Passively modelocked 50 GHz Er:Yb:glass laser

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A diode-pumped Er:Yb:glass miniature laser has been passively modelocked to generate 2.0 ps pulses at a 50 GHz repetition rate with up to 7.5 mW average power. By combining this laser with a dynamic gain equaliser, a flat optical spectrum has been generated with up to 10 discrete channels with a 50 GHz channel spacing locked to the 50 GHz ITU grid.

Introduction: As data transmission rates and the number of WDM transmission channels steadily increase, directly pulsed laser sources, such as passively modelocked solid-state lasers [1], harmonically modelocked fibre ring lasers [2], or hybrid modelocked semiconductor lasers [3] are becoming increasingly important for telecomms applications. The next generation of optical time division multiplexing (OTDM) systems using return-to-zero (RZ) formats will benefit greatly from the availability of simple, compact, transform-limited optical pulse generators, because wavelength domain, modelocked lasers generate a stable comb-shaped optical spectrum, where the spacing of the longitudinal modes exactly equals the pulse repetition rate. Therefore, pulse-generating lasers can be used as multi-wavelength sources (MWS) in dense wavelength division multiplexing (DWDM) systems [4]. Increasing the pulse repetition rate leads to a wider channel spacing. This often relaxes the demands on the filter characteristics of the channel add/drop nodes, and it allows for higher channel capacities. By slightly varying the pulse repetition rate and locking one longitudinal mode to a reference (i.e. a single ITU grid line), all modes of the MWS are automatically locked to the ITU grid, as the changes of the mode spacing in this condition are very small. With 50 GHz channel spacing, the maximum frequency offset between a longitudinal mode and a required reference line is 25 GHz. To remove this offset, the cavity length has to be changed by a quarter wavelength, leading to a change in repetition rate (and thus channel spacing) of only 6.4 MHz, which is well below the tolerance of the ITU channels. Compared to the classical DWDM approach, where one fixed-wavelength laser per channel is used, our approach significantly reduces the complexity of the system architecture and relaxes the demands on power budget and space requirements.

We recently presented a passively modelocked Er:Yb:glass laser, emitting picosecond pulses with a repetition rate of 40 GHz [5], while high-quality pulses with 77 GHz repetition rate have been generated at 1064 nm with Nd:YVO$_4$ [6]. Here we demonstrate a multi-wavelength source for the 50 GHz ITU grid by passively modelocking an Er:Yb:glass laser with a repetition rate of 50 GHz and locking its longitudinal modes to the reference grid. This laser was combined with a dynamic gain equaliser (DGE) to flatten the optical spectrum, resulting in a multi-wavelength source with ten channels of the 50 GHz ITU grid.

Experimental setup: For many reasons, Er:Yb:glass is well suited for telecomms applications. Its gain bandwidth covers the entire C-band, it can be pumped with standard 980 nm laser diodes, and it is robust and low cost. However, its small emission cross-section typically leads to a strong tendency for *Q*-switched modelocking (QML) [7]. To suppress these instabilities, we used a semiconductor saturable absorber mirror (SESAM, [8, 9]) design with a modulation depth below 1% and a low saturation fluence and we minimised the mode size on the SESAM. In contrast to harmonic modelocking (where stable operation requires sophisticated measures), our approach uses fundamental modelocking, i.e. with a single pulse circulating in the laser cavity. For 50 GHz, this leads to an extremely short optical cavity length of only 3 mm for a standing-wave cavity. We realised such a cavity by using very small and strongly curved mirrors in a folded geometry (Fig. 1). The output coupler has 1% transmission at the laser wavelength and over 99% transmission for the pump wavelength at 976 nm. The pump light with up to 230 mW is generated with a fibre-coupled (singlemode, polarisation maintaining) telecomms-grade laser diode. A dielectric mirror is used to separate the output pulses from the beam. The gain medium is a thin Er:Yb:glass plate (QX/Er from Kigre), mounted under Brewster's angle. As this pulse source is passively modelocked, no microwave driving electronics are required.

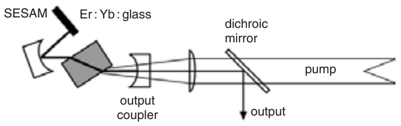

Fig. 1 *Cavity setup of 50 GHz miniature Er:Yb:glass laser*

SESAM: semiconductor saturable absorber mirror

Results: The autocorrelation (Fig. 2) at an average output power of 6.6 mW shows that the laser generates clean pulses with 2.05 ps duration and good extinction ratio. The optical spectrum has a full width at half maximum of 2.2 nm. This results in a time–bandwidth product of 0.57, which is 1.7 times the transform limit for ideal sech^2 pulses. Fig. 3 shows a high dynamic range optical spectrum, recorded with an Ando 6319B spectrum analyser (0.01 nm resolution).

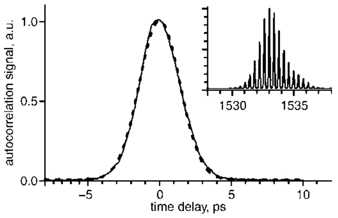

Fig. 2 *Autocorrelation trace of 50 GHz pulse train at average output power of 6.6 mW, together with fit (dashed) for sech^2-shaped 2.0 ps pulse*

Optical spectrum (inset) has full width at half maximum of 2.2 nm, and time–bandwidth product of 0.57

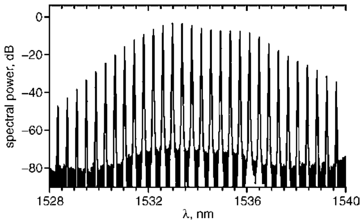

Fig. 3 *Optical spectrum of pulse train from high-resolution spectrometer, displayed on logarithmic scale*

Lines on upper graph indicate 50 GHz ITU grid

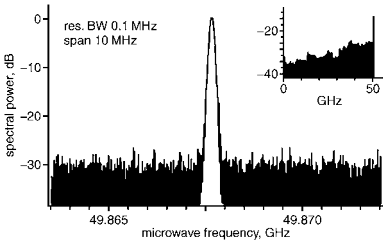

Fig. 4 *Microwave spectrum, demonstrating absence of Q-switching instabilities*

The displayed optical signal-to-noise ratio (OSNR) is 65 dB, probably limited by the spectrometer. The microwave spectrum (Fig. 4), recorded with a 45 GHz photodiode, an Agilent 83051A microwave amplifier and an Agilent 8565EC microwave analyser, shows a single peak at 49.8676 GHz and no side peaks on the instrument-limited noise floor. The operation is stable over hours. The output power is somewhat lower than compared to the earlier 40 GHz version; this is attributed to the lower quality of the mirrors. Polishing defects, which are more difficult to avoid for such strong curvature, introduce additional losses into the cavity, which degrades its performance.

For locking the longitudinal modes of this 50 GHz comb to the ITU grid, we used a simple feedback loop consisting of a wavelength locker from JDS Uniphase, a simple integrating circuit, and a 2 mm long piezo below the SESAM to tune the cavity length. Fig. 5 shows the optical spectrum of the MWS after flattening with a dynamic gain equaliser (ZettaManager 12-band from ZettaLight). Using the maximum dynamic range of the DGE (10 dB), up to 10 channels with a flatness <1 dB have been generated. The power in each of the equalised modes is −25 dBm.

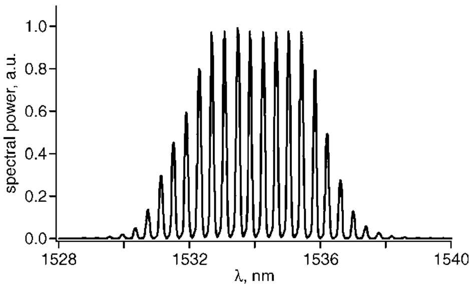

Fig. 5 *Optical spectrum after passing dynamic gain equaliser*

Ten channels with flatness of 1 dB. Resolution bandwidth is 0.08 nm

Conclusions: We have demonstrated a passively fundamentally mode-locked miniature Er:Yb:glass laser operating at the extremely high repetition rate of 50 GHz. The optical spectrum was locked to the 50 GHz ITU grid. With a dynamic gain equaliser, we obtained up to eight channels spaced by 50 GHz and with <0.4 dB deviation from flatness of the channels. Its combination of simplicity, high output power and good pulse quality with compactness and simplicity of the setup makes it very competitive against actively harmonically modelocked fibre lasers, semiconductor lasers and DBF lasers used in DWDM light sources.

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