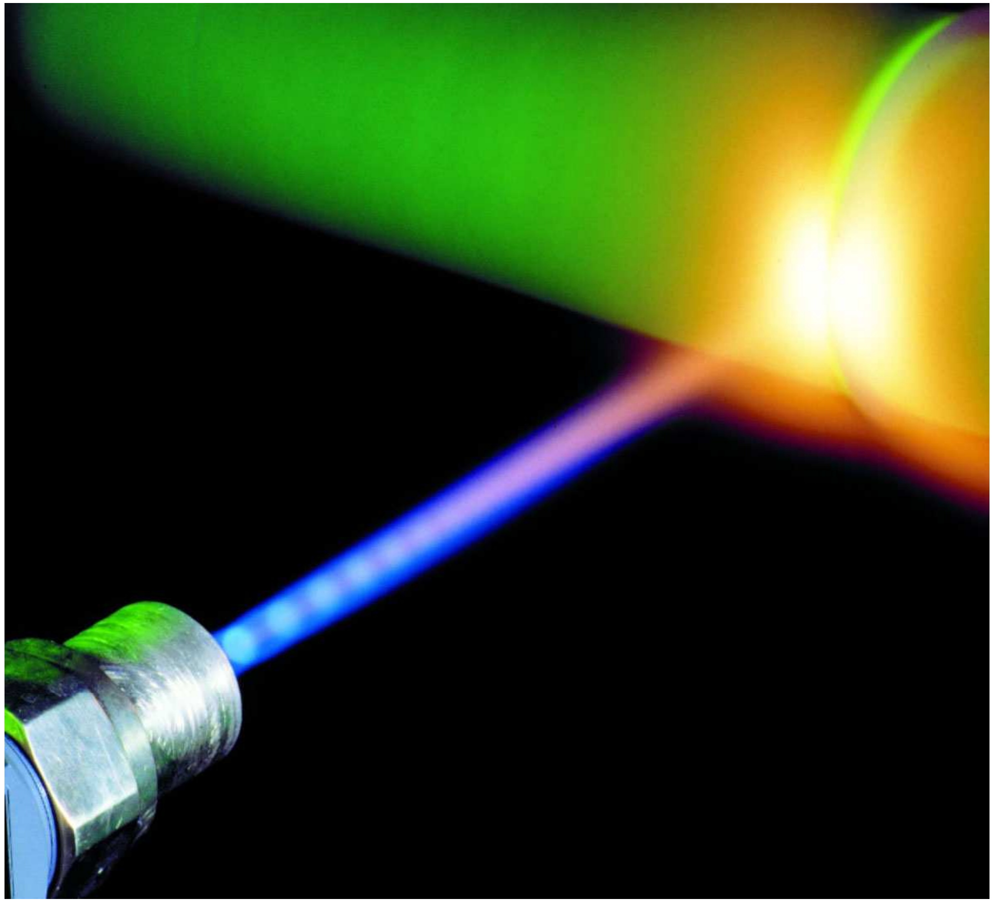
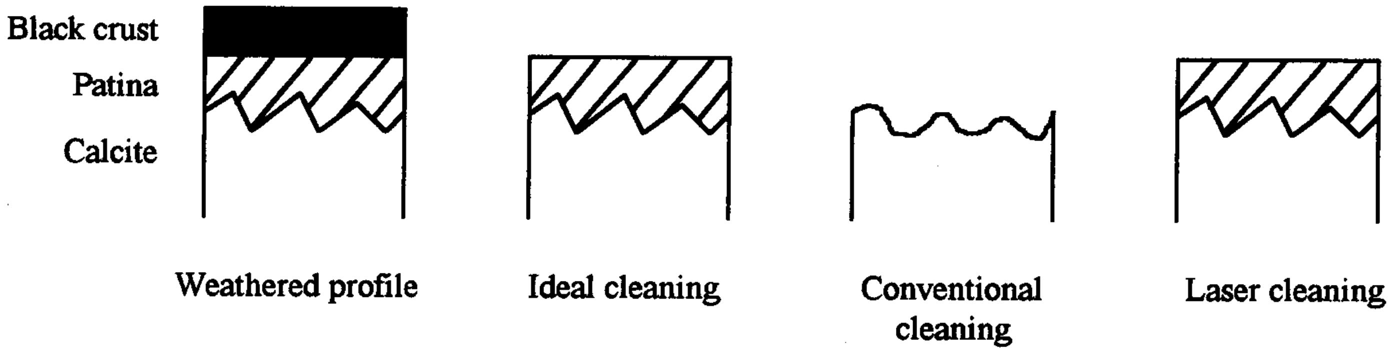
LASERY



Čištění laserovým paprskem

Nd:YAG
Excimer
Er:YAG
Pulsní CO2



Průmysl:

Polymerní povlaky
Koroze
Ropné produkty
Částice nečistot
Dezinfekce

Ochrana KD:

Koroze
Inkrustace
Sediment
Mikroorganismy
Graffitti
Přemalby

Čištění laserovým paprskem

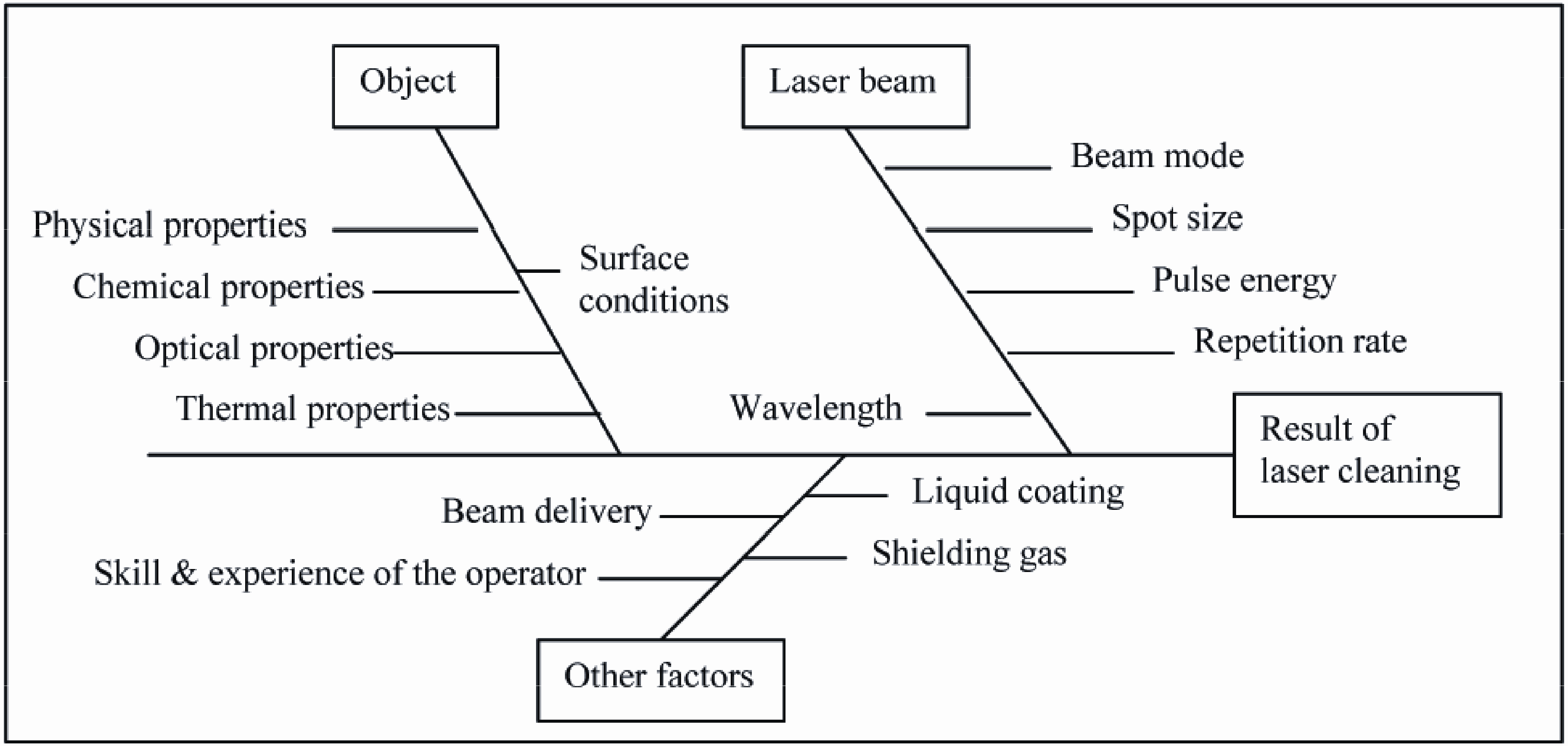


Figure 4. Ishikawa diagram of the factors affecting the laser cleaning process

Mechanismy čištění laserem

Fokusace laserového paprsku

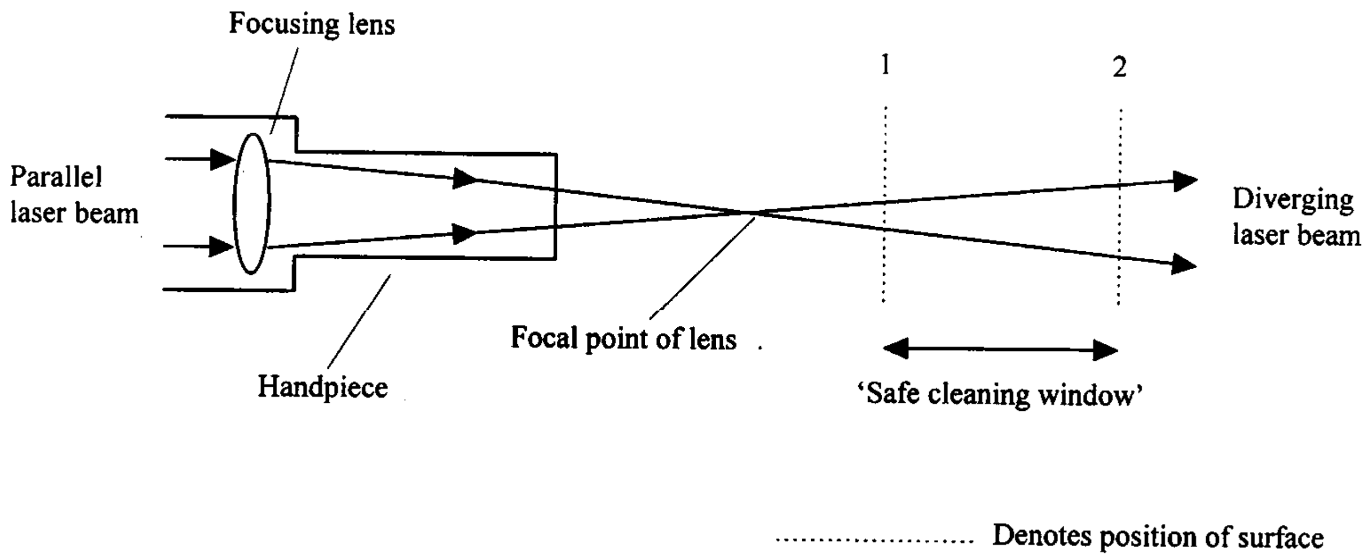
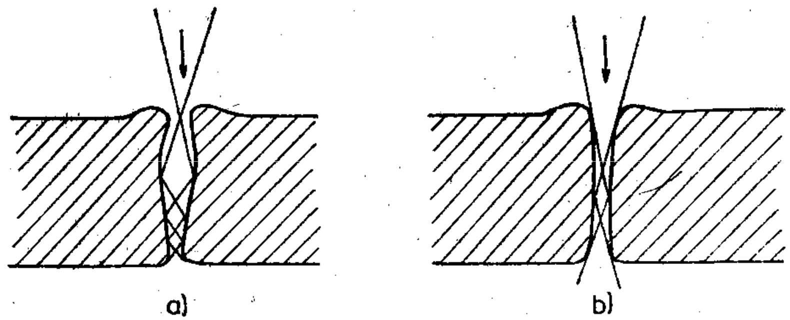


Figure 4.2. *Schematic representation of cleaning with a diverging laser beam.*



Obr. 64. Řez kráterem vypáleným laserovým svazkem při různých polohách ohniska fokusační techniky: *a*) ohnisko při povrchu materiálu, *b*) ohnisko pod povrchem

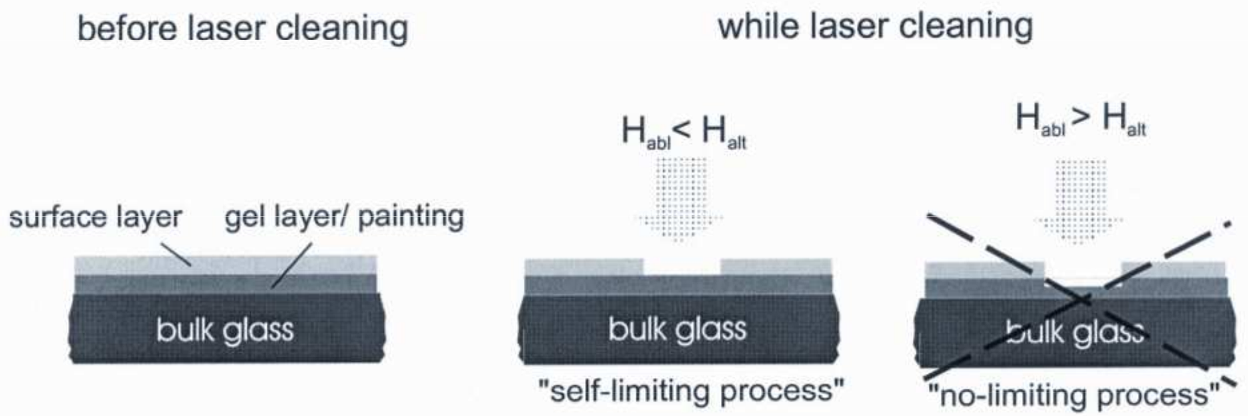
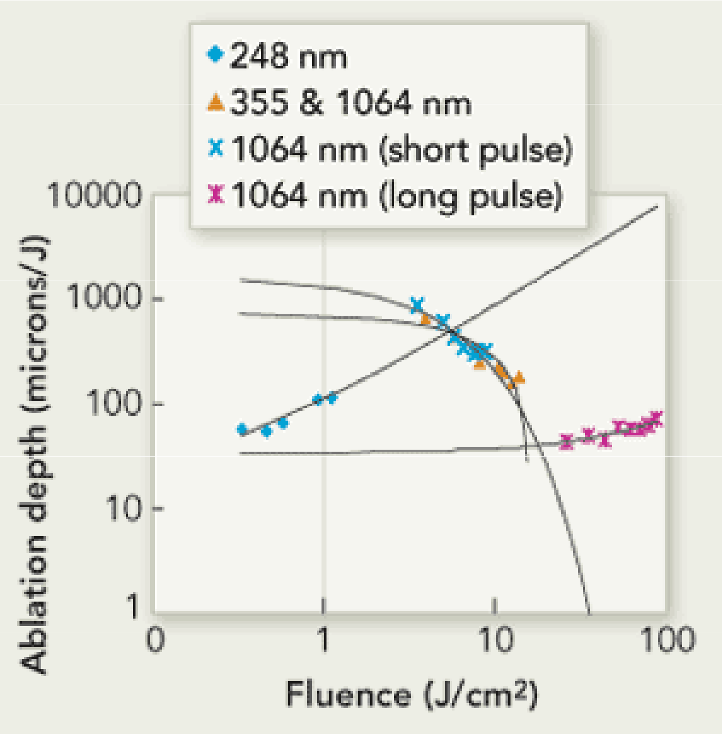
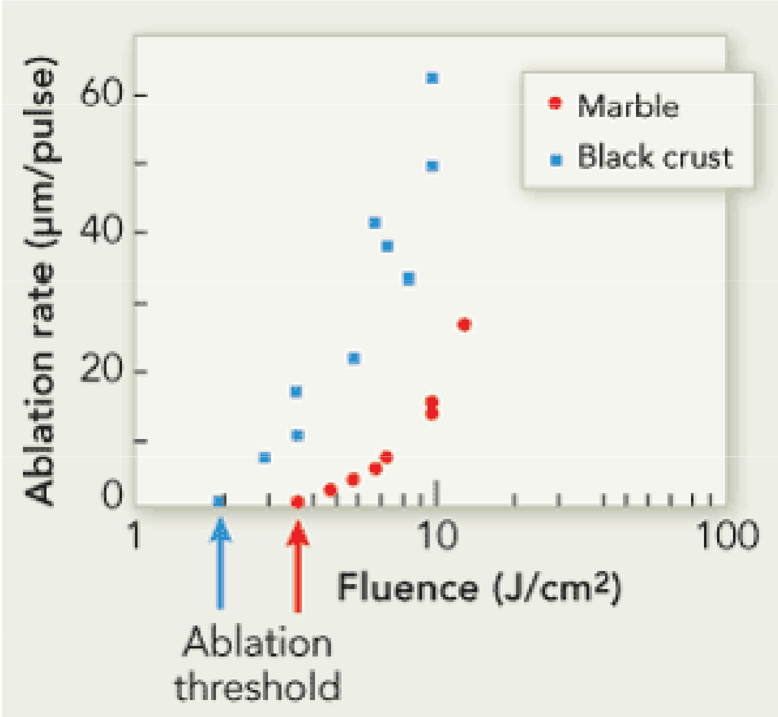
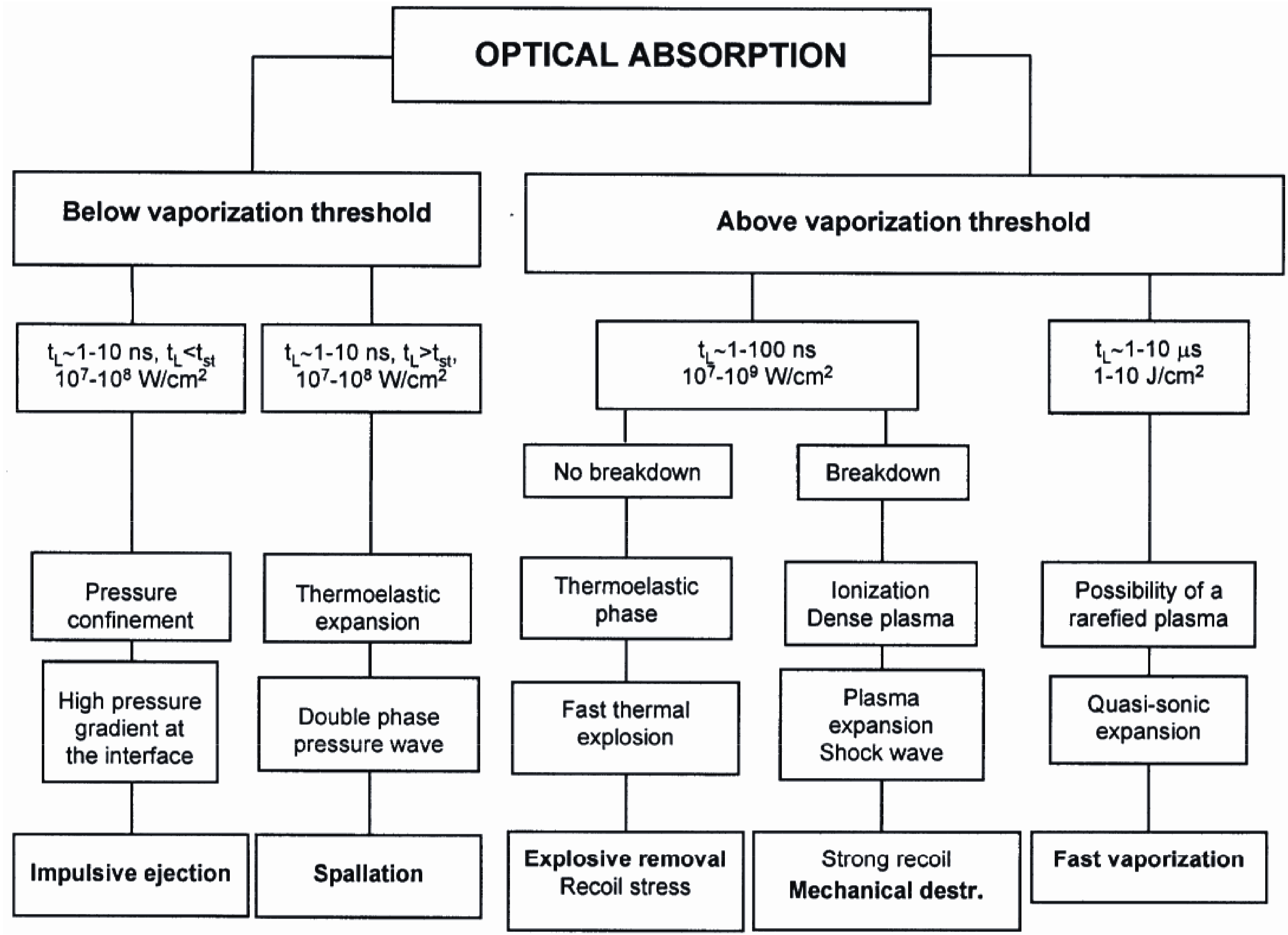
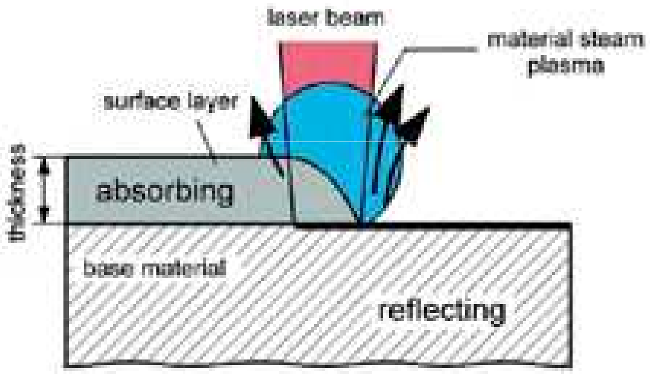


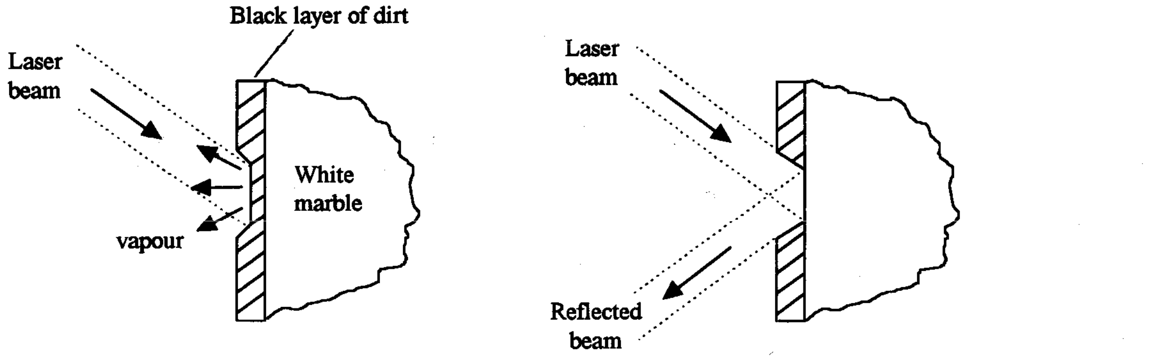
Figure 6. Schematic presentation of the assumed ablation characteristics of different layers and the consequences for the ablation process (H_{abl} = ablation threshold, H_{alt} = alteration threshold).






OPTICAL ABSORPTION
Below vaporization threshold
Above vaporization threshold
t_L~1-10 ns, t_L<t_{st}
10^7-10^8 W/cm^2
t_L~1-10 ns, t_L>t_{st},
10^7-10^8 W/cm^2
t_L~1-100 ns
10^7-10^9 W/cm^2
t_L~1-10 μs
1-10 J/cm^2
No breakdown
Breakdown
Pressure confinement
Thermoelastic expansion
Thermoelastic phase
Ionization Dense plasma
Possibility of a rarefied plasma
High pressure gradient at the interface
Double phase pressure wave
Fast thermal explosion
Plasma expansion Shock wave
Quasi-sonic expansion
Impulsive ejection
Spallation
Explosive removal Recoil stress
Strong recoil Mechanical destr.
Fast vaporization





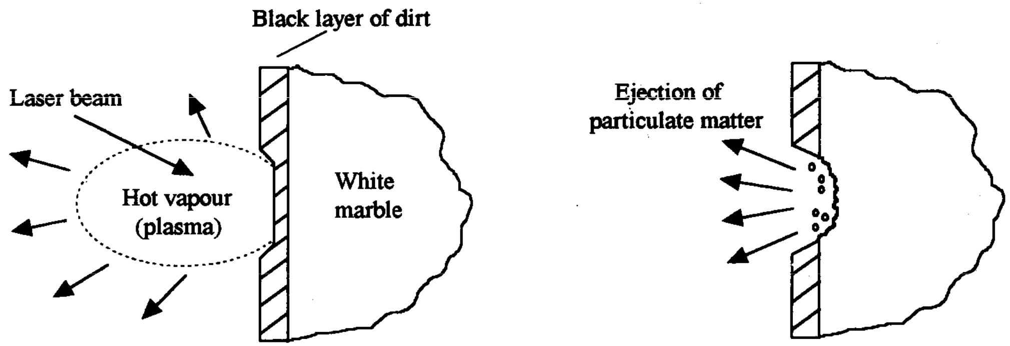
Absorption of laser beam

Reflection of laser beam

Initial interaction of long pulse radiation with a dark encrustation. Strong absorption of energy leads to vaporisation of material.

Final interaction of long pulse radiation with a dark encrustation. Once the encrustation has been removed further pulses are reflected from the weakly absorbing marble surface.

Figure 1.3. *Normal-mode cleaning (Asmus, 1973).*



Beginning of laser pulse

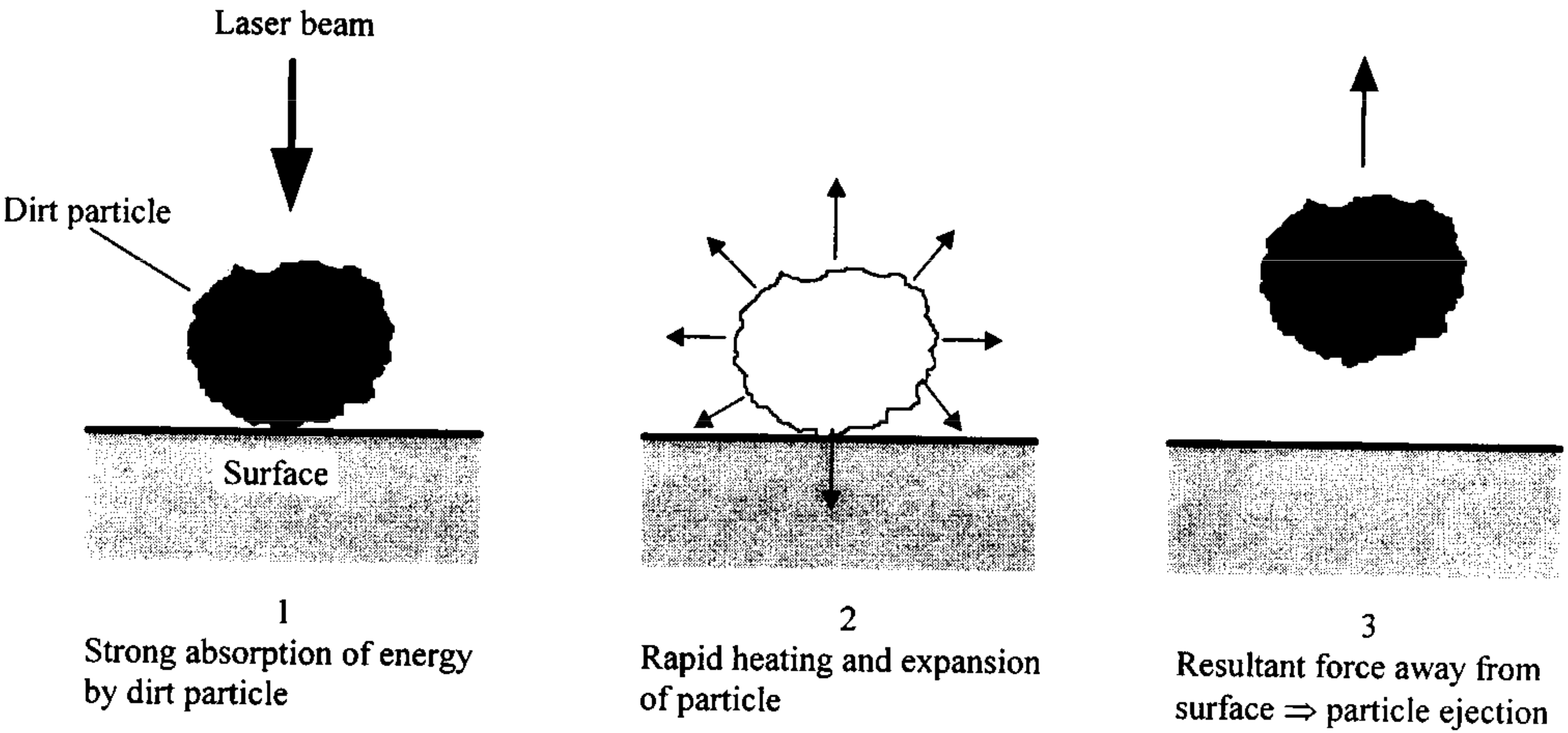
Vaporisation of encrustation occurs early during the pulse, leading to formation of a plasma. The temperature and pressure of the plasma increase rapidly as the incoming laser radiation is absorbed and a microscopic compression is applied to the surface.

End of same laser pulse

As soon as the laser pulse finishes the plasma expands away from the surface. The surface relaxes and a thin layer of material is ejected.

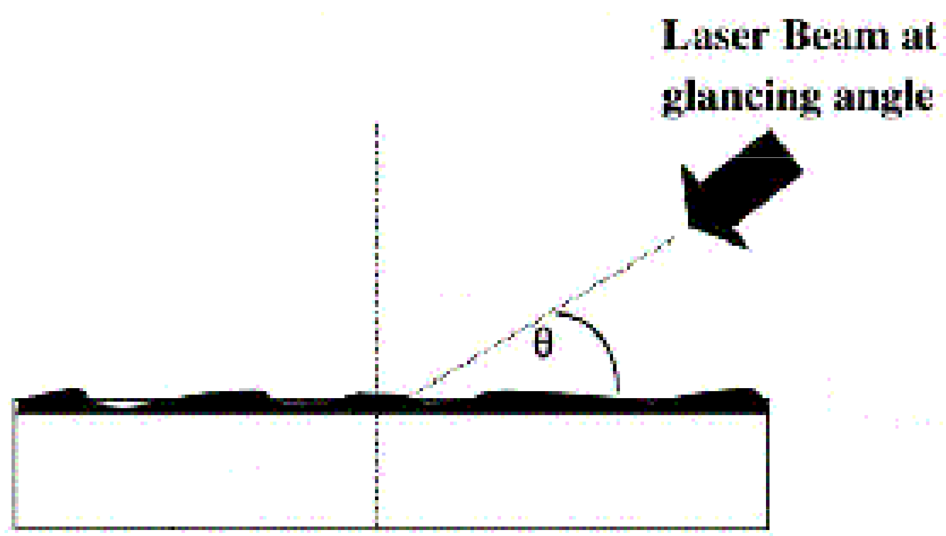
Figure 1.4. *Removal of material by Q-switched laser radiation (Asmus, 1973).*

Termická expanze částic



Removal of dirt particles by rapid thermal expansion.

Angulární čištění (α< 90°)



Efektivnější než klasicky používané kolmé uspořádání, největší absorptivita při Brewstrově úhlu.

Index lomu materiálu = tan(Brewstrova úhlu).

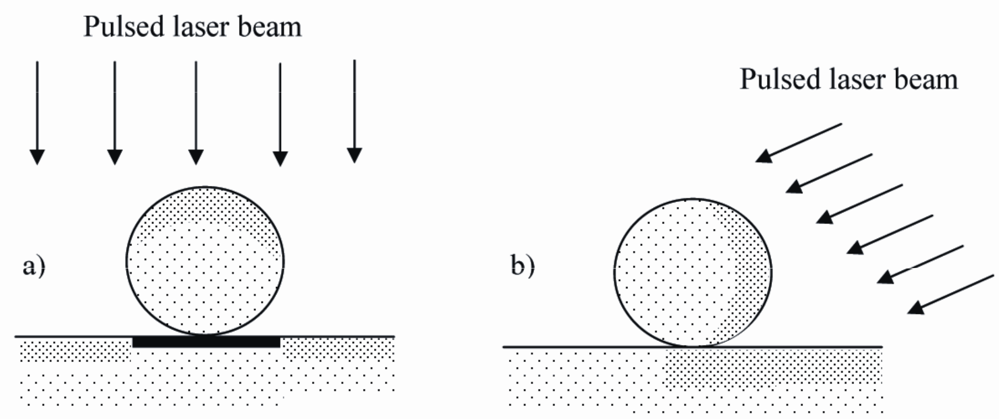


Fig. 3. Illustration of the laser absorption on the surfaces of the particle and the substrate for different laser incident angles (The density of "dots" indicates the amount of heating due to the laser absorption on the surfaces)

Čištění rázovou vlnou

Je účinná jen pro malé a silně vázané částice, pro čištění památek se nepoužívá.

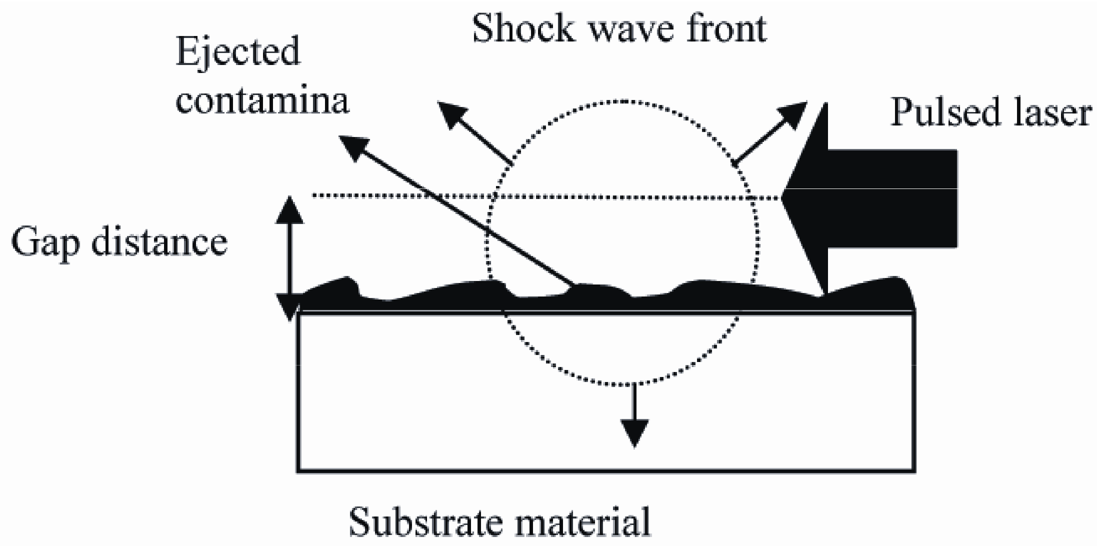


Fig 4: Schematic diagram of laser shock cleaning

Steam cleaning

= aplikace filmu kapaliny na povrch artefaktu

- Nečistoty jsou vázány pevně na povrch artefaktu a nelze je odstranit suchým čištěním.
- Povrch artefaktu je křehký a je tedy třeba použít menší hustotu energie.

Nejpoužívanější kapalinou je voda, možné je i použití organických rozpouštědel.

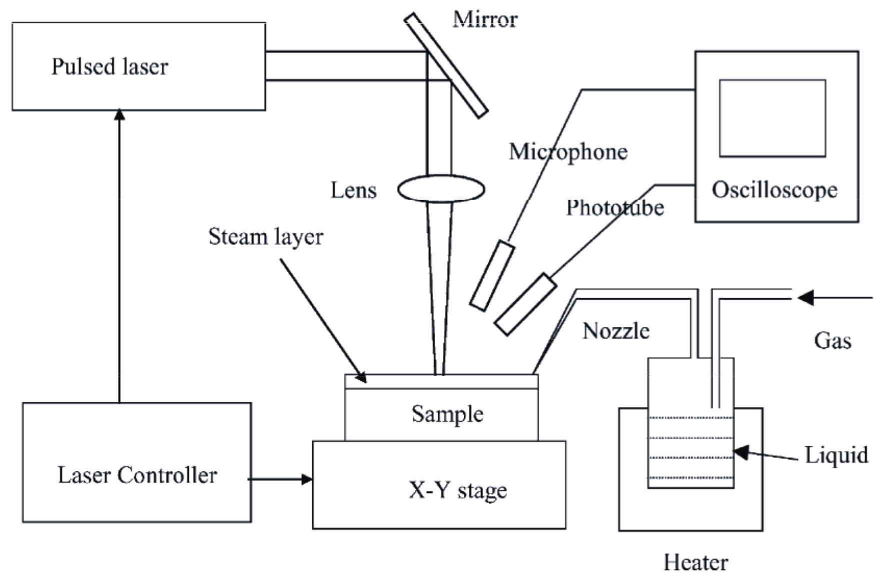
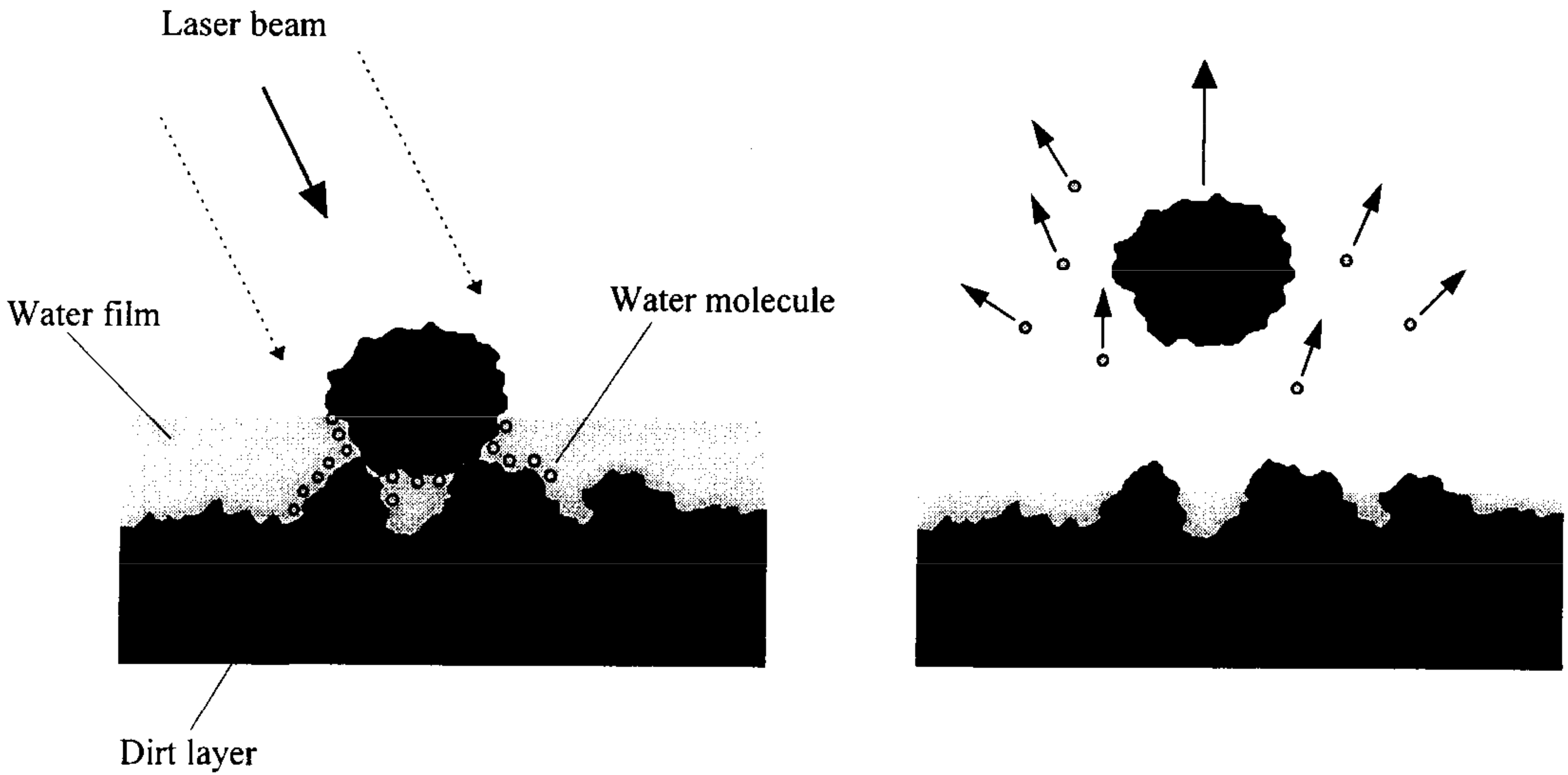


Fig. 1. Experimental set-up for steam-assisted laser ablation.

Kavitace – další možný mechanismus

Ablace v kapalině



Absorption of energy by dirt layer.
Rapid heating of water molecules at
water/dirt interface.

Explosive vaporization of water enhances
dirt removal from surface

Ablace koroze v kapalině (s vloženým napětím)

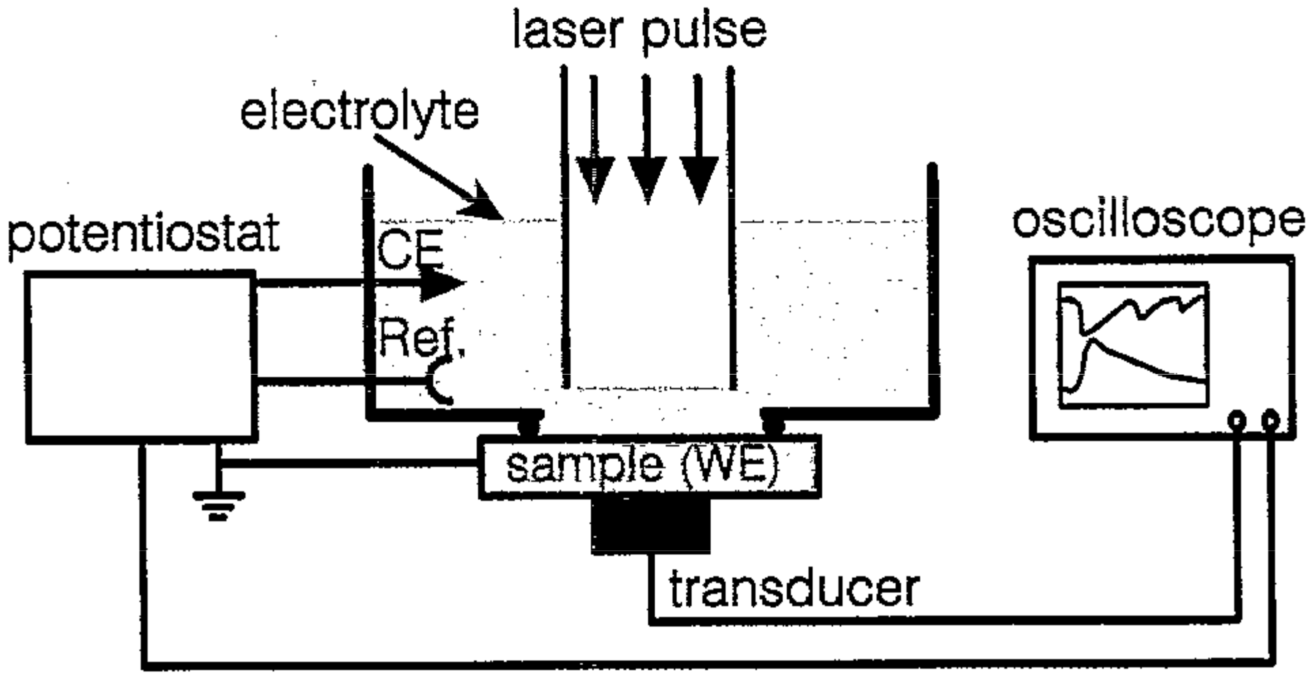


Fig. 1. Experimental configuration for the laser-induced oxide film removal in a liquid confinement at controlled electrochemical potential. Ref., reference electrode; CE, counter electrode; and WE, working electrode.

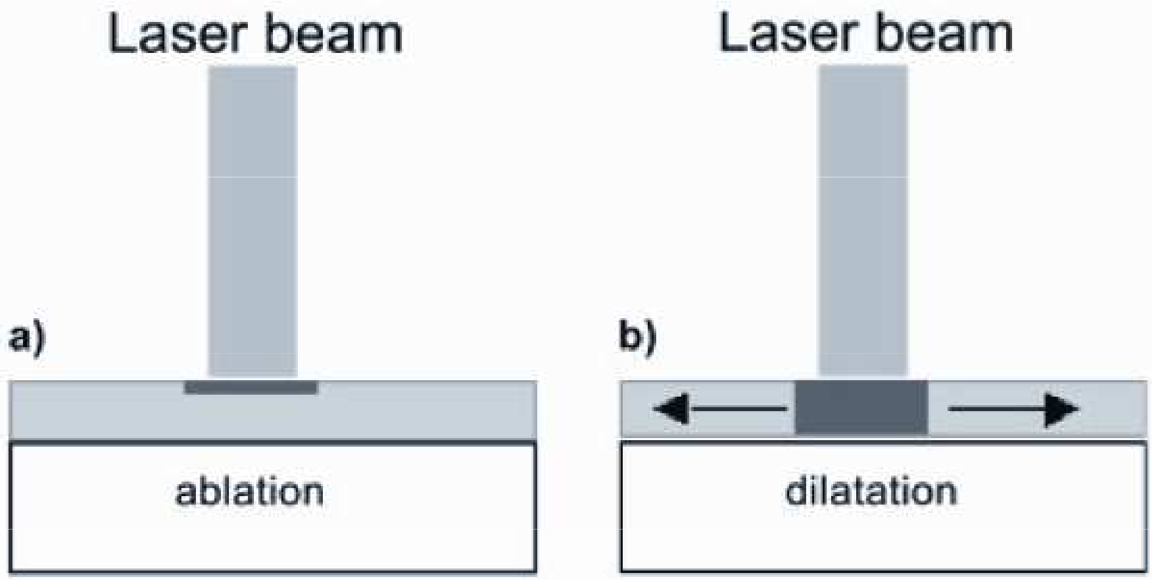


Fig. 4a,b. Schematic picture of the energy absorption in the Fe_3O_4 layer **a** before and **b** after electrochemical polarisation

Na železný předmět v borátovém pufru (pH = 10) v tříelektrodovém uspořádání (předmět = katoda) se vloží kontrolovaný potenciál (-2 V). Vodík vznikající katodickou redukcí se zachycuje na oxidové vrstvě. Laserový puls (Nd:YAG 1064 nm) způsobí rozpínání vodíku a mechanickou destrukci korozní vrstvy. Monitorování průběhu čištění se provádí např. cyklickou voltametrií.

Aplikace laserů pro likvidaci mikroorganismů

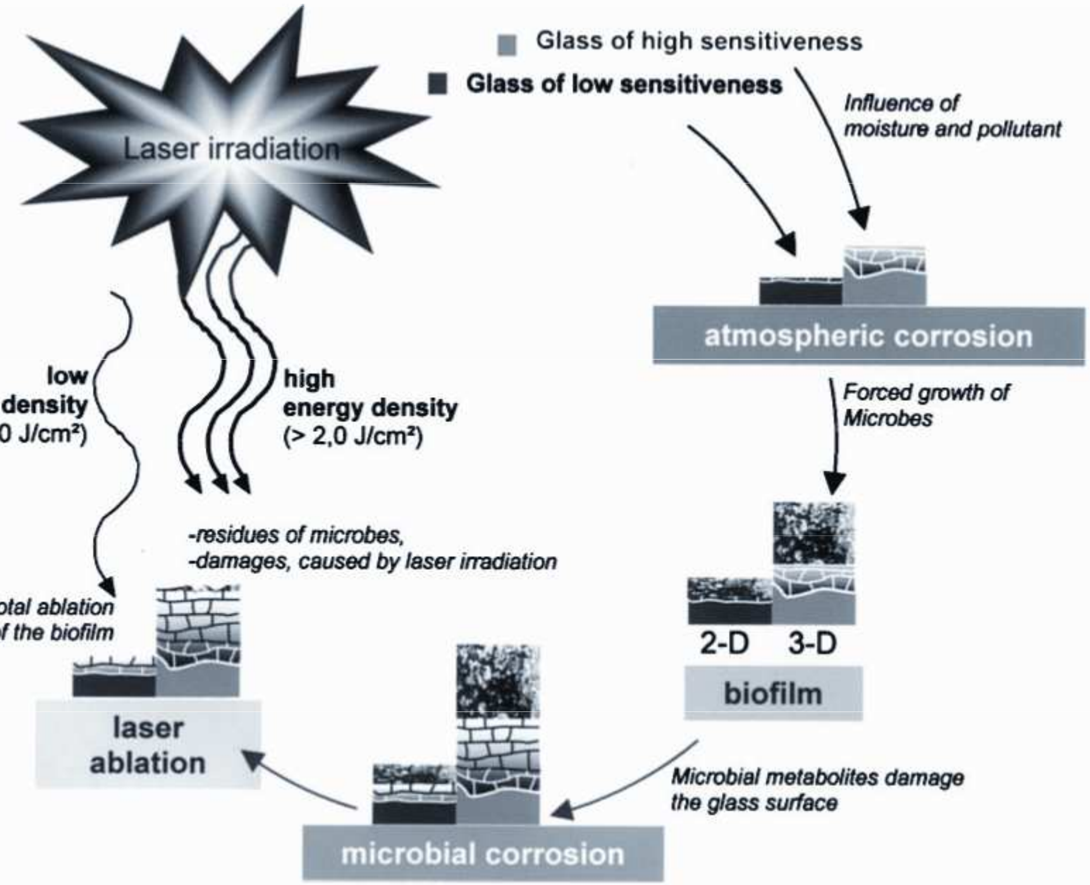


Figure 10. Interaction of glass and biofilm and the synergetic effect of glass composition, abiotic corrosion, biogenic corrosion and growth of biofilm, factors which influence the effectiveness of the laser cleaning.

- Bakterie
- Plísně
- Lišejníky

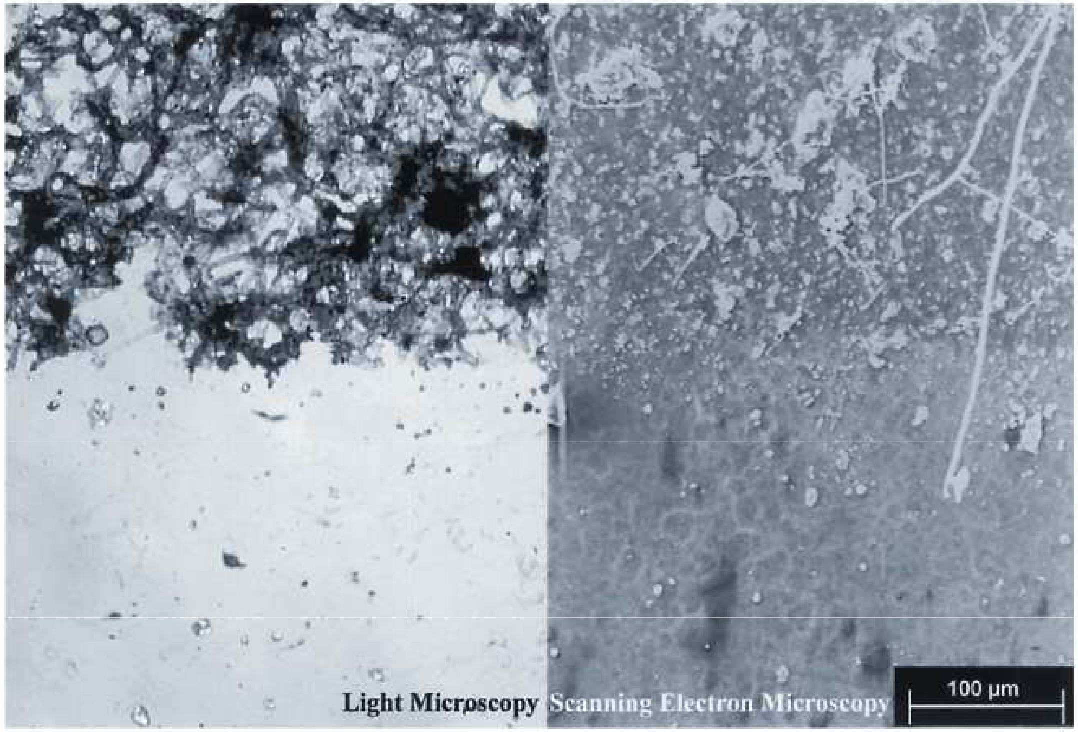
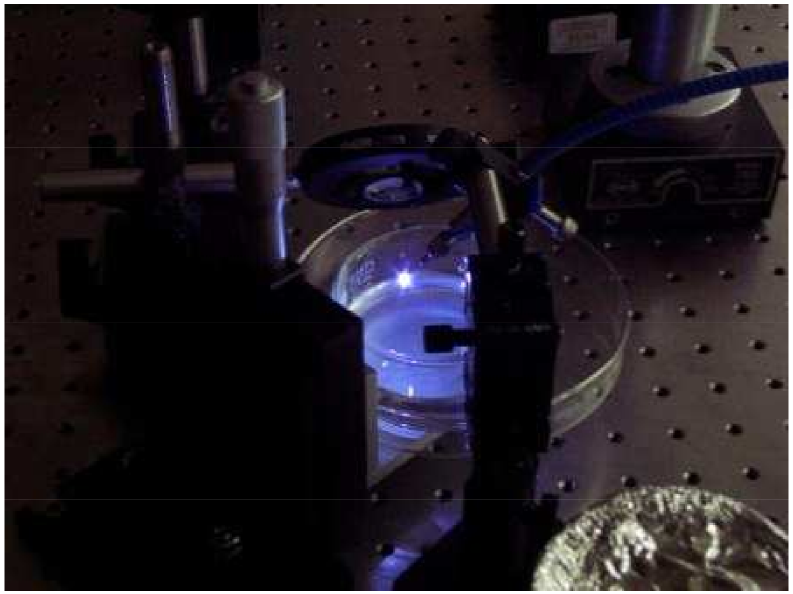
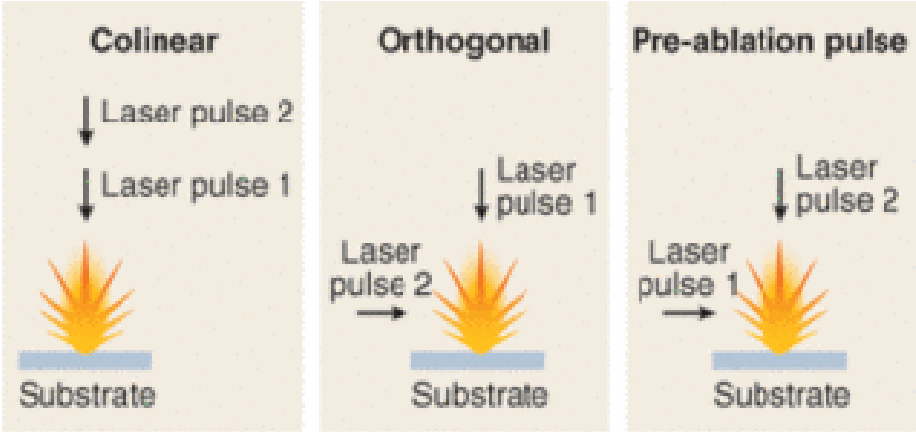


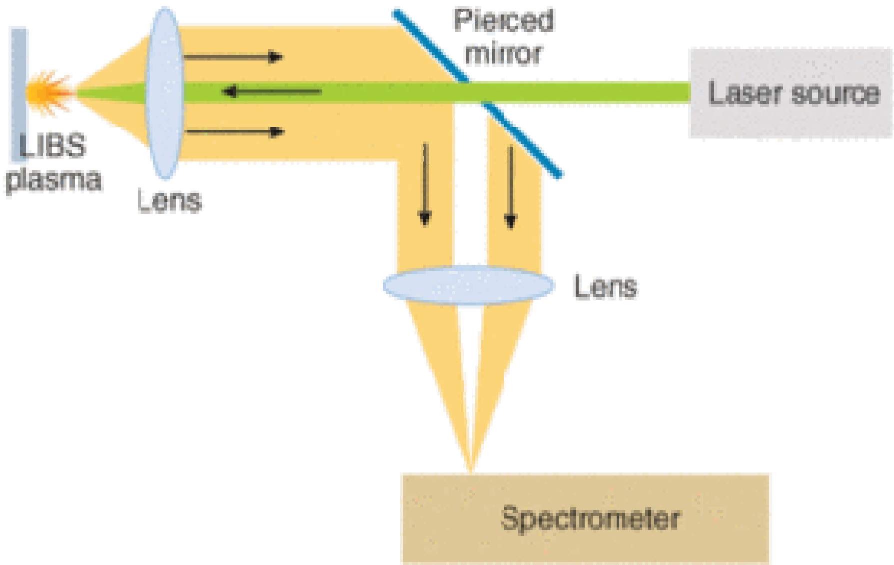
Figure 2. The laser cleaning of two-dimensional biofilms is successful with an energy density of 1.0 J/cm^2.

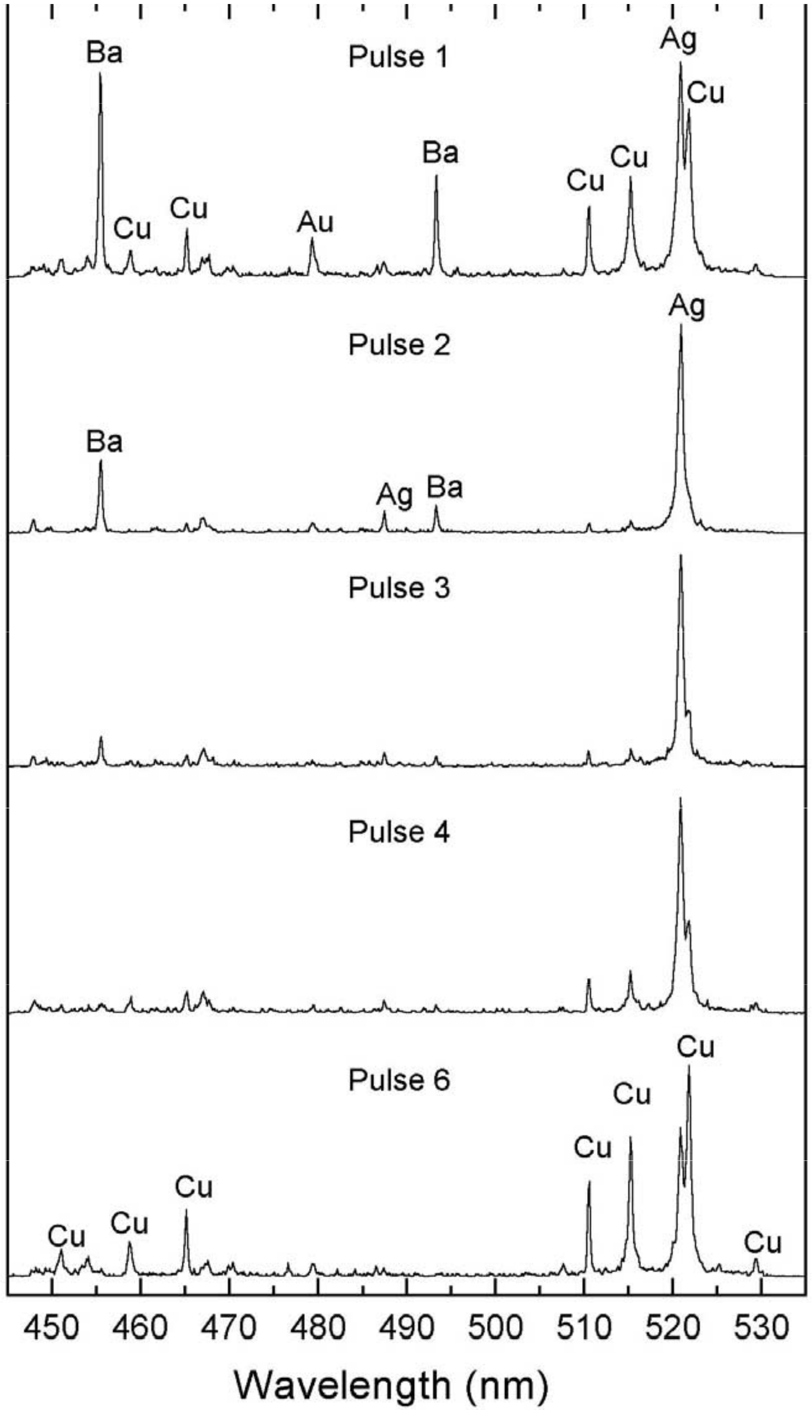


Monitorování procesu laserového čištění

LIBS







Daguerrotypie, 19. stol.

LIBS

Molekulové pásy →

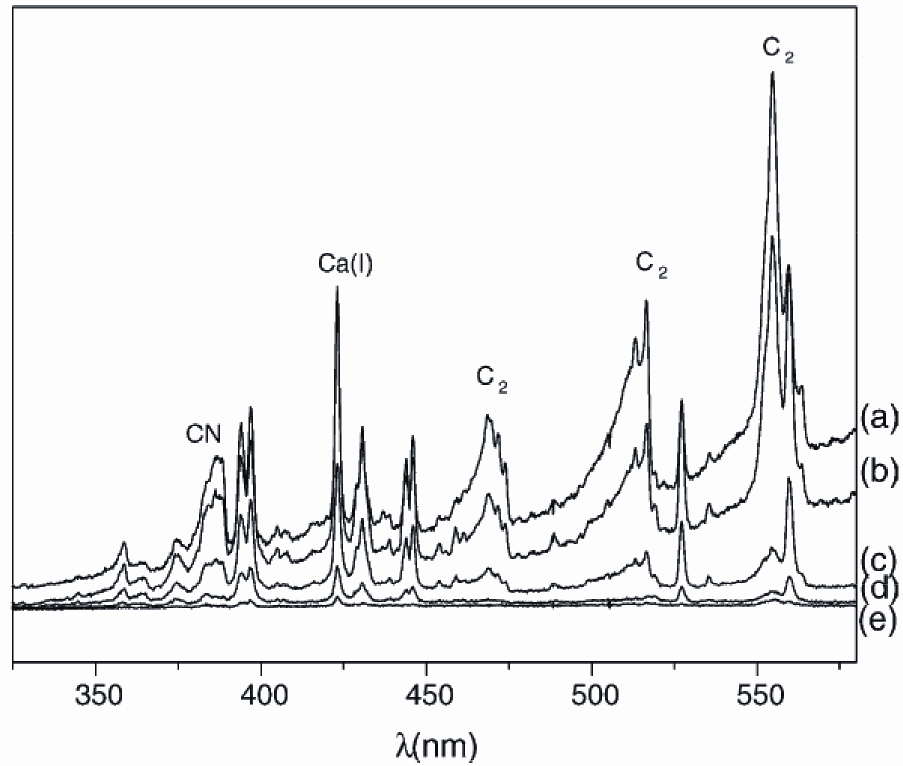


Fig. 6. Evolution of LIBS spectrum with the number of pulses during the removal of black paint on wood: (a) pulse 1, (b) pulse 2, (c) pulse 4, (d) pulse 7 and (e) pulse 9. Irradiation wavelength: 308 nm.

Spojení s Ramanovou spektrometrií

Měření na dané čáře v UV-VIS

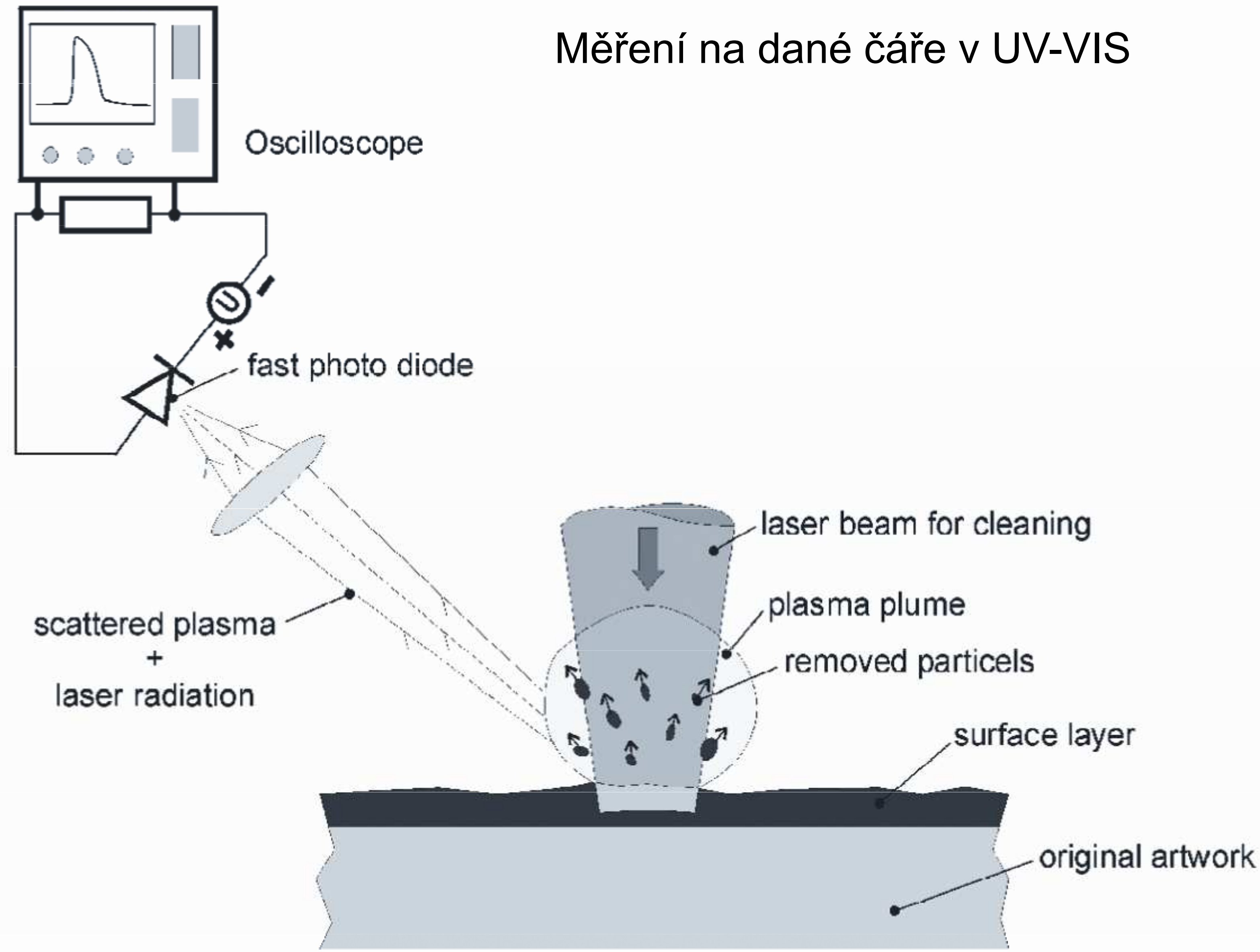


Fig. 1. Experimental set-up for detection of the scattered radiation during laser cleaning.

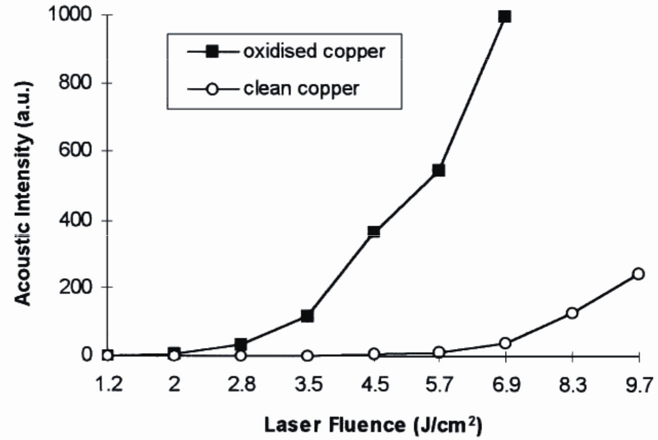
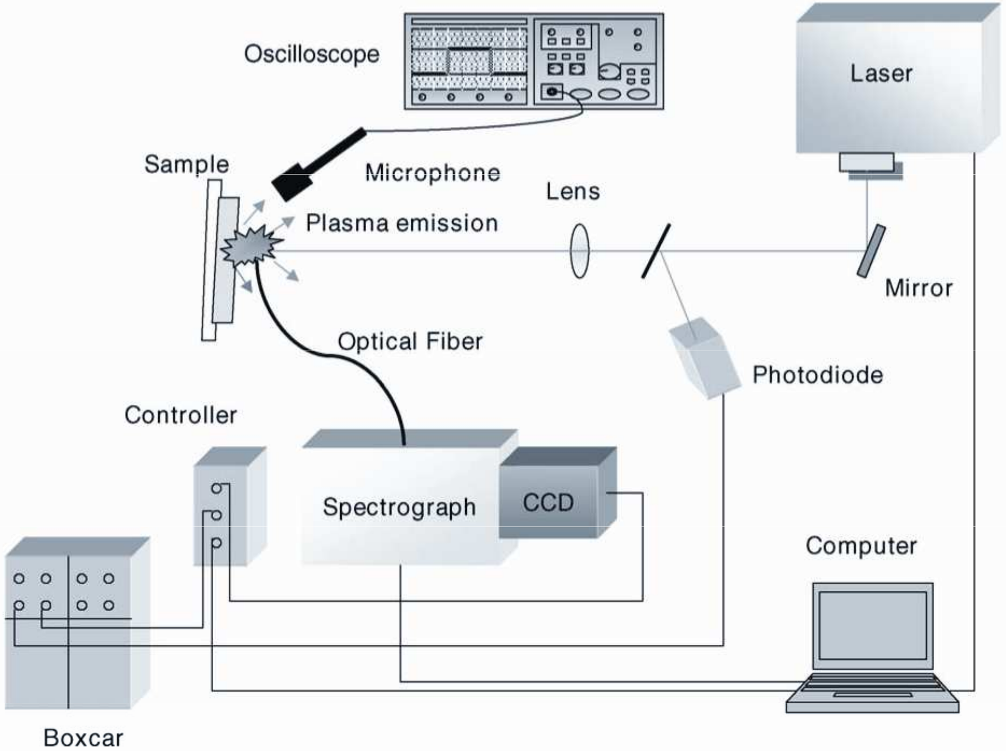


Fig. 3. Acoustic emission intensity as a function of laser fluence in the laser treatment of an oxidised copper surface and a clean copper surface.



Schematic diagram of the experimental set-up used for the LIBS experiments and for the photoacoustic measurements.

Sledování akustického projevu

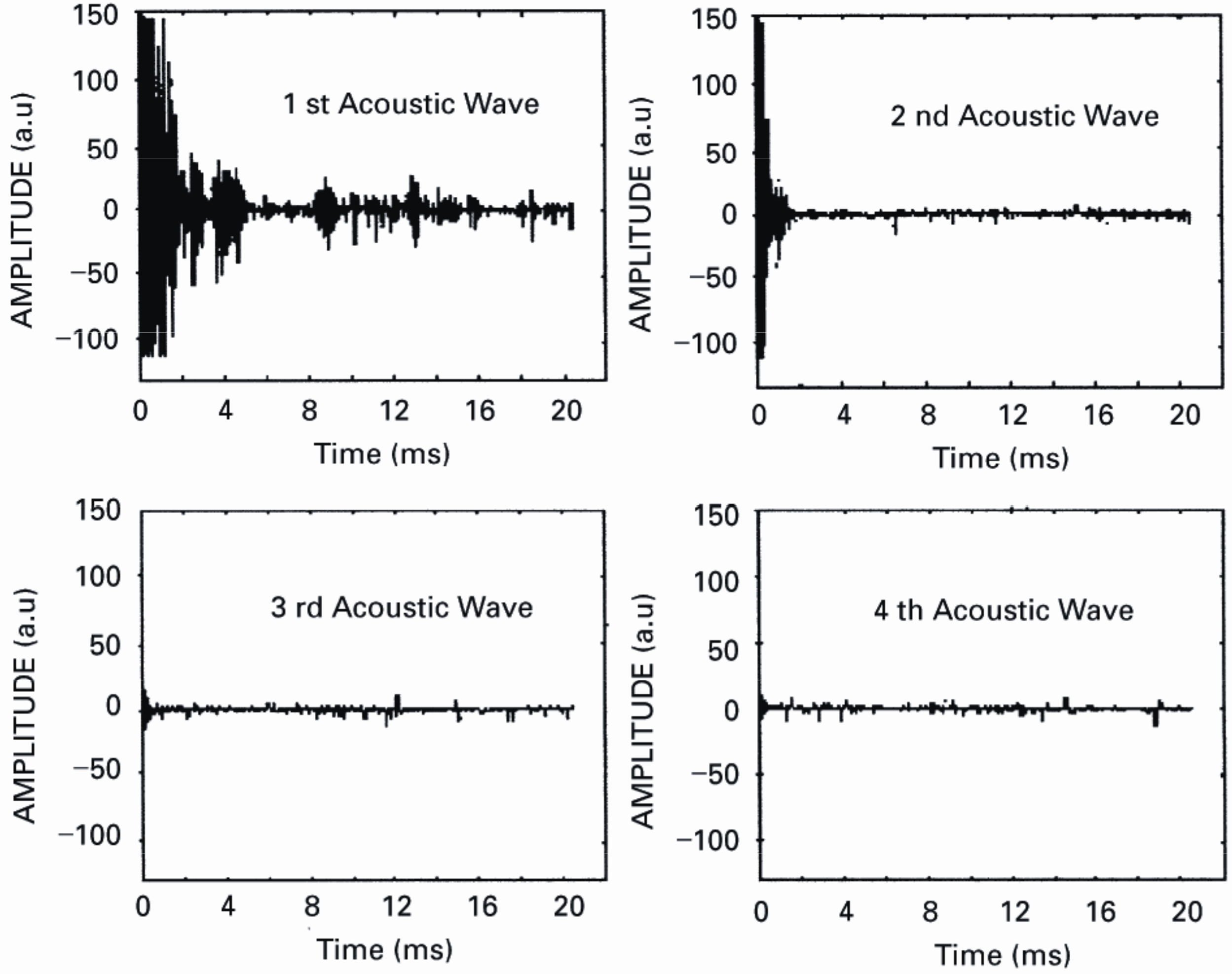


Fig. 2. Acoustic waves emitted from an oxidised copper substrate under laser irradiation from the first to the fourth pulse, respectively.

Zařízení na laserové čištění uměleckých artefaktů

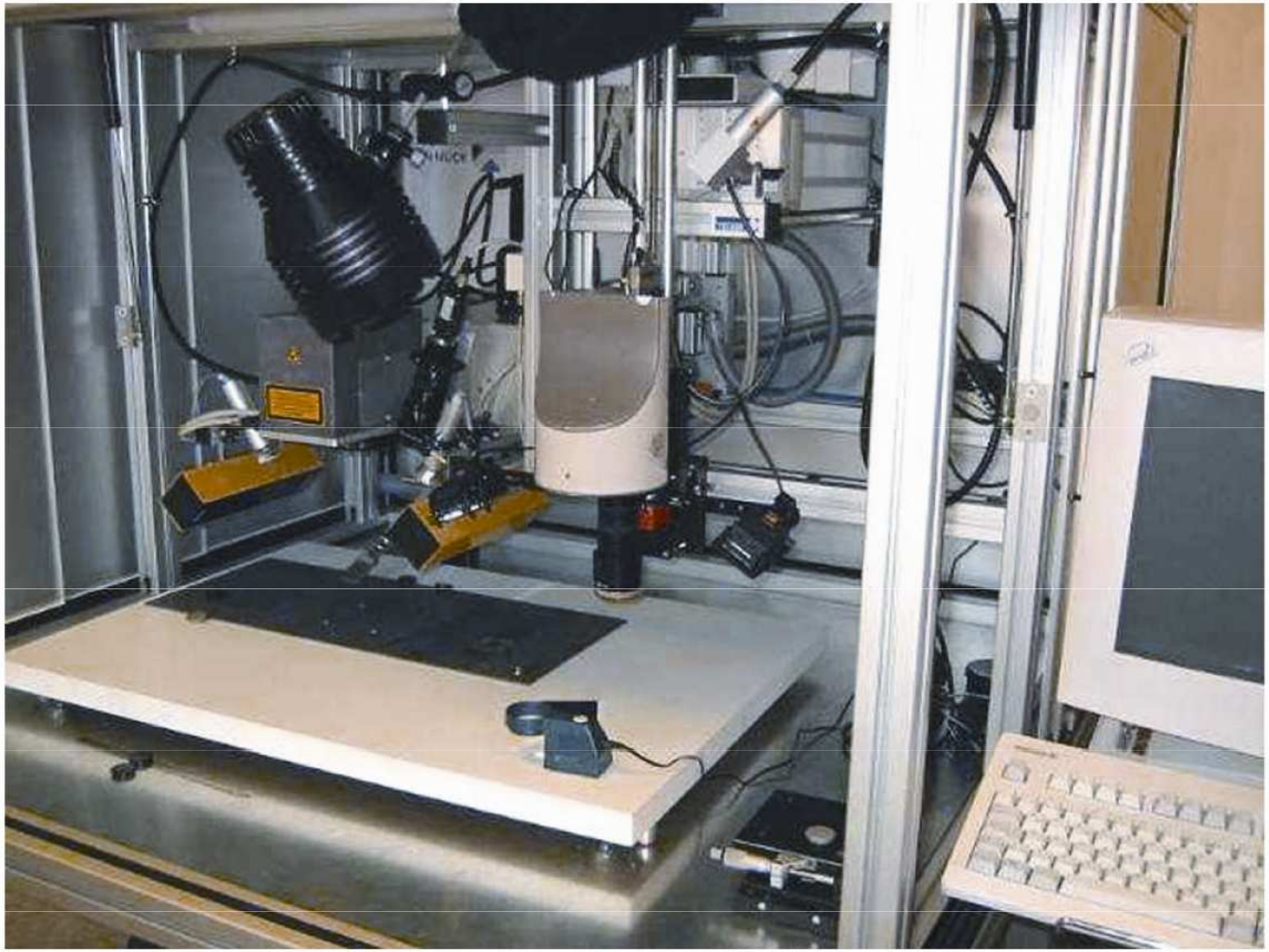


Figure 6.

The laser system developed for the cleaning of paper and parchment is organised in a closed box, providing maximum safety of operation. The set-up includes besides the laser imaging systems and a positioning table.

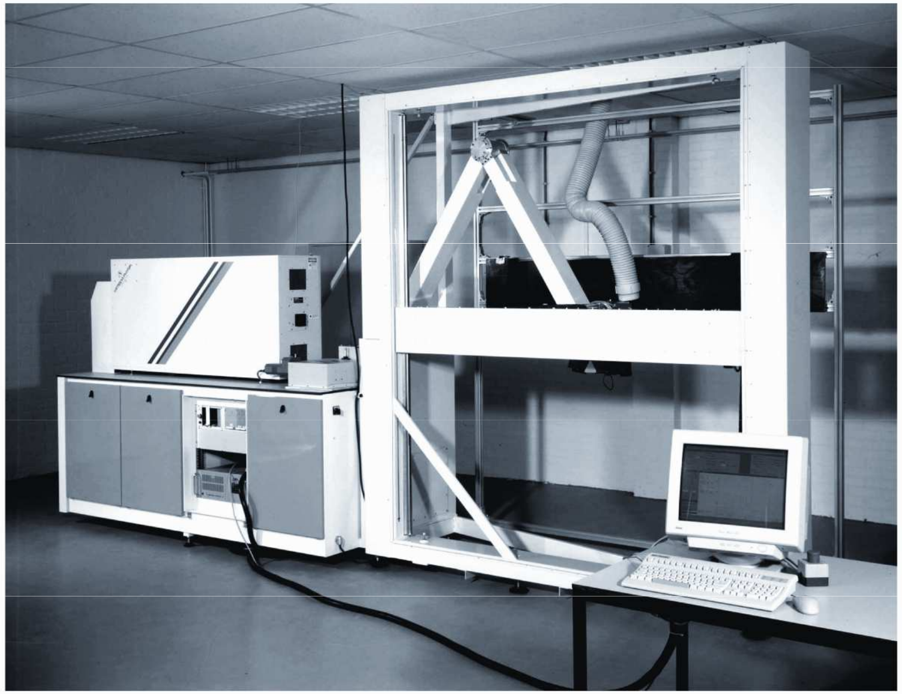
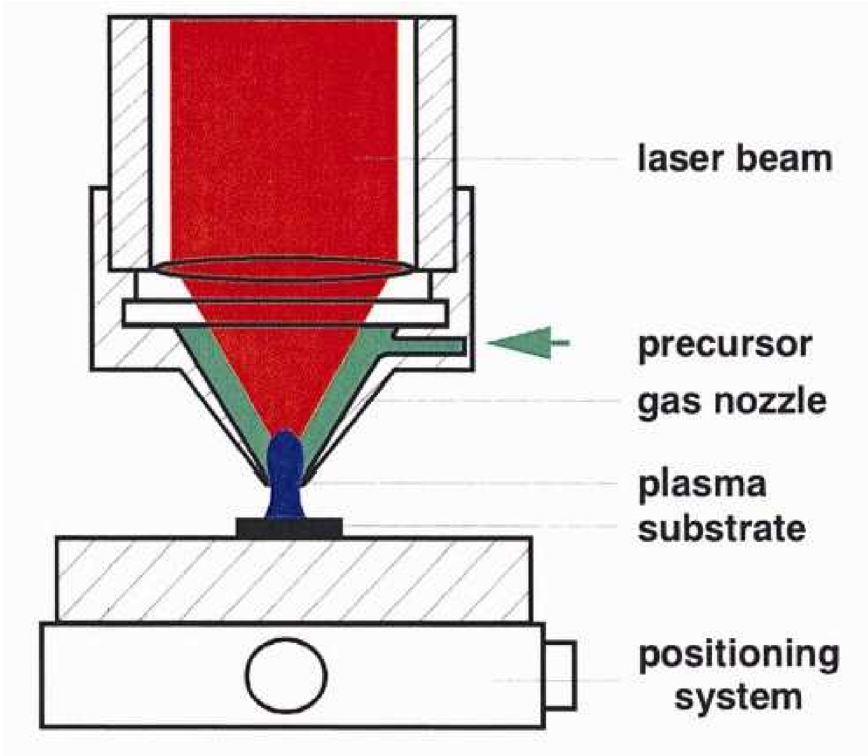


Plate 4.1. *Laser cleaning of sculptural detail on the outside of a building.*

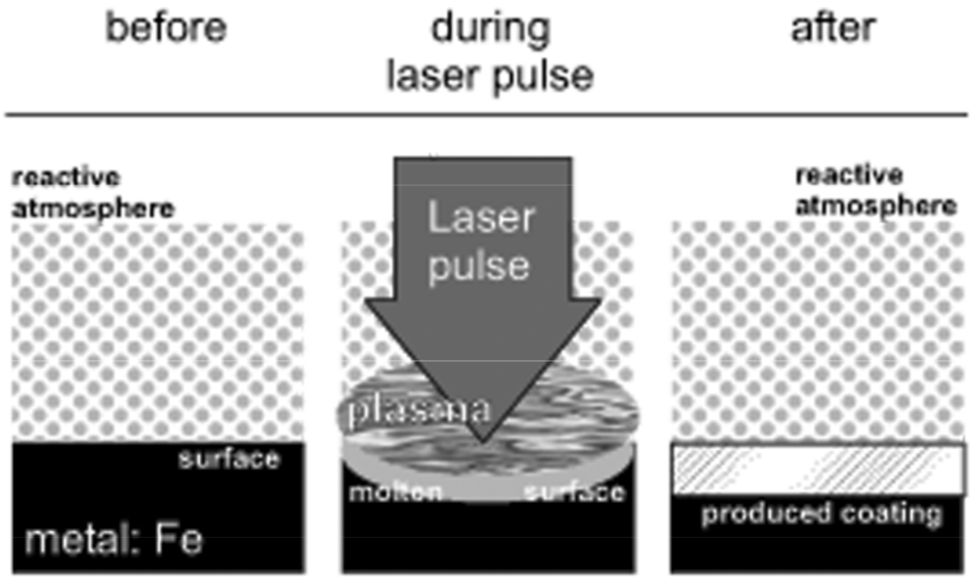
Povrchové úpravy

Nitridace a karburizace povrchu



Nitridace (N2)

Karburizace (CH4)



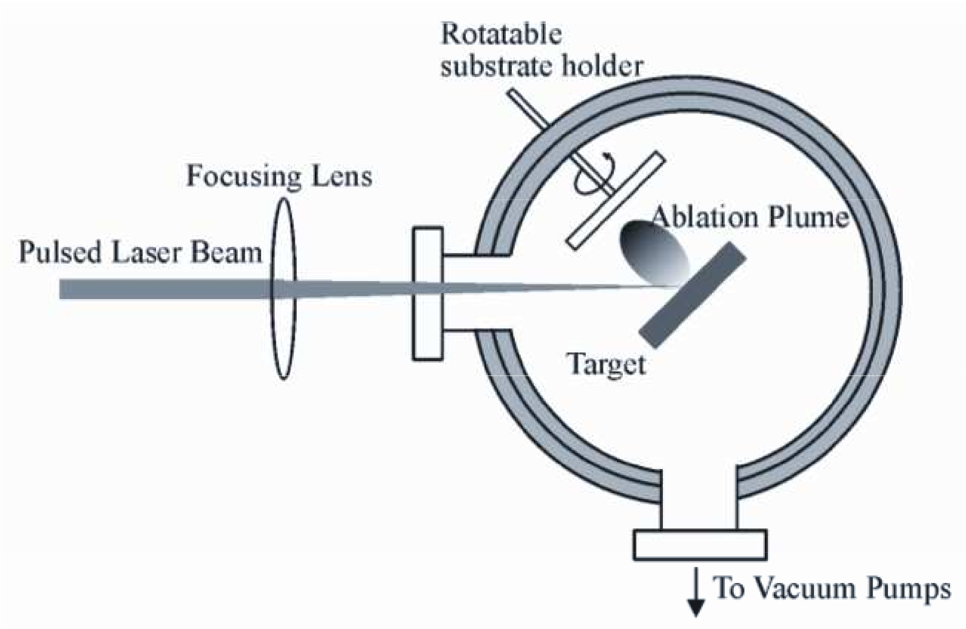
Snaha zabránit korozi železa.

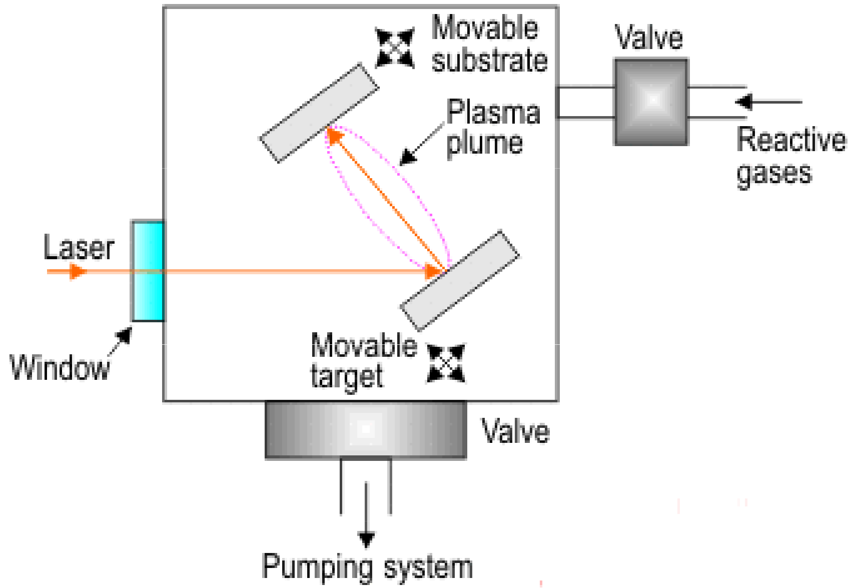
Naprašování povrchových vrstev

Kovy

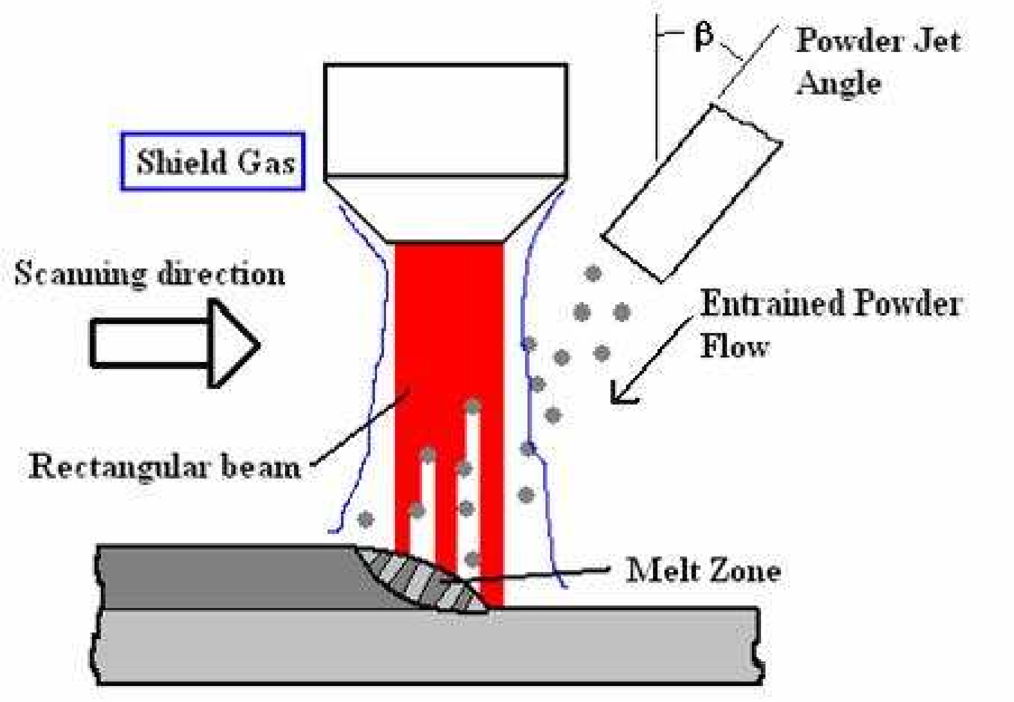
Polovodiče

Polymery



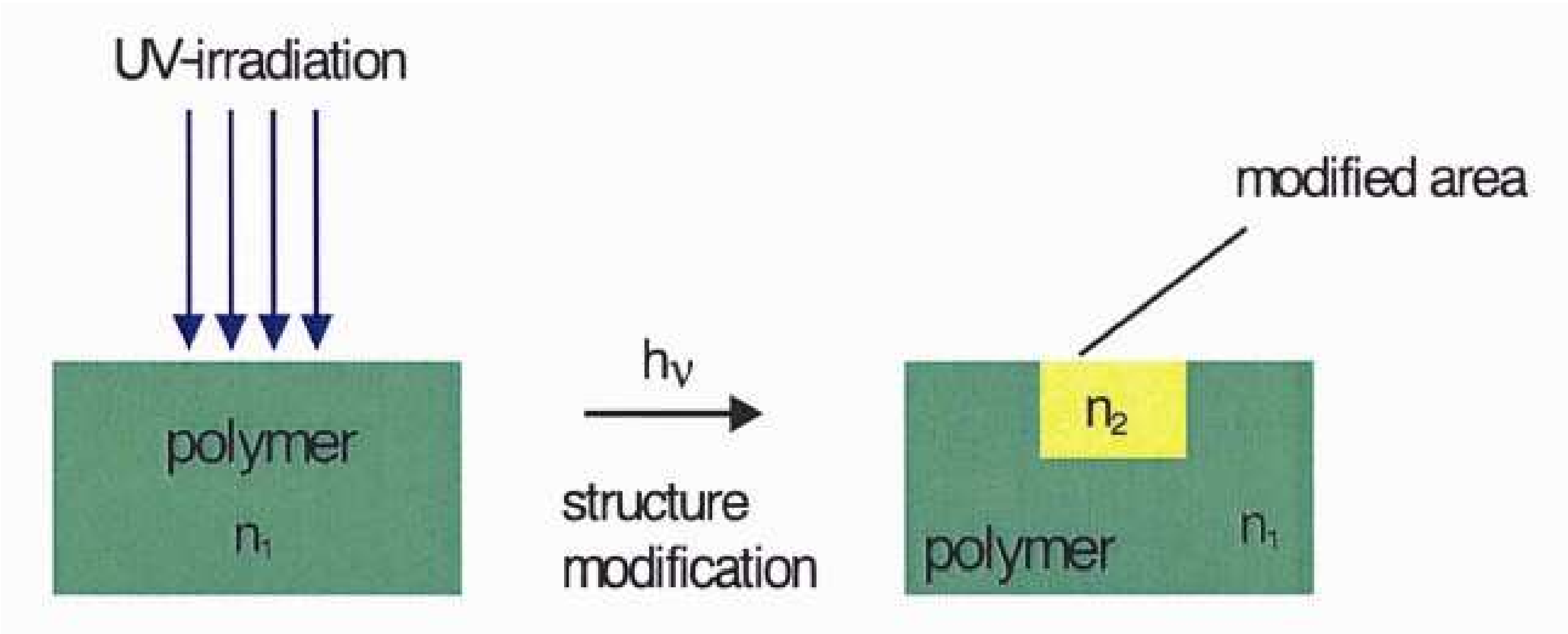


Natavování povrchových vrstev



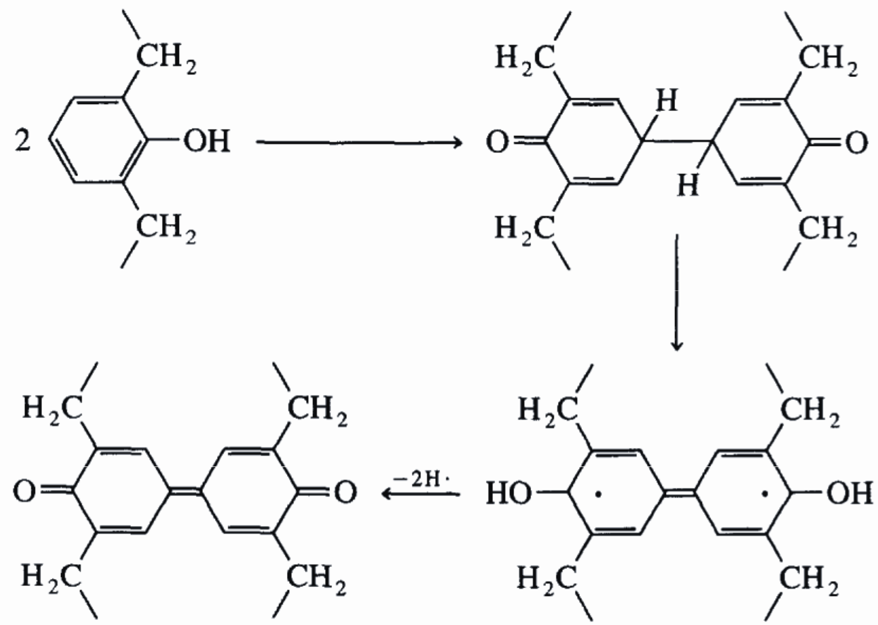
Změny fyzikálních vlastností

Změna indexu lomu polymeru



Změny fyzikálních vlastností

Vytvrzování polymerního materiálu působením UV laseru



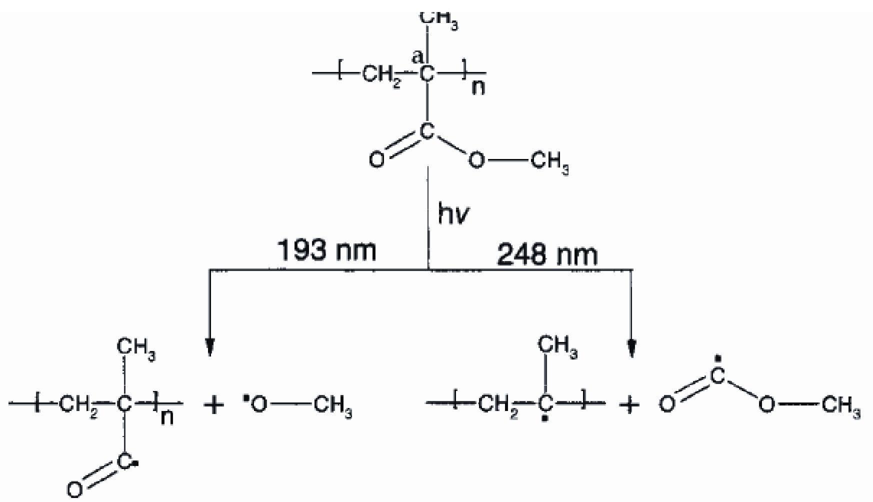


Fig. 11. Simplified photochemical modification scheme of irradiated PMMA.

F

Změny fyzikálních vlastností

Přechod sol-gel

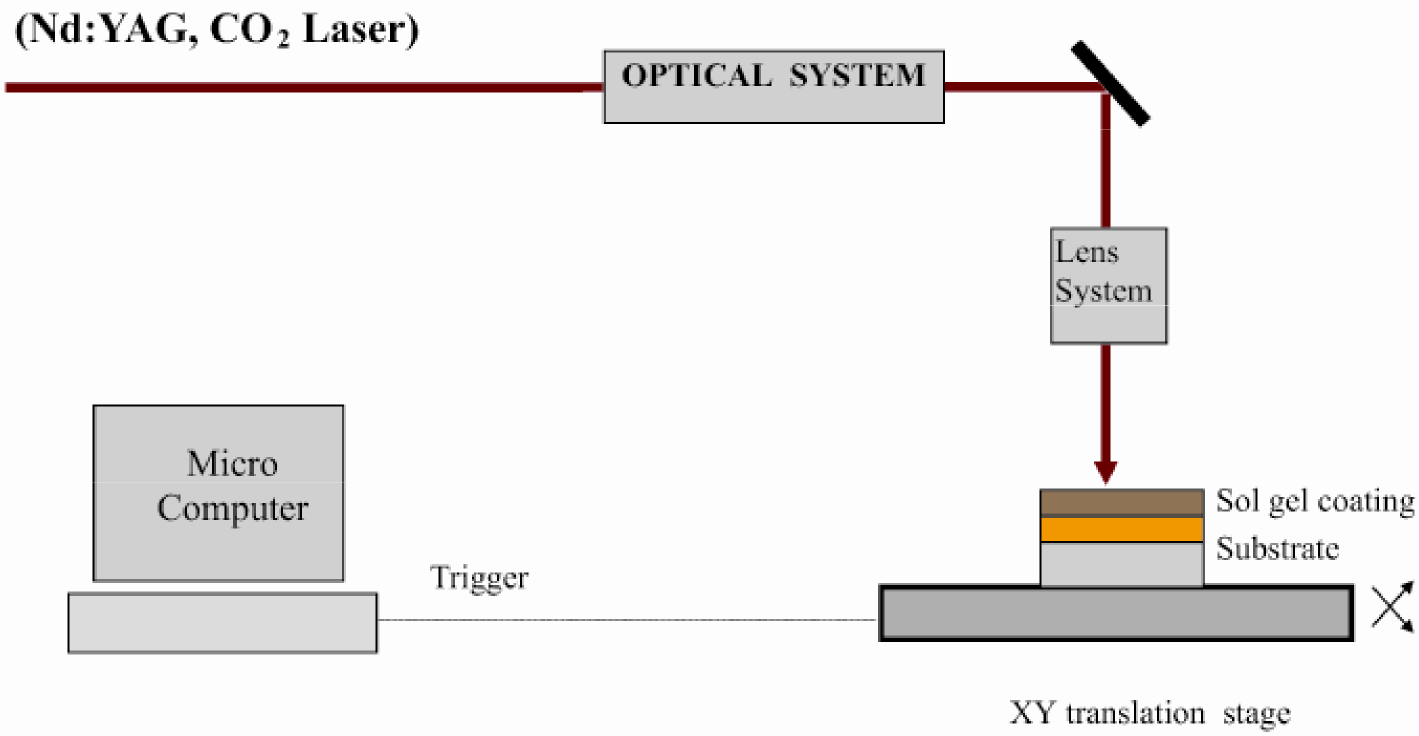


Fig. 1. Experimental setup of the process

Obrábění laserovým paprskem

Řezání

Vrtání

Rytí a leptání

Sváření

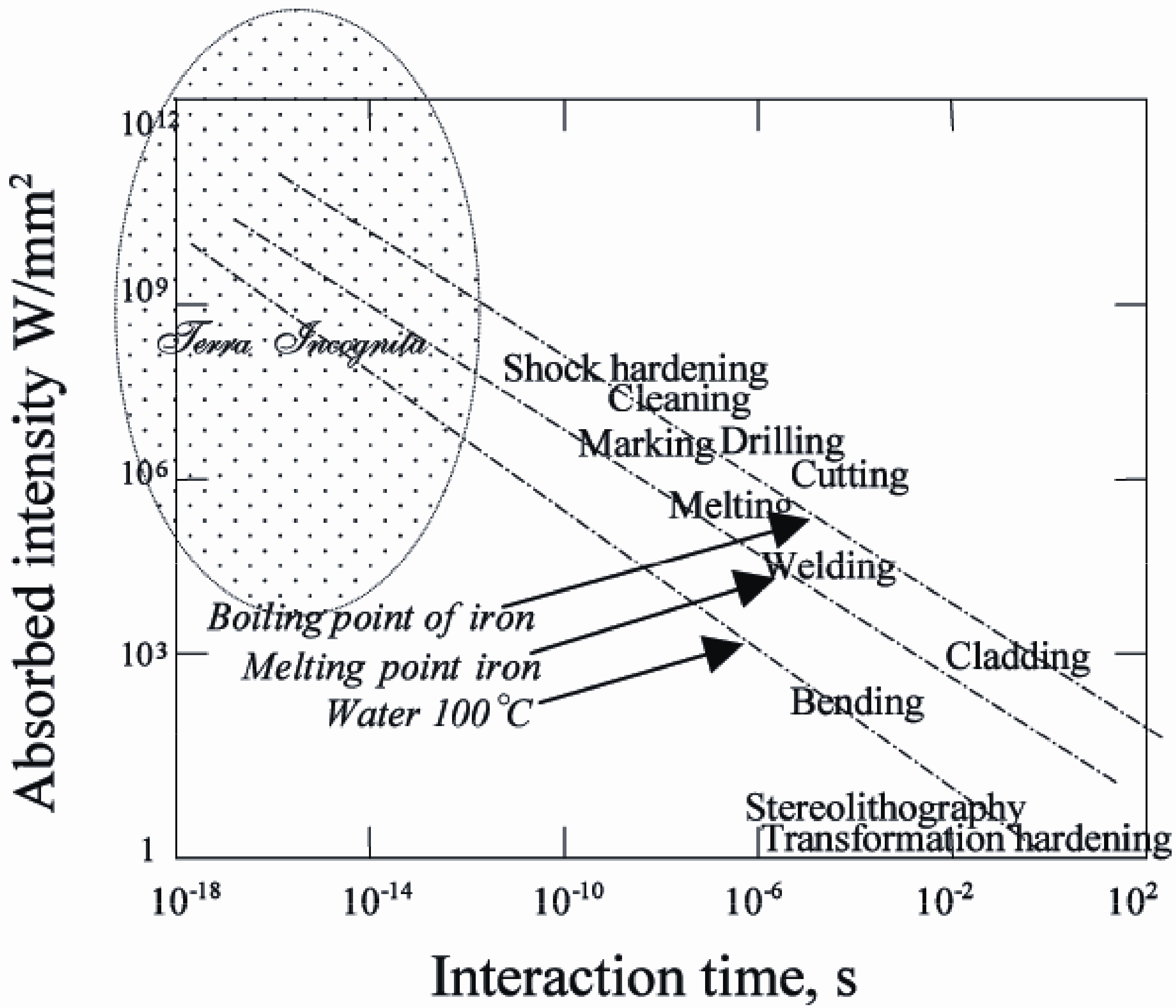
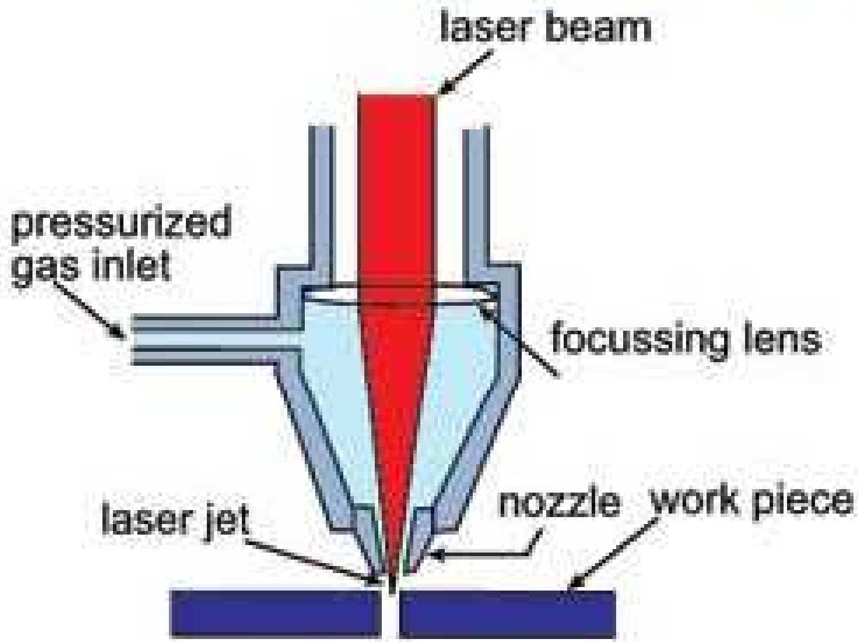
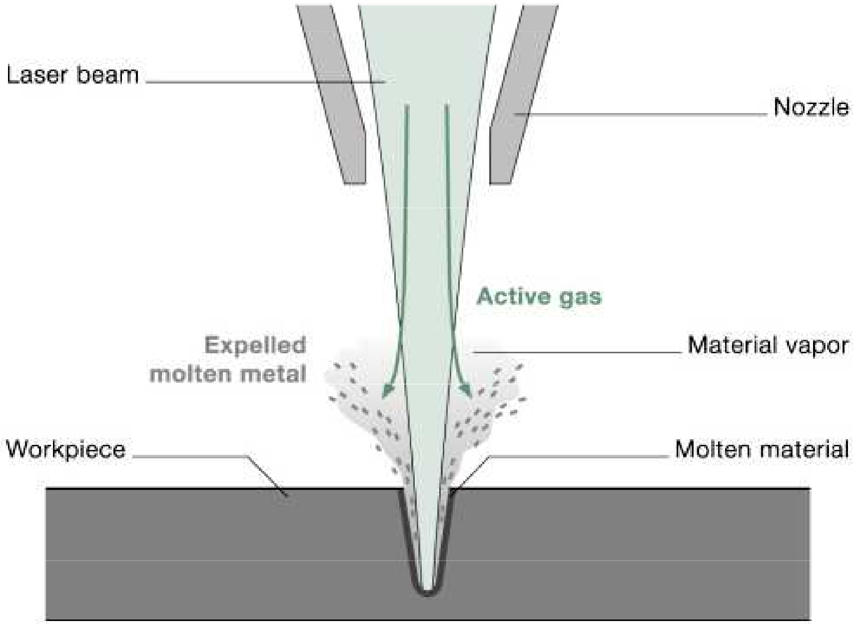


Figure 1. The range of processes.

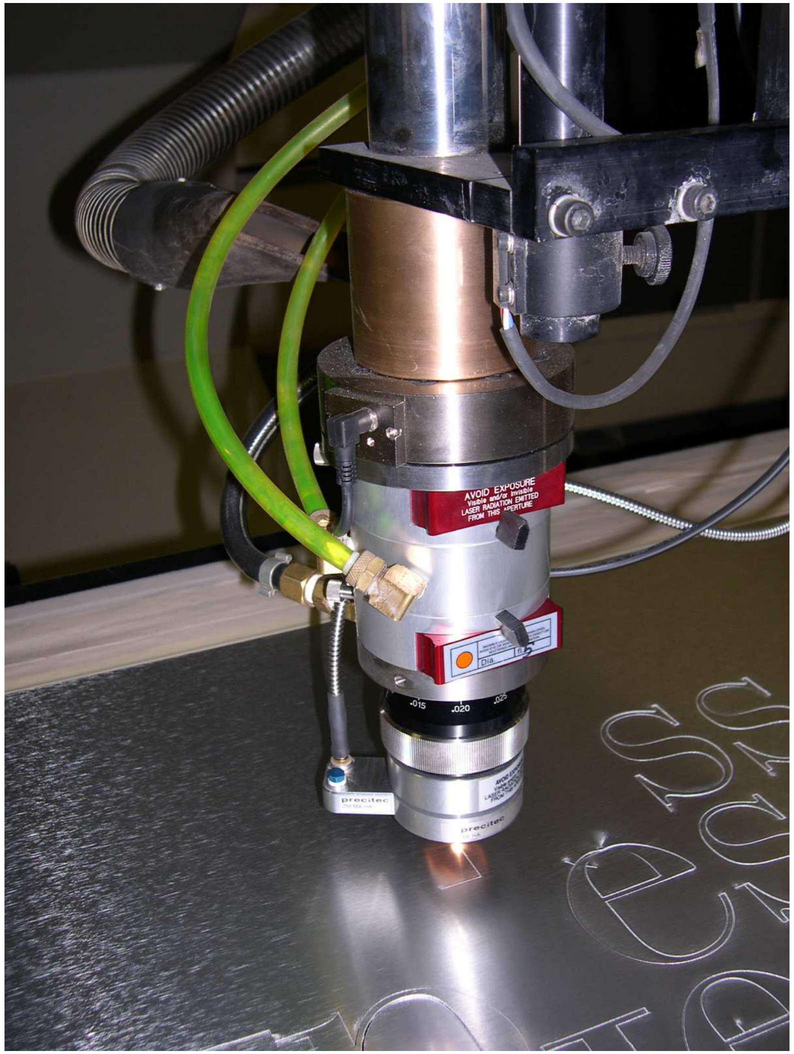
Řezání laserovým paprskem

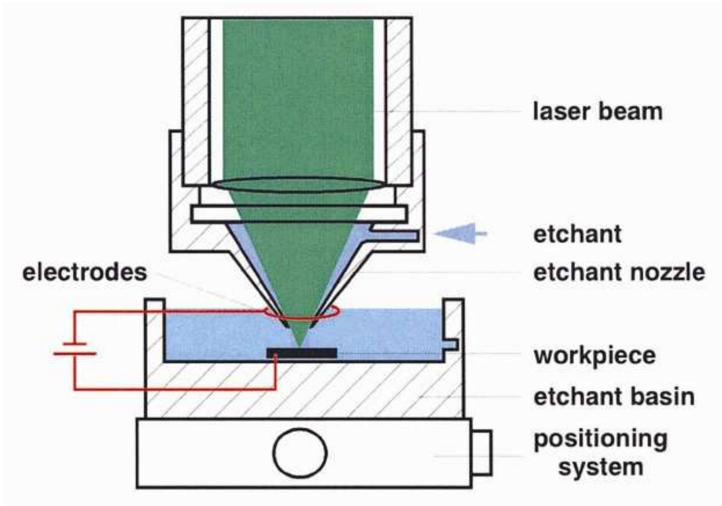


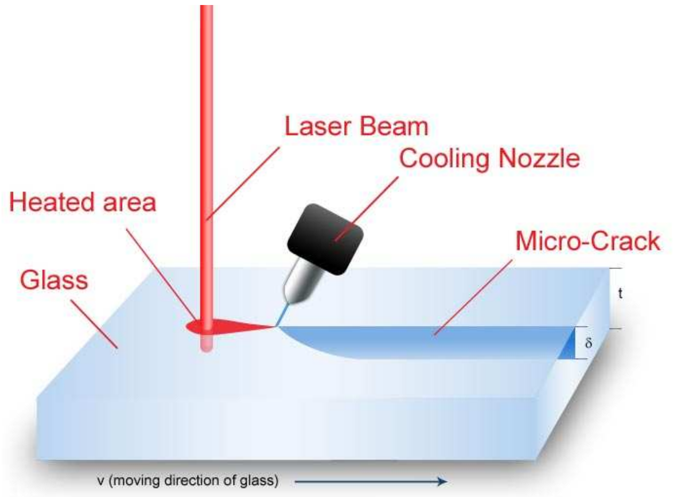
Vrtání laserem



Rytí a leptání







Sváření laserovým paprskem (laser welding)

Svařování různorodých materiálů

Navařování malých součástek