ME 677
Laser Material Processing
HW#1

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Assigned Date: January 21, 2019
Due Date: January 31, 2019

1. From the expression of the beam propagation in an optical cavity, derive the limits of stability. A He-Ne laser operating in a single mode TEM_{00} mode at 632.8 nm has a mirror separation of 0.5 m with mirrors where R_1=R_2=1 m. Calculate the beam waist and its location. Calculate the beam diameters at 1 m and 10 m away from the waist. Also find the beam diameter at the exit from the cavity.
2. A functionally graded material does not have uniform distribution of opaque particles instead there are more number of opaque particles in the center and reduce significantly towards outer edges.
   a) The volumetric density (particles/volume) is a function of radial distance from the center and could be modeled as $N(r) = N_0 e^{\left(\frac{-2r^2}{r_i^2}\right)}$. Where, N_0 is the maximum volumetric density (at the center), r = $\sqrt{x^2+y^2}$, and r_i is the radius of the inscribed circle. Assume x and y vary from –a to +a. The origin is located at the center of the plate. Derive an expression for Beer Lambert's law of absorption for such material.
   b) Repeat the same exercise if the intensity $I(x,y) = I_0 e^{\left(-\frac{2(x^2+y^2)}{r^2}\right)}$. Assume that the variation occurs only in y direction and the areal density remains constant along x-axis, where r is the beam radius ($1/e^2$ point). Plot the intensity profile at the center line along z axis as the beams travels from z=0 to z=0.1 mm. If the power is 100 W and absorption coefficient is 0.4 what is the incident power at z=0 and z=0.1 mm.

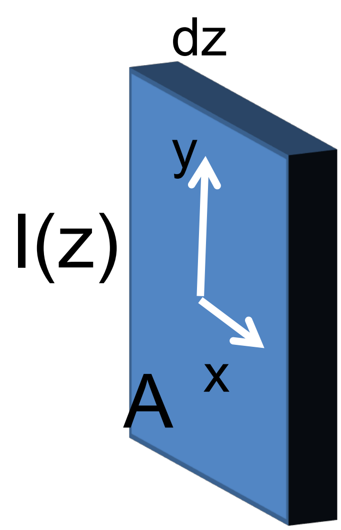

Fig. 1 Plate for Beer Lambert's law

3. Plot the stability graph for optical resonator. Locate the configurations mentioned in Fig. 2. on the stability chart. Find the stability for following conditions and place them on the chart as well.
   a. L=1.5 m, R_1=3 m, R_2=2 m
   b. L=1 m, R_1=0.5 m, R_2=2 m
   c. L=1 m, R_1=3 m, R_2=-2 m

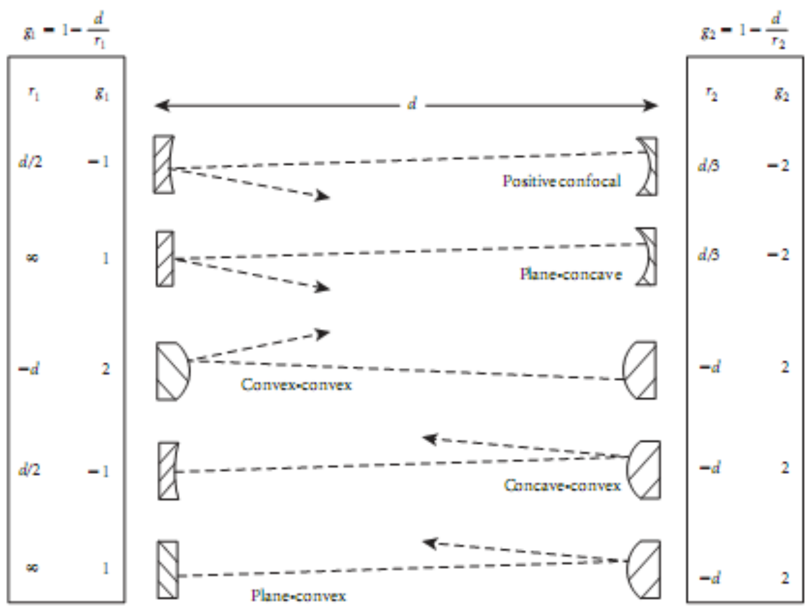

Fig. 2. Dimensions for optical resonators.

4. Find the power as a function of cooling efficiency for slow flow rod lasers, slow flow wave guide and fast axial flow. Using typical numbers make a comparison of power/length for all three configurations.

5. A single focusing lens is required for focusing the collimated beam from laser delivery system. Find the following:
   a) Focal length required for a 5 mm (z_l= 25.4 mm) collimated 1060 nm beam to be focused down to 100 μm. Find the prediction error when approximate formula is used.
   b) The beam size D(z) at z= 300 mm in the region between the focusing lens and the beam waist and plot it
   c) The depth of focus for the given focusing optics.
   d) Assuming that we need a much larger spot size, calculate what focal length will be required for a 600 μm spot size. If we have only 250 mm length available how to we achieve that spot size. Draw a schematic showing the location of optical elements. (Hint: use a focusing lens and a magnifying lens and use object image relationship.)

   Assume M^2=1.1.

6. The intensity (Power/area) distributions of parabolic rectangular and elliptical laser heat sources are given by Eqs. (1) and (2), respectively

$$I(x', y') = \frac{2*P}{A}[1 - \frac{y'^2}{b^2}][1 - \frac{x'^2}{a^2}] \quad (1)$$

$$I(x', y') = \frac{2*P}{A}[1 - \frac{y'^2}{b^2}][1 - \frac{x'^2}{a^2\left(1 - \frac{y'^2}{b^2}\right)}] \quad (2)$$

where P=laser power, A=area of rectangle/ellipse, the bounds of both the rectangle and ellipse are $-a \leq x' \leq a$ and $-b \leq y' \leq b$.

a) Plot the indicative intensity distribution using Mathematica or a software of your choice.
b) Find the value of total incident power (P_1) contained within the bounds mentioned above for:

   i) The parabolic rectangular source
   ii) The parabolic elliptical source

c) Calculate the beam widths in x and y direction based on the equations given in slide 24 of the notes. Feel free to use numerical values if symbolic computation becomes difficult. Comment on the comparison of dimensions computed from slide 24 and the actual distribution.

7. We are trying to calculate the distance to moon using a laser beam bounced of a reflector from moon. Let us assume that we have a 1 mm spot size 1.06 μm wavelength beam. The reflector diameter is 10 ft on the moon. We need at least 5 W of power on the reflector to concentrate and reflect the beam back to the base station on earth. Please find the actual beam power required and the spot size obtained on the moon. Assume that the M^2 value is 1.01. Also plot the spot size on moon as a function of M^2 value between 1.0 to 4.0. Recommend the kind of laser preferred for this.