University of Al-Mustaqbal

College of Science

Department of Medical Physics

Medical Laser Applications

Third Stage

Lec 2

Pulsed Lasers Introduction to Power and Energy Calculations

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1. Introduction to Pulsed Lasers

Definition and Key Characteristics

- A pulsed laser emits energy in the form of light pulses rather than a continuous beam.
- Pulse durations can range from nanoseconds (**ns**) to femtoseconds (**fs**).
- Pulsed lasers are characterized by high peak powers and are widely used in fields such as:
    - Material processing
    - Medical applications (e.g., laser surgery)
    - Scientific research (e.g., spectroscopy, time-resolved studies)

Applications in Science and Technology

- Pulsed lasers enable precise energy delivery in time-sensitive applications.
- Examples include:
    - Micromachining delicate materials.
    - Generating high-intensity electric fields for particle acceleration.
    - Studying ultrafast processes in physics and chemistry.

2. Understanding Power and Energy in Pulsed Lasers

Distinction Between (**CW**) and Pulsed Lasers

- Continuous-Wave (**CW**) Lasers: Emit a steady, continuous beam of light.
- Pulsed Lasers: Emit light in bursts, leading to significantly higher instantaneous power.

Key Terminologies

1. Pulse Energy ($\boldsymbol{E}$): The total energy contained in a single pulse, typically measured in joules (**J**).
2. Peak Power ($\mathbf{P_{peak}}$) : The maximum power achieved during a pulse, calculated as:

$$\mathbf{P_{peak}} = \frac{\boldsymbol{E}}{\boldsymbol{\tau_p}}$$

where:

- $\boldsymbol{E}$ = Pulse energy (**J**)
- $\boldsymbol{\tau_p}$ = Pulse duration (**s**)

3. Average Power ($\boldsymbol{P}_{\text{avg}}$) : The time-averaged power output, calculated as:

$$\boldsymbol{P_{avg}} = \boldsymbol{E} \times \boldsymbol{fr}$$

where:

- $\boldsymbol{E}$ = Pulse energy (**J**)
- $\boldsymbol{fr}$ = Pulse repetition rate (**Hz**)

3. Mathematical Framework for Calculations

Energy Per Pulse

- The pulse energy can often be measured or derived from the laser specifications and is a fundamental quantity in calculations.

Peak Power Calculation

- Pulsed lasers achieve very high peak powers due to the short duration of pulses.
    - For example, if a laser emits a **1mJ** pulse with a **10 ns** pulse duration, the peak power is:

$$\mathbf{P_{peak}} = \frac{\boldsymbol{E}}{\boldsymbol{\tau_p}}$$

$$\mathbf{P_{peak}} = \frac{1\times10^{-3}}{10\times10^{-9}} = 10^5 \ \ \textit{watt}$$

Average Power Calculation

- The average power is proportional to the pulse energy and repetition rate.
    - For a laser with a **1mJ** pulse energy operating at a **1kHz** repetition rate:

$$\mathbf{P_{avg}} = \mathbf{E} \times \mathbf{fr}$$

$$\mathbf{P_{avg}} = 1\times10^{-3} \times 10^3 = 1 \ \ \textit{watt}$$

4. Examples and Problem-Solving

Example 1: Calculating Peak Power

A pulsed laser emits light at a pulse energy of **0.5 mJ** and a pulse duration of **5 ns**. Calculate the peak power.

Solution:

$$\mathbf{P_{peak}} = \frac{\boldsymbol{E}}{\boldsymbol{\tau_p}}$$

$$\mathbf{P_{peak}} = \frac{0.5\times10^{-3}}{5\times10^{-9}} = 10^5 \ \ \textit{watt}$$

Example 2 : Calculating Average Power

A laser operates with a repetition rate of **10 kHz** and a pulse energy of **2 mJ**. Calculate the average power.

Solution:

$$\mathbf{P_{avg} = E \times fr}$$

$$\mathbf{= (2 \times 10^{-3}) \times (10 \times 10^{3}) \quad = 20 \ \ \textit{watt}}$$

Homework / Exercises:

1. A laser emits 1 μJ pulses with a pulse duration of **1 ps** and a repetition rate of **1 MHz**. Calculate the peak power and average power.
2. Compare the peak powers of a nanosecond and femtosecond laser, each delivering the same pulse energy of **1 mJ** .

Discussion

1. A pulsed laser emits light as:
A) Continuous beam
B) Thermal radiation
C) Light pulses
D) Random flashes
E) Infrared only
Correct answer: C

2. Pulse duration of pulsed lasers ranges from:
A) Seconds – minutes
B) ms – s
C) μs – ms
D) ns – fs
E) fs – hours
Correct answer: D

3. Pulsed lasers are known for high:
A) Average power
B) Beam divergence
C) Peak power
D) Wavelength spread
E) Noise level
Correct answer: C

4. Which is NOT a pulsed-laser application?
A) Material processing
B) Laser surgery
C) Spectroscopy
D) Time-resolved studies
E) Room lighting
Correct answer: E

5. Pulsed lasers deliver energy precisely in:
A) Time
B) Frequency domain
C) Space only
D) Temperature
E) Wavelength
Correct answer: A

6. Micromachining requires energy delivery that is:
A) Continuous
B) Slow
C) Random
D) Diffuse
E) Precise
Correct answer: E

7. CW laser output is:
A) Pulsed
B) Bursts
C) Intermittent
D) Steady
E) Discrete
Correct answer: D

8. Pulsed lasers emit light in:
A) Bursts
B) Waves
C) Sheets
D) Cones
E) Rings
Correct answer: A

9. Pulse energy is measured in:
A) Watt
B) Hertz
C) Joule
D) Tesla
E) Kelvin
Correct answer: C

10. Peak power represents:
A) Minimum power
B) Average power
C) Maximum power
D) Input power
E) Optical loss
Correct answer: C

11. Formula for peak power is:
A) E / τ
B) τ / E
C) $E \times \tau$
D) fr / E
E) $E \times fr$
Correct answer: A

12. Pulse duration is denoted by:
A) E
B) fr
C) P
D) τ_p
E) λ
Correct answer: D

13. Average power depends on energy and:
A) Wavelength
B) Duration
C) Refractive index
D) Repetition rate
E) Beam width
Correct answer: D

14. Average power formula is:
A) E / τ
B) $\tau \times fr$
C) $E \times fr$
D) P / fr
E) fr / τ
Correct answer: C

15. Repetition rate unit is:
A) Joule
B) Second
C) Watt
D) Hertz
E) Tesla
Correct answer: D

16. Shorter pulse duration causes peak power to:
A) Decrease
B) Stay constant
C) Vanish
D) Increase
E) Oscillate
Correct answer: D

17. A 1 mJ, 10 ns pulse has peak power:
A) 10^3 W
B) 10^4 W
C) 10^5 W
D) 10^6 W
E) 10^7 W
Correct answer: C

18. Average power increases with:
A) Longer wavelength
B) Shorter pulses
C) Higher fr
D) Lower energy
E) Beam diameter
Correct answer: C

19. A 1 mJ pulse at 1 kHz gives:
A) 0.1 W
B) 1 W
C) 10 W
D) 100 W
E) 1000 W
Correct answer: B

20. Time-resolved studies require:
A) CW lasers
B) Long pulses
C) Ultrafast pulses
D) Low intensity
E) Wide beams
Correct answer: C

21. Nanosecond pulse duration is:
A) 10^{-3} s
B) 10^{-6} s
C) 10^{-9} s
D) 10^{-12} s
E) 1 s **Correct answer: C**

22. Femtosecond pulse duration is:
A) 10^{-3} s
B) 10^{-6} s
C) 10^{-9} s
D) 10^{-12} s
E) 10^{-15} s **Correct answer: E**

23. Same pulse energy, shorter pulse gives:
A) Lower peak power
B) Same peak power
C) Higher peak power
D) Zero power
E) Random power **Correct answer: C**

24. Particle acceleration needs:
A) Low fields
B) Continuous beams
C) High electric fields
D) Visible light only
E) Long pulses **Correct answer: C**

25. Pulse energy multiplied by repetition rate equals:
A) Peak power
B) Photon energy
C) Beam intensity
D) Pulse duration
E) Average power **Correct answer: E**