NOLM-Based Mode-Locked Bismuth-Doped Fiber Laser at 1.31 Microns

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Ps and sub-ps lasers at 1.3 microns have a lot of practical applications especially in medicine due to moderate absorption of biological tissues near this wavelength. For a long period of time only Cr:forsterite [1] and ZBLAN fibers doped with ions of Pr [2] were used in mode-locked lasers at 1.3 microns. Fortunately, recent development of phosphorosilicate fibers doped with bismuth allows one to create ultra-fast lasers based on them [3]. This kind of active media is of great interest because of silica-based fibers are much more convenient for manipulation and splicing with all fiber components, moreover lasers based on Bi-doped fibers posses high efficiency and have quite broad absorption band for pumping and quite low lasing threshold.

In this work we report on the all-fiber ultrashort pulse laser based on phosphorosilicate fiber doped with bismuth operating at 1310 nm and demonstrating the best characteristics of pulse energy and duration among existing fiber analogous.

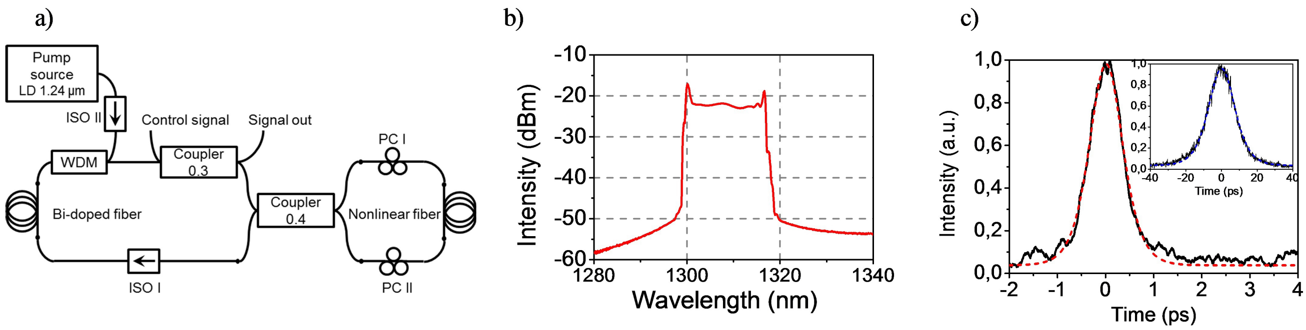

Figure 1: a) – The F8L scheme of the pulsed bismuth doped fiber laser. b) – Spectrum of solitons. c) – Autocorrelation functions of the pulse signal obtained at the output of laser (inset) and after compressor

Optical scheme and components features. The setup uses figure of eight laser scheme (F8L) with nonlinear optical loop mirror (NOLM) and operates in regime of dissipative solitons (DS) (Fig. 1a). The fiber core is made of phosphosilicate glass with the cutoff wavelength at 0.99 μm. The index difference between the core and the cladding is $\Delta n = 5{\times}10^{-3}$. The concentration of bismuth ions in the core glass is below 0.1 wt.%. When pumping at 1.24 μm the small signal gain at the 1.31 μm is 0.17 dB/m. The active media was pumped with commercially available single-mode laser diode with power of up to 350 mW and Raman fiber laser with output power up to 600 mW both operating at 1.24 μm.

Results. Adjusting the polarization controllers (PC) we achieved cw lasing. To start the mode-lock regime the initiation process was required. The laser configuration yielded pulses as short as 11.3 ps assuming sech. profile (Fig. 1c, inset). Fig. 1b shows output spectrum of the laser. The repetition rate was 3.6 MHz and an average power of the signal was about 6 mW that corresponds to pulse energy of $\sim$1.65 nJ. The spectrum of output signal has specific steep edges characteristic to DS lasers with quite wide spectral width of about 17 nm if the side peaks induced by self-phase modulation (SPM) are not taken into account. Time-bandwidth product of the pulses was 33.5 indicating a strongly-chirped solitons generation. Therefore we tried to compress the pulses. Because of silica fibers have too small anomalous dispersion in the region of 1.3 μm, for pulse compression we used pair of diffraction gratings with 600 lines per mm. By means of them the chirped pulses was compressed down to 530 fs (Fig. 1c). The output signal of the laser could also be passed through bismuth fiber amplifier that allows reaching average power of 30 mW that match to 8.3 nJ pulse energy. The growth of the power was accompanied with extension of the spectrum width and appearing of more pronounced SPM peaks. Amplified pulses showed a compression extent analogous to the original one except for the fact that these pulses had higher pedestal. We assume that is due to the effect of SPM which grows with the signal power.

In summary, we demonstrated the mode-locked bismuth fiber laser built using the F8L scheme with NOLM operating near zero-dispersion region for silica based fibers using DS regime.

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