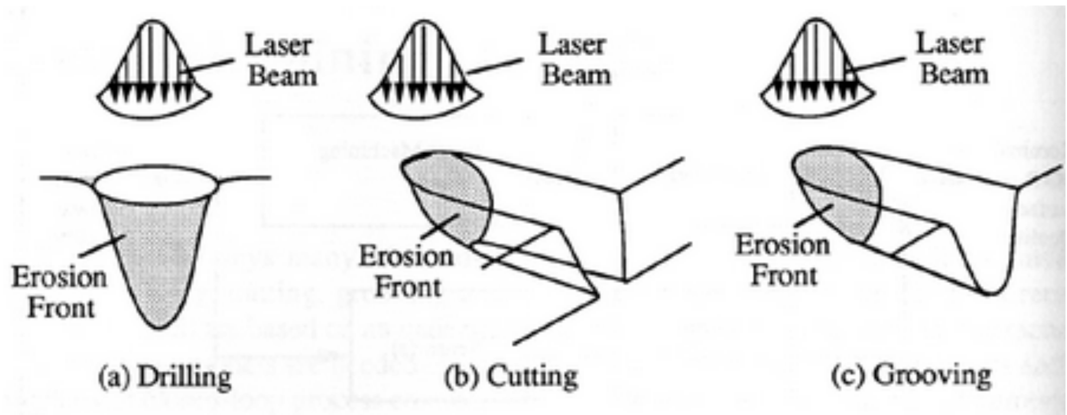
Physics of Laser Cutting

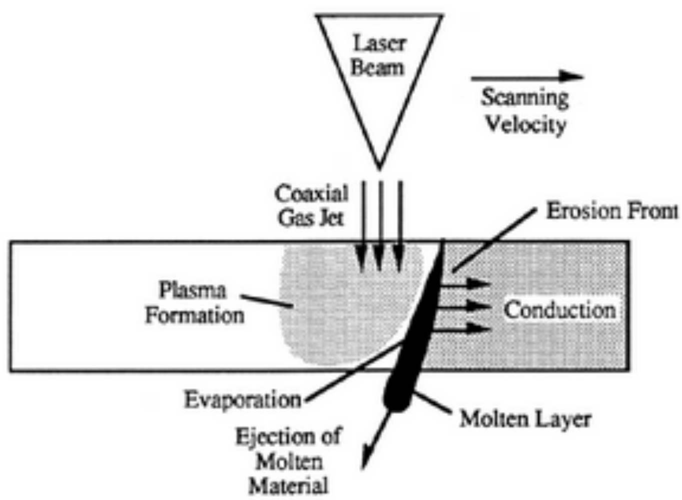
Laser Machining Processes

Several major laser machining processes are illustrated below. (The notable omission is welding, beyond the scope of this document.)



(Chryssolouris, 1991)

This diagram illustrates the cutting process in cross section. Note that a gas assist can be used to speed cutting of metals.



(Chryssolouris, 1991)

Drilling Rates

A simple method of analysis is proposed in (Wilson, 1987).

The energy to vaporize a mass m of solid material at intial temperature T is

$E_v = m(C_S(T_m\text{-}T)+C_L(T_v\text{-}T_m)+L_f+L_v)$

C_S = solid specific heat capacity
C_L = liquid specific heat capacity
T_m = melting point
T_v = boiling point
L_f = latent heat of fusion
L_v = latent heat of vaporization

Usually, $L_f << L_v$ and $T << T_v$, and C_s » $C_L = C$. We then have the simple form $E_v = m(CT_v+L_v)$. Now, consider a circular laser beam of area A boring into the surface of such a material with a velocity v_s directed into the material. It must remove a section of mass $v_{sr}A$ per unit time. Ignoring reflectance from the material surface, the heat flow is equal to the beam power P. Assuming a beam with diameter d and equal power over A, we have $P = v_s\rho(p\ d^2/4)(CT_v+L_v)$.

If v_s exceeds the normal rate of heat diffusion into the material, this equation is fairly accurate for estimating drilling rates or hole depths. To find hole depths, solve for the quantity v_st, where t is the duration of the beam pulse. For example, consider a 100-msec pulse from a 10W laser with a beam diameter of 1mm. If this were to strike a Perspex (methyl methacrylate) sheet, the resultant hole would have a depth of 1.6mm.

Note the inverse-square dependence of hole depth on beam diameter. Halving the beam diameter results in a hole four times deeper. This highlights the importance of beam focusing in laser machine design.

Cutting Rates

This model can be used to estimate cutting rates as well. Consider the laser scanning over the surface of the material with velocity v_b. As it scans, it cuts through the material to a depth $z = v_sd/v_b$. We now have

$$P = (p\ /4)zv_{br}\ \rho d(CT_v+L_v)$$

The following table can then be used to approximate the laser power necessary to cut a given material.

Table 5.1

Material	Thermal conductivity†(K) ($W\ m^{-1}K^{-1}$)	Thermal diffusivity (κ) ($m^2\ s^{-1}$)(10^{-6})	Specific heat capacity (C) ($J\ kg^{-1}K^{-1}$)	Density(ρ) ($kg\ m^{-3}$)	Melting point(T_m) (K)	Boiling point(T_v) (K)	Latent heat of vaporization(L_v) ($J\ kg^{-1}$)(10^6)
Aluminum	238	97.3	903	2 710	932	2 720	10.90
Copper	400	116.3	385	8 960	1 356	2 855	4.75
Iron	82	23.2	449	7 870	1 810	3 160	6.80
Mild steel	45	13.6	420	7 860	1 700		
Stainless steel (304)	16	4.45	460	7 818	1 700		
Nickel	90	22.8	444	8 900	1 726	3 110	6.47
Silver	418	169	235	10 500	1 234	2 466	2.31
Alumina (ceramic)	29	9.54	800	3 800	2 300		
Perspex	0.2	0.11	1 500	1 190	350		
Silicon	170	103	707	2 330	1 680	2 628	10.6

†Measured at 300 K, values fairly strongly temperature dependent.

(Wilson, 1987)

(Chryssolouris, 1991) describes a model that accounts for the material absorptivity as well.

$$z = \frac{2aP}{(\rho v d \sqrt{\pi})(c_p(T_v - T) + L_f)}$$

s = cutting depth
a = material absorptivity
P = laser beam power
ρ = material density
v = scanning velocity
d = beam spot diameter
c_p = specific heat
T_v = temperature at surface (melting temp.)
T = temperature of ambient
L = latent heat of fusion

Note the following:

- The cutting depth is proportional to *P/vd*, which is the energy input per area of workpiece.
- Cutting depth is small for materials with a high melting point and a high latent heat of evaporization.