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High Repetition Rate, High Average Power, Femtosecond Erbium Fiber Ring Laser

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Abstract: A 301 MHz fundamentally mode-locked erbium fiber ring laser generating 108 fs pulses is demonstrated. Novel combination of gain fiber with anomalous group-velocity dispersion and intra-cavity silicon with normal group-velocity dispersion yields a stretched-pulse operation.

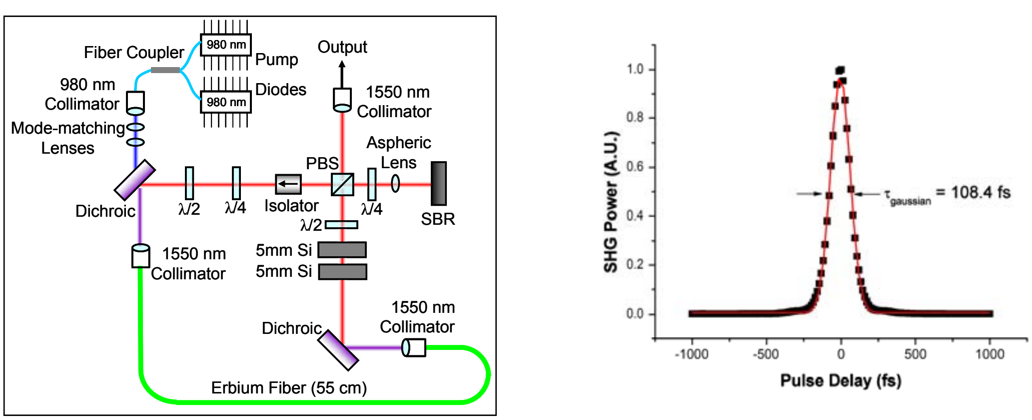
OCIS codes: (140.7090) Ultrafast lasers; (140.3510) Lasers, fiber

1. Introduction

Femtosecond lasers operating near 1550 nm wavelength are important sources for high speed optical communications, frequency metrology, and time resolved spectroscopy. To enable ultrashort pulses, both polarization additive-pulse mode-locking (P-APM) [1] and/or saturable Bragg reflector (SBR) mode-locking [2,3] can be used. These schemes have been applied successfully to soliton [4-6,8] and stretched-pulse [7] fiber lasers. A ring laser taking advantage of both mode-locking mechanisms was previously reported [8]; this paper reports a system that scales the repetition rate beyond 300 MHz using a novel design. This is the first time to our knowledge that a fundamentally mode-locked erbium fiber ring laser has exceeded 300 MHz while maintaining high output power.

2. Laser Design

The laser, illustrated in Figure 1 a), is pumped by two, 750 mW, 980 nm diodes that are polarization multiplexed to output up to 1.2 W. The pump light is coupled into the cavity via free space optics to avoid the need of fiber couplers that would extend the overall cavity length. The gain fiber is pumped through a short-wave-pass 980 nm/1550 nm dichroic mirror. The second short-wave-pass dichroic allows unabsorbed pump to exit the cavity, and the anti-reflection coated silicon flats ensure that no pump light will interfere with SBR operation. The half-wave plate (HWP) controls the output coupling at the polarization beam splitter (PBS). The PBS acts both as the output coupler and the polarization-dependent loss mechanism. The vertically polarized (relative to the optical table) portion of the beam enters the linear arm of the cavity, and is focused on the SBR by an aspheric lens. The linear path includes a quarter-wave plate (QWP) oriented so that the vertically polarized beam returns to the PBS horizontally polarized. After the PBS, a polarizing isolator ensures unidirectional operation. Finally, a HWP and QWP allow control of the polarization state that is launched into the gain fiber.



a) b)

Figure 1. a) Compact cavity mode-locked fiber laser design, b) autocorrelation data with Gaussian fit

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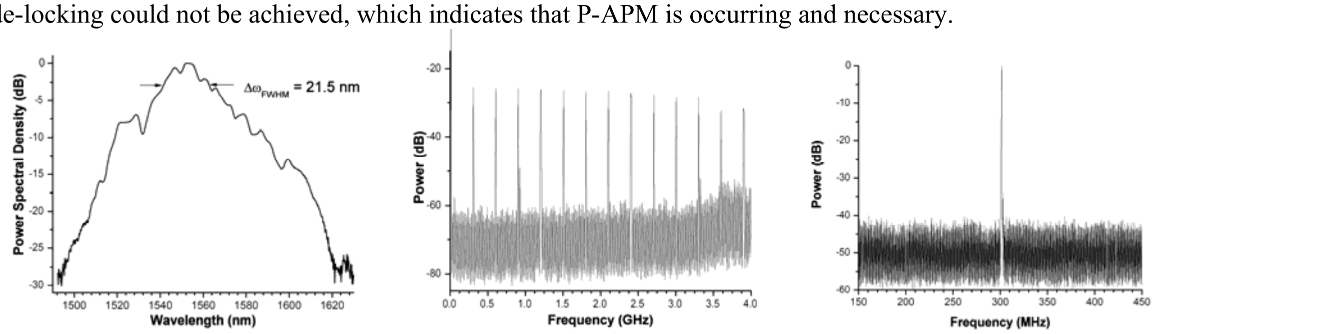
The laser was designed to reduce the free space cavity length down to 16 cm, including the double pass in the linear section. This allowed for longer lengths of gain fiber, which enables higher powers and repetition rates.

In typical stretched-pulse erbium fiber ring lasers [7] the normal group-velocity dispersion (GVD) gain fiber is balanced by anomalous GVD single-mode fiber. The net cavity GVD is small, but the alternating sign of the GVD causes the pulse width to stretch and compress dramatically as it traverses the cavity. Alternatively, this design balances the gain fiber's anomalous GVD with the large normal GVD of silicon flats. This enables stretched-pulse operation at a higher repetition rate and accommodates a longer gain fiber length to maintain higher output power.

3. Results and Discussion

Mode-locking is achieved through a hybrid scheme that employs a SBR to initiate and P-APM to sustain. The laser is self-starting and stably mode-locks with a SBR mirror in the linear arm. Because the laser does not mode-lock when the SBR is replaced by a silver mirror, the SBR must enable the self-starting. When the polarization launched into the gain fiber is approximately in a linear state, thereby minimizing the nonlinear polarization rotation, mode-locking could not be achieved, which indicates that P-APM is occurring and necessary.



a) b) c)

Figure 2. a) optical power spectrum, b) detected RF mode beats, c) detected fundamental RF mode

Figure 1 b) provides an autocorrelation and Gaussian fit of the shortest observed pulse, which corresponds to a 108 fs pulse. This was obtained using -11,236 fs^2 of GVD to compensate the output pulse chirp. Measurements of pulse duration versus compensating GVD indicate that further optimization should yield pulses as short as 86 fs. Figure 2 a) shows the measured optical power spectrum, which is consistent with a pulse as short as 84 fs. The absence of resonant sidebands and the significant normal chirp of the output pulses indicate that the laser is operating in the stretched-pulse regime.

Figure 2 b) shows the RF spectrum of the laser output. The flat spectral envelope, combined with the smooth optical spectrum verifies single-pulse operation. Figure 2 c) shows the 301 MHz fundamental mode beat, which displays greater than 40 dB of noise suppression and provides further evidence of a clean, single-pulsing mode-locked state. Combined with the 61.1 mW of measured output power, a pulse energy of 203 pJ is demonstrated.

In conclusion, we have demonstrated a fundamentally mode-locked erbium fiber ring laser operating at a repetition rate of 301 MHz, with a pulse energy of 203 pJ, a pulse duration full-width half-maximum of 108 fs and an average output power of 61.1 mW.

4. References

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