C7: Introduction to Fibre Amplifiers

Aims, Objectives and Outline

This lab aims to provide you with:

- A basic working knowledge of the properties of laser diodes.
- Experience working with optical spectrum analysers (OSA).
- an opportunity to construct your own fibre amplifier and fibre laser.

By the end of the lab you should be able to:

- use an OSA to measure the basic properties of a laser such as the wavelength and power.
- Measure the amplified spontaneous emission of an amplifier
- Understand the role of feedback in lasers.
- Understand the increase in noise in amplifier systems

Laser Safety Awareness

It is essential for your safety that all due care is taken when dealing with lasers and especially infrared lasers since high powered focussed lasers can damage your eyesight. The lasers used in this experiment are all contained within fibres and as such are not dangerous in normal operation. Under no circumstances point the fibre ends towards anyone's face as this is potentially dangerous. The equipment is interlocked and thus the lasers cannot be operated unless the enclosed is closed and so any attempts to tamper with the interlock is forbidden. Lastly as a matter of precaution **do not turn on the drive currents to either diode** until the lid is closed and all the fibre ends are either in the enclosure or attached to the appropriate measuring device

Before you can start the experiment you must print out and sign the laser safety awareness form. You then need to hand the form to the supervisor who will then give you the interlock for the system allowing you to operate the lasers

Also the diodes used in this experiment are sensitive to sudden changes in the drive current. Hence switching the power off at the mains might damage the diodes if they are running and this should be avoided unless absolutely necessary. Instead the drive currents to the diodes should be turned down to zero. At which point there is no laser radiation being emitted and the box can safely be opened.

BACKGROUND: OSAs theory and operation

Background: Spontaneous and Stimulated Emission: Optical amplifiers and lasers operate via the principle of stimulated emission. For light interacting with an atom there are three possible processes. The first is absorption when a photon of light is absorbed by an electron which then jumps from its ground state to an excited state (the difference in energy between the two states must be $\hbar\omega$ where $\hbar$ is Planck's constant and ω is the frequency of the photon). Alternatively if the electron is already in an excited state an encounters a photon of frequency ω it can emit a 2^{nd} photon with the same frequency and wavevector. This process is know as stimulated emission and is responsible for the amplification. Lastly if no photons are present the excited electron will decay to the ground state by emitting a photon of frequency ω in a random direction. This process is known as spontaneous emission. Thus we can describe the change in intensity of the light by the following rate equation:

$$\frac{dI}{dz} = -\alpha N_1 I + \alpha N_2 I + \beta N_2$$

where $N_{1,2}$ are the populations densities of electrons in the lower and upper states respectively and I is the intensity of the light as a function of the propagation distance z. Note that the three terms in the above equation correspond to absorption, stimulated emission and spontaneous emission respectively. If we neglect spontaneous emission for the move we find the solution

$$I = I_0 e^{\alpha(N_2 - N_1)z}$$

Clearly from the above equation in order for a light beam to experience gain stimulated emission must win out over absorption (i.e $N_2 > N_1$). This can only happen if there are more electrons in an excited state than in the ground state. The only way to do this is to "pump" the electrons into the excited state via some other means and creating what is known as a population inversion. In an erbium doped fibre amplifier (EDFA) the gain is provide by Er^{3+} ions which are incorporated into the core of the silica fibre. These ions are pumped to the excited state by a laser beam at 980nm. The excited electrons then undergo a fast non-radiative decay (i.e. they don't emit any photons) to the appropriate energy level suitable for amplifying 1550nm radiation. The wavelengths that can be amplified can be seen by pumping the EDFA and seeing at what wavelength the spontaneous emission occurs at.

Units used: In most optics experiments power is measured in units of dBm. To covert from a power in mW to a power in dBm the conversion factor is

$$P_{dbm} = 10\, log_{10}\left(\frac{P_{mW}}{1mW}\right)$$

where P_{mw} is the optical power in mWs. Often relative rather than absolute units are used especially when talking about gain. For example a gain of 10dB means that the power is increased by a factor of 10, while a gain of 3dB means that the power is approximately doubled.

In some parts of the experiment you will be asked to measure the signal to noise ratio (SNR) of the signal. This is the ratio of the maximum signal power with the maximum noise power (at some different wavelength). If the two powers are P_1 and P_2 then the SNR is defined by

$$SNR = \frac{P_1}{P_2}$$

where P1 and P2 are measured in Watts. If we wish to express the SNR in dB then it can be shown that

$$SNR(dB) = P_1(dB) - P_2(dB)$$

As part of the preparation show that above equation can be proved using the definitions of the dB and the SNR.

At the output of the amplifier there is a 10% coupler which means that only 10% of power is being measured. Thus if the measured output power is P_{meas} mW the real output power P_{out} is given by

$$P_{out} = 10\ P_{meas}$$

where again the power is in mWs. Express the above equation in dB.

Finally suppose that the output power is doubled, i.e. $P_2 = 2\ P_1$. Express this in dBs. How does this compare to the original statement that a gain of 3dB means that the power is approximately doubled?

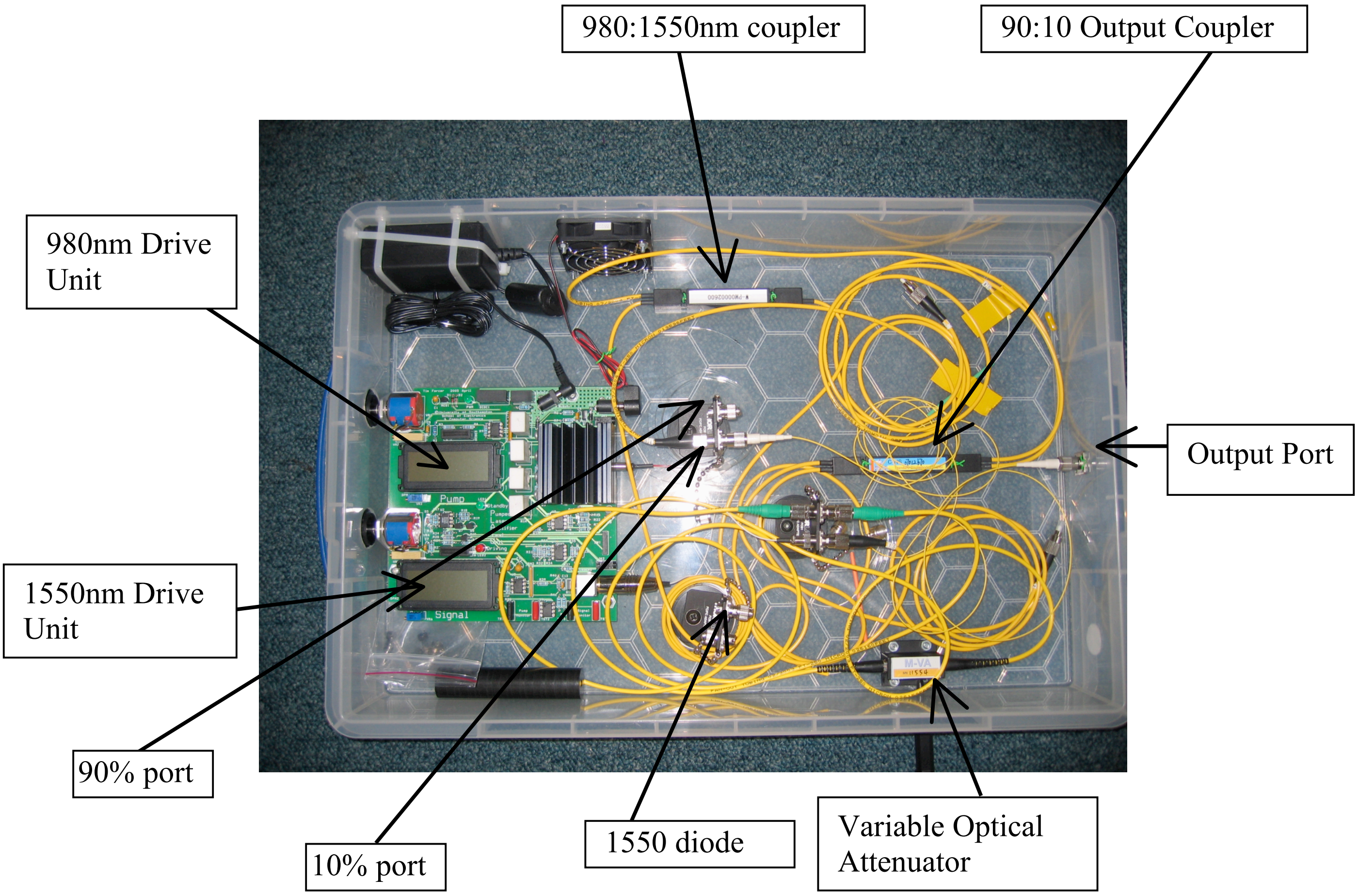
Optical Spectrum Analysers: The OSAs used in this experiment are all designed to measure the power per unit Hz in the optical domain typically with units of dB/hz. Each spectrum analyser is slightly different so detailed instructions cannot be given. However there are some basic controls. To use the OSA you will need to set the centre wavelength (1550nm is a good start), the span (try 20nm) and set the machine running (usually under sweep, repeat). You will also need to set the resolution of the device the actual resolution will depend on the span – larger spans need lower resolutions (0.5nm or greater) while smaller spans can have higher resolutions (0.02nm). Other controls are either relatively straightforward or unimportant. On the HP and Agilent OSA's you will also need to set the sensitivity to be less than -60dBm. On the newer HP scopes this can be done by pressing the "amplitude" key and then change the sensitivity. On the older scopes there is a separate button marked "sen".

When trying to measure points on the spectrum analysers, there are "marker" functions on the OSAs which allow you to read the values off the screen. In addition most of the OSAs allow you to put two markers on the screen and then the OSA will calculate the difference in wavelength and power between the marks.

Fibre Basics: All of the equipment here is based around standard fibres which are connected using fibre uniters. ***In order to avoid damaging the*** fibre ends the following precautions must be used: When connecting or disconnecting the fibres always switch off the lasers beforehand (i.e turn the drive currents to zero). This will also ensure that you are never exposed to the laser radiation. In addition try to avoid touching the fibres or creating any sharp bends as this can damage or break the fibres as well as introducing loss into the system which will interfere with the experiment.

When using the fibre uniters make sure that the flange on the end of the fibre pigtails is fully inserted into the slot on the uniters. If this is not done then there is a significant amount of excess loss in the system resulting in very little gain.

When handling the fibres it is **important never to touch** the ends of the connectors. This can lead to optical damage of the connectors as well as increase the loss and will make the results much harder to understand.



<u>Experimental Setup:</u> A schematic of the experimental apparatus is shown above. The drive unit contains the 980nm pump diode and the 1550nm diode. The current supply to these can be controlled by turning the large knobs on the end of the unit. In order for the diodes to be switched on the interlock must be connected which can be seen by the red LED being lit up. If the interlock is disconnected then the green LED is connect and no current is supplied to the diodes.

The output of the drive unit consists of two fibres – one for the pump which is connected directly to the WDM coupler while the signal fibre (which is white) is unconnected. The WDM coupler takes the two inputs at different wavelengths and combines them into a single output fibre. This fibre is the spliced onto the Er doped fibre which is then spliced onto the 90:10 output coupler. The 90:10 output coupler splits the input light into two output fibres, the 90% arm getting 90% of the power while the 10% arm gets 10% of the light.

The optical box has one output port which is connected to a thin yellow patchcord. The other end of this patchcord can then be connected to which-ever device is currently under investigation. The apparatus also contains several fibre connectors which can be used to complete the optical circuit. In addition there is a separate patchcord used to connect the output port to either the hand-help power meter or the spectrum analyser.

<u>Laboratory work</u>

1. Determination of the Laser Threshold

The first part of this lab examines the 1550nm laser diode. This laser emits light at 1550nm and should have a maximum output power of approximately 1mW (0dBm). To do this connect the output of the 1550nm diode (the white fibre) to the spare yellow patchcord using the uniter provided and then connect the other end of the patchcord to either the spectrum analyser or the power meter.

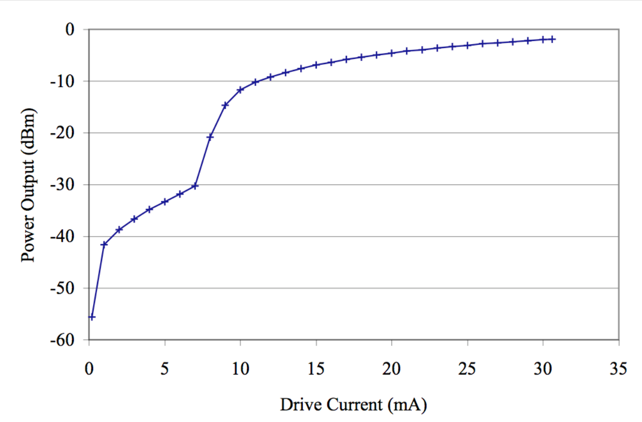


Fig. 2: Typical power v current curce for a laser diode. Taken by Charles Asquith 2006

The diode is connected to a variable optical attenuator and you will initially need to set this to the minimum value. To do this connect the hand held power meter to the output of the box and turn the 1550 drive current to the maximum value (about 30mA). Then using the screw-driver provided set the attenuator so that the power output is maximised (i.e. as close to 0dBm as possible).

The next step is to measure and plot the output power of the laser against the drive current (i.e. produce a graph like the one above). Starting with 0mA on the lower LCD panel slowly increase the signal current while measuring the output power using one of the handheld power meters. Also measure the spectrum of the laser at several points along the curve. The two things to look for will be the will be the signal to noise ratio of the laser (i.e. how much the peak is above the background) and the threshold current. When the laser is above threshold the output power should increase exponentially with drive current and so the plot of output power in dBm v signal drive current should be a straight line (this threshold value should be approximately 6mA). For future parts of the lab record note the maximum output power. Finally using the spectrum analyser measure the output wavelength and try and estimate the 3dB bandwidth of the source (i.e. the wavelength range over which the power is more than 50% of the maximum power). How does this bandwidth compare with the instrument's resolution?

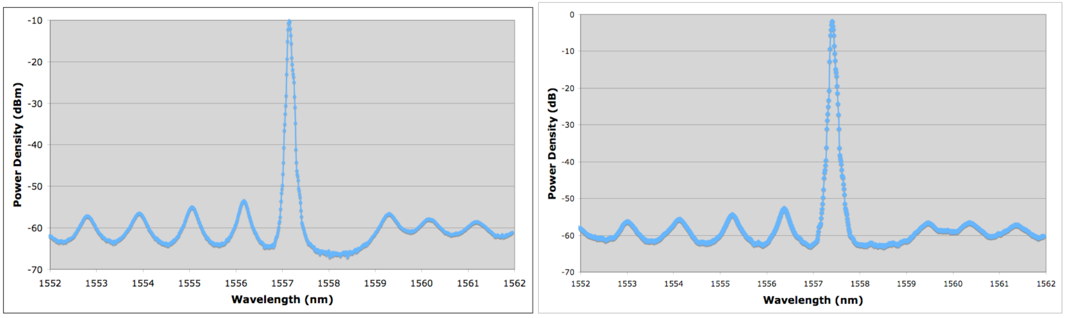


Fig. 3: Typical spectra of the 1550 diode at low (on the left) and high power. Note the increase in signal to noise ratio at high powers and the low power oscillations on the spectrum.

If you set the 1550nm diode to maximum power and examine the spectrum (set a span of 20nm) you should see a series of ripples approximately -50dB down from the main peak (see Fig.2). These are due to round trip oscillations within the laser cavity and can be used to estimate the length of the laser. The difference in frequency between two adjacent peaks should be 2*c/L where c is the speed of light and L is the cavity length. We can use this to estimate the cavity length. The frequency of the nth peak should be ν_n= n 2 c/L and so the frequency difference between two peaks should be $\Delta\nu = (m-n) \times \frac{2c}{L}$. This can be easily solved for L.

Using two widely spaced peaks calculate the average wavelength separation between the peaks. Also record the two absolute wavelengths and hence obtain an estimate for the length of the laser cavity. Remember that the spectrum analysers display wavelengths in nanometres rather than frequency so you will need to convert from nanometres to Hertz. How does your estimate of the cavity length compare with the external size of the laser?

Now measre the signal to noise ratio of the 1550nm diode at full power. Express this value both in dB and as a ratio of linear powers. How noisey is the source?

Lastly using the power meter set the VOA so that the output from the 1550nm laser is -20dBm at the maximum drive current. Check that the signal to noise ratio of the diode is not affected by the VOA.

2. Investigation of ASE

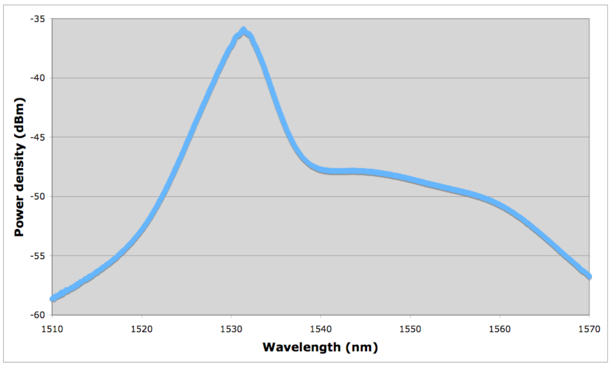


Fig. 4: ASE spectrum for an erbium doped fibre.

The next experiment looks at the properties of the amplifier itself. To do this turn down the current to both lasers and disconnect the 1550nm diode from the patch cord. Using the uniter connect the 1550nm diode to the input port of the WDM (the yellow patchcord with 15 near the end). Then connect the output from the 90:10 coupler (the yellow patchcord with 10 at the end) to the fibre patch cord and connect the other end to the OSA. Set the span on the OSA to be 70nm and the centre wavelength to be 1540nm.

Now start to increase the pump drive current while the signal diode is still turned off. You will start to see the ASE spectrum of the amplifier which should be peaked around 1532nm as in Fig. 3. It is important not to increase the pump current too much or else the amplifier might start to lase (see Fig. 6). With the pump current set to maximum value before lasing occurs measure the peak ASE level and the bandwidth over which the ASE power is within 10dB of the maximum. This value represents the maximum wavelength range over which the amplifier can provide gain. Describe how the gain spectrum changes as the drive current increases and sketch the change in the ASE shape.

3. Measurement of the small signal amplifier gain:

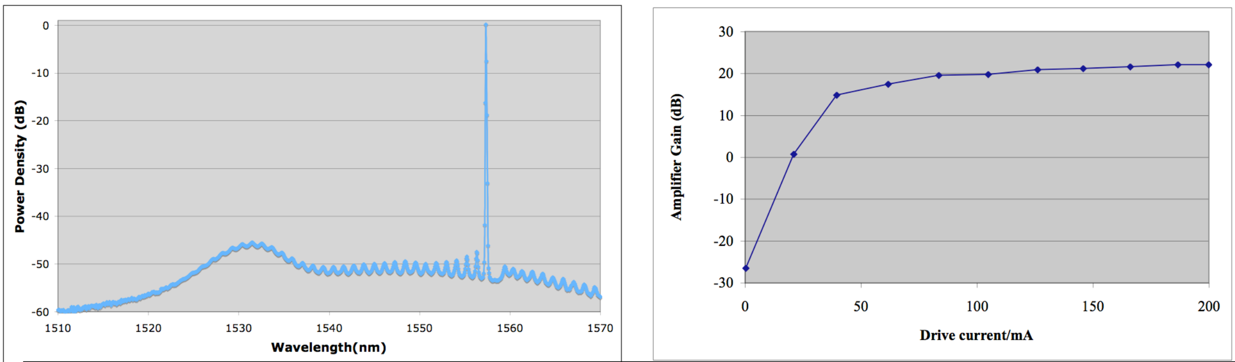


Fig. 5: Small signal response of the amplifier on the left and the gain of the amplifer for small signals on the right. (Plot by Ben 2006)

First we need to determine the loss through the doped fibre. Recall that the VOA is set so that output power is -20dBm. Turn off the current supply for the 980nm diode and turn up the 1550nm diode and measure the output power on the spectrum analyser. Calculate the loss of the amplifier for this case (remembering that you are only measuring 10% of the output power).

Next turn up the current to the 980nm diode and measure the spectrum on the OSA. Sketch the spectrum which should look like that in Fig. 5a. Calculate the maximum gain of the amplifier.

Finally take measurements of the gain of the amplifier as a function of the pump current and plot the results. At what pump current does the amplifier have a gain of 0dB? Also what is the signal to noise ratio of the output signal when the gain is at a maximum.

4. Measurement of amplifier gain for large input signals

Turn off the pump current and adjust the VOA so that the output power is a maximum and then turn up the pump current the signal. Measure the peak gain of the amplifier. Is this more or less than the result before? What about the output power? What about the signal to noise ration? Try varying both the pump current and the VOA until you find the range of parameters which gives (a) the maximum signal to noise ratio. Also discuss how the gain of the amplifier varies? What do you need to do to get the maximum gain?

5. Examining properties of amplifiers with feedback:

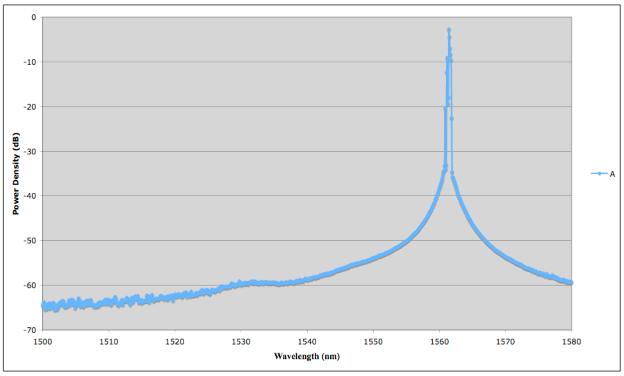


Fig. 6: Spectrum of the amplifier with feedback.

In the last part of the lab we will look at the amplifier with feedback and no external input. To do this turn off both lasers and disconnect the 1550nm diode from the input port of the WDM coupler. Instead connect the 90% port from the 90:10 output coupler and connect it to the input port of the WDM coupler. Now very slowly turn up the gain on the amplifier and observe what happens. You will need to set the OSA so that it has a span of 100nm with a starting wavelength of 1500nm. As the pump power increases you should see a very sharp peak appearing at a particular wavelength (when I did it it was at 1567nm). Observe the properties of this and try to measure the bandwidth of the peak. Next try turning up the amplifier gain with (a) nothing connected to the 1550nm port of the WDM and (b) the 10% port of 90:10 coupler connected to the input port. Are there any differences in the three cases? Can you explain what is happening by relating the output spectrum to the ASE spectrum of the amplifier?

Acknowledgements: The Erbium doped fibre in these experiments was donated by Fibercore Ltd. (www.fibrecore.com) and we would like to thank them for this.

Troubleshooting:

The following are a list of some of the most common problems:

1) The fibres are not properly connected. Make sure that the copper flange of the patch cord is aligned with the groove in the uniter.
2) The fibre is bent too tightly causing excess losses. Make sure that the patch-cords connecting the box to the OSA or power meter is loose and has no tight bends.

3) Low output power: Make sure that the variable optical attenuator is adjusted correctly.
4) The spectrum on the OSA is very noisey. Make sure that the senstitivity is set correctly.

Laser Safety Awareness Form

Please read and sign the following:

1) **I have read the relevant extract from the CVCP "Notes for Guidance for laser users"**
2) **I will not undertake any laser work without a supervisor present in the room.**
3) **I will not look directly at the laser beam or fibre ends.**
4) **I will not attempt to interfere with the interlock on the device.**
5) **I will not turn on the laser unless either the output port is closed or there is a fibre connecting the output port to a optical measuring device.**
6) **I will try to ensure that the laser output is never pointing towards anyone.**

Signed:

Date: