Cladding-pumped passively mode-locked femtosecond fiber lasers

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Many currently pursued applications of femtosecond erbium fiber lasers would greatly benefit from the availability of higher pulse energies and higher pulse repetition rates than presently available from compact oscillator designs. How-ever, though erbium oscillator designs have been developed that allow the gen-eration of femtosecond pulses with en-ergies in excess of 1 nJ and passive har-monic mode-locking has allowed the extension of achievable repetition rates into the GHz regime, the distribution of such lasers has been limited because they

relied on the use of expensive high-power pump lasers such as MOPAs[1] or Ti:sapphire lasers.[2]

Here we demonstrate for the first time that high-power and high-repetition-rate femtosecond fiber lasers can be con-structed that require only simple broad-area diode-array pump lasers. To allow pumping with diode arrays, the standard single-mode erbium fiber of conventional oscillator designs is replaced with dou-ble-clad erbium/ytterbium fiber. Reliable femtosecond pulse operation is ensured by exploiting nonlinear polarization ev-olution for steady-state pulse shaping in an environmentally stable cavity.[3] Fur-thermore the use of chirped Bragg grat-ings[4] allows the extension of the opera-tion range of these types of laser into the picosecond regime.

The experimental setup for a clad-ding-pumped passively mode-locked fi-ber oscillator is shown in Fig. 1. As the gain medium we used a single 2–4 m length of Er^{3+} /Yb^{3+} doped fiber to allow pumping of Er^{3+} via energy transfer from Yb^{3+}. Additional lengths of standard tele-com or dispersion-compensating (non-soliton supporting) fiber could also be spliced into the cavity, giving fundamen-tal cavity repetition rates between 8 and 30 MHz.

The active fiber was pumped through a dichroic mirror with a standard 1 W, 100 × 1 μm broad-area diode array op-erating at 976 nm. Even with an active fiber length as short as 2.0 m a cw output power up to 40 mW could be achieved.

For pulse start up and to enable soli-ton repulsion in the cavity, we employed semiconductor saturable absorbers with a range of different life-times. A mini-mum pulse width of around 170 fsec (bandwidth-limited) was generated, lim-ited by the relatively narrow bandwidth of the Er /Yb fiber. A typical autocorre-lation and the corresponding pulse spec-trum of a 200 fsec pulse are shown in Fig. 2. At a fundamental repetition rate of 30 Mhz a mode-locked output power up to 3 mW was obtainable, whereas passive harmonic mode-locking at 200 MHz pro- duced an output power of ≈10 mW. The number of pulses (for a fundamental repetition rate of 8.33 MHz) in the cavity measured when ramping the pump-cur-rent up and down is shown in Fig. 3. In this a pump current of 1400 mA corre-sponds to a launched pump power of ≈ 500 mW. A significant amount of hysteresis is observed between up and down-ramping of the pump power. In down-ramping the number of pulses drops reliably one by one. This indicates a well-defined stability range for each repetition rate in the laser.

Due to the small residual pulse jitter in passive harmonically mode-locked la-sers, sidebands in the RF-spectrum show up at the fundamental cavity frequency. We were able to obtain a sideband sup-pression of > = 70 dB, with an estimated corresponding pulse jitter of less than 10 psec.

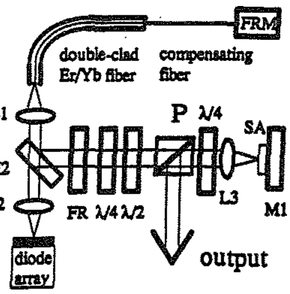

Fig. 1 Setup of a harmonically mode-locked cladding-pumped fiber laser. FR = Faraday rotator, P = polarizer.

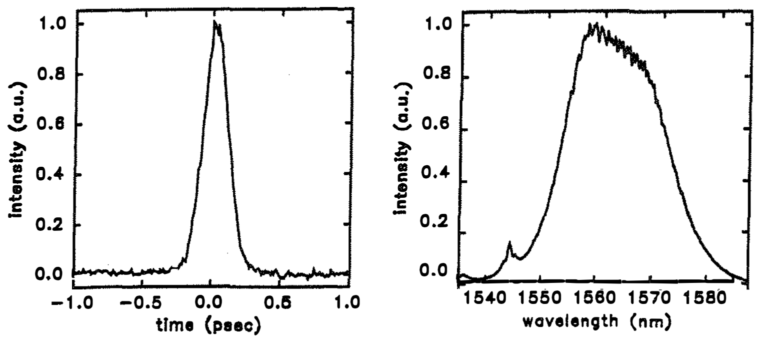

Fig. 2 Typical autocorrelation and pulse spectrum of a generated 200 fsec pulse.

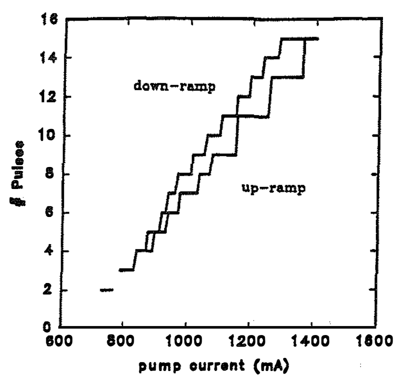

Fig. 3 Number of pulses in cavity for a fundamental repetition rate of 8.33 MHz as a function of slow up-and down-ramping of the pump current.

Finally, we were also able to operate the lasers in the psec regime by adding a chirped fiber Bragg grating to the cavity.

In this case 3 psec, 1 nJ pulses with an average output power of 20 mW were obtained.

1. G. Lenz, *et al.*, Opt. Lett. **20**, 1289 (1995)
2. A. B. Grudinin, *et al.*, Electron. Lett. **29**, 1860 (1993).
3. M. E. Fermann, *et al.*, Opt. Lett. **19**, 43 (1994).
4. M. E. Fermann, *et al.*, Opt. Lett. **20**, 172 (1995).