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Microsecond Optical Frequency Tuning of DFB Laser Diodes for Coherent Optical Frequency Domain Reflectometry

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Summary:

Optical frequency tuning ranges up to 600 GHz or 4.8 nm have been achieved within microseconds and a standard telecom DFB laser diode operating at 1550 nm. The dynamic optical frequency tuning is induced by electrical current pulse injection and measured using an interferometric setup. Potentially, low-cost sensor systems based on optical coherence tomography (OCT) or coherent optical frequency domain reflectometry (c-OFDR) could be realized, achieving sub-mm two-point range resolution or even better single-point range precision within a few microseconds for a single measurement.

Keywords: tunable lasers, semiconductor lasers, fiber optics, wavelength shift, fiber sensing

Tuning of laser diodes

Fiber bragg grating interrogators, c-OFDR and OCT exploit optical frequency tuning. Strain, temperature and distance can be measured using these techniques.

A larger optical frequency tuning range (FTR) enables better two-point range resolution in reflectometry, which is inversely proportional to the FTR. By driving a laser diode (LD) with a current pulse, the temperature and carrier density in the active zone dynamically changes which in turn produces a fast tuning of the optical frequency.

The FTR for sensor applications had first been investigated for current pulses in the millisecond-range [2]. The strong initial FTR led to the investigation of current pulses in the nanosecond-range with amplitudes exceeding the specified operating current by a factor of 30. Thereby, an FTR of 1.5 THz or 12 nm has been achieved with DFB-LD [1].

This work examines the relevant parameters for optical frequency tuning in the microsecond regime. Compared to nanosecond-pulses it might be possible to provide more energy within the optical pulse and therefore improve the signal-to-noise ratio.

Measurement setup

The optical tuning rate $\mathrm{d}\nu(t)/\mathrm{d}t$ of the LD is encoded in the optical power $P(t)$ (interferogram) at the Output of the Mach-Zehnder interferometer (MZI). The interferogram oscillates with the instantaneous beat frequency $f_{\mathrm{beat}}(t)$, which is calculated using the Hilbert Transformation Compensation Method. The instanteneous optical frequency

$$\nu(t) = \tau \cdot \int_{t_0}^{t_0+T} f_{\mathrm{beat}}(t)\,\mathrm{d}t \qquad (1)$$

during a time interval of duration T can then be calculated using the MZI delay τ. The FTR corresponds to the difference of the optical frequency at the beginning and end of the optical pulse.

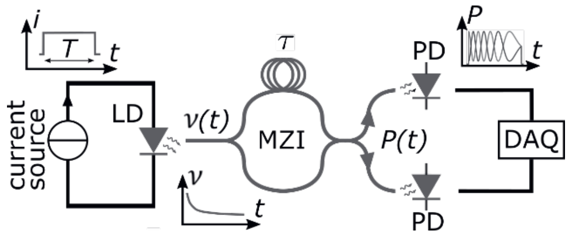

Fig. 1. A fiber-coupled LD is pulsed in the µs-range with an injection current. The thermal increase of the junction leads to optical frequency tuning which creates an interferogram at the MZI output.

Tab. 1 shows the specifications of the used DFB-LD LDM5S515-005.

Tab. 1. Specifications of the used DFB-LD.

LDM5S515-005			
Coax-package, optically isolated, fiber-coupled			
$\mathbf{I_{th}}$	12 mA	$\boldsymbol{\lambda_0}$	1549 nm
$\mathbf{P_{cw}}$	12 mW (optical)	$\mathbf{I_{cw}}$	150 mA

Results

Fig. 2 shows the dynamic tuning behavior for a 2 µs current pulse at 200 mA in 100 ns intervals.

During the injection, the LD incorporates a constant heating power. The transition of the junction temperature is exponentially dampened. Hence, the optical tuning rate $\mathrm{d}\nu(t)/\mathrm{d}t$ decreases with increasing time of current injection. During the first 100 ns, the FTR is 18 GHz and then drops to 2 GHz after 1 µs within equal observation length. Hence, 25% of the total 71 GHz FTR occur during the initial 5% of the optical pulse (and thus the optical energy).

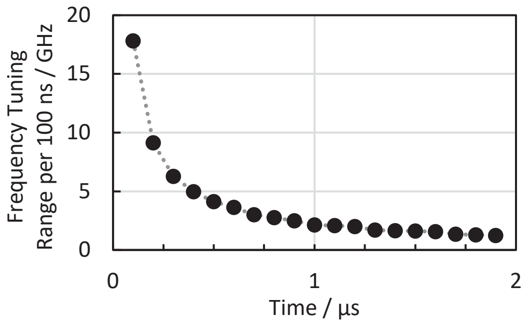

Fig. 2. FTR per 100 ns at 200 mA.

Fig. 3 shows the logarithmical dependence of the FTR on the current pulse width in the µs-range. Increasing the current pulse width from 1 µs to 10 µs doubles the FTR from 54 GHz to 106 GHz (196%), whereas a further increase to 20 µs yields an FTR of 121 GHz (114%). The optical tuning rate decreases for long pulses because the junction temperature reaches an equilibrium.

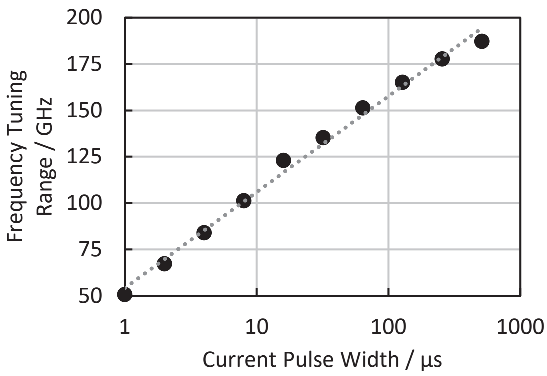

Fig. 3. FTR versus current pulse width at 200 mA.

At first, the optical tuning rate enhances when increasing the current pulse amplitude, followed by a section of linear dependency before the FTR seems to saturate (shown in Fig. 4 for a current pulse width of 10 µs). The maximum measured FTR for 1200 mA is 600 GHz (about 4.8 nm at 1550 nm). For higher current pulse amplitudes, light emission eventually drops to zero after some microseconds. This is likely due to the temperature dependent optical power and is yet to be examined. Therefore, measurements with current amplitudes above 1200 mA were not taken into account.

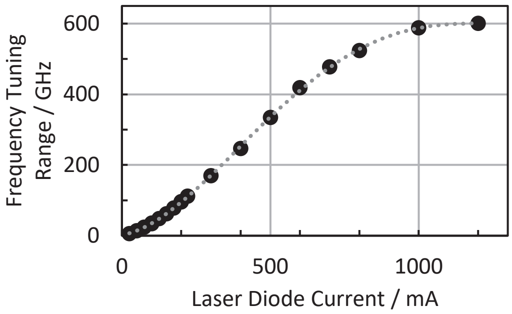

Fig. 4. FTR of a 10 µs pulse versus LD current.

Conclusion

The dynamic optical frequency tuning of a current pulsed standard 1550 nm telecom DFB laser diode in the microsecond regime has been measured with an interferometric setup. By using short current pulses with amplitudes up to eight times the specified cw-current, optical frequency tuning ranges of 600 GHz or 4.8 nm have been achieved.

While the optical frequency tuning range over current pulse width shows the expected behavior dominated by thermal transients in the laser chip, the maximum tuning range starts to saturate at high currents. This will be part of further examinations, together with reliability considerations and methods to linearize the strongly non-linear temporal frequency sweep.

With the presented results, low-cost sensor systems based on OCT or c-OFDR using standard telecom DFB lasers could be realized potentially, achieving sub-mm two-point range resolution or even better single-point range precision within microseconds. Beyond that, precision is largely dominated by the signal-to-noise ratio and thus, the object reflectivity, not discussed here.

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