Electronic Supplementary Information (ESI†)

Efficient continuous-wave and short-pulse Ho^{3+}-doped fluorozirconate glass all-fiber lasers operating in the visible spectral range

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1. The comparison of temporal behaviors of the green Ho:ZBLAN all-fiber lasers using the output mirror M2 (*i.e.*, 10% transmission), with the active fiber lengths of 6 cm and 12 cm, respectively.

At the available P_{in} range, the green all-fiber laser with 6-cm-long active fiber always operates in CW regime, despite manipulating the PC position in the cavity. For instance, an oscilloscope trace at P_{in} = 150 mW is recorded, as shown in Fig. S1(a). No regular pulse train was observed, indicating the CW operation. In contrast, the green all-fiber laser with 12-cm-long active fiber could oscillate in self-pulsing mode. Stable self-Q-switched operation initiated at P_{in} = 217 mW. Here, we recorded the output oscilloscope trace at P_{in} = 231 mW with a pulse repetition rate of 84.39 kHz, showing stable Q-switching operation.

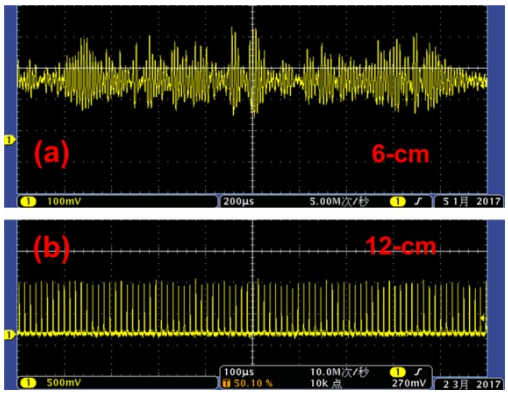

Figure S1. Comparison of green laser output pulses for (a) 6-cm-long active fiber at P_{in} = 150 mW and (b) 12-cm-long active fiber at P_{in} = 231 mW, respectively.

2. Long-term stability of the proposed self-Q-switched green Ho:ZBLAN all-fiber laser based on the output mirror M2 (*i.e.*, 10% transmission) and 12-cm-long active fiber.

Figure S2 shows the long-term stability characterization of the proposed self-Q-switched green Ho:ZBLAN all-fiber laser at P_{in} = 266 mW. One can see in Fig. S2(a), the output pulse train with a repetition rate of 91.36 kHz is exhibited, corresponding to a single pulse duration of 672 ns [see the inset (right) of Fig. S2(a)], that has a symmetric Gaussian-like intensity profile. The repeated pulse repetition rates recorded every 10 minutes over 1 h are plotted in the inset (left) of Fig. S2(a). No significant pulse repetition rate variations were measured. Meanwhile, the repeated output spectra scanned within an hour are depicted in Fig. S2(b), with the lasing wavelengths of 548.1 nm and 549.7 nm, respectively. Neither the central wavelength movement nor the new wavelength component was observed. These results from both cases outlined above indicate the good stability of the proposed green Q-switched all-fiber laser, which is suitable for practical applications.

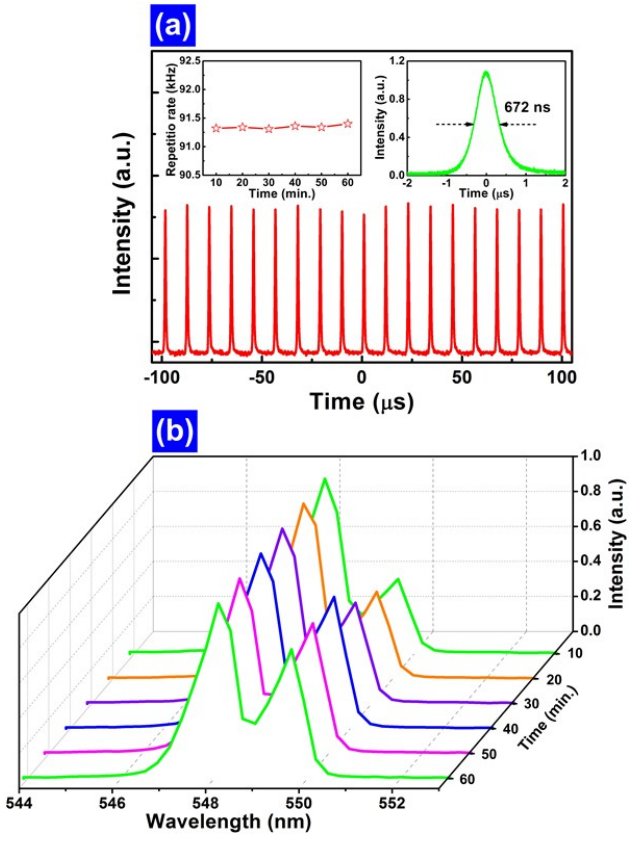

Figure S2. (a) A typical pulse train. Insets: (left) the pulse repetition rates measured across an hour and (right) the corresponding single pulse shape. (b) Output optical spectra recorded under different times.

3. Output temporal characteristics of the self-Q-switched green Ho:ZBLAN all-fiber laser based on the output mirror M2 (*i.e.*, 10% transmission) and 15-cm-long active fiber.

Figure S3 shows the temporal characteristics of the proposed self-Q-switched green Ho:ZBALN all-fiber laser using the M2 (*i.e.*, 10% transmission) and 15-cm-long active fiber. At P_{in} = 376 mW, the output spectrum was measured with a central wavelength of 548.7 nm, as plotted in Fig. S3(a). A magnified image at 548.7 nm is given in the inset of Fig. S3(a), where a measured FWHM was 1.10 nm (*i.e.*, $\delta\lambda$ = 1.10 nm). Meanwhile, we characterize the RF output spectrum. As shown in Fig. S3(b), a ~38 dB SNR is observed at the fundamental repetition rate (f_0) of 96.25 kHz. And inset of Fig. S3(b) depicts the typical pulse train with a time period of 10.39 μs, corresponding to the f_0 = 96.25 kHz, and less than 5% pulse intensity-fluctuation was measured. These results indicate the Q-switching operation is stable. Furthermore, the output pulse characteristics, including average output power, single pulse energy, pulse repetition rate and pulse duration, are investigated. When the pump power is increased from 317 to 397 mW, the change of average output power and single pulse energy with respect to the incident pump power is recorded in Fig. S3(c). The average output power boosts linearly to be ~16 mW and the single pulse energy increases correspondingly to be ~161 nJ. At the same time, the dependence of repetition rate and pulse duration on the incident pump power is presented in Fig. S3(d). The repetition rate increases from 87.56 to 100.3 kHz, while the pulse duration decreases from 628 to 446 ns.

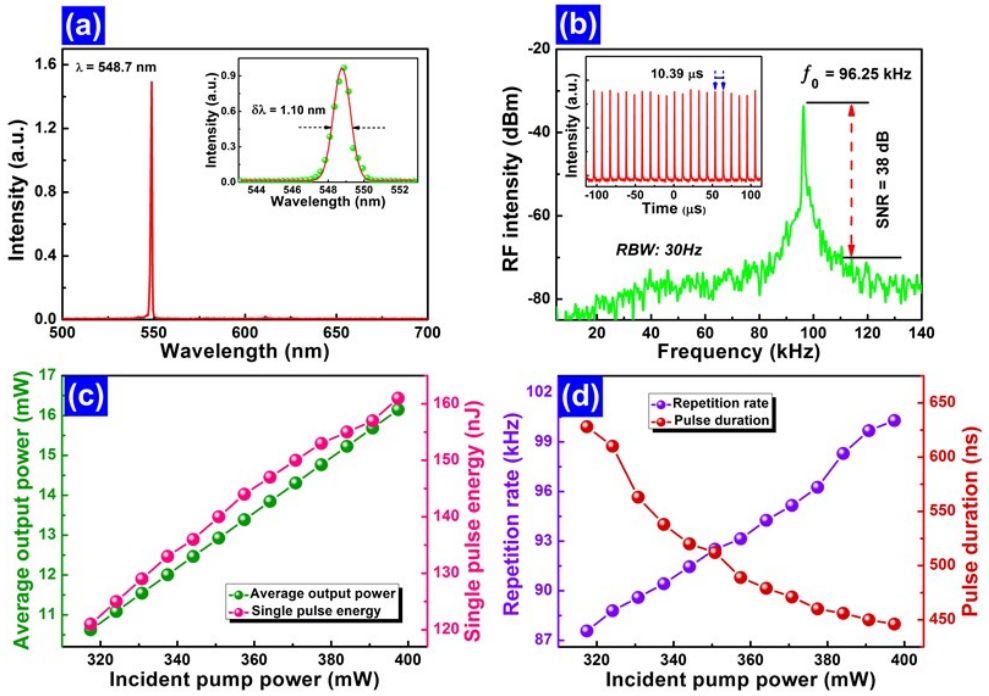

Figure S3. (a) Output optical spectrum. Inset: a zoom-in look at 548.7 nm. (b) RF spectrum at the fundamental frequency of 96.25 kHz. Inset: the corresponding oscilloscope trace. Both are at P_{in} = 376 mW. (c) Average output power and single pulse energy. (d) Repetition rate and pulse duration as a function of the incident pump power.

4. Measured temporal features of the self-Q-switched green Ho:ZBLAN all-fiber laser using the output mirror M1 (*i.e.*, 3% transmission), with the active fiber lengths of 12 cm and 15 cm, respectively.

We investigate the temporal features of the self-Q-switched green Ho:ZBLAN all-fiber lasers based on the output mirror M1 (*i.e.,* 3% transmission) with the active fiber lengths of 12 cm and 15 cm, respectively. At the available Pin range, two types of all-fiber lasers could operate in self-pulsing state. However, compared to both cases of the output mirror M2, these two Q-switching operations behave intensive instability and are not suitable for practical applications. Here, Figures S4(a) and S4(b) exemplify the output pulse features of the self-Q-switched green all-fiber laser for 12-cm-long active fiber at P_{in} = 277 mW. We measured a typical pulse train with a time interval of 10.76 μs, corresponding to a pulse repetition rate of 92.94 kHz, as shown in Fig. S4(a). And the corresponding single pulse profile with a pulse duration 620 ns was given in the inset of Fig. S4(a). Meanwhile, the measured RF output spectrum at the fundamental frequency of 92.94 kHz was shown in Fig. S4(b), indicating a low SNR of ~34 dB. Furthermore, Figures S4(c) and S4(d) present the output pulse features of the self-Q-switched green all-fiber laser for 15-cm-long active fiber at P_{in} = 324 mW. As given in Fig. S4(c) and its inset, a typical pulse train was recognized with a time interval of 10.59 μs (*i.e.*, pulse repetition rate of 94.43 kHz) and a single pulse duration of 608 ns. The corresponding RF spectrum at the fundamental frequency of 94.43 kHz was shown in Fig. S4(d), illustrating a low SNR of ~33 dB.

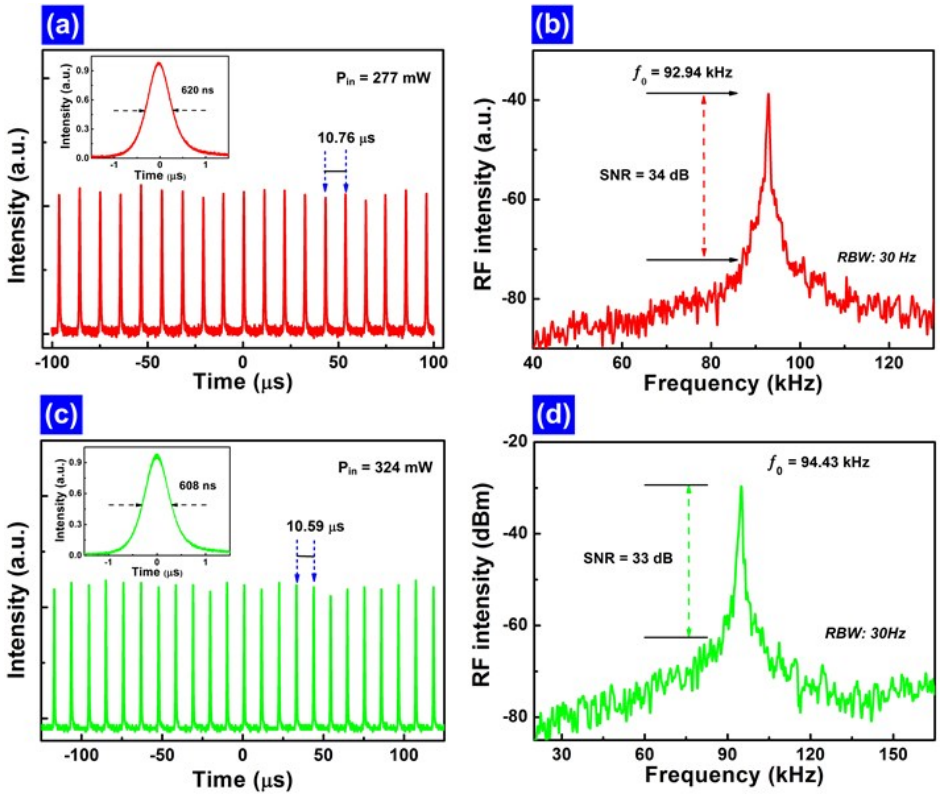

Figure S4. Measure output pulse features of the self-Q-switched green Ho:ZBLAN all-fiber lasers based on the output mirror M1 with (a) and (b) 12-cm-long active fiber, (c) and (d) 15-cm-long active fiber, respectively.