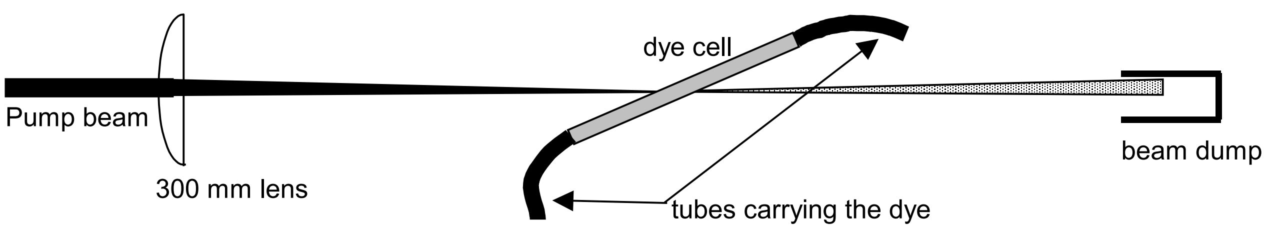
880 Quantum Electronics Optional Lab – Construct A Pulsed Dye Laser

The goal of this lab is to give you experience aligning a laser and getting it to lase more-or-less from scratch. There is no write-up for you to turn in. Your job is to build a dye laser, learn how to optimize its performance, study its modes, and, if there is time, explore different cavity configurations.

You may not take this lab unless you have read the laser safety manual for my laboratory. A link to this manual is on the class web page.

Introduction.

The gain medium and optical pump.
I'll forego detailed discussion of the gain medium since we will cover that in class soon. For now, suffice it to say that the gain medium is the dye Rhodamine 590 (R590) dissolved in methanol. This is one of the highest gain dyes available and it can lase over a broad range of wavelengths. The liquid dye is pumped in a recirculating system through a quartz cell that has a 2 mm square cross-section, and is several cm long. You will excite the dye, or pump it (meaning the optical sense now), with a pulsed, intracavity frequency doubled Nd:YLF laser. It delivers 527 nm pulses at a 1 kHz repetition rate. The pulse energy can be as high as 15 mJ, however only a maximum of about 2.5 mJ will be available to you. The pulse width is of the order of 150 ns. The dye concentration is such that roughly 80% of the pump energy is absorbed passing through the cell. For excitation at 527 nm, the dye's gain is largest at roughly 560 nm. The cell and pumping geometry are as shown in the figure.



The pump is horizontally polarized and enters the cell near Brewster's angle to minimize reflection losses. The gain is highest for light polarized the same as the pump, so the dye laser will also be horizontally polarized. Ideally, the cell will be at Brewster's angle for the laser beam.

Is it possible for the cell to be at Brewster's angle for both the pump and the laser?

Because you will be pumping with a pulsed laser, the dye laser will technically never be in steady state, the case we have considered in class so far, although it comes close to that during the peak of the pump pulse. However, since we are focusing on cavity alignment and design, this is not important. That kind of consideration would come into play if you wanted to explain the time behavior of the pulsed output of the dye laser. The real consequence of using a pulsed pump laser for you is that the gain will be fairly high, making it easier to get the laser to lase.

The chief hazard will be from the pump laser. You can expect spurious reflections from the lens and from the cell. Are they trapped? Make sure you know where all the reflections are going. The laser will also have spurious reflections from the cell once it starts lasing, of course, especially if the cell is off from Brewster's angle as it will likely be when you first get things lasing.

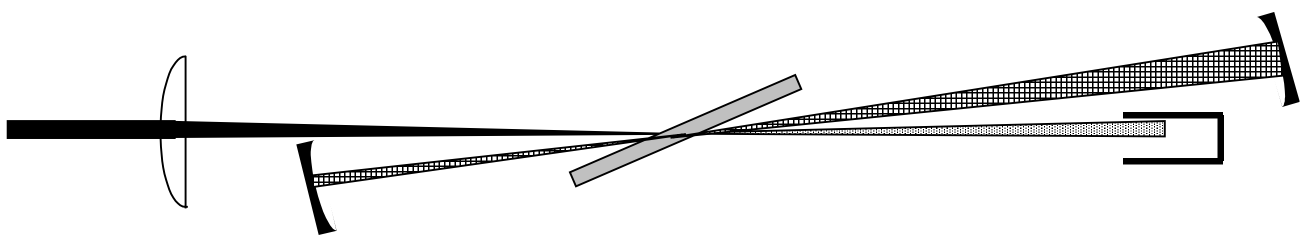
Goggles that absorb the pump light will be provided. They transmit reasonably well over the R590 emission curve so you will be able to see the fluorescence. In fact, by preventing the 527 nm scatter from reaching your eyes, your goggles will *greatly* simplify the alignment task. You should have your goggles on at all times except when you need to see the pump itself. Bear in mind that the pump beam will pass very near one of your cavity mirrors. Don't get your fingers in the beam when you adjust the mirror.

The Cavity.
Here are several cavity configurations you can consider:

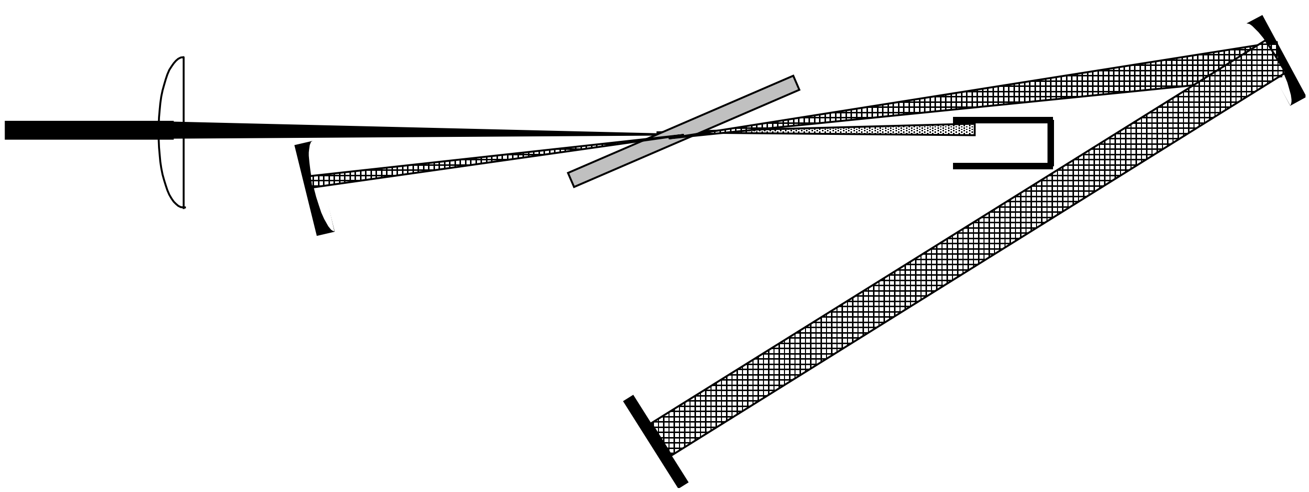
1) Nearly concentric.
2) Nearly confocal.
3) Hybrid. The cell is roughly at the radius of curvature of one mirror and the focus of the other.
4) Folded. For this case, the left cavity mirror is spaced roughly one radius from the cell, the right mirror is spaced roughly one focal length from the cell, and the end mirror is flat.

We have mirrors with radii of curvature of R = 200 mm and R = 600 mm. I suggest you start by using R = 200 mm for the left curved mirror and R = 600 mm for the right.

Nearly Concentric, Confocal, or Hybrid



Folded



Instrumentation.
Your most important tools will be your eyes and paper cards to place in the beam path, however, two other items will be useful. You will use a power meter to measure the minimum pump energy required for lasing. This value, called the threshold, is one of the best measures of the health of your laser and should be under 250 μJ/pulse. The power meter measures power, not pulse energy. Given that we are using a 1 kHz pulsed pump source, the conversion is trivial. If the meter is set to read 100 mW full scale, then, in terms of pulse energy, it reads 100 μJ per pulse full scale.

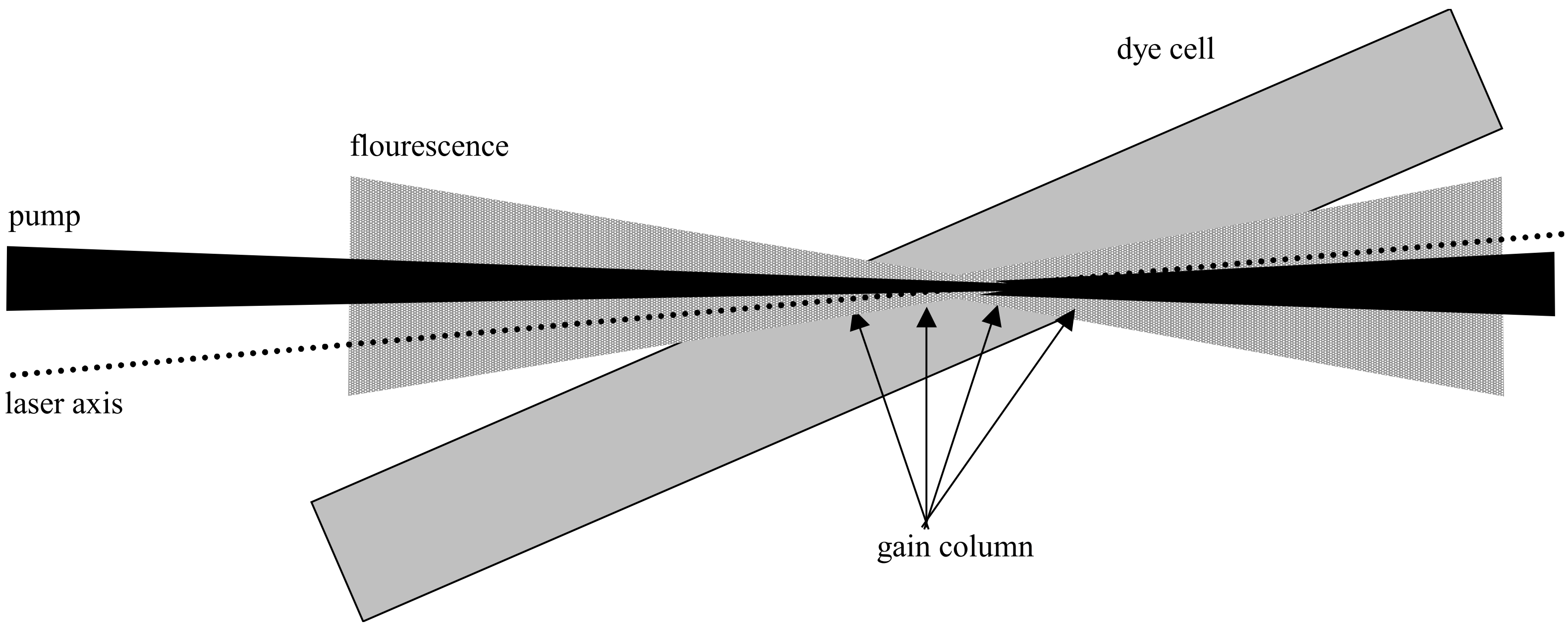
The other tool available to you, should you wish to use it, is a photodiode and oscilloscope to observe the time variation of the output pulses.

The Lab.
This discussion will be based on the concentric cavity. The others I leave to your exploration as time and interest permit. Some suggestions are offered at the end of this write-up.

For convenience, lets define the left curved mirror to be the "front" mirror and the right curved mirror to be the "back" mirror. Usually the output coupler is called the front mirror, but you will be working with mirrors that are nearly 100% reflecting. Output coupling for this laser is done by cavity dumping using an electro-optic switch. You will have the opportunity to explore that aspect in a different lab after you have learned a little more. For now, you must content yourself with a laser with no output coupling. You will have no trouble seeing when it lases. Even though the mirrors are of good quality, more than enough light is scattered from them to see the laser. In fact, the laser is bright enough that there is enough Rayleigh scattering to see the beam as it propagates in through the air. Generally, when you first try to get a laser to lase, you use all 100% reflective mirrors anyway to minimize cavity loss and lower the threshold pump power required.

Your first and primary task is to get your laser to lase. The pump beam has already been aligned for you. Generally when first trying to get a laser running you pump as hard as you can, within constraints set by optical damage either from the pump or the laser itself. However, you will have plenty of gain if you pump at 1 mJ/pulse. The energy level is set by a variable attenuator near the dye cell. The attenuator consists of a half-wave plate followed by a Glan-Laser polarizer and is adjusted by rotating the wave plate which is in a rotary stage. The polarizer is also in a rotary stage – adjusting it will create a *serious* eye hazard as described in the Safety Manual. The best place to measure the pump energy is after the lens, so that reflection losses are taken into account. Do not place the power meter too far down stream from the lens or the focused beam will damage the power meter's absorbing surface.

The fluorescence from the dye exits the cell in two large angle cones. The fluorescence is not isotropic because the region in the cell where there is gain forms a cylinder and the single pass gain along the cylinder axis is enough to begin to define a beam.

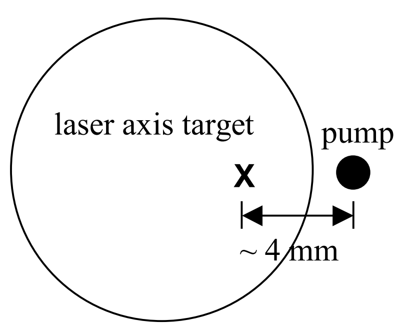


Position the front mirror.
The laser will work best if its axis is close to that defined by the pump beam. To facilitate this you should position the front mirror as close to the pump beam as possible.

Find the fluorescence collected by the front mirror.
To get your laser working, you will need to place the mirror at normal incidence to the fluorescence - your best guess will probably do to get you started. The fluorescence is dim and diffuse near the mirror, but the light collected by the mirror and retro-reflected back through the cell will be more beam like and brighter. (Why?) Hold a card downstream from the cell and see if you can find this light. You may want to give the front mirror an extra counter-clockwise tilt to guarantee the light appears somewhere between the lines defined by the pump beam and the dye cell axis. This step can be difficult because the region by the cell is very bright making it difficult to find the light you want. Bear in mind that the cell's vertical extent is small, so the vertical alignment of the front mirror is tightly constrained. When you find the spot, steer the mirror up and down to observe the cell boundaries and verify that the center of the collected light passes through the center of the cell.

Define a laser axis.
To start with, try to define a laser axis that places the laser beam on the front mirror at the same height as the pump beam and ~4 mm from the pump. To do this place your card downstream of the cell so that it is the same distance from the cell as the front mirror. Then position the fluorescence spot so that it is ~4 mm from the pump beam.

Front Mirror Looking Upstream



Place the back mirror.

Place the back mirror so that it catches the light from the front mirror and retro-reflects it. Naturally, besides retro-reflecting the light from the front mirror, the back mirror is also collecting fluorescence of its own and directing that towards the front mirror. Place a card in front of the front mirror and see if you can find the light collected by the back mirror. (Hold this card with your hand. You don't want it to accidentally slide into the pump beam.) Position the light from the back mirror on the target location on the front mirror. You now have a cavity that is roughly self-consistent. It if is better than roughly self-consistent you also have a working laser. If not, read on.

Improve self-consistency and observe lasing.

Hold your card near the dye cell on the side closest to you (that is, near the flexible tube carrying the dye). Tilt the back mirror counter-clockwise until you can see the spot from it. Since you are holding your card near the cell, the spot will be fairly small and easy to see. If all is well, you will see two spots. One is from the light collected by the front mirror, the other from the light collected by the back mirror. If you see two spots, figure out which is which. If you don't, scan the front mirror until you do. Make the spots overlap. Then tilt the back mirror until its spot is again at the target location. If all is really well, the laser will lase. If it doesn't, scan the back mirror until it does.

If you cannot get the laser running, consider whether you need to change the spacing between one or both of the mirrors and the cell. If you think you have picked reasonable positions for the mirrors, go back to the step "*Define a laser axis*" and try again.

Optimize the cavity.

Measure the threshold pump energy. Tweak the mirrors to maximize lasing and measure again.

You can control the laser axis by walking the mirrors. For example, suppose the lasing spot on the front mirror turns out to be much higher than the pump beam. To correct this, tilt the back mirror downwards. As the spot on the front mirror moves downward it will start to dim. Correct for this by tilting the front mirror.

- Before you adjust the front mirror, decide in advance which way it should be tilted: upwards or downwards?
- Why does this technique work? Once you have optimized lasing by adjusting the front mirror, is it possible that the spots will end up back where they started?

Repeat the walking procedure and also adjust the axis horizontally to optimize power and mode. Measure threshold again. It should be well under 250 μJ.

Another thing you can check is the dye cell angle. It should be at Brewster's angle for the dye laser beam. The easiest way to check this is to rotate it and try and minimize the light reflected from it. Be careful that you don't stress the cell and break it. If you do, dye will quickly spray over the surrounding area and it doesn't wash out.

Experiment with the laser.

- Rayleigh scattering is strongest in the forward direction. Look upstream and downstream and note the amount of Rayleigh scattered pump light and compare to the amount of scattered dye laser light.
- Look at the fluorescence and see if it changes intensity when you prevent lasing by blocking one of the cavity mirrors. Does it change? Should it?
- If you misalign either of the mirrors you can excite different spatial modes.
- How does the laser mode and threshold vary if you change the spacing between either mirror and the cell. The back mirror is the easiest one to move. Explore the meta-stable region illustrated in Fig. 7.4 in the text. With a little practice, you can slide the mirror to a new position and recover lasing in a few seconds.
- Look at the pulse shape using the photodiode and oscilloscope.
- Try other configurations. I suggest switching first to the hybrid configuration, then to the folded one. How long can you make the cavity? Feel free to use extra flat or curved mirrors to introduce more folds. You can also add lenses to the cavity if you like.
- Add a prism to the cavity so that the output wavelength can be tuned.
- If you know how to use a doubling crystal, you can try intracavity doubling.

I will be satisfied if you get your laser lasing with a reasonable threshold. There certainly will not be enough time for you to do all this. Pick what interests you most.