

Optical Pulse Generation at Frequencies up to 20 GHz Using External-Injection Seeding of a Gain-Switched Commercial Fabry–Pérot Laser

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Abstract—We demonstrate that by using strong external-injection seeding of gain-switched Fabry–Pérot (FP) lasers, it is possible to generate optical pulses at repetition rates far in excess of the laser bandwidth. Experimental results illustrate the generation of optical pulses at frequencies up to 20 GHz from a FP laser with a 3-dB bandwidth of only 8 GHz. The optical pulses generated have a duration around 12 ps, and a spectral width of 40 GHz.

Index Terms—External injection, gain-switching, optical communications, optical pulse generation, semiconductor lasers, ultra-fast optics.

I. INTRODUCTION

THE DEVELOPMENT of optical pulse sources at high repetition rates (>10 GHz) is extremely important for use in future high-speed optical communications systems [1]. One of the simplest and most reliable techniques available to generate high-quality, single-mode, optical pulses involves self- or external-injection seeding of a gain-switched Fabry–Pérot (FP) laser [2]–[7]. This technique has been shown to be capable of producing very low-jitter optical pulses [3], [6] that can be tuned over wavelength ranges approaching 40 nm. As for the repetition rate, at which pulses can be generated using a gain-switched laser diode, it is essentially limited by the bandwidth of the device. In order to achieve gain-switched operation at frequencies in excess of 10 GHz, it is usually necessary to have specially developed laser diodes with bandwidths greater than 10 GHz [5], [7]. However, by using strong external-injection of light into a laser, it has also been shown that the laser bandwidth can be significantly enhanced [8], [9]. This bandwidth improvement should thus be useful for increasing the frequency at which pulses can be generated using the gain-switching technique with commercial lasers. In this letter, we experimentally demonstrate how strong external-injection into a gain-switched FP diode increases the bandwidth of the laser such that pulses can be generated at frequencies up to 20 GHz, which is far beyond what would be possible with the laser's inherent bandwidth of 8 GHz. The optical pulses generated have pulsewidths around 12 ps and spectral widths of 40 GHz.

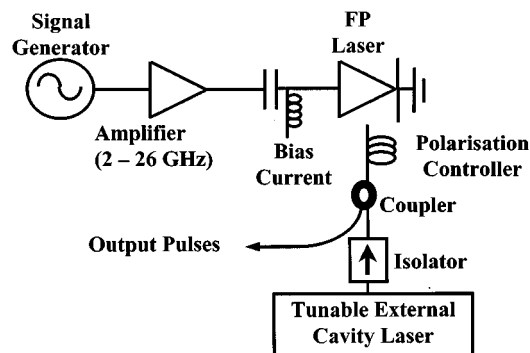


Fig. 1. Experimental setup for external-injection seeding of gain-switched FP laser.

II. EXPERIMENTAL SETUP AND RESULTS

Fig. 1 shows our experimental setup. The FP laser used was a commercial $1.5\text{-}\mu\text{m}$ InGaAsP device from NTT Electronics, with a threshold current of 26 mA and a longitudinal mode spacing of 1.25 nm. The laser is manufactured for use in 10-Gb/s systems and has a specified bandwidth of around 8 GHz at an injection current level of 50 mA. Gain-switching was carried out by applying a dc bias current in conjunction with a sinusoidal modulation to the laser, and the optical signal from the laser was then coupled into fiber using a GRIN lens fiber pigtail, which is antireflection coated (to prevent reflections back into the laser). External-injection seeding of the gain-switched laser was carried out by injecting light from a tunable external cavity laser (ECL) into the gain-switched laser diode via an isolator, a fiber coupler, and a polarization controller. The optical pulses generated from the experimental arrangement were then characterized in the spectral and temporal domains. The optical spectra were examined using an optical spectrum analyzer with a resolution of 0.07 nm, and the temporal measurements were conducted using a 50-GHz pin detector followed by an Agilent 50-GHz sampling oscilloscope. The total time resolution of our measurement system is 12 ps; this has been measured with the use of a subpicosecond optical pulse source [10].

Before gain-switching the laser, we initially measured its modulation response with and without external injection, using a 40-GHz network analyzer. Fig. 2 shows the response when the free-running laser was biased at 40 mA. The relaxation frequency was 7.3 GHz, and the 3-dB bandwidth was around 8.4 GHz in this case. We then injected light from the ECL into the FP laser, as shown in Fig. 1, and tuned the wavelength of

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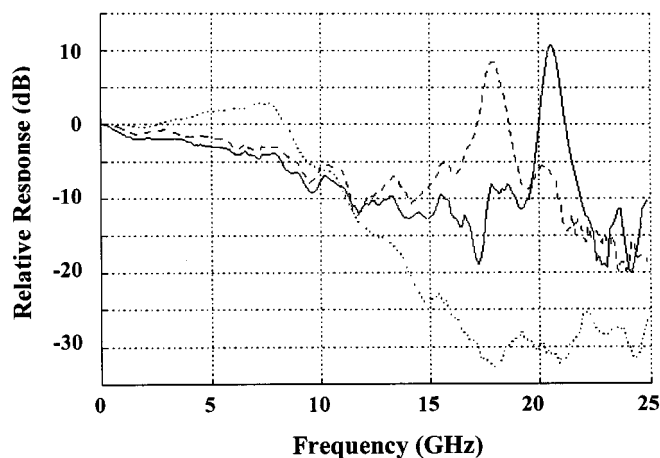


Fig. 2. Modulation response of free running FP laser diode with applied bias current of 40 mA (dotted line), and response of laser diode with external injection levels of 3 mW (solid line) and 1.5 mW (dashed line) from tunable ECL.

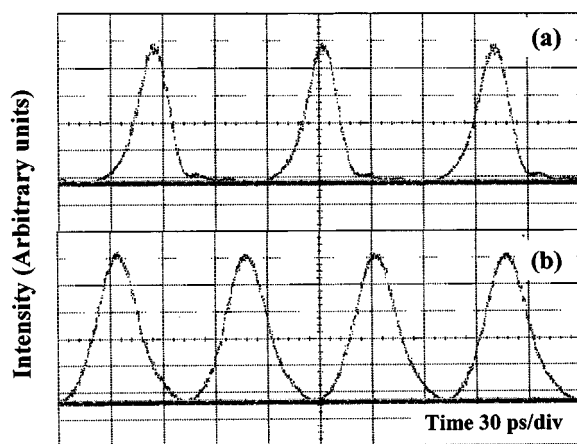


Fig. 3. Optical pulse train from gain-switched FP laser without external-injection at frequencies of (a) 10 GHz and (b) 13 GHz. The zero optical power level is also shown in the figure.

the injected light to one of the longitudinal modes of the FP laser. The polarization controller was varied to maximize the sidemode suppression ratio (SMSR) of the output spectrum from the laser, in order to ensure maximum coupling of light from the ECL laser into the FP diode. The output power from the ECL was then set to 4 dBm (maximum possible), and its wavelength was tuned slightly to obtain the maximum relaxation frequency. The resulting response of the laser (biased at 40 mA) was as shown in Fig. 2, and we can see that the relaxation frequency was greatly enhanced to 21 GHz. By gradually reducing the output power from the external cavity laser, we were also able to reduce the relaxation frequency from 21 GHz to any frequency down to 10 GHz. The modulation response when the output power from the ECL was set to 1 dBm is also shown in Fig. 2.

The laser was then initially gain-switched at a frequency of 10 GHz without external injection, and optimum operation (minimum output pulsewidth) was achieved with a bias current of 42 mA and a sinusoidal modulation power of 28 dBm. Fig. 3(a) displays the optical pulses generated from the FP laser; the pulsewidth (after deconvolving the time resolution of

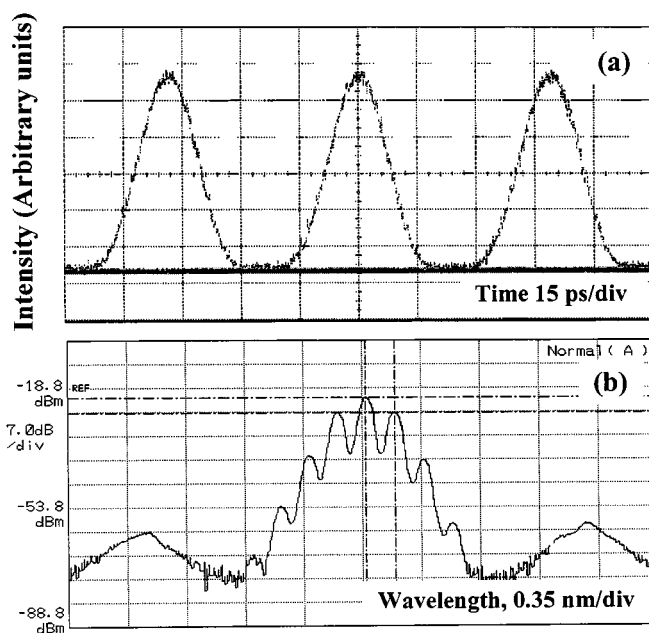


Fig. 4. (a) 20 GHz optical pulse train (with zero optical power level shown) and (b) associated optical spectrum, from gain-switched laser with external-injection level of 4 dBm from ECL.

the measurement system) was around 18 ps. We then proceeded to increase the frequency of the modulation signal applied to the laser diode, and adjust the bias current to obtain optimum pulses from the setup. At frequencies around 13 GHz, it became increasingly difficult to properly gain switch the laser [as shown in Fig. 3(b)], due to the limited bandwidth displayed in the dashed line of Fig. 2, and at frequencies beyond 15 GHz, the modulated optical signal from the laser became negligible. We then injected light from the continuous-wave (CW) external cavity laser into the gain-switched FP laser, as shown in Fig. 1, and tuned the wavelength of the injected light, and the polarization controller as explained earlier. The output power from the CW laser was set to 4 dBm, and taking into account the attenuation of the isolator and the fiber coupler, and the coupling loss between the GRIN lens and the laser diode, we estimate the external injection level into the FP laser to be around -4 dBm. The laser was subsequently gain-switched at 10 GHz as before with a modulation power of 28 dBm; however, this time the optimum bias current required was 29 mA. The frequency of the applied modulation signal was then increased, and the bias current adjusted to optimize the laser gain-switching. Fig. 4 displays the optical output pulses and associated spectrum when the laser was gain-switched using a bias current of 48 mA, and a modulation signal power of 26 dBm at 20 GHz. The pulse duration (after deconvolving the measured pulsewidth with the resolution of the measurement system) and spectral width were 12 ps and 40 GHz, respectively, giving a time-bandwidth product of 0.48, which is close to the time-bandwidth product of transform-limit Gaussian pulses (0.44). We can also see from Fig. 4(b) that the SMSR of the pulse source was nearly 40 dB. By subsequently tuning the wavelength from the ECL to different modes of the FP laser diode, we were also able to successfully tune the high-frequency pulse train over a range of around 12 nm. Fig. 5 displays the temporal output from the

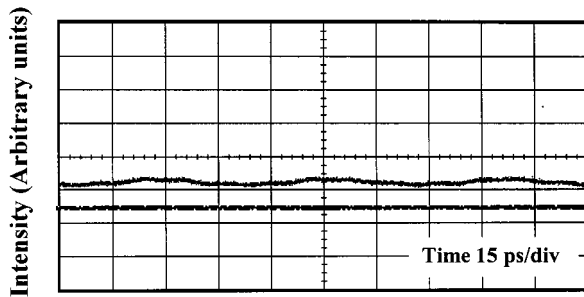


Fig. 5. Output signal from laser diode when injection level from ECL was reduced to 1 dBm (with the zero optical power level also displayed) with 20-GHz modulation applied.

laser under the same conditions as those used for Fig. 4, except that the injected power from the ECL was set to 1 dBm. As we can see, the reduced injection level alters the response of the laser (see Fig. 2) such that it cannot be gain-switched at 20 GHz.

III. DISCUSSION

Previous studies on the bandwidth enhancement of lasers diodes under the influence of external-injection have shown that it is possible to increase the bandwidth by a factor of around three [8], [9]. In our experiment, we use a laser with a free running bandwidth of around 8 GHz, and we have managed to achieve a resonance frequency of beyond 20 GHz by using the strong external-injection. This bandwidth enhancement thus makes it possible for us to gain-switch the laser at far higher frequencies than what would be possible with the lasers inherent bandwidth. It should also be noted that the optical pulses generated from the setup are nearly transform limited (time-bandwidth product of 0.48). This is because the external injection is not only responsible for the bandwidth enhancement, but also results in significant chirp reduction on the output signal [7], [8], [11].

The resulting optical pulsewidth due to injection seeding, as the wavelength of the injected light is varied, has been studied in [7]. It was found that for negative frequency detuning, the distortion in the pulse waveform can result in shorter optical pulses than would be obtained without injection seeding. In addition, from [8], the optimum improvement in relaxation frequency is obtained by external injection at frequencies which are negatively detuned. Since our ECL is tuned to optimize the relaxation frequency, this is therefore consistent with the slight reduction in pulsewidth obtained between the 10-GHz pulses

without injection-seeding, and the 20-GHz gain-switched pulses with external injection. In addition, the pulsewidth generated under gain-switching conditions will normally decrease as the frequency of the electrical modulation applied increases (laser will turn off faster, resulting in a reduced fall time on the pulse).

In conclusion, we have demonstrated the generation of optical pulses at frequencies up to 20 GHz by using strong external-injection into a gain-switched laser. The commercial FP laser used has an inherent bandwidth of 8 GHz, but the external-injection increases the bandwidth sufficiently to generate near transform-limit pulses at repetition rates well in excess of the lasers free-running bandwidth. By employing this technique with higher speed lasers, it should thus be feasible to develop optical pulse sources suitable for use in optical systems with single-channel bit rates of 40 Gb/s.

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