Energy scalable passively mode-locked mid-IR Tm-fiber laser

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Recently a lot of interest is drawn towards development of high-energy Tm-fiber lasers, operating around 2 µm – an attractive wavelength for LIDAR, ranging and remote-sensing applications, where µ to mJ pulse energies are required. Such energy frontiers are usually achieved by the chirped pulse amplification outside an oscillator [1]. However, our approach - direct µJ femtosecond pulse generation in the positive dispersion regime - does not require external amplification. This radically different from traditional soliton formation mechanism was first suggested by us in [2] and later further developed in [3]. Here we present the results of theoretical and experimental analysis of the mode-locked Tm-fiber laser, based on a highly Ge-doped fiber. The study paves the route towards pulse energy scaling in the positive dispersion regime from alternative LMA fibers.

The simulations based on the generalized Ginzburg-Landau model [1] allow obtaining two-dimensional master diagrams, which represent the stability conditions of a fiber oscillator (Fig. 1). The corresponding dimensionless parameters are $c = \alpha \gamma / |b| \zeta$, $b = \gamma / \zeta$ and the energy $E$ is normalized to $\sqrt{\alpha / \zeta}$ ($\beta$ is the net-dispersion, $\gamma$ is the net self-phase modulation coefficient, $\zeta$ and $\mu$ are the inverse saturation power and the modulation depth of a polarization modulator, respectively; $\alpha$ is the squared inverse bandwidth of a spectral filter). Some reachable energies are subscribed for both anomalous (ADR) and normal dispersion (NDR) regimes (Fig. 1, curves correspond to the stability thresholds). Scaling properties of the NDR (magenta curve) excels substantially those of the ADR (blue curve). It can be seen that there exists the asymptotical branch for the NDR: $c \to \text{const}$ for $E \to \infty$. As a result, such a regime is perfectly scalable by scaling: i) gain saturation energy (e.g. fiber length scaling) and/or ii) mode area. For the case of Fig. 1, the small fiber mode areas are assumed to be $\approx 10^{-20}$ µm². However, our analysis demonstrates that the LMA fibers (e.g. similar to LMA35) fabricated from SF66, AMTIR (for the NDR) or silica (for the ADR) can provide substantial growth of pulse energy, especially for NDR.

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References