Active mode-locking of miniature fiber Fabry-Perot laser (FFPL) in a ring cavity

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Abstract:

We demonstrate active mode-locking at 10GHz of a 10mm-long fiber Fabry-Perot laser (FFPL) in a ring cavity. We obtained very stable pulse trains without supermode noise. The pulsewidth was about 10ps, which could be shortened to 1.6ps by insertion of highly-nonlinear fiber.

Index Terms:

fiber lasers, mode locking, supermode noise

Actively and harmonically mode-locked fiber ring lasers have been studied intensively because they can generate high-repetition-rate and transform-limited short pulses. However, their typical cavity length is 10-100m, and the corresponding order of harmonics is 500-5000 for 10GHz mode locking, which results in unstability due to the external perturbation and the large supermode noise. Use of an intracavity Fabry-Perot interferometer has been proposed to avoid the supermode noise[1,2]. By adjusting the free spectral range (FSR) of the Fabry-Perot interferometer equal to the modulation frequency, only one set of supermode can be selected. However, this method has a few difficulties. One is that the finesse of the Fabry-Perot interferometer has to be high enough to select only one set of supermode, which is difficult for long cavity lasers. The other is the difficulty to identify the exact FSR of the interferometer, because it is a passive device. In this paper, we demonstrate stable active mode-locking operation at 10GHz of a 10mm-long erbium:ytterbium (Er^{3+}:Yb^{3+}) fiber Fabry-Perot laser (FFPL)[3-5] in a ring cavity.

The experimental setup is illustrated in Fig.1. It is a fiber ring cavity simply composed of a FFPL, a $LiNbO_3$ (LN) intensity modulator with a polarizer, an isolator, a 3dB fiber coupler, a polarization controller (PC), a tunable bandpass filter (BPF) having 1nm bandwidth, and a fiber strecher. The FFPL consists simply of 10mm of phosphosilicate Er^{3+}:Yb^{3+} fiber with high reflectivity (~98.6%) dielectric mirrors deposited on the two polished end-faces, and single mode fibers epoxied on both ends for coupling the pump and output emissions. The Er^{3+}:Yb^{3+} fiber has Er^{3+}:Yb^{3+} concentrations of 1750:14000 parts in 10^6, signal absorption of 0.1dB/mm at 1535nm, and pump absorption of 2.4dB/mm at 976nm. The FFPL is pumped with a 980nm laser diode (LD) through a wavelength-division multiplexed (WDM) coupler. The free-running FFPL is in very unstable multimode at around 1544nm, owing to the homogeneous gain saturation of the

Er^{3+}:Yb^{3+} fiber. The output power is ~10mW with the pump LD power of 100mW. The exact FSR of the FFPL is easily found to be 10.173GHz by looking at the RF spectrum. The modulator is driven by the RF signal generator at 10.173GHz, and the light from the 3dB couper is taken as an output. The fiber strecher is used to set the FSR of the FFPL (=10.173GHz) an integral multiple of the FSR of the ring cavity. To compensate the loss in the ring cavity (~10dB), an erbium-doped fiber amplifier (EDFA) having the small signal gain of about 20dB can be inserted in the cavity. The cavity length is 20m without the EDFA, and 50m with the EDFA.

The laser could be mode-locked without the EDFA, whereas the operation was not very stable due to large loss in the ring cavity. With the EDFA, the operation was more stable, whereas the waveform was still noisy, probably because of the mirror reflectivity (~98.6%) in the FFPL is too high. On the contrary, by reducing the pump power just above the lasing threshold of the FFPL, we found that the operation was drastically improved. Figures 2 are the measured (a) waveform with a sampling scope having 30GHz bandwidth, (b) optical spectrum, (c) RF spectrum around 10.173GHz, and (d) auto-correlation trace, when the EDFA was inserted and the FFPL was operating just above lasing threthold. The waveform in Fig.2(a) is very stable and has no noise at all. In the optical spectrum in Fig.2(b), the 10GHz-spaced mode structure is clearly seen, and the estimated spectral width is 33GHz. Looking at the RF spectrum in Fig.2(c), only a strong line exists at 10.173GHz. These results show that the laser has no supermode noise. The estimated pulsewidth from Fig.2(d) is 10ps, which means that the pulse is nearly transform-limited. The laser could be tunable from 1535nm to 1561nm, which is currently limited by tunability of the BPF used in the experiment.

In order to obtain shorter pulse, we inserted a highly nonlinear dispersion-shifted fiber (HNL-DSF)[6] in the ring cavity. We used 1km-long HNL-DSF whose zero-dispersion wavelength is 1542nm, dispersion slope is 0.035ps/km/nm^2, and nonlinearity coefficient is about 20W^{-1}km^{-1}. We set the operation wavelength at 1560nm to optimize the soliton effect. The auto-correlation trace and the optical spectra are shown in Figs.3(a) and (b). The estimated pulsewidth is 1.6ps, although there still remains a small pedestal. The optical spectra is spread to around 190GHz with good visibility. However, we found the fluctuation in the waveform, indicating that supermode noise could not be suppressed due to very long cavity length. More stable operation without supermode noise is possible with shorter HNL-DSF.

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Figure Captions

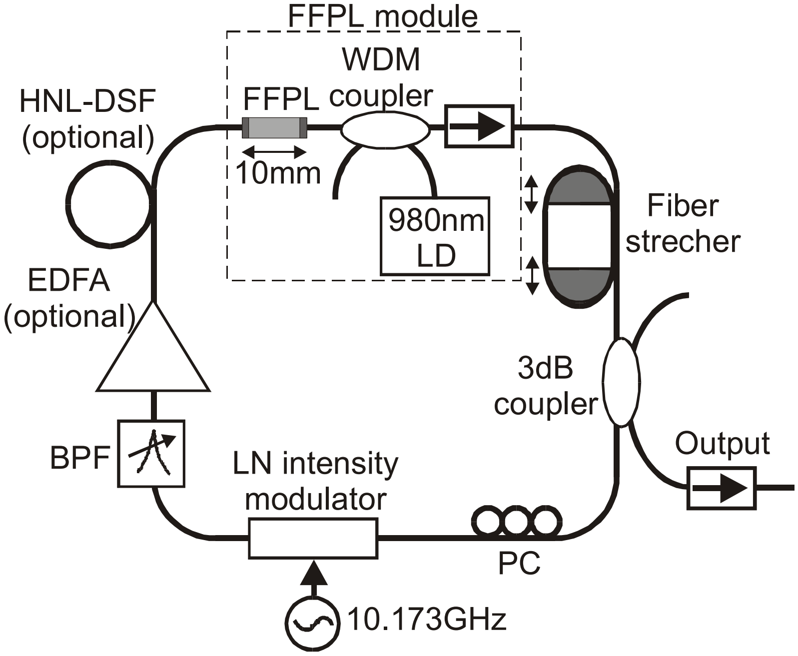
Fig. 1: Acitive mode-locking of the 10mm-long FFPL in a fiber ring cavity.

Fig. 2: Measured waveform, optical spectrum, RF spectrum, and auto-correlation trace.

(a) waveform measured with a sampling scope (b) optical spectrum (c) RF spectrum around 10.17GHz (d) auto-correlation trace

Fig. 3: Measured optical spectrum and auto-correlation trace when the 1km-long HNL-DSF were inserted.

(a) optical spectrum (b) auto-correlation trace



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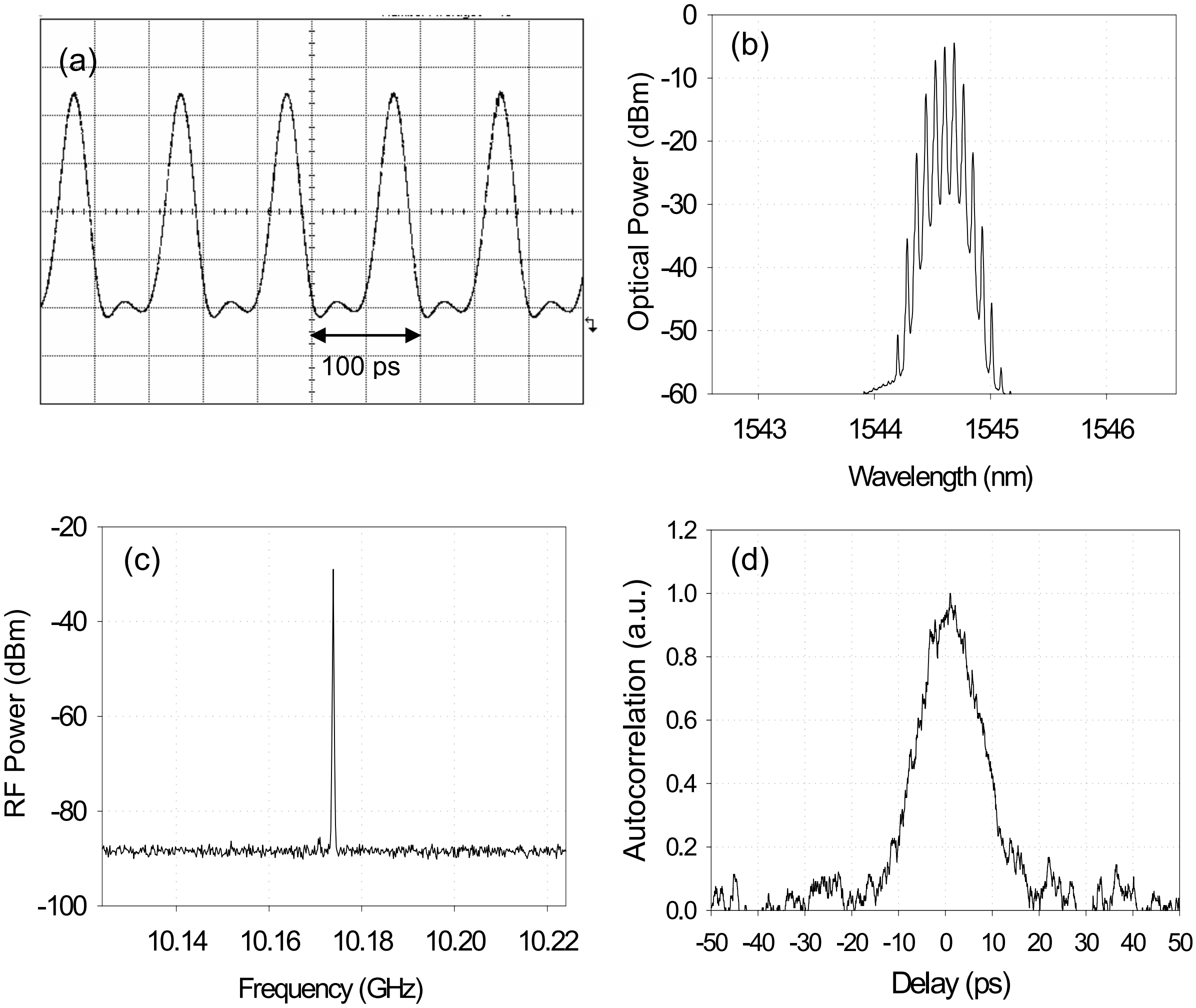

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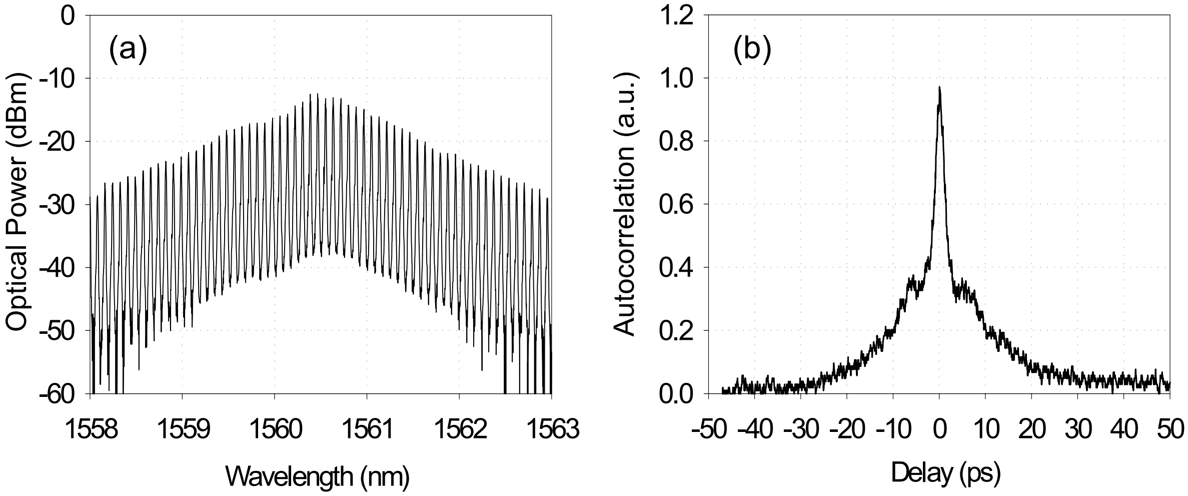

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(a) optical spectrum (b) auto-correlation trace