Midterm #1 Prep

Revision: 2018/01/20

Professor M. Csele, Niagara College

Safety

- ✓Finding MPE for a laser
- ✓Calculating OD of glasses
- ✓Using EasyHaz
- ✓Choosing the right lenses
- ✓NHZ concepts
- ✓Laser Classes (I-IV) and regulations
  (e.g. power levels, wavelengths, exposure times – IR and Vis)

Ref: Lab #1A questions, Safety presentation

This section will be **heavily** emphasized on this test

Laser Cavity Optics

- ✓Shared Levels (ULL, LLL)
  - ✓λ Selection (mirror design – suppressing lines)
    (e.g. GreenNe mirrors, concept from PHTN1300, purely review)
- ✓Stability of a cavity
  - ✓G-parameters
- ✓Linewidth of a transition ($\Delta\nu$)
  - ✓For a gas laser using Doppler shift formula
  - ✓For a solid-state laser using conversion $\lambda \rightarrow f$
- ✓FSR and longitudinal modes
  - ✓# modes calculations
- ✓ Etalons
  - ✓Selection based on thickness

Ref: Lab #1B questions, Cavity Optics presentation, Ion Lasers Summary

Laser Gain Saturation and Models

- ✓Homogeneous vs. Inhomogeneous Media
  - ✓Calculation of SATURATION POWER
    (review from PHTN1300, see lab #5)
  - ✓Calculation of output power using both models
    (some review from PHTN1300,again see lab #5)
- ✓Pass-by-pass Model
  - ✓Basic formulae for saturated gain, power
    (Ultimately, gain must agree with g_{th}, P with above)

Ref: Lab #1B questions, Ion Lasers Summary

Solid State Lasers (Up to but not including Q-Switching)

- ✓Diode Pumping:
  - ✓Wavelength shift with temperature
  - ✓Reading datasheets
  - ✓Choosing an operating temp, current
  - ✓Temperature tuning of a diode
- ✓Thermal populations
  - ✓Calculating inversions and gain
  - ✓ULL population required to reach threshold where a LLL thermal population is present
  - ✓Calculating Re-absorption loss ($\gamma_{thermal}$)

Ref: Lab #2, Lectures, SS Lasers presentation

Expect COMPLETE SOLUTION questions where you need to perform multiple steps (like the prelabs, for example).

"Determine the number of modes in the output of a CO_2 laser then determine, using the appropriate model, the predicted output power"

This requires you to perform many steps (determine FSR, determine Δf, determine # modes, determine saturation power, determine output power using homog/inhomog model as appropriate).

What did you THINK an employer might have you doing next year ??

Some prerequisite material is from last term

- Formulation and use of the Threshold Gain equation (e.g. solving for reflectivities)
- Most material from chapter 3 (Quantum) and chapter 4 (Laser fundamentals)

Study Problems: 4.4, 4.5, 4.8, 4.9

Example Problems from last term:

A solid-state YAG laser consists of a 5cm long laser rod with an HR of 99.9% reflectivity and an OC of 90% reflectivity. Absorption of the rod is $0.2cm^{-1}$. Compute the threshold gain of this laser.

Assuming the small-signal gain of the amplifier is $0.3cm^{-1}$, the HR remains at 99.9% reflectivity and a absorption of the rod is $0.2cm^{-1}$. Compute the minimum reflectivity of the OC which will allow the laser to oscillate.

Now, a 90% transmission (on a single pass) neutral density filter is inserted inside the same laser cavity described above, between the rod and one mirror. Recalculate the new threshold gain.

This material is the basis for problems in this course and so all concepts outlined here are "fair game" – see the Entrance Exam for details

Q1: (From LAST YEAR)

A helium-neon laser is to be operated on the weak green transition (543.5nm) which has a gain of 0.06 times that of the stronger red transition (632.8nm) which has a known gain of $0.135m^{-1}$ – the gain of the green transition is hence $0.0081m^{-1}$. The actual plasma tube length is 30cm and you may assume there is *no attenuation* in the lasing medium.

Assuming the HR mirror is 99.999% reflecting, what is the **minimum reflectivity** of the output coupler at 543.5nm in order to allow the laser to oscillate?

Q2: (From LAST YEAR)

The green and red transitions share an upper-energy level so that if the red transition is allowed to oscillate, the green will not. If the OC has a reflectivity of 99.8% at 543.5nm, determine the **maximum reflectivity** of an OC at 632.8nm in order to allow green laser output.

PRACTICE QUESTIONS …

Q1: Choosing Safety Glasses

Compute the required OD for a set of safety glasses rated for use with a 5W argon laser operating at 488nm.

What *percentage* of light at 488nm passes through these glasses?

What markings are required on these glasses?

If these glasses took a "direct hit" from a 20W argon laser, what power would enter the user's eyes?

Is a set of glasses marked "490-532nm OD 4+" suitable for use with this laser?

Q1: Choosing Safety Glasses

A 20mW air-cooled argon laser is to be used with a set of glasses labeled “390-540nm OD 1.5+” …

- What class is this laser?
- Are safety glasses required for this class of laser?
- What is the maximum class of laser which may be used without safety glasses?
- What power would enter the user’s eyes if they took a “direct-hit” from this laser

Q1: Answers

Answers:

MPE=2.55E-3W/cm2
OD=3.7

0.01995%

"488nm OD 3.7+"

3.99mW Passes through

No … the OD is high enough but it doesn't cover the wavelength range required

IIIb

Yes

IIIa and below

20mW*10^-1.5 = 0.63mW

Q2:

A diode laser operating at 808nm has an observed spectral width of 1.5nm. Compute $\Delta\nu$ for this laser.

Assuming the cavity of the above diode laser is 300μm in length (and GaAs n=3.7), compute the FSR of the diode cavity

How many modes exist in the output of the above diode laser?

Q2: Answers

<u>Easy way:</u>
Convert each wavelength to a frequency and subtract (keeping MANY digits of precision!)

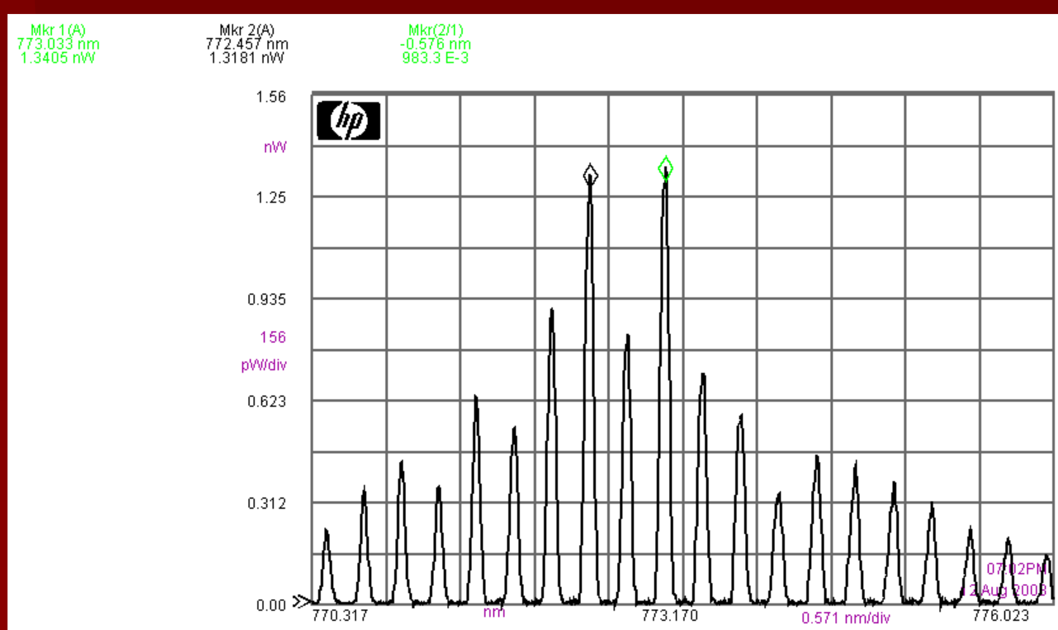
808nm → 3.71287E14 Hz

809.5nm → 3.70599E14Hz

So $\Delta\nu$ = 6.879E11 Hz

FSR=1.35E11Hz

Six Modes (see diagram below)



Etalons and Modes

(Covered primarily in the section on ion lasers)

Q3: Example Question: Etalons

(Similar to 6.3 in the textbook – a good practice example)

An argon laser, with a plasma temperature of 5500K, has a 90cm cavity. An etalon of quartz (n=1.46) is to be inserted into the cavity to allow single-frequency operation. How thick must the etalon be?

Assume argon weighs 40 amu and the laser operates at 488nm

Solution - Etalons and Modes

- Determine the Doppler linewidth of the laser ($\Delta\nu$)
- Set the FSR of the etalon equal to the linewidth
- Solve for the thickness of the etalon to obtain desired FSR

Start with the linewidth from chapter 4:

$$\Delta\nu = 2\nu_0\sqrt{\frac{2kT\ln(2)}{Mc^2}}$$

Be sure you know how to do this – try it well in advance ! There is a good example in chapter 4 of the textbook.

Q3: Answers

Argon is 40 amu so M=6.64E-23g
Use λ=488nm
$\Delta\nu$=5.16E9Hz (5.19 GHz)
(Did you convert to kg ??)
FSR=1.67E8Hz
31 modes with no etalon installed
(Round UP to the nearest integer)

Etalon thickness: 1.99 cm MAX

Q4: More practice problems on modes and etalons …

1) Compute the linewidth of a HeNe laser operating at 632.8nm at a discharge temperature of 400K (The Ne-22 isotope of Neon was used here)
2) Compute the FSR of a HeNe laser 30cm in length
3) Compute the number of longitudinal modes present in the output of this laser
4) Calculate the thickness of quartz etalon (n=1.46) required to force this laser to oscillate as a single frequency laser. Is this a minimum or maximum thickness?
5) Compute the linewidth of a carbon-dioxide laser, prove a 4m long laser is single-mode.

Answers:

1. M=3.65E-26kg, $\Delta\nu$=1.45E9Hz
2. 500E6Hz
3. 2.89 – round up to 3 modes (three modes, 500MHz apart, can lase with a linewidth between 1GHz and 1.5GHz)
4. 7.08cm max
5. CO_2 is 44amu, about 150C so linewidth is 62.8MHz. FSR is 37.5MHz so laser is two modes, not single mode

Q5: A Solid-State Mode Problem …

An Nd:YAG laser with a 0.5m cavity has a known spectral width ($\Delta\lambda$) of 0.45nm and an output wavelength of 1064nm.

Compute the number of modes that will potentially oscillate in this configuration.

Answer:

$\Delta\lambda$=0.45nm so Δf=1.19E11Hz (ensure you know how to compute bandwidth in Hz given bandwidth in wavelength), and FSR is calculated to be 3E8Hz, so the number of modes is 397. Of course homogeneous media are often single mode

Q6: g-parameters and Cavity Stability

An ion laser with a 1.15m long cavity has a flat HR. Using g-parameters, compute the range of values of radius-of-curvature which can be used for the OC?

Answers:

1. For the HR, Rhr=infinity so g1 =1. The valid range is defined by g1g2=0 and g1g2=1. The range is g2=0 to g2=1.15. g2=infinity (flat) to g2=1.15m

Q7: Inhomogeneous and Homogeneous Solutions

Calculate the output power of an argon laser (95%R OC, 100%R HR, 90cm atten length, 65cm gain length, beam diameter=1.3mm) using both homogeneous and inhomogeneous solutions. Parameters for the argon laser are found in LM table 8.2 pp.225.

Answer:

Saturation Power=0.2703W, Homogenous solution = 66mW output (1.32W intra-cavity). Inhomogeneous solution is 778mW.

Q8: Calculate the expected output power for a carbon-dioxide laser with x_a=2.5m, x_g=3m, tube diameter =19mm, HR=100%, OC=85%. Explain which model was used and justify why it

Q8: Hint: Calculate this in order …

- ❑ Saturation power
- ❑ Threshold gain of the optical configuration
- ❑ FSR of the cavity
- ❑ Spectral width of the transition
- ❑ Number of longitudinal modes
- ❑ Output power (using the correct model)

This is the same question as prelab 1B and lab 1B so sorry, no answer to be found here (although it can be discussed in class when lab 1B is returned)

Q9: Diode Wavelength Stability

A pump diode has an observed center wavelength of 803.0nm at 20C. Assuming the slope of the curve is 0.26nm/C, what temperature is required for the diode to be optimal for pumping vanadate (with an absorption peak at 808.6nm)?

Answers

The wavelength needs to shift 5.6nm so the temp must be increased to 41.5C

Make sure you know when to heat or cool a diode to shift the wavelength shorter or longer.

Q10: Diode Wavelength Stability

Referring to the datasheet on the next page, a SONY SLD302V-21 diode (a specific member of the SLD302 family of diodes) has a nominal wavelength of 798nm at 20C. At what temperature must this diode be operated to pump vanadate effectively? Is this even possible?

SONY **SLD302V**

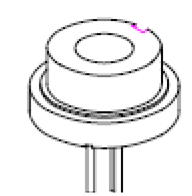
200mW High Power Laser Diode

Description

The SLD302V is a gain-guided, high-power laser diodes fabricated by MOCVD.

MOCVD: Metal Organic Chemical Vapor Deposition

M-248



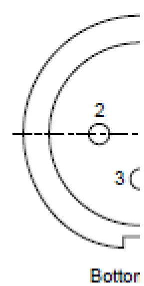
Features

- High power
  Recommended power output Po = 180mW
- Low operating current

Applications

- Solid state laser excitation
- Medical use

Pin Configuration



Structure

GaAlAs double-hetero-type laser diode

Operating Lifetime

MTTF 10,000H (effective value) at Po = 180mW, Tc = 25°C

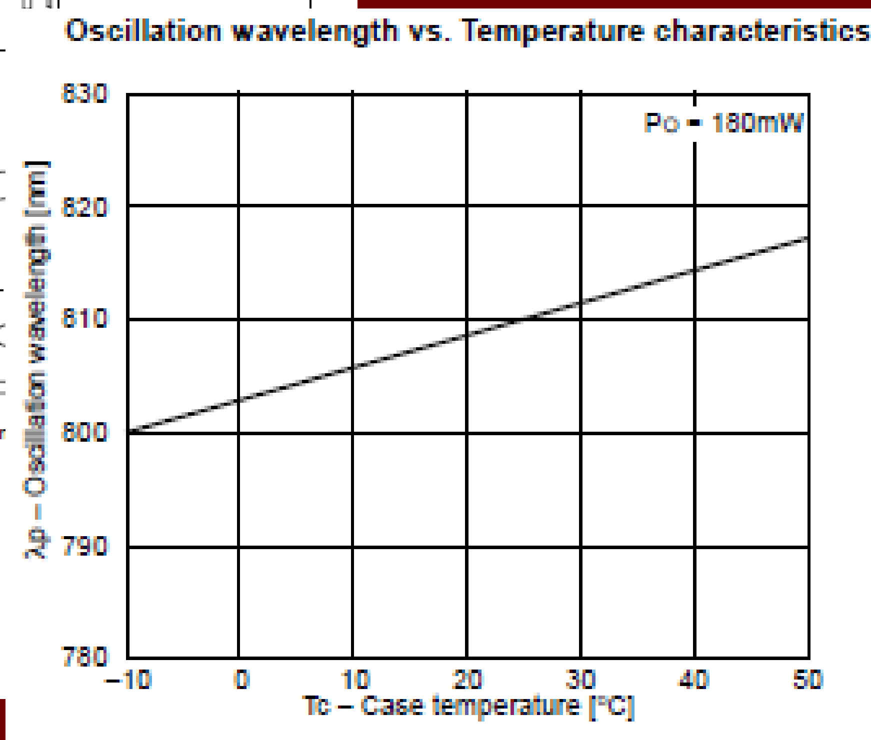
Absolute Maximum Ratings (Tc = 25°C)

• Optical power output	Pomax		200	mW
• Reverse voltage	V_R	LD	2	V
		PD	15	V
• Operating temperature	Topr		–10 to +50	°C
• Storage temperature	Tstg		–40 to +85	°C

Warranty

"Typical" wavelength curve below …

(it is a "family" of diodes so it is not specific)



Answers

57.2C

This is beyond the device specs which state that the device can run between -10C and +50C … it will burn out!

Q11: Diode Wavelength Stability

A pump diode used to pump vanadate (808.6nm peak) has an observed center wavelength of 808.0nm+/-3nm at 20C and the slope of the curve is 0.26nm/C

Any individual device can vary from 805nm to 811nm at 20C. Each diode, then, must be tuned *individually* for the correct wavelength.

Given a large sample of devices, what would be the range of maximum temperatures required to tune these diodes?

Answers

The range required is 33.85C to 10.77C

Once again, know when to heat and when to cool a diode.

Q12: Re-absorption Loss

An Nd:YAG laser has a rod 5cm in length and 4mm in diameter. The optics consist of a 100%HR, 90%OC. It is operating at a normal temperature of 300K and oscillates at 1064nm.

The doping density of YAG is $1.46*10^{26}m^{-3}$, the cross-section of the 1064nm transition is $2.3*10^{-23}m^{-2}$, and the LLL for this transition is only 0.2466eV above ground state.

Calculate the threshold gain for the system including re-absorption loss

Answer:

$N_{thermal}$=6.74E15

$\gamma_{thermal}$=0.242

g_{th}=1.59

Q13: Re-absorption Loss and Output Power

An Nd:YAG laser operates at 1064nm. The LLL for this transition is 0.246eV above ground level. The rod is 5cm in length and the mode inside the rod is 2mm in diameter. The OC is 90%R, the HR is essentially 100%R. The entire laser is water cooled and operates at 300K. Parameters for the Nd:YAG for this question may be found in Laser Modeling Table 8.7

Calculate the predicted output power of the laser taking all losses into account.

Answer:

$\gamma_{thermal}$=0.281
Optical g_{th}=1.353
g_0=5 (given)

Psat=91.14W

Pout=9.388W