40 GHz Dual Mode-Locked Widely-Tunable Sampled-Grating DBR Laser

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Abstract: Generation of 40 GHz alternate-phase pulses is demonstrated using a dual mode-locked sampled-grating DBR laser. More than 10 dB extinction and >20dB sidemode suppression ratio is measured over the >40nm tuning range of the laser. Based on captured phase noise spectra, the timing jitter is estimated in the 0.35ps-0.41ps range. The demonstrated pulse dual-mode laser would form an attractive basis for an integrated 40 Gbps RZ transmitter.

1. Introduction

High-speed optical communications systems with transmission rates of 40 Gbps have been developed for future wavelength multiplexed high-capacity systems. It has been found that using return-to-zero (RZ) modulation format instead of the non-return-to-zero (NRZ) counterpart is advantageous in terms of tolerance to fiber nonlinearity [1] and receiver sensitivity [2]. Usually, transmitters with RZ modulation format require pulse-carving and data encoding. An attractive option is to use a dual mode-locked laser for optical pulse generation, where two lasing modes are synchronized either by optical or electrical injection of a clock-reference. All generated optical power here contributes to the generated pulse train, eliminating the insertion loss unavoidable using a modulator based approach. Further, spectrally compact alternate-phase pulses, also termed carrier suppressed RZ (CS-RZ) optical pulses are formed. Although several dual mode optical sources have been demonstrated for 40 GHz applications [3-6], none has to date demonstrated wide wavelength tunability in a monolithically integrated source.

In this paper, we demonstrate a widely tunable dual-mode pulse source based on a sampled-grating distributed Bragg reflector (SGDBR) laser, integrated with a semiconductor optical amplifier (SOA), producing a 40 GHz clock source over a tuning range exceeding 40 nm. Similar devices have previously been monolithically integrated with a Mach-Zehnder modulator [7], and in an extended perspective, the source described in this paper can be monolithically integrated with a fast MZ modulator to form a widely tunable RZ transmitter for either amplitude or phase encoded pulses. Alternative potential applications include wavelength-agile optical clock recovery [8], or carrier-generation for millimeter-wave analog applications [9].

2. Experiment

The device used for this demonstration is a widely-tunable SG-DBR laser, integrated with a semiconductor optical amplifier (SOA) and an electroabsorption modulator (EAM). A schematic of the device is shown in Fig. 1. The device uses a common bulk quaternary waveguide for all sections. Passive sections, such as modulator and laser tuning sections are defined by selective removal of an offset quantum-well layer. Wide tunability of the laser is achieved by imposing a different periodicity of the comblike reflection spectra of the sampled grating mirrors, such that only one pair of reflection peaks can overlap at a time. A small change in mirror tuning current will allow a different set of reflection peaks to come into alignment, resulting in a large shift in wavelength, i.e., the Vernier effect. A phase section is used for fine alignment of Fabry-Perot cavity modes with the mirror reflection peaks. An SOA and an EAM are also integrated with the SG-DBR. The former is employed to allow wavelength independent power leveling. The latter could be used for data encoding, but here it is designed for 2.5 GHz operation. More details about the device are given in reference [10]. Typical performance of an SG-DBR laser integrated with an SOA is more than 20 mW fiber-coupled output power, lower than 2 MHz linewidth, lower than –140 dB/Hz RIN and more than 40 dB sidemode suppression ratio over more than 40 nm wavelength tuning range.

The sampled grating mirrors are designed so that only one single stable axial mode can be supported at a time. Mode-jumps between cavity modes can be achieved by tuning the phase section of the SG-DBR laser, and unstable operation is observed at the boundary due to mode competition. When the device is used in dual mode operation for pulse-generation, the phase section is reversed biased and will function as a Franz-Keldysh modulator, with a higher bandgap than that of the gain section. The phase between the cavity modes is then adjusted by the combination of mirror tuning and gain section tuning. Ideally, a separate modulator section would have to be included in the cavity for improved operation. In an optimized device, front and back mirror sections are also optimized for a wide stable dual mode operation range, while retaining high sidemode suppression ratio. When injecting an RF carrier into the phase section, enhanced small signal modulation is generated if the modulation frequency matches to the cavity mode-spacing, illustrated by the captured oscilloscope trace shown in Fig. 2. After adjusting the phase between two cavity-modes, stable dual-mode operation is now achieved and synchronized by the injected RF carrier. The two modes will result in an envelope modulation with high modulation index. An extinction ratio better than 10 dB is estimated from Fig. 2, where the zero-level is limited by the bandwidth of the oscilloscope and the photodetector used to capture the waveform, both specified at 50 GHz. Because the phase section has not been designed for neither high-speed nor efficient loss-modulation, the required RF power is here large, up to +20 dBm, even to achieve the small modulation depth needed for mode-synchronization. In principle, using a modulator section designed for high speed electroabsorption modulation, a smaller modulation signal is sufficient for pulse generation, compared to that needed when an external optical modulator is used. Because of the asymmetric location of the modulator within the laser cavity, these two modes can be locked at two different phases, corresponding to forward and backward-traveling waves. Even though single phase is observed under most operating conditions, simultaneous dual-mode locking at the two different locked phases can be observed at a balancing point.

3. Results

Mode synchronization is achieved in a narrow frequency range centered on the cavity-mode spacing, in this particular device centered around 40.2 GHz. As the injected RF frequency is detuned, the extinction ratio is reduced and the amplitude balance between the two modes is shifted until dual-mode synchronization is no longer possible, illustrated by Fig. 3. The 1-dB frequency range is around 300 MHz, and the frequency range with mode-synchronization is 900 MHz.

Dual mode-locking is possible at any wavelength within the tuning range of the laser. However, after tuning the wavelength, dual-mode operation will need to be reoptimized by a combination of gain and mirror tuning. When tuning the gain section from optimization, the resulting shift in cavity phase will first unbalance the power of the two modes and eventually transition to single-mode behavior. The 1-dB gain section tuning range is about 10mA, sufficiently large for stable long-term dual-mode operation. Figure 4 shows captured optical spectra for low, center and high wavelength. In all cases, the sidemode suppression ratio is better than 20 dB. Like other mode-locked laser where the mode-spacing is defined by the effective cavity length, the range of locking frequencies is determined and limited by device design. The center frequency remains well within the 1-dB frequency range throughout the tuning range of the laser. Similar frequency tolerance was observed with changing chip-temperature. The output power variations over the tuning range is consistent to what is observed during conventional single-mode laser operation, the gain and SOA bias held constant.

Figure 5 shows the captured RF spectrum at 100 kHz frequency span centered around 40.2 GHz signal and reveals the generation of a pure tone with little excess noise. At larger spans some minor noise peaks can be observed in the MHz-region. This noise is due to random modulation of laser tuning sections originating from current sources and free-space RF pick-up. The magnitude of these noise peaks will be reduced if a shielded package and decoupling capacitors are used. This enhancement of noise in the MHz region can be seen in Fig. 6 where the phase noise spectral densities measured at three wavelengths; 1531 nm, 1548 nm and 1569 nm are compared to that of the injected RF carrier. The phase noise of the generated signal follows that of the reference down to >100 kHz, after which the excess noise is clearly visible. Integrating the phase noise from 1 kHz to 500 MHz, a total timing jitter of 0.41 ps, 0.35 ps and 0.38 ps were obtained for 1531 nm, 1548 nm and 1569 nm, respectively. The timing jitter of the reference was 0.19 ps, obtained in the same manner. Even though the timing jitter obtained from the phase noise spectra does not accurately represent all sources of timing jitter present in a real 40 GHz system, it serves well in giving a comparison to other sources when timing jitter has been obtained in a similar manner.

4. Summary

For the first time, a monolithically integrated source combining more than 40 nm wide tunability with 40 GHz pulse-generation is demonstrated. The device consists of a sampled-grating DBR laser where an intracavity EA modulator is formed by reverse biasing the phase section. Alternate-phase pulses are then generated by locking two cavity modes to an injected 40 GHz RF signal. The extinction ratio is estimated to be better than 10 dB and the sidemode suppression ratio is better than 20 dB throughout the tuning range of the laser. Timing jitter is calculated by integrating phase noise spectra and is in the 0.35 ps to 0.41 ps range. Improved jitter-performance will be obtained using proper packaging of the device. The robust frequency tolerance to temperature and wavelength variation would enable the design of a practical pulse-source for 40 or 43 Gbps applications with only minor design modifications compared to present devices. Further, the device is readily integrated with high-speed modulators and semiconductor amplifiers, to potentially form a compact, monolithically integrated 40 Gbps RZ transmitter.

5. References

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Figures:

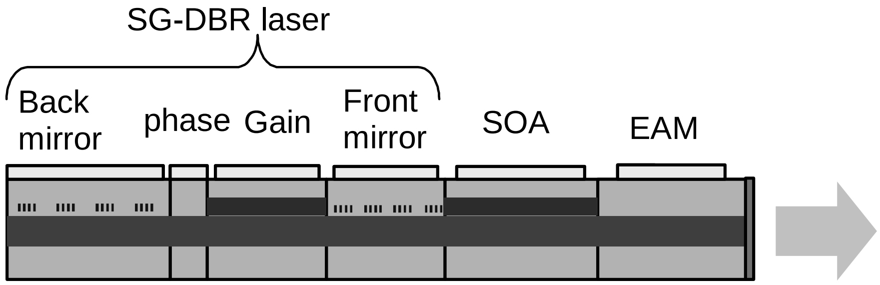

Fig. 1: Device schematic including the sampled-grating DBR laser, semiconductor amplifier and modulator.

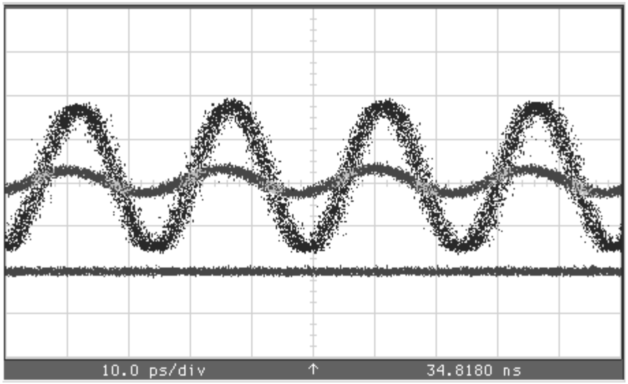

Fig. 2: Captured waveforms showing enhanced small signal modulation at the cavity mode-spacing and single-mode operation, pulse-generation by synchronized dual-mode operation, and the zero-level.

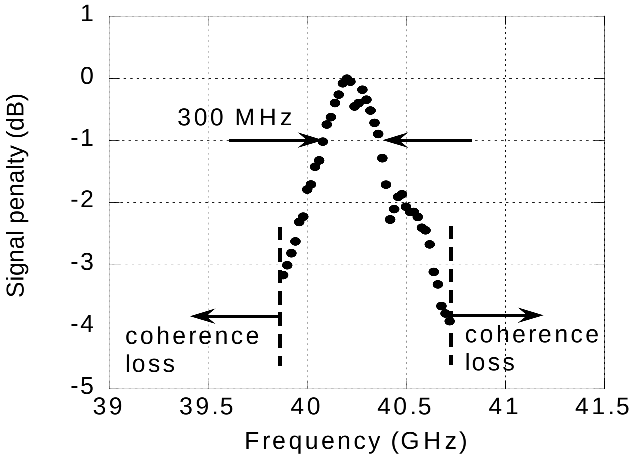

Fig. 3: Measured penalty in generated signal as a function of RF frequency at 1548nm with 1-dB frequency locking range and synchronization frequency range indicated.

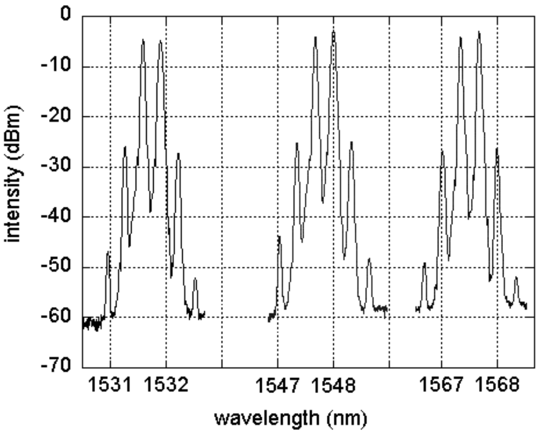

Fig. 4: Captured dual-mode optical spectra at low, center and high laser wavelength. Resolution bandwidth: 0.08 nm.

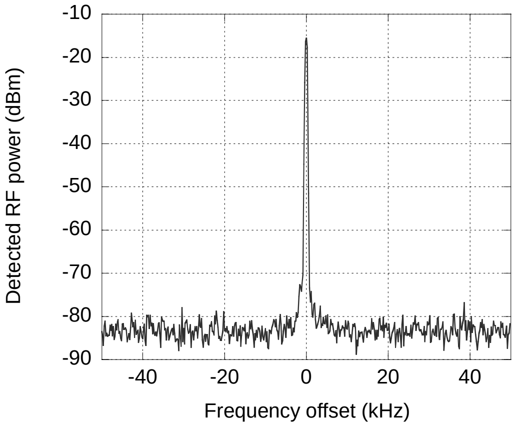

Fig: 5: Detected RF spectrum at 40.2 GHz and 100 kHz span. Resolution bandwidth: 1 kHz.

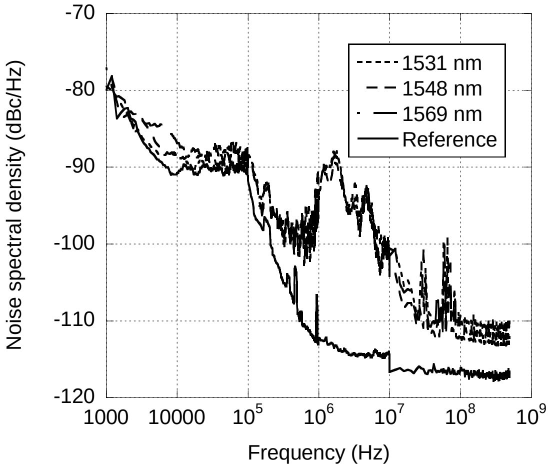

Fig. 6: Detected single-sideband phase-noise spectral density for low, center and high wavelength, and for the RF reference.