Laser micromachining

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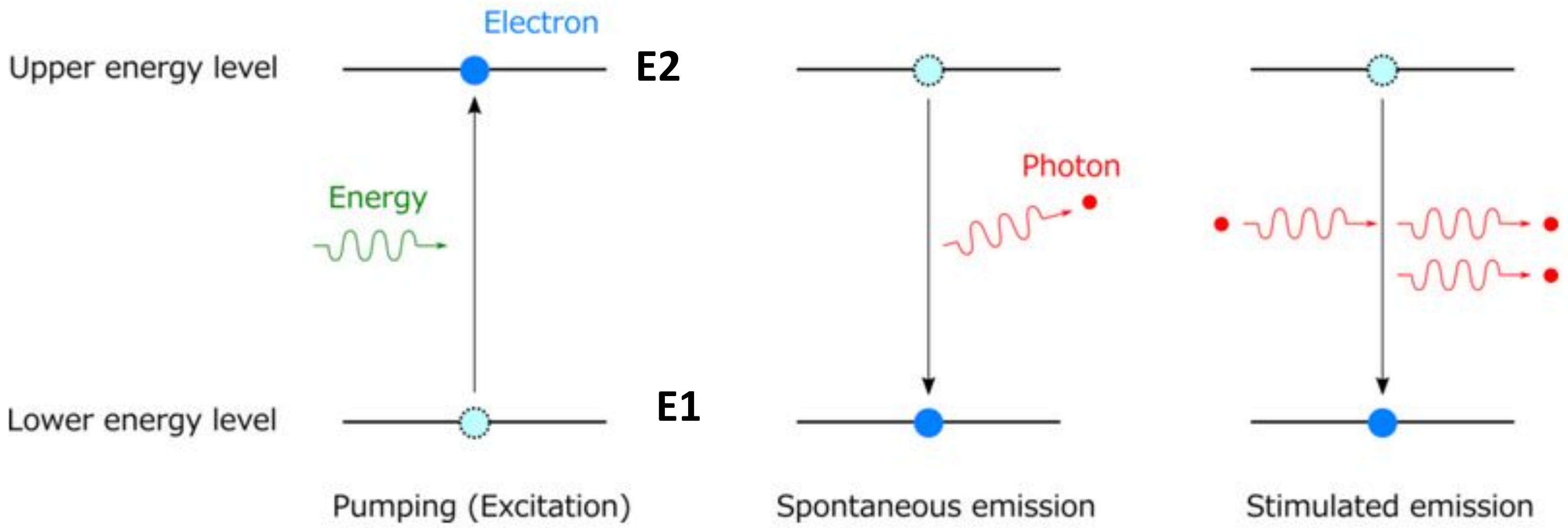
- Types of machinable materials
- Types of lasers
- Mechanism of interaction ablation in different types of lasers
- Where to use
- Industrial applications

LASER

"**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation"



Laser beam is a coherent and focussed beam of photons; coherent means its all one wavelength, unlike ordinary light having many wavelengths.

Characteristics of Laser Light

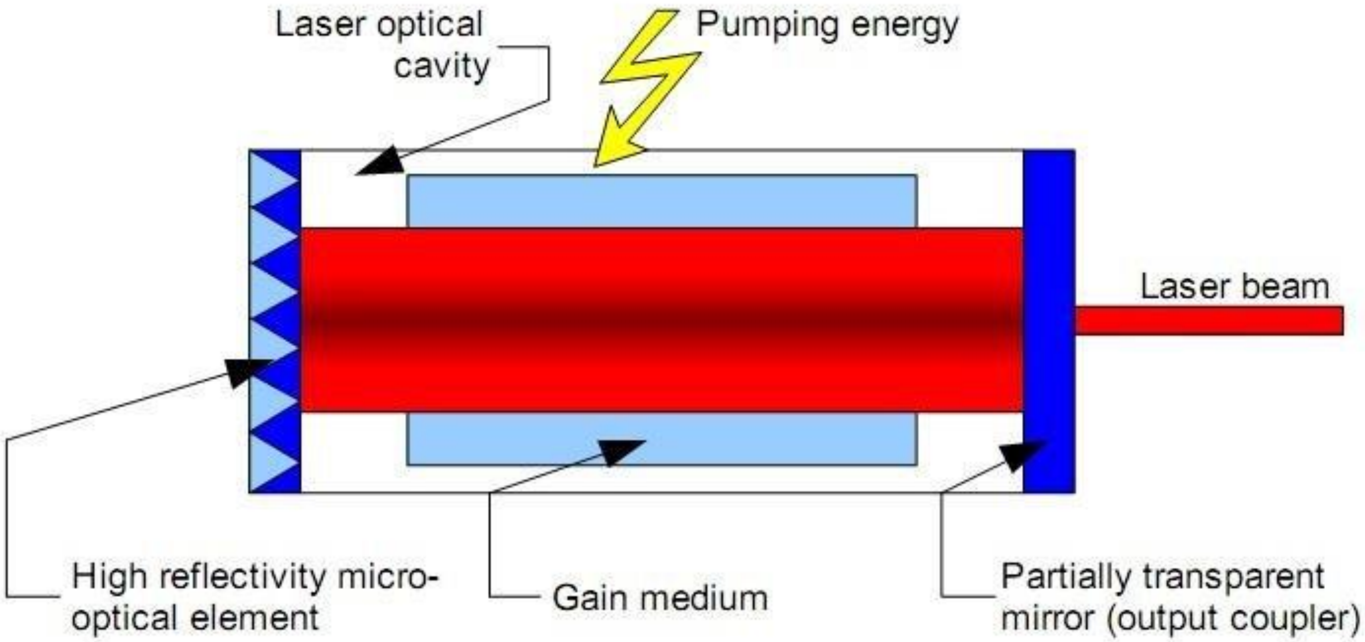
- Coherent. Different parts of the laser beam are related to each other in phase. These phase relationships are maintained over long enough time.
- Monochromatic. Laser light consists of essentially one wavelength, having its origin in stimulated emission from one set of atomic energy levels.
- Collimated. Divergence negligible- Because of bouncing back between mirrored ends of a laser cavity, those paths which sustain amplification must pass between the mirrors many times and very nearly perpendicular to the mirrors. As a result, laser beams are very narrow and do not spread very much.

Basic design to produce laser

- **Gain medium/active laser medium**- gain refers to amount of amplification; A laser gain medium is a medium which can amplify the power of light (typically in the form of a light beam)

- **Resonator**-the laser radiation can circulate and pass again medium which compensates the optical losses. resonator typically contains multiple laser mirrors, one of them being an output coupler, a laser gain medium, and possibly additional optical elements.

- **Pumping energy**- optical or electronically;



Types of Laser

(*A*) *By active media*

- *Solid state laser -* crystal, or glass, doped with impurities, e.g. ruby laser, Ti:sapphire laser, semiconductor laser.
- *Gas laser -* e.g. He-Ne laser, Ar^+ laser, CO_2 laser, N_2 laser, HCN laser.
- *Dye laser -* active medium: dye molecules in liquid solvent (sometimes in solids also).

(B) By mode of operation

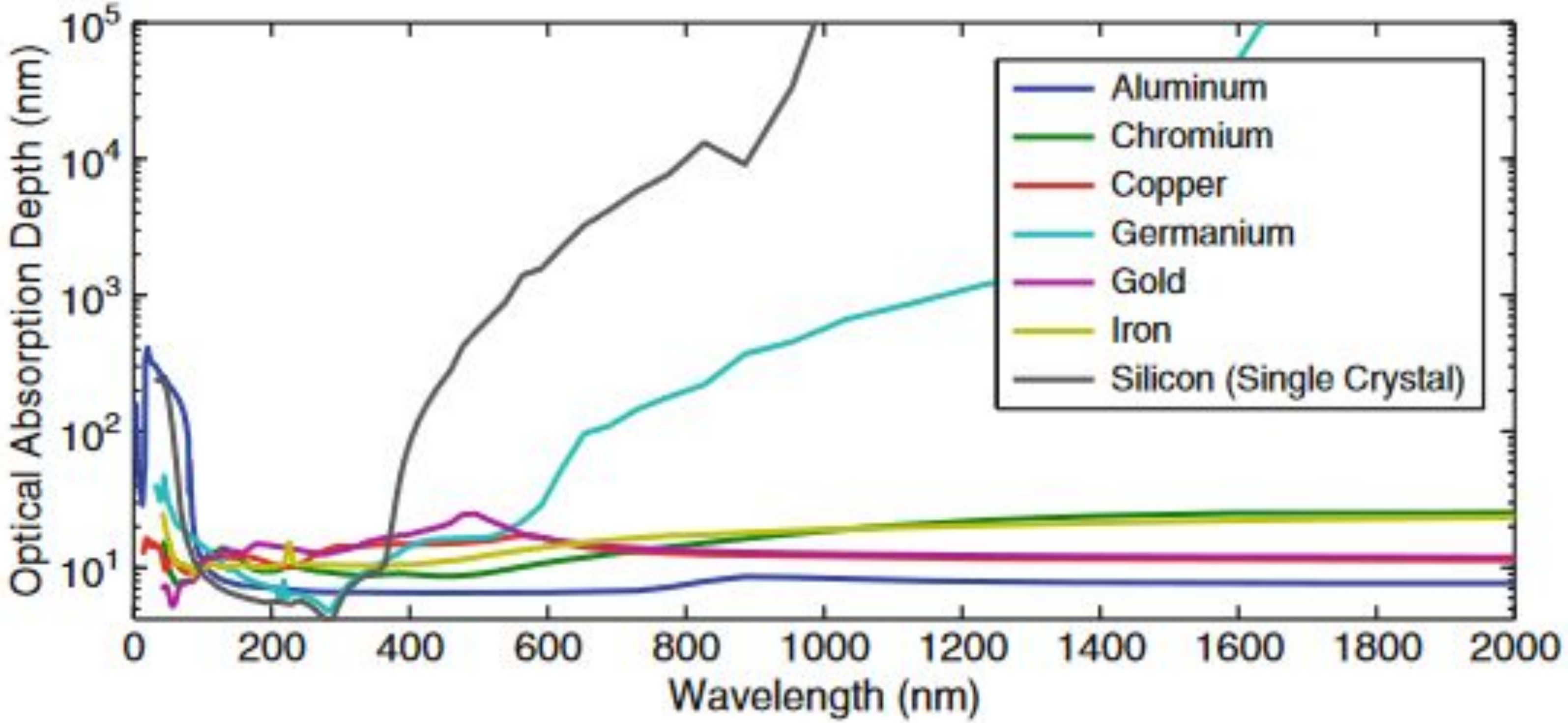
- CW
- Pulsed

(C) By pumping and laser levels

- 3-level laser
- 4-level laser

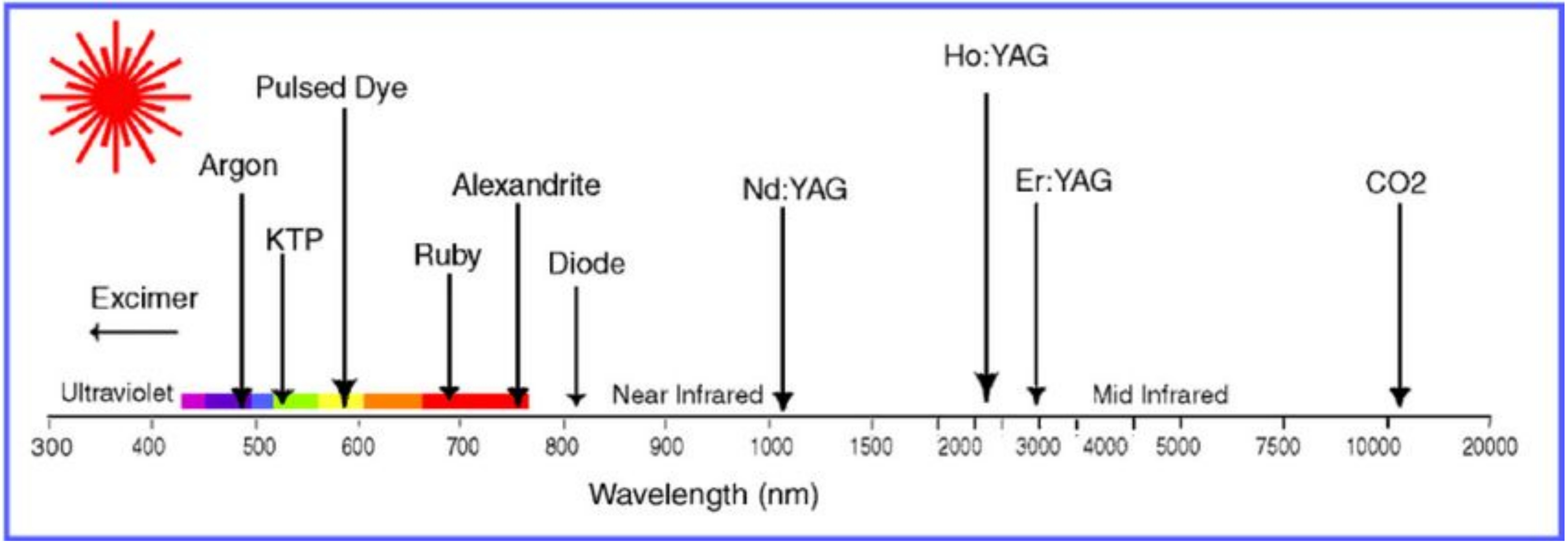
Machinable materials

❑ Materials
- Metals
- Non-metals
- Dielectric materials
- Ceramics



✔ Depends- laser absorptivity

Laser produces different wavelengths



Laser parameters and its effects

Process Parameters	Effect
Wavelength, Focal length of lens	Feature size
Beam shape	Feature shape
Beam energy, Pulse width	Size of heat affected zone
Depth of focus	Aspect ratio

	Practical Resolution Limit	Attainable Aspect Ratio*	Taper	Undesirable Side Effects	Status of Technology Development
Excimer Laser	5 mm	>100:1	yes	Recast Layer	low
CO2 Laser	200 mm	100:1	yes	Recast Layer, Burring, Thermal	high
Nd:YAG	50 mm	100:1	yes	Recast Layer, Burring, Thermal	high
EDM	100 mm	20:1	No	Surface finish	moderate
Chemical Etch	250 mm	1:1.5	Yes	Undercutting	moderate
Mechanical	Ø 100 mm	10:1	No	Burring	moderate

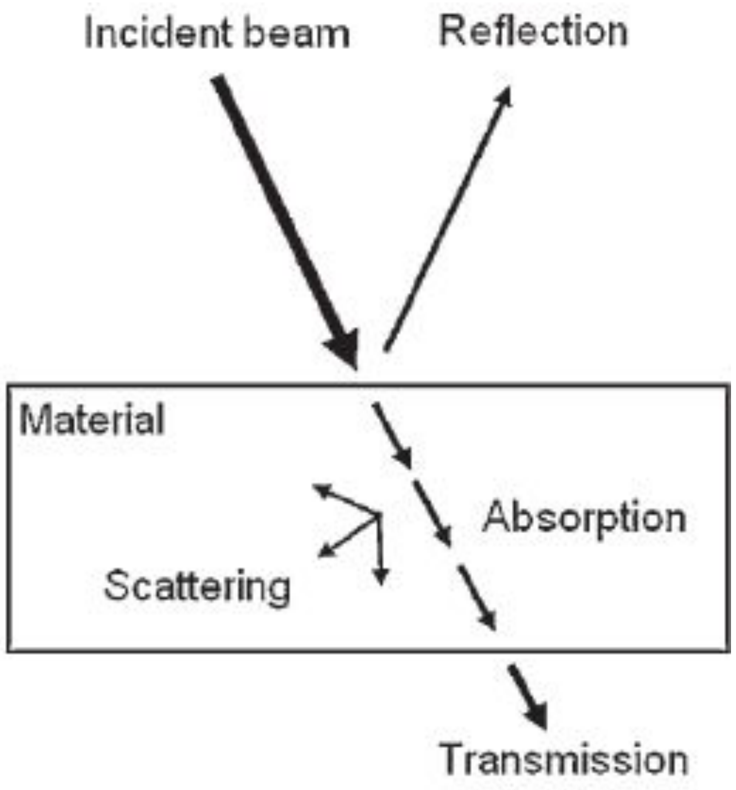
Working principle

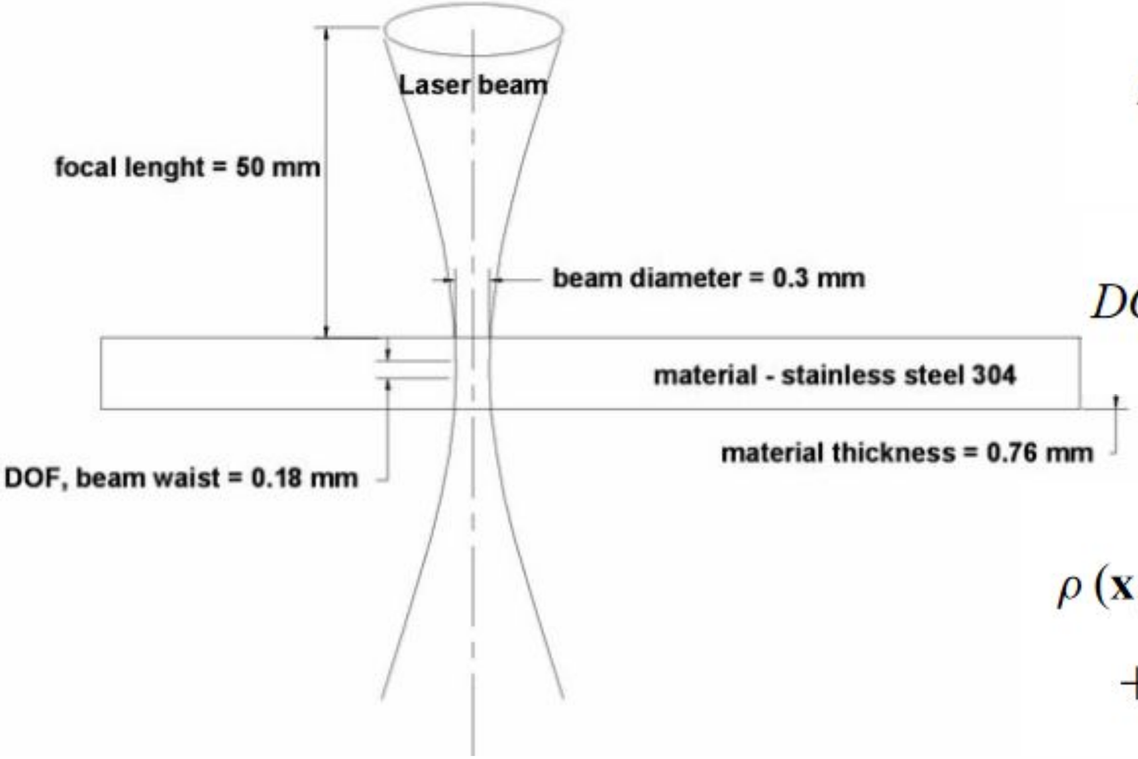
- When light strikes the surface of a material, a portion will be reflected from the interface due to the discontinuity in the real index of refraction and the rest will be transmitted into the material.

$$R = R_s = R_p = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

- Inside the material, absorption causes the intensity of the light to decay withdepth at a rate determined by the material's absorption coefficient α.

- Intensity decay: Beer lamberts law $I(z) = I_0 e^{-\alpha z}$





$$\Delta E = h \cdot \upsilon = \frac{h \cdot \nu_s}{\lambda} = \frac{h \cdot \nu_s \cdot n}{2L}$$ Photon energy…………………… (2)

$$DOF = \frac{8 \cdot \lambda}{\pi} \cdot \left[\frac{f}{D}\right]^2 = 2.44 \cdot \lambda \cdot \left[\frac{f}{D}\right]^2$$ Depth of Focus……………… (3)

$$\rho(\mathbf{x}, T)\, c_\rho(\mathbf{x}, T)\, \frac{\partial T(\mathbf{x}, t)}{\partial t} - \nabla\left[\kappa(\mathbf{x}, T)\, \nabla T(\mathbf{x}, t)\right] + \rho(\mathbf{x}, T)\, c_\rho(\mathbf{x}, T)\, \mathbf{v}_s \nabla T(\mathbf{x}, t) = Q(\mathbf{x}, t)$$

Heat equation…… (4)

- The material response will depend on the particular material system and the laser processing conditions.

Advantages

- Easy capability of being automated
- Straightforward process monitoring
- Forceless and contactless machining
- Minor heat-affected zone
- Marginal modifications to the microstructure
- Machining free of burr and bulging
- High flexibility regarding design of tiny structures
- High machining speed
- High precision
- Constant machining quality
- No additional tooling costs by wear
- No solvent chemicals used
- Material removal rate controllable down to the nanometer scale

Disadvantages

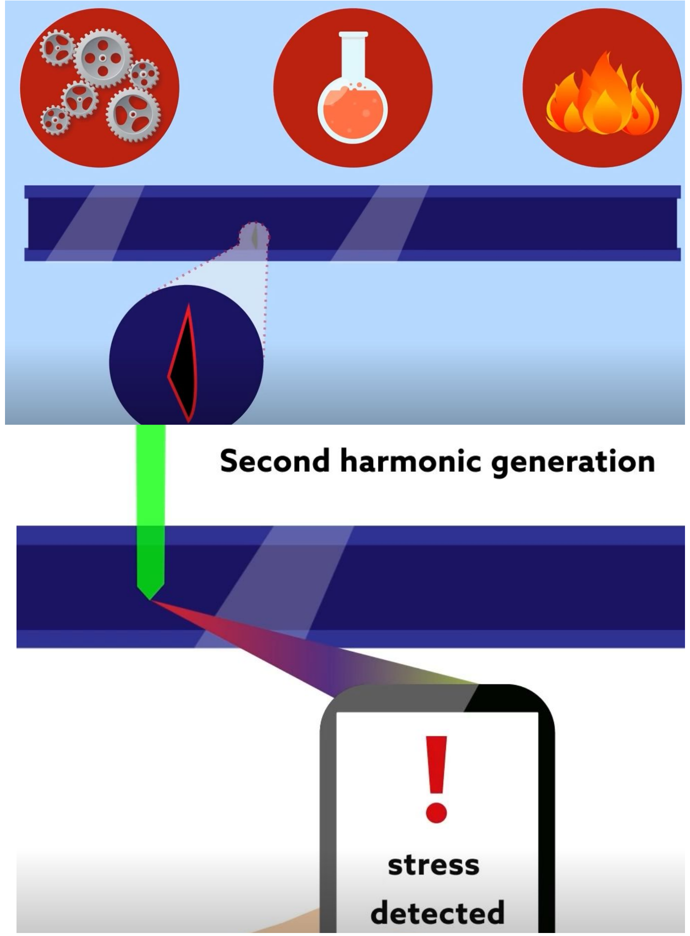
- The equipment required for micro machining is very costly than other cutting processes.
- Need highly skilled persons to operate micro machining systems.
- Material limitations (including crystalline and reflective materials)
- Reflected laser light can present a safety hazard

Industrial applications

- Solid-state lasers are used in materials processing, spectroscopy, ultrashort pulse research, multiphoton microscopy, and medical applications.

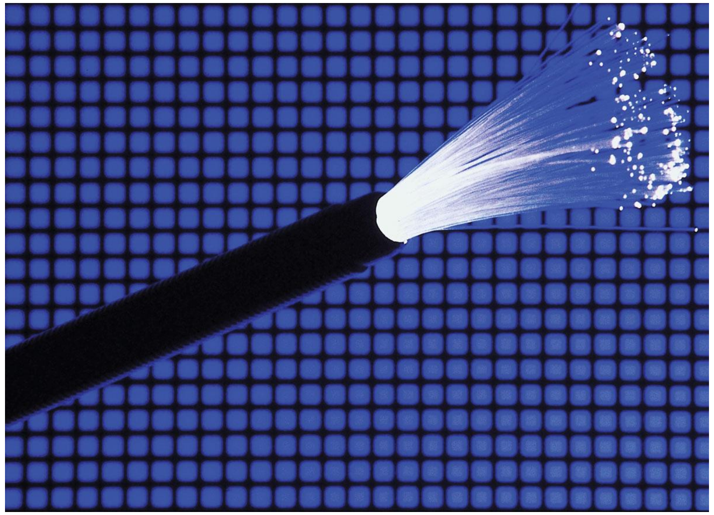
- https://youtu.be/a_qg4jC-HXM

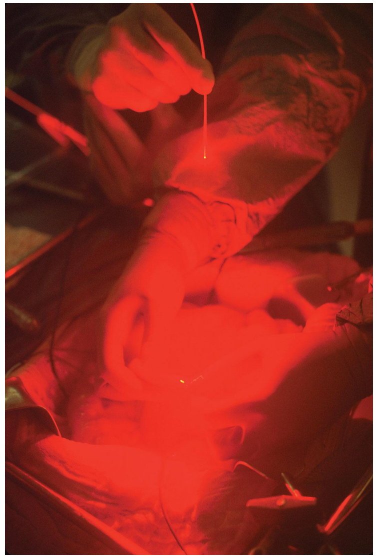
Industrial applications

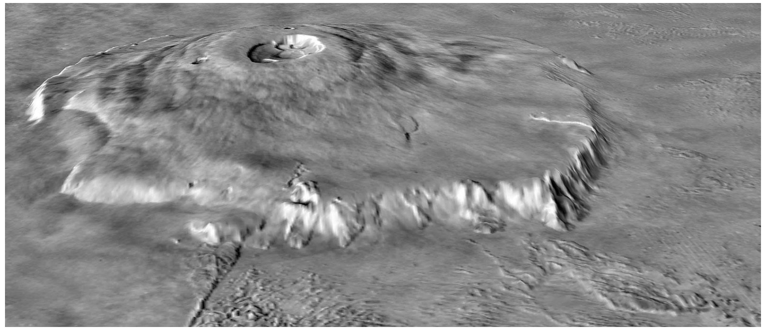


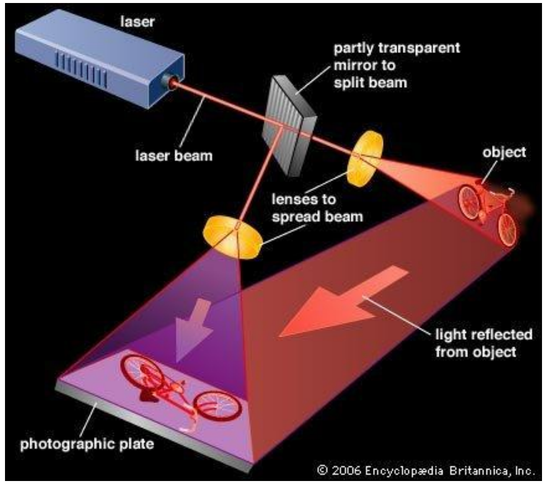
Laser testing of metals


Laser scanners


Optical communication


Medical surgery


Surveying



Holography