Supplemental Information

Mode-locked 2.8 μm fluoride fiber laser: from soliton to breathing pulse

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**1 Numerical simulation**

The propagation of the optical-field envelopes *τ* and *τ* inside the fiber is governed by the coupled Ginzburg–Landau equations. In a time frame moving with the group velocity of the signal, the coupled Ginzburg–Landau equations can be expressed as follows:

, (1)

(2)

Here, and are the slowly varying amplitudes of the pulse along the x and y directions, respectively; the propagation coordinate; and the time-delay parameter. and are the group velocity dispersion (GVD) and third-order dispersion (TOD), respectively. The propagation-constant difference is defined by

, (3)

where and are, respectively, the refractive indices in the x and y directions and is the central wavelength. The gain coefficient is given in the frequency domain by

, (4)

where is the small signal gain coefficient, the intracavity pulse energy, the gain saturation energy, the central angular frequency, and the gain bandwidth. The intracavity pulse energy is given by

. (5)

The nonlinearity parameter is given by

(6)

where is the Kerr coefficient, the speed of light, and the effective mode area in the fiber.

The parameters used in the numerical simulation agree with the experimental conditions. The following parameters were used: for the ZBLAN fiber, a fiber length of 2.3 m, fiber core diameter of 16.5 μm, NA of 0.12, small signal gain of 8 m-1, gain saturation energy of 1.15 nJ, gain bandwidth of 120 nm, central wavelength of 2.78 μm, propagation-constant difference of 0.72, GVD of −83 fs2/mm, TOD of 476 fs3/mm, and Kerr coefficient of 2.1×10-20 m2/W [18, 22]; for the Ge rod, a length of 6 cm, GVD of 1685 fs2/mm, and TOD of 3376 fs3/mm [19]; and an OC transmittance of 40%. By choosing suitable waveplate orientations, stable mode-locking is achieved in the numerical simulation, and the results are shown in Fig. 5.

**2 Supplementary** **experimental** **results for positive net intracavity dispersion**

While the net intracavity dispersion was positive, the mode-locked Er:ZBLAN fiber laser produced picosecond pulses. For example, with the use of a 20-cm Ge rod to compensate for the anomalous dispersion of a 3.0-m-long Er:ZBLAN fiber at a net intracavity dispersion of +0.087 ps2, the laser generated 1.78-ps pulses with a spectral bandwidth of 18 nm, as shown in Fig. 1S.



**Fig. 1S** (a) Autocorrelation trace and (b) spectrum of mode-locked pulses from an Er:ZBLAN fiber laser when the net intracavity dispersion was +0.087 ps2.