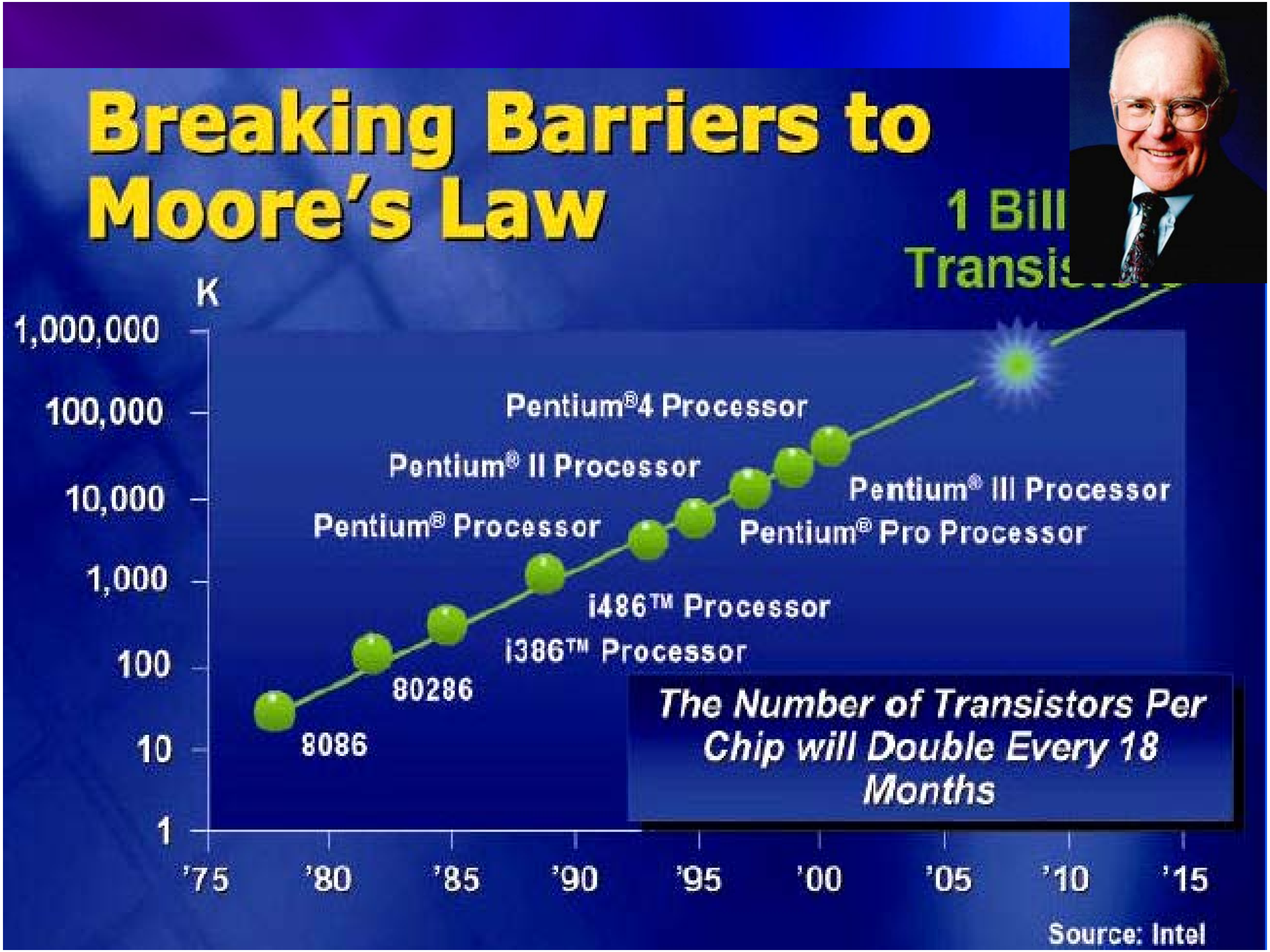
University of Electronic Science and Technology of China

Sub-MicroMachining with Ultrafast Pulse Laser Interference for the Drilling of Microvias

Prof. Yongqi Fu

Miniaturization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Pentium® Pro Processor
i486™ Processor
i386™ Processor
80286
8086
The Number of Transistors Per Chip will Double Every 18 Months
Source: Intel

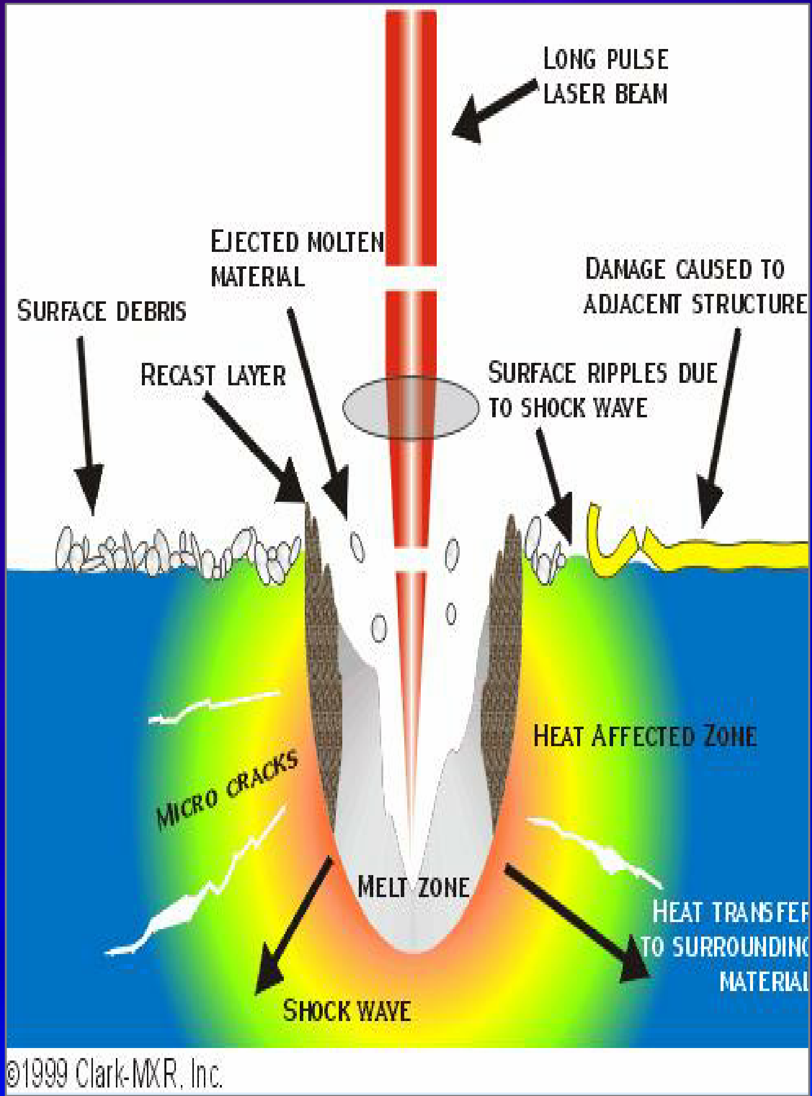
Ultrafast Laser Sub-spot Ablation Mechanism

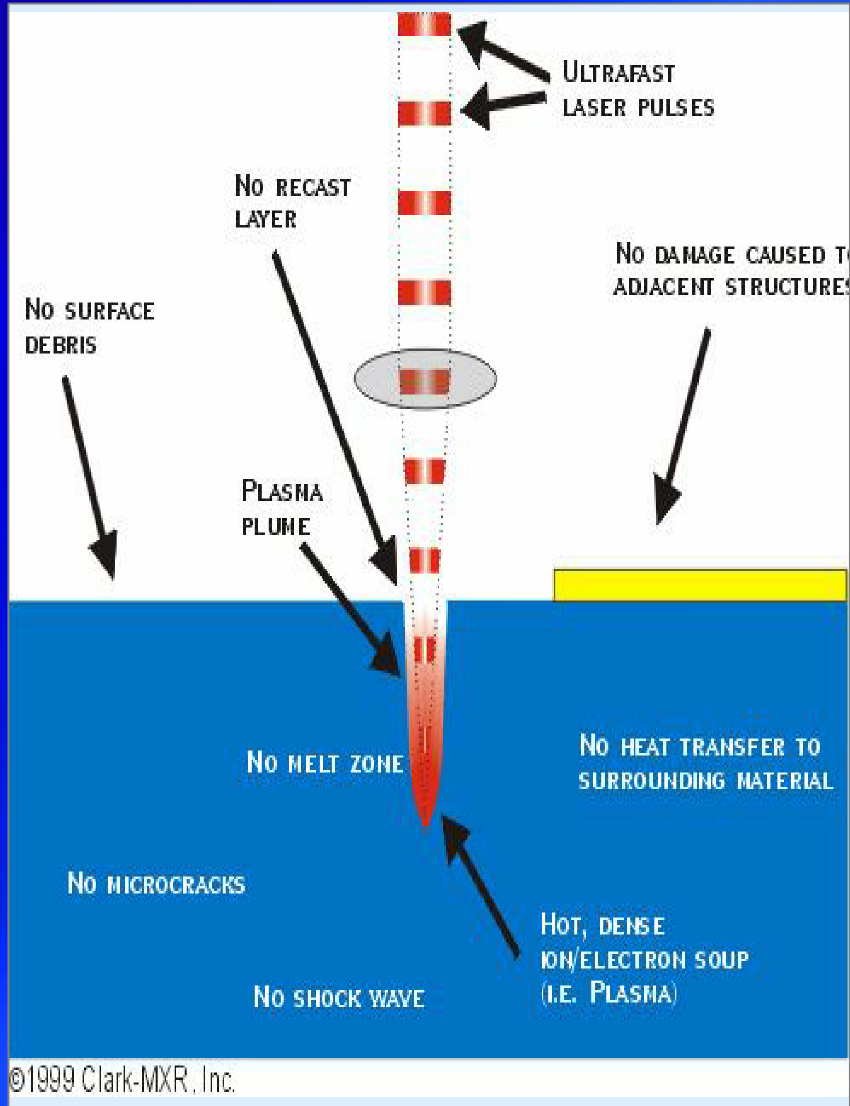
- permits the ablation of features smaller than the focal spot size when operated near threshold as only a fraction (the central region) of the focused light will exceed the threshold intensity.

- with a **femtosecond pulsed laser**, it is possible to control that only 1/10 (10%) of the focal spot size will machine.

WHY FEMTOSECOND PULSED LASER

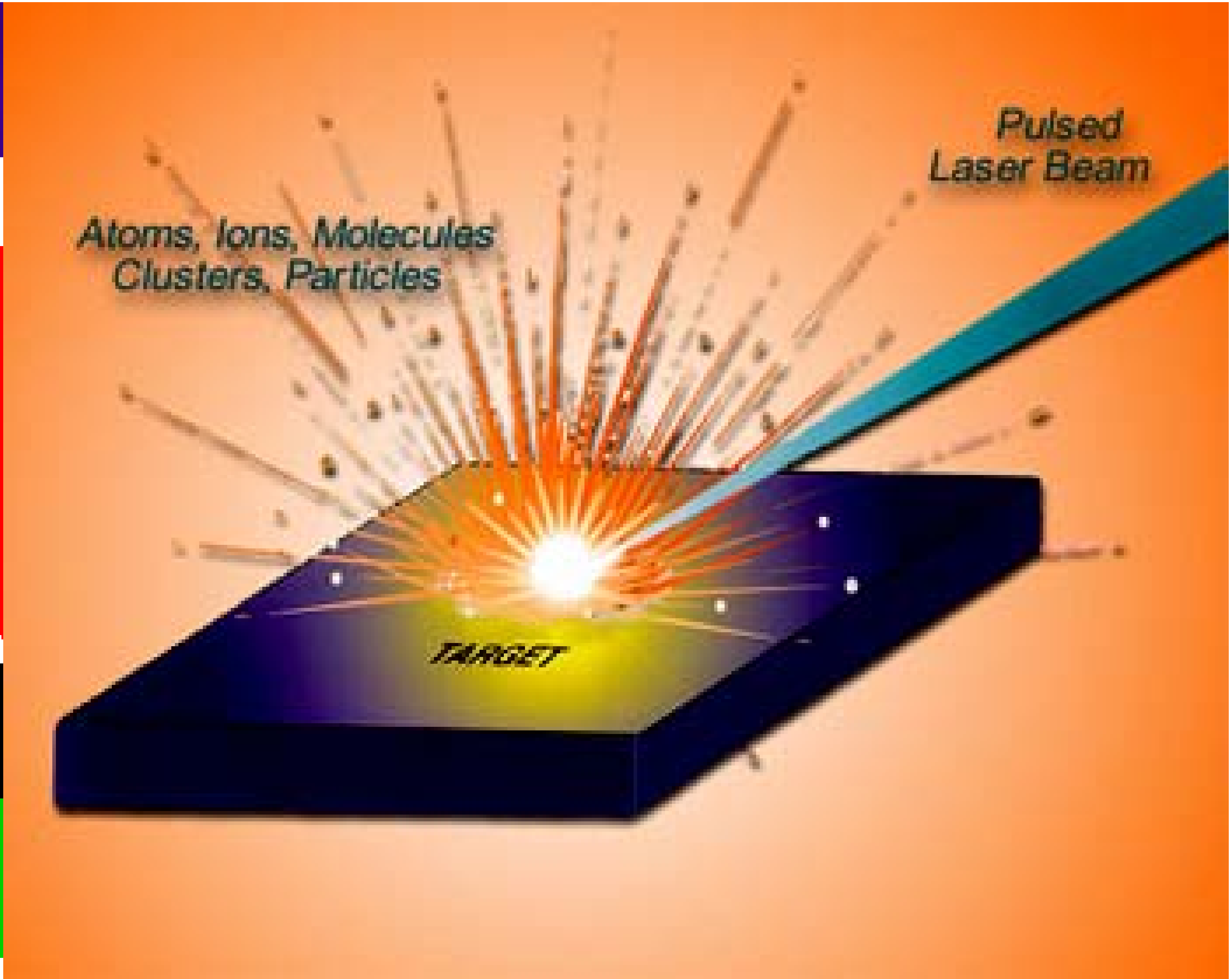
Long pulse Vs Ultra short pulse





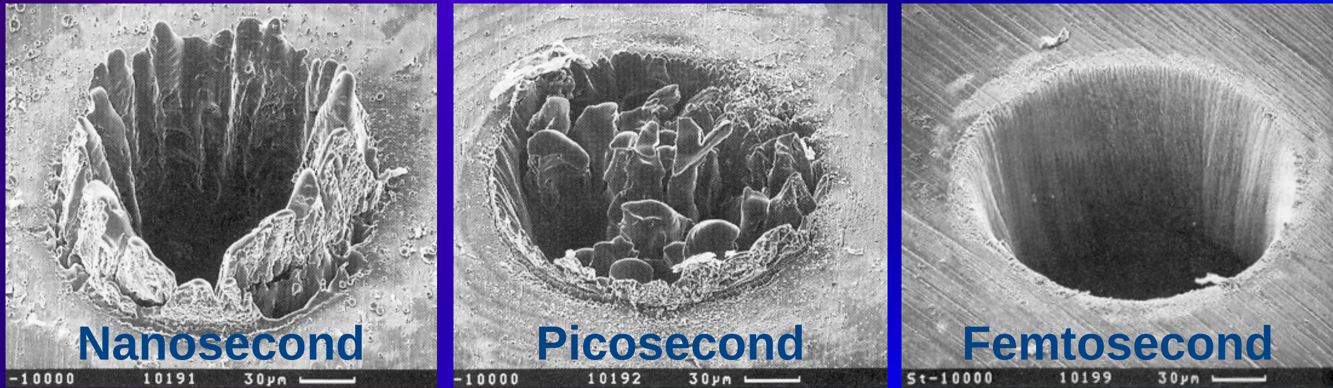
Handbook of Micromachining - Clark-MXR, Inc.

c.w

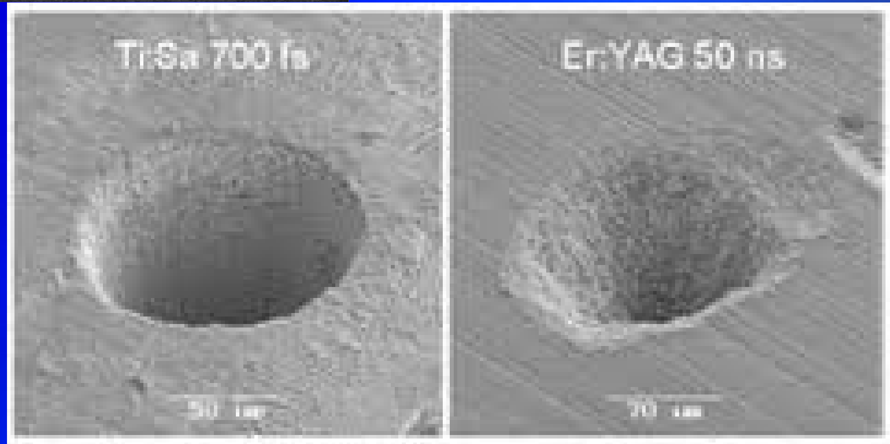


Shock waves

WHY FEMTOSECOND PULSED LASER



M. Carsten et. al., 1996, Optics Communications

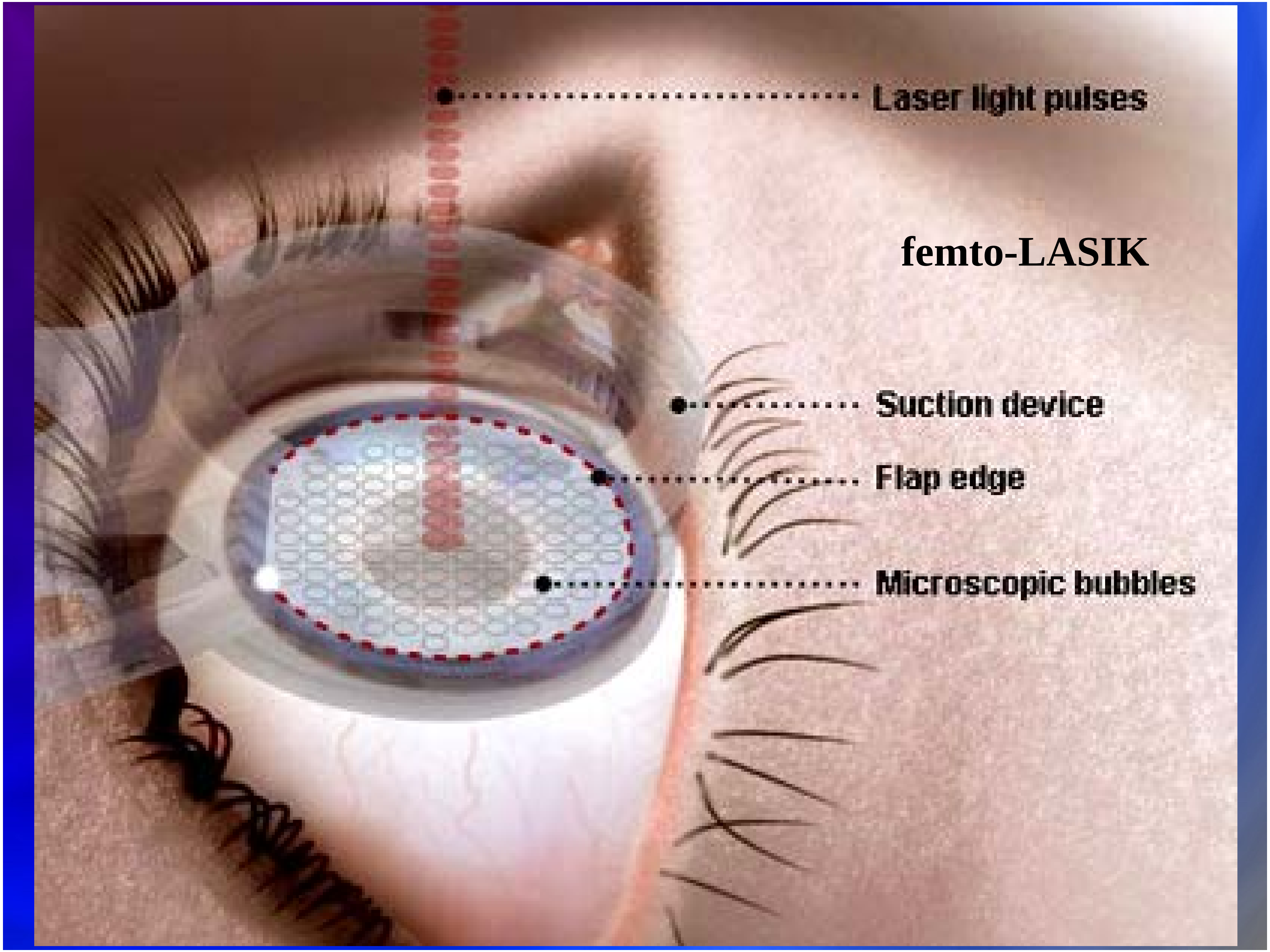


- **Can machine any materials**
- **No melt zone, no microcracks**
- **Highly reproducible**
- **Does not affect surrounding material**
- **Can machine sub-micron features**
- **Can machine inside transparent materials**

Limitation of Current Laser Ablation Technology:

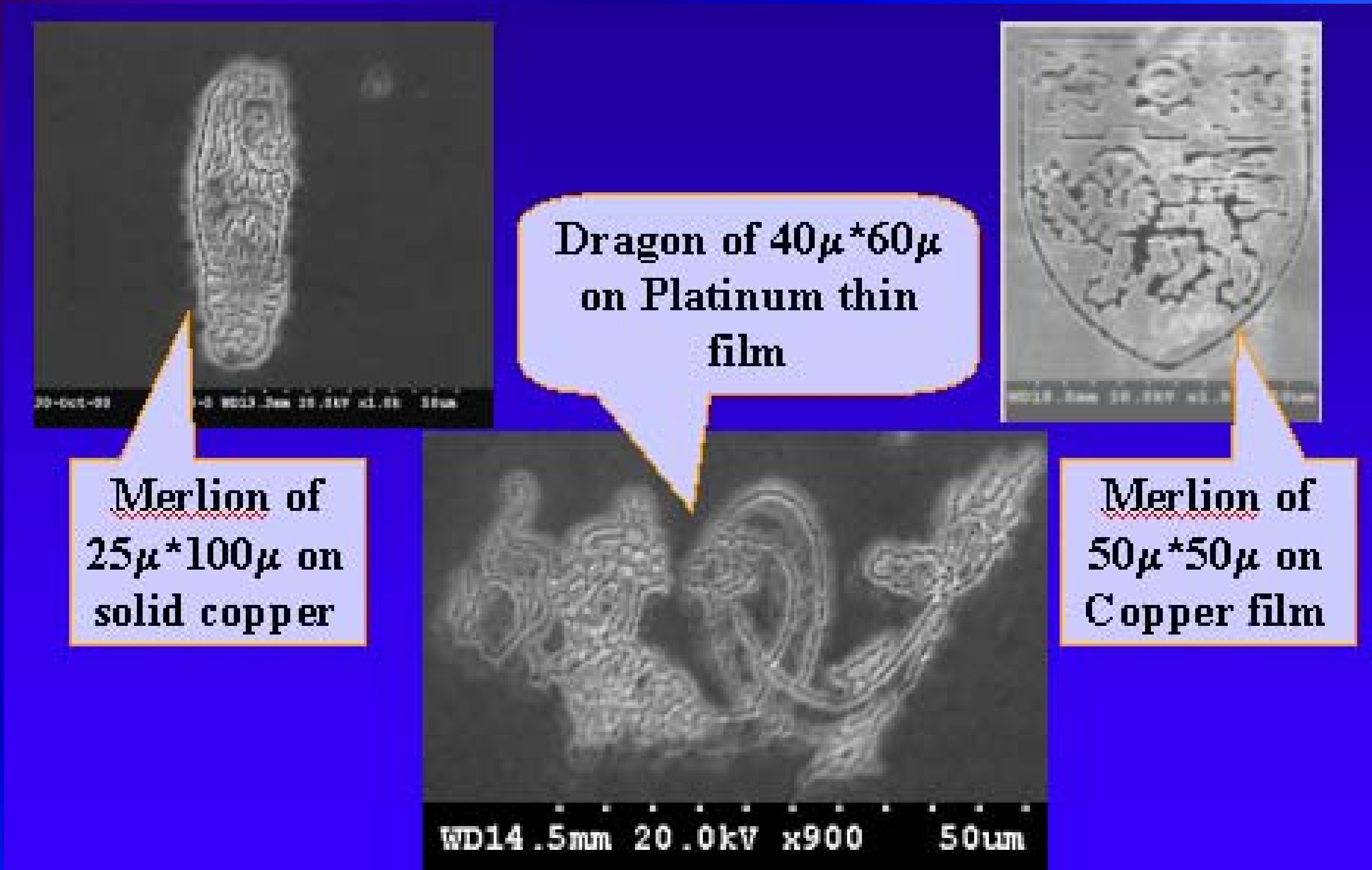
- reached its lowest limit when it hit the 1/10th of the laser focal spot size range
- smallest ablation feature reported is 200 nm [1]
- the smaller the ablation feature size, the more pronounced the problem of tapering & low aspect ratio

[1] Simon, P. and Ihlemann, J., *Applied Surface Science*, Vol. 109 n 110, 1997, pp. 25-29

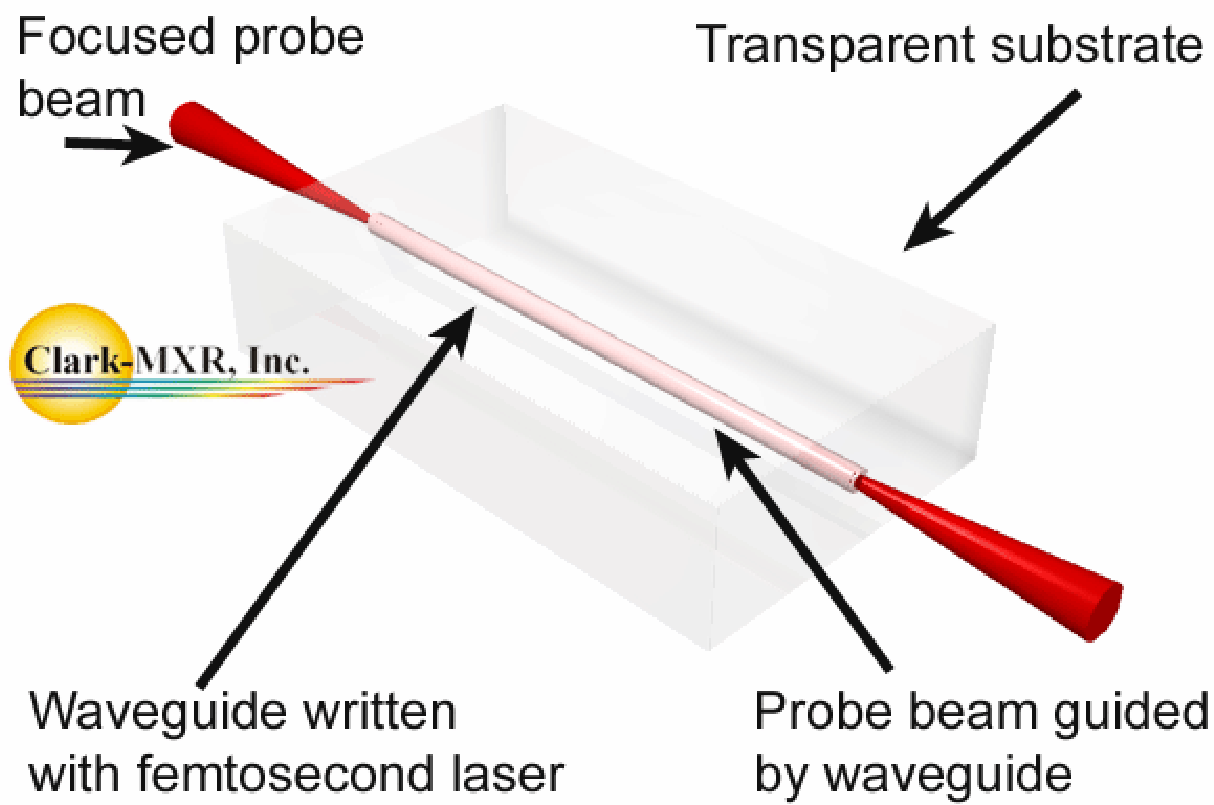

Laser light pulses
femto-LASIK
Suction device
Flap edge
Microscopic bubbles

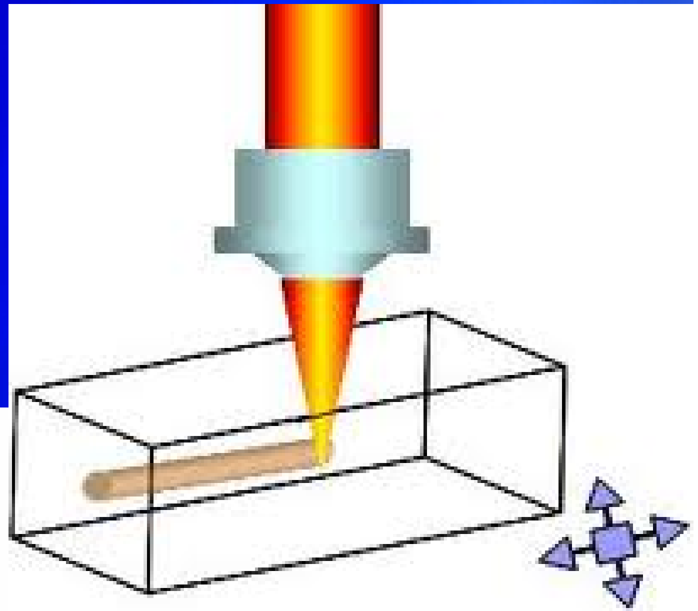
Femtosecond Laser Micromachining

SUB MICRON MACHINING



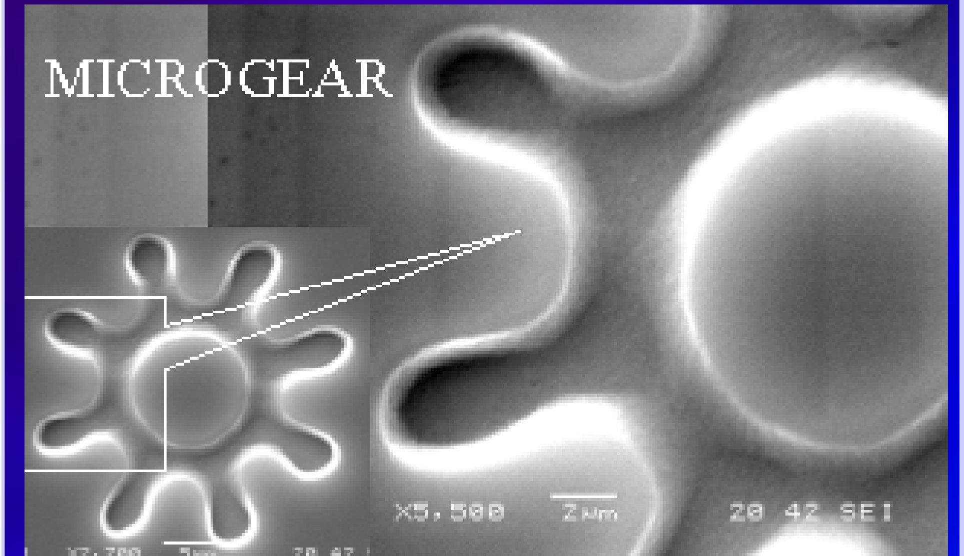
Machining inside transparent materials





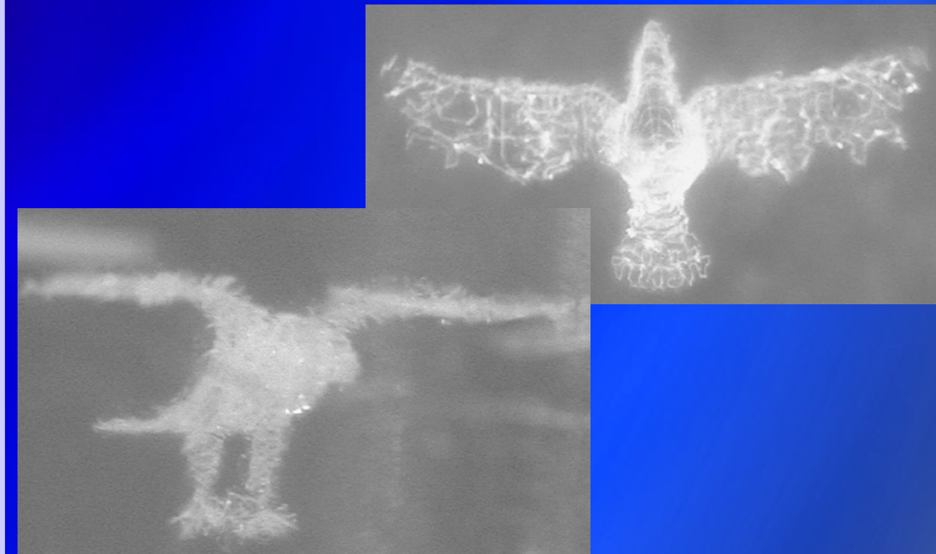
Femtosecond Laser Micromachining

Photomask Development



Micro-gear (25µm X 25µm) fabricated by lithography with the mask fabricated by novel system

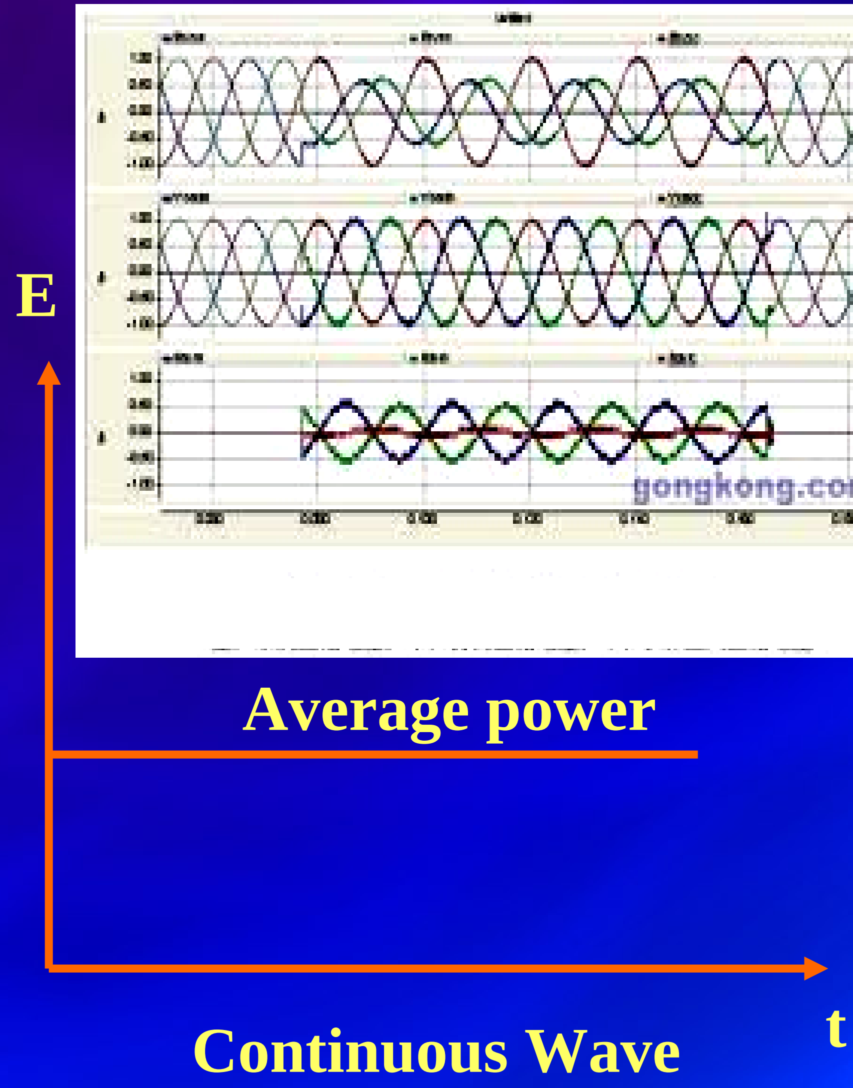
Inside surface machining

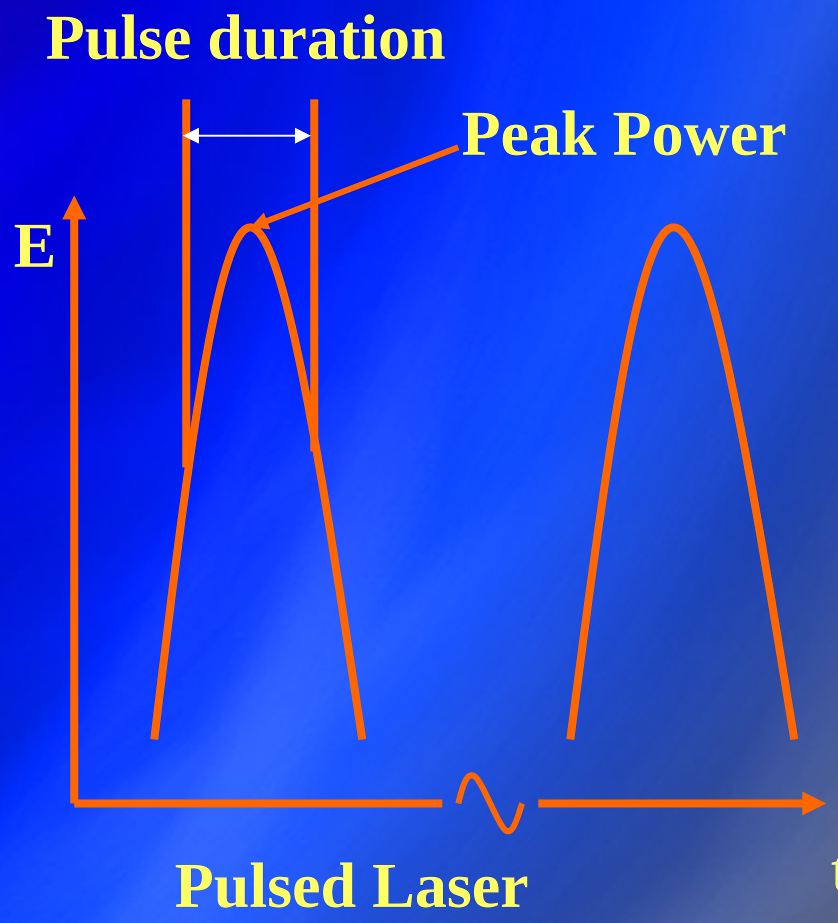


Internal 3-D micromachining micro eagle inside transparent materials Using Femto-second Laser

Submicron machining

CW AND PULSED LASERS

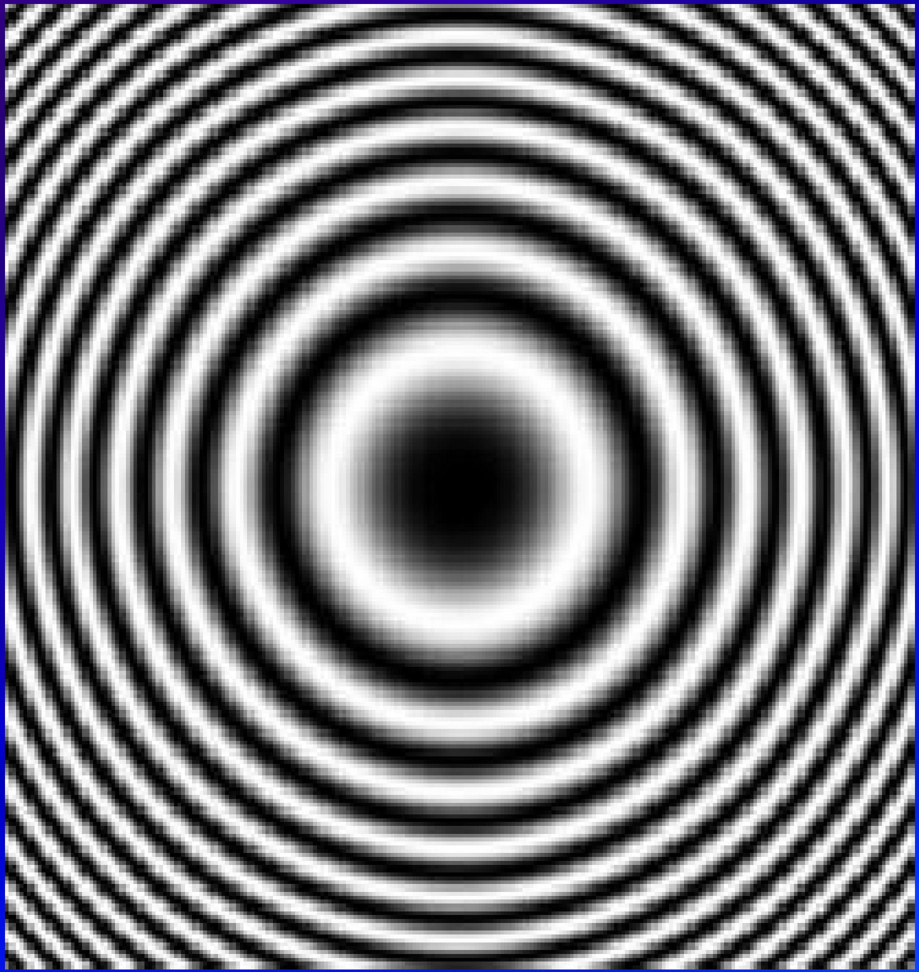


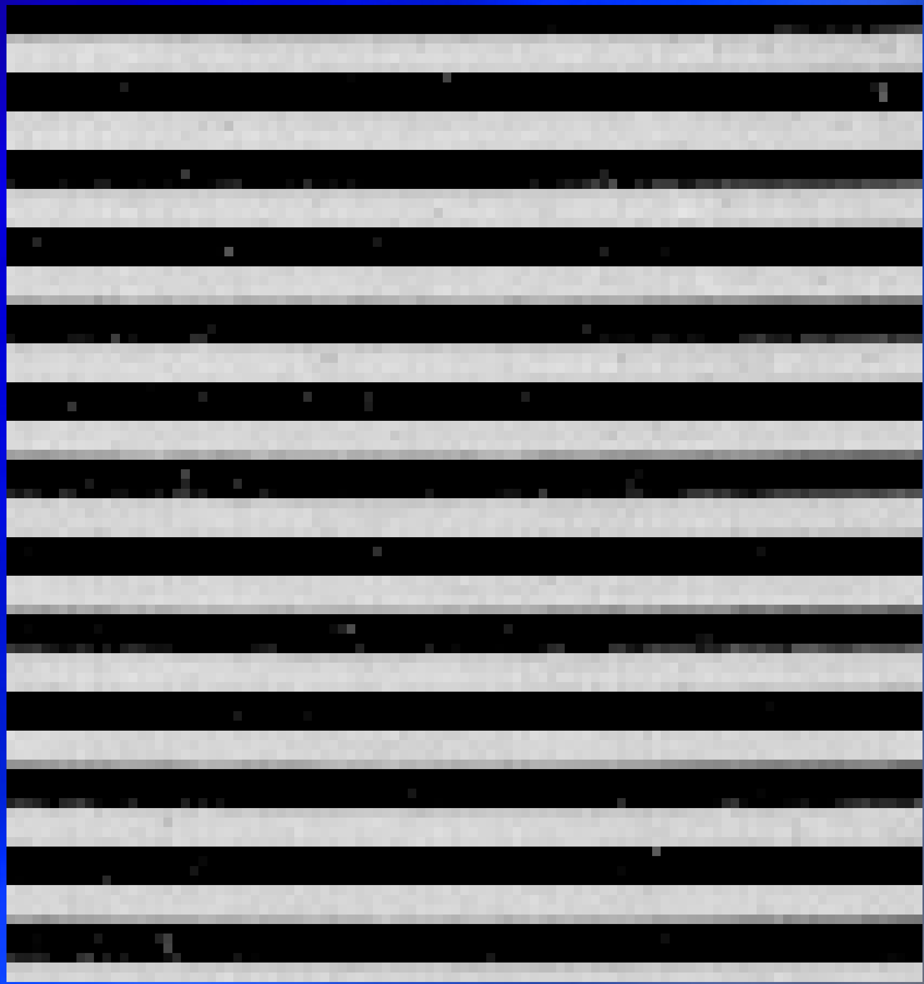


Solution!

Ultrafast Pulse Laser Interference

Interference is the phenomenon where two or more beams overlaps resulting in a series of bright & dark bands called ***fringes***





Laser Interference

Interferometry

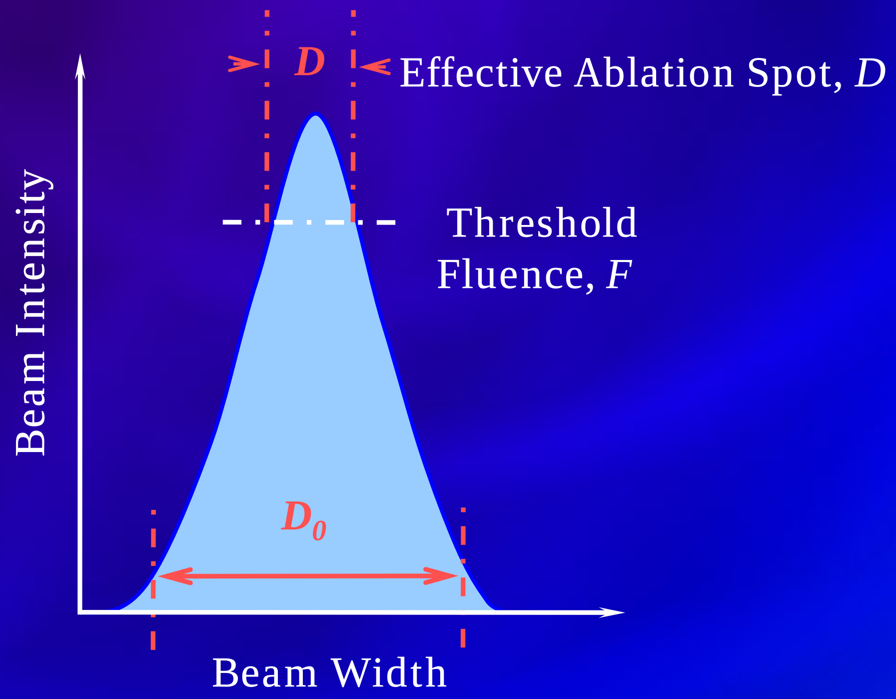
- Spectroscopy
- Metrology

Bragg gratings on optical fibers

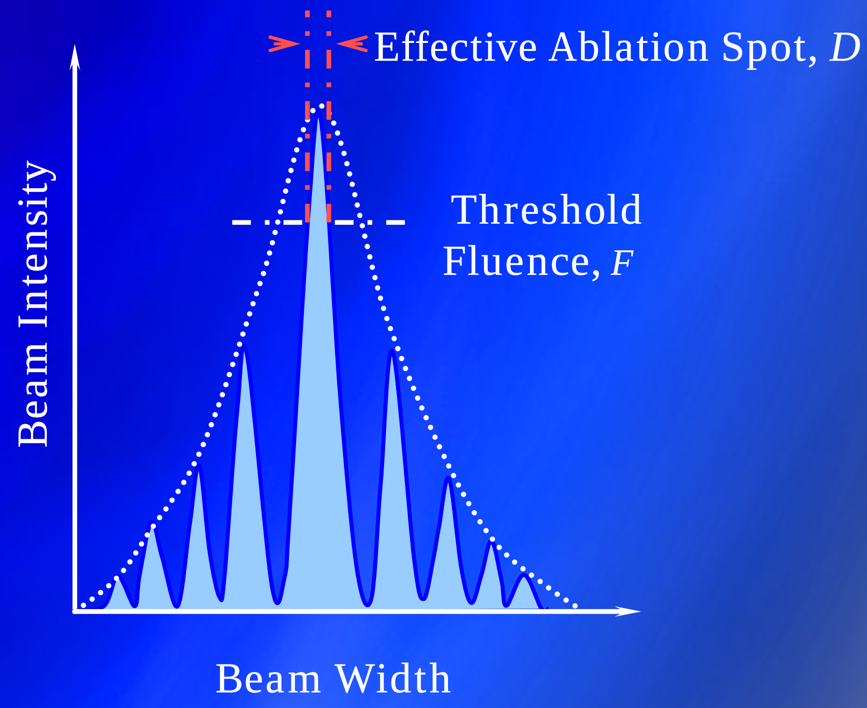
Micromachining

How will the interfered laser beam give better machining performance?

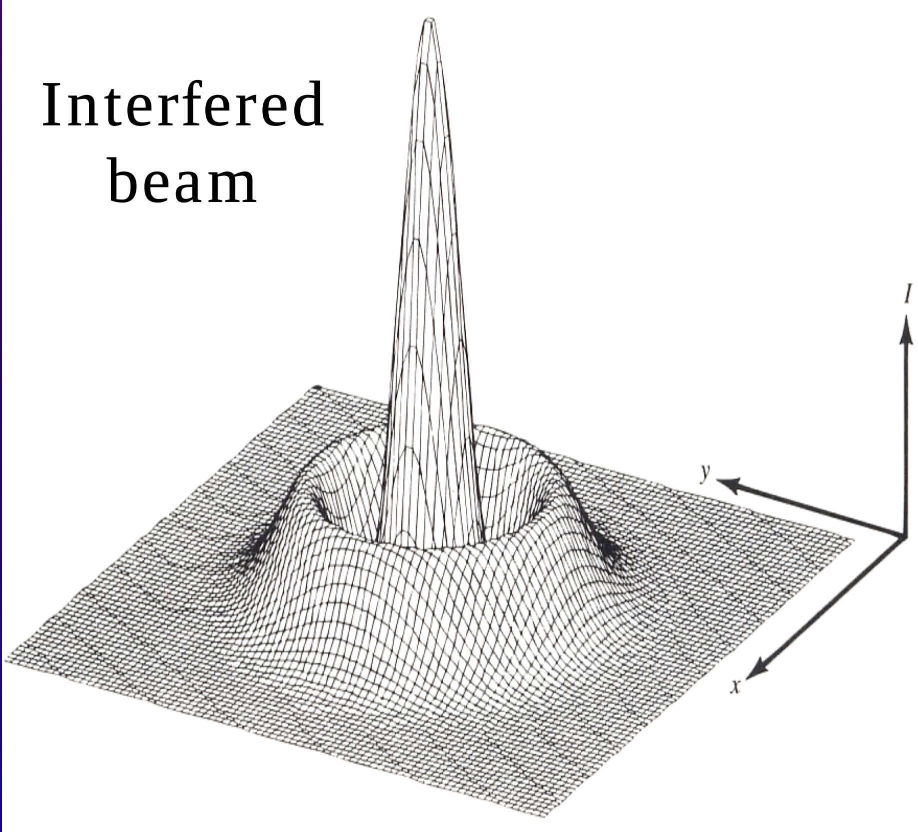
Conventional Non-Interfered Laser Beam vs. Interfered Laser Beam

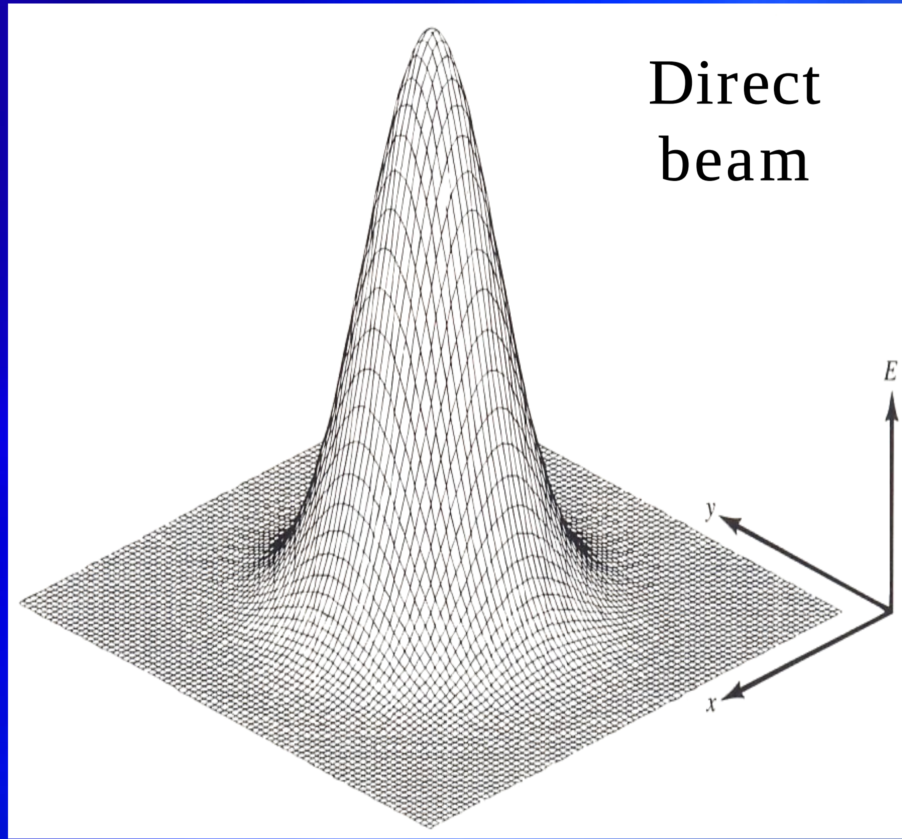


2D profile of the conventional non-interfered Gaussian laser beam



2D profile of the interfered Gaussian-like laser beam

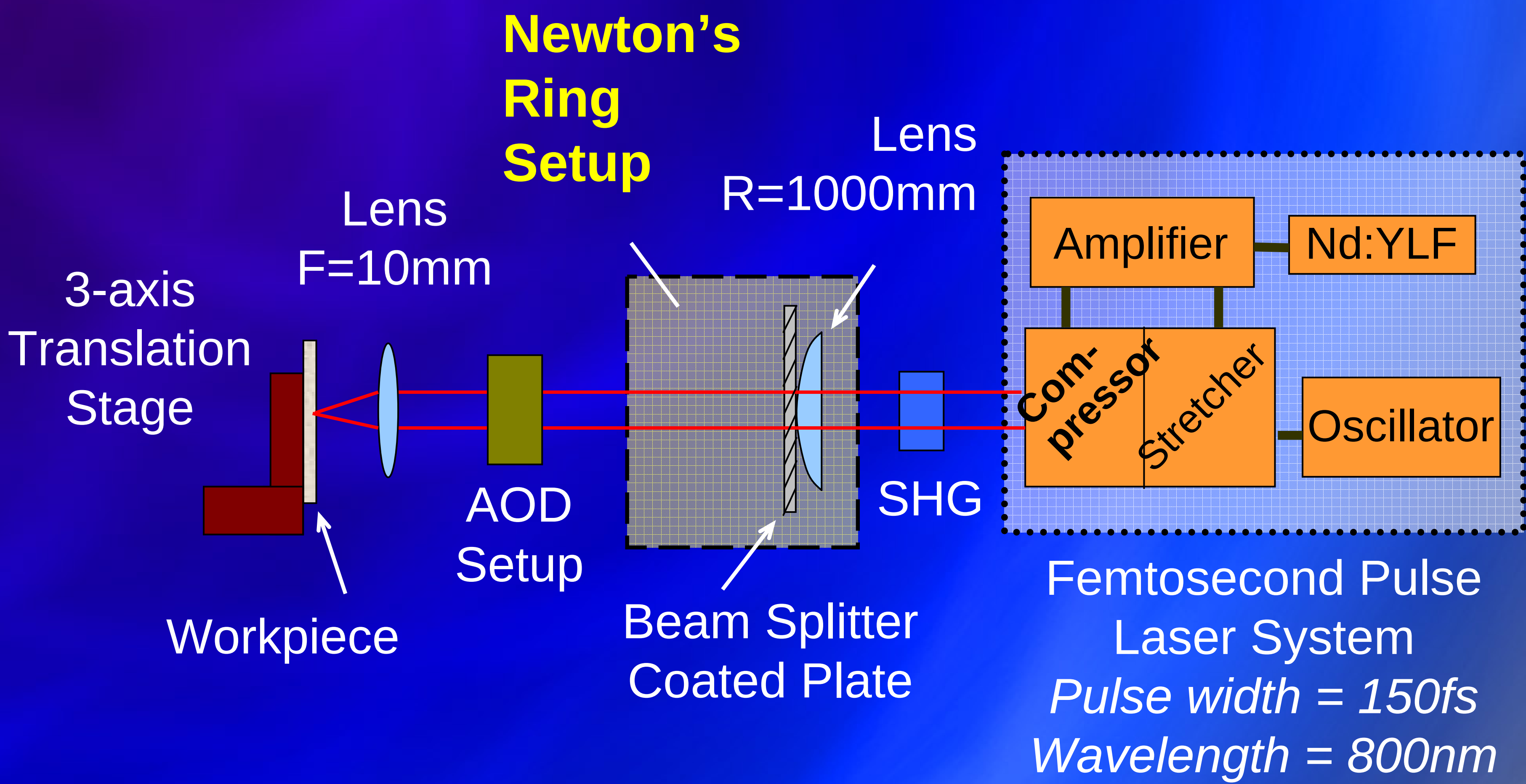




3D profile of the interfered Gaussian-like laser beam

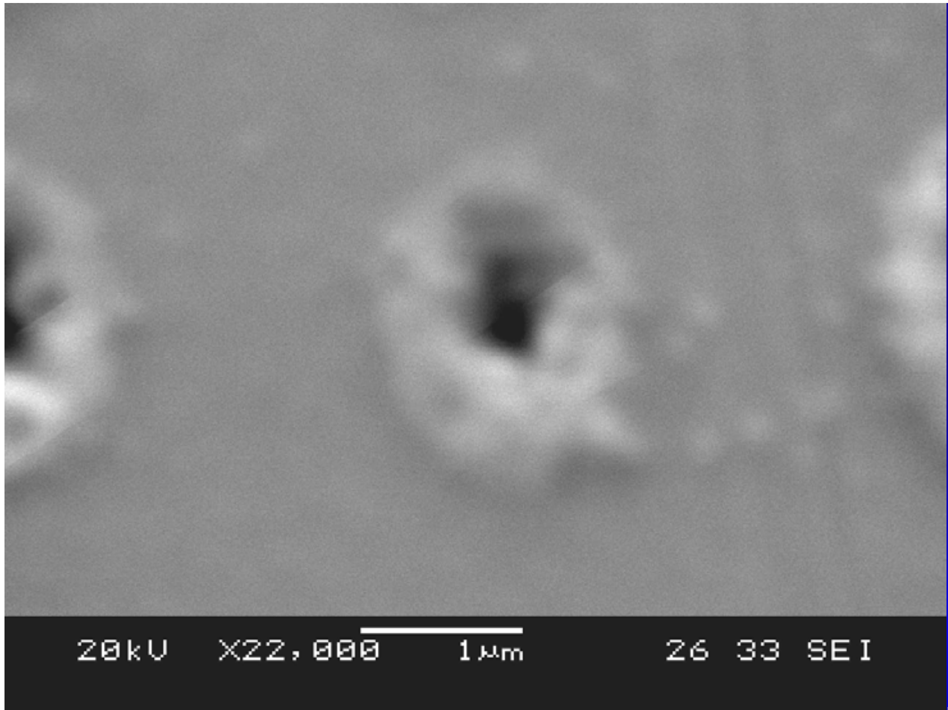
3D profile of the conventional non-interfered Gaussian laser beam

Experimental Set-up



Experimental Details:

Experimental Variables	Value
Pulse length	150fs
Wavelength	400nm
Repetition rate	1kHz
Environment	Ambient condition
Workpiece material	100nmCopper Film



Interfered beam

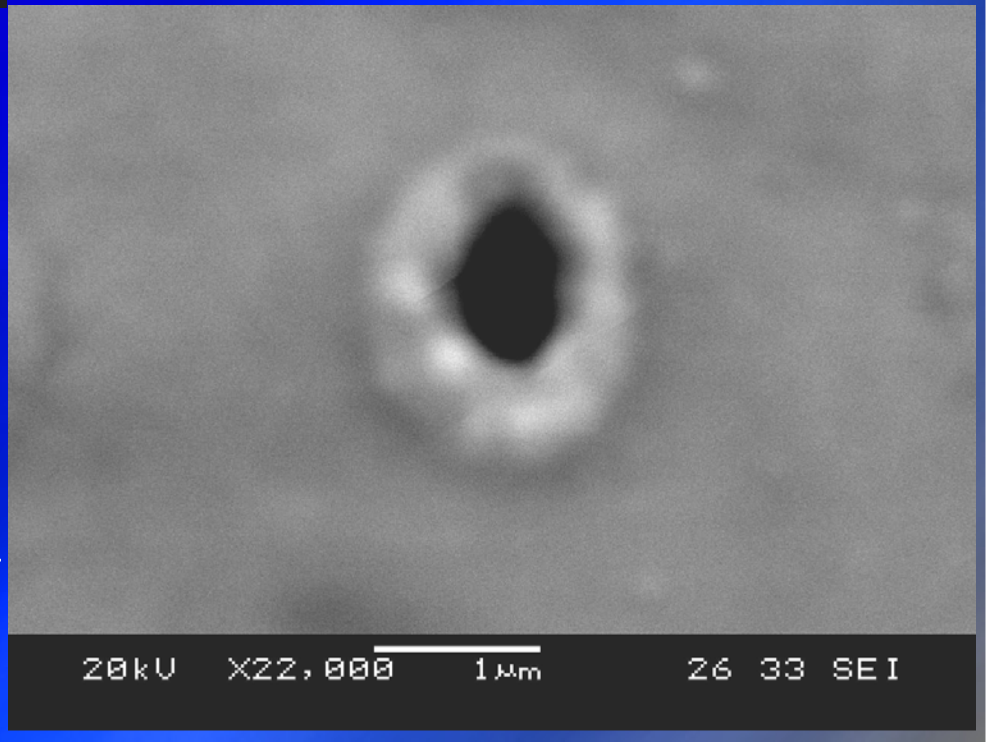
Hole diameter ☯ 300 nm

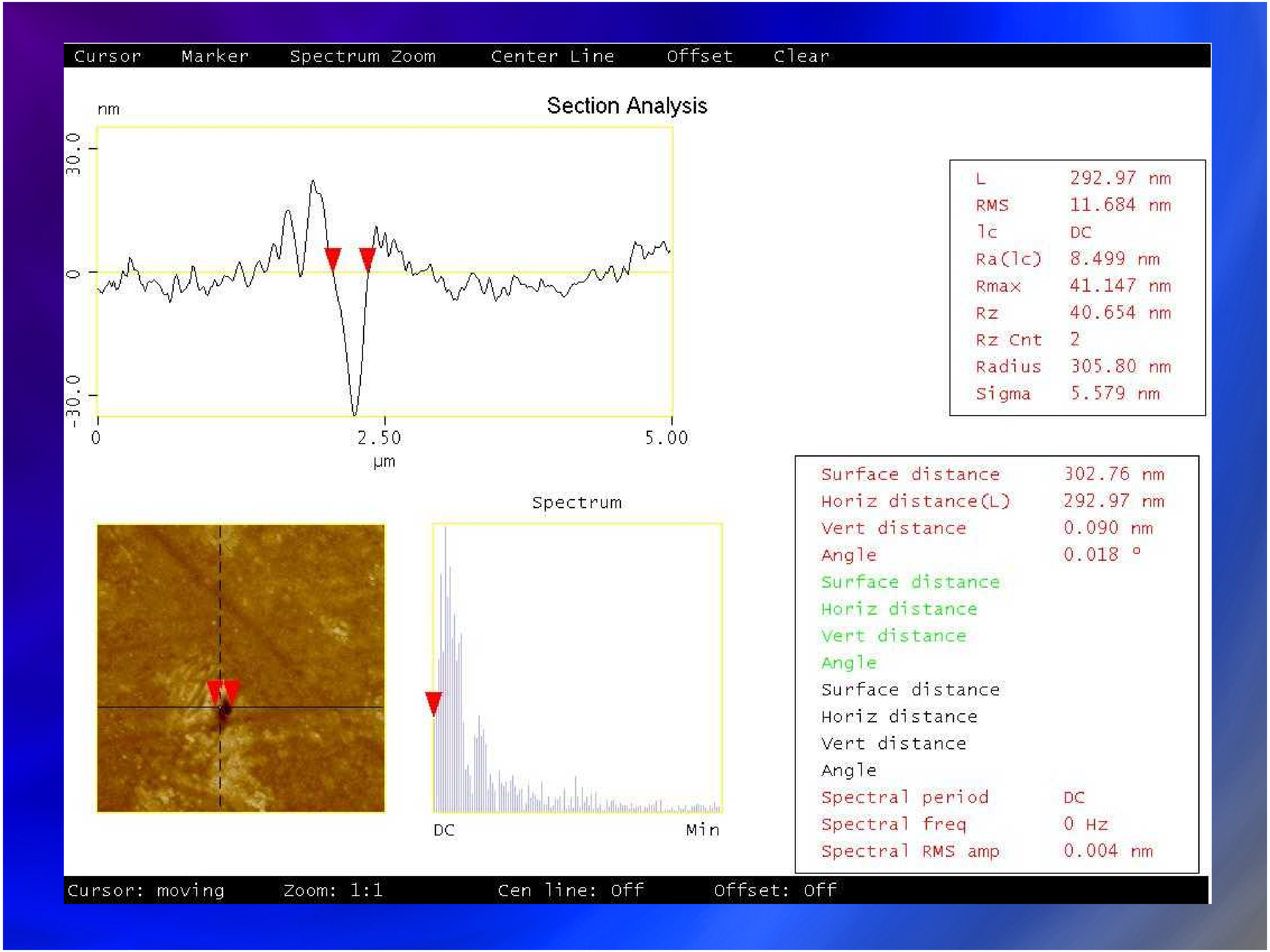
Beam energy: 5 nJ

Direct beam

Hole diameter ☪ 1µm

Beam energy: 5 nJ




Cursor
Marker
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Ra(lc) 8.499 nm
Rmax 41.147 nm
Rz 40.654 nm
Rz Cnt 2
Radius 305.80 nm
Sigma 5.579 nm
Spectrum
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Surface distance 302.76 nm
Horiz distance(L) 292.97 nm
Vert distance 0.090 nm
Angle 0.018 °
Surface distance
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Angle
Surface distance
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Spectral period DC
Spectral freq 0 Hz
Spectral RMS amp 0.004 nm
Cursor: moving
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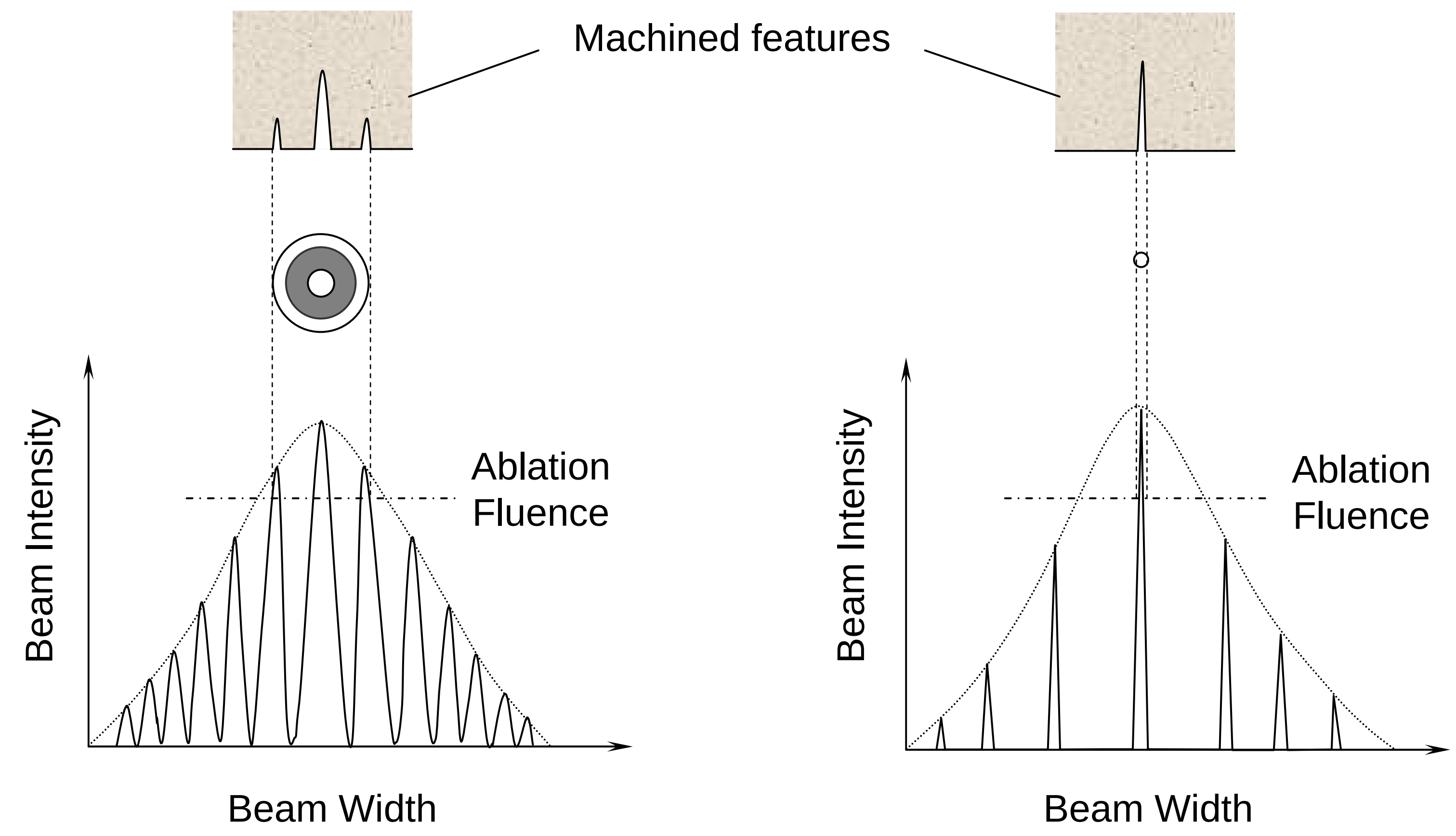
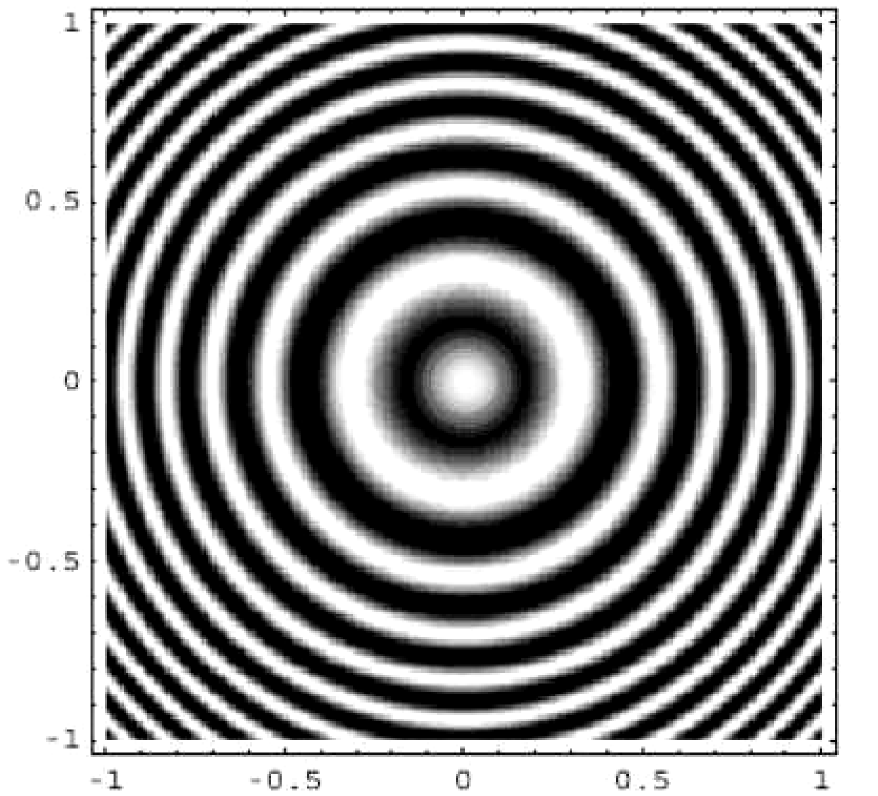
Plans for Future Improvement

- to obtain finer features, sharper & finer fringes must be achieved. This may be done by:
  - * changing the curvature of the lens used
    (the larger the curvature, the more fringes will be obtained, the denser the fringe pattern obtained)
  - * multiple interference (Fabry-Perot etalon)
  - * obtaining a Bessel beam (axicon)
  - * zone plate (multiple diffraction)

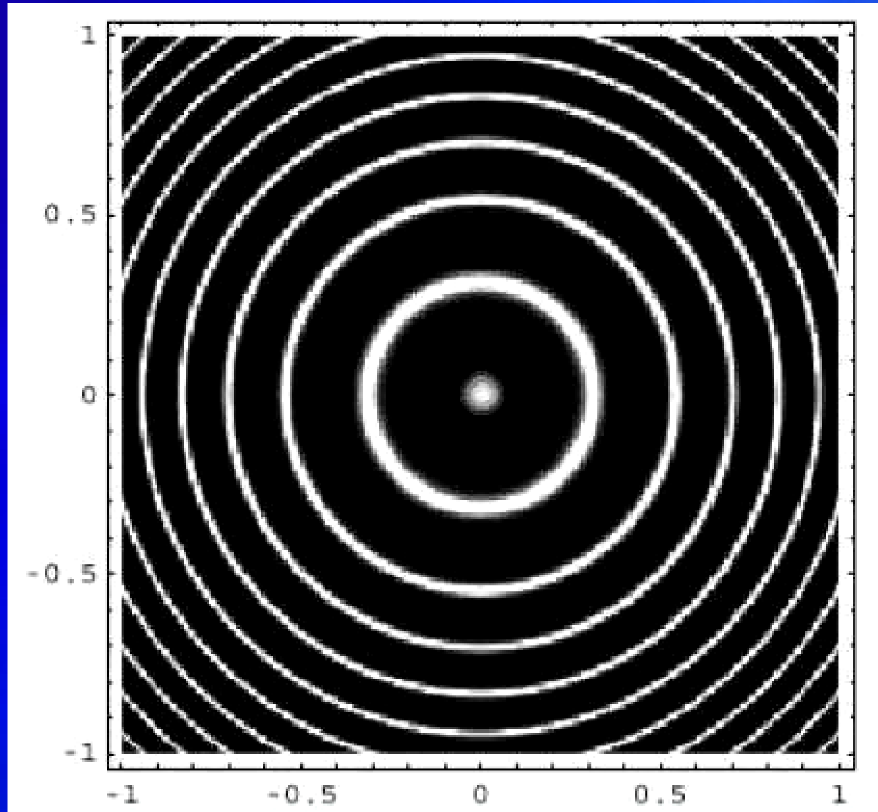


Beam profile of 2-beam interference fringe

Beam profile of multiple interference fringe



Two-beam interference fringes



Multiple-beam interference fringes

For constructive interference, when the 2 waves are in phase, the total intensity is proportional to $(E_1 + E_2)^2$

$$I_{total} \propto E_{total}^2 = (E_0 + E_0)^2 = 4E_0^2 \rightarrow I_{total} = 4I_0$$

Hence , 2 constructively interfered beams will give us light of **four(4) times** the intensity of either wave.

THALES LASER

Alpha 1000/S

Output Specifications

Model	Standard		Picosecond Extension
Repetition rate (kHz)	1		
Wavelength (nm)	800 ± 20 (1)		
Pulse duration	< 100 fs (2)		< 1.5 ps (3)
Energy per pulse	800 µJ up to 2 mJ (4)		> 600 µJ
Pulse-to-pulse stability (% rms)	< 1.3		
Pre-pulse contrast ratio	> 500 : 1		
Post-pulse contrast ratio	> 100 : 1		
Typical picosecond contrast	> 1,000 : 1	@ 1 ps	
	> 10,000 : 1	@ 5 ps	
	> 100,000 : 1	@ 10 ps	
Typical time-bandwidth product	1.5 x Fourier-transform limit		
Beam profile before compressor	Gaussian		
Typical M^2	< 1.3		
Pump system	YLF 12 W @ 527 nm		

The threshold of a material can be calculated from the equation:

$$F_{th} \approx \frac{\Omega \rho \lambda}{4 \pi k A}$$

where,

Ω = latent heat of evaporation by unit mass

ρ = density of the material

λ = wavelength of laser light

k = extinction coefficient of the material

A = absorptivity of the material

Calculated ablation threshold at laser wavelength of 400nm

Material	Latent Heat of Evaporation Ω	Density ρ	Extinction Coefficient at 400nm k	Absorptivity A	Threshold Value F_{th}
Platinum	2405 J/g	21.45 g/cm^3	2.84 cm^{-1}	48%	120 mJ/cm^2
Gold	1738 J/g	19.30 g/cm^3	4.56 cm^{-1}	20%	117 mJ/cm^2
Copper	4796 J/g	8.96 g/cm^3	2.21 cm^{-1}	84%	72 mJ/cm^2

$$\text{Coherence Length} = \frac{\lambda^2}{2\Delta\lambda}$$

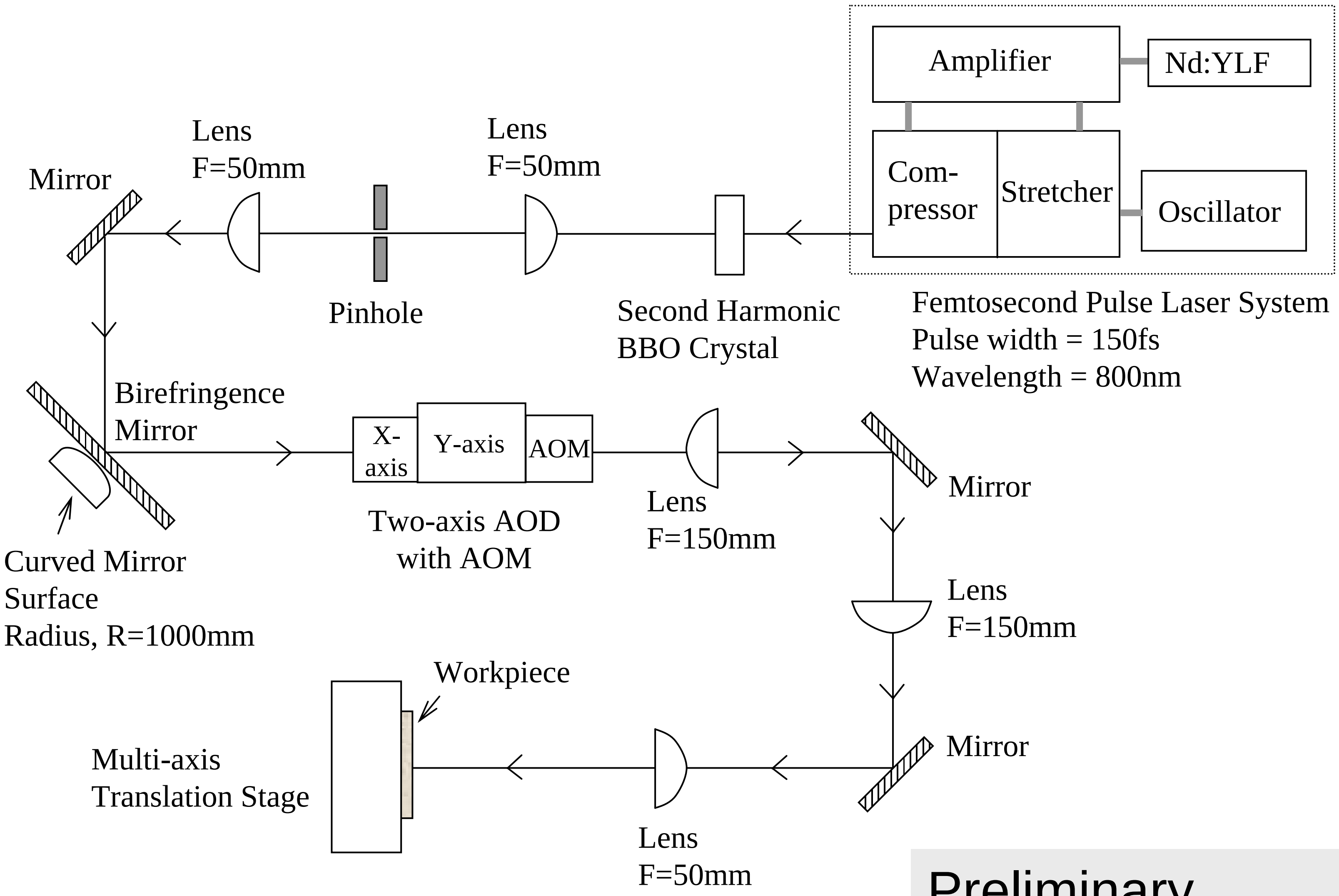
$$= \frac{800^2}{2(10)} = 32 \times 10^3 \text{nm}$$

$$= 32\,\mu\text{m}$$

where,

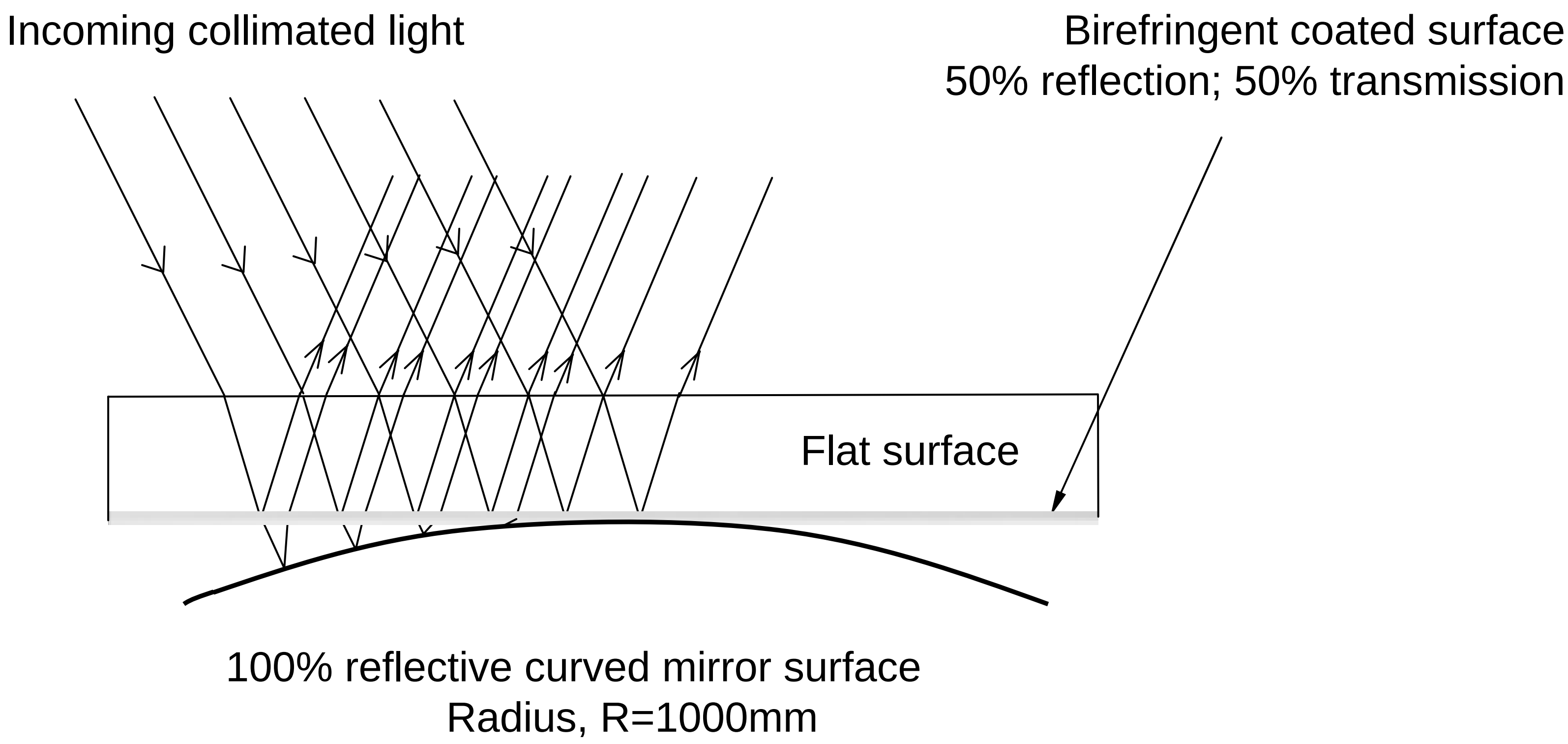
λ = laser wavelength in nm

$\Delta\lambda$ = laser bandwidth in nm



Preliminary experimental set-up

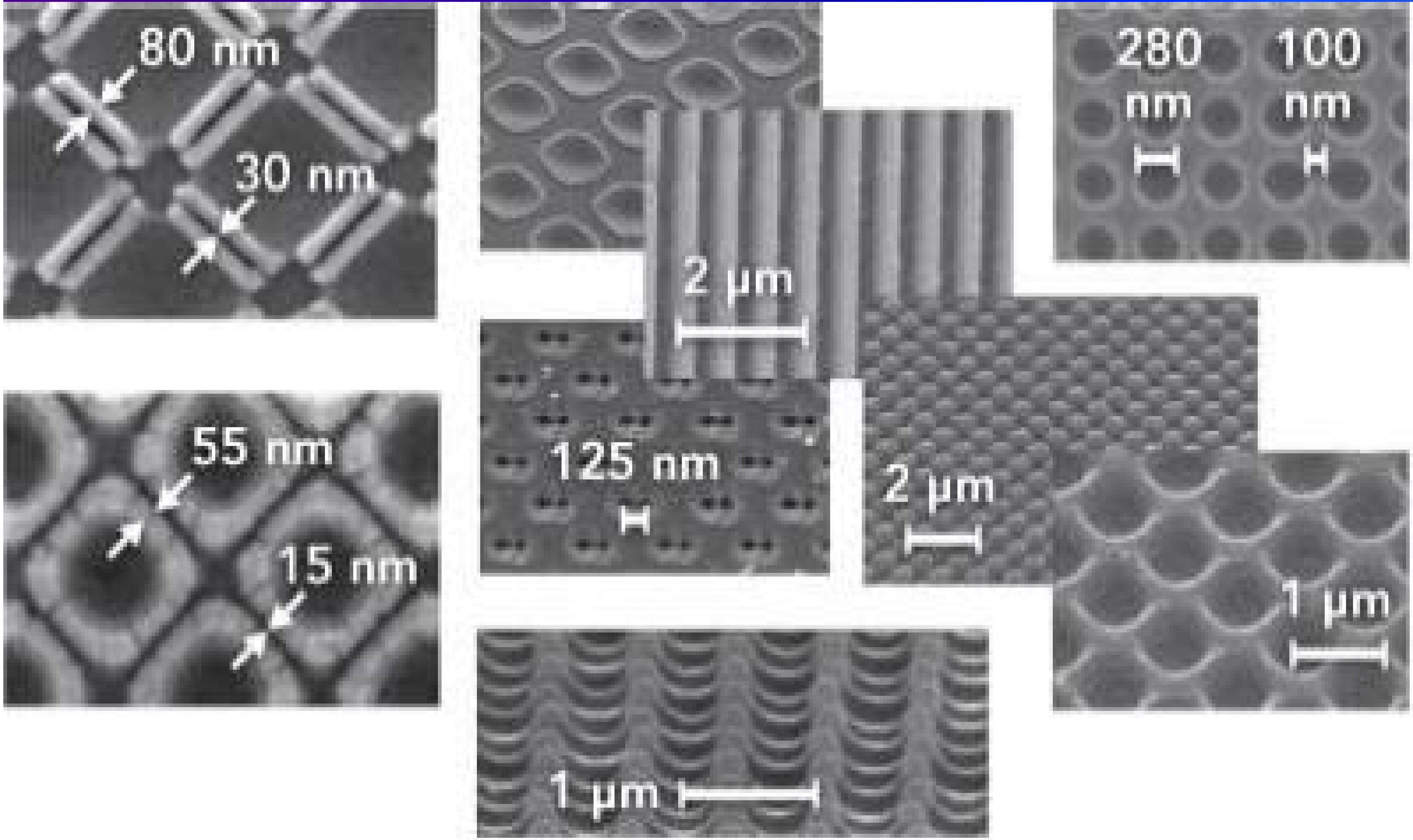
Newton’s Ring Setup



Results:

- 300nm holes were drilled using the interfered laser beam on the 100nm thick Cu film compared to the 1μm holes drilled with the conventional non-interfered laser beam at the same beam energy and machining parameters.

- This is equivalent to a **300%** decrement in feature, a substantial reduction and improvement in feature size.



Source: Laser Laboratorium Göttingen e.V.

The layers of the organic solar cell are structured by means of ultra-short pulse laser. Source: 3D-Micromac.

Applications:

- drilling of microvias in the semicon industry
- micro-drilling of microscale fluidic devices such as ink-jet printer nozzles and drug-delivery systems
- direct writing on mask for lithographic applications
- microsurgery & non-intrusive surgical techniques
- the potential is limitless as the quest for miniaturization is endless!!

Thank you