Laser structuring

- Principle of laser operation
- Types of lasers
- Laser-matter interaction
- Glass microstructuring
- Applications
- References

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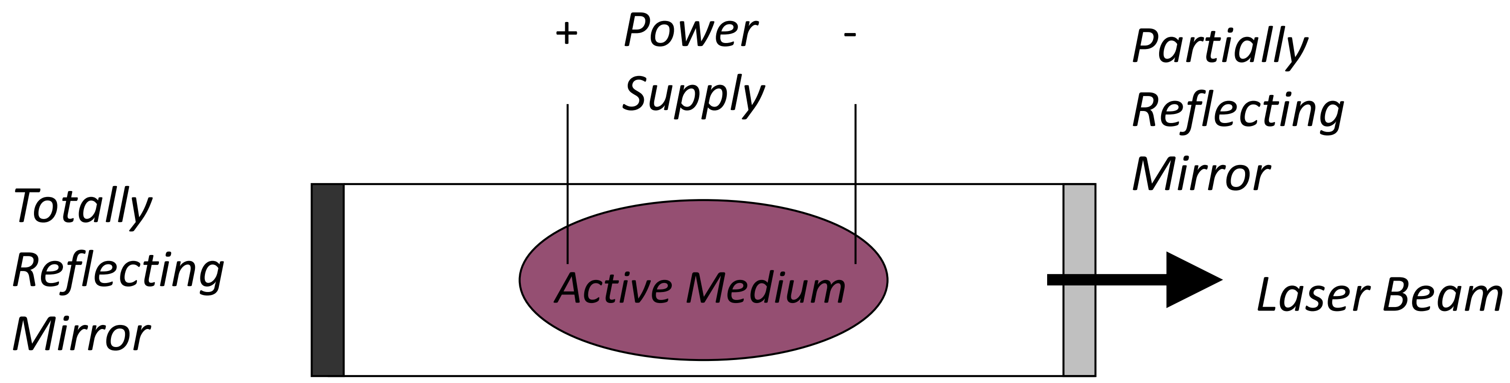
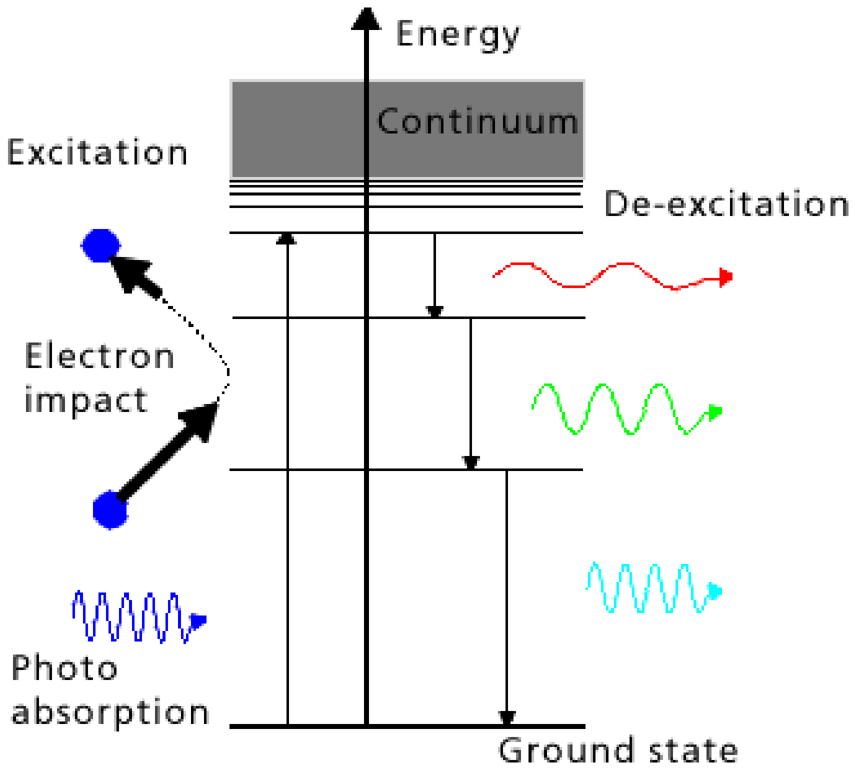
What is a laser?

- **L**ight **A**mplification by **S**timulated **E**mission of Radiation (The first working laser was invented by Maiman in 1960)
- Three main parts in a laser
  - Energy source for 'pumping'
  - Active medium
  - Optical resonator



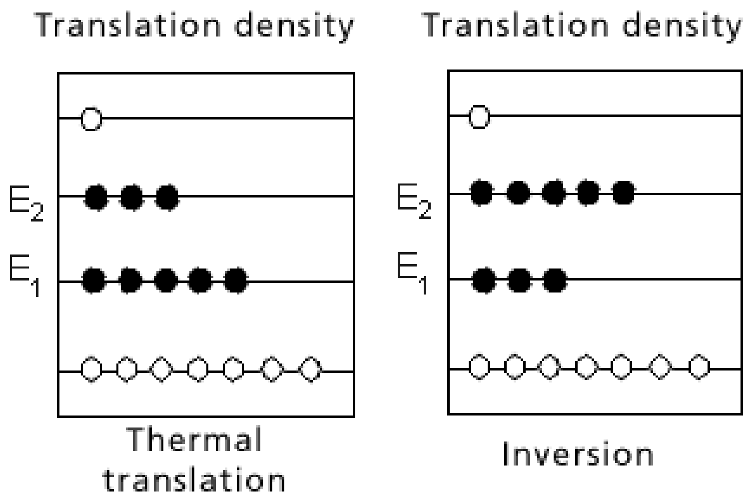
Active medium

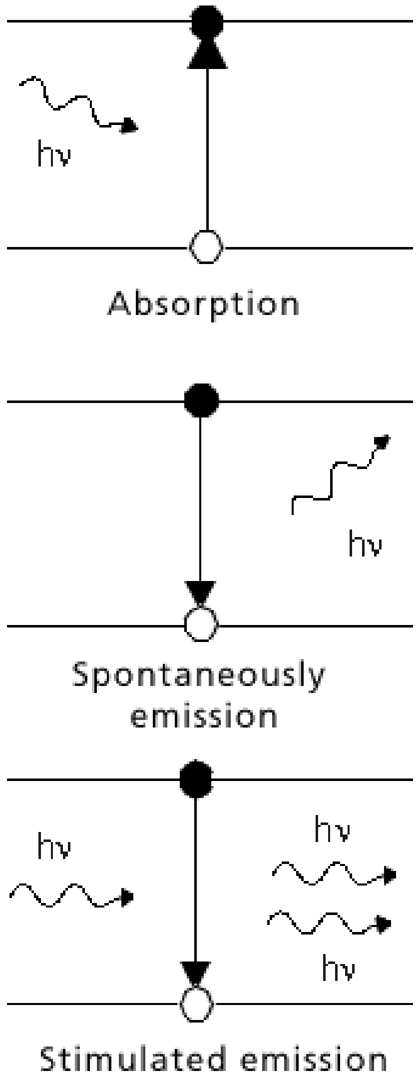
- Transfers highly entropic energy to 'ordered energy'
- Kind of media
  - solid (crystalline or amorphous)
  - liquid
  - gaseous or plasma
- Electrical discharge or optical pumping



Laser principle

- Realisation of population inversion
- Coherent light by stimulated emission of radiation





Types of lasers

- Solid state lasers
  - Nd:YAG laser (λ = 1064 nm, P = 5 kW, pulsed and continuous wave (CW))
- Gas lasers
  - Excimer laser (λ = 193 nm, 248 nm, 355 nm (UV laser), P = 1 kW- 100 MW, pulsed)
  - CO_2 laser (λ = 10.6 μm (IR laser), P = 1 kW- 100 MW, pulsed and CW)
  - HeNe laser (λ = 632.8 nm, P = 1 mW- 1 W, CW)
  - Argon-ion laser(λ = 515, 458 nm, P = 1 mW- 100 W, pulsed and CW)
- Semiconductor diode lasers

  (λ = 300 nm - few μm, P = 1 mW- 0.1 W, pulsed and CW)

CO_2 laser

- Active medium : ionized mixture of He, N_2 and CO_2
- Wavelength determined by vibrations of CO_2 molecule
- Length of active medium ~ 1 m, λ = 10 μm, mirror ~ 1 cm → Gaussian laser beams → easy beam focussing and very high intensities ~ MW/cm^2
- $h\nu$ = 0.2 eV → multiphoton micromachining process
- Can heat, melt a on earth

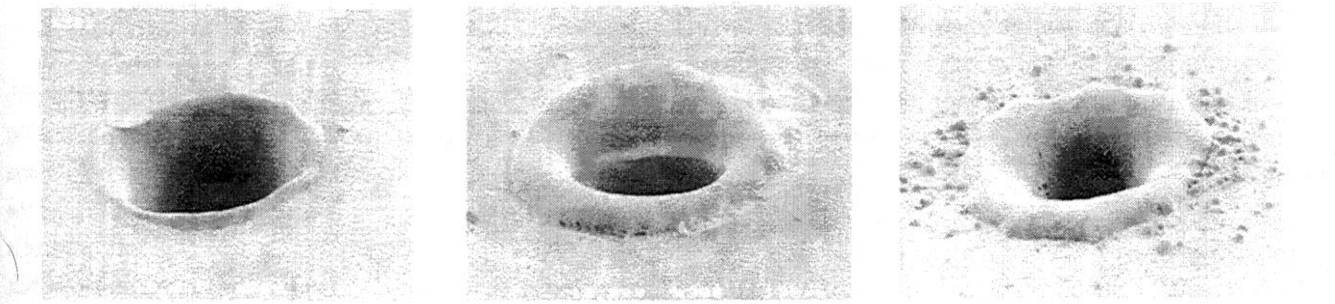
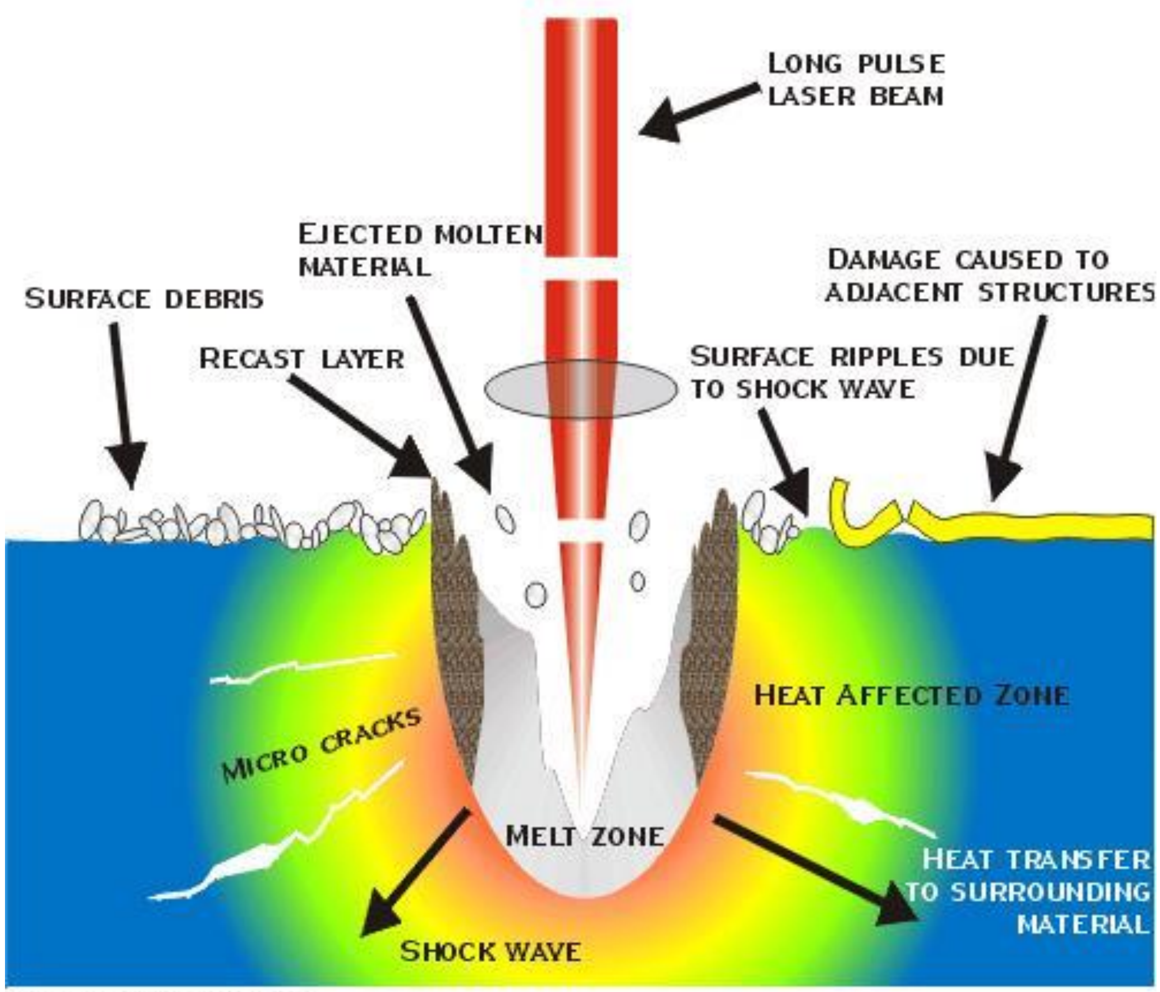


Fig.3 Scanning electron micrographs of the holes from the laser input surface. (a) Synthetic quartz, (b) Pyrex glass and (c) Soda-lime glass.

Laser - matter interaction

- Electrons are excited (multi-photon process) and free electrons absorb laser energy → avalanche ionisation
- Material is heated, melts, then evaporates
- Relevance of thermal properties of the workpiece (thermal conductivity, specific heat, density,..)
- Heat diffusion (long pulse length > 1 ns)
  - takes away energy of spot
  - temperature lowering →contamination of globs of molten material
  - diminishes resolution of microfabrication process
  - creation of Heat Affected Zone (HAZ) with defects

Micromachining with long pulse (ns) laser beams



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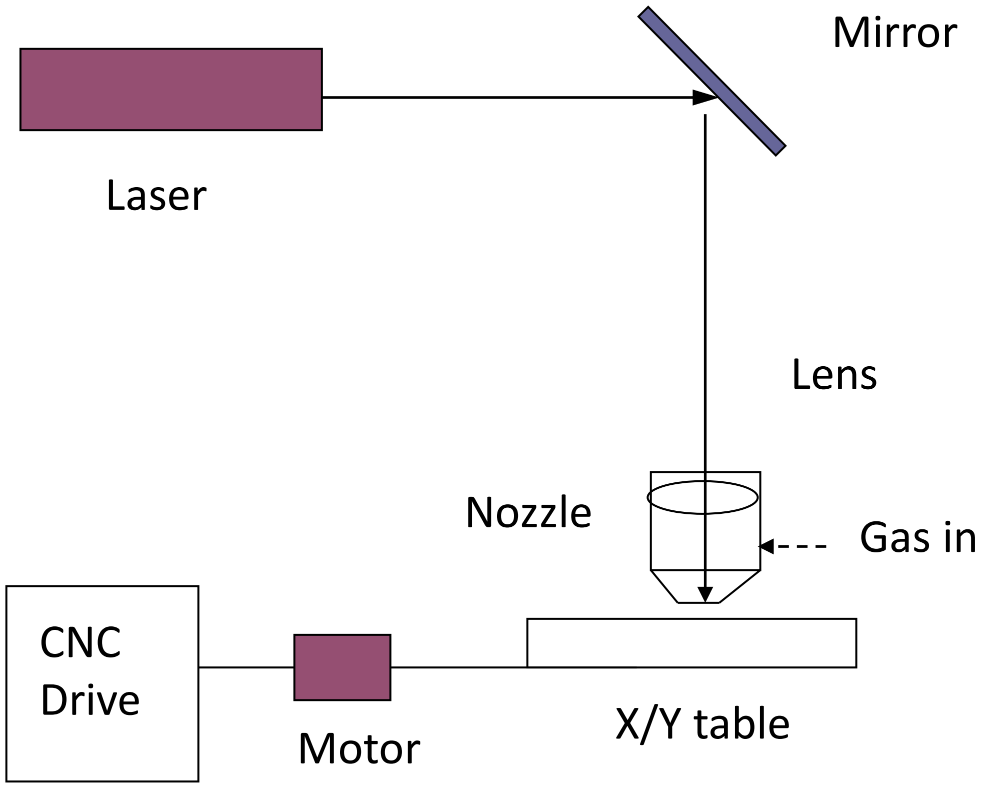
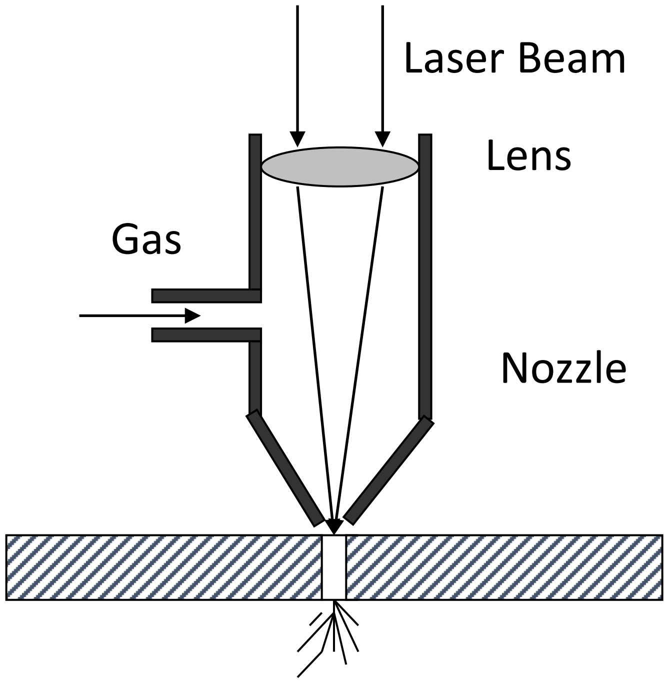
CO_2 laser cutting system



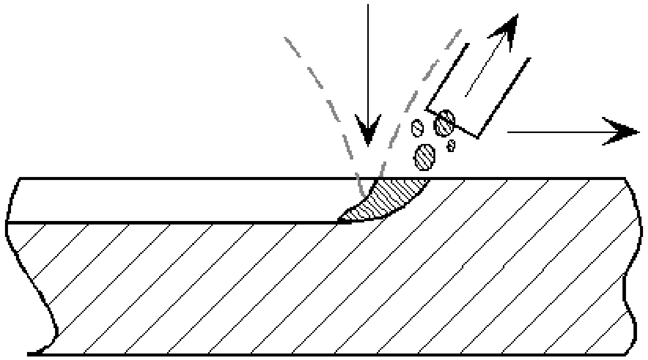


'Gas assisted laser cutting' :

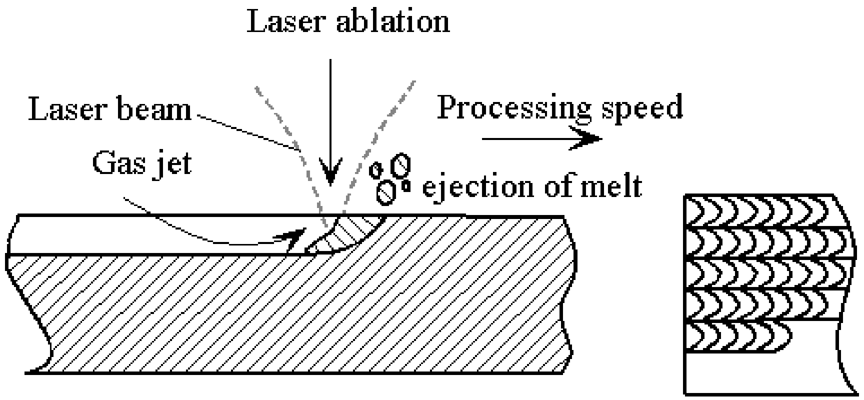
- gas flow removes molten material
- protects the lens from contamination
- cools the lens

Other laser machining techniques

- Laser suction
  - Melt is sucked away by a vacuum nozzle
  - No expensive gases needed



- Laser planing
  – Narrow shallow grooves are formed on the surface



Excimer lasers

- Excited artificial noble gas – halogen molecule :’excimer’
- Release of excimer binding energy (~ eV) → UV light emission (λ = 200 – 300 nm)
- Creation of free electrons → avalanche ionisation
- Short active medium → many laser modes → ’top hat’ intensity profile
- To avoid overheating of gas and electrodes → only pulsed mode (1 - 10 ns)

Excimer laser glass machining

- Conditions
  - ArF excimer : λ = 193 nm [ν = 1.55 10^{15} Hz, hν = 6.42 eV]
  - F_2 : λ = 157 nm [ν = 1.90 10^{15} Hz, hν = 7.89 eV]
    Vacuum UV (VUV) laser
  - 500 pulses at fluence of 6.5 J/cm^2
- 157 nm gives better results than 193 nm
- Band gap of fused silica ~ 8.3 eV
- Higher λ → no machining at given fluence

(Lambda Physik, Göttingen, Germany)

Excimer laser glass machining

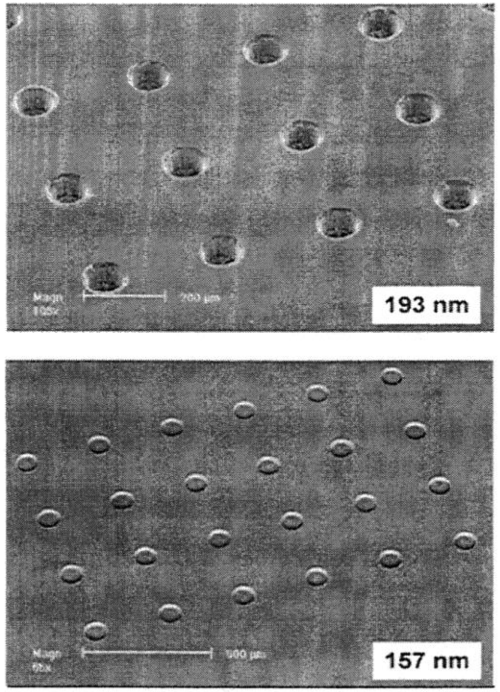


Fig. 4 Blind holes in glass, processed at 193 nm (upper 157 nm (lower)

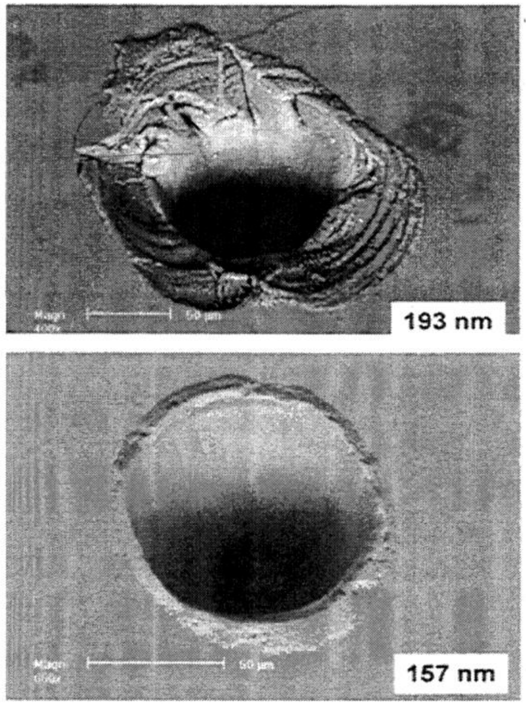


Fig. 5 Fused silica, processed at 193 nm (upper) and 157 nm (lower)

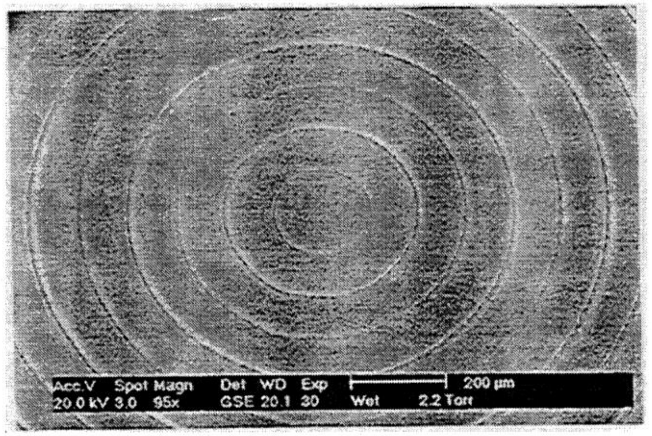


Fig. 5. Fresnel lens fabricated in fused silica by F_2 laser ablation.

(Lambda Physik, Göttingen, Germany)

Solid state lasers

- x-YAG (Yttrium Aluminium Garnet)
  - Pumping with visible light
  - λ = 1 (Nd-YAG), 2 (Er-YAG), 3 (Ho-YAG) μm
  - Bad heat conduction of the host crystal →limited in- and output power
- Ti-sapphire
  - λ = 800 nm
  - Femto-second pulsable

Femtosecond lasers

- Peak power of 5 – 10 GW, Intensity ~ 10^{12} W/cm^2
- Target material reaches plasma state
- No melt phase and droplet formation
- No negative effects related to the heat affected zone
- Problems
  - Low pulse energy : ~ mJ
  - Low average power → low throughput
  - Expensive system (10^6-10^7 $)

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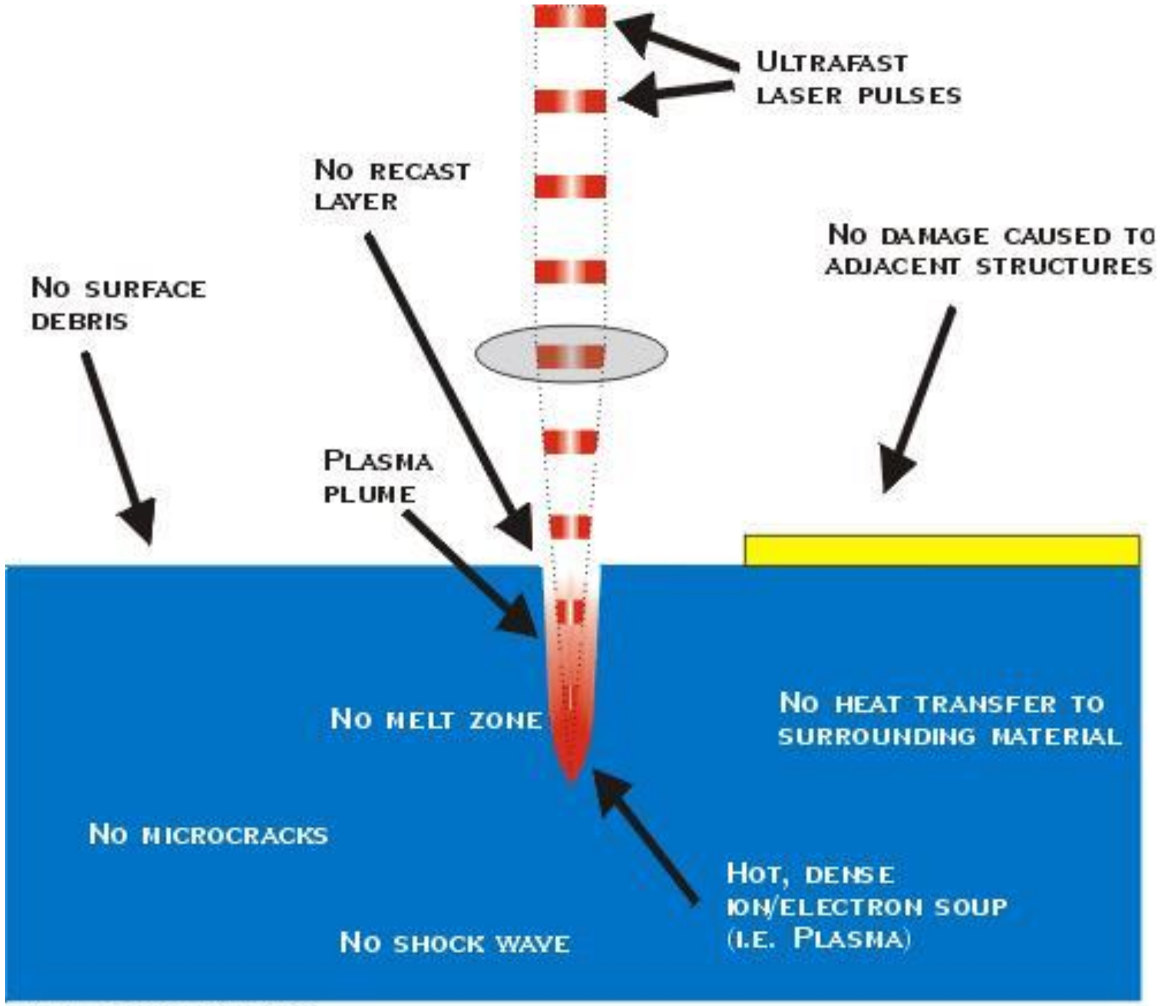
Micromachining with short pulse (fs) laser beams



Femtosecond laser machining

Figure 2: Long-pulse machining of a copper alloy aperture. This piece clearly shows heat-related effects (HAZ, recast, microcracks etc.) This item was not post-processed.

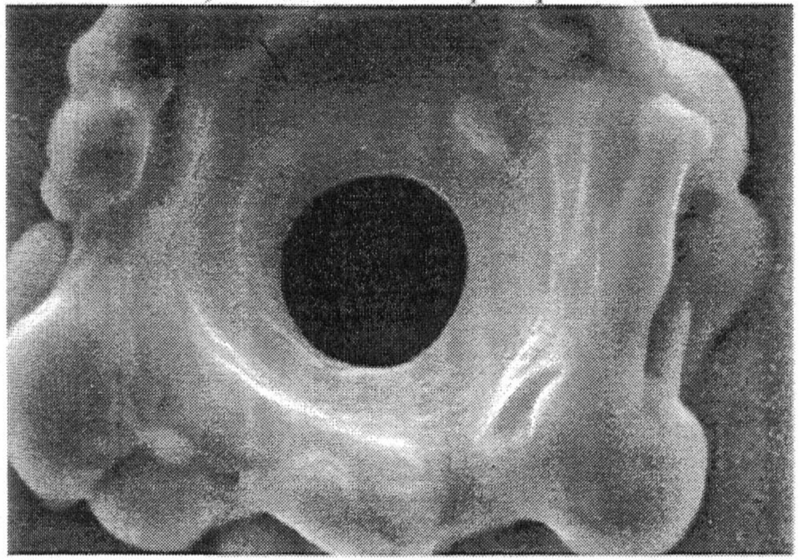
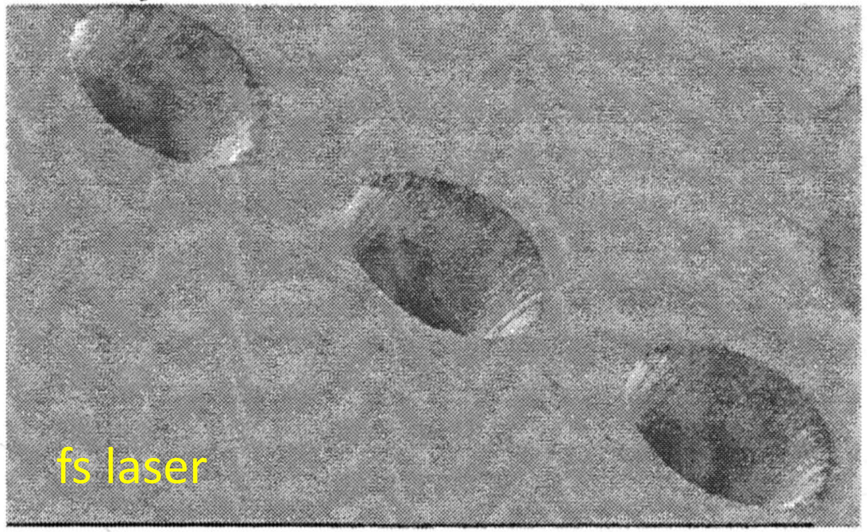


Figure 4: These three 100-micron diameter holes were machined in stainless steel as part of a reproducibility study. Accuracy was found to be of the order of 1 %.



Internal modification of glass using fs lasers

- 130 fs, 800 nm Ti:sapphire laser
- Glass is transparent to this wavelength but can be melted internally → rise of refractive index
- Voids can be created internally

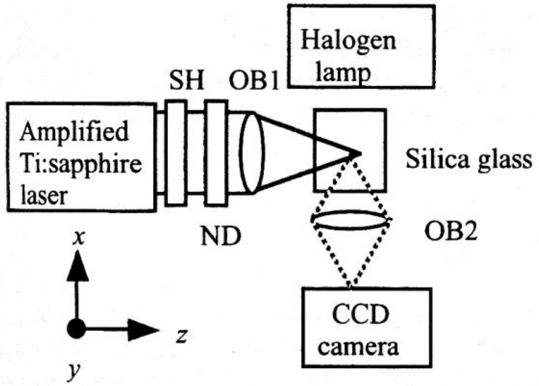


Figure 1 Schematic of experimental setup for creation and in situ observation of voids in silica glass by femtosecond laser pulses; OB1 and OB2 denote objectives. ND and SH denote a neutral density filter and a shutter, respectively.

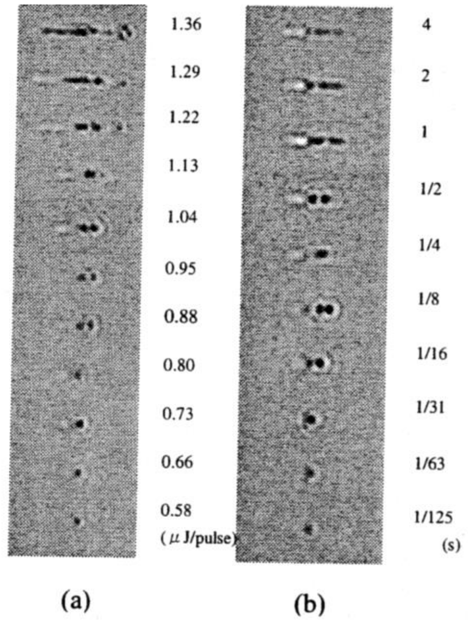


Figure 2 Creation of voids by varying exposure time and incident energy; (a) Incident energy is varied form 0.58 μJ to 1.36 μJ under fixed exposure time (1/125 s), (b) Exposure time is varied form 1/125 s to 4 s under fixed incident energy (0.73 μJ).

Waveguides and photonic crystals

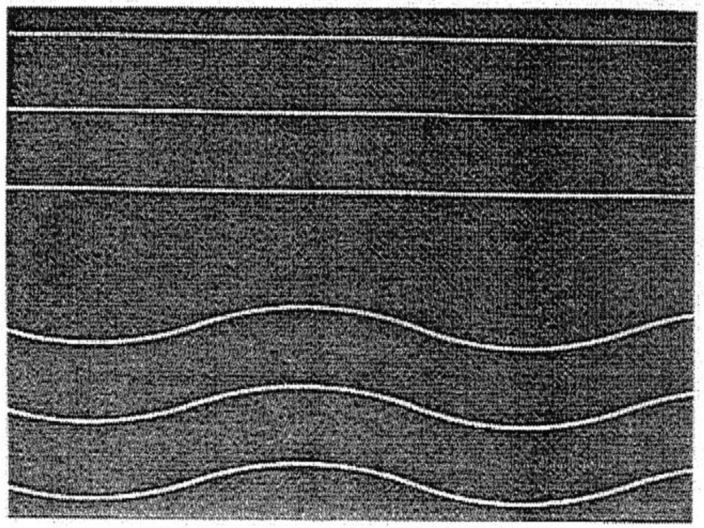


Fig. 2. Low-loss optical waveguides with various shapes fabricated within any place of the glass.

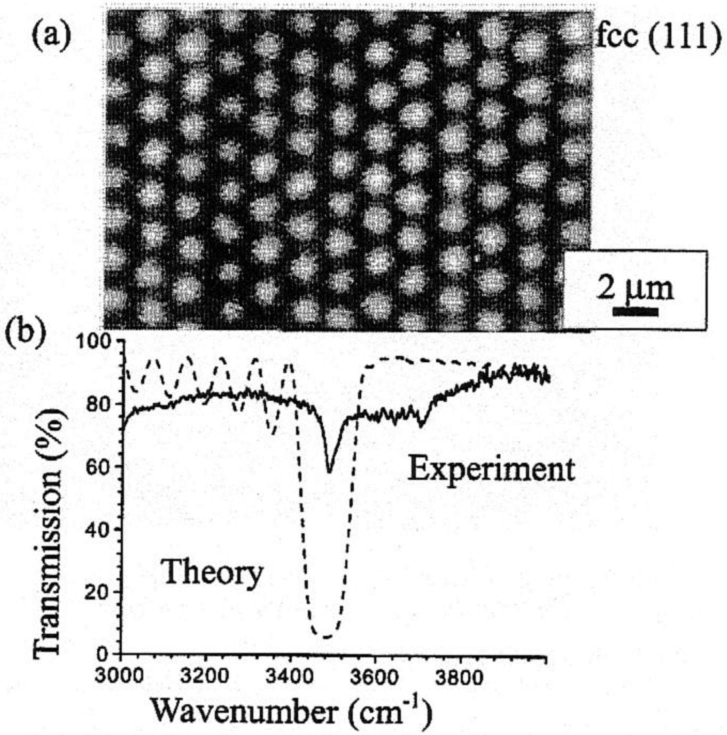


Fig. 3. (a) Optical microscopic image of photonic crystal fabricated in fused silica by fs laser microexplosion, and (b) FTIR transmission spectra of fabricated structure.

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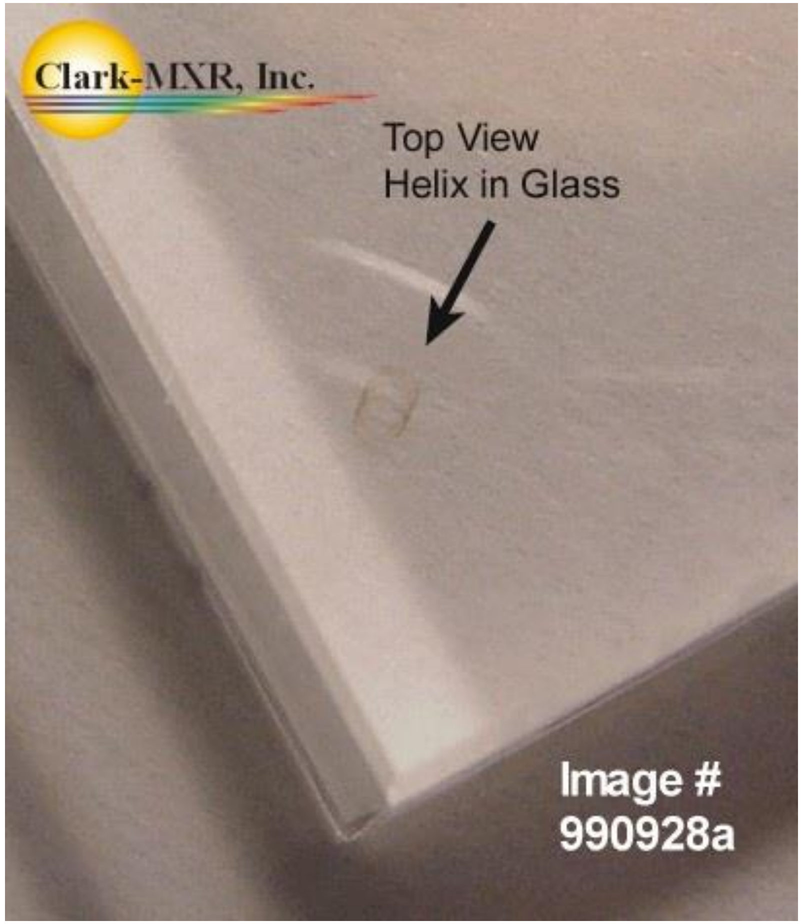
Waveguides


Clark-MXR, Inc.
Top View
Helix in Glass
Image #
990928a


Clark-MXR, Inc.
Image #
990927d

Hybrid laser processing (i)

- Interaction of a conventional laser beam and another medium on the material surface
- Example : Laser-Induced Backside-Wet-Etching (LIBWE)
  - KrF excimer laser
  - Backside of the sample is in contact with pyrene solution
  - Laser energy is deposited at the rear surface

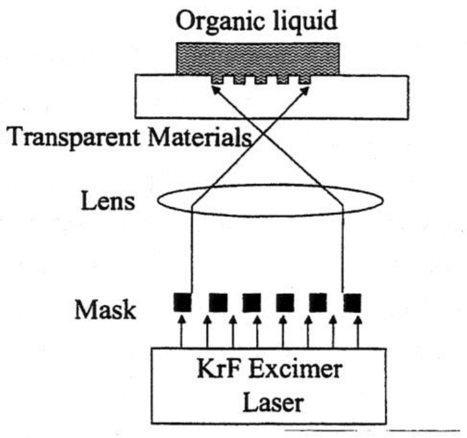


Fig. 6. Experimental scheme of LIBWE.

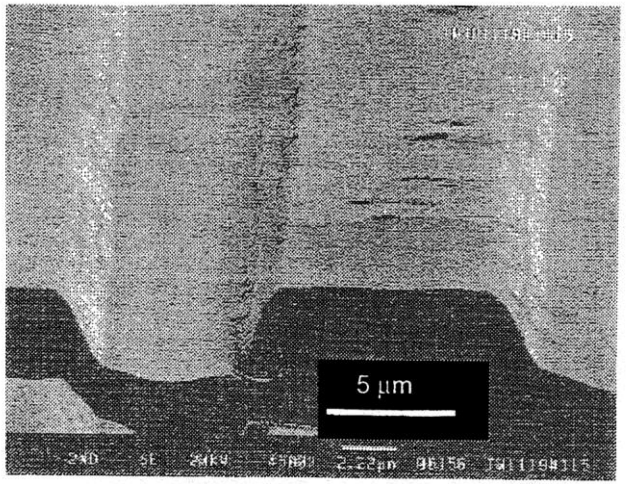


Fig. 7. Microstructure fabricated in fused silica by LIBWE.

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Hybrid laser processing (ii)

- Example : Vacuum UltraViolet – UV laser combination
  - F_2 - KrF excimer laser
  - VUV laser has small energy density (mJ/cm^2), simultaneous UV laser has 1 J/cm^2)

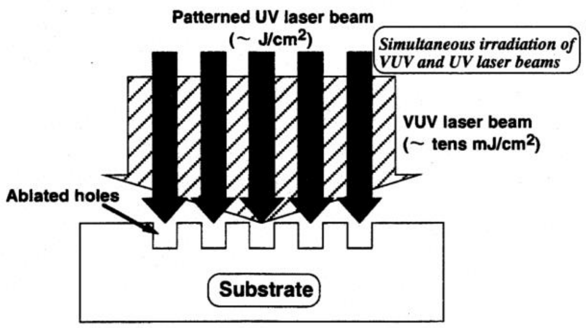


Fig. 8. Schematic illustration of concept of multi-wavelength excitation process.

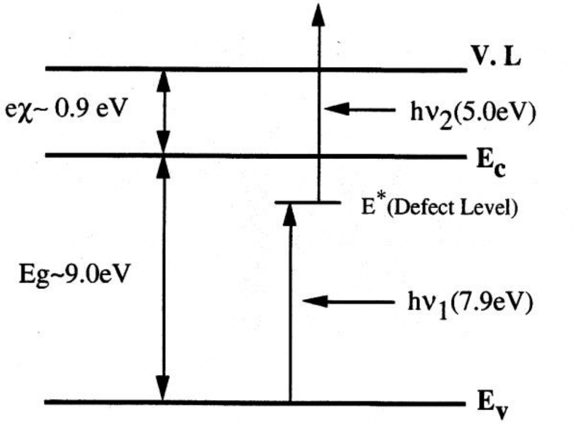
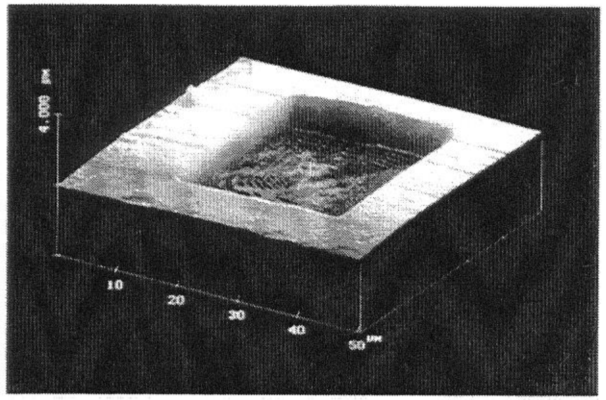
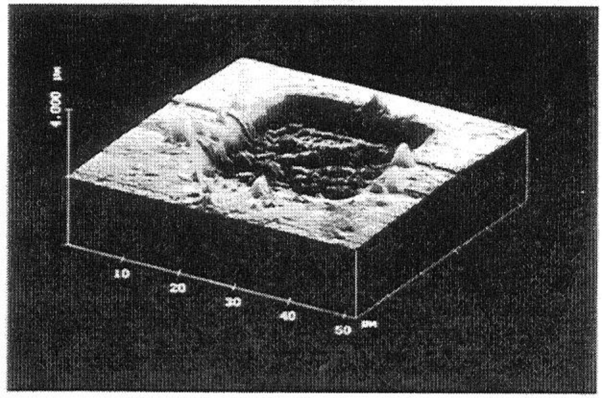


Fig. 10 Band structure of fused silica and excited-state absorption process.



(a) F_2 - KrF excimer lasers



(b) KrF excimer laser

Fig. 9. AFM images of ablated fused silica.

Hybrid laser processing (iii)

- Example : Laser-Induced Plasma-Assisted Ablation (LIPAA)
  - Laser beam goes through transparent substrate, where energy is absorbed by metal target
  - Laser-induced plasma generates ablation at the rear surface

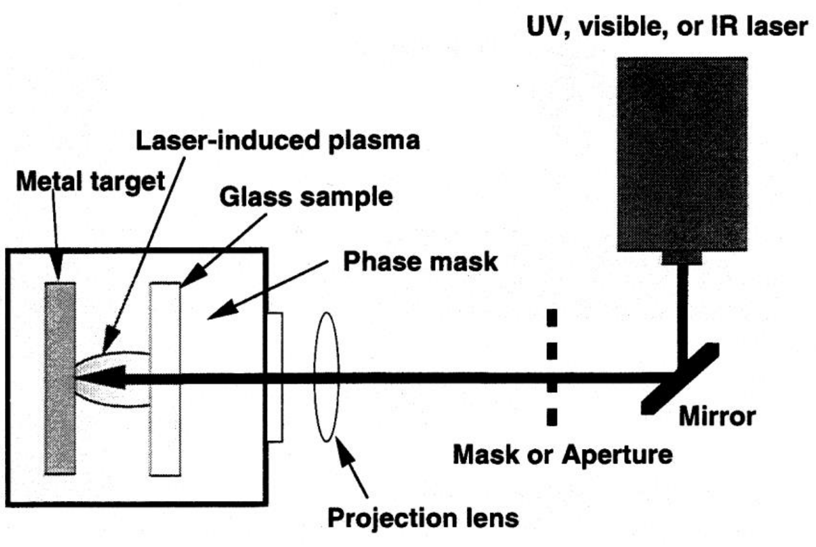


Fig. 11 Experimental scheme of LIPAA.

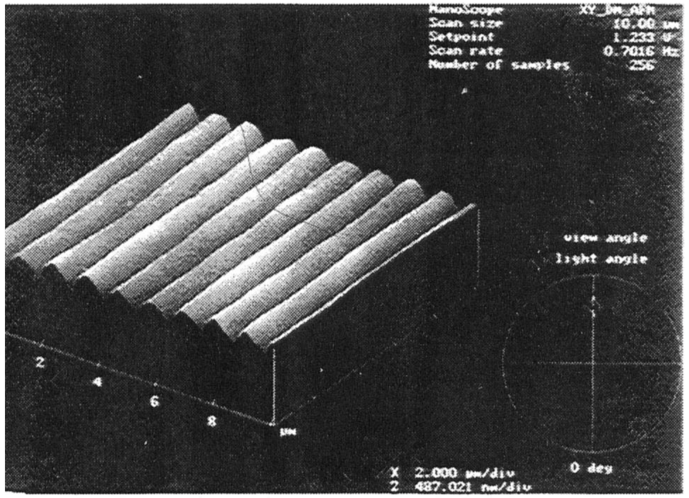


Fig. 12. AFM image of grating structure fabricated in fused silica by LIPAA using a KrF excimer laser and a phase mask.

Advantages of laser microfabrication

- High precision (tolerance and surface finish)
  - small cut widths/welds
  - point source, can move in any direction
- Productivity (high speed and low cost)
- Non-contact (soft tooling: forceless for fragile parts), no tool wear
- Automation (CNC, robot, etc.)
- All materials can be processed (hard, abrasive, soft, sticky materials)
- Quality and reliability
- Synthesis of new materials

Other applications of lasers

- Medical: visual correction, tattoo and hair removal, laser surgery...
- Space: communication, measurements
- Military: laser guided missile
- Environment: pollution detection
- Consumer: laser printing, recording, laser scanning (e.g. reading bar codes), finger print detection...

References

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