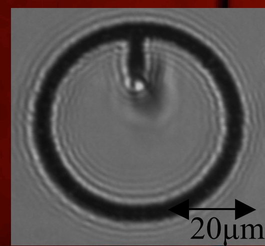
Translation Step: 1µm

Exposure Time : 3 × s /point (48 pulses)

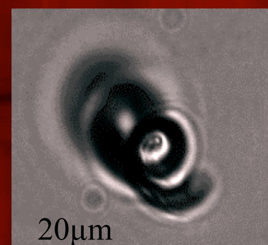


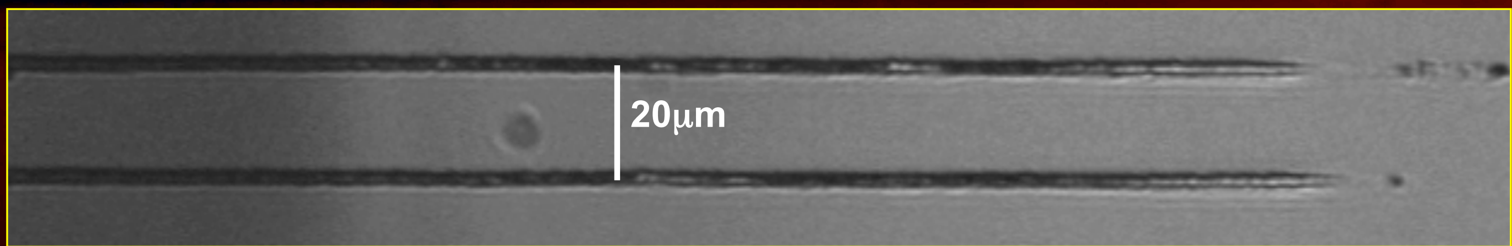


- **Small diameter**
- **High aspect ratio (>50)**
- **Well-defined wall**



Circular & Helical holes





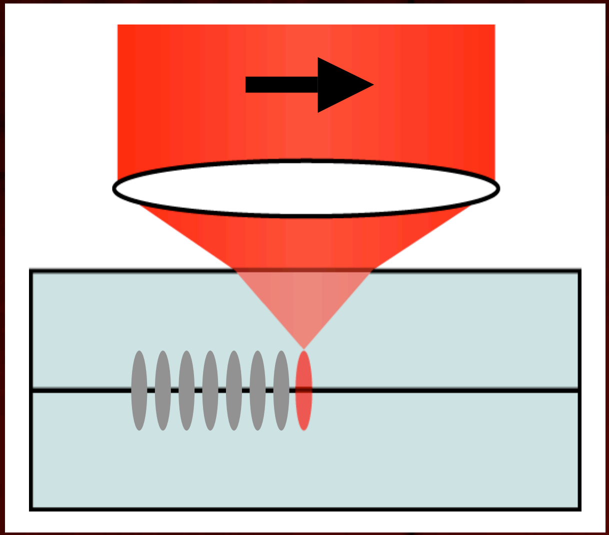
- Ultra-fast laser micro-welding of glass with filaments

Takayuki Tamaki, Wataru Watanabe, Junji Nishii, and Kazuyoshi Itoh, Jpn. J. Appl. Phys., Vol. 44, No. 22, L687-L689 (2005).

Takayuki Tamaki, Wataru Watanabe, and Kazuyoshi Itoh, Optics Express, Vol. 14, Issue 22, 10460-10468 (2006).

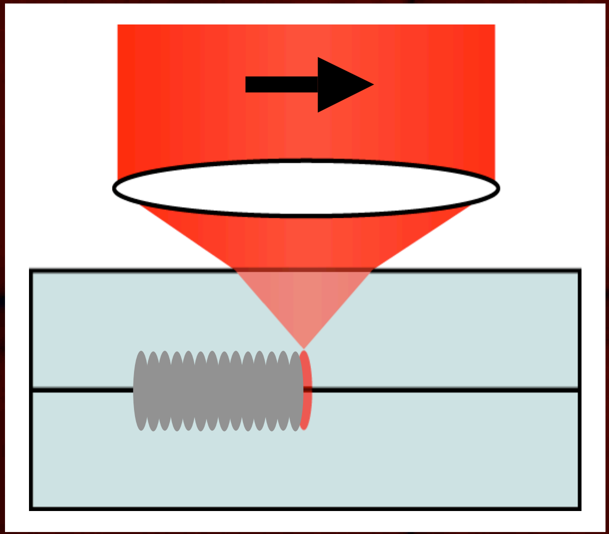
W. Watanabe, S. Onda, T. Tamaki, and K. Itoh, Appl. Phys. B, Vol. 87, pp. 85-89 (2007).

Scanning the filament



Low repetition source
Fast scanning

~ Gap

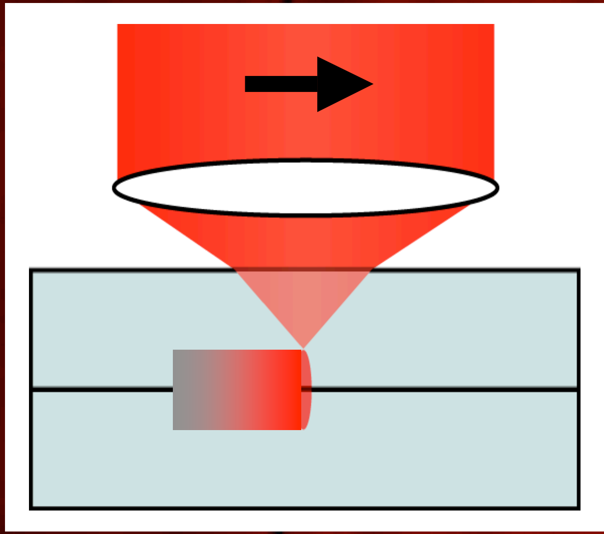


Low repetition
Slow scanning

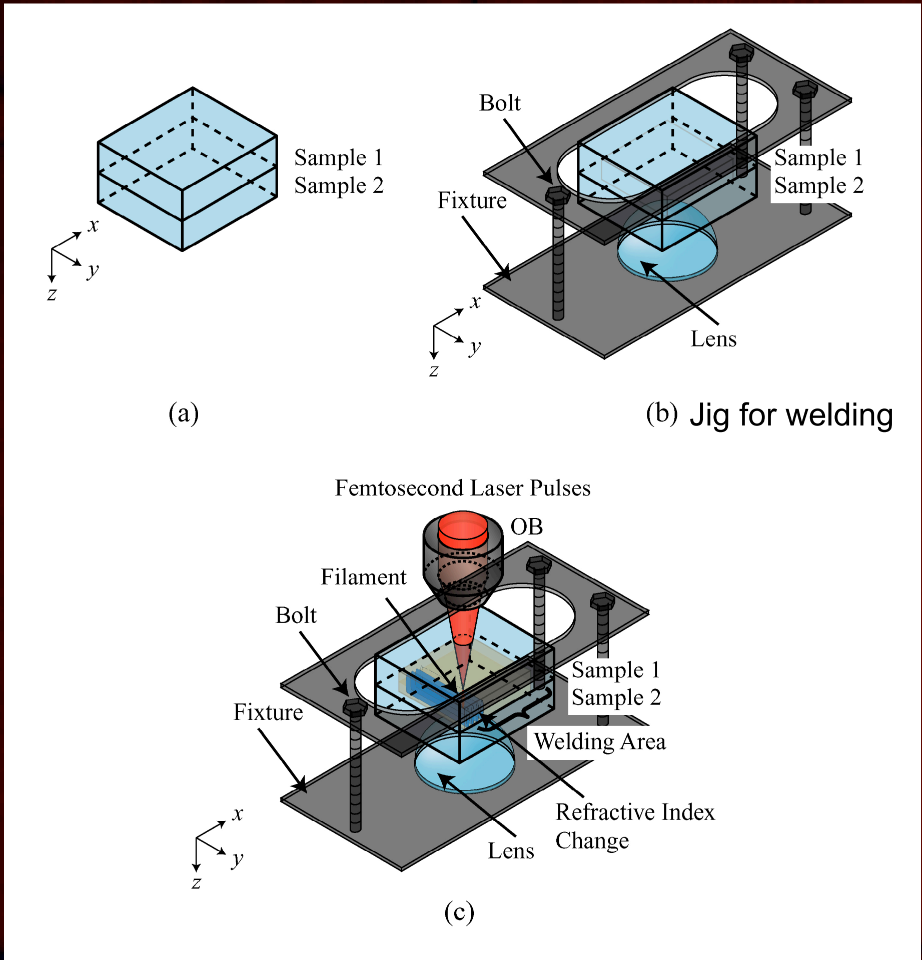
~ No gap

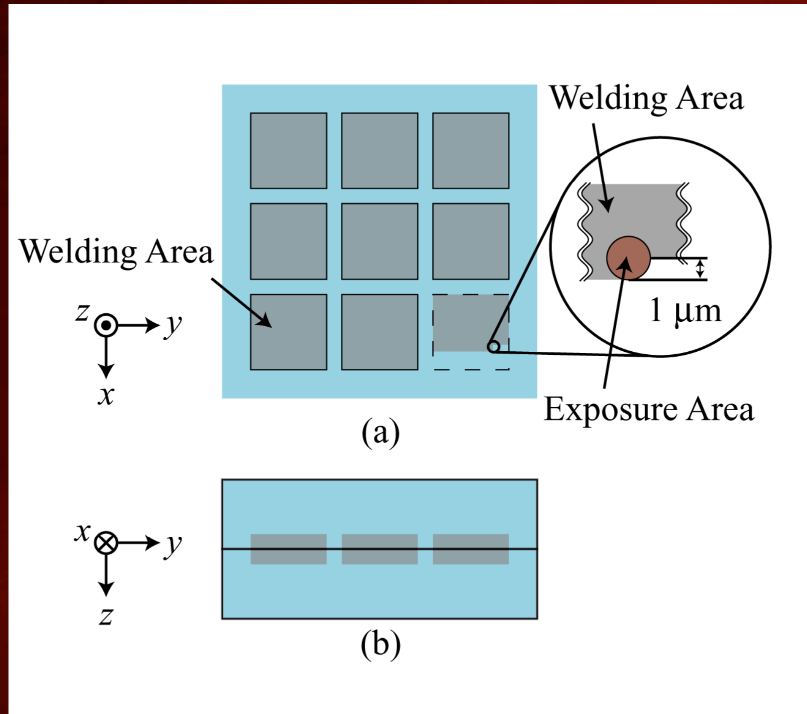
High repetition source

~ Accumulation of heat

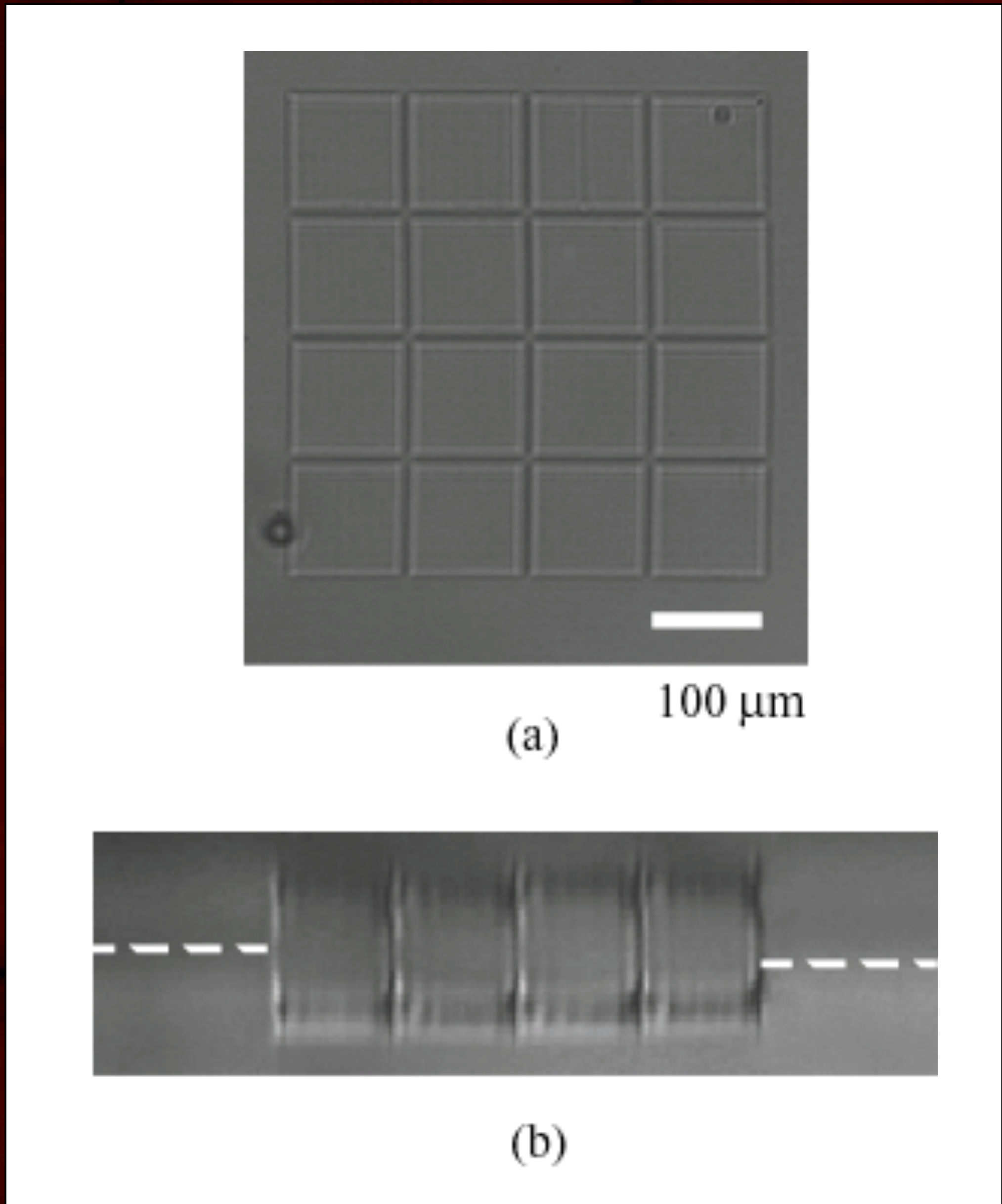


Welding flat samples





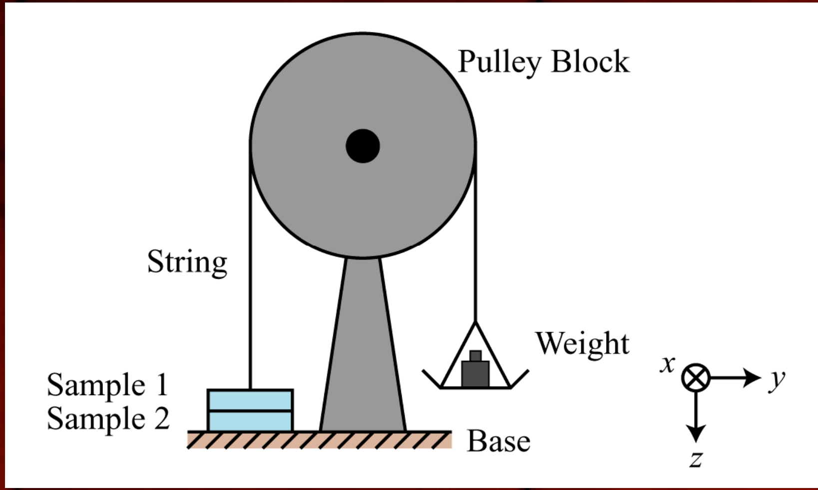
Micrographs

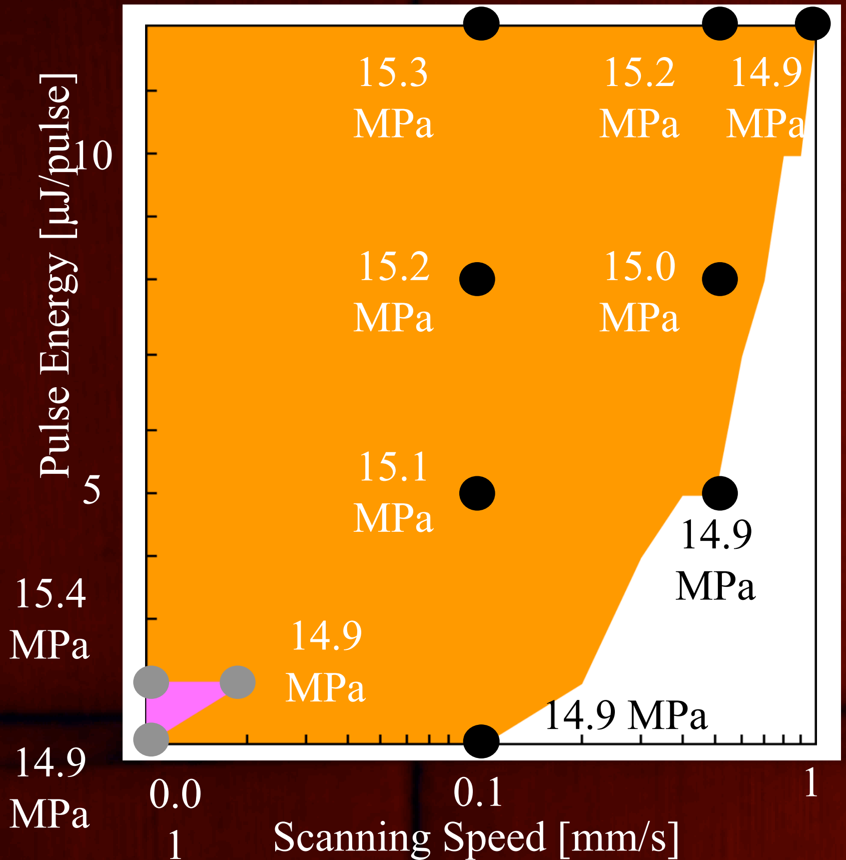


Top view

Side view

Joining strength (Same material)





Borosilicate glass

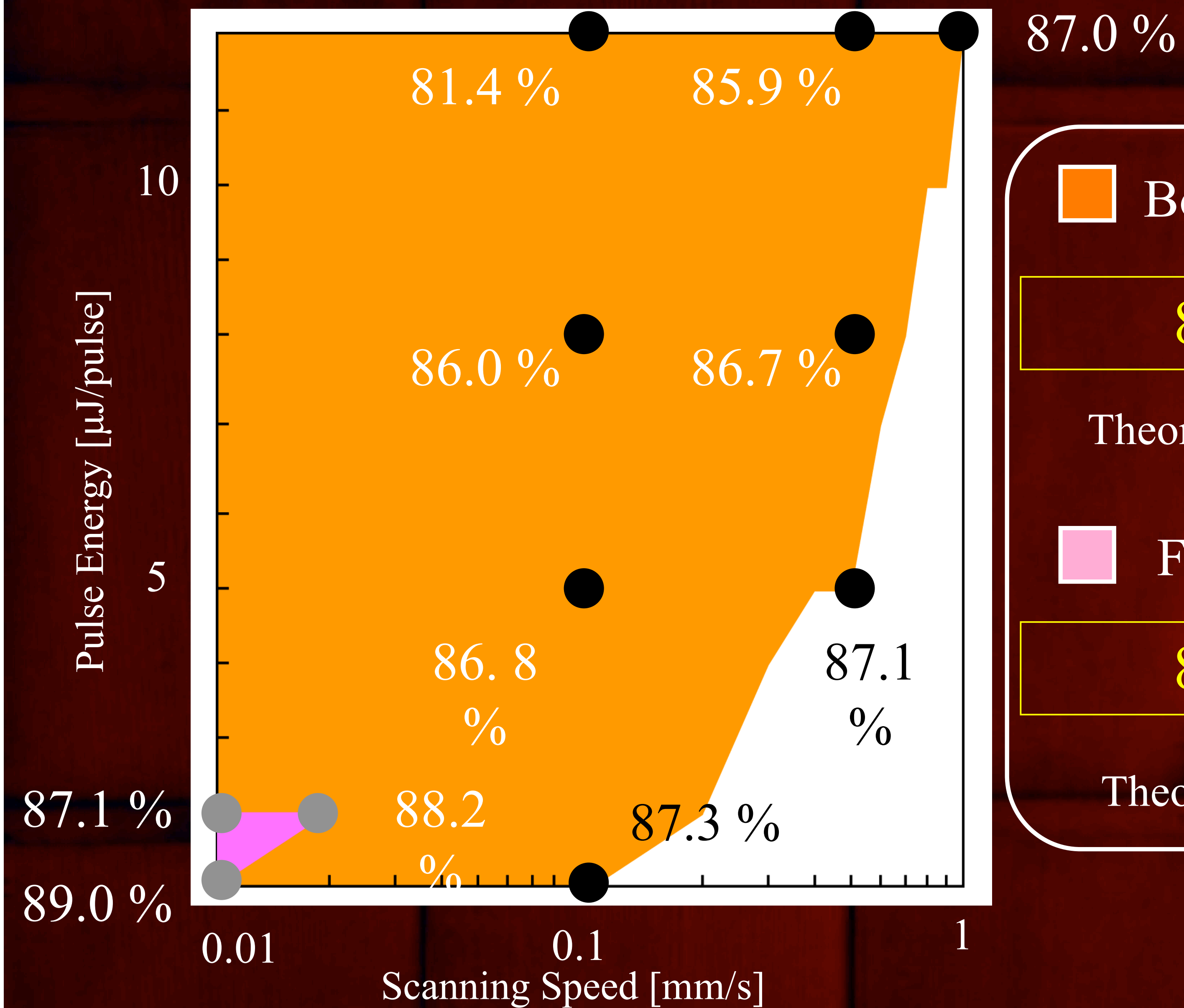
Fused silica glass

15 MPa ~ 150 kgf/cm^2

Usual adhesive ~ 50 kgf/cm^2

(kgf: kilogram force)

Optical transmittance



Borosilicate glass

81 ~ 87 %

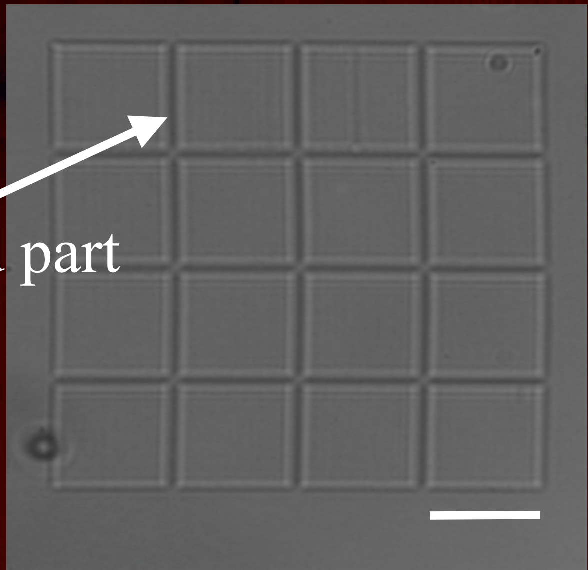
Theoretical limit: 92 %

Fused silica glass

87 ~ 89 %

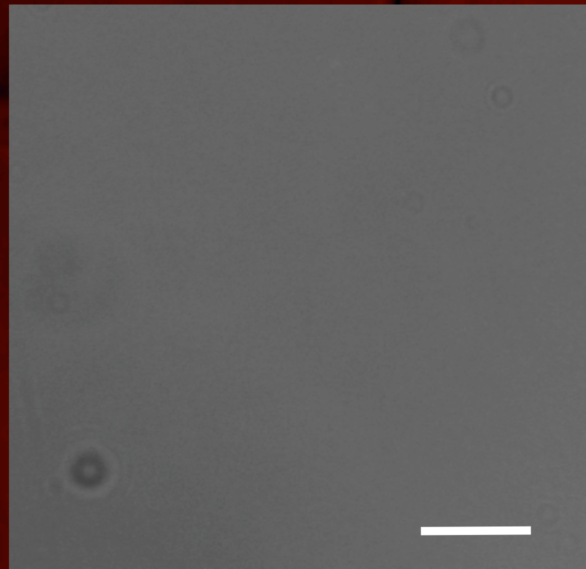
Theoretical limit: 93 %

Effects of Annealing



100 μm

Micrograph
before annealing



100 μm

Micrograph
after annealing

Annealing makes welded part invisible.
(Implication of disappearance of defects.)

Enhancement of joining strength & optical transmittance

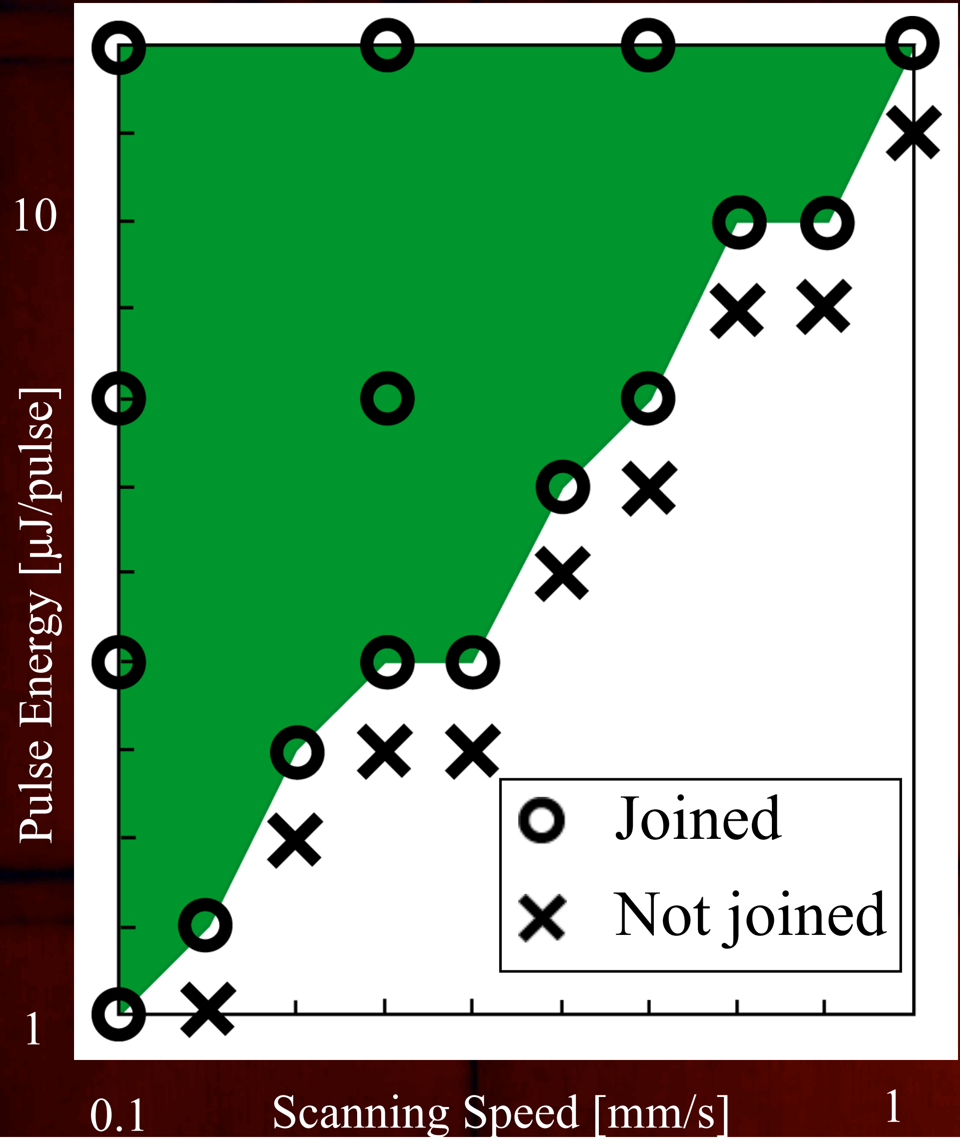
Joining strength	**Borosilicate glass**	**Fused silica glass**
Before annealing	**15 MPa**	**15 Mpa**
After annealing	**33 MPa**	**33 MPa**

Optical transmittance		
Before annealing	**88 %**	**87 %**
After annealing	**92 %**	**91 %:**
	Theoretical limit: 93 %	Theoretical limit: 92 %

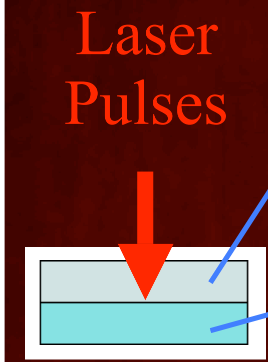
- Ultra-fast laser micro-welding of different glass

Heterogeneous welding:

dissimilar kinds of glass



Geometry



Borosilicate glass

39* [×10 -7/℃]

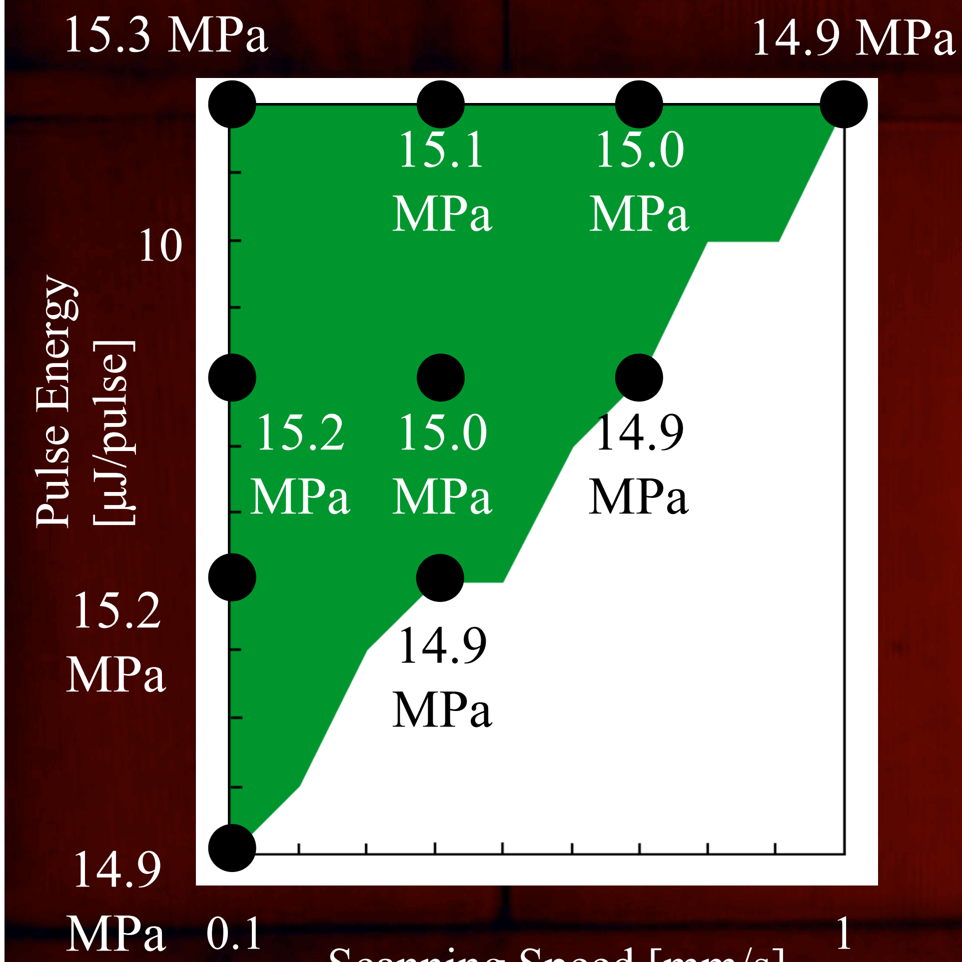
Fused silica glass

5.9* [×10 -7/℃]

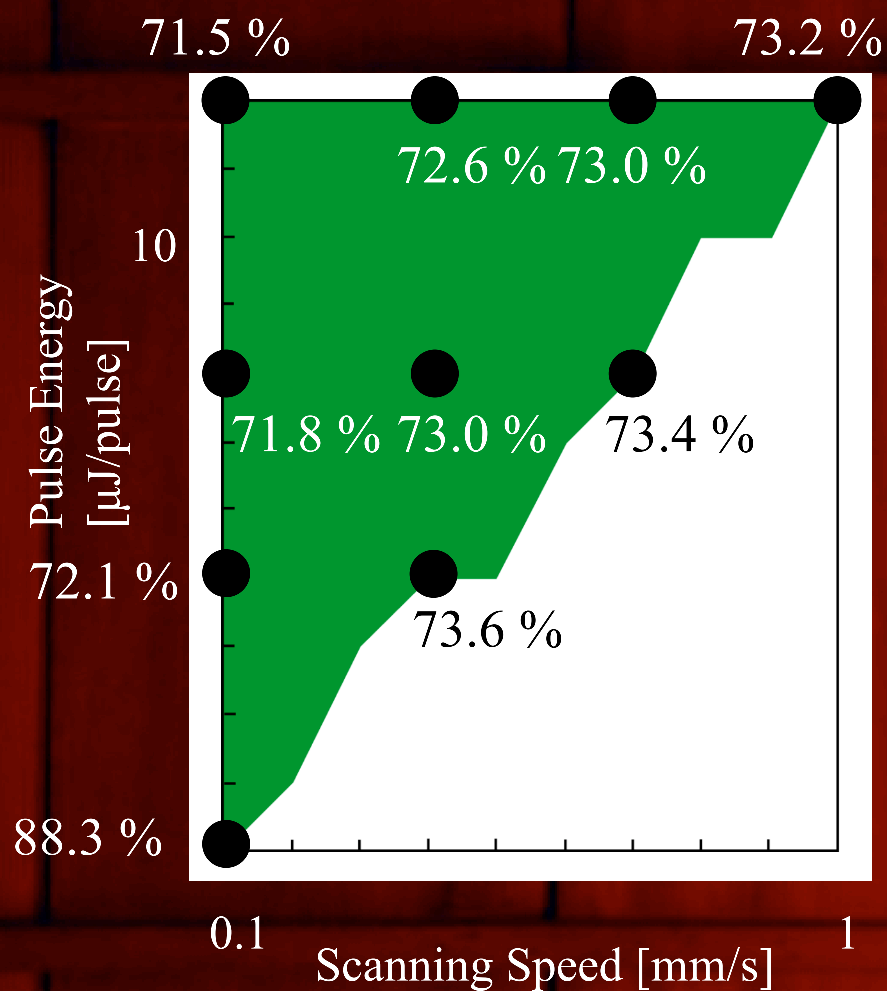
*Thermal expansion coefficient

Wataru Watanabe, Satoshi Onda, Takayuki Tamaki, Kazuyoshi Itoh, and Junji Nishii,
Appl. Phys. Lett., Vol. 89, No. 2, 021106 (2006).

Joining strength and transmittance



Joining strength

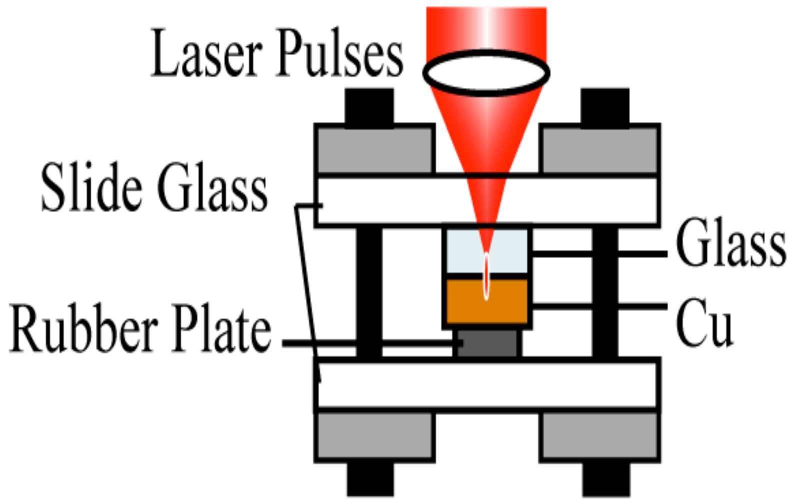


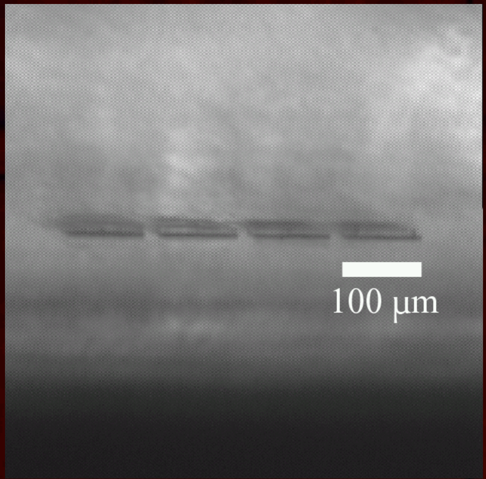
Optical transmittance

- Ultra-fast laser micro-welding of glass and metal

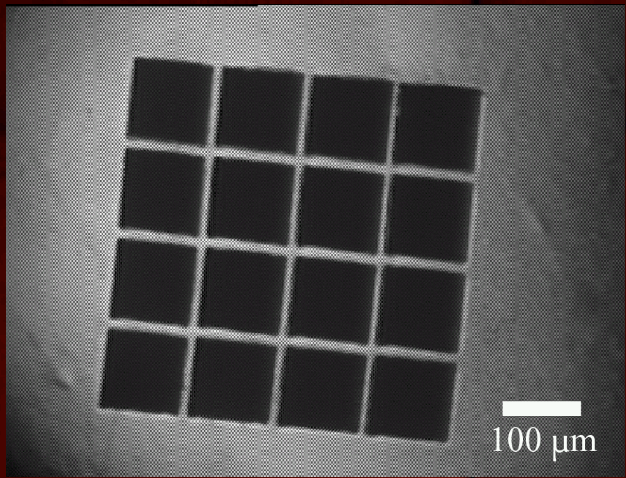
Ultra-fast Laser Micro-welding of Glass and Copper

Realizing tight contact between glass and copper

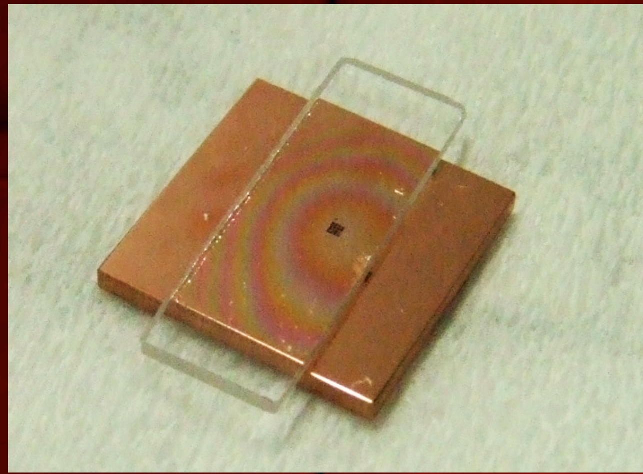




(a) Side view



(b) Top view



(c) Whole image

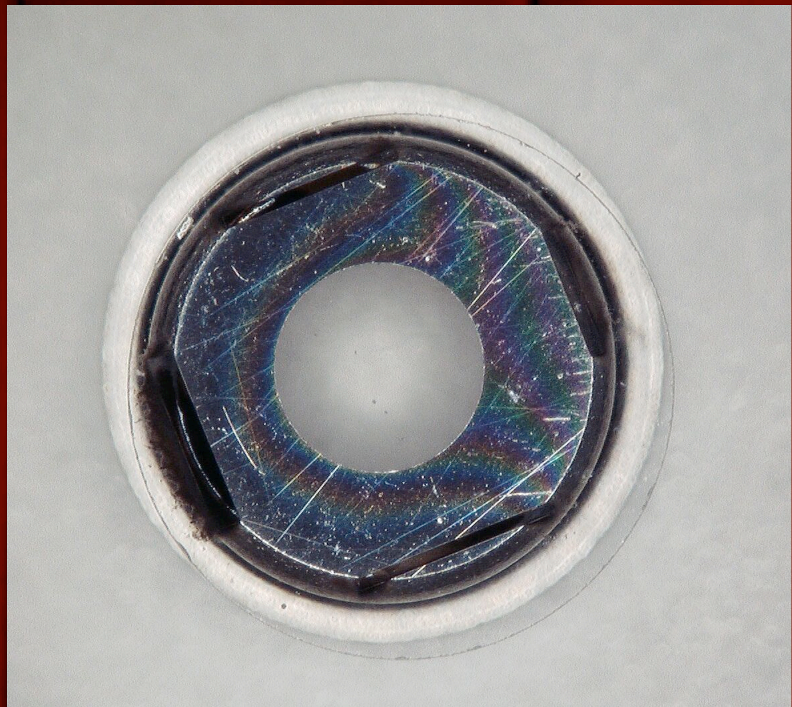
Optical microscope images

Laser source: Regenerative Ti:sapphire laser
(Spectra Physics, Spitfire)
Central wavelength: 800 nm
Pulse duration: 130 fs
Repetition rate: 1 kHz
Pulse energy: 4 μJ/pulse
Scan speed: 1 mm/s

Joining strength: 23 MPa

Application of Ultra-fast Laser Micro-welding to Metal Package (Glass & Kovar)

(a) Birds-eye view



(b) Top view

Coworkers:

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Dr. Yasuyuki OZEKI and Mr. Tomoyuki INOUE

Osaka University

Mr. Satoshi ONDA

Yokogawa Electric Corporation

Mr. Seiji SOWA

Konica Minolta Opto, Inc.