

Testing Solutions for VCSELs

With High Resolution Array Spectroradiometer

The unique properties of vertical-cavity surface-emitting lasers (VCSELs) make them a workhorse for price-sensitive laser-based applications, e.g. in consumer electronics. In production, this demands mass-market-suitable, fast and highly reliable quality control of VCSELs. Instrument Systems provides hard- and software solutions for the characterization and inspection of the optical properties of laser diodes in production as well as in the laboratory. The all-new pulsed VCSEL tester PVT 100 extends the standard system configuration with fast-pulse driver electronics and a fast photodiode. This facilitates in-depth investigations of nanosecond-pulse driven VCSELs. The PVT 100 provides access to temporal electrical and optical key parameters such as pulse shape, duration and energy, as well as enabling full access to spectral information.

APPLICATION NOTE

1. INTRODUCTION

Most of the research activities in vertical-cavity surface-emitting lasers (VCSELs) started already as early as 1979. Since that time, VCSELs have become a mature technology, competing in many applications with edge-emitting laser diodes (EEL) and even replacing them in certain applications like short-range fiber optical communication. The emission of light, perpendicular to the epitaxial layers makes them very suitable for mass production and allows already optical testing and binning on the wafer level. Additionally, nowadays precise manufacturing process control made it possible to reduce the price for VCSELs below EELs. The lower price together with favorable properties like a symmetric beam profile, low power consumption and high modulation bandwidth lead to their wide spread use in applications as diverse as laser printers, optical mice or optical data communication. In recent times, VCSELs and especially 2D VCSEL arrays appear also as an enabling technology for a wide range of emerging applications and markets, such as

- » Face & gesture recognition
- » Autonomous driving
- » Novel security concepts
- » Geographical mapping with drones, etc.

Instrument Systems provides customizable solutions (hardware & software) for the characterization and quality control of the electro-optical properties of VCSELs in the lab as well as in production environments.

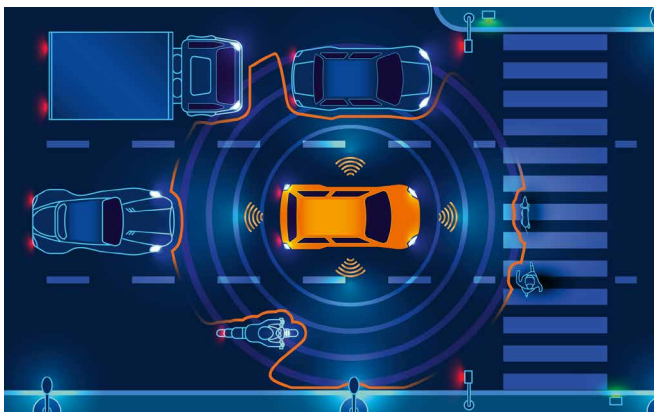


Fig. 1: Short-range LiDAR systems are investigated as a potential application for VCSELs.

2. VCSEL TESTING IN PRODUCTION LINES

Quality control of VCSELs and EELs in production lines requires the full optical characterization of a device-under-test (DUT) within milliseconds. For this, the combination of an integrating sphere (ISP) and a high-resolution array spectroradiometer (CAS) is the ideal system for fast and reliable tests of semiconductor laser diodes (Fig. 2), determining key characteristics like the centroid wavelength and the radiant power (Fig. 3). The high measurement speed requires that such spectral measurements are usually carried out with only a single, millisecond long optical pulse in the integration time window of the spectroradiometer.

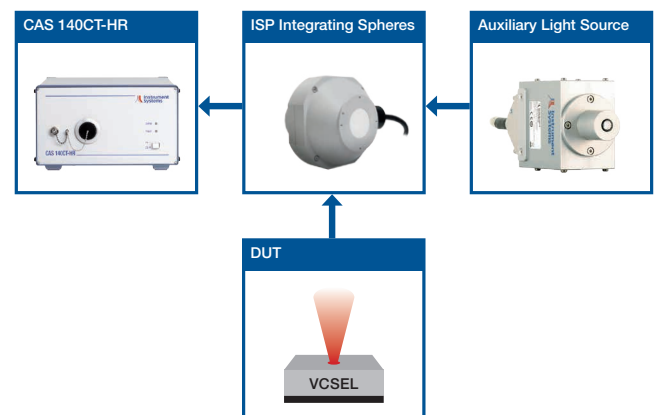


Fig. 2: High-resolution array spectroradiometers with integrating spheres allow the fast and reliable spectral characterization of VCSELs.

In such systems, the integrating sphere homogenizes the light field and the array spectroradiometer provides the necessary measurement speed. It is recommended for high precision measurements to correct for deviations due to the wavelength-dependent reflectivity of the DUT with the self-absorption correction method. For this, it is necessary to choose an appropriate auxiliary light source with a suitable spectral power density distribution. The narrow spectral bandwidth of VCSELs – typically in the range of a nanometer – requires spectroradiometers with sub-nanometer spectral resolution. Instrument Systems offers with the CAS 140CT-HR and the CAS 120-HR two

production grade high-resolution spectrometer platforms and additionally integrating spheres and suitable auxiliary light sources for semiconductor laser diode testing. This makes it possible to provide customers a broad bandwidth of measurement solutions:

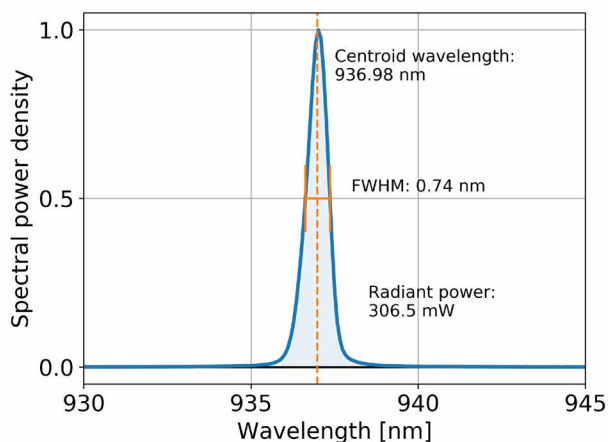


Fig. 3: Example spectrum of a 2D VCSEL array measured with a CAS 140CT-HR.

Key features

- » High spectral resolution down to 0.12 nm
- » PTB traceable measurements
- » High sensitivity for high throughput (UPH)
- » Short integration times down to 9 ms with CAS 140CT-HR & 4 ms with CAS 120-HR
- » Optional auxiliary light source for DUT specific self-absorption correction

Key results

- » Optical spectrum
- » Peak wavelength
- » FWHM
- » Radiant power

3. TIME-RESOLVED NANOSECOND PULSE TESTING IN THE LAB

Advanced applications in the field of consumer electronics and LiDAR push the driving pulses for VCSELs towards shorter and shorter durations, while the required peak powers are ever increasing. Nowadays standard test procedures drive VCSELs with few millisecond long electrical pulses. However, novel test schemes require working with pulses in nanosecond regime and many ampere peak currents. Instrument Systems covers this demand by offering with the PVT 100 an electro-optical test system for lab applications, working with driving pulse as short as only one nanosecond and at the same time providing up to 10 A peak currents. The PVT 100 makes the complete electro-optical characterization of VCSELs possible by following a multi-sensor approach (Fig. 4).

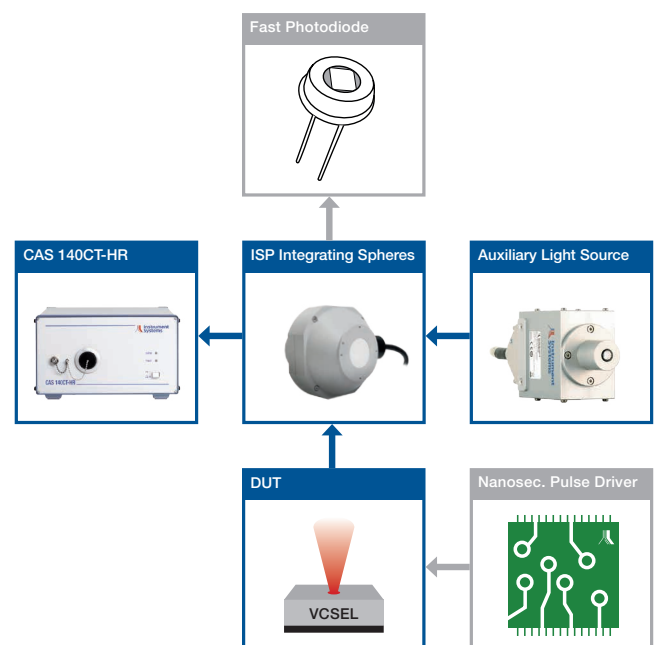


Fig. 4: PVT 100: High spectral resolution VCSEL inspection (blue) combined with time-resolved short-pulse testing (gray).

This system integrates additional to a high-resolution CAS for the spectral characterization, a fast photodiode to measure time-resolved the optical nanosecond pulse train generated by the semiconductor laser. Simultaneously, the VCSEL driver PCB developed by Instrument Systems enables the measurement of the electrical driving pulses. This allows linking the driving with the detected pulses and makes thorough investigations of the DUTs possible (Fig. 5).

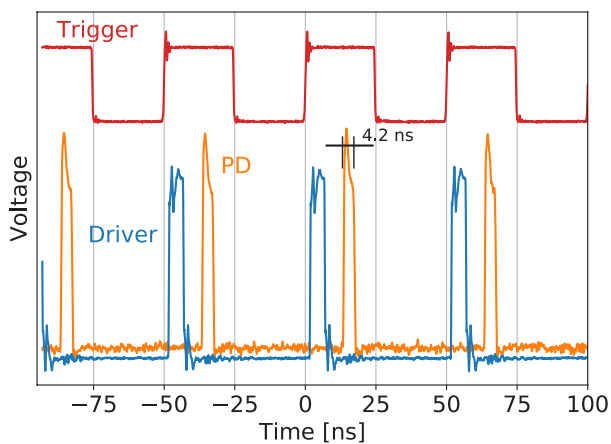


Fig. 5: Electrical driving pulses and detected optical signals for a 20 MHz train of 4.2 ns pulses.

The pulse driver electronics allows generating highly customizable pulse trains. Fig. 6 shows an example in which millisecond long sections of nanosecond pulses are interrupted by millisecond long breaks to avoid extensive heating of the DUT. The durations of the sections, breaks and pulses can be freely adjusted within a broad range. For example, pulse durations from nanoseconds up to microseconds are possible. This high flexibility allows finding the optimal driving pulse pattern for the intended application.

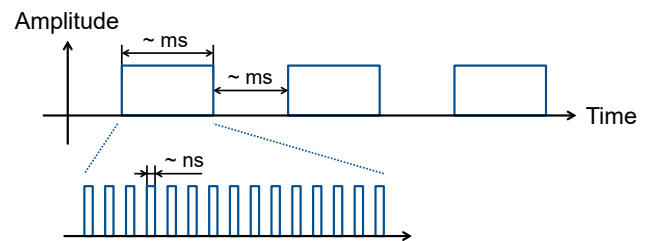


Fig. 6: Schematic of a possible driving pulse train with millisecond-long sections of nanosecond pulses.

Fig. 7 illustrates that the peak current varies linearly with the average driving voltage within the measurement range. However, the IV-characteristic depends for nanosecond pulses strongly on the driving pulse duration, while approaching asymptotically a steady state for longer pulses. This underlines the necessity of characterizing VCSELs precisely with the nanosecond pulse pattern to be implemented in the future application. Further investigations show that for fixed pulse duration, the observed IV-characteristic is independent of the duty cycle.

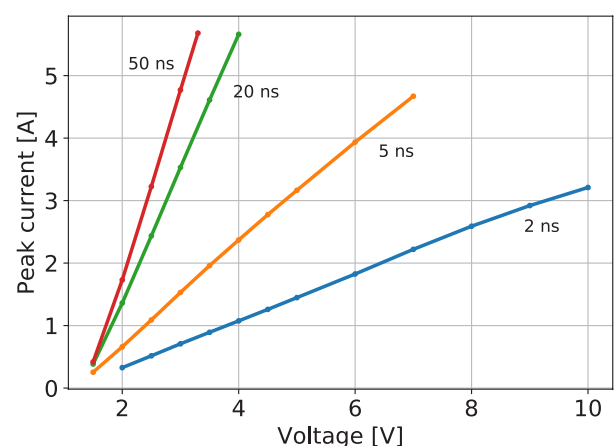


Fig. 7: Peak current of VCSEL driving pulses depending on the driving voltage and pulse duration for a fixed duty cycle of 20%.

It is known, that VCSELs are temperature sensitive devices. The spectrum of a VCSEL changes due to the temperature dependence of the refractive index and the thermal expansion of the resonator material. Fig. 8 shows exemplarily the spectral change and the shift of the peak wavelength, when the operating temperature of the DUT is varied. Such measurements are important for characterization as well as for further studies to make VCSEL more robust to temperature variations.

Nanosecond-driven VCSELs seem to open up very promising applications in mass markets, like consumer electronics. However, in-depth characterization in the laboratory and continuous quality control in production lines is essential to ensure the intended operation and reduce failure-rates. The laboratory measurement system PVT 100 for time-resolved electro-optical short pulse testing of VCSELs from Instruments Systems provides customers with:

Key features

- » High spectral resolution down to 0.12 nm
- » Pulse duration down to 1 ns
- » Peak currents up to 10 A per pulse
- » Pulse trains with up to 100 MHz repetition rate
- » Time-resolved electro-optical characterization
- » Temperature-dependent IV & LIV sweeps
- » Flexible pulse train definitions

Key results

- » Full spectral information of CAS
(e.g. peak wavelength, radiant power, bandwidth ...)
- » Pulse shape, duration & energy
- » Pulse peak power & current
- » Average voltage & current

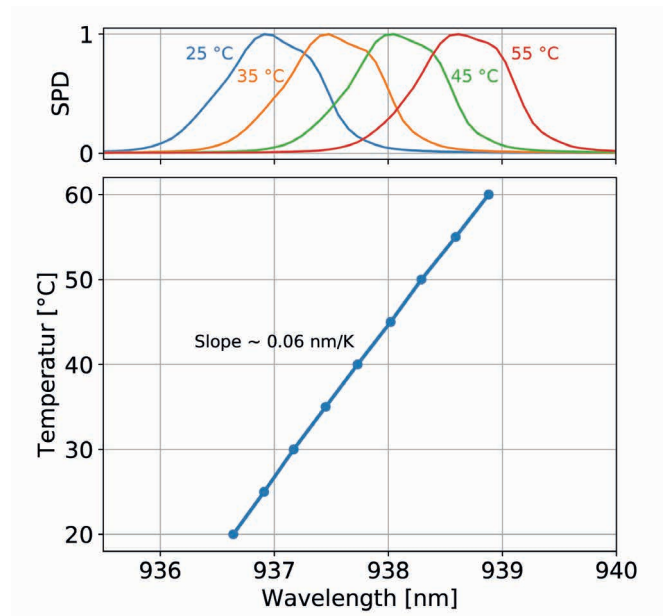


Fig. 8: Top: Normalized VCSEL spectra at different temperatures (SPD: Spectral power density). Bottom: Temperature dependent shift of the VCSEL's peak wavelength.

4. OUTLOOK: TIME-RESOLVED MEASUREMENTS FOR PRODUCTION

Demanding applications that are based on time-of-flight measurements of nanosecond pulses – like LiDAR for autonomous driving – will make it necessary to transfer laboratory-proven tests for VCSELs also to production lines. Especially for security-relevant components, like laser scanners in cars, manufacturers will have to ensure that each VCSEL responds correctly to the driving pulses in the final device. Time-resolved optical testing with predefined driving pulse patterns in production can make this feasible. However, one of the major challenges is here the development of production grade contacting for driving the DUTs with high-frequency pulses, which have bandwidths in the gigahertz range. Instrument Systems plans to transfer the optical detection system of the PVT 100 also to VCSEL tests in production and can support customers in this field with our longstanding optical metrology experience in mass production of light-emitting semiconductors.



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