Diode-pumped, 6.8 GHz, solid-state waveguide laser mode-locked at 1.5 μm by a quantum-dot SESAM

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Abstract: In this paper, we present a diode-pumped, solid-state waveguide laser operating near 1550 nm that is passively mode-locked using a quantum-dot SESAM. A fundamental repetition rate of up to 6.8 GHz with an output power of 30 mW was achieved during mode-locked operation. Pulse durations as short as 2.5 ps were measured at a repetition rate of 4.8 GHz. Fine control of the of the repetition rate was demonstrated by varying the pump power and a tuning range of up to 1 MHz was demonstrated.

OCIS codes: (140.4050) Mode-locked lasers; (230.7380) Waveguides, channeled; (230.5590) Quantum-well, -wire and -dot devices

1. Introduction

Sub-picosecond, mode-locked lasers with pulse repetition rates > 1 GHz can have applications in real-time ultrafast optical sampling, arbitrary optical and microwave waveform synthesis, optical frequency comb spectroscopy, frequency comb calibration of high-resolution astronomical spectrographs and non-linear optical microscopy. Harmonic mode-locking [1] has been widely used to achieve high repetition rates; however, such lasers have multiple pulses circulating in the cavity which can lead to pulse-to-pulse energy fluctuations and a high timing jitter.

To reach multi-GHz repetition rates from a fundamentally mode-locked laser, an optical cavity length shorter than ~15 cm is required, which can be technologically challenging. Additionally, such laser systems operate at reduced intra-cavity pulse energy that demands careful optimisation of saturable absorber and cavity parameters. Nevertheless, repetition rates in excess of 100 GHz have been obtained using carefully engineered solid-state laser cavities [2, 3].

Solid-state lasers in waveguide geometry have attractive features like a low threshold operation, a high slope efficiency and the possibility of development of fully integrated and monolithic sources with a foot print of < 1 cm^2. Using ion-exchanged Yb^{3+}-doped glass waveguide lasers, we have successfully demonstrated self-starting mode-locking at a repetition rate of 4.9 GHz and an average power of 80 mW around 1 μm [4]. Recently, we have increased the repetition rates to as high as 15.2 GHz from such class of waveguide lasers [5]. However, to date mode-locked waveguide lasers with a repetition rate of >1 GHz operating near the 1.5 μm spectral region are not very developed mainly due to lack of reliable ultrafast saturable absorbers.

In this respect, quantum dot (QD) SESAMs [6] offer a low saturation fluence, fast recovery time and low non-saturable losses and are promising candidates for passive mode-locking at high pulse repetition rates. Recently, a QD-SESAM using a dot in well (DWELL) structure has been used for the first time to achieve mode-locked pulses around 1.5 μm [7].

In this paper we present, to the best of our knowledge, the first waveguide laser mode-locked by a QD-SESAM. A repetition rate of 6.8 GHz at an average power of 30 mW is achieved during stable mode-locked operation in an ion-exchanged Er,Yb:glass waveguide laser around 1.5 μm. Tuning of the repetition rate by more than 1 MHz is demonstrated by varying the pump power during mode-locked operation.

2. Experimental details

The waveguides were fabricated in commercially available Er^{3+},Yb^{3+} doped phosphates glasses (IOG-1 from Schott glass technologies, Inc) using a standard ion-exchange process [4]. After fabrication, the waveguide samples were polished to lengths of 20 mm and 14.5 mm. From the prism-coupling technique, the index contrast and the diffusion depth were measured to be 5.1×10^{-3} and 14.6 μm respectively at 1553 nm.

The QD-SESAM used for the experiments was grown using a molecular beam epitaxy reactor (VG 90). The InGaAs/GaAs QDs were placed in an asymmetric InGaAs quantum well pair (DWELL structure) and was capped by a GaAs layer. The distributed Bragg reflector (DBR) structure consisted of 31 pairs of GaAs and AlGaAs. More details about this SESAM structure can be found in Ref.7.

The waveguide was pumped by a single-mode, fibre-coupled laser-diode with a maximum power of 850 mW and a central wavelength of 974 nm. The pump was collimated using a ×20 objective (f = 8 mm) and was focused into the Er,Yb:IOG-1 waveguide using a ×10 objective (f = 15.4 mm). The waveguide was thermo-electrically cooled to a constant temperature of 18°C. A half-wave plate and an isolator were also put in the setup to protect the laser diode from back-reflections from the waveguide. The laser cavity was formed by a 2% output coupler (through which the waveguide was pumped) and the QD-SESAM. A beam splitter was installed before the input focussing lens to separate the laser and pump beams. The gap between the QD-SESAM and the uncoated waveguide was controlled in order to vary the total group velocity dispersion (GVD) via the formation of a Gires-Tournois interferometer (GTI) structure [4].

3. Results

Continuous wave (CW) mode-locking was observed in the 20-mm-long waveguide sample at the incident pump power of 513 mW and a corresponding output power of 6.7 mW. The gap between the SESAM and the waveguide at which stable, self-starting mode-locking was achieved was ~13 μm and the total round-trip GVD was estimated to be about – 2000 fs^2. The radio frequency (RF) spectrum was measured using an RF spectrum analyser at a span of 10 MHz and resolution bandwidth (RBW) of 10 kHz and is shown in Fig. 1(a). A sharp peak around 4.8 GHz can be observed with a signal to noise ratio (SNR) >50 dB. The maximum output power was measured to be 9 mW during mode-locking. The autocorrelation trace is shown in Fig. 1(b) and a pulse duration of 2.5 ps was deduced assuming a $sech^2$ intensity profile. The optical spectrum was centred at 1556 nm with a bandwidth of 1.15 nm as seen from Fig. 1(c). The time-bandwidth product is 0.357, implying nearly transform-limited pulses.

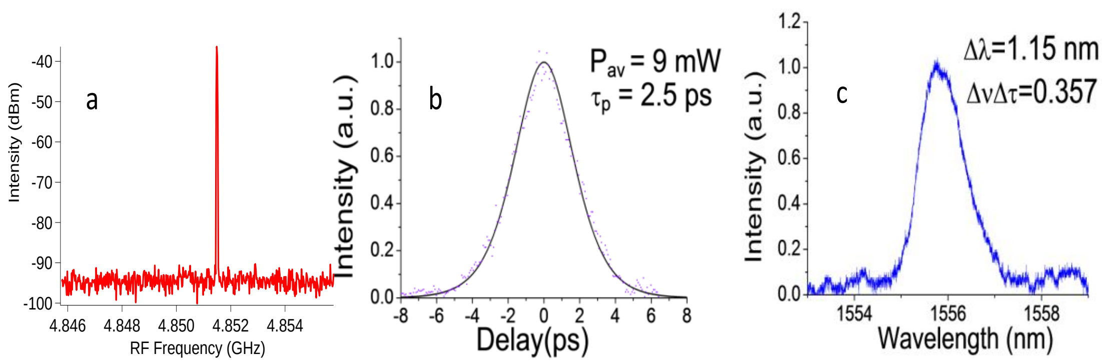

Fig. 1. (a) Radio Frequency spectrum, (b) autocorrelation trace, and (c) optical spectrum for the 20-mm-long waveguide laser.

For the 14.5-mm-long waveguide laser, self-starting mode-locking was observed at an incident pump power of 558 mW and an output power of 25 mW. Mode-locking was found to occur for a similar gap between the SESAM and the waveguide as for the longer sample. At maximum pump power, the output power was measured to be 30 mW. The measured RF spectrum is shown in Fig. 2(a) and a sharp peak at 6.8 GHz can be observed with an SNR >50 dB . Figs. 2(b) and 2(c) show the autocorrelation trace and the optical spectrum from which a pulse duration of 5.4 ps and a central wavelength of 1544.4 nm can be observed respectively.

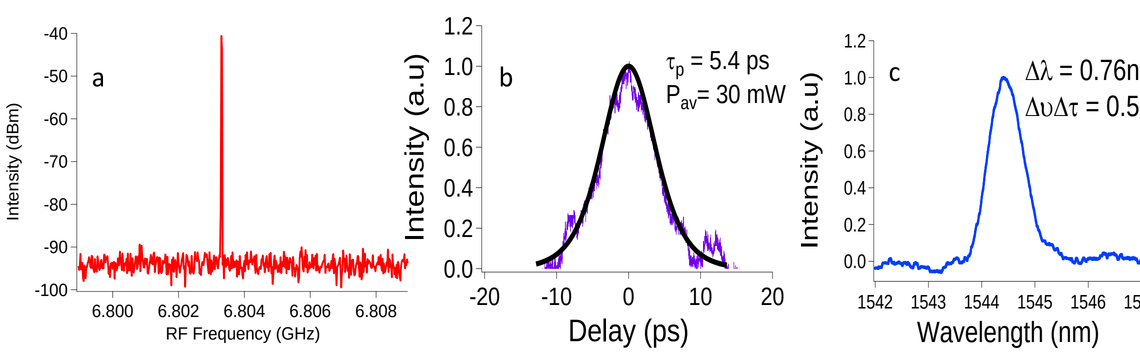

Fig. 2. (a) Radio Frequency spectrum, (b) autocorrelation trace, and (c) optical spectrum for the 14.5-mm-long waveguide laser

With mode-locking achieved at a repetition rate of 6.8033 GHz, the pump power was varied from 586 mW to 684 mW in order to tune the central frequency. The repetition rate of the laser decreased by more than 1 MHz when the pump power was increased by ~100 mW, as seen from Fig. (3). We attribute this effect to the thermal expansion of the waveguide due to the increase in pump power.

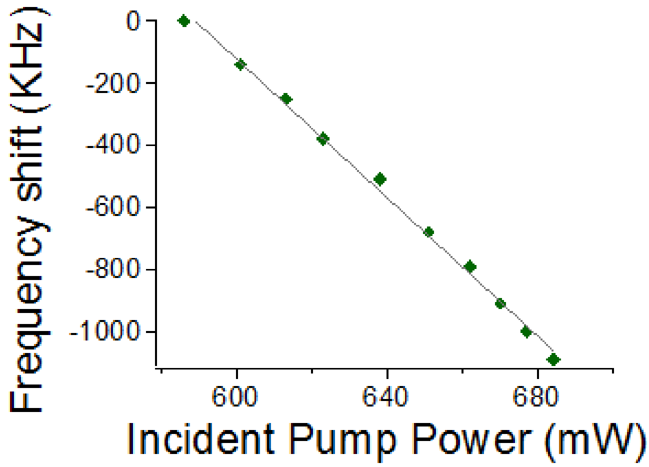

Fig. 3. Effect of increasing the incident pump power on the repetition rate of the mode-locked laser.

4. Conclusions

In conclusion, we have presented, to the best of our knowledge, the first mode-locked waveguide laser using a QD-SESAM as a saturable absorber. The highest repetition rate of 6.8 GHz from a fundamentally mode-locked Er^{3+}-doped waveguide is also reported. An output power of 30 mW was achieved during stable continuous wave (CW) mode-locked operation at a fundamental repetition rate of 6.8 GHz. Nearly transform-limited $sech^2$ pulses with a pulse width of 2.5 ps were also generated at a fundamental repetition rate of 4.8 GHz. The repetition rate of the laser was tuned by more than 1 MHz by varying the pump power, which may be used for future integrated stabilisation. Such compact, diode-pumped, mode-locked, ultra-fast sources could open the path for various exciting applications.

5. References

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