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12 nm spectral shift with a VCSEL in the near infrared in a 10 µs time interval

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Summary:

An optical wavelength tuning range up to 12 nm has been achieved within 10 µs, using VCSELs operating in the near infrared. The range has been measured with an interferometric setup and an optical spectrum analyzer respectively. Potentially, low-cost sensor systems based on tunable diode laser absorption spectroscopy or coherent optical frequency domain reflectometry 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, VCSEL

Tuning of laser diodes

We present a method to tune the wavelength of a VCSEL in the near infrared (NIR) by 12 nm in a time interval of 10 µs. The heat dissipation from a current pulse induces a shift in the emission wavelength. This enables use in applications such as coherent optical frequency domain reflectometry (c-OFDR) or tunable diode laser absorption spectroscopy (TDLAS).

Previous publications in this field aim to tune a wide range of wavelengths within nanoseconds [2]. Another research focus is the linearization of wavelength sweeps [3].

The method presented here offers various advantages over other approaches of wavelength tuning and its linearization over time. The experimental setup is very simple and consists of only few and commercially available components. The overall spectral shift of 12 nm is considerably high for dynamic tuning in the microsecond range. The short duration of the pulse provides a possibility for measurements with only limited time available for data acquisition. Moreover, the lifetime of the laser diode (LD) increases by a low duty-cycle. Compared to wavelength tuning with nanosecond pulses, more energy is available due to the longer pulse duration, which potentially improves the signal-to-noise ratio.

Measurement setup

We measure both the overall spectral shift and the instantaneous wavelength during a 10 µs time interval.

The fundamental wavelengths of the used Vertilas VCSEL-LDs in TO-46 packages are 1577 nm and 1545 nm, respectively.

A laser diode controller (Thorlabs LDC 202C) injects a current into the LD. A signal generator applies a square pulse to its analog modulation input. The limited 3 dB-bandwidth of the LDC creates a gentle rise in the LD current, which is composed of the bias current i_{B} and a pulse amplitude i_{P} (Fig. 1). A temperature controller regulates the LD equilibrium temperature to approximately 21°C (thermistor $R_{\mathrm{TH}} = 12\ \mathrm{k\Omega}$). A fiber optic isolator prevents reflection of optical power into the LD.

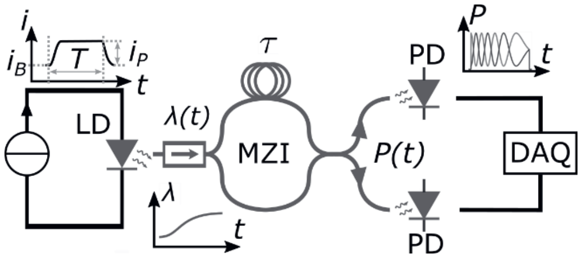

Fig. 1. Measurement of the instantaneous wavelength applying the Hilbert Transformation Compensation Method.

The optical signal passes through a fiber optic Mach-Zehnder-interferometer (MZI) with an imbalance τ of $1\ \mathrm{ns}$. We record the oscillating optical power (interferogram) at the two outputs with photodetectors DET08CFC from Thorlabs (PD) and a Keysight oscilloscope MSOX3104T. The instantaneous wavelength is then calculated using Hilbert Transformation Compensation

Method [1] (HTCM). The overall spectral shift $\Delta\lambda$ corresponds to the difference between the end and start value of the instantaneous wavelength. The results for the overall spectral shift have been validated with an optical spectrum analyzer.

Results

Increasing the peak LD current to approximately double the recommended current limit results in a maximum of 12 nm overall spectral shift for the VCSEL at 1545 nm (11 nm for the VCSEL at 1577 nm). Higher currents are of no benefit for pulse lengths of 10 µs. The optical power drops significantly due to the excess heat, so that no usable spectral components are emitted (thermal roll-off).

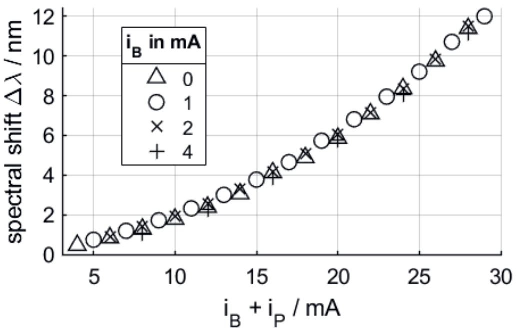

Fig. 2. The overall spectral shift within 10 µs depends on the sum of the current pulse amplitude i_P and bias current i_B (VCSEL at 1545 nm).

The overall spectral shift depends on the sum of the bias current and pulse amplitude (Fig. 2). A variation of the bias close to the laser threshold (approximately $1\,\mathrm{mA}$) does not influence the maximum overall spectral shift. Instead, thermal roll-off occurs when the sum of the currents exceed a critical level.

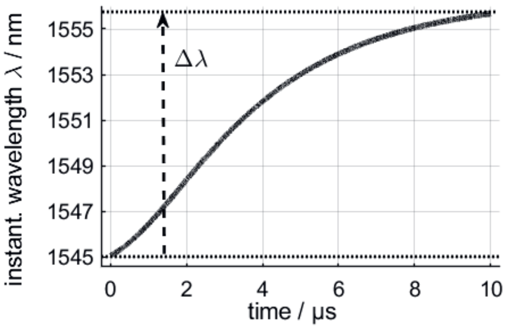

Fig. 3. Instantaneous wavelength and overall spectral shift during a 10 µs interval ($i_P = 26\,mA,\ i_B = 1\,mA$).

While a square pulse leads to an exponential increase in instantaneous wavelength [4], the gentle rise of the LD current leads to a more linear wavelength sweep as depicted in Fig. 3.

Tab. 1. Overall spectral shift depending on the equilibrium temperature for the VCSEL at 1577 nm

$i_\mathrm{B} = 1\,\mathrm{mA}, i_\mathrm{P} = 10\,\mathrm{mA}$					
R_TH / kΩ	8	10	12	14	16
ϑ / °C	30	25	21	17	15
$\Delta\lambda$ / nm	1.36	1.33	1.32	1.30	1.29

The overall spectral shift varies in the range of tenths of a nanometer for temperatures between 15°C and 30°C (Tab. 1).

Conclusion

In this work, a method for tuning the wavelength of a VCSEL over 12 nm within 10 µs was presented.

The overall spectral shift depends on the peak current (sum of bias and pulse amplitude). The equilibrium temperature has no noticeable influence on the width of the overall spectral shift. An increase in the pulse amplitude beyond a critical value leads to the thermal roll-off of the LD, so that no further increase in overall spectral shift can be observed.

The gentle rise of the LD current produces a more linear wavelength sweep compared to a square pulse LD current. Therefore, detector electronics with smaller bandwidths can be used.

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