Chapter 5
Summary

5.1 Summary

The harmonic mode-locking dynamics of a backward optical injection modulated SOAFL has been investigated. The effects of gain-depletion time and modulation frequency on the mode-locked pulse shape and power have also been theoretically analyzed and experimentally demonstrated. The backward dark-optical combs modulation is much easier to initiate harmonic mode-locking in SOAFL than the bright-optical combs modulation, which generates pulsewidth as short as 5.4 ps at 10 GHz. The effects of gain-depletion time and gain-recovery time on the build-up of the mode-locked SOAFL pulse-train are elucidated, and the dark-optical pulse-train are found to be extremely suitable for XGM induced mode-locking. The difficulty in mode-locking the SOAFL by optical short pulse injection is also demonstrated and explained, which is attributed to the insufficient gain-depletion time (as well as modulation depth). The analytical results indicate that the SOAFL mode-locked by backward dark-optical combs injected SOA exhibits better mode-locking capability than that a bright-optical combs SOA when the SOA is nearly transparent. Later on, a DCF spool is employed to compensate the negative chirp of the mode-locked SOAFL pulse. An explicit expression for the optimum compression condition under the first-order approximation is described as $D_{DCF}L = -\Delta t/\Delta\lambda$, where $D_{DCF} = -80$ ps/km/nm is the dispersion parameter of DCF in ps/km/nm, L is the fiber length, Δt is the FWHM of the input pulse, and Δλ is the chirped spectral width. The dispersion compensated pulses is further amplified and the compressed via a nonlinear soliton pulse compression in a SMF spool. Under a $sech^2$ pulse shape with appropriate peak power, the optical soliton is a balanced result of the interaction between the group velocity dispersion (GVD) and the self-phase modulation (SPM) effects in SMF with anomalous dispersion. The finite gain-bandwidth limitation of the SOAFL pulse can thus be released by the SPM-induced linewidth broadening effect, and the SOAFL pulse is concurrently shortened by compensating the SPM induced residual frequency chirp with the anomalous GVD in SMF. In principle, the peak power of the input pulse required for obtaining the N^{th}-order soliton pulse was theoretically derived as $P_N = 3.11\ N^2\beta_2/\gamma\tau^2 = 3.11\ N^2 D_{SMF}\lambda^2/2\pi c\gamma\tau^2$, where λ is the input wavelength, c is the speed of light, $\tau = 8.6$ ps is the input pulsewidth, $\gamma = 1.3\ W^{-1}\ km^{-1}$ and $D \cong 20$ ps/km/nm at 1550 nm denote the nonlinearity coefficient and the dispersion parameter, respectively, for the SMF with a core diameter of 9.3 μm. In experiment, the maximum peak power of the DCF dispersion compensated SOAFL amplified by a booster EDFA is up to 51 W (corresponding to an average power of 440 mW at repetition frequency of 1 GHz), which is sufficiently to generate an eighth-order soliton in the SMF spool. However, it should be cautionary that the multiple-pulsing effect could manifest at extremely high pulse energies. The soliton theory indicates that the high-order soliton will follow a periodic evolution with its original pulse shape recurring at multiples of the soliton period Z_0, which is given by $Z_0 = 0.332c\tau^2\pi^2/D_{SMF}\lambda^2$. In our case, the optimized fiber length to obtain the shortest compressed pulse for an eighth-order soliton is approximately equal to $0.072Z_0$ or 112 m, where the estimated soliton period (Z_0) is about 1.6 km at 1550 nm.

Fortunately, the intensity dependent polarization characteristic of the amplified SOAFL pulse in the SMF spool intensity-dependent nonlinear birefringence, which results in an efficient discrimination between the high intensity peak and the low intensity pedestal, This offers an alternative way to further suppress the unwanted pedestal of the eighth-order soliton pulse after passing through the SMF spool of optimized length. Consequently, the high intensity peak and the low intensity pedestal with different polarization states at the fiber output can be orthogonally separated each other by passing through a $\lambda/4$-wave plate and a linear polarizer. The polarization-mode dispersion induced side-lobe in the auto-correlated trace of the backward optical-comb injection-mode-locked SOAFL pulse shape can be gradually suppressed via the fine tune of the linear polarizer. The pedestal-free pulse is eventually narrowing to 180 fs.