Experimental measurement and numerical modelling of narrow-bandwidth Yb-doped fiber laser spectrum and time dynamics

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We present experimental measurement and full numerical modelling of spectral and temporal properties of narrow-bandwidth Ytterbium doped fiber laser.

Introduction

Recently, temporal and statistical properties of quasi-CW fiber lasers has attracted a great attention. In particular, properties of Raman fiber laser (RFLs) have been studied both numerically and experimentally [1-6]. However, experimental investigation of temporal and statistical properties of quasi-CW RFLs is challengeable, as the optical bandwidth (typically hundreds of GHz) is much bigger than real-time bandwidth of oscilloscopes (up to 60GHz for the newest models, but typically less than 6 GHz).

Ytterbium-doped fiber lasers are more suitable for experimental investigation, as their generation spectrum usually 10 times narrower. Moreover, recently ultra-narrow-band generation has been demonstrated in YDFL [7] which provides in principle possibility to measure time dynamics and statistics in real time using conventional oscilloscopes.

In this work we study experimentally optical spectra and time dynamics of radiation in Yb-doped fiber laser scheme with narrow output spectrum having optical bandwidth of few GHz, thus providing possibilities to real-time measurements of spectral and statistical properties. At the same time, full numerical modeling of time dynamics and statistical properties is performed for the first time of our knowledge.

Experiment

Experimental setup is shown in Fig. 1 (Left). The 4 meter long YDFL cavity is comprised of 3 meter Yb-doped double-clad polarization maintaining fiber and 1 meter passive fiber. The Yb-ions concentration in active fiber equals to $9.7\cdot 10^{25}$ m^{-3}. The FBG with 98 % reflectivity at the left end of the cavity has spectral width of ~200 pm. At the other end, the laser resonator was formed by the narrow FBG with ~50 pm spectral width and 25% reflectivity at 1064 nm. FBGs were not centered precisely since there was temperature shift of narrow Bragg grating. Pump was provided by two laser diodes, operating at 970-976 nm depending on pump current and temperature. The laser operates in the CW regime with maximal output power of 3.5W.

An important feature of the experimentally measured laser output was a narrow spectrum of ~2GHz width only. Nevertheless, the laser still should be considered as multimode since it maintains about 100 different modes. So the total radiation is quasi-CW and exhibits strong intensity fluctuations on sub-nanosecond scale. Such narrow generation spectrum allows us to measure the dynamics of this fluctuations in real time by means of conventional oscilloscope of bandwidth 2.5 GHz only.

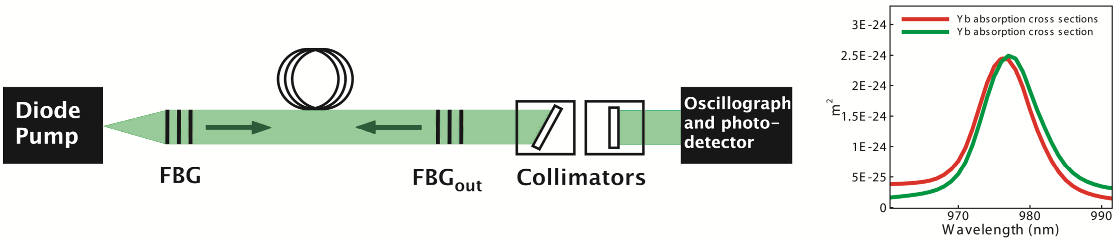

Fig. 1 (Left) Experimental setup. (Right) Ytterbium absorption and emission cross sections.

Numerical modelling

We numerically investigated the properties of generated at 1064 nm radiation using an NLSE-based model previously reported to be efficient for modeling of RFLS [1,8,9] combined with material equations, see [10] for details. Signal evolution inside the active fiber is described by the NLSE, when inhomogeneous gain distribution is described by the rate equations for effective 2-level ytterbium system. Power is averaged over numerical time window T that in our simulation is equal to the roundtrip time. A short length of laser cavity allows us to model time dynamics over the entire round trip. Indeed the roundtrip time corresponding to the experimental setup in Fig. 1 equals to 38.7 ns (T_R=2nL/c, where L=4m is fibre length, n=1.45 – refractive index, c – speed of light). Such a numerical time window doesn’t imply very time consuming computations.

Note that experimentally measured pump wavelength varies in the range from 970 nm to 976 nm depending on pump current and temperature. Ytterbium absorption and emission cross sections change sharply in this region (Fig. 1, right), which influences strongly the device performance. We assume a linear dependence of pump wavelength on the laser diodes power to accurately describe the laser slope efficiency.

Results and discussions

In this section we analyze the numerical results compare where possible them to the experimental data. Comparison of numerical modeling with the experimental results for the output power versus pump power is shown in Fig.2. The efficiency of signal generation changes with pump power growth due to pump wavelength shift from 970 to 976 nm.

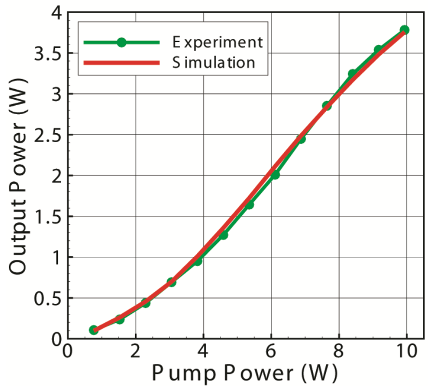

Fig.2. Total output power versus pump power in experiment and simulation

The experimentally measured and calculated output spectra are shown in Fig. 3, upper row. Fig. 3, bottom row, depicts dependence of output spectrum width on pump power. Spectra in simulations demonstrate the same behaviour as in the experiment, i.e. the numerical model accurately describes nonlinear spectral broadening inside the laser cavity.

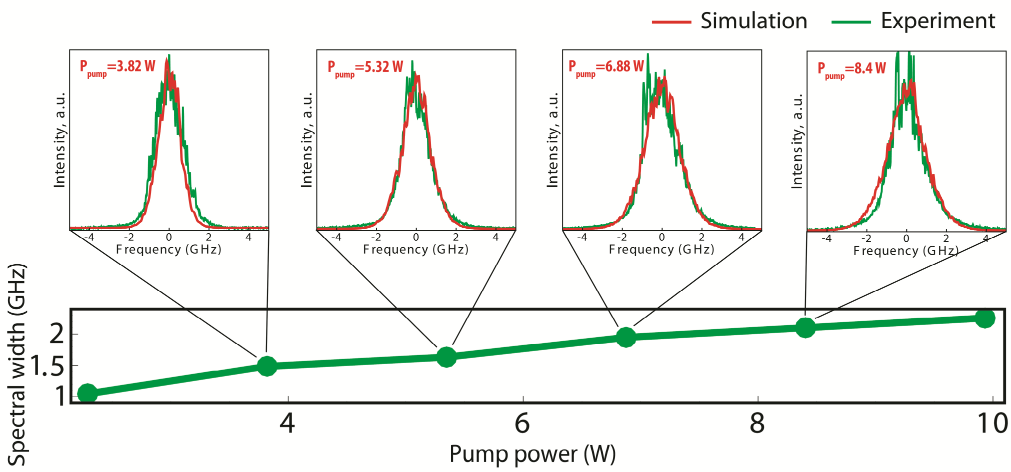

Fig. 3: (Bottom row) Output spectra width as a function of pumping power. (Upper row) Output spectra as a function of pumping power in experiment and simulation.

A time dynamics of output radiation in experiment and simulation is shown in Fig.4. We can conclude, therefore, that numerical results demonstrate the same quasi-CW behavior of laser output with strong intensity fluctuations on sub-nanosecond scale as experimental data.

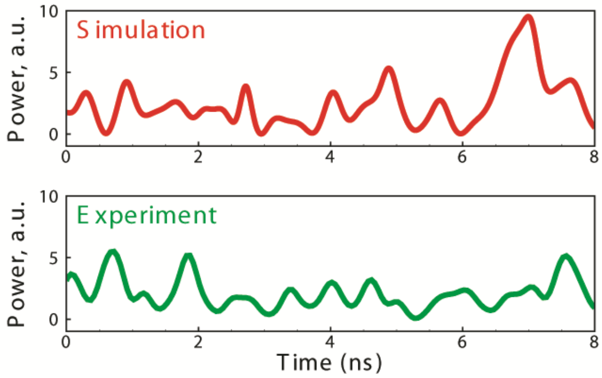

Fig. 4. Time dynamics of output radiation in experiment and simulation (pump power equals to 6.88 W).

Conclusion

Thus, we present an experimental and numerical investigation of spectral and temporal properties of the narrow-band Ytterbium doped fiber laser. The real time dynamics of quasi-CW radiation is measured for the first time to our knowledge. Result of numerical modelling and experiments are in good quantitative agreement.

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