Introduction to Diode Lasers

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The goal of this document is to guide you through a series of simple experiments and measurements that will help you become familiar with diode laser technology and the simple spectroscopic techniques used in many areas of modern atomic physics. The document does not aim to fulfill the role of a *lab script*; rather it is expected that you will need to find supplementary information from text books or research papers to complete the measurements.

OVERVIEW - BUILDING YOUR OWN DIODE LASER

Diode lasers play an important role in all of the AtMol experiments in Durham and it is essential that you understand their operation and have the knowledge and confidence to adjust (or repair!) the lasers on your experiment. The best way to gain these skills is through the construction and characterisation of your own diode laser system, following the steps detailed in the subsequent sections. You may also want to read some or all of the following resources before getting too far into the tasks below:

1. *"Using diode lasers for atomic physics"*, C.E.Wieman and L.Hollberg, Rev. Sci. Instrum. **62**, 1 (1991).
2. *A narrow-band tunable diode laser system with grating feedback, and a saturated absorption spectrometer for Cs and Rb*, K.B.MacAdam, A.Steinbach, and C.Wieman, Am. J. Phys. **60**, 1098 (1992).
3. *Basic Description of the operation of diode lasers (Advanced optics lab laser primer).*

These are available on the resources page along with many of the other documents referred to below.

Note: the lasers you will use are class 3B and must be operated safely at all times. Make sure you have read and understood the departmental laser safety guidelines (they can be downloaded from http://www.dur.ac.uk/physics/internal/safety/). These guidelines should be adhered to at all times. Failure to do so may lead to your experiment being shut down.

SETTING UP AND CHARACTERISING YOUR FIRST DIODE LASER

To turn a commercial diode laser into a device useful for experimental atomic physics research requires careful control of the parameters affecting the laser wavelength, principally the temperature and current. This is, in essence, your first task. However, as you'll see in the following section even this is insufficient and *optical feedback* is required to deliver enhanced control of the laser wavelength and linewidth.

You should have been provided with all you need to mount a 780 nm laser diode in the latest homebuilt mount design. Below is a brief guide explaining how to mount and then characterise the diode. Note that the characterisation measurements can be completed in any order.

Assembly:

1. Check you have all the mechanical parts (including electrical connectors) to build your laser. Comparison with an existing laser will help, if you can provide someone kind enough to show you theirs. If the parts have just come from the workshop, make sure they are clean of all machining oil.
2. Solder up the following electrical connections to the baseplate:
   - Laser current connector to diode protection circuit to diode connector (Note: take care - it is a *diode* laser and as such the *polarity* matters. For more information, see online resources and laser data sheets. Make sure you understand the purpose of the protection circuit).
   - Piezo connector to bare leads (Note: the piezo stacks will be added later).
   - TEC connector to TEC (Note: take care bending the leads on the TEC, they can easily snap off).
   - Temperature sensor connector to thermistor (Note: this is often best done once the mount has been assembled. Sheathing from a wire can be used to insulate the leads of the thermistor, rather than heatshrink).

3. Assemble the mount. A thin layer of thermal compound should be used on each side of the TEC. Nylon screws ensure the laser mount is isolated from the base. This could be a good time to check that the temperature stabilisation will work (see below).

Mounting and collimating the laser:

1. The optical output of the laser diode is very divergent, and so we need to use a lens close to the laser facet to *collimate* the output. We commonly use a "collimation tube" from Thorlabs (*e.g.* LT230P-B). Diode lasers are extremely sensitive to static discharges, therefore when mounting the diode in this tube make sure that you wear an anti-static wrist band. Connect the laser diode to the lead from the baseplate. Note, as a general rule, a grounding cap should be used to protect the diode when it is not connected to the current controller. Mount the collimation tube in the laser mount.

2. Having checked the polarity of the current driver turn on the current to the laser diode and slowly increase until lasing is observed (a sudden increase in the brightness of the output viewed on an IR card). The beam should be elongated and divergent. Rotate the collimation tube in the laser mount until the long axis of the beam is horizontal. Note the laser is linearly polarised along the long axis of the *facet*. How does this tally with the beam and why?

3. *Collimate* the laser output by adjusting the position of the lens with the collimation tool wrench. Note the laser output is (roughly) Gaussian. What do we mean by *collimate*? How does the aspect ratio (ratio of long to short beam widths) of the beam vary with distance from the laser? Is this to be expected?

Temperature stabilising the laser:
The operation of most temperature stabilisation circuits is essentially the same, though the description below assumes you are using one of the wavelength electronic devices.

1. Read and understand the manual.

2. Take the lid off the device and check that the settings are appropriate. You need to choose a sensing current appropriate to the value of the thermistor you have used in the laser mount and you need to check that the current limit is not too low.

3. Make the appropriate cables to connect the device to the laser and power supply. Note that you will frequently need to check both the set-point and monitor point on the connector and therefore you may wish to solder BNC connectors to these terminals.

4. Make all the connections, except the one to the TEC from the temperature controller (taking care to insulate the TEC connections). Turn on the device and check the monitor-point (it should be below 10V).

5. Set the set-point to be close (close is determined by the response of your thermistor (see data sheet) and the sensing current being used) to the monitor-point.

6. Turn the device off, connect the TEC and turn the device back on. Check that the monitor-point stabilises to be equal to the set-point. You can then vary the temperature by varying the set-point, checking that the monitor-point follows. It is good to calibrate your thermistor. This can be done by remotely sensing the temperature of the laser block - with obvious limitations.

Characterising the laser:
With luck, you should now have a functioning temperature stabilised diode laser ready for characterisation. This characterisation provides an essential baseline on the "health" of your laser and you may need to refer back to some of these measurements in the future (*e.g.* if your laser starts to function poorly you may find your supervisor asks you "has the laser threshold changed?").

1. **Power versus current.** Just as the title says measure the output power of the diode versus the injection current. The power can be measured with a power-meter or a calibrated photodiode (this could be a good time to construct your own calibrated photodiode!). Take care not to exceed (i) the maximum operating current and output power of the laser and (ii) the maximum power on the power-meter (usually around 40mW. An attenuator is available for higher powers). Plot your data and determine a value (and error) for the threshold

current by fitting the data above threshold. (Note: we usually use Origin to plot and fit data, though care must be taken in using and understanding the fitting routine. It is a heinous crime to claim "the error is x.y because Origin says so.")

2. **Beam dimensions and aspect ratio.** Measured using the knife-edge technique (see separate guide) close to the laser output. As you'll have noticed the aspect ratio of the laser output is far from being unity. In order to correct this we can use a pair of "anamorphic prisms" at the appropriate angles (see the datasheet from Optima). Your measurements will therefore tell you how to setup the prisms, in addition to revealing "how Gaussian" the output really is (later you may measure the M^2 value of the laser output, as discussed in the knife-edge guide).

3. **Wavelength versus temperature.** For this you will need to use the group's HighFinesse wavemeter. (Manuals and instruction will be available.) This is a fibre coupled device, and so you will also get some exposure to aligning light into an optical fibre. You should vary the temperature from about 16 to 25 degrees Celsius recording the wavelength (make sure you note whether it is in vacuum or air). Ideally you would like to run the laser at a temperature where the *free running* wavelength is close to that of the D2 transition in rubidium (what is this wavelength?). The measurement should be taken at a sensible operating current and during the measurement you may need to adjust this current slightly (but note any changes). You may separately wish to try and measure how the wavelength tunes with laser current. Physically, why does the temperature (and current) change the wavelength?

EXTENDED CAVITY DIODE LASERS (ECDLS)

To enhance our control of the laser frequency and to reduce the linewidth of the laser output we need to build an additional cavity around the laser diode. This is commonly achieved by using a diffraction grating to inject a fraction of the laser output back into the diode facet (via the first order beam), whilst out-coupling the majority of the light (via the zeroth order). This optical injection *seeds* the laser giving preference to laser action at a wavelength determined by the external cavity. Importantly we can now control the wavelength by changing the parameters of the external cavity, specifically the cavity length and angle of the diffraction grating. Moreover by mounting the grating on a piezo-electric transducer, we can achieve sub-MHz control of the frequency via the piezo voltage.

To fully understand how the laser can be precisely tuned using the external cavity make sure you read the laser-primer.pdf document and the references therein. You should also make sure you can answer the following simple questions:

- Estimate the free spectral range associated with the "internal" diode cavity for a typical laser diode.
- Repeat the above calculation for a typical "external" cavity.
- Estimate the spread in frequency of the light reflected back into the laser from the grating assuming the resolving power of the grating $\nu/\Delta\nu = N$ (where N is the total number of grating lines illuminated by the laser) and that the transverse width of the laser beam is 5mm. Convert your answer into a wavelength.
- Assuming the angle of the grating is altered by turning a screw with 80 threads per inch located 25mm from the pivot point, estimate the expected change in wavelength due to one complete turn of the screw. Ignore any changes in the cavity length and assume a rubidium diode with the above grating.
- Calculate the change in wavelength resulting from a change of the cavity length equal to one turn of the 80 tpi screw above.

Constructing the ECDL:
Constructing the ECDL is straightforward, though care must be taken handling the diffraction grating.

1. Before beginning familiarize yourself with all the elements that need to be assembled to construct the ECDL, and think in detail about the order in which you plan to put the device together. The grating is attached via the piezo transducers to an angled adaptor which is in turn mounted in a commercial mirror mount. For a grating with 1800 lines/mm, what grating angles are needed for the laser to function correctly at the Rb and Cs wavelengths? Make sure you have the correct adaptor!

2. Attaching the grating to the angled adaptor is best achieved in two stages. Firstly, glue (using PermaBond or similar) two piezo transducers to the angled adaptor in the recesses shown. This is easiest if you mount the angled adaptor in the mirror mount (Thorlabs KS05/M) and then mount the mirror so that the face of the angled adaptor is horizontal. The leads can be fed out through the hole in the adaptor.

3. Secondly glue the grating to the piezos (once the glue has adequate time to set). The orientation of the grating is important - the rulings must be vertical. It is worth downloading a response curve for the grating . You will see that the fraction of light diffracted into the first order depends on whether the light is polarised parallel or perpendicular to the lines on the grating. You may wish to measure the diffraction efficiency of your grating once it is secured in the laser mount. Check that the position you plan to mount the grating is correct by first sliding the mirror mount into the housing and noting the position of the laser output. When handling the grating wear gloves and only hold the edges (without the gloves the oil and grease on your fingers moves up the lines of the grating onto the face even if you are careful to only hold the edge). Note: only small amounts of glue are required and you should aim to only place the glue on the *ends* of the piezo stacks (their performance may be impaired if the glue runs down the sides).

4. Mounting the grating/mirror assembly to the laser block, requires the removal of the four nylon screws. Then screw into the mirror mount using both of the holes available. Finally reattach the block to the base, taking care to press down evenly onto the TEC.

5. Finally, complete the electrical connections to the piezos by wiring them in parallel.

Aligning the grating:
Injecting light back into the laser from the grating gives rise to a build up of light at a frequency determined by the external cavity, leading to preferential lasing on this *mode* and concomitantly a reduction in the laser threshold. Observing the change in the laser threshold therefore provides the simplest way to align the grating using one of several equivalent techniques detailed below. Before pursuing one of these approaches it is important to make sure the grating is crudely aligned, which can usually done by physically checking that the first order reflected light is heading back into the collimation lens. Note when the alignment is close you can commonly see two spots in the zeroth order reflected beam. One of these is the laser output and the other is a reflection of the first order light from some point on the laser diode junction. If you reach this stage then further course alignment is simple - you simply adjust the grating mount until the two spots overlap (a description of this method can be found in the manuals of commercial diode laser systems, *e.g.* the Sacher laser manual). Note also that the vertical alignment is the most critical, as generally the laser will inject over a range of wavelengths (equivalently grating angles or horizontal know position) whereas in the vertical direction there is only one correct alignment.

Vertical flash test. Having crudely aligned the grating, operate the laser at a current close to threshold. This current may be just above or just below, and should be adjusted as the alignment progresses. View the laser output on the IR card whilst adjusting the vertical alignment of the grating. When the laser is injected the threshold is reduced, the output power therefore increases suddenly and a *flash* is observed on the IR card (the biggest flash is observed when the laser is initially below threshold, so experiment with different laser currents). The laser current can then be reduced and the process repeated iteratively to converge on the best alignment and lowest threshold. It is instructive to also observe the behaviour as the horizontal grating alignment is changed. Usually you find that the laser is injected at several grating angles, but the threshold is not always reduced by the same amount, the lowest threshold being achieved when the wavelength determined by the external cavity is close to the peak of the gain profile of the laser (this emphasizes the value in setting the temperature such that the free running laser wavelength is close to the desired wavelength).

Power meter/photodiode approach. The IR cards are not the most sensitive detectors. Another approach is to monitor the laser output using a power meter or a photodiode. The method for aligning the grating to get the lowest threshold is then essentially the same as for the vertical flash test. This is particularly nice method if you have access to a power meter with a needle display. You can then operate the power meter on a appropriate setting (say 0 to 1mW or 0 to 300μW and set the laser current so that the needle is in the middle of this range. As the grating alignment is adjusted you should see the power change very sharply when the laser is injected. Again iterate current and alignment to get the best injection.

Scanning current method. The above methods can be taken one step further by modulating the laser current with a sawtooth waveform over up to 5mA. If the laser power is then monitored on a photodiode and displayed on an oscilloscope you get a real time monitor of the laser threshold (*i.e.* you see the knee in power that you recorded when measuring the output power versus current for the bare diode). Alignment of the grating then shifts the position of this knee and the optimum injection is found when the threshold is again reduced to a minimum (the knee is furthest to the left on the oscilloscope, assuming you are triggering the oscilloscope sensibly!).

Finally, having satisfied yourself that the grating is now well injected, **record the power versus current curve** again around threshold in order to determine the new threshold current. This will form a future reference point that will allow you to determine whether the laser is still well injected.

Tuning to an atomic transition:
Although the grating is now aligned so that the injection is optimized it is unlikely that the laser will be operating at a wavelength coincident with an atomic transition ("on transition"). Tuning the wavelength so that the laser is on transition requires adjustment of the horizontal grating alignment together with the laser current (and possibly the temperature):

- Direct some or all of the laser output through an atomic vapour cell and observe the cell with an infrared viewer. What do you expect to see when the laser is resonant with an atomic transition? Apply an appropriate ac voltage to the piezo stacks to scan the laser frequency. Then, firstly vary the laser current and look for fluorescence in the cell. You probably won't see anything - don't be alarmed. Set the laser current to something appropriate (usually determined by the power you require out of the laser for your experiment, but in this case make sure it is well above threshold, but not at its maximum) and then adjust the horizontal grating alignment until you see fluorescence in the cell.

- Having achieved fluorescence you have either tuned the laser on transition or completely misaligned the grating so that the laser is now multi-mode, with a small fraction of the output hitting the transition. To check this and to improve the laser tuning you need to monitor the transmission of a weak probe beam through the cell using a photodiode connected to an oscilloscope (triggered from the piezo ramp voltage or (TTL synchronization output)). What do you expect to see if the laser is scanning across an atomic transition? With this monitor setup you can fine tune the grating angle, including possible small adjustments of the vertical alignment (mirror mounts are not perfect and large adjustments on one axis often lead to small changes in alignment on the other axis) in order to maximize the length of the single mode scan. Record at what laser currents you observe a transition. Are all the transitions the same? You may also wish to alter the laser temperature to see if you can improve the scan range. There is no substitute for experience when aligning a laser on transition so play around and don't be afraid to misalign the laser and try again.

- You can finally do a quick check on the purity of the laser mode. Gently heat the cell with the hot-air gun until you see the absorption feature flatten out at the bottom. Record the transmitted light levels on and off resonance. This gives a quick measure of the fraction of light not in the desired laser mode - you should be concerned if your result is not around 1-2%.

SIMPLE ATOMIC SPECTROSCOPY

You should now have a functioning laser tuned to one (or more atomic transitions) and are ready to do some atomic spectroscopy.

Probe only spectroscopy:

You have already been recording probe only spectra when aligning the grating. There we were concerned with discerning information about the laser. Now we will use the spectra to learn something about the atom.

1. Record on the oscilloscope, download and plot spectra of all the absorption features accessible with your laser. Can you identify the features? We would like to produce plots of transmission versus frequency, but this requires calibrating the frequency axis. Can you use the features to do this?

2. A better way of calibrating the scan is to use an etalon. See if you can borrow an etalon and align some of the laser light into the etalon. Use a second photodiode to monitor the etalon transmission. You can now calibrate your laser scan. How far does the laser scan between *mode-hops*? What are the widths in MHz of the absorption features? What determines these widths? What shape are the absorption features and why?

3. Record the peak absorption on each feature. What factors determine the peak absorption? Investigate the variation in the peak absorption with laser power and produce a plot of absorption versus power? Measure the

beam size at the cell and modify your plot to show absorption versus intensity. Would you expect this plot to change for a beam with different dimensions? You may wish to expand the beam with a simple telescope (two lenses separated by the sum of their focal lengths) and repeat your measurements. Read the article by Smith and Hughes ("The role of hyperfine pumping in multilevel systems exhibiting saturated absoprtion").

Pump-Probe spectroscopy:

The Doppler broadened features obtained in probe only spectroscopy obscure a lot detail in the atomic spectra. These features can be identified using a sub-Doppler pump-probe technique (also commonly known as *saturation spectroscopy*).

1. Modify your setup to include a pump beam in the standard configuration illustrated in the article by Smith and Hughes. Take care over the alignment and choice of pump and probe powers. Record and plot sub-Doppler spectra on the transitions accessible with your laser. It is useful to record the probe only spectra too in order to show directly how the absorption is modified by the presence of the pump beam.

2. Understand the spectra. How many sub-Doppler features do you see and why? Relate the sub-Doppler features to an atomic energy level diagram? What determines the width of the sub-Doppler features?

3. You can now use the sub-Doppler features to calibrate your laser scan. But before doing so, use the etalon to measure the separations of the sub-Doppler features in your spectra? How do the positions of these features compare to what you expect from the atomic energy level diagram?

4. (*Optional*) It is sometimes useful to remove the Doppler broadened background. One way of achieving this is to simultaneously record a probe only spectrum and then to subtract the two photodiode signals.

5. (*Optional*) A more sophisticated approach is to *amplitude modulate (chop)* the pump beam and use phase sensitive detection or lock-in on the probe beam. This is a very powerful approach and is worth investigating and understanding. The amplitude modulation can be achieved either using a mechanical beam chopper or an acousto-optic modulator (AOM). The frequency of modulation can be much higher with the AOM. Why is this beneficial.

SPECTROSCOPIC TECHNIQUES FOR LASER-LOCKING

Our experiments often require laser light of a well defined frequency and we therefore commonly wish to stabilize the laser frequency to a particular atomic transition. The spectroscopic techniques explored so far can be used to do this using a *side of fringe* locking technique. There is, however, a whole host of other techniques available each with their advantages and disadvantages. These techniques all lead to a dispersive-like *error signal* with a stable well defined zero crossing to which the laser frequency can be stabilized. At this stage you should explore the literature and build up a catalogue of laser-locking techniques (there could be a prize for the student you finds the most distinct techniques). Then, using the published literature, setup and explore one or more of the spectroscopic techniques listed below. Note these are techniques used at Durham and although your choice should be influenced by the technique used on your experiment you should also feel free to experimentally investigate other techniques that interest you. The culmination of this task should be the locking of your laser to atomic feature.

Polarization spectroscopy: See, for example, C.P.Pearman *et al.* J. Phys. B **35**, 5141 (2002).

Dichroic Atomic Vapour Laser Lock: See, for example, K.L.Corwin *et al.* Appl. Opt. **37**, 3295 (1998).

Dithering the laser frequency: See, for example, G.D.Rovera *et al.* Rev. Sci. Instrum. **65**, 1502 (1994).