

Single Longitudinal Mode Oscillates in Q-Switched Fiber Laser

Short resonator pushes modes apart, facilitates single-mode operation.

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Q-switched fiber lasers are useful in many applications, including metrology and nonlinear frequency conversion (see, for example, “Two Q-Switched Fiber Lasers Generate Terahertz Radiation” on page 103). Recently, scientists at NP Photonics and at the University of Arizona, both in Tucson, have demonstrated what they believe is the first reported actively Q-switched, all-fiber laser in the important 1- μm spectral region. They also believe that the maximum repetition frequency of their laser, 700 kHz, is significantly faster than the frequency achieved in similar lasers reported to date.

The scientists fabricated their laser with ytterbium-doped phosphate-glass fiber because phosphate glass can accept higher Yb doping (in this case, 6 percent by weight) than conventional silica glass, they could reduce the length of active fiber to 2 cm. Together with the fiber Bragg gratings that served as resonator mirrors, the total resonator length was 3.5 cm, corresponding with a longitudinal-mode spacing of ~ 3 GHz (Figure 1). This wide spacing enabled the researchers to force single-longitudinal-mode oscillation by proper thermal adjustment.

The nature of the fiber Bragg gratings in polarization-maintaining fiber forced polarized operation of the laser and provided the mechanism for Q-switching. The high-reflectance grating (Figure 1 left) was fabricated in normal (i.e., not polarization-maintaining) fiber and had a bandwidth of ~ 0.31 nm. The grating that served as the output coupler was fabricated in polarization-maintaining fiber and reflected about 50 percent of the incident light with a bandwidth of ~ 0.03 nm.

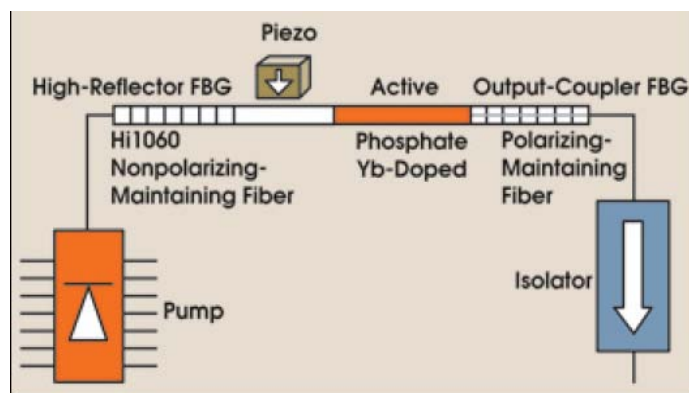


Figure 1. An all-fiber laser was fabricated from a 2-cm length of Ybdoped phosphate-glass fiber and two fiber Bragg gratings (FBGs) that served as resonator mirrors. Images reprinted with permission of Optics Letters.

Because the fiber was polarization maintaining, the reflectance peaks for the two orthogonal polarizations were offset by ~ 0.3 nm from each other. Thus, the scientists could arrange for only one polarization to be reflected from both gratings, and only that polarization oscillated in the resonator.

With the laser forced to oscillate in a single polarization, any intracavity birefringence would cause a loss to that polarization and spoil the cavity's Q. The scientists introduced a time-dependent birefringence — that is, they Q-switched the laser — by applying pressure to the side of the fiber with a piezoelectric transducer. The pressure, applied at a 45° angle with respect to the cavity's polarization, caused as much as 50-dB intracavity loss.

The scientists studied several aspects of the laser's performance as a function of pulse repetition frequency. The laser produced shorter pulses at lower repetition rates, presumably because a longer interval between Q-switched pulses allowed the population inversion to build to a higher level. Stimulated emission generally produces shorter pulses with higher population inversions.

As the interval between pulses grows significantly longer than the Yb spontaneous lifetime, however, one would expect the pulse duration to be relatively independent of repetition frequency because the population inversion saturates, losing energy to spontaneous emission as fast as it gains energy from the pump source. This is the behavior the scientists observed (Figure 2 left).

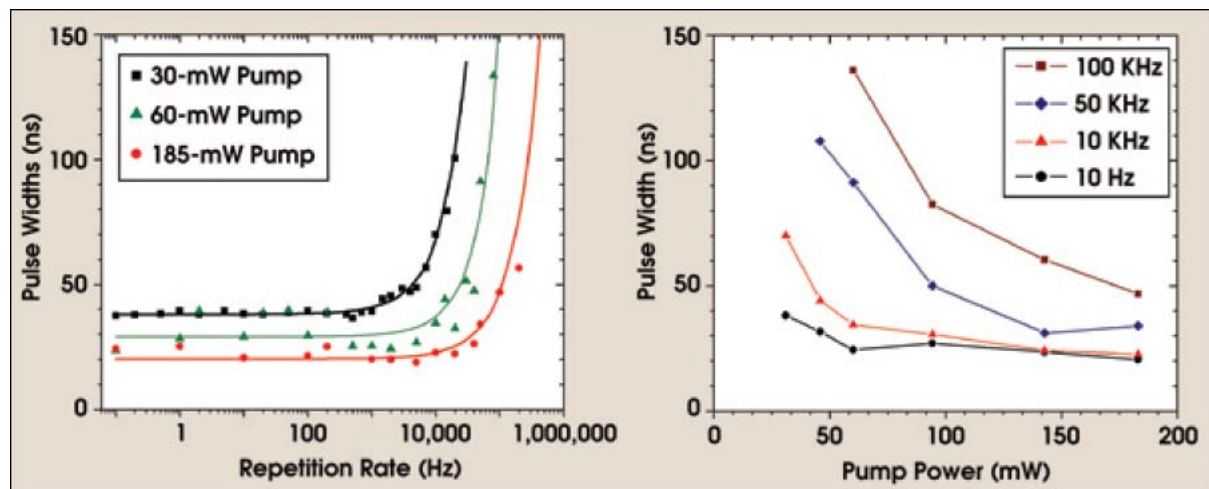


Figure 2. The pulse duration increased with increasing repetition frequency at higher frequencies but was relatively constant at low frequencies (left). The pulse duration decreased with increasing pump power at all repetition frequencies (right).

As expected, the pulse duration decreased with increasing pump power because more pump power means more population inversion, and more population inversion means shorter pulses (Figure 2 right).

The average power of the laser saturated at a fairly steady value at high repetition frequencies. At these high frequencies, the interval between pulses is shorter than the spontaneous lifetime, so relatively little population inversion is lost to spontaneous emission between pulses. At lower frequencies, however, the average power diminishes with lower repetition frequencies because the interval between pulses exceeds the spontaneous lifetime, and increasing portions of the population inversion leak off in spontaneous emission. In the laboratory, the scientists observed a

maximum average power of 31 mW at the maximum repetition frequency of 700 kHz and the maximum pump power of 185 mW.

Experimentally, the laser's pulse energy was fairly constant at low repetition frequencies but decreased with frequency at higher frequencies. At higher frequencies, where the average power is independent of frequency, the same average power must be divided among more pulses, resulting in lower energy per pulse as the frequency increases. At lower frequencies, where average power increases with frequency, that increase balances the increasing number of pulses, so that each pulse gets roughly the same amount of energy, regardless of repetition frequency. The peak power of a pulse is proportional to the ratio of the pulse energy to pulse duration. At high frequencies, the pulse duration is increasing with frequency, and the pulse energy is decreasing, so one would expect the peak power to decrease with frequency. That is the behavior the scientists observed (Figure 3). At lower frequencies, where both pulse energy and pulse duration were constant, the peak power also was constant.

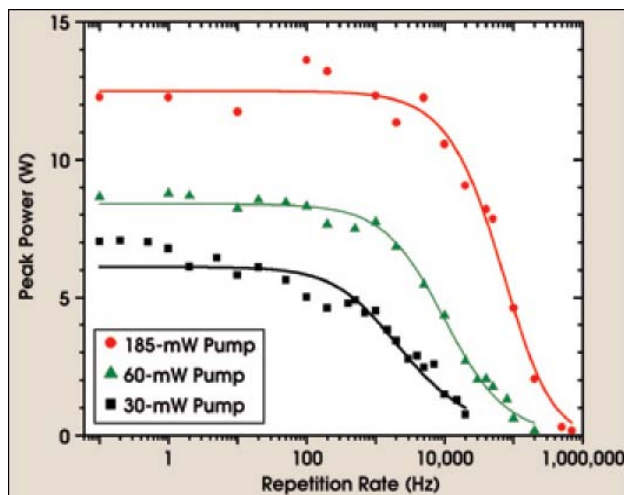


Figure 3. The peak power, important in many applications of *Q*-switched lasers, was independent of repetition rate at low frequencies but decreased at higher frequencies.

The scientists forced the laser to oscillate in a single longitudinal mode by thermally tuning the reflectance peaks of the two fiber Bragg gratings. The output coupler's bandwidth was ~ 0.03 nm, the other grating's bandwidth was ~ 0.3 nm, and the longitudinal modes were separated by ~ 0.01 nm. By carefully setting the peak of the narrowband grating at the edge of the wideband grating, the researchers provided sufficient discrimination to allow only one mode to reach threshold.