CHAPTER 6

CONCLUSION

Through the research and experimental work that have been performed, we can make a conclusion and summarize of all the results that have been discussed in the previous chapters. This dissertation is a study on the Brillouin effect in a Photonics Crystal Fiber (PCF), with a length as short as 20m. PCF is a highly nonlinear material with a highly tailorable dispersion value and high birefringence. PCFs are a class of microstructure fibers which are made from a single material, but they are different from conventional silica fibers, with a periodic array of air holes along the entire fiber length. High nonlinearity means various nonlinear effects can happen in a short length of the fiber, and that is our justification for using such short fiber lengths in this study.

In this dissertation, a stimulated Brillouin scattering effect in a nonlinear medium is used to generate a single wavelength and multi-wavelength laser. The interaction between the BP signals from the external laser cavity with the SMF or PCF material causes acoustic mode vibrations in the fiber material. It caused density inhomogeneity and gives different refractive indices in this material. Due to the interaction of incident light with the fiber material which has different refractive indices, incident light will be reflected or refracted at any point depending on the refractive indices. This generates a back-reflected light which is called a Brillouin stokes.

One of the primary objectives of this dissertation is to study the Brillouin effect in the PCF. In order to prove the existence of the Brillouin effect in the PCF, the configuration as shown in figure 3.5 is used. The transmitted light is observed at the end of PCF while the reflected light is observed at port-3 of an optical circulator. It is measured by an optical power meter. From this test, the wavelength of reflected light should be shifted to the longer wavelength, but because the length of the PCF is not sufficient, the wavelength of reflected light cannot be shifted to any wavelength.

The performance of both open and close configurations in producing the nonlinear effect was studied. With comparison between both of these configurations, we found that the open resonator give a higher Brillouin spectrum as compared to the Brillouin spectrum of close resonator. However, the difference of the BP peak and Stokes peak from close resonator configuration is lower than the open resonator design. From these observations, we can deduce that the SBS effect is stronger in a closed resonator design.

In chapter 3 we also present an amplifier design. Firstly, a single stage bidirectional amplifier using bismuth-erbium doped fiber (Bi-EDF) is used as the gain medium. A gain as high as 7.86dB with 0dBm input signal power can be achieved. To increase the output power and amplifier gain, the configuration of the Bi-EDFA was modified with the addition of a single stage 5m erbium doped fiber (EDF) inserted at in the front of the Bi-EDFA. We called the combination of these both amplifiers the Bi-Si-EDFA. It can give higher amplifier gain; as high as 19dB with a 0dBm input BP power from a TLS. The best potential of Bi-Si-EDFA was showed by a comparison of ASE spectrum and gain bandwidth spectrum. These enhancements of modification give a broader gain bandwidth compared to the previous amplifier EDFA. The lower noise figure occurs at around 1540-1570nm. However, the best wavelength region by this amplification using Bi-Si-EDFA is around 1530-1570nm; at this region, the gain is high and flattened out and the noise figure is lowered.

In chapter 4, 25km-long single mode fiber (SMF) was used using a simple BFL cavity to generate a Brillouin fiber laser. From this experiment, a single wavelength Brillouin fiber laser was obtained without any amplifier source to amplifies the BP. A single Brillouin Stokes line is obtained when the threshold power was reached at around 0dBm of the BP. Then an amplifier applied into the resonator to boost up the BP. With a high BP power injected into the SMF, we obtain a comb of multi-wavelength Brillouin fiber laser. Then, the generation of multi-wavelength Brillouin Bi-Erbium fiber laser applied on the 20m of PCF fiber. First of all, a comb multi-wavelength Brillouin Bi-erbium fiber laser using a single stage of bidirectional Bi-EDFA was discussed that is in a conventional ring cavity configuration. The free running or self lasing occurs at every mode with separation wavelength around 0.5nm observed via its spectrum and 0.525 nm obtained via calculation.

With the injection of a BP signal from a TLS, a multi-wavelength Brillouin comb is obtained with seven Brillouin Stokes including anti-Stokes lines. The influence of the 1480nm pump and Brillouin pump powers were analyzed. From our observations, all Brillouin Stokes and anti-Stokes peak power values increasing 1480nm with increasing pump power and BP power. The number of Stokes lines generated increased with increasing pump power and BP power as well. This is due to the higher erbium gain with the higher 1480nm pump power as well as the higher Brillouin gain with the higher BP power.

Wavelength region covered the entire free running spectrum also been studied to find the effective wavelength. From the observation, the peak power for each Brillouin Stokes was found at every wavelength fluctuations. It cannot be constant because of the high nonlinearity effect in PCF. Besides that, the microstructure of PCF with different shape of air holes gives a big influence in this case. The structure of the PCF is changing dramatically along the length, which yields different values of modal index along the length. However, we are not very sure of the other reason for this observation.

Through the conventional configuration laser ring cavity as discussed in the previous paragraph, we perform the modifications to enhance the output measurement. The Bi-Si-EDFA is placed into the cavity as an amplifier to amplify the first Stokes for generating the higher order Brillouin Stokes. The laser cavity is similar to the previous laser cavity except a minor loop was built up to crossover the PCF. It is used to loop back a portion of light. So with modification of the laser cavity, the output spectrum was measured and compared with the Brillouin spectrum from the conventional laser cavity. The comparison and enhancement is shown in figure 5.2. From these figure, the enhanced configuration gives the better spectrum with higher peaks for every Brillouin Stokes. The different of each peak power have viewed from figure 5.3. The number generated of Brillouin Stokes in enhance configuration is more than the previous configuration which is the conventional configuration can generate about 7 lines while, through the enhancement, 9 lines can be obtained. From studies on the effect of laser diode (LD) pump power and Brillouin pump (BP) power, we can see that the optimum power from laser diode is around 67mW in the cavity while at the same time 20dBm of BP were injected. However, the Brillouin comb spectrum was destroyed over the higher amplifier pump power in the cavity. It is because it exceeds the saturated power from BP power. It also affects the number of Brillouin lines Stokes, whereby the optimum number of Brillouin lines is 9 lines obtained at 67mW pump power and the number of lines was decreased when pump power is increased.

Chapter 5 also studied about the position of output coupler. As discussed in previous chapter, we test the output position whether the output coupler were placed at the front of the Bi-Si-EDFA known as output 2 or behind the Bi-Si-EDFA known as output 1. From the result observation, the output measurement at output 1 is better than output measurement at output 2. The optical circulator was replaced by optical 3dB coupler to measure the potential of it as a bridge to guide BP signal of light into the cavity. However, from previous discussions, the configuration with an optical 3dB coupler give lower output measurements compared to the configuration using an optical circulator. It is because of the 3dB loss from the optical coupler. That is why the entire configuration of the experiment uses an optical circulator. The Brillouin threshold of PCF also showed that the output peak power of Stokes will increase rapidly when it reaches around ~65 – 75mW or 16dBm pump power.

The performance of BFL with Raman amplification on 25km length normal SMF has also been studied. The performance of BFL is investigated through different ratio of coupler represent the amount of injected pump powers and resonator cavity loss. The Spectrum of single wavelength BFL is generated for every coupler ratio except on 3dB coupler because of not enough amount of power to inject into the SMF. The BFL was generated through injected of 70% till 90% amount of power. With using the 3dB coupler, it only can reach spontaneous Brillouin scattering. As a conclusion, the threshold power for BP and Raman pump are obtained at around 5~6dBm and 250mW, respectively for the coupler ratio between 70~90% coupler.

As a conclusion of this dissertation, PCF can generate a comb multiple-wavelength with using a very short length of fiber compared to conventional SMF need to use as long as 25km to generate the same multiple wavelength BFL with using Bi-Si-

EDFA as booster. Raman amplification also studied on normal SMF through different amount of power injected into the cavity.

For the next research, we can propose for use the combination of Bi-EDFA and Raman amplification in generation a flat comb of multiwavelength BFL on PCF. According to the Govind P. Agrawal in Nonlinear Optic,3rd edition, the combination of Raman and EDFA can give a better amplification with wide band wavelength.