Passive mode locking of Er^{3+}-doped-fiber lasers using a semiconductor saturable absorber and an integrated Bragg stack

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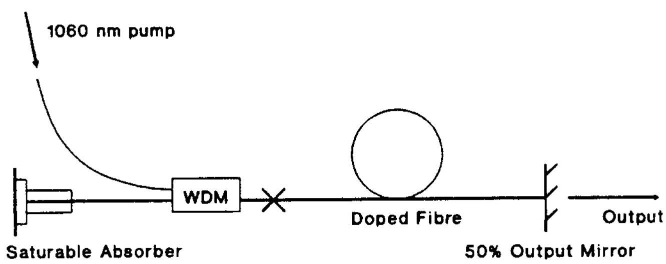
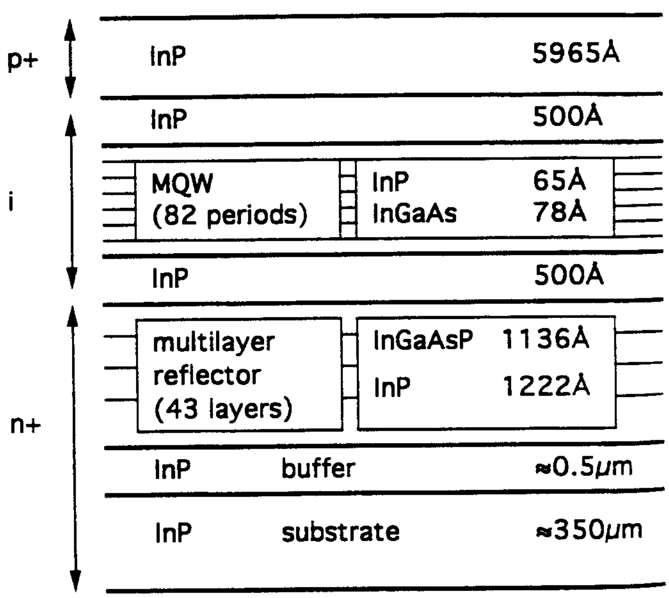
Fiber lasers are attractive candidates for convenient and compact sources of short optical pulses. Various passively mode-locked fiber lasers have been demonstrated by incorporating fiber loops and ring configurations,[1-3] which, however, depend sensitively on the birefringent state of the fiber. A linear cavity design, though, should be impervious to changes in the birefringence and hence may be more desirable. We report here the successful realization of such a configuration.

Figure 1 shows the experimental configuration. The doped Er^{3+}/Yb^{3+} fiber (Er^{3+} concentration of900 parts in 10^6, Yb^{3+}/Er^{3+} ratio of 12:1) is spliced to a WDM that couples in the pump light from a YAG laser source. The laser is formed by butting the



TuM2 Fig. 1. Experimental configuration: WDM, wavelength-division multiplexer.



TuM2 Fig. 2. Schematic diagram of the nonlinear mirror structure. Layers are lattice matched to InP (InGaAs ≡ $In_{0.53}Ga_{0.47}As$, InGaAsP ≡ $In_{0.65}Ga_{0.35}As_{0.75}P_{0.25}$).

doped-fiber end against a 50% output mirror and butting the other fiber end (polished) against the nonlinear mirror, which consists of a multiple-quantum-well saturable absorber (with the exciton peak at 1.55 μm) integrated with a Bragg-reflector stack (90% reflectivity centered at 1.55 μm). The nonlinear mirror, grown by molecular-beam epitaxy, is shown in Fig. 2. Details of the growth will be published elsewhere.

The citing of the Bragg stack just beneath the quantum wells simplifies the laser cavity considerably since the fiber end can be brought into contact with the semiconductor sample without requiring intermediate coupling optics. The common problem of étalon effects (which hinders mode locking) due to the sample is also removed since the effective étalon is now between the Bragg stack and the front surface of the sample, which is only a few micrometers thick and should thus cause no significant modulation of the lasing spectrum.

With 3.5 m of doped fiber and a total fiber cavity length of 6.2 m, cw passive mode locking was observed for a minimum launched pump power of 250 mW. (Below this pump power, the laser operates in a Q-switching mode.) The mode locking was insensitive to the birefringent state of the fiber, with only one pulse observed per cavity round trip. The average output power was 4 mW, and the optical pulse width was 22 ps, measured with an autocorrelator. The shortest pulses of 7.6 ps (Fig. 3) were obtained by using just 2 m of doped fiber, with a corresponding increase in the minimum pump power required to sustain cw mode locking to 300 mW. It is worth noting that once the laser is mode locked, it will typically stay mode locked for hours without interruption. It has also been observed to immediately resume mode locking after the pump has been turned off and then on again several hours later, barring any mechanical misalignments due to drift. The configuration here thus has considerable potential for a simple and compact picosecond optical pulse source.

Using the same nonlinear mirror as the mode-locking element and a similar linear cavity configuration, we have also just achieved mode locking with direct diode pumping by using a 962-nm diode array and a double-clad Er^{3+}/Yb^{3+}-doped fiber,[4] where the pump is launched into the multimode cladding and is subsequently absorbed into the core. Optical pulse widths of 20–30 ps have been observed with this fiber. The feasibility of direct diode pumping demonstrated here should make this mode-locking configuration even more attractive.

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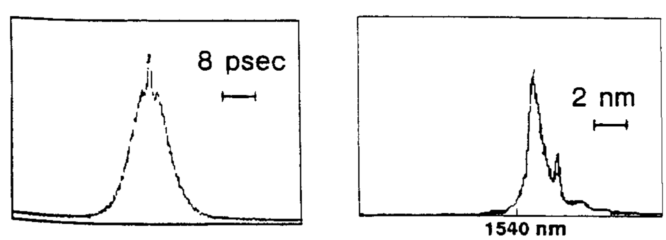

TuM2 Fig. 3. Nonlinear autocorrelation trace (left) and optical spectrum (right), indicating an optical pulse width of 7.6 ps.