Generation of Widely Tunable Picosecond Pulses With Large SMSR by Externally Injecting a Gain-Switched Dual Laser Source

A. M. Clarke, P. M. Anandarajah, and L. P. Barry

***Abstract*—The authors demonstrate a procedure of generating picosecond optical pulses that are tunable over a wide wavelength range (65 nm) and have very high spectral purity side-mode suppression ratio [(SMSR)$>$ 60 dB]. The large tuning range is obtained by employing external injection into a gain-switched source containing two Fabry–Pérot lasers. The use of a widely tunable Bragg grating at the output improves the SMSR such that it exceeds 60 dB over the entire tuning range.**

***Index Terms*—External injection, optical fiber communications, optical pulse generation, semiconductor laser, wavelength tunable source.**

I. Introduction

As THE demand for high-speed communications applications such as wavelength-division multiplexing (WDM) and optical time-division multiplexing (OTDM) continues to grow, there will be an increasing need to develop optical pulse sources suitable for these systems. Current trends may result in the operation of optical communication systems at line rates of 40 Gb/s and beyond, thereby making it more likely that return-to-zero coding be used for data transmission, as it is easier to compensate for dispersion and nonlinear effects in the fiber [1]. Furthermore, next-generation WDM systems that employ dynamic provisioning with the use of wavelength tunability are attracting a lot of interest. Thus, the key requirements on picosecond pulse sources to be used in high-speed communications applications will include broad wavelength tuning range, a high side-mode suppression ratio (SMSR), variable repetition rates, low timing jitter, and small frequency chirp [2]–[4].

Picosecond pulse generation can be accomplished through various methods, such as external modulation of a continuous-wave (CW) light signal [4], mode locking [5], and gain switching [6]. Gain switching of a semiconductor laser diode is probably one of the most reliable methods to generate optical pulses, and by employing self seeding [7] of a gain-switched Fabry–Pérot (FP) laser, it is possible to obtain high-quality wavelength tunable single-mode pulses which have low timing jitter and good spectral purity. Nonetheless, a major disadvantage with the self-seeded gain-switched (SSGS) scheme is that the length of the external cavity has to be continuously tuned so that the pulse repetition frequency is an integer multiple of the cavity round-trip frequency. An alternative technique entails external injection of light from a CW source into a gain-switched laser [8]–[10]. No adjustment of the repetition frequency or external cavity length is required in this case. Thus, external injection provides a more stable operation, even though a CW tunable laser is commonly required. Recent work has established that as the number of channels in a WDM system using SSGS pulse sources increases, the specifications on the required SMSR due to cross-channel interference may become very stringent [3]. Thus, if externally injected gain-switched lasers are to be used in future high-speed systems, it will be necessary to improve the SMSR of these sources to beyond 30 dB.

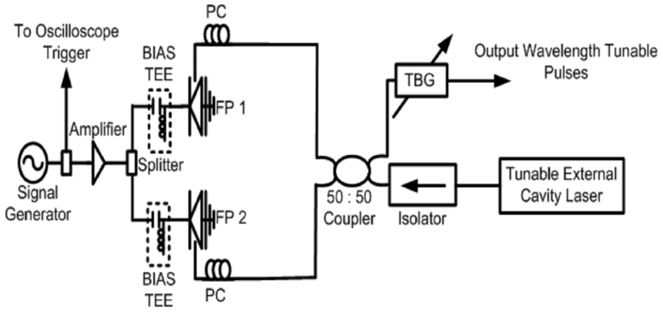

Fig. 1. Experimental setup for the generation of widely tunable externally injected gain-switched pulses.

In this letter, we build on recent research we have undertaken which involved self-seeding of a gain-switched dual laser source [11]. This article demonstrates the use of external injection into a gain-switched transmitter comprising of two FP lasers to generate picosecond pulses that are tunable over 65 nm, with SMSRs in excess of 60 dB over the entire tuning range. This is the largest tuning range and SMSR that has ever been achieved for an optical pulse source based on gain-switched laser diodes.

II. Experimental Setup

The experimental setup is illustrated in Fig. 1. The lasers FP1 and FP2 are commercial 1.5-μm InGaAsP devices, with threshold currents of 19 and 26 mA, respectively. The lasers were chosen so that their gain profiles provided only a small overlap, which corresponds to the maximum wavelength of FP1, and the minimum wavelength of FP2, at which we can achieve

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The authors are with the Research Institute for Networks and Communications Engineering, School of Electronic Engineering, Dublin City University, Dublin 9, Ireland (e-mail: liam.barry@eeng.dcu.ie).

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suitable SMSRs using the external injection configuration. Continuous wavelength tuning of the laser modes over the gain profiles of the two devices can be achieved by temperature controlling the diodes. The gain-switching process involves applying a sinusoidal modulation signal (peak-to-peak current ~200 mA; frequency ~2.5 GHz) to both lasers, in addition to dc bias currents of 15 and 26 mA for FP1 and FP2, respectively. The optical signal from both lasers is then coupled into fiber using a GRIN lens fiber pigtail. External injection requires injecting CW light from a tunable external cavity laser (ECL) into one of modes of the two FP lasers via an isolator, a 3-dB coupler, and a polarization controller (PC). The PC is varied in order to ensure optimum coupling of the injected light from the ECL into the selected FP laser cavity, which in turn optimizes the SMSR of the laser output. The output power of the CW source is set at -3 dBm, however, taking into account various losses, we estimate the injection level into the gain-switched sources to be about -13 dBm. The resulting single-mode output obtained after external injection into one of the FP lasers, together with the gain-switched signal from the FP laser that is not affected by the external injection (because the signal injected from the ECL does not lie within the gain curve of this FP diode), is then passed through a tunable Bragg grating (TBG) filter. The TBG has a bandwidth of 0.23 nm, a wavelength tuning range of 1460–1575 nm, and an insertion loss of 5 dB. The filter is used to eliminate the optical output from the gain-switched FP laser that is not influenced by the external injection, and also to enhance the SMSR of the generated pulses. The output pulses are characterized using a 50-GHz photodiode in conjunction with a 50-GHz oscilloscope, and an optical spectrum analyzer (OSA) with a 0.05-nm (6 GHz) resolution.

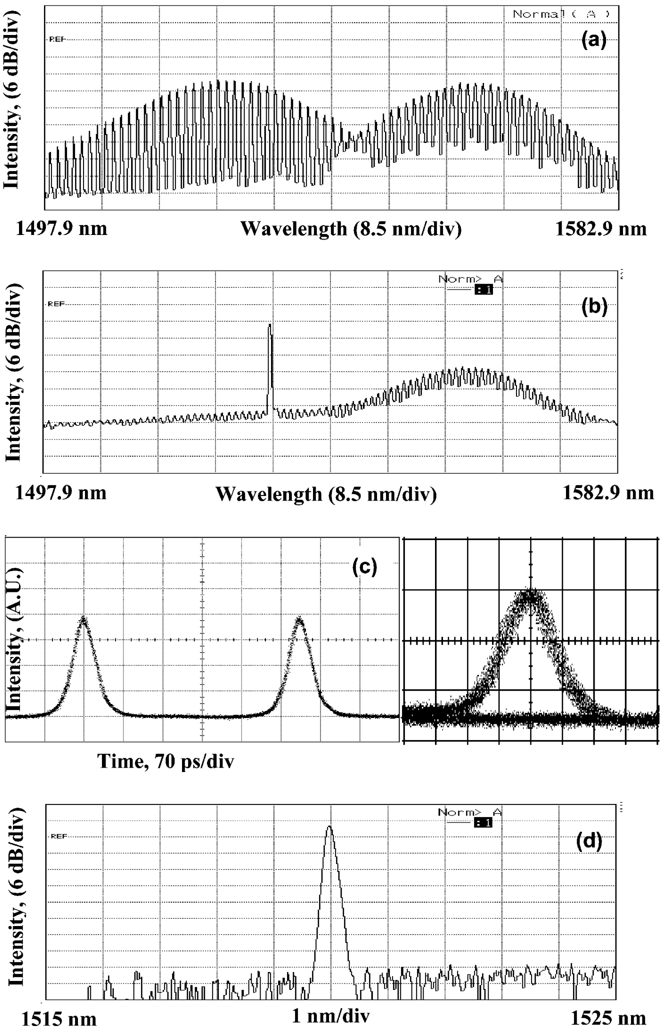

Fig. 2. (a) Optical spectrum of dual gain-switched source, (b) spectrum before the filter at 1519.9 nm, (c) pulse at 1519.9 nm (with inset showing extinction ratio), and (d) spectrum after the filter at 1519.9 nm.

III. RESULTS AND DISCUSSION

The optical spectrum of the dual wavelength signal from the gain-switched lasers, without external injection, is shown in Fig. 2(a). It can clearly be seen that by combining the output of the gain-switched lasers in the wavelength domain, the composite span of the laser profiles that could be used for seeding has been greatly increased. The peak of the spectrum for FP1 is at 1524 nm, while the peak of the spectrum for FP2 is at 1561 nm. As we can see from the composite spectra of the two gain-switched lasers, the spectra from the individual gain-switched devices overlap at about 16 dB down from the peak of the spectra.

Different longitudinal modes of each FP laser were selectively excited when the seeding wavelength from the ECL was tuned near the center of any desired mode. Fig. 2(b) displays the resulting spectral output before the optical filter showing good SMSR for the seeded gain-switched diode. With the addition of the filter, the optical output from the unseeded FP laser is eliminated, and the SMSR of the output pulses is improved such that it becomes almost impossible to detect the side-modes above the noise floor of the OSA. The resulting SMSR is around 60 dB for the entire wavelength tuning range that can be achieved with this setup. Examples of the temporal (nonaveraged) and spectral profile of the output pulse (at 1520 nm) are shown in Fig. 2(c) and (d), and we can clearly see the excellent temporal and spectral purity of the pulse source. The pulse duration was about 28 ps while the spectral width was approximately 20 GHz (this spectral width is clearly not limited by the bandwidth, 29 GHz, of the optical filter), resulting in a time-bandwidth product of 0.56 (slightly larger than that for transform-limited Gaussian pulses). The extinction ratio of the generated pulses was measured to be 25 dB, and the timing jitter was estimated to be less than 1 ps. The timing jitter was measured to be 1 ps by using histogram analysis on an Agilent Digital Communications Analyzer, however, given that 1 ps is the lower limit on this measurement, we conclude that the jitter is actually less than 1 ps.

Fig. 3 illustrates the SMSR as a function of wavelength, across the tuning range of the pulse source. We obtain values greater than 60 dB over the complete wavelength span. It is important to note that the use of the filter in this setup is dependent on achieving a suitably high SMSR from the gain-switched externally injected laser before the filter (we have verified that this value remains above 30 dB in our work). If this is not the case then mode-partition-noise could seriously affect the temporal quality of the pulse source (from Fig. 2(c), this is clearly not the

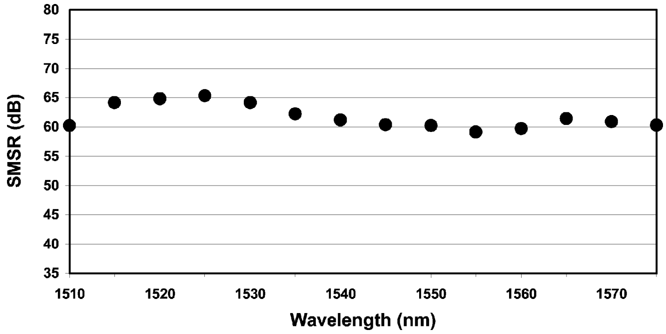

Fig. 3. SMSR of output pulses as a function of wavelength.

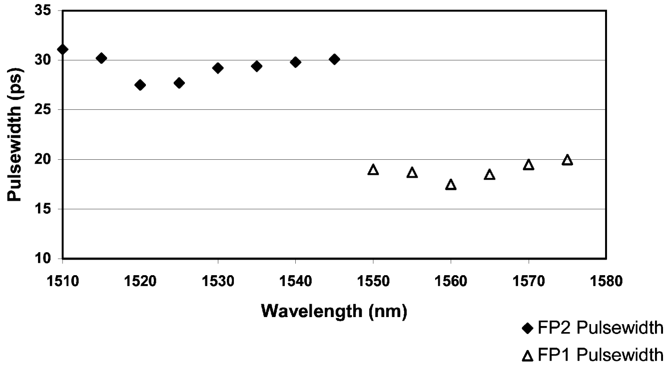

Fig. 4. Pulsewidths of optical output pulses as a function of wavelength tuning range.

case). Fig. 4 shows the variation in pulsewidth over the tuning range. The variation in pulsewidth around 1545 nm is due to the external injection from the ECL changing from seeding FP1 to seeding FP2. Differences in various physical parameters (e.g., gain) of the two lasers are responsible for the variation in output pulsewidth. In addition, the output spectral width from the higher wavelength laser (FP2) is slightly increased (from 20 to 29 GHz), and in this case, does become limited by the bandwidth of the output filter. Our experimental results exhibited very stable operation even at the crossover section from operation with FP1 to FP2. This is achieved because there is no overlap between the modes from the two different FP lasers, and thus, we never inject light into the same mode of both FP lasers at the same time.

IV. CONCLUSION

This experiment has demonstrated a simple and effective procedure of generating widely tunable ($\sim$65 nm) pulses with impressive SMSR ($>$60 dB) by using external injection into a source consisting of two gain-switched FP lasers. Such a source could play a vital part in ensuring the optimal performance of high-speed hybrid WDM/OTDM optical communication networks. It should also be noted that the tuning range could be expanded further by introducing a third FP laser with an appropriate spectral profile, and that by simultaneously injecting light into the FP lasers used, it may also be possible to develop a multiwavelength pulse source.

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