3. Conclusion

A stable, dispersion-tuned HMLFRFL has been demonstrated. SMN was significantly reduced by introducing a SOA into the ring cavity (13-dB improvement in side-mode suppression). Only a 0.25-MHz variation in the modulation frequency was needed to achieve a 10-nm smooth wavelength tuning. Both temporal and spectral widths remained approximately the same during tuning. A 3.3-ps pulse width was obtained at 10 GHz with pulse compression.

References


### ThGG28 5:30 pm

**Single Output Polarization Control of Fiber DFB Laser using Injection Locking**

W.H. Chung and H.Y. Tam, Photonics Research Center, Department of Electrical Engineering, The Hong Kong Polytechnic University, Hong Kong, China, Email: ewchun@inet.polyu.edu.hk

L.Y. Chan and P.K.A. Wai, Photonics Research Center, Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, Hong Kong, China, Email: eewai@polyu.edu.hk

1. **Introduction**

Distributed feedback fiber lasers (DFB-FL) based on fiber Bragg gratings (FBGs) written in Er3+ or Er3+/Yb3+ doped fibers are promising candidates for optical communication and sensor applications because of their single longitudinal mode output, narrow linewidth, and ease of fabrication with highly accurate lasing wavelength obtained by current phase mask writing method. Most fiber lasers output consists of two orthogonal linear polarizations if they were fabricated with low birefringent fibers. In contrast, single polarization operation is desirable for optical communication applications. Several techniques have been developed to make fiber lasers operate in single polarization. They included twisting the fiber lasers, introducing a birefringence phase-shift in the fiber lasers, and self-injection locking that employs a polarization dependent/independent feedback to the cavity. In this paper, we investigated the use of active injection locking technique. By injecting the output of a DFB-FL to a Fabry-Perot laser diode (FP-LD), we showed that stable and highly polarized output can be achieved. A power penalty improvement of 3.8 dB was also demonstrated in a 41-km 10 Gb/s transmission test.

2. **Experiments and results**

Figure 1 shows the experiment configuration used to stabilize the polarization of a DFB-FL output. The DFB-FL was fabricated by scanning a phase mask in a 5 cm long hydrogenated Er/Yb fiber using a 248 nm excimer laser. We introduced an additional π phase shift in the fiber at 28 mm from the output end by shifting the phase mask half a grating pitch using a high precision piezo-electric stage during the UV scanning process. The lasing wavelength and linewidth of the DFB-FL were 1551.5 nm and less than 500 kHz respectively. The measured linewidth was limited by the spectral linewidth of the tunable diode laser used for heterodyne beating.

Figure 2a shows the output spectrum of the DFB-FL. The output power and side mode suppression ratio (SMSR) of the DFB-FL were 5 mW and 75 dB, respectively. The pump power of the 980 nm pump laser was 70 mW. Dual polarization operation was confirmed by heterodyne beating with a single mode external cavity tunable diode laser using a fast detector. We observed a frequency difference of 850 MHz between the two polarization modes. We then injected the DFB-FL output into the FP-LD using a polarization independent circulator. We monitored the injection locked signal from the output port of the circulator. The FP-LD was a double channel planar buried heterostructure (DC-BBH) type diode laser with a center wavelength of 1548.7 nm and a threshold current (Ith) of 11 mA. Figure 2b shows the spectrum of the FP-LD after it is injection locked by the DFB-FL. Injection locking was achieved by fine-tuning the operating temperature of the FP-LD. When the FP-LD was injection locked, the mode located at 1551.5 nm was amplified by 25 dB. All other sidemodes are strongly suppressed by 20 dB. The sidemodes are also red-shifted by 0.07 nm. The SMSR of the injection locked DFB-FL output was 45 dB which can be easily improved to about 65 dB by filtering the laser output with a thin-film bandpass filter. We observed that the linewidth of the injection locked laser was reduced from 0.3 nm to less than 500 kHz. Heterodyning the injection locked laser

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**ThGG27 Fig. 3.** Wavelength tuning: frequency origin is 9,999 MHz without the SOA and 10,000 MHz with the SOA.

**ThGG28 Fig. 1.** Experiment setup.
with an external cavity tunable diode laser showed that by adjusting the polarization controller (PC1), the DFB-FL can operate in either one of the two polarization modes.

We measured the polarization characteristics of the DFB-FL and the injection locked laser using a polarization analyzer (Profile PAT 9000 B). Inset of Fig. 2a shows the state of polarization (SOP) of the DFB-FL output on a Poincaré sphere. The measurement period was 30 seconds and the sampling rate was 30 Hz. The degree of polarization (DOP) was 2.4% and the SOP was unstable throughout the measurement period. After injection locking, the SOP of the injection locked laser was very stable over the same time interval and the DOP was 91.77% as shown in inset of Fig. 2b. The FP-LD is an internally strained semiconductor laser and operates in single transverse electric (TE) polarization. When one of the polarization modes of the fiber laser was aligned to the TE mode of the FP-LD, it will be amplified resonantly by the injection locking effect whereas the other orthogonally aligned polarization mode will be strongly absorbed.

We then studied the effect of different bias currents to the FP-LD on the DFB-FL by adjusting the variable attenuator (VA1). Three different bias currents (1.1Ith, 1.45Ith, and 1.8Ith) of the FP-LD were used. We found that the sidemode power decreases when the injection power or the FP-LD bias current increased. The SMSR is 47 dB for injection locked FP-LD. Wherein, the sidemode power increased when FP-LD bias current increases but decreases when injection power increases. Therefore, it is necessary to optimize the bias current of the FP-LD and the injection power in order to optimize the DOP and SMSR of the injection locked laser.

The transmission performance of using the DFB-FL and the injection locked FP-LD as the optical sources were compared by the experiment setup shown in Fig. 1. The injection power was −5 dBm and the bias current of the FP-LD was 20 mA (1.8Ith). The corresponding DOP and SMSR were 97% and 43 dB. Insets of Fig. 3 show the 10 Gbps NRZ externally modulated eye diagrams of the DFB-FL and the injection locked lasers recorded by a sampling oscilloscope operated in 10-second persistence mode. The fluctuations in the SOP of the DFB-FL output resulted in amplitude jitter after the polarization sensitive modulator and led to partial eye closure. An open eye was obtained after injection locking. The lasers were then modulated by 2^31 – 1 pseudo random bit sequences and bit error rates (BERs) were recorded after transmitting through 41-km standard single mode fiber. Figure 3 shows the BER measurements using the lasers as sources. A 3.8 dB improvement in power penalty was achieved at BER of 10^−9.

3. Conclusions
In conclusion, we used an active injection locking technique to stabilize the output polarization of a fiber DFB laser. By adjusting the operating current and injection power of the FP-LD, we achieved nearly linear polarized output with DOP larger than 95% and SMSR higher than 45 dB. We had also shown that this technique can eliminate the amplitude jitter of an externally modulated DFB-FL, and observed a 3.8 dB power penalty improvement in a 10 Gb/s 41-km transmission experiment. Our results indicate that highly polarized multi-wavelength sources can be realized by injection locking of a single low-cost FP-LD with several fiber lasers.

References