CHAPTER 5

CONCLUSION AND FUTURE WORK

This dissertation presents the characteristics of single and multiple signal of EDFL. The study was started with the experiment to conform that the already developed EDFL was in continuous wave (i.e. not in pulsed wave). The EDFL’s output was measured by using an oscilloscope (HP 54510A) in time domain and then by comparing it with the output of standard modulated-laser diode (HP 81554 SM).

The polarisation controller from THORLAB (FPC 030) was then inserted (by using FC/PC connectors) at various positions in the ring cavity to control or change the Polarisation State (SOP) of pump and oscillating signal. The spectrum output was then studied and it showed that all fibre-based optical components used in our configuration are insensitive to the polarisation condition of pump and signal.

The instability of power and wavelength of pump source (ETEK SN 968281) was checked on OSA (ANDO AQ 6315A) and scope (HP 54510A) whether it has any effect on the EDFL power or signal. Results in section 3.2.3 showed that the EDFL output was not affected by the pump conditions due to the faster fluctuation of the pump source (1.5μs) compared to the EDFL (10ms). Therefore most experiments done in this thesis used ORTEL laser diode (SN 1096) which has a built-in Bragg grating to reduce wavelength fluctuation.

The dependence of output power, side mode suppression ratio (SMSR) and EDFA gain on pump power were studied in section 3.2.3.3. The first two were showed to increase with the pump powers. The gain of EDFA was proved to be higher at short wavelength region (around 1530nm) when the pump power is high and reverse for a low pump power.
Isolators, besides preventing back reflected power from disturbing oscillating signal, also prevents a formation of standing wave by forcing the oscillating signal to oscillate in one direction. As a result, the formation of a travelling wave occurs, which reduces spatial hole burning (SHB). The results in section 3.2.4 show that the elimination of SHB would give a better linewidth and more stable output signal. In this case the spectral width has been reduced from 1.2nm (counter-pumped system) and 1.1nm (co-pumped system) for the system without an isolator to 0.6nm and 0.55nm for the system with an isolator. The output power of system with an isolator is twice to that of the system without an isolator (KAIFA SN SC050).

Reflectivity effects on output power, threshold power, SMSR, SNR, slope efficiency and signal wavelength were studied in section 3.2.5. The first shows an optimum reflectivity R_{opt}, after which the output power decreases. However, the output power measured directly after the gain medium, EDF (not the one out from the system) increases with R and so on for SMSR and SNR. The threshold power always decreases with R even though the slope efficiency has an optimum point. For a high R, it is shown that the signal lases in a long wavelength region of the spectrum and the reverse is true for a small R.

The output power increases with the EDF lengths (section 3.2.6) but after a certain length (optimum length), it decreases. A minimum threshold power also occurs at a particular EDF length (optimum length - L_{opt}) therefore the EDF length which is less or longer than the L_{opt} contributes to a higher pump threshold. SMSR measured by OSA (ANDO AQ 6315A) from the output of the system follows the trend of the output power. In contrast to R, a long EDF length contributes to a high gain to the signals at long wavelength bands. In this section too, we show the relation
between optimum reflectivity and EDF length, where there is an optimum EDF length ($L_{\text{opt}}$) at which the lowest optimum reflectivity ($R_{\text{opt}}$) could be used.

Two types of back reflection were studied and presented in section 3.2.7. First, back reflected signal was an injected signal from the other signal source and second it was back reflected from the EDFL source itself (i.e. the source under a study). If the back reflected power is sufficient to interrupt the oscillating gain, the output power and wavelength of the actual signal would fluctuate. Moreover, the output power and the slope efficiency increase if the system is free from the back reflection effect. In this work an isolator (KAIFA SN SC050) was used to block the back-reflected power from going back onto the gain medium.

In section 3.3 the comparisons between the system with and without a BP filter were studied. For a system with the BP filter, the effects of positioning the filter before and after the output coupler on the output power, ASE power, spectral width, SMSR and the peak power fluctuation were studied.

Incorporation of a BP filter in a tuneable system after the output coupler showed a higher output power compared to the system with the BP filter before the output coupler. However for SMSR measurement, the position of the filter before the output coupler showed a higher SMSR due to a lower ASE level. In a linewidth and peak power fluctuation measurement, there is no difference between both positions because the filter only blocks significantly the ASE power not the signal power.

A threshold power for the system with a filter was shown to be higher than the one without a filter due to the filter’s insertion loss and the loss caused by the difference between the internal peak wavelength and the filter’s peak wavelength. By the same argument, the output power of the tuneable system (a system with a filter) at
a particular signal wavelength is less than the non-tuneable system. The results in section 3.3.2.2 show that the loss due to the difference between the internal peak wavelength and the filter’s peak wavelength increases when the difference is increased. As a result the peak output power decreases with the difference.

The tuneable system produced a higher SMSR (74dB at 250mA-pump current) due to less competition among modes. An objective in the study of ASE level and gain for the tuneable system are not for the comparison with the non-tuneable system. However the results show that after the threshold, the ASE level at a particular signal wavelength was clamped irrespective of pump power increment. The ASE level at the filter’s signal wavelength was also shown to be less than the ASE at the internal (original) signal wavelength.

In chapter four the discussion was on a dual-ring EDFL with a single port and double ports. The discussion was started with the advantages and disadvantages of this configuration over other designs that have been done by some researchers. The next was a loss allowance which is the fundamental term needs to be understood in the multiple cavity system. In section 4.1.2, a technique that could be used to measure the loss allowance was presented and then the gain difference (between two signals) lower than the loss allowance was shown to be able to produce two signals simultaneously.

The characteristics that have been studied in chapter four are the signal’s output power, tuning range, signals spacing, signal wavelength, power exchange between the signals and pump current threshold. Their studies were based on pump power, reflectivity, EDF length, fixed signal and attenuation loss.
Increase of pump power would increase the signals' output power, tuning range and maximum spacing. However minimum spacing decreases for the reason explained in that section. The lower limit of tuneable wavelength shifted to a shorter wavelength and reverse for the upper limit when the pump power increased.

A choice for the reflectivity ratio at coupler 1 (Figure 4.8) was important in determining the laser signal wavelength. The trends of tuning range against R has been shown to have a minimum point at a certain fixed signal 1 but it shows an equal increment of pump power (at any R) when the pump power was increased. The wavelengths at which the lasing took place were dependent on R and on the difference between the gain difference and loss allowance. The output power and so the signal wavelength showed an optimum point at certain percent of R due to the gain provided by R and the difference between the gain difference and loss allowance. Comparison of the output power of two signals against reflectivity, reveals the existence of a point of reflectivity at which both signals have the same power, $R_{\text{opt}}^{1,2}$ and the same threshold power $P_{\text{th}}^{1,2}$.

In fact, the three pieces of different EDF length used are not sufficiently enough to study the lasing characteristics. However the results show that when the pump power is not too high, a long EDF length would cause the system to lase at a long wavelength spectrum. But when it was too long (23.7m for this system), a high pump power would be needed to make the system lase. The trend was also the same for the tuning range whereby its range becomes smaller if the EDF is too long.

Power exchange occurred between the two signals, when one of them was tuned close or away relative to the other and showed an intercepting point at certain spacing (between them). This intercepting point was considered as the same power
produced by the both signals. The spacing at which both signals have the same power was independent on pump power even though the signal power itself increases with the pump power. The threshold pump power for the both signals also intercept at a particular spacing when one of the signals was tuned relative to the other. Tuning range was shown to be dependent on the gain difference between the signals and the region of wavelength in which the tuneable signal lased.

Controlling the gain difference between the signals using an attenuator (HP 8156A) showed the increment of tuning range from 6.92nm to 28.88nm for signal 2 fixed at 1530nm as discussed in section 4.1.7. Thus the wavelengths at which tuneable signal taking place was independent on the value of R. At high pump power, much more attenuation loss must be imposed to the system in order to get a large tuning range.

All the results so far were achieved from the system with one output coupler. By designing a system with a two output coupler (one for each ring), a few tuning ranges were found to occur at different places along the EDFA gain spectrum at a same pump power and same fixed signal. The results also showed a same output trend whether the system was counter pumped or co-pumped.

For further studies on multiple wavelength fibre lasers (MWFL), it is proposed here that by designing multiple ring cavity by using N x N coupler (N \(>2\)) or by inserting fibre Bragg grating and circulator into the ring cavity may produce a multiple wavelength laser. Injecting an external signal into a long piece of SMF placed in the cavity is another technique to design multiple wavelength sources and is called Brillouin erbium fibre laser (BEFL). Further studies that can be carried out on this system are a cascaded BEFL and frequency doubler of BEFL.
APPENDIX A

Output power from laser diode ETEK SN 968281 and ORTEL SN 1096.

Figure 1: A configuration for measuring the output powers from a laser diode at different drive currents.

Figure 2: Laser diode's output power (Pump power for EDFL) against laser diode's drive current from ETEK SN 968281.
Figure 3: Laser diode's output power (Pump power for EDFL) against laser diode's drive current from ORTEL SN 1096.