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Third Stage

Lec 10

Optical cavity and laser gain

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Optical Cavities (Resonator)

For some people, the expression **spot size of a laser beam** means its smallest diameter at the focal plane when focused by a lens, whereas for other people they mean the laser beam's diameter when it exits the laser, or at any other place where they need to measure it.

It is important to make a distinction between the two cases because the approach to measurement is different.

Round trip Gain (G)

Figure below show the round trip path of the radiation through the laser cavity. The path is divided to sections numbered by 1-5, while point "5" is the same point as "1".

Round trip gain, determines if the output power of the laser will increase, decrease, or remain constant. It includes all the losses and amplifications that the beam has in a complete round trip through the laser.

By definition, Round trip Gain is given by:

G = I$_5$/ I$_1$

G = Round trip Gain.

I$_1$ = Intensity of radiation at the beginning of the loop.

I$_5$ = Intensity of radiation at the end of the loop.

OPTICAL RESONATORS AND EIGENMODES

Important Concepts

• Stability

• Resonance (Eigen modes)

• Photon Lifetime

<u>Optical cavities</u>

The optical cavities (also known as optical resonators) are made to amplify the light within the cavity, so the mirrors used are highly reflective. Essentially, light enters the cavity through one mirror, reflects off the opposite mirror, and returns to the first mirror, while some of it is transmitted (exits the cavity) through each mirror. This light transmitted through the first mirror in each arm is the light that interferes at the beam splitter to form the signal.

Various types of optical resonators The cavity is designed so that the beam will remain entirely within the cavity's mirrors. These are referred to as follows where R_1 and R_2 are the radii of curvature of the mirrors and L is the distance between the mirrors:

a) plane-parallel $\qquad$ $R_1 = R_2 = \infty$

b) concentric (spherical) $\qquad$ $R_1 + R_2 = L$

c) confocal $\qquad$ $R_1 + R_2 = 2L$

d) hemispherical $\qquad$ $R_1 = L, \ R_2 = \infty$

e) concave-convex $\qquad$ $R_1 \gg L, \ R_2 = L - R_1$

There are five different types of stable two-mirror optical cavities, as shown in Figure 1. These types of resonators differ in their focal lengths of the mirrors (governed by the mirror's radius of curvature) and in their distance between the mirrors (cavity length). As you can see from Figure 1, some beams have different shapes within the cavity and are thus chosen for different purposes.

There are simple mathematical formulae that indicate whether or not a cavity is stable. In its simplest form, the rule can be stated as follows: Given a cavity made of two spherical mirrors (of radii of curvature R1 and R2) separated by a distance L, the cavity is stable .

Threshold Gain Coefficient: To sustain laser oscillations the gain coefficient must be at least large enough to overcome the losses in the laser system. The sources of loss include the following:

1. Transmission, absorption and scattering by the mirrors.

2. Diffraction around the boundary of the mirrors.

3. Absorption and scattering in the laser active medium.

The minimum or threshold gain coefficient kth required from the condition that the round trip gain G in the irradiance of the beam must be at least unity. If G < unity then the oscillations would die out, and G > unity then the oscillations would grow. In traveling from M1 to M2 in the laser resonator cavity, the beam irradiance increases from **I_o** to **I**

The spot size of a laser beam cutter ranges from 15 μm to 170 μm (0.003 to 0.007 inches), depending on the lens you are mounting. The shorter the focal length of the lens, the smaller the spot, which allows for the engraving of finer details. However, smaller spots are not suitable for working with thick materials.

Discussion

1. Spot size may refer to:

    A) Smallest focus

    B) Exit beam size

    C) Any beam diameter

    D) All of these

    E) None

    Answer: D

2. Round trip gain (G) is:

    A) I_1 / I_5

    B) I_5 / I_1

    C) $I_1 \times I_5$

    D) $I_5 - I_1$

    E) None

    Answer: B

3. For constant output, G must be:
    A) < 1
    B) $= 0$
    C) $= 1$
    D) > 1
    E) ∞
    Answer: C

4. Photon lifetime relates to:

    A) Energy level

    B) Time inside cavity

    C) Wavelength

    D) Spot size

    E) Mirror radius

    Answer: B

5. Optical cavity mirrors are:

A) Transparent

B) Opaque

C) Reflective

D) Absorptive

E) None

Answer: C

6. Plane-parallel cavity has:

A) $R_1 = R_2 = \infty$

B) $R_1 + R_2 = L$

C) $R_1 + R_2 = 2L$

D) $R_1 = L$

E) $R_2 = 0$

Answer: A

7. Concentric cavity condition:

A) $R_1 = R_2 = \infty$

B) $R_1 + R_2 = L$

C) $R_1 + R_2 = 2L$

D) $R_1 = L$

E) $R_2 = \infty$

Answer: B

8. Confocal cavity condition:

A) $R_1 + R_2 = L$

B) $R_1 = R_2 = \infty$

C) $R_1 + R_2 = 2L$

D) $R_1 = L$

E) $R_2 = \infty$

Answer: C

9. Hemispherical cavity:

   A) $R_1 = \infty$, $R_2 = L$

   B) $R_1 = L$, $R_2 = \infty$

   C) $R_1 + R_2 = L$

   D) $R_1 = R_2$

   E) $R_2 = L - R_1$

   Answer: B

10. Concave - convex cavity:

    A) $R_1 = L$

    B) $R_1 \gg L$, $R_2 = L - R_1$

    C) $R_1 = \infty$

    D) $R_2 = \infty$

    E) $R_1 = R_2$

    Answer: B

11. Stable cavity formula involves:

    A) Mirror reflectivity

    B) Spot size

    C) R_1, R_2, L

    D) Gain only

    E) None

    Answer: C

12. If $G < 1$, oscillations:

    A) Grow

    B) Die out

    C) Stay same

    D) Explode

    E) None

    Answer: B

13. If $G > 1$, oscillations:

   A) Die out

   B) Grow

   C) Stay same

   D) Stop

   E) None

   Answer: B

14. Loss sources include:

   A) Mirrors

   B) Diffraction

   C) Medium absorption

   D) All of these

   E) None

   Answer: D

15. Threshold gain coefficient ensures:

   A) $G < 1$

   B) $G = 0$

   C) $G \geq 1$

   D) $G > 2$

   E) None

   Answer: C

16. Spot size with short focal lens:

   A) Larger

   B) Smaller

   C) Same

   D) Zero

   E) None

   Answer: B

17. Smaller spot allows:

A) Thick cutting

B) Finer details

C) More power

D) Larger beam

E) None

Answer: B

18. Larger spot better for:

A) Fine engraving

B) Thick materials

C) Thin sheets

D) Mirrors only

E) None

Answer: B

19. Spot size of cutters ranges:

A) 1–5 μm

B) 5–10 μm

C) 15–170 μm

D) 0.1–1 mm

E) None

Answer: C

20. Beam splitter forms signal by:

A) Absorption

B) Reflection

C) Interference

D) Diffraction

E) None

Answer: C

21.Resonance in cavity means:

A) No oscillation

B) Eigenmodes

C) Absorption

D) Loss

E) None

Answer: B

22.Round trip path labeled:

A) 1–3

B) 1–5

C) 1–10

D) 1–7

E) None

Answer: B

23.I1 represents:

A) End intensity

B) Start intensity

C) Mirror loss

D) Photon energy

E) None

Answer: B

24.I5 represents:

A) Start

B) Middle

C) End intensity

D) Loss only

E) None

Answer: C

25. Optical resonator role is:

A) Absorb light

B) Destroy photons

C) Amplify light

D) Scatter photons

E) None

Answer: C