Optical Fiber Amplifiers

GOALS:

Build and characterize an Erbium doped fiber amplifier system capable of amplifying incoming signal light between 1525-1600nm. Understand its basic components. Learn how to handle single mode fibers and other fiber optical components.

TOOLS:

1. 1525 to 1600nm tunable laser source (including power and cooling)
2. Either:
    2.1. 980nm laser source (including power and cooling) and 980/1550nm WDM (wavelength division multiplexer)

    2.2. 1480nm laser source (including power and cooling) and 1480/1550nm WDM
3. Two 1550nm isolators
4. Er-doped fiber (approx. 18.5m)
5. OSA (optical spectrum analyzer)
6. Standard fiber and connectors
7. Burleigh Wavemeter
8. White light source

BACKGROUND

An erbium-doped optical fiber amplifier, or EDFA, is an optical repeater that amplifies an optical laser beam directly, bypassing opto-electronic and electro-optical (O/E and E/O) conversion. The EDFA uses a short length of optical fiber that has been treated or "doped" with the element **erbium**. When the laser that carries the signal causes the signal to pass through this fiber, energy is applied to boost, or amplify, the level of the signal.

In fiber optic systems amplification of the signal is necessary because no fiber material is absolutely transparent. This causes the infrared light (usually around 1530nm) carried by a fiber to be attenuated as it travels through the material. Because of this attenuation, repeaters must be used in spans of optical fiber longer than approximately 100 kilometers.

The operating wavelength range of a standard EDFA spans over the entire so-called “C band” (1530 to 1560 nm) and therefore allows amplification of a variety of wavelength channels that are used in wavelength division multiplexing (WDM) applications. This is a major advantage over methods in which the optical signal is converted into an electrical signal, amplified and converted back to light. Due to the last step, such O/E-E/O regenerators require the demultiplexing and multiplexing of each single WDM channel at each regenerator site and an O/E-E/O pair for each channel.

Operation Principle

The basic operation principle is illustrated in Fig.1. Of the many energy levels of the Er ion only three are depicted. The pump laser (980nm or 1480) excites the ion into an excited state which has a fairly long lifetime. This way energy is stored in the amplifier fiber that can be used by the signal. Through stimulated emission the signal can release the energy. The created photon will have the same wavelength and direction as the incoming signal photon and hence leads to an amplification. In the absence of the signal beam we will have spontaneous emission that goes in

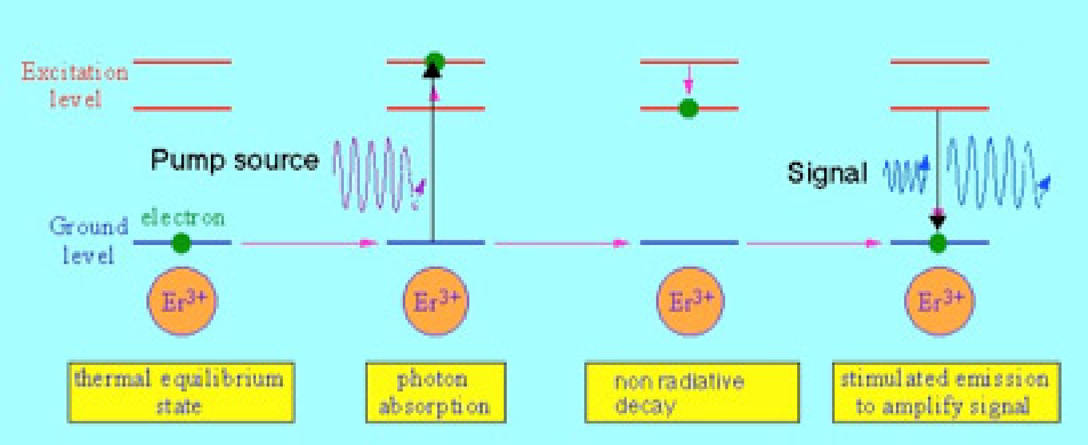

Fig. 1. Basic Principle of an EDFA

all directions, and is therefore weak along the fiber. This emission, however, adds to the noise and limits the performance of the amplifier.

More details about the energy levels of the Er ion

While for the basic operation of the EDFA the simplified energy level scheme of Fig. 1 is sufficient, details of the behavior require a more detailed energy level scheme. Most notably, you will notice a green color of the fiber, while it is pumped with the 980nm laser.

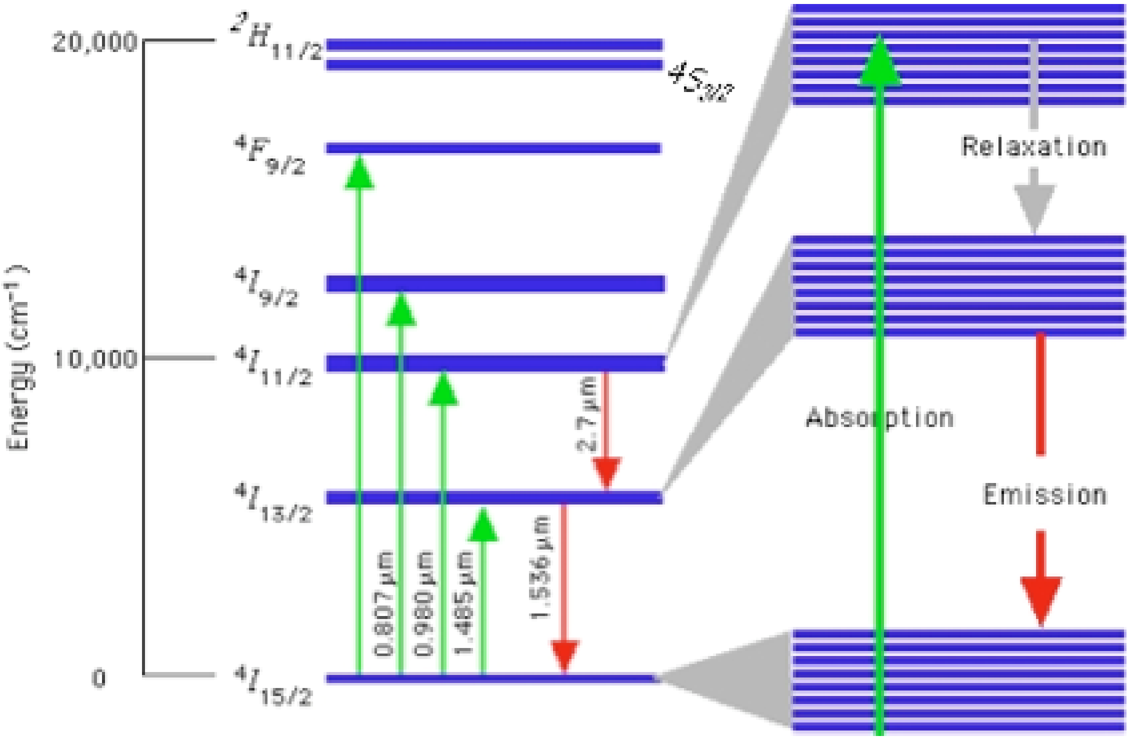

Fig. 2. Detailed energy level scheme

The Erbium ion is one of the rare earth ions (what are others?) that are characterized by an unfilled 4f-shell. These valence electrons are well shielded from their environment by filled 5s, 5p shells that have a larger radial extent. Due to electron-electron, spin-orbit interaction the 4f energy levels are split. The individual levels are denoted by the LS-coupling scheme, although the latter does not hold perfectly. In this scheme, the angular momenta and spins of the electrons are added up first giving the quantum numbers L and S. To obtain the total momentum J, L and S are added as vectors. The labels indicate the approximate value for L, S, and J in the following form: $^{2S+1}L_J$, L is denoted with a letter (S,P, D,F,G,.. for L=0,1,2,3,4...).

The interaction with the host ions is small and just leads to a splitting of the (2J+1) degenerate levels, as shown for three levels in Figure 2. Although comparably small, this splitting allows amplification and lasing between the two lowest states. The relative populations of the sublevels within each level is governed by the Boltzmann distribution at a given temperature. For that reason, the absorption and emission spectra are not identical as seen in Figure 3 and gain can be achieved on the low energy (long wavelength) side by pumping in the high energy (short wavelength) side of the absorption. We have effectively a quasi-four level system.

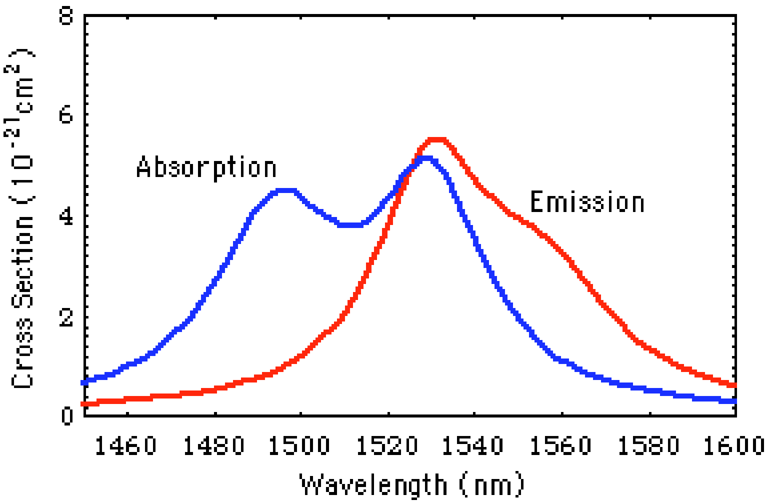

Fig. 3. Emission and absorption spectrum

Principle Set-up of an EDFA

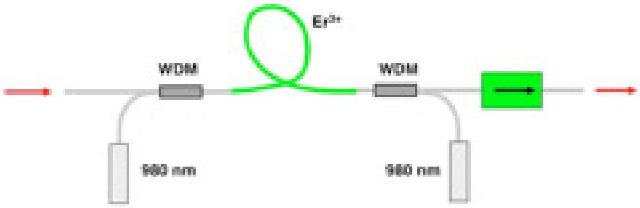

Fig. 4. (a) Basic set-up of a EDFA

The principle set-up of an EDFA is shown in Fig. 4. The pump and the signal light are combined using a wavelength division mulitplexer (WDM). They co-propagate in the Er-doped fiber and can be separated using a second WDM. The latter can also be used to the add another pump source that will counter-propagate throught the fiber. In this case the pump laser diodes need to be protected using a fiber optical isolator. Isolators are based on Farady rotation. Details can be found for instance at http://www.fdk.co.jp/laboratory/hikariai-e.html. In our experiment will will not use the second WDM but an isolator that will reduce back-reflection and will filter out the 980nm light as well.

TASKS

- Determine approximate energy levels of the Er^{3+} in the fiber
- Determine the 'gain window' of the Erbium-doped fiber
- Determine the wavelength characteristics of the EDFA
- Determine the saturation of the EDFA.
- Calculate the conversion efficiency.

PROCEDURE

Check all fiber connectors:

In order to avoid damage to the critical components of the experiment, we will make sure that all the fiber connectors are clean. For that purpose, we use a Fiberscope in the Fiber Optics Lab in the Whitaker building.

Splicing a fiber:

In case a fiber end is damaged and cannot be saved by cleaning it, we will need to splice another fiber with a good connector to the component. You will be shown how to use the Fusion Splicer.

Note

Fiber connections are very sensitive – always make sure that when connecting fibers, the connectors are aligned and the connections are not over-tightened.

Measurement of the ASE

You will be able to determine a great deal about the system's amplification abilities without actually amplifying the signal. This section will help you understand some different methods of analysis and how they can be used to understand the results from later sections.

Amplified spontaneous emission (ASE) results from the Er-doped fiber amplifying everything, including noise. Since noise can be considered 'white' (equal for all wavelengths), looking at how much noise is amplified will give us a good idea of which wavelengths are preferentially amplified by our EDFA system.

1. Connect the amplification system as follows:
    - Connect the end of the 980nm laser to the input on the WDM marked '980'
    - Place a cap on the '1530' input
    - Connect one end of the Er-doped fiber to the output of the WDM
    - Connect the other end of the Er-doped fiber to the input of the OSA

2. Turn on the OSA and the temperature controller to the 980nm laser (first push the 'power' button on the left side of the temperature controller and wait until it starts up, then push the 'TEC' button). The actual temperature should now stay between 21.9 and 22.1°C - if it ever varies from this immediately turn of the current source. If the temperature is set to something other than 22°C, set the temperature by pushing the 'set temp' button and turning the knob to the appropriate value.

3. Set the OSA to the following values:
   - Span: 1500nm to 1620nm
   - Setup: Resolution: 0.5nm (the smallest without causing an error)
   - Setup: Averaging: 3 (will average the last 3 sweeps for display)
   - Sweep: repeat

4. Ensure the current source is set to 'const I', the limit switch is turned fully CW (otherwise the current supply will not reach 200mA), and the knob above output is turned CCW (so that when output is pressed, the current source will start at 0mA).

5. Turn on the current source by pushing the 'power' button, followed by the LDD button, similarly to how the temperature controller was powered. After the initial value is displayed (should read zero at this point), turn the output knob until 30.0mA is driven through the laser. The OSA should now show a fairly flat range between 1530nm and 1570nm, with two peaks, as shown in Figure 3.

6. Now save these results to a floppy disk. Now save these results to a floppy disk by pressing 'floppy', 'write' (first button from the top next to the display), 'file name' (5th button – use the wheel and enter for letters and the number pad for numbers), done (7th button), execute (7th button), then return (8th button).

Note

Each time before pressing 'output' on the current source, follow the flow of the fibers to make absolutely sure that no connection is left open. Certain parts of these experiments will deal with levels of infrared light that are not eye-safe (are above 10mW), so it is imperative that each fiber ends in a cap or a device.

7. Now repeat these results for 40mA, 50mA, 100mA, and 200mA to see how quickly the EDFA system saturates. In your lab report, make sure to note how close the 50mA peak and the 200mA peak are (i.e. 5dB, 10dB, 15dB). This will give you a fairly good idea of which frequencies will be preferentially amplified, and why it is important in communications to create a 'flat-band' amplification system so that some frequencies do not get significantly more amplification than others.

8. One of the energy levels of Erbium happens to be around 550nm (green), but is mostly robbed of energy by the 1530nm emission. With the current source at 200mA, set the span on the OSA from 500nm to 650nm and see if you can detect green emission (look for regions where there are no dips below 60dBm). Turn off the current to the 980nm laser when you are finished.

Characterization of the components

Now that you have an idea of what the main components of the EDFA system are, it is a good idea to find out exactly how each of the components 'treats' different frequencies of light. To do this, connect each of the following pieces in turn between the white light source and the OSA. Set the span from 500nm to 1750nm, the resolution to the minimum without causing an error (10nm), the average to 3, and remember to save the results of each component to disk.

- *Any piece of connecting fiber*. In addition to showing how little the fiber affects most wavelengths, this will also show the range of the white light source (becomes irregular below 600nm, and unusable below 500nm). It is a good idea to do this for each piece of fiber you use, to check that the fiber will pass the desired wavelengths without too much attenuation. An example of this is illustrated in the following picture, which shows that one of the fibers absorbs much more of the 1500-1625nm range than the other two fibers (arrow) and should not be used for our experiments.
- *An optical isolator.* If the isolator is aimed at use around 1550nm, it will most likely absorb everything below about 1µm, since it contains magnetically-sensitive materials that do not work for all wavelengths. This is important, since you must remember that these isolators should not be used in between fiber that needs to continue carrying, for example, the 980nm pump laser.
- *The Er-doped fiber*. The 'dips' in this diagram will show the different energy levels. Erbium, like most rare-earth elements, has an immense number of energy levels, three of which are used for EDFA systems
  (E2 – E1 = 1530nm, E3 – E1 = 980nm). Notice that broadening of the energy levels allows pumping at 1480nm (bottom of E1 to top of E2) to cause emission at 1530nm (middle of E2 to middle of E1).
- *The WDM.* It is not necessary to save these results to disk, but notice that sending the white light into the 980 input and measuring at the output results in an almost identical spectrum as sending the white light into the output and measuring at the 980 input. The same is also true for the 1530 input. A WDM can thus be used for combining two frequencies on separate fibers onto one fiber (multiplexing or muxing), as well as taking two frequencies on one fiber and splitting them in two (demultiplexing or demuxing).

Gain Characteristics

Now that you understand the limitations of each part of the EDFA, you will investigate the behavior and limitations of the system in amplifying signals. The main task will be to obtain gain vs. wavelength data that will look very similar to the ASE obtained in Part 1 using the 100mA and greater currents.

As you will soon discover, tunable semiconductor lasers can lase at a wide band of frequencies, but the output power vs. current will decrease significantly toward the limits of the lasers. Thus, to be able to obtain data that is consistent over the entire range, you must use the same output power for each wavelength, rather than using the same amount of current.

1. Determine the operating parameters for the tunable laser:

- Connect the tunable laser directly to the OSA and turn on the cooling to the laser (in an integrated console, do this simply by turning the key on the console to start the power and the automatic cooling).
- Turn on the OSA. Once started, set to the following:
    - Span: 20nm
    - Center: 1560nm
    - Setup: Averaging: 1
    - Setup: Resolution: 0.2nm
    - Turn on the laser diode and set the current ≥ 85 mA.
- Tune the laser until the output matches the center frequency as closely as possible (make sure there is only one mode – if there are two, tune slightly toward the center frequency until the second mode disappears).
- The goal is to find the currents for each frequency that will output both -10 ± 0.5 dBm and 0 ± 0.5 dBm. For 1560 nm, these outputs will occur with input currents between 50-70mA, and 85-105 mA, respectively. Write down these values on the following chart as you acquire them.

2. Now that you know that the tunable laser is set to 1560nm and what currents are required to output -10dBm and 0dBm to sufficient accuracy, turn off the laser diode and on the OSA, press sweep: stop.
3. Make the following connections:
    - Connect the tunable laser diode to the input on the WDM marked ‘1530’.
    - Connect the 980nm pump laser into the WDM input marked ‘980’ (if not already connected).
    - Connect the output of the WDM to the Er-doped fiber.
    - Connect the other end of the Er-doped fiber to the input of the optical isolator, and connect the output of the isolator to the OSA. Once again follow the flow of the fibers to make sure that each fiber is connected at both ends.
4. Turn on the laser diode of the tunable laser and check that the current is still set so that the laser outputs either -10dBm or 0dBm.
5. On the OSA, press ‘peak search’ to find the level of laser power that is being passed through the system and record this level. Notice that this output power is much less than the amount of energy at the input, which means that the EDFA system must first overcome this ‘intrinsic’ loss before being able to amplify the system above its original level.
6. Make sure the cooling to the 980nm laser is still set, and pump 100mA of power through the system. Record the output and repeat for 200mA.

7. Repeat these results for the remaining four wavelengths (1520, 1530, 1540, 1550nm).

Plot and Calculations

With the data you have now collected, you will be able to see how your particular fiber amplifier behaves compared to other fiber amplifiers and amplifiers in general.

1. *Gain vs. Wavelength plot*
   With the data from Part 2, you can now make the following plots. The first should look very similar to the ASE of the 980nm laser, and the second shows the actual gain vs. wavelength after the losses through the system are added.

2. *Threshold Pump Power* P_p^{th}
   The first calculation is to show that, ideally, the threshold pump power is independent of the input power. The threshold pump power can be defined as the pump power at which the amplifier is transparent (gain is zero). Many factors can affect this value so in your experiments it will not be perfect, but it should be close enough for you to be able to estimate the actual threshold pump power.

3. *Conversion Efficiency* η
   This calculation will show that although useful, the conversion efficiency of this amplifier configuration is far from approaching the theoretical maximum ($\lambda_{pump}/\lambda_{signal}$). Conversion efficiency can be calculated by dividing the output signal light by the input pump power (both in mW, not dBm).

4. *Stimulated Emission Cross Section* σ_s
   Knowing this value is very important in designing and evaluating an amplifier system, since many of the gain equations are dependent on the stimulated emission cross section. The following is a simple way to calculate this value, but many of the approximations can be calculated more accurately using better fits. One of the more difficult steps is to calculate the full-width half-power point of the unfiltered ASE spectrum ($\Delta\lambda$). The other required values (wavelength, refractive index, and spontaneous emission time) are simply constants. To find the FWHP point of the ASE spectrum, you can follow the following steps, or as mentioned above, try more accurate fits.

   - Measure the ASE of the 980nm laser

   - Insert the ASE into a numerical software program, attenuating the main peak to create an amplifier that provides equal gain for the majority of the spectrum. You are trying to find the FWHP point of the whole spectrum, not just the peak at 1530nm.

   - Find the area under the entire ASE curve, and then, on top of the ASE, plot a Gaussian with the same area. Now adjust the three parameters of the Gaussian (amplitude, mean, and variance) until they best overlap the ASE.

   - Find the FWHM of the Gaussian (the points, in mW, where each side has reduced to half of the maximum). The value should be in the tens of nm.

   - Use this FWHM ($\Delta\lambda$) to compute the stimulated emission cross section as follows:

$$\Delta v = c\left(\frac{1}{\lambda - \Delta\lambda} - \frac{1}{\lambda + \Delta\lambda}\right) * 10^{6} \ \text{(Hz)}$$

$$g_l(v) \sim \frac{1}{\Delta \nu} \ (\text{Hz}^{-1})$$

$$\sigma_s = \quad \frac{1}{8}\frac{\lambda^2 g_l(v)}{\pi n_1^{2}} \ * 10^{-2} \ (\text{m}^2)$$

Fiber Laser

GOALS:

Build and characterize a Erbium doped fiber laser. Understand its basic components. Learn how to handle single mode fibers and other fiber optical components.

TOOLS:

1. Fiber gratings at desired
2. Either:
   2.1. 980nm laser source (including power and cooling) and 980/1550nm WDM (wavelength division multiplexer)

   2.2. 1480nm laser source (including power and cooling) and 1480/1550nm WDM
3. One 1550nm isolators
4. Fiber Optical Circulator
5. Er-doped fiber (approx. 18.5m)
6. OSA (optical spectrum analyzer)
7. Standard fiber and connectors
8. Burleigh Wavemeter
9. White light source

10. BACKGROUND

Lasers based on fiber optical components have become very popular in recent years. They make use of the versatility of fiber optical devices and the progress that has been made in doped fibers with low propagation losses. One of their main advantages is that they do not need any adjustment of optical components and are therefore very stable.

Operation Principle

The basic operation of Er-doped fiber laser is a logical extension of the fiber amplifier. To the EDFA design a feedback is added through fiber Bragg gratings. These gratings can be manufacture by illuminating properly doped fibers with interferometric patterns of UV light and are very narrow band.

For further background on the Er ion see “EDFA experiment”. You may have noticed that when you build the amplifier a lasing effect occurred under some conditions. This due to the small reflection add the fiber ends. The high gain of our medium does not require high reflective mirrors. The Bragg gratings that we are using will therefore mainly act as frequency selector. For that purpose, one grating is sufficient. The laser can be tuned by changing the grating either mechanically or thermally.

TASKS

- Determine approximate energy levels of the Er^{3+} in the fiber
- Determine the 'gain window' of the Erbium-doped fiber
- Characterize the different components

PROCEDURE

Check all fiber connectors:

In order to avoid to the critical components of the experiment, we will make sure that all the fiber connectors are clean. For that purpose, we use a Fiberscope in the Fiber Optics Lab in the Whitaker building.

Splicing a fiber:

In case a fiber end is damaged and cannot be saved by cleaning it, we will need to splice another fiber with a good connector to the component. You will be shown how to use the Fusion Splicer.

Note

Fiber connections are very sensitive – always make sure that when connecting fibers, the connectors are aligned and the connections are not over-tightened.

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You will be able to determine a great deal about the system's amplification abilities without actually amplifying the signal. This section will help you understand some different methods of analysis and how they can be used to understand the results from later sections.

Amplified spontaneous emission (ASE) results from the Er-doped fiber amplifying everything, including noise. Since noise can be considered 'white' (equal for all wavelengths), looking at how much noise is amplified will give us a good idea of which wavelengths are preferentially amplified by our EDFA system.

1. Connect the amplification system as follows:
    - Connect the end of the 980nm laser to the input on the WDM marked '980'
    - Place a cap on the '1530' input
    - Connect one end of the Er-doped fiber to the output of the WDM
    - Connect the other end of the Er-doped fiber to the input of the OSA
2. Turn on the OSA and the temperature controller to the 980nm laser (first push the 'power' button on the left side of the temperature controller and wait until it starts up, then push the 'output' button). The actual temperature should now stay between 21.9 and 22.1°C - if it ever varies from this immediately turn of the cur-

rent source. If the temperature is set to something other than 22°C, set the temperature by pushing the 'set temp' button and turning the knob to the appropriate value.

3. Set the OSA to the following values:
   - Span: 1500nm to 1620nm
   - Setup: Resolution: 0.5nm (the smallest without causing an error)
   - Setup: Averaging: 3 (will average the last 3 sweeps for display)
   - Sweep: repeat
4. Ensure the current source is set to 'const I', the limit switch is turned fully CW (otherwise the current supply will not reach 200mA), and the knob above output is turned CCW (so that when output is pressed, the current source will start at 0mA).
5. Turn on the current source by pushing the 'power' button, followed by the output button, similarly to how the temperature controller was powered. After the initial value is displayed (should read zero at this point), turn the output knob until 30.0mA is driven through the laser. The OSA should now show a fairly flat range between 1530nm and 1570nm, with two peaks, as shown in Figure 3.
6. Now save these results to a floppy disk. Now save these results to a floppy disk by pressing 'floppy', 'write' (first button from the top next to the display), 'file name' (5th button – use the wheel and enter for letters and the number pad for numbers), done (7th button), execute (7th button), then return (8th button).

Note

Each time before pressing 'output' on the current source, follow the flow of the fibers to make absolutely sure that no connection is left open. Certain parts of these experiments will deal with levels of infrared light that are not eye-safe (are above 10mW), so it is imperative that each fiber ends in a cap or a device.

7. Now repeat these results for 40mA, 50mA, 100mA, and 200mA to see how quickly the EDFA system saturates. In your lab report, make sure to note how close the 50mA peak and the 200mA peak are (i.e. 5dB, 10dB, 15dB). This will give you a fairly good idea of which frequencies will be preferentially amplified, and why it is important in communications to create a 'flat-band' amplification system so that some frequencies do not get significantly more amplification than others.
8. One of the energy levels of Erbium happens to be around 550nm (green), but is mostly robbed of energy by the 1530nm emission. With the current source at 200mA, set the span on the OSA from 500nm to 650nm and see if you can detect green emission (look for regions where there are no dips below 60dBm). Turn off the current to the 980nm laser when you are finished.

Characterization of the components

Now that you have an idea of what the main components of the EDFA system are, it is a good idea to find out exactly how each of the components 'treats' different frequencies of light. To do this, connect each of the following pieces in turn between the white light source and the OSA. Set the span from 500nm to

1750nm, the resolution to the minimum without causing an error (10nm), the average to 3, and remember to save the results of each component to disk.

- *Any piece of connecting fiber*. In addition to showing how little the fiber affects most wavelengths, this will also show the range of the white light source (becomes irregular below 600nm, and unusable below 500nm). It is a good idea to do this for each piece of fiber you use, to check that the fiber will pass the desired wavelengths without too much attenuation. An example of this is illustrated in the following picture, which shows that one of the fibers absorbs much more of the 1500-1625nm range than the other two fibers (arrow) and should not be used for our experiments.
- *An optical isolator.* If the isolator is aimed at use around 1550nm, it will most likely absorb everything below about 1µm, since it contains magnetically-sensitive materials that do not work for all wavelengths. This is important, since you must remember that these isolators should not be used in between fiber that needs to continue carrying, for example, the 980nm pump laser.
- *An fiber-optical circulator.* This component is related to a isolator as it lets light travel only in one direction. It has three parts A, B, C. Light can go from A to B, from B to C, and from C to A, but not hte other way around
- *The Er-doped fiber*. The ‘dips’ in this diagram will show the different energy levels. Erbium, like most rare-earth elements, has an immense number of energy levels, three of which are used for EDFA systems
  (E2 – E1 = 1530nm, E3 – E1 = 980nm). Notice that broadening of the energy levels allows pumping at 1480nm (bottom of E1 to top of E2) to cause emission at 1530nm (middle of E2 to middle of E1).
- *Fiber gratings.* Characterize the reflection characteristic of the gratings using the optical circulator. What is the reflectivity of the grating.
- *The WDM.* It is not necessary to save these results to disk, but notice that sending the white light into the 980 input and measuring at the output results in an almost identical spectrum as sending the white light into the output and measuring at the 980 input. The same is also true for the 1530 input. A WDM can thus be used for combining two frequencies on separate fibers onto one fiber (multiplexing or muxing), as well as taking two frequencies on one fiber and splitting them in two (demultiplexing or demuxing).

Building the fiber laser

1. Connect the laser system as follows:
   - Connect the end of the 1480nm laser to the input on the WDM marked ‘1480
   - Connect one end of the Er-doped fiber to the output of the WDM, and connect the other end of the Er-doped fiber to one of the fiber gratings
   - Connect the ‘input’ end of an isolator to the input of the WDM marked ‘1530’ so that the isolator points away from the WDM, and connect the Optical Wavemeter to the ‘output’ end of the isolator

1. Turn on the wavemeter and the temperature controller to the 1480nm laser (first push the ‘power’ button on the left side of the temperature controller and wait until it starts up, then push the ‘output’ button). The actual temperature should now stay between 21.9 and 22.1°C - if it ever varies from this immediately turn of the current source. If the temperature is set to something other than 22°C, set the temperature by pushing the ‘set temp’ button and turning the knob to the appropriate value.
2. On the wavemeter, set averaging to 6 and make sure that averaging is turned on, and start with a wavelength range of 1520 to 1627nm. Now, using the horizontal position and horizontal scale functions, set the scale to roughly 1520 to 1550nm (assuming the gratings are 1530nm and 1545nm – if not, make sure the scale will show the wavelengths of all of the gratings).
3. Turn on the current source, and try to find the minimum current that causes the output to peak at the grating’s wavelength. Record this output to disk (use the ‘save data’ function – ‘save display’ will just save a picture of the current display). The wavemeter does not seem to have a way to set filenames, so it may be worthwhile to take the disk to a computer after each save to change the filename.
4. Record the output for pump current values of 100mA and 200mA.
5. Remove the isolator from the system and repeat the measurements for the threshold current value, 100mA, and 200mA. Based on what you know about modes in a laser, what do you think this will do to the output linewidth (narrower or broader)? Plot the data from your two experiments, and for each pump current value, see if your prediction was true.
6. To obtain the threshold pump power for your laser, connect the pump laser directly to the wavemeter and set the current to your threshold obtained in steps 4 and 6 (to obtain the values with and without the isolator, respectively). This will give you the threshold pump power in dBm and mW.