High-energy all-fiber all-positive-dispersion mode-locked ring Yb laser with 8 km optical cavity length

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It has been demonstrated recently in [1] that lengthening of the optical resonator in mode-locked fiber laser can be used as a design tool to increase energy of pulses generated in such systems. In this work we report stable mode synchronization in all-fiber pulsed laser using resonator with a record optical path of 8 km. The laser system scheme is shown in Fig 1. Laser mode synchronization was achieved by exloiting the nonlinear rotation of generated radiation polarisation. The cavity length has been controlled applying standard single mode fiber SMF-28. Average output power of radiation did not exceed 150 mW, a level that was limited by the maximal working power of fiber polarization beam splitter used for the out-coupling of the generated emission. Figure 2 demonstrates autocorrelation function of the generated laser pulses with duration about 10 ns and the energy of 4 μJ. Measured power spectrum of the generated output pulses is shown in Fig. 3.

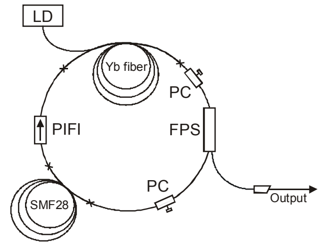

Fig. 1. Configuration of all-fiber all-positive-dispersion 8km-long mode-locked ring Yb laser: PC – polarization controller, PIFI – polarization-independent fiber isolator, FPS – fiber polarization splitter, LD – pump laser diode.

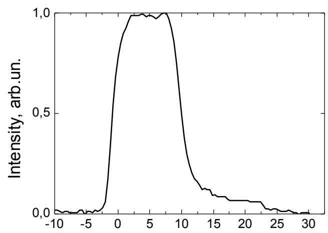

Fig. 2. Measured temporal distribution of output pulses intensity

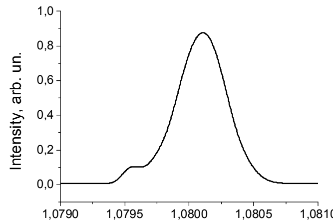

Fig. 3. Measured power spectrum of output pulses

Generated pulse energy E_{out} out-coupled through the FPS can be estimated using the cavity energy balance equation that for the considered scheme reads: $E_{out} = \frac{P_{sat} nL}{c} \times \{g_0 L - A - \ln\left(1 + \frac{E_{out}}{E_{in}}\right)\}$, here n – is the refractive index n=1.45, P_{sat} is the Yb gain saturation power, L is a physical length of the cavity, $g_0 L$ accounts for small signal gain in Yb span and A includes all accumulated cavity losses (mostly in SMF), $E_{in} \approx E_{out}$ is a fraction of the energy that is returned to the cavity after the FPS. Multi-parametric system design emphasises the importance of the numerical modelling. First, we have performed optimisation of the system parameters for a pure Yb-based fiber laser and demonstrated mode-locking regimes shown in Fig 4, though already this step required rather time consuming optimisation and adjustment of system parameters for considered configuration. Parameters used in simulations shown in Fig. 4 include 6 m of active fiber, small gain of 30 dB, saturation energy of 1 nJ, fiber group velocity dispersion of 20 ps^2/km, nonlinearity parameter gamma = 4.7 km^{-1} W^{-1}. Three varying parameters of the polarisation elements have been respectively adjusted to achieve mode-locking. We have combined here a semi-analytical approach and full modelling based on the coupled nonlinear Schrödinger equations. Full detail of two-stage modelling approach and the obtained results will be presented at the conference.

To the best of our knowledge, we demonstrated a mode-locked pulsed laser with the longest cavity of 8 km optical path. Such a long cavity allows us to generate pulses with the energy of 4 μJ that is a record value for families of fiber and fiber/bulk lasers not using Q-switching, cavity dumping techniques, or additional optical amplifiers.

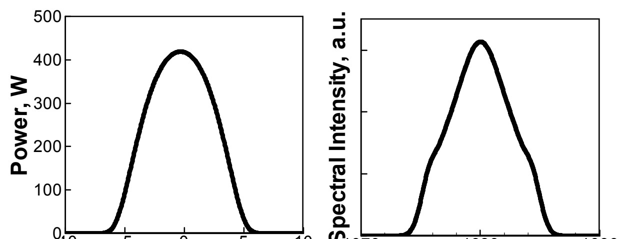

Fig. 4. Typical modeling results demonstrating mode-locking regimes

References

[1] S. Kobtsev, S. Kukarin, and Y. Fedotov, "Ultra-low repetition rate mode-locked fiber laser with high-energy pulses," Optics Express, **16**, 21936 (2008).

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