Hybrid mode-locked ultrashort-pulse erbium-doped fiber laser

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Abstract. One of the implementations of fs-laser with CNT-film for mode-locking is considered. Scheme of single-pulse, self-starting, stable mode-locked laser generation by appropriate polarization controllers adjustment is suggested. The mechanism of cavity length stabilization for a femtosecond fiber laser based on the pump source modulation is considered. Bandwidth of the feedback frequency stabilization system based on pump source modulation method is defined.

1. Introduction and background

In this paper, we employ the NPE as a fast saturation mechanism inside the ring cavity of the erbium-doped fiber laser mode-locked by carbon nanotubes (CNT). We compare the output parameters of ultra-short pulses in fiber laser based on a common ring scheme with a scheme that uses birefringence fiber. The NPE is initiated by including into the ring the birefringent “PANDA” – type silica-glass fiber that also possesses a polarizing effect – so-called PZ-fiber [3]. PZ-fiber also contributes to the suppression of the unwanted spectral spike at the wavelength of 1530 nm.

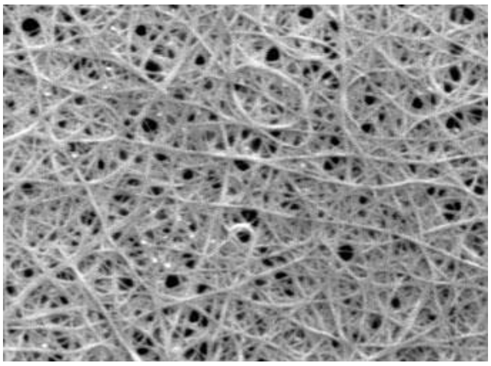

Figure 1. Carbon nanostructures.

The scheme of the mode-locked erbium-doped fiber ring laser is shown infigure 2. It consists of the active erbium-doped alumina-silicate fiber pumped by the 980 nm laser diode through a 980/1550 WDM. It should be noted, that erbium-doped fiber in the cavity possess positive group velocity dispersion (GVD) in the spectral band between 1500 and 1600 nm. Slow saturable absorber is based on carbon nanotubes incorporated in the polymer film (CNT-film) which is incorporated into the SAINT module.

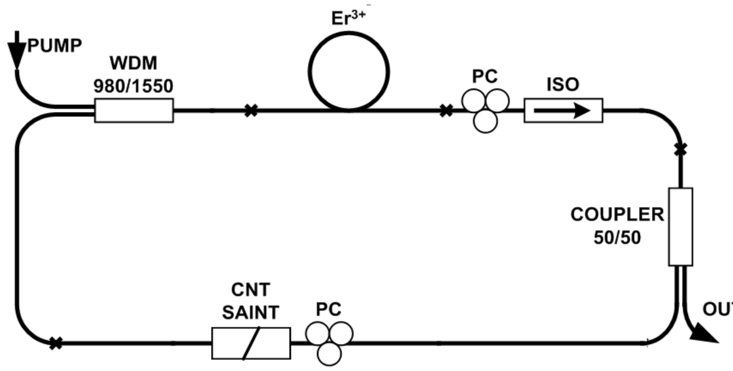

Figure 2. Scheme of the mode-locked erbium-doped fiber ring laser.

The setup of the mode-locked erbium-doped fiber ring laser with polarized birefringent fiber is quite similar the abovementioned standard ring scheme (figure 3). For effective realization of the NPE mechanism, the ring cavity contains two polarization controllers at both sides of the PZ–fiber (PZF). A commercial fiber isolator (ISO) ensures the unidirectional generation inside the cavity. The generated radiation is coupled out the cavity through the 3dB coupler.

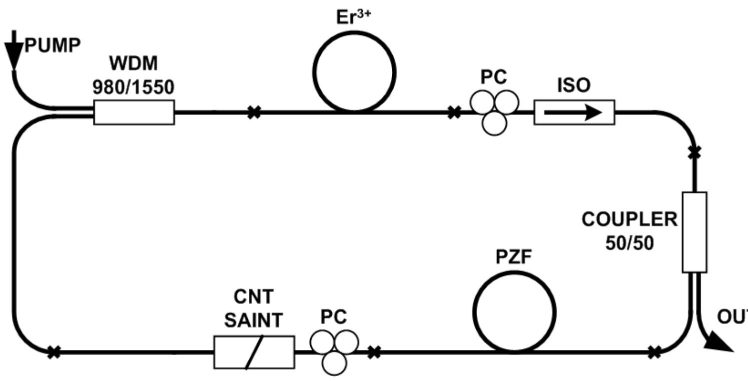

Figure 3. Scheme of the mode-locked erbium-doped fiber ring laser with PZ–fiber.

We have realized single-pulse, self-starting, stable mode-locked generation by appropriate polarization controllers adjustment. The ultrashort pulse characteristics have been measured through the varying of the CNT-film non-saturated transmission value (in the range 54–85%) and the pump power level. The shortest pulse duration was reached to be less than 250 fs in the case of the NPE mechanism implementation. Thus, the laser pulse-length was shortened by more than 2X in the presence of NPE mechanism inside the laser cavity.

Using of carbon nanostructures as a saturable absorber, can significantly extend the service life of the laser in comparison with similar lasers implemented on SESAM. Low power pulses does not have a strong influence on the life of the other components of the laser. On this basis one can conclude that hybrid mode-locked ultrashort-pulse erbium-doped fiber laser has a high service life. It's important to note that the price of carbon nanotubes is much lower than the cost of SESAM. It's possible to get the pulse generator with high power in combination with the Erbium-doped fiber amplifier. Operational life of the system will depend on the resources of the amplifier, which can be replaced by a reserve amplifier. The pulse duration of 250 fs allow to use this system in the optical frequency standards. Another significant advantage of the femtosecond laser is the ease assembly of the ring scheme.

Femtosecond lasers, emitting a sequence of ultrashort pulses, are a source of continuous equidistant narrow spectral lines, the interval between them is equal to the pulse repetition rate and the total length of the spectrum is determined by the duration of a single pulse. In other words, the femtosecond laser is not only a source of ultrashort pulses, but the comb generator of highly-monochromatic optical frequencies. If any component of the comb generator spectrum stabilize by the frequency standard, the absolute frequency values of all the components are known. In fact, it turns out the optical range, which can be used to effectively solve the problem of measuring optical frequencies.

2. Stabilized cavity length

One possible implementation of the frequency divider is a femtosecond laser with a stabilized cavity length. There is a variety of mechanisms for such stabilization: modulation of the pump source; using of the piezo-drive, which tensile and compressive optic fiber, as well as the use of electro-optic modulators. In this paper we study the mechanism of cavity length stabilization by means of pump source modulation. The mechanism is based on the length of the optical resonator, which is associated with a nonlinear refractive index of an optical fiber depended on the pump power. In this paper the band of feedback system of frequency stabilization was studied.

It is necessary to implement the feedback and adjust the length of the resonator fs-laser to stabilize the frequency of the fs-laser with He-Ne/CH_4 optical frequency standard (OFS). The mechanism is based on the length of the optical resonator, which is associated with a nonlinear refractive index of an optical fiber depended on the pump power:

$$l = nS, \quad (1)$$

where n - the refraction index of an optical fiber [4], S - geometric path length. Presented expression shows that changing of the pump source power can change the optical length of the resonator. In an experiment we determined the bandwidth of the feedback for frequency stabilization system. The setup of this experiment is shown in figure 4.

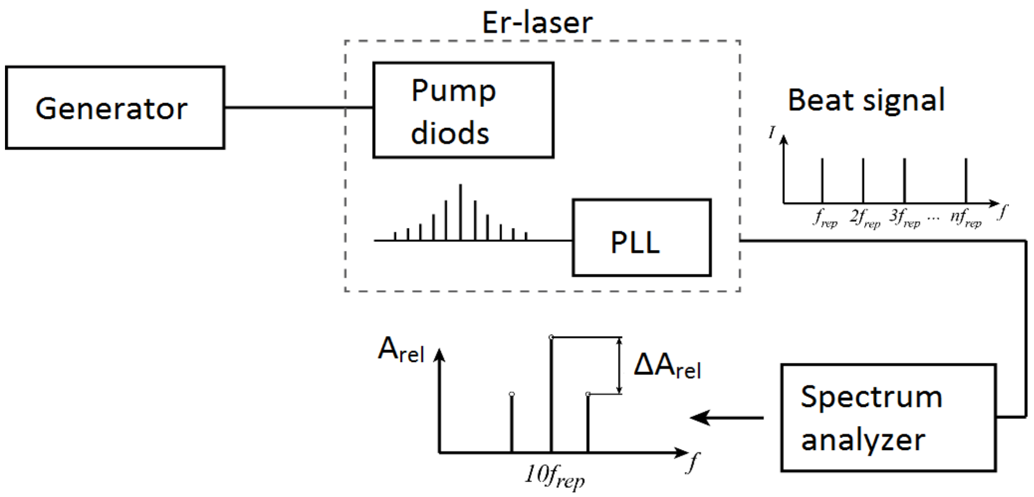

Figure 4. The experimental setup for determining the feedback bandwidth.

On this scheme sinusoidal signal generator is connected to a power supply pumping diodes fs laser. Beat signal optical frequency comb generated by a femtosecond erbium laser was recorded by the radiation detector, which is connected to an electrical spectrum analyzer. The pump power modulation result in the appearance of side components at each harmonic in the beat signal. The measurements were performed at the 30th harmonic of the beat signal. Difference between carrier amplitude and sideband amplitude was measured. Measurements results are plotted in figure 5.

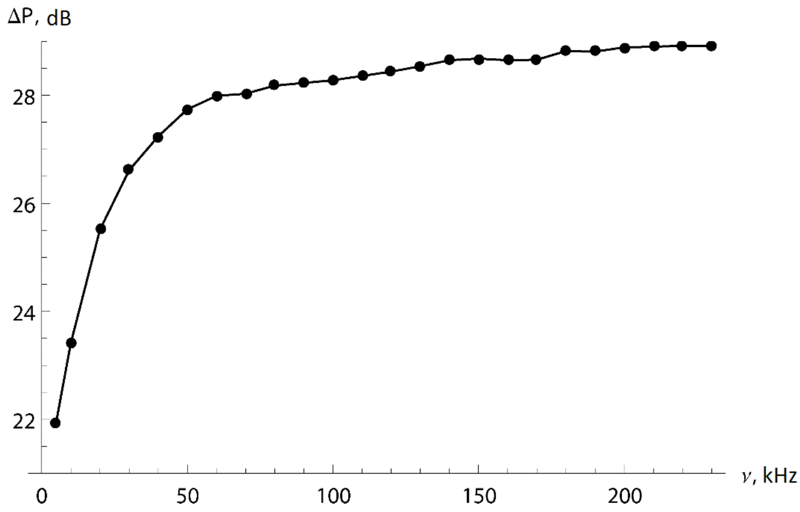

Figure 5. Results of measuring a bandwidth of the feedback for frequency stabilization system.

The graph shows that starting from 150 kHz, the changes are minor. Thus, the presented method allows to change the length of the cavity with feedback band of 150 kHz, which is better than the method of adjusting the cavity length based on the piezo-actuator, which feedback bandwidth is approximately 50 kHz.

3. Conclusion

In conclusion, we have compared pulse shortening by implementing the NPE mechanism inside the ring cavity of the CNT mode-locked erbium-doped fiber laser. We use an active erbium-doped fiber with positive group velocity dispersion (GVD) in the spectral band between 1500 and 1600 nm. The shortest pulse duration was less than 250 fs.

References

[1] Nelson L E, Jones D J, Tamura K et al. 1997 Ultrashort-pulse fiber ring lasers *Appl. Phys. B* **65** 277-294
[2] Set S Y, Yaguchi H, Tanaka Y, Jablonski M 2006 Ultrafast fiber pulsed lasers incorporating carbon nanotubes *IEEE J. Sel. Top. Quantum Electron.* **1** 137-146
[3] Koh J, Chen X, Li M J,et al. 2006 New polarizing optical fibers *Proc. SPIE* **6351** 63510L
[4] Akhmanov S A, Nikitin S Y 1998 *Physical Optics* (Oxford University Press. Oxford) p 656