160-GHz-class optical-clock circuit with semiconductor optical amplifiers

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ABSTRACT

The authors investigate improved mode-locking characteristics for delayed- interference wavelength converter (DISC)-loop type pulse generators. We are aiming at the generation of high quality single mode pulses by using a high finesse etalon to suppress the spectral components associated to the long cavity length. Our results show that a high finesse etalon (40GHz of free spectral range, finesse of 93, 3dB bandwidth of 430MHz) inserted in a EFRL with equivalent cavity length improves the side mode suppression ration by 39dB. These results pave the way to high quality 160GHz lasers to be used in future optical networks.

1. INTRODUCTION

Ultrashort pulses with repetition rates as high as 40 GHz are needed for the optical time-division multiplexed (OTDM) systems, which will operate at 160 Gb/s in the near future. OTDM rests on the generation of high quality mode-locked pulses with a high repetition rate. Mode-locking techniques can be roughly divided into two main categories: passive mode locking using a saturable absorber and active mode locking. The fragility of the saturable absorber is the main drawback of the former method, whereas the latter needs a very fast electronic drive. The DISC-loop type pulse generator using DISC [1] (Figure 1) was proposed to solve these problems [2] (Figure 2).

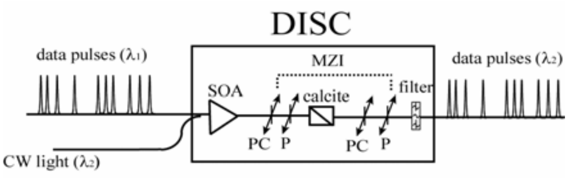

Fig. 1: DISC structure
SOA : Semiconductor Optical Amplifer, MZI : Mach-Zehnder interferometer, PC : polarization controller, P : polarizer

The pulse repetition rate, full-width at half-maximum (FWHM) is determined by free spectral range (FSR) of etalon, delay time of calcite. DISC-loop can generate short pulse such as 1ps, so we expect to drive it with 160GHz. Recently, the pulse generation at repetition rate = 40GHz, FWHM = 2ps was reported [2]. However, these results were operated with multimode oscillation. If multimode oscillation is occurred, the pulse repetition rate isn't settled. We must drive DISC-loop with singlemode oscillation to be settled pulse repetition rate. About previous results, if using an etalon 3dB bandwidth = 400MHz, we can drive DISC-loop with singlemode oscillation.

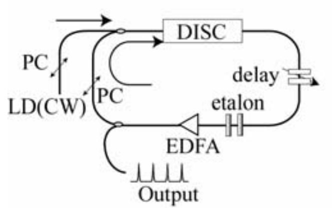

Fig. 2: DISC-loop type pulse generator
DISC : switch CW, etalon : determining repetition rate
delay : adjust cavity length, EDFA : compensate loss in loop

In this letter, we measured the oscillation bandwidth of Erbium doped fiber amplifier ring laser (EFRL) with the same cavity length as our DISC-loop and using a high finesse etalon to test whether the 3dB bandwidth is enough narrow.

2. EXPEREMENTAL SETUP

Figure 3 shows the experimental setup. The gain medium of the EFRL was an Erbium-doped fiber amplifier (EDFA). The cavity length was 46m. In EFRL, polarization controller (PC) and polarizer (P) were used to be output with single polarity.

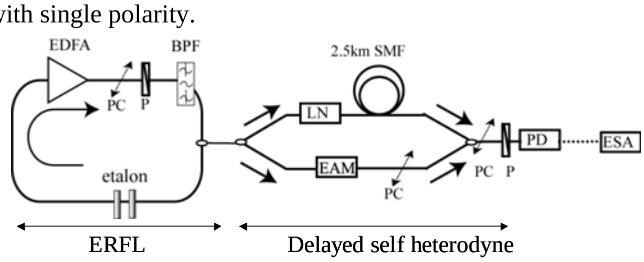

Fig. 3 : Experimental setup
solid line : optical path, dashed line : electric path

A cavity length determines frequency space of multimode oscillation. When cavity length is 46m, frequency space is 5.1MHz. Delayed self heterodyne is useful to measure bandwidth with oscillating such narrow space. In generally, a acoustic optical modulator is used. But measurement range of oscillation is limited about 100MHz. We used a $LiNbO_3$ modulator (LN) and a Electro-Absorption modulator (EAM) to expand the range. The LN and EAM modulated the EFRL output (modulation frequency of 6.24GHz and 0.90GHz, respectively), and mixed these to generate beat signal. The beat signal was converted electric signal by the photo detector (PD), and measured by the electric spectrum analyzer (ESA). The frequency resolution of the delayed self heterodyne is determined by fiber length of delay. We used a single mode fiber (SMF) with a length of 2.5km, giving a frequency resolution of 19kHz.

3. RESULT

Fig.4 shows pump power vs. output power and output spectrum from EFRL when using a etalon (FSR = 40GHz, finesse = 93, 3dB bandwidth = 0.43GHz, etalon-#a). When the pump power = 28mW, laser oscillation was occurred. We set pump current = 60mA to align condition of DISC-loop. Total gain in EFAL is threshold + 15dB [5]. Optical signal noise ratio (OSNR) of the output is 50dB.

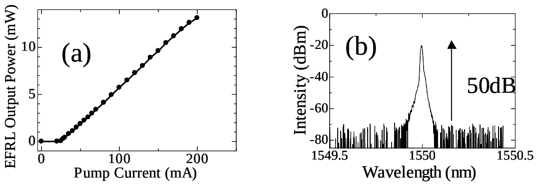

Fig. 4 : (a) EFRL output characteristic using etalon-#a, threshold pump current = 28mA (threshold pump power = 10mW)
(b): EFRL output spectrum, pump current = 60mA (pump power = 31mW, Total gain = threshold + 15dB)

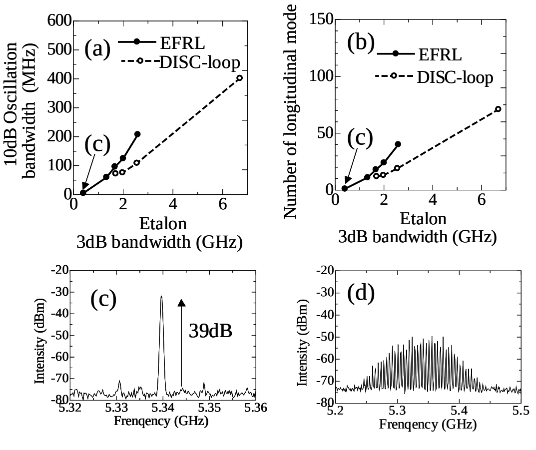

Fig. 5. (a):Comparison EFRL oscillation bandwidth and DISC-loop one. (b):Comparison EFRL number of longitudinal mode and DISC-loop one.
(c):RF spectrum using etalon-#a (3dB bandwidth =430MHz)
(d):RF spectrum using etalon-#b (3dB bandwidth = 2.0GHz)

Figure 5 shows results of heterodyne. From figure 5 (a), we found that oscillation bandwidth of Erbium-doped fiber amplifier ring laser (EFRL), same cavity length as DISC-loop and using the same etalon, were coincident with oscillation bandwidth of pulse from DISC-loop. From figure 5 (b) shows number of longitudinal mode in 10dB bandwidth. When using etalon-#b, FSR = 40GHz, finesse = 20, 3dB bandwidth = 2.0GHz, the number was 24. Figure 5 (c) and 5 (d) show RF spectrum obtained by delayed self heterodyne. When using the etalon-#a, side mode suppression ratio (SMSR) is 39dB. And the SMSR is 0dB, 10dB oscillation bandwidth is 96MHz when using etalon-#b. When we drove DISC-loop using etalon-#b, 10dB oscillation bandwidth was 72MHz and the number of longitudinal mode was 12 [6].

4. CONCLUSION

We have demonstrated that the use of a high finesse etalon in a EFRL results in the generation of single mode pulses with a side mode suppression ratio of 39dB. The application of the same technique to a DISC-loop pulse generator, with its intrinsic advantages for independent selection of temporal pulse-width and repetition rate, will give rise to the generation of high-quality single mode pulses at high repetition rates for future OTDM networks.

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