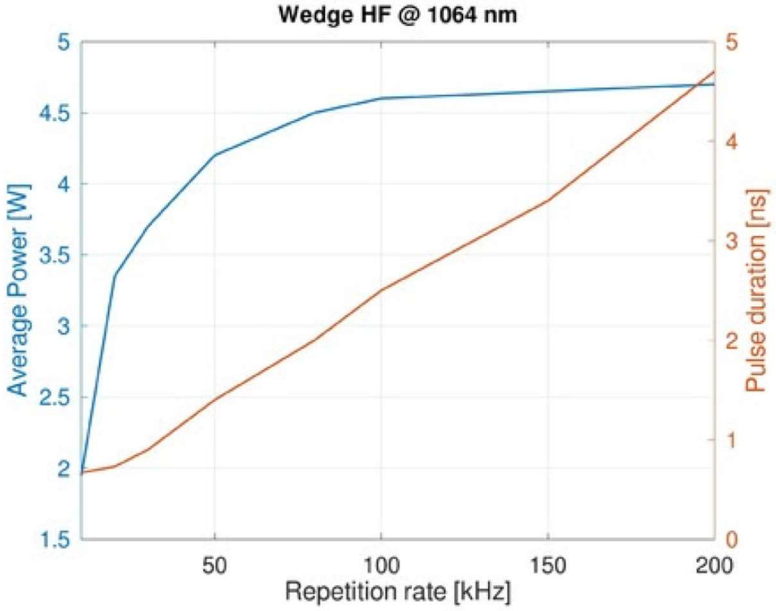
Peak Power and Average Power in ns and sub-ns lasers

A major well-recognized difference between lasers and conventional uncoherent light sources is the possibility to concentrate laser emission in short pulses with durations going down to a few femtoseconds, containing potentially only a few optical cycles. Certainly, also uncoherent LED sources could be driven by current pulses and emit down to nanosecond-long light pulses. However, each pulse would have a maximum power (i.e. a peak power) equal to the average power of the same device in case it would have been continuously biased. Only laser cavities can concentrate the stored energy in active materials in such a way to achieve peak powers order of magnitudes higher than their average power, up to the exceptional PW-level recently reported in research publications.

The extremely high peak power levels achievable by pulsed laser sources is actually one of the main reason for the their success in most of the their applications emerged in the last decades. Therefore, a precise extimation of the laser peak power, given other operational parameters such as average power, pulse duration and repetition rate, is fundamental to select the best option for a particular application among the different commercial alternatives.



In principle, the calculation is quite simple, even though some considerations should be done, based on the actual temporal profile of the laser pulse. By assuming a train of continuously repeated periodical square pulses with repetition rate f_R, pulse duration t_P and average power P_{AV}, the pulse energy E_P and peak power P_P calculation is trivial, with pulse energy given by the ratio between average power and repetition rate and peak power given by the ratio between energy and pulse duration:

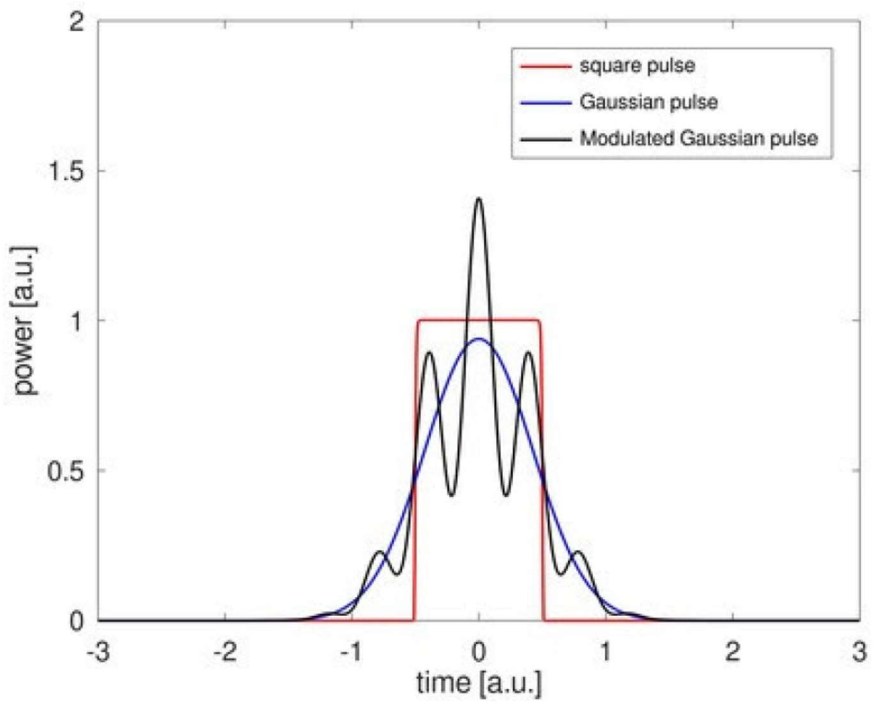
$$P_P = \frac{E_P}{t_P} = \frac{P_{AV}}{f_R \cdot t_P}$$

Of course, this simple relationship holds for laser pulses with a temporal square or flat-top profile, which is rather uncommon in practice. Usually, laser pulse temporal profiles could be more precisely approximated with bell-shape functions, such as Gaussian profile or Sech2 profile, the latter relevant mainly for ultrashort pulses obtained by the passive mode-locking regime.

In this cases, first of all, pulse duration itself has to be redifined, being full-width half-maximum (FWHM) value a commonly accepted parameter. Since the energy concentration in a Gaussian pulse with FWHM duration t_P is slightly different with respect to a square pulse with equal pulse duration, the above formula should be adjusted:

$$P_P \approx \frac{0.94 \cdot E_P}{t_P} = \frac{0.94 \cdot P_{AV}}{f_R \cdot t_P}$$

Essentially, the smoother leading and trailing edge of a Gaussian pulse slightly reduce (by a factor 0.94) the peak power for a given pulse energy or average power. The point is that the situation might be further complicated when lasers emitting few-nanosecond-long or sub-nanosecond pulses come into the picture. Usually, a Gaussian pulse shape is a very good approximation for the real pulse profile of Q-switched DPSS laser, even though it is essentially correct only for laser operating in single longitudinal mode (SLM). Most commercially available Q-switched lasers actually rely on multiple longitudinal modes, oscillating at the same time and interfering at all time. This effect is clearly visible by aquiring optical pulses with sufficiently fast photodiodes and digital oscilloscopes, showing an amplitude modulation superimposed to the Gaussian pulse shape. Period and depth of the modulation depends on the number of longitudinal modes oscillating together. For tens-of-nanoseconds-long pulses, resonators support so many modes that the modulation is nicely averaged out and hardly visible, but for sub-nanosecond operation only a few modes are left, giving rise to deep modulation on the pulse envelope and strong deviation for the ideal Gaussian shape. A full-width half-maximum pulse duration definition becomes questionable and more refined statistical definition should be employed, giving rise to a corretion factor for the peak power higher than 1 (potentially a factor of 1.5 could be a reasonable guess).



By considering for example the performance curves of a standard Bright Solutions's Wedge HF laser at 1064 nm, the average power at 100 kHz is 4.6 W and pulse duration is about 2.5 ns, giving a peak power of ~ 18 kW.

$$P_P = \frac{E_P}{t_P} = \frac{P_{AV}}{f_R \cdot t_P} = \frac{4.6W}{100kHz \times 2.5ns} \approx 18kW$$

At lower repetition rate, the pulse duration of Wedge HF laser is shorter, while pulse energy is higher, giving an higher peak power. Therefore, for instance, at 10 kHz, with pulses of ~ 700 ps and average power of ~ 1.8 W, the peak power rises up to ~ 260 kW. For a more detailed comparison between different industrial-grade laser sources at 1 µm, the table hereunder summarizes peak power and other critical parameters.

	Wedge HF	Onda	Fiber laser	DPSS laser
Average power	1.8 W @ 10 kHz	8 W @ 10 kHz	50 W	20 W
Pulse duration	700 ps	2 ns	30 ns	< 10 ns
Repetition rate	10 kHz	10 kHz	50 kHz	20 kHz
Pulse energy	180 µJ	800 µJ	1 mJ	1 mJ
Peak power	260 kW	400 kW	33 kW	100 kW

Table 1: comparison between average and peak power for different types of laser: Bright Solutions' WedgeHF and Onda @ 1064 nm, mJ-level nanosecond pulsed fiber laser and 20-W 10-ns DPSS laser

In the table above, it is clear the advantage in terms of peak power achievable by shorter pulse durations, even with much lower average power levels. The laser models indicated in the table have similar beam quality (M2 < 1.5 for all of them) . Therefore, they could be focused on similar spot sizes and the application relevant peak power densities change proportionally to the reported peak powers.