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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.

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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 often 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:

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

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

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:

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

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

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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:

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

$$\mathbf{P_{peak}} = \frac{\mathbf{0.5 \times 10^{-3}}}{\mathbf{5 \times 10^{-9}}} \quad = \mathbf{10^5} \ \ \boldsymbol{watt}$$

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:

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

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

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. What is a pulsed laser?

A) A laser that emits a continuous beam.

B) A laser that emits light in pulses.

C) A laser with no energy output.

D) A laser used only for medical applications.

E) None of the above.

Correct Answer: B

2. Which of the following ranges can describe pulse durations in pulsed lasers?

A) Microseconds to seconds

B) Hours to days

C) Nanoseconds to femtoseconds

D) Milliseconds to minutes

E) None of the above

Correct Answer: c

3. What is a key characteristic of pulsed lasers?

A) Low peak power

B) High peak power

C) Constant beam intensity

D) No repetition rate

E) Weak energy delivery

Correct Answer: B

4. In which field are pulsed lasers NOT commonly used?

A) Material processing

B) Cooking

C) Medical applications

D) Scientific research

E) Ultrafast process studies

Correct Answer: B

5. What differentiates pulsed lasers from continuous-wave lasers?

A) Continuous-wave lasers emit light in pulses.

B) Pulsed lasers emit a steady, continuous beam.

C) Pulsed lasers emit light in bursts with higher peak power.

D) Both emit light in the same manner.

E) Pulsed lasers are always larger.

Correct Answer: c

6. What does the term "pulse energy (E)" represent?

A) The energy in the entire laser system.

B) The energy contained in a single pulse.

C) The time duration of a pulse.

D) The repetition rate of the pulses.

E) None of the above.

Correct Answer: B

7. How is peak power (P_{peak}) calculated?

A) $P_{peak} = E \times fr$

B) $P_{peak} = \tau p / E$

C) $P_{peak} = E \times \tau p$

D) $P_{peak} = E / \tau p$

E) None of the above

Correct Answer: D

8. What is the unit of pulse energy (E)?

A) Watts

B) Joules

C) Seconds

D) Hertz

E) Newtons

Correct Answer: B

9. If a laser emits a pulse energy of 2 mJ and the pulse duration is 4 ns, what is the peak power?

A) 0.5 W

B) 50 MW

C) 500 W

D) 500 Kw

E) 1 MW

Correct Answer: E

10. What is the formula for calculating average power (P_{avg})?

A) $P_{avg} = fr / E$

B) $P_{avg} = E \times \tau p$

C) $P_{avg} = E / \tau p$

D) $P_{avg} = E \times fr$

E) None of the above

Correct Answer: D

11. If a laser has a pulse energy of 1 mJ and a repetition rate of 1 kHz, what is its average power?

A) 1 W

B) 10 W

C) 0.1 W

D) 100 W

E) 0.01 W

Correct Answer: A

12. What does the term "repetition rate (fr)" represent?

A) The total energy in a pulse.

B) The frequency of pulses per second.

C) The duration of a single pulse.

D) The speed of light in the laser.

E) None of the above.

Correct Answer: B

13. What happens to peak power as pulse duration decreases?

A) It increases.

B) It decreases.

C) It remains constant.

D) It depends on repetition rate.

E) None of the above.

Correct Answer: A

14. Which of the following applications uses pulsed lasers?

A) Micromachining delicate materials

B) Boiling water

C) Generating radio waves

D) Long-distance communications

E) None of the above

Correct Answer: A

15. If the pulse energy is 5 mJ and the repetition rate is 2 kHz, what is the average power?

A) 10 W

B) 0.01 W

C) 1 W

D) 100 W

E) None of the above

Correct Answer: A

16. What is a typical repetition rate for industrial pulsed lasers?

A) 10 Hz

B) 10 Khz

C) 10 Ghz

D) 1 Mhz

E) 1 Hz

Correct Answer: B

17. How is pulse duration represented in formulas?

A) fr

B) τp

C) E

D) Pavg

E) None of the above

Correct Answer: B

18. If Ppeak is 50 MW and τp is 10 ns, what is E?

A) 0.5 J

B) 5 J

C) 0.05 J

D) 50 J

E) 500 J

Correct Answer: C

19. What is the unit for repetition rate (fr)?

A) Watts

B) Joules

C) Seconds

D) Hertz

E) Volts

Correct Answer: D

20. Why are pulsed lasers preferred for ultrafast processes?

A) High continuous power

B) High average power

C) High peak power and short pulse duration

D) High energy consumption

E) None of the above

Correct Answer: C

21. What is the average power of a laser emitting 1 mJ pulses at 5 kHz?

A) 5 W

B) 0.5 W

C) 0.1 W

D) 10 W

E) None of the above

Correct Answer: A

22. What determines the energy per pulse in a pulsed laser?

A) Peak power

B) Repetition rate

C) Average power

D) Pulse specifications

E) None of the above

Correct Answer: D

23. What is a typical application of pulsed lasers in medicine?

A) Micromachining metals

B) Generating radio waves

C) Laser surgery

D) Studying molecular structure

E) None of the above

Correct Answer: C

24. If a pulse has a duration of (2 ns) and energy of (0.4 mJ) what is the peak power?

A) 0.2 MW

B) 2 MW

C) 20 MW

D) 200 MW

E) 0.02 MW

Correct Answer: B

25. Pulsed lasers are commonly used for studying which processes?

A) Time-resolved phenomena

B) Long-term changes

C) Energy loss in systems

D) Continuous-wave modulation

E) None of the above

Correct Answer: A