Tunable picosecond pulse-generating laser with repetition rate exceeding 10 GHz

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A compact, fundamental-repetition-rate modelocked, optically-pumped Er : Yb : glass laser producing near transform-limited picosecond pulses at a repetition rate of 10.67 GHz and average power exceeding 10 mW is presented. Wavelength tuning over the entire C-band is demonstrated at 2 GHz.

Introduction: As data transmission rates continue to increase, pulsed lasers are becoming increasingly important for telecom applications. Transmission systems at 10 GHz and higher often use RZ pulse formats and soliton dispersion management techniques. These approaches would benefit greatly from the availability of simple, compact, transform-limited optical pulse generators. There are many compelling reasons to use a pulsed laser directly as an optical source in telecommunications systems. First, this eliminates the need for a modulator to create the pulses and thereby simplifies system architecture, increases efficiency, and reduces cost. Secondly, the extinction ratio of pulsed lasers is typically very good and much higher than for modulated CW sources. This improves system signal-to-noise ratio and allows further scaling to higher repetition rates through optical time-division multiplexing. Furthermore, pulsed lasers can have a transform-limited (chirp free) output, which occupies the minimum optical bandwidth for a given pulse duration (and thus bit rate).

Passively modelocked, optically pumped lasers have been presented with repetition rates up to 77 GHz in the 1 μm wavelength regime [1]. They are very simple, powerful and compact. However, at telecom wavelengths, fundamental repetition rates had previously been limited to 2.5 GHz. These results were achieved only with actively modelocked Er : Yb : glass lasers [2]. In addition, passively modelocked Cr : YAG lasers produced pulse repetition rates as high as 2.6 GHz but with limited stability [3].

Results: We demonstrate an Er : Yb : glass laser oscillator (see Fig. 1) which produces a continuous train of picosecond pulses at repetition rate of 10.67 GHz, a centre wavelength of 1534 nm and an average output power of up to 15 mW. We obtained nearly transform-limited pulse durations (time-bandwidth product < 0.47) of 3.8 and 16.8 ps with different laser parameters. Tuning over the entire C-band in a similar laser at 2 GHz was demonstrated. These pulses are obtained using passive modelocking, i.e. the laser requires no microwave drive signal to produce pulses, and there is only one laser pulse per round-trip inside the cavity (fundamental modelocking as opposed to harmonic modelocking).

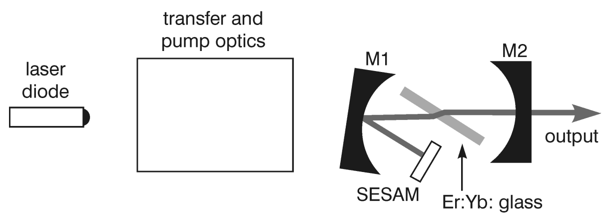

Fig. 1 *Schematic diagram of laser and pump setup*

For many reasons, Er : Yb : glass is well-suited for telecom applications. Its gain bandwidth covers approximately the entire C-band, and it can be pumped with standard 980 nm laser diodes used in EDFAs. Er : Yb : glass can be produced with excellent quality and in large quantities. It is robust and low-cost. Compared to Cr^{4+} : YAG, another bulk gain material in this wavelength regime, Er : Yb : glass has a much higher small-signal gain and pump absorption, relaxing the requirements on the pump source substantially. However, its small emission cross-section typically limits the ability to operate at high repetition rates without *Q*-switched modelocking (QML), a regime where the modelocked pulse train is underneath a lower frequency *Q*-switch envelope, leading to large amplitude and pulse energy variations [4]. To date, the repetition rate of passively modelocked Er : Yb : glass lasers has been limited to 114 MHz [5].

In this laser, we avoid QML by the combination of an optimised cavity design with small mode areas in the gain and on the saturable absorber, and a semiconductor saturable absorber mirror (SESAM) [6, 7] with low saturation fluence and modulation depth. We use an Er : Yb : glass plate in a three-mirror cavity, consisting of two curved mirrors, with the SESAM forming one end of the laser cavity. The total cavity length for 10.67 GHz is approximately 13.4 mm. The laser gain element is pumped through the curved cavity-folding mirror by a singlemode diode laser emitting up to 400 mW at 980 nm (Nortel G06d). With appropriate pump optics the output of the pump laser is focused tightly into the gain medium to achieve mode matching to the laser mode. The output coupler transmission was 0.5%.

Pulses as short as 3.8 ps with an average output power of 12 mW at a repetition rate of 10.52 GHz were obtained as shown in Fig. 2. The pulse shape corresponds very well to an ideal $sech^2$ function indicating a good extinction ratio (currently limited by detector signal-to-noise). By changing the SESAM parameters and pump power, we obtained pulse durations up to 16.8 ps (Fig. 3) with 10 mW average power at a repetition rate of 10.67 GHz and an optical bandwidth of 28 GHz giving a time bandwidth product of 0.47. The spacing of the longitudinal modes is 0.08 nm.

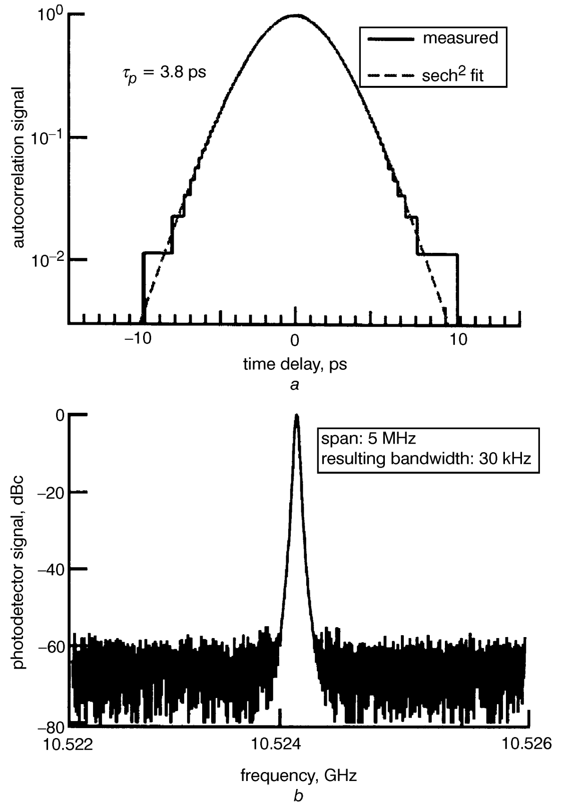

Fig. 2 *Autocorrelation trace and microwave spectrum*

a Autocorrelation trace of 3.8 ps pulse with logarithmic scale. Extinction ratio limited by the detection noise
b Microwave spectrum
No other features shown other than laser harmonics at 10.52 GHz and its multiples

Owing to physical size constraints of the 10 GHz laser, preliminary tuning experiments were carried out using a longer cavity with a repetition rate of 2 GHz allowing for a bulk intracavity tuning element. Fig. 4 shows the measured output power at the threshold for QML and the pulse duration against the centre wavelength, together with the corresponding normalised spectra. Tuning was achieved by tilting a 25 μm air-spaced etalon with a free spectral range of 47 nm (6 THz). The laser operates in CW modelocking over the tuning range of 1529 to 1569 nm (i.e. covering the entire C-band). The pulse duration, output power at the QML threshold, and spectrum do not vary significantly over the tuning range. Similar results are expected at 10 GHz with miniature tuning elements.

Passively modelocked lasers are routinely synchronised to reference clock sources using phase-lock loop techniques. These lasers have very low open-loop phase noise, allowing for straightforward incorporation of a synchronisation system. Such systems consist of a feedback loop to lock the cavity length with a servo controlled piezoelectric or similar transducer. Large, laboratory-scale passively modelocked lasers have been synchronised to timing jitter values below 20 fs rms [8]. The lasers reported here have similar or better opto-mechanical characteristics compared to these lasers.

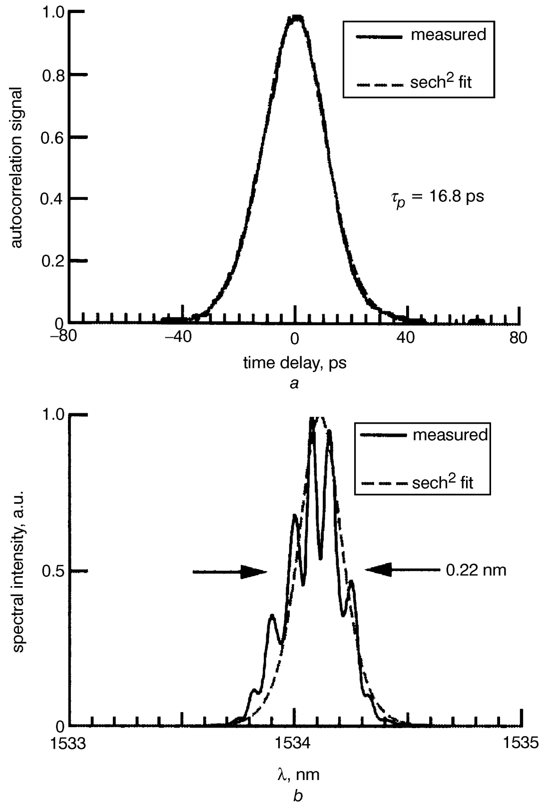

Fig. 3 *Autocorrelation trace and optical spectrum of 10.67 GHz pulse train*

a Autocorrelation trace
b Optical spectrum
Measured optical spectrum of 28 GHz FWHM bandwidth gives time-bandwidth product of 0.47
Modulation in optical spectrum due to resolved longitudinal modes

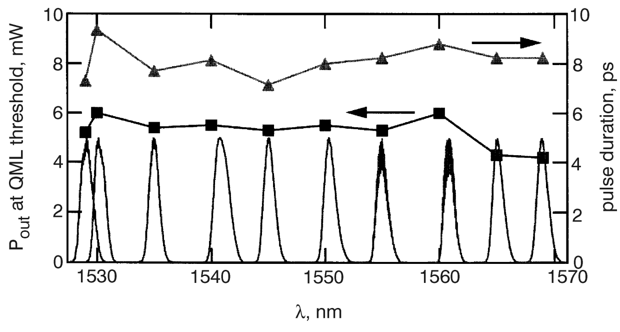

Fig. 4 *Measured output power at QML threshold and pulse duration against wavelength, together with different spectra for 2 GHz laser similar to the one described in text tuned with 25 μm air-spaced etalon*

Conclusion: We have demonstrated a simple pulse-generating laser operating at frequencies exceeding 10 GHz with picosecond pulses and average power exceeding 10 mW, tunable over the entire C-band. Compact micro-mechanical packaging of this device will enable applications in RZ and dispersion-managed DWDM systems, high-speed test and measurement, and all-optical functionality such as 3R and wavelength conversion. The high output power and a very high extinction ratio enable simple time division multiplexing to 40 GHz or higher while still yielding a high quality pulse train.

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