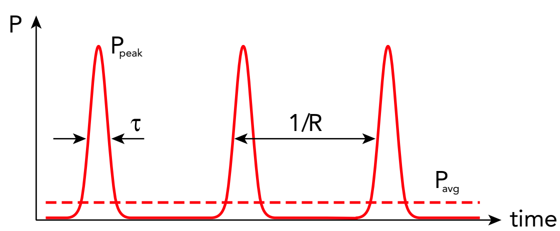
TECHNICAL NOTE

Laser Damage Threshold

Laser damage to optical filters is strongly dependent on many factors, and thus it is difficult to guarantee the performance of a filter in all possible circumstances. Nevertheless, it is useful to identify a Laser Damage Threshold (LDT) of pulse fluence or intensity below which no damage is likely to occur.

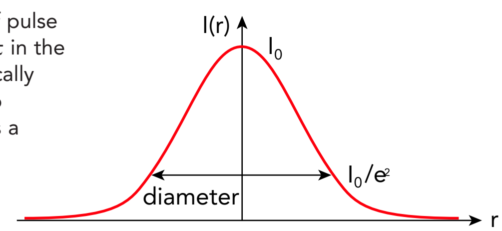
Pulsed vs. continuous-wave lasers: Pulsed lasers emit light in a series of pulses of duration τ at a repetition rate R, with peak power P_{peak}. Continuous-wave (cw) lasers emit a steady beam of light with a constant power. Pulsed-laser average power P_{avg} and cw laser constant power typically range from several milli-Watts (mW) to Watts (W) for most lasers. The diagram and table below illustrate and summarize the key parameters that are used to characterize the output of pulsed lasers.

Symbol	Definition	Units	Key Relationships
τ	Pulse duration	sec	$\tau = D / R$
R	Repetition rate	Hz = sec^{-1}	$R = D / \tau$
D	Duty cycle	dimensionless	$D = R \times \tau$
P	Power	Watts = Joules / sec	$P_{peak} = E / \tau$; $P_{avg} = P_{peak} \times D$; $P_{avg} = E \times R$
E	Energy per pulse	Joules	$E = P_{peak} \times \tau$; $E = P_{avg} / R$
A	Area of laser spot	cm^2	$A = (\pi / 4) \times diameter^2$
I	Intensity	Watts / cm^2	$I = P / A$; $I_{peak} = F / \tau$; $I_{avg} = I_{peak} \times D$; $I_{avg} = F \times R$
F	Fluence per pulse	Joules / cm^2	$F = E / A$; $F = I_{peak} \times \tau$; $F = I_{avg} / R$



Note that because fluence and intensity on the surface of the component are the critical parameters, the area of the laser spot is also critical. Even very high-power lasers may be transmitted through, or reflected off of, a durable optical filter if the spot size is sufficiently large to minimize the fluence and/or intensity. The diameter of a laser spot with a Gaussian profile is most commonly measured at the $1/e^2$ intensity points as shown in the diagram below.

Long-pulse lasers: LDT is perhaps most accurately specified in terms of pulse fluence for "long-pulse lasers." Long-pulse lasers have pulse durations τ in the nanosecond (ns) to microsecond (ms) range, with repetition rates R typically ranging from about 1 to 100 Hz. Because the time between pulses is so large (milliseconds), the irradiated material is able to thermally relax – as a result damage is generally not heat-induced, but rather caused by nearly instantaneous optical field effects. Usually damage results from surface or volume imperfections in the material and the associated irregular optical field properties near these sites, rather than catastrophic destruction of the fundamental material structure. Most Semrock filters have LDT values on the order of 1 J/cm^2, and are thus considered "high-power laser quality" components. An important exception is a High-Q laser-line filter in which the internal field strength is strongly magnified, resulting in an LDT that may be an order of magnitude smaller.



As an example, suppose a frequency-doubled Nd:YAG laser at 532 nm emits 10 ns pulses at a 10 Hz repetition rate with 1 W of average power. This laser has a duty cycle of 1×10^{-7}, a pulse energy of 100 mJ, and a peak power of 10 MW. If the beam is focused down to a 100 μm diameter spot on the surface of a component, the pulse fluence is 1.3 kJ/cm^2, and thus it will almost surely damage a component with a 1 J/cm^2 LDT. However, if the spot diameter is 5 mm, the pulse fluence is only 0.5 J/cm^2, and thus the component should not be damaged.

cw lasers: The LDT for cw lasers is more difficult to measure, and therefore is not specified as often as the long-pulse laser LDT. Damage from cw lasers tends to result from thermal (heating) effects. At this time Semrock does not test nor specify cw LDT for its filters. As a very rough rule of thumb, many all-glass components like dielectric thin-film mirrors and filters have a cw LDT (specified as intensity in kW/cm^2) that is 10 – 100 times the long-pulse laser LDT (specified as fluence in J/cm^2).

Quasi-cw lasers: Quasi-cw lasers are pulsed lasers with pulse durations τ in the femtosecond (fs) to picosecond (ps) range, and with repetition rates R typically ranging from about 10 – 100 MHz for high-power lasers. These lasers are typically mode-locked, which means that R is determined by the round-trip time for light within the laser cavity. With such high repetition rates, the time between pulses is so short that thermal relaxation cannot occur. Thus quasi-cw lasers are often treated approximately like cw lasers with respect to LDT, using the average intensity in place of the cw intensity.