Generation of Transform-Limited Picosecond Pulses at 1.0 µm from a Gain Switched Semiconductor Laser Diode

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***Abstract*— We report the generation of short, transform-limited, ~18 ps optical pulses from an external fiber Bragg grating (FBG) stabilized semiconductor laser diode. Up to 7.2 pJ of pulse energy and a peak power of 400mW were achieved when operating at a repetition frequency of 832.6 MHz, a multiples of the cavity round trip frequency. A small detuning in the repetition frequency resulted in broader optical pulses. We have shown experimentally that an active mode-locking rather than gain switching mechanism is behind the generation of transform limited optical pulses at the optimum operating frequency.**

Keywords*— *Semiconductor lasers, Laser mode locking.

I. Introduction

Gain switching is a simple technique for the generation of picosecond optical pulses directly from a semiconductor laser diode (SLD) with the flexibility of pulse on demand [1]. Optical pulses with duration of tens of picoseconds have been demonstrated in the 1.06 µm wavelength region. The minimum pulse duration is dictated by the device properties and parameters of the modulated current pulses. The ease of generating stable trains of optical pulses and the attractiveness of operating at any desire repetition frequency have made this technique a popular choice of seed laser in a Master Oscillator Power Amplifier (MOPA) system.

The optical pulses generated usually exhibit a red shift in lasing wavelength due to the time-varying carrier density within the gain medium which leads to a large refractive index modulation. This results in chirped optical pulses with a corresponding time-bandwidth-product many times the Fourier limit. Several chirp compensation techniques have been demonstrated in recent years but these bring additional complexity to the setup. For instance, using a chirped fiber Bragg grating (CFBG) [2], highly dispersive fiber [3], nonlinear optical loop mirror [4] and a spectral filtering technique using a Mach Zehnder interferometer [5].

On the other hand, gain switched optical pulses suffer from pulse to pulse timing jitter. Timing jitter originates during the build-up of optical pulses from spontaneous noise, causing random fluctuations in photon density [6]. However, timing jitter can be reduced using the injection seeding technique. This has been demonstrated either by using an external laser source [7], or by self-seeding [8].

The use of a fiber Bragg grating (FBG) to self-seed a gain switched SLD avoids the need for using any additional laser for the purpose of injection seeding. This method is not only cost efficient but also simplifies the system architecture. Using the same cavity configuration it is possible to actively mode-lock an SLD, resulting in stable, transform limited optical pulses. Such a cavity has been shown to produce 50 ps, actively mode-locked pulses in the 1.55 µm wavelength region [9].

Herein, we experimentally demonstrate a simple configuration to generate short, transform-limited 18 ps optical pulses at a wavelength of 1.035 µm with pulse energy of 7.2 pJ corresponding to a peak power of 400mW. Furthermore, we show experimentally that mode-locking is the underpinning mechanism allowing the generation of these short optical pulses.

II. Experiment

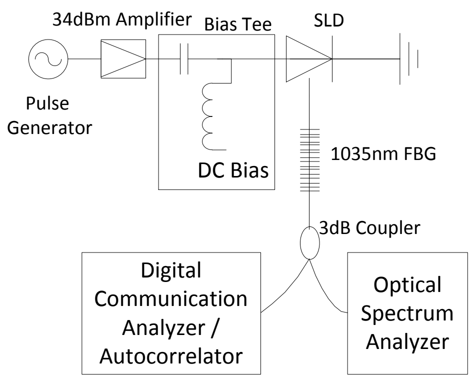

Fig. 1 Experimental setup of the picosecond pulse source.

Fig. 1 shows the experimental setup of the gain switched system. The semiconductor laser diode used in this experiment was a commercial Fabry-Perot SLD at 1035 nm. The measured longitudinal mode spacing was 0.032 nm. The SLD was mounted on a modified printed circuit board (PCB) with resistors in series in order to match the impedance of the transmission line. In order to realize gain switching operation, the SLD was driven by a stable train of sinusoidal electrical pulses with a peak-to-peak current of 632 mA and superimposed on a DC bias current of 20 mA. The laser threshold current was 25 mA. The pigtail of the SLD was spliced to a polarization maintaining 1035 nm FBG with 3 dB bandwidth of 0.24 nm and a reflectivity of ~12%. The fiber length between the SLD and the FBG was ~2 m. The fundamental frequency of the cavity was ~51.7 MHz and the system was operated at 832.6 MHz which corresponds to the 16th harmonic. A polarization maintaining 3-dB fused fiber coupler was spliced to the output end of the grating so that both temporal and spectral profiles could be measured simultaneously with a Digital Communication Analyzer (DCA) and an Optical Spectrum Analyzer (OSA) respectively.

III. RESULTS AND DISCUSSION

In the unseeded case, a broad spectrum with a FWHM of approximately 6 nm and pulse width of ~94 ps was measured as illustrated by the red colored line plots in Fig. 2. The broad spectrum generated in the process consisted of a large number of longitudinal modes. The emission of optical pulses was accompanied by a red-shift in wavelength from the leading to trailing edge as the electron concentration decreases across the active region [10]. As a result, the optical output pulses were heavily chirped with an estimated time bandwidth product of ~158. Moreover, the pulses exhibited significant amplitude noise whilst the RMS timing jitter was measured to be ~5 ps.

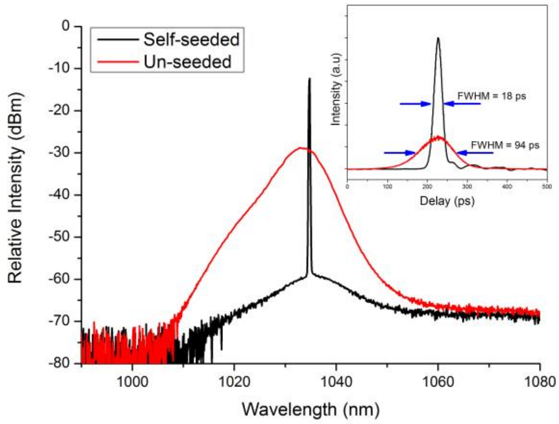

Fig. 2. Spectral profiles of the gain-switched SLD with (black line) and without (red line) FBG. (Inset) Temporal profiles for the seeded (black line) and unseeded (red line) cases.

When the SLD was seeded by an external FBG and the repetition frequency was matched to the round trip time of the SLD-FBG cavity, we observed a reduction in both spectral bandwidth and pulse width as shown by the black colored line plots in Fig.2. At a repetition frequency of 832.6 MHz, transform-limited optical pulses of 18 ps duration were measured with an intensity autocorrelator as shown in the inset of Fig. 3. This indicates an almost 5 times reduction in pulse width compared to the unseeded case. A side mode suppression (SMSR) of ~50 dB and FWHM spectral bandwidth of 0.09 nm were measured, corresponding to an almost 67 times reduction of bandwidth in the spectral domain. The estimated time bandwidth product (TBP) was 0.45, close to time-bandwidth limited assuming Gaussian shaped optical pulses. Furthermore, the pulse-to-pulse timing jitter was measured to be less than 2 ps (limited by the resolution of the measurement equipment used). The average optical power was ~6 mW corresponding to a pulse energy of 7.2 pJ and a peak power of 400 mW. As shown in Fig. 3, a stable, uniform amplitude pulse train was measured with a fast photo-detector (Agilent 83440D) and a DCA.

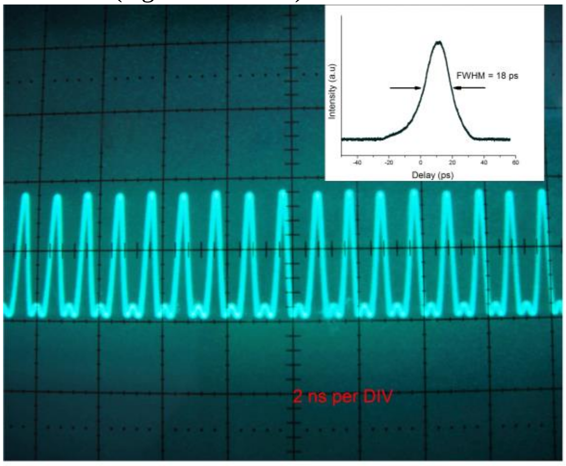

Fig. 3. Snap shot of pulse train at 16th harmonics (832.6 MHz). (Inset) Trace of intensity autocorrelator resulted in ~18 ps optical pulses.

A small detuning in repetition frequency resulted in substantial changes in pulse widths and pulse shapes. Fig. 4 shows the pulse width variation as well as the measured pulse shapes as the operating frequency was varied. At frequencies below 832.6 MHz, broad, distorted and unstable optical pulses were observed. When the repetition frequency was tuned to 832.6 MHz, distortion free optical pulses with a width of ~18 ps were obtained. As the frequency was increased by 0.2 MHz (832.8 MHz), the pulse width started to increase (~30 ps). Further increases in frequency to 833.0 MHz resulted in 40 ps optical pulses and beyond that the benefit of seeding was lost and the optical pulse width returned to the original unseeded value of ~94 ps.

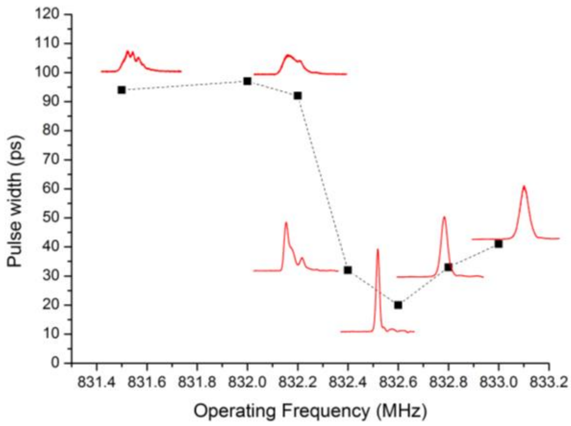

Fig. 4. Optical pulse width measured at different repetition frequencies and (Color) the corresponding optical pulse shapes

The lasing wavelength of the output pulses was also affected as the repetition frequency was detuned. Fig. 5 shows the reflection spectrum of the FBG. The red highlighted section represents the operating wavelengths where the optical pulses became unstable and distorted (corresponding to the repetition frequencies of 832.4 MHz or lower). The green highlighted section illustrates the region of stable operation producing relatively short and distortion free optical pulses when the repetition frequency varied between 832.6 MHz and 833.0 MHz.

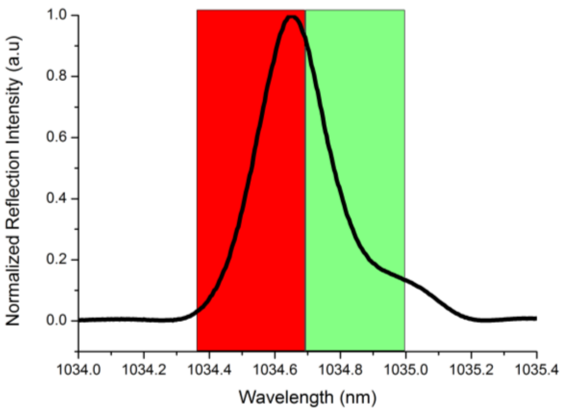

Fig. 5. Red shaded part defines the region of unstable and distorted optical pulses whilst the green shaded section represents the region for stable and clean optical pulse operation.

At the exact frequency of 832.6 MHz (16th harmonic of the cavity round trip frequency), a resonance condition was achieved in the cavity (between SLD and FBG). The locking bandwidth observed was modest (1MHz locking range). At resonance the peak of the output spectrum was red-shifted away from the grating peak wavelength (as highlighted in green in Fig. 5). This shift results from self-phase modulation within the SLD due to carrier depletion and its interplay with the grating characteristics. Similar observations were reported in the 1.5 µm wavelength region [11].

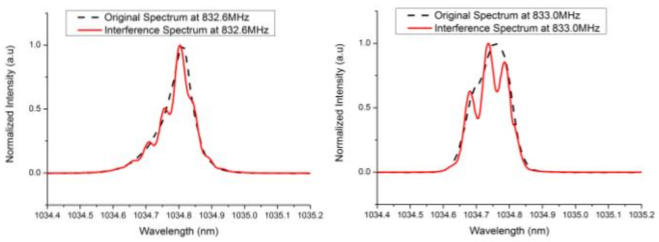

Fig. 6. Interference patterns between the 1st and the 10th optical pulses for two different operating frequencies corresponding to different operating regimes. The separation between peaks corresponds to the temporal separation between the two interfered optical pulses.

Since the constituent longitudinal modes of a mode-locked optical pulse will have a defined phase relationship, an interference measurement was carried out to confirm that the mode-locking mechanism is indeed responsible for the generation of short optical pulses. Interference patterns are clearly visible in the spectral domains as shown in Fig. 6 for repetition frequencies of 832.6 MHz and 833 MHz. The interference pattern was lost completely above 833 MHz and at or below 832.0 MHz, indicating that the mode-locking mechanisms no longer exist in these operating regimes. Instead, injection seeding dominates the pulse generation process.

IV. CONCLUSION

We have demonstrated a simple cavity configuration incorporating a gain switched SLD and an external FBG to produce transform limited optical pulses of 18ps in duration with pulse energy of 7.2 pJ and peak power of 400 mW. Moreover, we have identified that a mode-locking mechanism is responsible for the generation of short picosecond pulses. We have also investigated the impact of repetition frequency on the spectral and temporal evolutions of the pulse.

ACKNOWLEDGMENT

The author would like to acknowledge A.Heidt, M.Berendt and M.Tokurakawa for their valuable discussions and Public Service Department (PSD) of Malaysia for the financial sponsorship. This work was supported in part by the UK Technology Strategy Board project SMART LASER and the UK EPSRC project RIR-PLD.

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