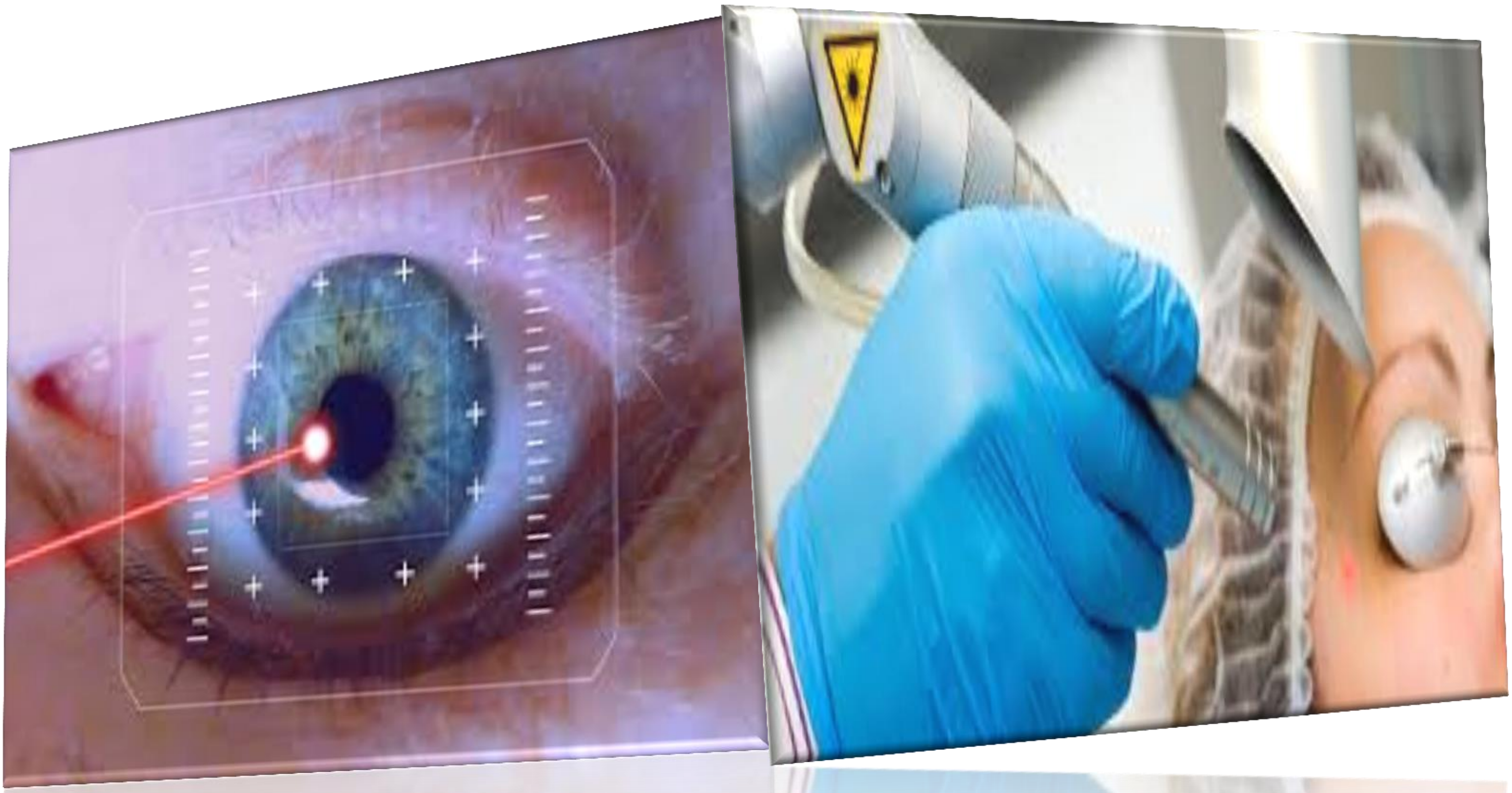
AL MUSTAQBAL UNIVERCITY

Department of Medical Physics

Medical Laser Applications



M SC . Murtadha kadhim selman

second lecture

Pulsed Lasers Introduction to Power and Energy Calculations

Pulsed laser and CW laser, does it make a difference?

Bursts of light cause different effects than constant streams of light.

• Pulsed lasers emit bursts of light spaced in time.
• Between pulses, the laser emits no light.
• The period is the time from the start of one pulse to the next.
• The pulse duration (pulse width) is the time measured across a pulse, often at its full width half maximum (FWHM).

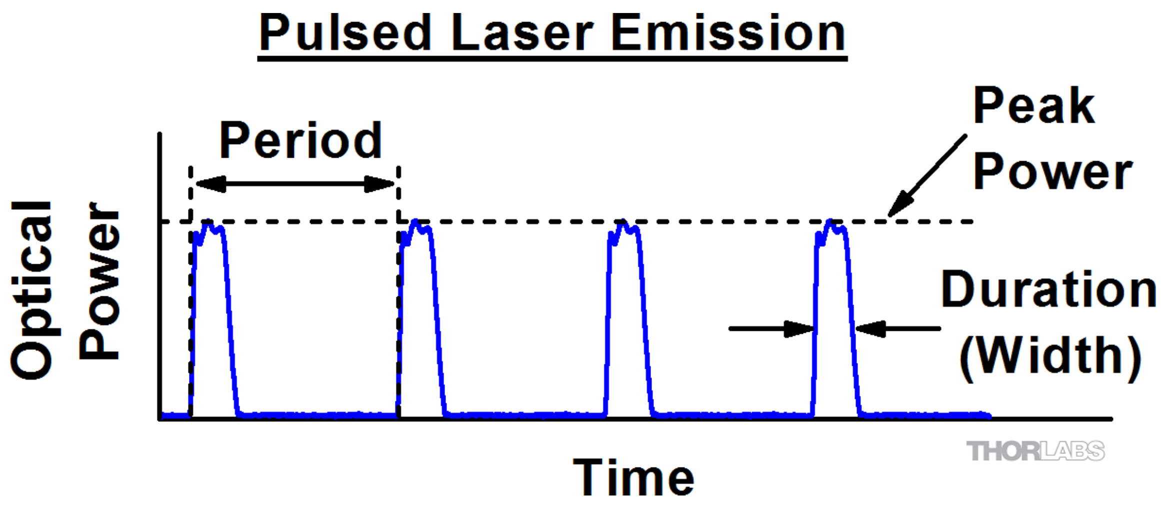


Figure 1. Pulsed lasers emit bursts of light, spaced in time. There is no emission between pulses

• Continuous wave (CW) lasers provide steady emission.
• Peak, minimum, and average powers are approximately identical.
• Period and pulse width do not apply unless the light is modulated.

•Help, harm, or underperform: it depends on the pulse width, peak power, ***and*** period.

• Short pulses and long periods may protect illuminated samples from overheating, by allowing them to cool down between bursts of light.

• Short pulses with high peak powers and long periods may destructively ablate surface material, but heat the surrounding area minimally.

• Long pulses and/or short periods may deliver damaging total emission, even if the peak power is moderate.

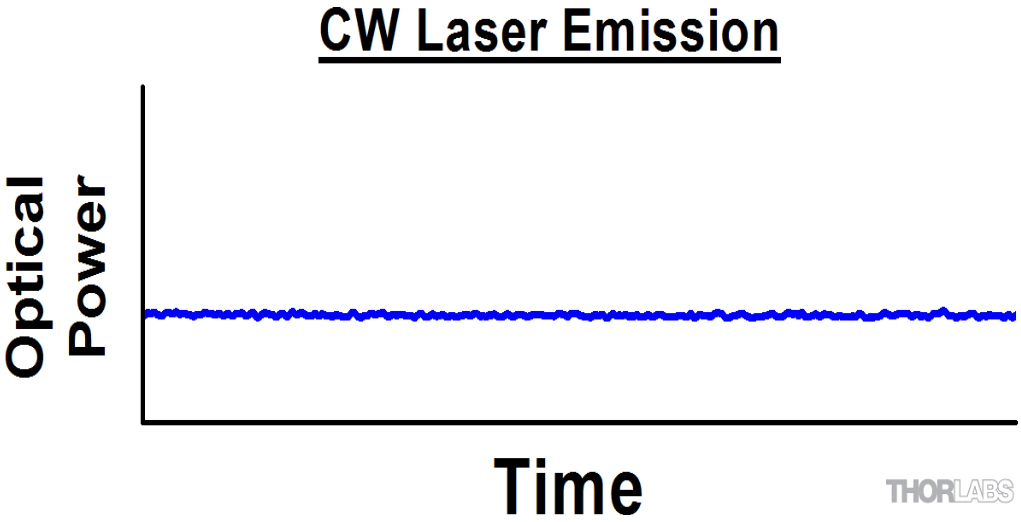


Figure 2. CW lasers emit light whose optical power is approximately constant with time.

What is the effect of changing pulse width or period?

Pulse width and period control the average power emitted by the laser.

Pulse width:

• Both pulse energy (shaded area) and average energy (dotted green line) depend on pulse width.

• Increase (or reduce) pulse width to increase (or reduce) both pulse energy and average power.

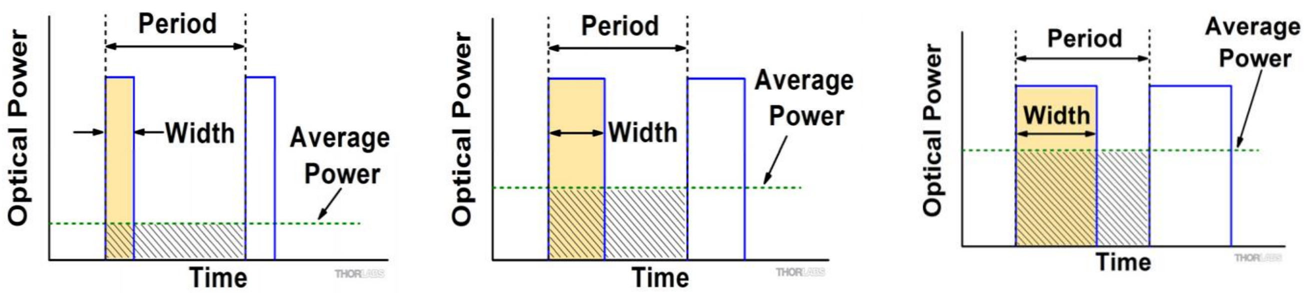


Figure 5. Changing the pulse width changes the pulse energy by changing the length of the pulses. The average power changes, since the total time light is emitted by the laser changes.

Period:

• Pulse energy (shaded area) does not depend on period, but average energy (dotted green line) does.

• Reduce the period to increase the average power (or increase the period to reduce the average power).

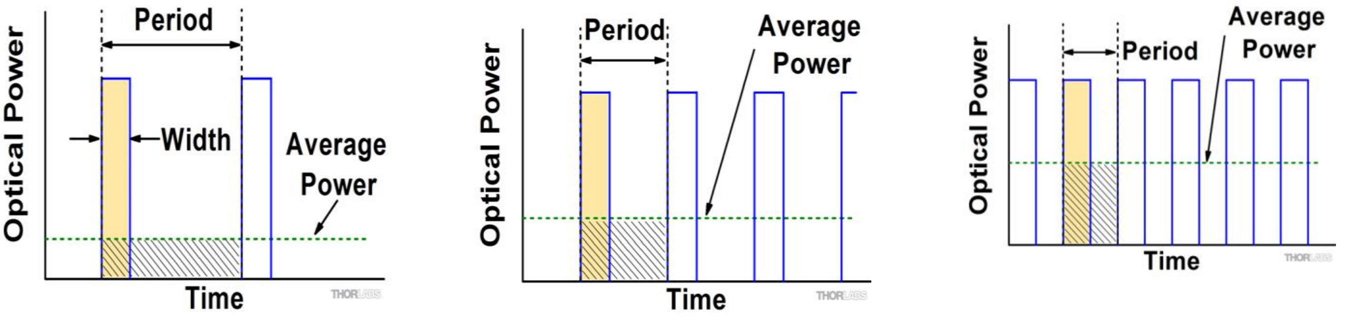


Figure 6. Changing just the period does not change the pulse energy, since the pulse width and peak power donot change. The average power changes due to pulses being delivered more (or less) frequently.

How are pulse energy and peak power calculated?

Pulses are often modeled with a rectangular shape as shown in Figure 8.

- Period and repetition rate are reciprocal:

$$\Delta t = \frac{1}{f_{rep}} \quad \text{and} \quad f_{rep} = \frac{1}{\Delta t}$$

- Pulse energy calculated from average power:

$$E = \frac{P_{avg}}{f_{rep}} = P_{avg} \cdot \Delta t$$

- Average power calculated from pulse energy:

$$P_{avg} = \frac{E}{\Delta t} = E \cdot f_{rep}$$

- Peak pulse power estimated from pulse energy:

$$P_{peak} \approx \frac{E}{\tau}$$

- Peak power and average power calculated from each other:

$$P_{peak} = \frac{P_{avg}}{f_{rep} \cdot \tau} = \frac{P_{avg} \cdot \Delta t}{\tau} \qquad P_{avg} = P_{peak} \cdot f_{rep} \cdot \tau = \frac{P_{peak} \cdot \tau}{\Delta t}$$

- Peak power calculated from average power and duty cycle*.

$$P_{peak} = \frac{P_{avg}}{\tau/\Delta t} = \frac{P_{avg}}{duty\ cycle}$$

*Duty cycle is the fraction time during which there is laser pulse emission.
duty cycle = $\tau / \Delta t$

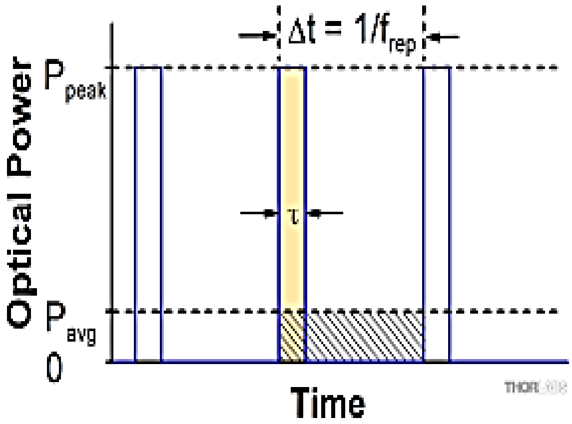


Figure 8. Laser Pulse Parameters

Δt	Pulse Period
E	Energy per Pulse
f_{rep}	Repetition Rate
P_{avg}	Average Power
P_{peak}	Peak Power
τ	Pulse Width

Example Calculations

The attenuated average output power of a pulsed Ti:sapphire laser beam is ***1 mW***. A detector specifies a maximum peak optical input power of ***75 mW***. Is it safe to use this detector to measure this attenuated beam?

Δt	Pulse Period
E	Energy per Pulse
f_{rep}	Repetition Rate
P_{avg}	Average Power
P_{peak}	Peak Power
τ	Pulse Width

- Beam Specifications:
  - Average Power: 1 mW
  - Repetition Rate: 85 MHz
  - Pulse Width: 10 fs
- Energy per Pulse:

$$E = \frac{P_{avg}}{f_{rep}} = \frac{1\,mW}{85\,MHz} = \frac{1\,x\,10^{-3}W}{85\,x\,10^{6}Hz} = 1.18\,x\,10^{-11}J = 11.8\,pJ$$

... this *seems* low, but ...

- Peak Pulse Power:

$$P_{peak} = \frac{P_{avg}}{f_{rep}\cdot\tau} = \frac{1\,mW}{85\,MHz\,\cdot 10\,fs} = \frac{1\,x\,10^{-3}W}{85\,x\,10^{6}Hz\cdot 10\,x\,10^{-15}s} = 1.18\,x\,10^{3}\,W = \mathbf{1.18\,kW}$$

This scenario is ***not safe***. The peak power of the pulses is *>5 orders of magnitude higher* than the detector's specified maximum peak optical input power!

Example Calculations

A pulsed laser provides the option of adjusting its pulse width and repetition rate independently, while keeping the peak power constant at 50 mW.

- ***Adjusting the pulse width***: How does average power change if pulse width is reduced from 39 ns to 12 ns, while keeping the repetition rate at 1 MHz?
  - Equation: $P_{avg} = P_{peak} \cdot f_{rep} \cdot r$
  - Average power for 39 nm pulsewidth: $P_{avg} = (50\ \text{mW})(1\ \text{MHz})(39\ \text{ns})$
    $= (50 \times 10^{-3}\ \text{W})(1 \times 10^{6}\ \text{Hz})(39 \times 10^{-9}\ \text{s})$
    $= 1.95 \times 10^{-3}\text{W} = 1.95\ \text{mW}$
  - Average power for 12 ns pulsewidth: $P_{avg} = (50\ \text{mW})(1\ \text{MHz})(12\ \text{ns}) = 0.6\ \text{mW}$
  - **Average power drops by same factor as pulse width:** $\frac{12\ \text{ns}}{39\ \text{ns}} = \frac{0.6\ \text{mW}}{1.95\ \text{mW}} \approx 0.31.$

Δt	Pulse Period
E	Energy per Pulse
f_{rep}	Repetition Rate
P_{avg}	Average Power
P_{peak}	Peak Power
r	Pulse Width

- ***Adjusting the repetition rate***: How does average power change if repetition rate is increased from 5 MHz to 10 MHz, while maintaining a 20 ns pulse width?
  - Equation: $P_{avg} = P_{peak} \cdot f_{rep} \cdot r$
  - Average power for 5 MHz repetition rate: $P_{avg} = (50\ \text{mW})(5\ \text{MHz})(20\ \text{ns}) = 5\ \text{mW}$
  - Average power for 10 MHz repetition rate: $P_{avg} = (50\ \text{mW})(10\ \text{MHz})(20\ \text{ns}) = 10\ \text{mW}$
  - **Average power increases by same factor as pulse width:** $\frac{10\ \text{MHz}}{5\ \text{MHz}} = \frac{10\ \text{mW}}{5\ \text{mW}} = 2.$

Average power scaling is proportional to changes in pulse width and repetition rate.