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DIODE PUMPED, TUNABLE, Q-SWITCHED Tm:glass FIBER LASER

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Abstract

A tunable, Q-switched Tm:glass fiber produced >100 mW, >40 μJ/pulse at 2.8 kHz, in a single pulse and 300 mW in multiple pulses. Wavelength and multiple pulsing depended on several pumping and Q-switching parameters that are explained here.

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Summary

The capabilities of the diode pumped, Tm:glass fiber laser have now been extended to include both tuning and Q-switching. Previously, a high power, Tm:glass, fiber laser demonstrated wide tuning around 2.0 μm [1]. Now, a diode pumped, Q-switched, silica based glass fiber, laser produced >100 mW, >40 μJ/pulse at 2.8 kHz, in a single pulse and 300 mW in multiple pulses with a beam quality approaching diffraction limits. Slope efficiencies for continuous and 2.8 kHz Q-switched operation are about 0.20 and 0.16, respectively. Tuning has been demonstrated between 1.91 and 2.01 μm. With no tuning element, the laser wavelength depended on the pump power, which pulse in the multiple pulse train, and the time interval between Q-switching. This can be understood by using the principle that the mode with the highest gain, rather than the lowest threshold, dominates [2]. With a grating tuning element, the wavelength stabilized and, with a better Q-switch, much better performance is expected.

Tm:glass fiber lasers were selected for Q-switching based on the measurement of several spectroscopic parameters including the emission cross section and upper laser manifold lifetime. With a small emission cross section, for example $0.13 \bullet 10^{-24}$ m^2 at 1.96 μm, more energy can be stored allowing a higher Q-switched energy per pulse. Because a plethora of levels exist in the upper and lower laser manifolds and the wide lines associated with a glass laser material, continuous tuning is possible. A long lifetime, measured as 0.54 ms, provides low thresholds and abets efficient operation at lower pulse repetition frequencies.

Fiber lasers provide high gain despite the low emission cross section by providing long lengths; fiber lengths in excess of 4.0 m were used here. Long fiber lengths with an index of refraction of 1.45, provide long round trip time intervals. In turn, this implies long pulse evolution time intervals and thus allows the use of slowly opening Q-switches. A rotating chopper at an internal focus in the resonator was used here because of availability. Based on the finite width of the chopper blade, a optimum beam radius at the focus was calculated as about 20 μm, and the resonator was designed accordingly. To prevent quasi continuous lasing, thin slits were used. An acousto optic Q-switch would yield faster openings, higher pulse repetition frequencies, and thus better performance.

A single bar laser diode pumped the Tm:glass fiber laser, Figure 1. Pump radiation from the laser bar was collimated with a fiber lens, circularized with a pair of mirrors, and focused into the double clad fiber [1]. A dichroic mirror, before the focusing lens, separated the laser beam from the pump beam. A double clad Tm:glass fiber, with 20 μm core and 200 μm inner cladding diameters, was used. At the other end, a lens imaged the fiber output to a focus. A 25 mm radius of curvature mirror or a second lens and a 600 g/mm grating reflected the radiation.

Differences between continuous laser and Q-switched slope efficiencies are explained by the storage efficiency. Typical performance for continuous and Q-switched laser output power versus incident pump power appears in Figure 2. While 2 pulse repetition frequencies appear, 5 were actually evaluated. Slope efficiency for the continuous case is nearly 0.20. At 2.8 kHz, slope efficiency is 0.16 at low powers where a single Q-switched pulse is produced. As the pump power increases, the first pulse begins to occur before the chopper is fully opened, decreasing the slope efficiency. With further power increases, the output appears in 2 pulses, in 3 and eventually 4 pulses.

Multiple pulses at higher pump could be caused by: higher order transverse modes, relaxation oscillations, laser gain differences as a function of wavelength, inhomogeneous spectral hole burning, or slow opening of the Q-switch. Several tests were conducted to determine the origin of multiple pulsing and results indicate that the slowly opening Q-switch is the cause. With a faster Q-switch, multiple pulsing would be eliminated and the performance would increase greatly as Q-switch losses were minimized; it would follow the slope efficiency of first pulse.

The initial slope efficiencies versus the time interval between Q-switching were fit to a slope efficiency curve, that is $(\tau_2/\Delta t)(1-\exp(-\Delta t/\tau_2))$. Curve fitting yields a value for the upper laser manifold lifetime, τ_2, of 0.48 ms. This value is a little shorter than the measured lifetime and is attributed to amplified spontaneous emission. Q-switched pulse length showed the expected decrease with increasing pulse energy, decreasing to less than 200 ns at the highest single pulse energy.

Wavelength of the Q-switched laser varied with pump power; which pulse in the multiple pulse train; and the time interval between the Q-switched pulses. Wavelength variation of the Q-switched pulses can be understood in terms of 2 effects. First is the mode having the highest gain, rather than the lowest threshold, dominates [2]. Second is a variation of resonator losses with wavelength. Although water absorption around 1.9 to 2.05 μm in fused silica is small, a small absorption over a 4 m length makes a difference. Because of these small absorptions, tuning can be discontinuous but generally proceeds to shorter wavelengths as the stored energy increases. Data on the laser wavelength versus pump power, position of the pulse, and time interval between pulses all indicate that as the stored energy increases, the wavelength becomes shorter.

1. R. A. Hayward, W. A. Clarkson, P. W. Turner, N. P. Barnes, J. Nilsson, A. B. Grudinin, and D. C. Hanna, CLEO Conference, 2000
2. C. J. Lee and N. P. Barnes, IEEE J. Quant. Elect. QE-32, 105 (1996)

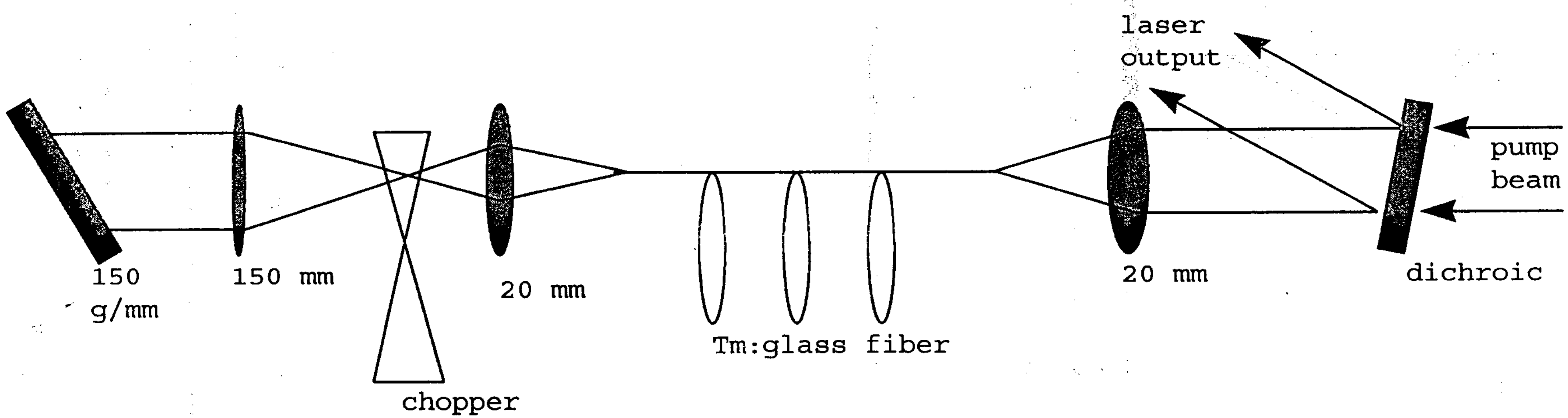
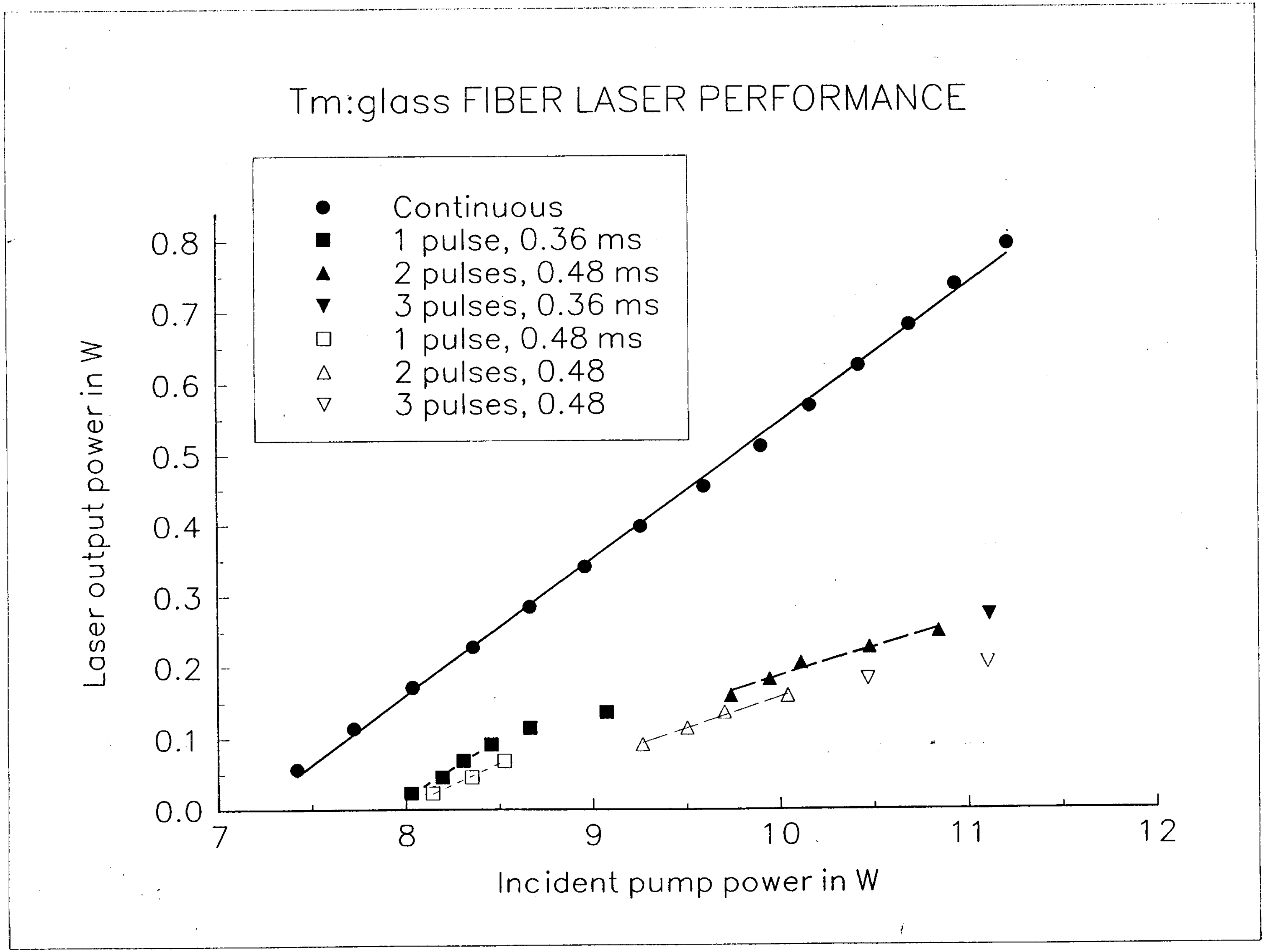


Figure 1. Experimental arrangement with grating in position


Tm:glass FIBER LASER PERFORMANCE
Continuous
1 pulse, 0.36 ms
2 pulses, 0.48 ms
3 pulses, 0.36 ms
1 pulse, 0.48 ms
2 pulses, 0.48
3 pulses, 0.48
Laser output power in W
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
7
8
9
10
11
12
Incident pump power in W