Cavity Length Independent Continuous Repetition Rate Tuning of a Self-Seeded Gain-Switched Fabry–Pérot Laser

R. D. Maher, *Student Member, IEEE*, P. M. Anandarajah, *Member, IEEE*, and L. P. Barry, *Member, IEEE*

***Abstract*—We propose a novel method that allows continuous repetition rate tuning of a self-seeded gain-switched Fabry–Pérot laser without the need for change in cavity length. This is achieved by employing a linearly chirped fiber Bragg grating with a large dispersion parameter. The dispersed pulses overlap to produce a continuous-wave-like feedback into the gain-switched laser cavity. By using the proposed experimental setup, we demonstrate pulses portraying sidemode suppression ratios of at least 30 dB and widths of about 30 ps over the entire repetition rate tuning range of 2.5–10 GHz.**

***Index Terms*—Gain-switching, linearly chirped fiber Bragg grating (LC FBG), optical pulse generation, self seeding, sidemode suppression ratio (SMSR).**

I. INTRODUCTION

SHORT optical pulse generation is extremely important for use in high-speed communication systems, especially in applications such as optical time-division-multiplexing (OTDM) or hybrid wavelength-division-multiplexing/OTDM systems. Picosecond pulses can be generated by employing several different techniques such as external modulation of continuous-wave (CW) light with an electroabsorption modulator (EAM), mode-locking, or gain-switching. Mode-locking is a common technique used to generate short optical pulses operating at high fixed frequencies. However, cavity complexity and limited tunability of the mode-locking repetition rate act as major disadvantages associated with this technique [1]. Pulse carving with an EAM offers short pulse generation over a wide wavelength range, although it suffers from a large insertion loss and requires the use of expensive components, namely the EAM itself [2].

One of the simplest and most reliable techniques of generating picosecond optical pulses involves gain-switching a Fabry–Pérot (FP) semiconductor laser [3]. Gain-switching of FP lasers, as opposed to DFB lasers, is more attractive since these lasers are more cost-effective and they yield pulses with lower jitter [4]. However, a problem associated with employing FP lasers in such a gain-switched configuration is the multimoded output that would lead to the pulses suffering from a large amount of dispersion when transmitted through standard single-mode fiber. Injection of light, at an appropriate wavelength, into the gain-switched FP laser is a simple solution that could be used to achieve single-moded pulse generation. By varying the injected wavelength to select out different modes, the FP laser could potentially be used as a source of wavelength tunable pulses [5]. Other positive attributes brought about by light injection are enhancement in generated pulse quality where temporal jitter is improved and the chirp is reduced. Generally, the process of light injection can be achieved by external injection [3] or self-seeding [6].

External injection is a propitious way to inject CW light into the gain-switched FP laser in order to achieve high-quality single-mode pulses. Nevertheless, the requirement of an external CW source adds to the cost and the complexity of the overall system. Self-seeding of gain-switched lasers, on the other hand, is a much simpler technique since it negates the need for an additional CW source by using a wavelength-selective element placed in an external cavity. A small fraction of the output light, at a chosen wavelength, is re-injected back into the gain-switched laser. However, to ensure optimum operation [pulses with reduced jitter and chirp and enhanced sidemode suppression ratio (SMSR)], the light must be re-injected into the laser cavity during the pulse build-up time (within a given time window). This could be achieved in two ways, namely, by tuning the repetition rate to a multiple of the inverse of the light round-trip time in the cavity, or by using an optical delay line to change the external cavity length [7]. Such an imposition reduces the flexibility of the self-seeding technique, as a minor alteration in the cavity length would require tuning of the repetition rate or vice versa.

In this letter, we propose a novel self-seeding technique that yields cavity length independent operation allowing continuous repetition rate tuning of the self-seeded gain-switched (SSGS) laser. This attribute is achieved by employing a highly linearly chirped fiber Bragg grating (LC FBG) as a wavelength-selective element in the external cavity. The reflected gain-switched pulses are dispersed to such an extent that temporal overlap occurs between them. This overlap creates a pseudo-CW-like signal that is re-injected into the gain-switched laser. Hence, optimum single-moded SSGS pulse generation with cavity length independent continuous repetition rate tunability is achieved.

II. EXPERIMENTAL SETUP

The experimental setup used in this work is illustrated in Fig. 1. The FP laser used was a commercially available 1.5-μm InGaAsP device manufactured for use in 10-Gb/s systems, with

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The authors are with the Research Institute for Networks and Communications Engineering, Dublin City University, Glasnevin, Dublin 9, Ireland (e-mail: robert.maher@eeng.dcu.ie).

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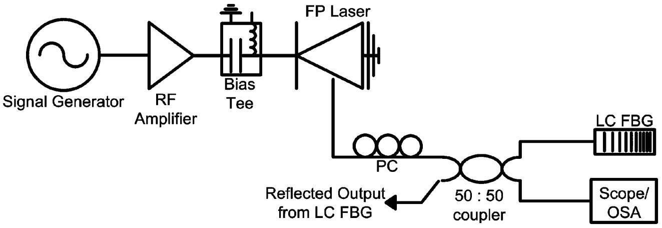

Fig. 1. Experimental setup.

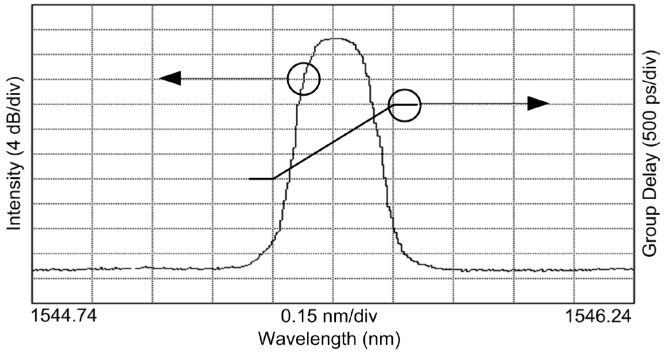

Fig. 2. FBG reflection and group delay profiles.

a threshold current of 10 mA and a longitudinal mode spacing of 1.2 nm. The laser output power, at a bias of 50 mA, was measured to be 6 mW after being coupled via a GRIN lens fiber pigtail. Gain-switching of the FP laser was achieved by applying a dc bias of 50 mA in conjunction with a 28-dBm sinusoidal signal at a repetition rate of 10 GHz (using a bias tee). This provided a current swing of 250 mA, which is sufficient to bring the laser well below threshold, thus providing a good ON–OFF extinction (>30 dB). Self-seeding of the gain-switched laser diode was accomplished using an external cavity (length of cavity: 4 m) containing a polarization controller (PC), a 3-dB splitter, and an LC FBG. As shown in Fig. 2, the LC FBG had a central wavelength of 1545.13 nm, with a 3-dB reflection bandwidth of 0.128 nm and a peak reflectivity of 85.1%. The grating was 131 mm in length with a rejection ratio greater than 30 dB and portrayed a dispersion coefficient of 4957.8 ps/nm.

In order to achieve optimum SSGS pulse generation, the peak emission wavelength of the FP laser was temperature tuned to the corresponding reflection wavelength of the grating. The target wavelength of 1545.13 nm was achieved by temperature tuning the FP laser to 22 °C. The SSGS pulses were characterized using an optical spectrum analyzer with a resolution of 0.05 nm and a 50-GHz pin photodetector in conjunction with a 50-GHz digitizing oscilloscope. The reflected pulses that are dispersed and fed back to the gain-switched laser were monitored at the second input arm of the 50 : 50 coupler (as shown in Fig. 1).

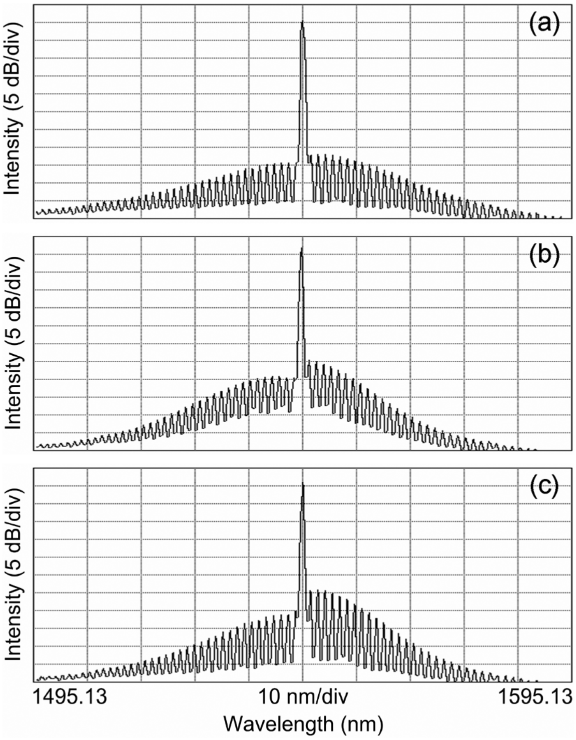

Fig. 3. Single-moded optical spectra at varied repetition rates of (a) 10, (b) 5, and (c) 2.5 GHz.

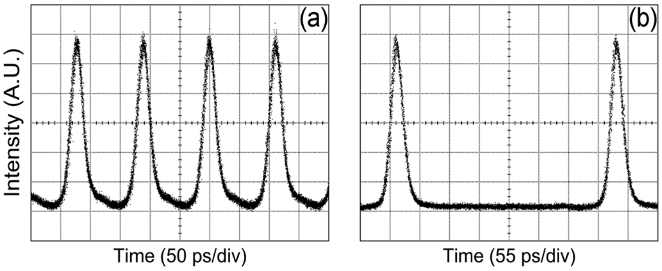

Fig. 4. SSGS pulses at repetition rate of (a) 10 and (b) 2.5 GHz.

III. Results and Discussion

The repetition rate was tuned from 10 GHz down to 2.5 GHz (500-MHz steps) in order to verify the cavity length independence under self-seeding with the highly LC FBG. Fig. 3 shows the spectra of the SSGS pulses at various repetition rates (10, 5, and 2.5 GHz). These figures clearly illustrate the fact that the SSGS pulses still portray an acceptable SMSR of about 30 dB [8] at each of the repetition rates. It is important to note that the frequencies mentioned are exact values and not frequencies tuned to a subharmonic of the inverse cavity roundtrip time. In all previous work carried out on self-seeding of gain-switched lasers, the repetition frequency or the cavity length was altered in order to keep within the limits of the feedback time window that ensures optimum pulse generation.

Combined with a constant SMSR, the temporal duration of the gain-switched pulses remained almost constant over the entire repetition rate tuning range of 7.5 GHz. Fig. 4 displays the output SSGS pulses at repetition rates of 10 and 2.5 GHz.

The measured widths (full-width at half-maximum) of the pulses at 10- and 2.5-GHz repetition rates were 30 and 31 ps, respectively. The 3-dB spectral width was measured to be around 0.58 nm which when combined with a pulsewidth of 30 ps yields a time bandwidth product (TBP) of 2.2. Such a large TBP indicates that the pulses are heavily chirped. This chirp should enable the pulses to be compressed to durations less than 10 ps [9].

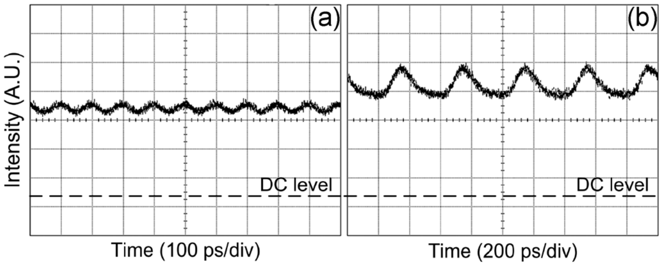

Fig. 5. Optical feedback from LC FBG (a) 10 and (b) 2.5 GHz.

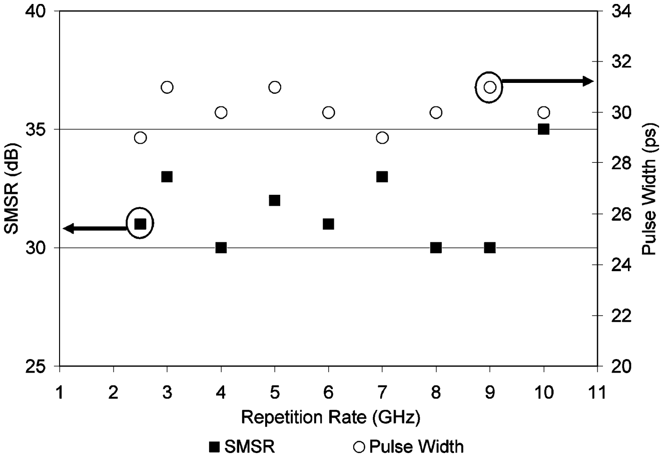

Fig. 6. SMSR and pulsewidth as a function of repetition rate.

Oscilloscope traces of the reflected (feedback) signal from the highly LC FBG at two different repetition rates of 10 and 2.5 GHz are shown in Fig. 5(a) and (b), respectively. The average signal powers fed back at 10 and 2.5 GHz are −10 and −9 dBm.

The high dispersion factor associated with the LC FBG used is responsible for the broadening of the pulses which causes temporal overlap between them. As can be seen in Fig. 5, this overlap yields a CW-like feedback into the gain-switched laser cavity. The degree of overlap between these dispersed pulses is much higher when the repetition rate is at 10 GHz rather than 2.5 GHz. This is essentially due to the 10-GHz period being much smaller (100 ps) than the 2.5-GHz period (400 ps). The ripples observed in the feedback signal cause minor fluctuations in the width and SMSR of the output pulses. However, within the range of the repetition rates used (10 to 2.5 GHz), it is important to note that the SMSR is always >30 dB and the pulsewidth is <32 ps. This could be attributed to the signal having sufficient CW power (adequate overlap due to broadening). The variation of the SSGS pulse SMSR and temporal widths as a function of the repetition rate have been plotted in Fig. 6.

The SMSR remains relatively stable over the entire frequency range. More importantly, it remains above 30 dB at all repetition frequencies, which is deemed adequate for high-speed optical communication systems. The pulsewidth also remains approximately constant demonstrating that the pulse source operates consistently across the entire repetition frequency tuning range.

IV. CONCLUSION

We have demonstrated a novel self-seeding technique that incorporates an LC FBG that disperses the output gain-switched pulses. The dispersed pulses provided a CW-like feedback into the gain-switched laser cavity. This CW feedback, mimicking an external injection scenario, overcomes the limitation associated with the self-seeding technique. Hence, using the proposed method, we have the potential of continuously tuning the repetition rate and maintaining optimum pulse generation without tuning the cavity length. Experimental results obtained show that pulses exhibiting 30-dB SMSR and 30-ps widths are generated over a wide range of modulating frequencies. Further development of this pulse source may be achieved by using a wavelength tunable grating, to achieve wavelength tunable pulse generation. The cost and footprint of such devices could also be reduced by integrating the FBG and FP laser.

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