CHAPTER 1

INTRODUCTION

1.1: A Review of Fiber Laser System.

A fibre laser is a resonant waveguiding device, with waveguiding properties provided by an active medium made from rare-earth doped fibre and the resonance is provided by two reflecting mirrors at both ends of the active medium as shown by Figure 1.1, or by the active medium looped into a ring shape as shown Figure 1.2. These cavity designs which are mostly known as Fabry-Perot and ring cavities have their own advantages when compared to each other.

![Figure 1.1: A simple diagram of EDFL with Fabry-Perot cavity.](image1.png)

![Figure 1.2: A simple diagram of EDF ring laser consists of laser diode, wavelength division multiplexing (WDM), band pass (BP) filter and output coupler.](image2.png)
Basically, a Fabry-Perot system requires one input mirror with very high transmission and reflectivity at pump and signal wavelengths respectively, an active medium to provide amplification via stimulated emission and output mirror with moderate high reflection at signal wavelength. While at least, only the active medium is required for the ring configuration since the multiple reflections of photons in the Fabry-Perot system is converted into one direction of travelling photons.

Even though the ring laser provides higher cavity loss due to insertion loss from the extra inserted components, it is preferable in this study because of its better energy confinement into one direction which, as a result gives higher output powers (will be proved later) and narrower output linewidths. All this can be achieved through the use of an isolator.

The second advantage of this system is that it can be made-up of all-fibre components, thus making it easier for set-up and allows many configurations to be designed and with virtually unlimited fibre length. In contrast, a long cavity length will produce a non-single longitudinal mode output that, in turn causes the wavelength and power instabilities.

Fibre lasers can be made to lase in a continuous wave (CW) or pulsed form at a single wavelength or multiple wavelengths. The CW single wavelength system is the most common fibre laser, while pulsed and multiple wavelength are subjected to particular applications, such as for the systems in need of high output power pulses or in WDM systems.

Mode-locking and Q-switching are the most familiar techniques for pulsed systems and needs extra understanding as well as components to achieve, as does the multiple wavelength fibre laser systems, however in this dissertation a single and
multiple wavelength system are studied. A less straightforward method of set-up for multiple wavelength is due to the fact that the homogeneous line broadening is more dominant at room temperature, however a few different techniques have been reported which are able to produce wavelengths up to eight to sixteen channels. One of them used liquid nitrogen to reduce homogeneous broadening effect while in this dissertation we used two variable couplers and attenuators to control the gain that shares the same active medium.

1.2: Fibre Laser Parameters and Characteristics.

Fiber lasers can be assessed based on a number of characteristics that include power, wavelength, spectral width, modulation bandwidth, stability, threshold, efficiency and side mode suppression ratio (SMSR). These characteristics are briefly introduced here as the basis for most of the theoretical and experimental works that are carried out in the subsequent chapters.

1.2.1: Optical Power.

The optical power with a unit of mW or dBm is the parameter of a light source system to be known and understood since they refer to linear and logarithmic scales respectively. The amount of power required depends on the application. In fiber optics telecommunications, the launched power is normally less than 4mW mostly due to sources used, input and output coupling, distance, unspliced components incorporated and cost. However, since high power sources are available at a reasonable price currently, the launched optical signal power can be higher. The maximum optical
power, however, is limited by a few factors, such as the non-linear scattering\textsuperscript{1}, the damage threshold of the components and the safety of the users.

In transmission systems, high powers can stimulate non-linear effects, especially Stimulated Brillouin scattering which requires a lower threshold power, typically a few milliwatts (mW) than for example the stimulated Raman Scattering in the order of watts\textsuperscript{2}. Components damage threshold consideration is particularly important when the pump sources used are solid state bulk laser or high sensitive equipment such as receiver used in amplifier systems.

1.2.2: Wavelength

This term refers to the spectrum component at which the optical signal power is maximal. There are three spectrum windows for optical fiber communications; 850nm, 1310nm and 1550nm\textsuperscript{3}, corresponding to the three least attenuated wavelengths as the signal propagates in silica fibers. However, currently 1550nm is the most widely used wavelength in single mode fiber due to the lowest absorption of silica at this wavelength thus reducing the attenuation loss, and due to lower cost of amplifier made from Erbium (signal at 1.5\textmu m) than Praseodymium doped fibre (signal at 1.3\textmu m). The other two wavelengths are used for short distances only mainly because they do not need an expensive source, standard fiber and receiver (cost factor).

1.2.3: Spectral width.

Spectral width is the term referring to the 3dB (full width at half maximum) spectral content of the signal. In telecommunication systems, the smaller the spectral
width the better it is whereas the requirement is reversed for sensor systems. A smaller spectral width source contributes to a smaller amount of the material dispersion of silica fibre, therefore allows for a broader bandwidth. However in a sensor system, the smaller spectral width contributes to a higher coherent noise\(^4\). The coherent noise is not a factor in the former because the transmission distance is long enough that the coherency is lost.

1.2.4: Modulation Bandwidth.

This term relates to the frequency response of the source. Between optical sources, light-emitting diode (LED) shows the lowest modulation bandwidth. These sources can be directly modulated by varying their driving currents at rates up to several gigahertz (GHz). External modulation can also be done on the continuous output of the sources in order to achieve a higher modulation speed, greater bandwidth and allow the use of sources which cannot directly modulated at high frequency\(^5\).

1.2.5: Stability.

This term refers to the temporal stability of the peak power and wavelength of the source. Many factors influence a source’s stability, such as temperature, pump condition and the gain dynamics. Laser diodes (LDs) and LEDs are very much temperature dependent whereas fiber laser is less severely affected. This dissertation will show that fiber laser is also very much pump fluctuation independent.
1.2.6: Threshold.

Threshold is practically defined as the minimum amount of pump power required for the system to lase. The lower the threshold is the better, since lower optical pump power consumption is required. It varies and depends on the pump wavelength used, doping concentration, medium length and cavity loss. Figure 1.3 shows the threshold point of a fiber laser system, in a curve of lasing power against the pump power. A threshold can be characterised by three phenomena that is the sudden increment of output power, the significant reduction in the spectral width to less than 0.1nm, and the clamping of the amplified spontaneous emission (ASE) level.

![Graph](image)

Figure 1.3: Output power against pump power graph showing 5mW of threshold power.

1.2.7: Efficiency.

Efficiency represents the ratio of the lasing output power over the pump power, or in other words, the conversion of the pump energy to the lasing energy. For
example, efficiency of a fiber laser system with Yb-Er co-doped fiber, has been reported to be about 53%\textsuperscript{6}. This value can be obtained from the slope of the transfer characteristic curve. For instance, the system which has a transfer characteristic shown in Figure 3 has a slope efficiency of 13.51%.

Efficiency is also being used to refer to the power coupling efficiency, which is input coupling between the source and the input end of the fiber and also output coupling between the output end of the fiber and the receiver. Theoretically, the coupling efficiency without lenses for LED is less than 15% while that for the LD is about 30%. Fibre laser has the best coupling efficiency of more than 95\%\textsuperscript{7}.

1.2.8: Side Mode Suppression Ratio (SMR).

There are a few types of noise associated with light sources. Mode competition noise\textsuperscript{8} or also known as mode partition noise is caused by the competing longitudinal modes in a non-single longitudinal mode (NSLM) source system. This noise contributes to wavelength and power instabilities of the signal. The spectral bandwidth of the source can also be affected by the mode competition noise. The feedback noise\textsuperscript{8} is associated with back reflections (Mie and Rayleigh scattering and Fresnel reflection) of the signal into the source. The feedback noise is particularly serious in LD systems\textsuperscript{8}. The back reflection noise can cause mode hopping in the source resulting in the wavelength fluctuation. The work shows that a fiber laser can be practically insensitive to back reflection. Other noise sources that should be considered while carrying out experiments are modal noise and polarization noise\textsuperscript{8}. The latter has been studied on single mode fiber at various different positions and is discussed in chapter 2.
However, a source is more generally characterized by the SMSR, referring to the ratio of the signal peak power to that of the next highest mode. Figure 1.4 depicts this definition more clearly. In this study, optical spectrum analyzer (OSA) is used to directly measure the SMSR within the mask range, which can be fixed by the user. A standard mask range used in this study is ± 1nm.

![Graph showing SMSR](image)

*Figure 1.4: The definition of SMSR.*

SMSR should not be confused with signal to noise ratio, SNR. SNR actually refers to the ratio between the peak signal point and the noise level. In transmission, the noise level may sometime be higher than the next mode level of the peak signal. This understanding is important in discussing the operation of the laser amplifier or optical amplifier in which this parameter affects the noise figure of those systems.
References to Chapter 1: