Passive Harmonically Modelocked Fiber Laser using a Tapered Er/Yb Waveguide Amplifier and a Saturable Bragg Reflector

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Abstract: Passive harmonic modelocking of 11 evenly spaced pulses is demonstrated in a cavity utilizing a tapered Er/Yb waveguide amplifier and single mode fiber. An autocorrelation measurement yields 770 fsec pulses with a 0.33 time-bandwidth product.

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The growing interest in compact, ultrafast sources has led to the investigation of using phosphate glass Er/Yb (codoped) waveguide amplifers to function as the gain medium inside fiber lasers.[1, 2] These amplifiers can be doped more heavily than fiber because the clustering effect of the rare-earth ions occurs less frequently in phosphate glass. Thus the small signal gain can exceed 2 dB/cm, about five times larger than the gain exhibited by regular codoped fiber. The higher gain is attractive for reducing the cavity length, hence leading to higher repetition rates. Saturable Bragg reflectors (SBRs) provide simple passive mechanisms for modelocking soliton fiber lasers [3, 4], and this technique has been extended to the use of waveguide amplifiers to generate picosecond pulses[1]. We extend this work of using SBRs in waveguide laser by reporting soliton harmonic modelocking of sub-picosecond pulses.

The laser presented here utilizes a recently designed tapered Er/Yb waveguide from Teem Photonics that adiabatically changes the mode size from 6.5 μm to 9 μm over a 2 mm distance near one of the facets. This allows for improved coupling to single mode fiber, while still maintaining single mode waveguiding and optimal overlap of pump (980 nm) and laser wavelengths over most of the waveguide. The processing technique forms the waveguides using titanium indiffusion on the codoped, phosphate glass substrate. The doping concentration of $2\text{x}10^{26}$ Er ions/m^3 and $3\text{x}10^{26}$ Yb ions/m^3 corresponds to a small signal gain peak of 13.6 dB at 1535 nm for the 4.8 cm waveguide. A group velocity dispersion measurement yielded D = -5 ps/nm/km at 1550 nm.

A dielectric coating of high reflectivity at 1550 nm and high transmission at 980 nm deposited on the facet with 6.5 μm mode size forms one end of the laser cavity. As shown in the diagram in Figure 1 a fiber to supply pump radiation and collect lasing radiation was brought close to the mirrored coating. To avoid damaging the delicate coating the fiber was kept about 5 μm from the facet, resulting in an additional 3 dB estimated loss incurred in coupling the laser power into the fiber.

A normal dispersion waveguide will not alone support harmonic modelocking of soliton pulses, so single mode fiber forms the remainder of the laser cavity, as Figure 1 details. The 9 μm mode size facet of the waveguide is angle polished at 8°and the fiber is also angle polished at 8°; the two facets are butt coupled together. The other end of the fiber directly contacts the single quantum well SBR. Cavities with between 1 and 2 m of fiber are used to compensate dispersion and to demonstrate the working principal of achieving harmonic modelocking.

An autocorrelation measurement of 770 fsec pulses is presented in (b) of Figure 2. The low output power necessitated an autocorrelator detection method using a 1.3 μm quantum well laser for two-photon absorption. The corresponding spectral measurement in (a) yields a time-bandwidth product of 0.33 that is within 5 % of true fundamental N=1 solitons. The cross-hatched points in (a) show a close sech^2 fit to the spectrum. Dispersive waves account for the side bands in the spectrum.

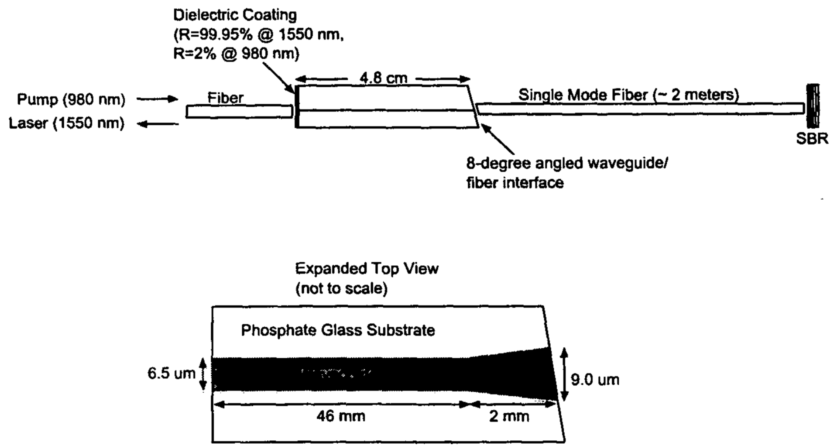

Fig. 1. Schematic of the waveguide laser cavity (top). The fundamental repetition rate of the cavity is 47.87 MHz. Exaggerated structure of the tapered waveguide amplifer (bottom).

We observe harmonic modelocking at 527 MHz with 11 pulses in this cavity, as indicated by the RF spectrum given in (d) of Figure 2. The SBR used in this waveguide laser is identical to the one used in the anomalous regime fiber laser that also produced nearly transform limited pulses in [3]. The corresponding optical spectrum in (c) of Figure 2 exhibits 4.7 nm of (FWHM) bandwidth centered at 1557 nm. Using the measured time-bandwidth product above yields approximately 560 fsec pulses. In addition to the harmonic operation and the time-bandwidth measurement above, the optical spectrum in (c) also fits to within 0.6% mean-square error of a sech^2. Harmonic modelocking with spectral widths exceeding 6 nm were observed as well, though with fewer pulses. The output pulse energies of 18.6 fJ owe largely from the resonator's highly reflecting output mirror and the coupling loss mentioned above.

Progress on achieving harmonic modelocking in a shorter cavity with less single mode fiber seems optimistic, and the shortest obtainable cavity satisfying the dispersion requirement should yield fundamental repetition rates in excess of 300 MHz. Future work may also involve engineering the tapered waveguide geometry to support anomalous dispersion.

References

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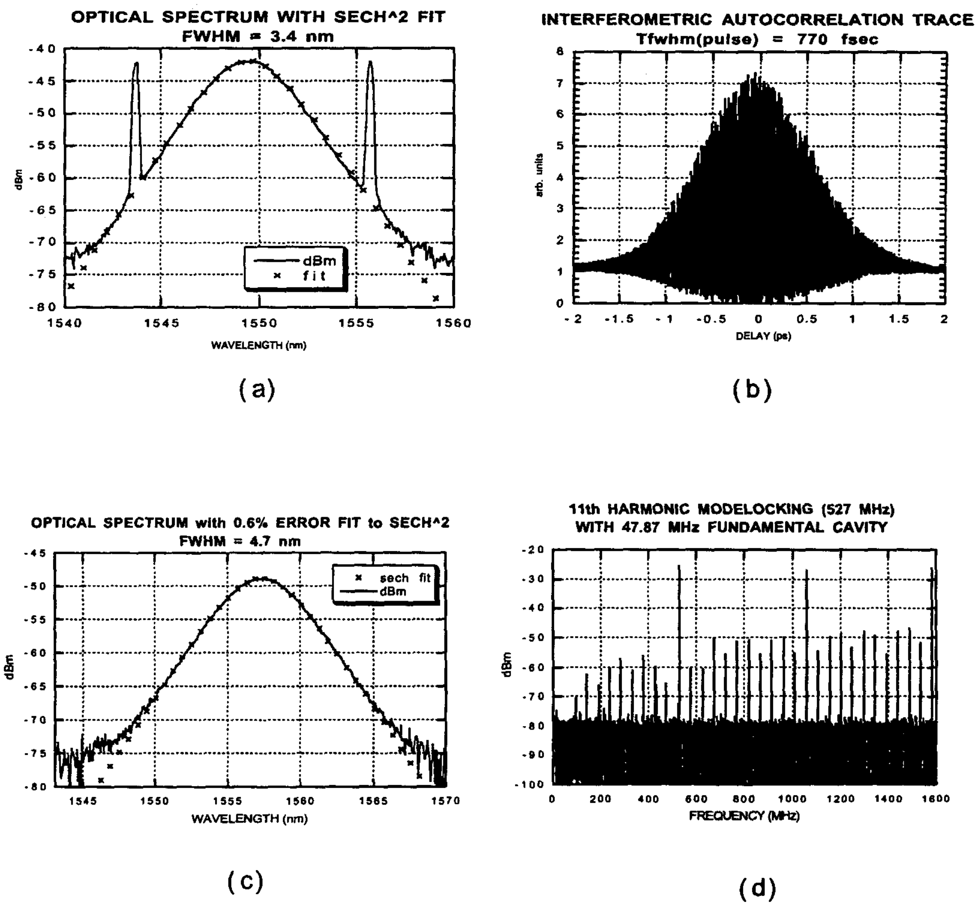

Fig. 2. The data in (a) and (b) represent the autocorrelation and spectral measurements yielding a 0.33 time-bandwidth product with 770 fsec pulses. The optical spectrum in (c) is taken while the laser is running harmonically with 11 pulses, as the RF spectrum plot in (d) shows. The optical spectrum in (c) corresponds to 560 fsec pulses when using the above time-bandwidth product 0.33.