Measurement of the Thermal Resistance of VCSEL Devices

K.H. Becks[a)], J. Dopke[a)], T. Flick[a)], P. Mättig[a)], P. Tepel[a)]

a) University of Wuppertal

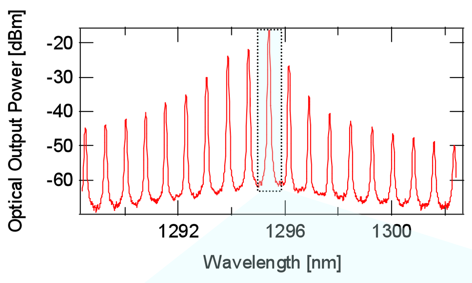
Future high energy physics experiments will operate at energies much higher than the present ones. To read out even the innermost detectors electronics and optical components must be developed to survive the harsh conditions during the lifetime of the experiments. It has been found that for VCSEL the irradiation hardness is connected to the temperature behavior of the device and that an increase of temperature above a certain value causes a loss of light power. A test stand to qualify the effect of heat in the device and the adoption of the heat sink has been realized. Measurements to show the effect of heat and measure the thermal resistance of laser devices are presented.

Introduction

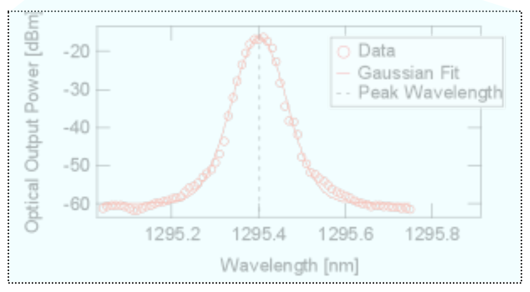
High energy physics detectors are read out using optical transmission links as the standard communication technology. Even though the innermost layer have to stand harsh radiation environments optical links can be designed to withstand these conditions and function properly.
To optimise the optical components and packages inside the detectors to work under more severe circumstances damages have to be understood and avoided.
The main damaging effects for lasers inside the detectors are:

- Radiation damages
- Temperature effects inside the semiconductor material (at the junction)

Mostly both effects come along together, but since radiation damage can not be avoided, heat can be cooled away.
This study is investigating the possibility to quantify a measure and prepare an improvement possibility for the cooling.



Typical wavelength spectrum of a Fabry-Perot type laser measured with an Optical Spectrum Analyzer



Using the wavelength spectrum of the lasers as an indicator of the device's internal temperature, it is possible to monitor and measure a property of the junction inside the laser: the Thermal Resistance.

The Thermal Resistance

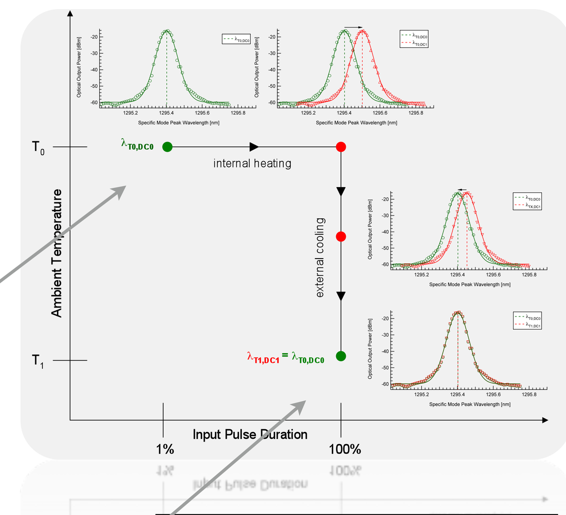
$$R_{th} = \frac{T_j - T_{amb}}{P_{diss}} = \frac{T_j - T_{amb}}{P_{in} - P_{opt}} = \frac{T_j - T_{amb}}{I^2 R_s + I_{th} V_j - P_{opt}}$$

- R_s is constant during irradiation → term is mainly affected by I
- I_{th} increases during irradiation → term is mainly affected by irradiation
- → P_{opt} is affected by I and by irradiation

The thermal resistance is defined by the temperature change over the power change

It can be measured using a „nulling method". Measuring the optical spectrum and keeping either the temperature or the power constant one can determine a ΔT, ΔP set for which the wavelength of a particular peak in the spectrum remains the same.
It describes the device's efficiency to release heat generated inside the laser.

$$R_{th} = \frac{T_{j,0} - T_0}{P_{in,0} - P_{opt,0}} \approx \frac{T_{j,0} - T_0}{P_{in,0}}$$



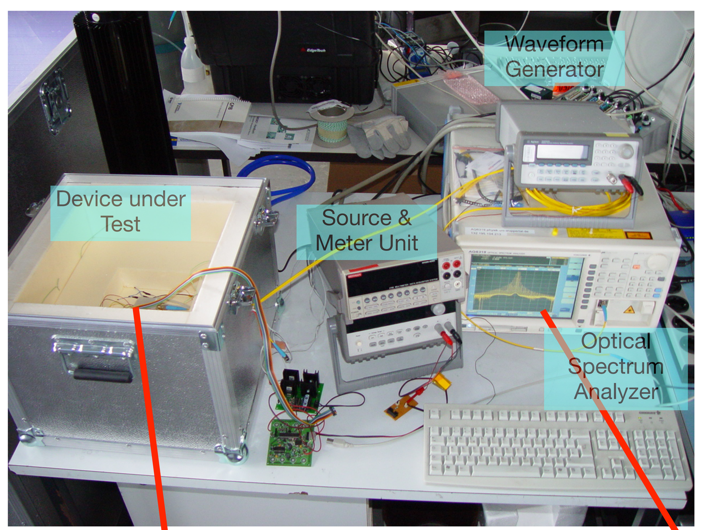
$$R_{th} \approx \frac{T_{j,1} - T_1}{P_{in,1}}, \quad T_{j,1} = T_{j,0}$$

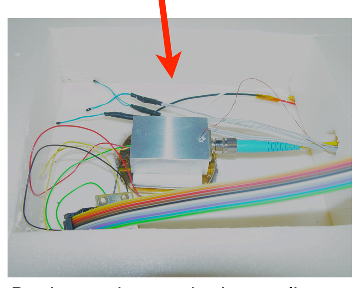
$$R_{th} = \frac{\Delta T}{P_{diss}} = \frac{T_j - T_{amb}}{P_{in} - P_{opt}} \approx \frac{\Delta\lambda / \Delta P_{in}}{\Delta\lambda / \Delta T_{amb}}$$

$$\Rightarrow \quad R_{th}(P_{in,1} - P_{in,0}) = (T_{j,1} - T_1) - (T_{j,0} - T_0) = T_0 - T_1$$

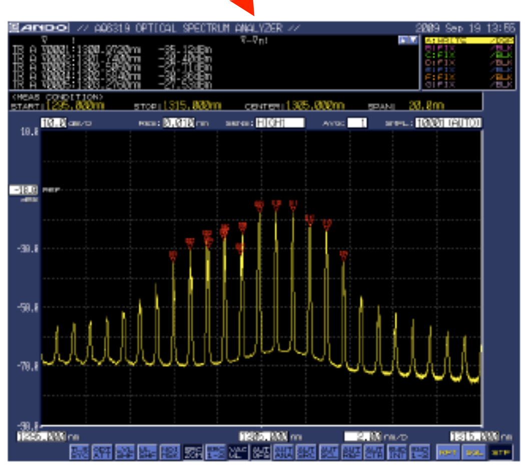
with $P_{in,x} = I_x \cdot V_x \cdot DC_x, x = 0,1$

Maesurement Setup

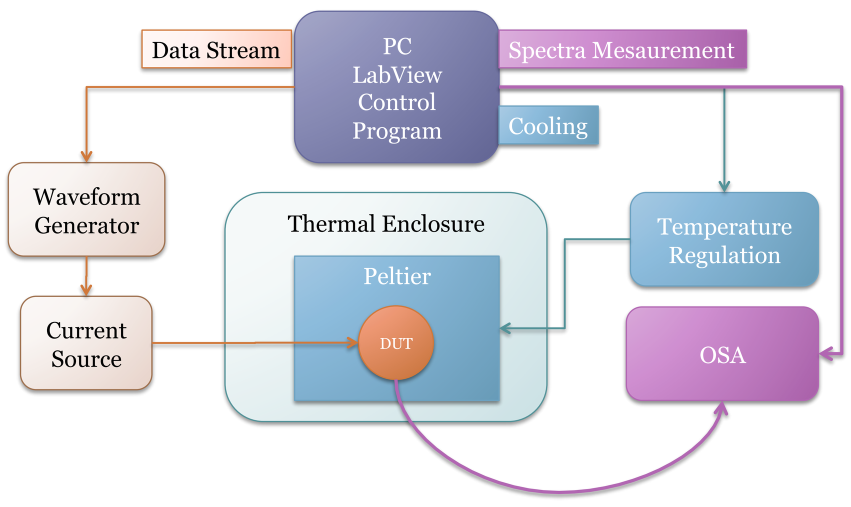




Device under test in the cooling box. A Peltier element performs the temperature control. The laser is housed in a metal shield for better temperature control. Temperature monitoring is done by using NTCs.

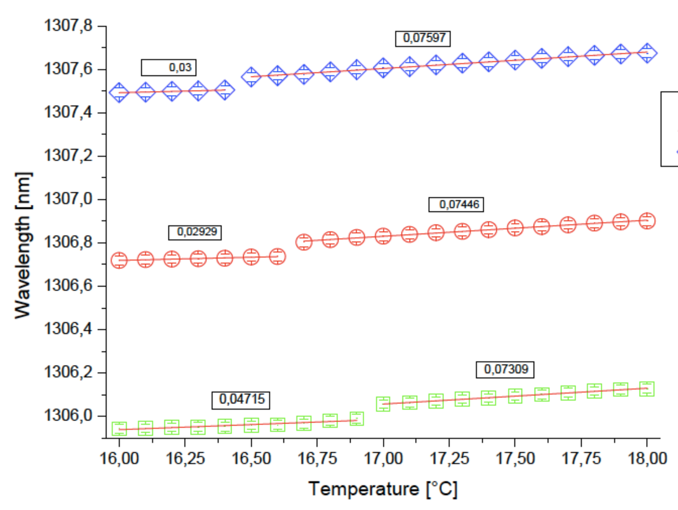


Typical waveform recorded by the Optical Spectrum Analyzer (OSA). Peak positions can be measured automatically and can easily be followed while changing power or temperature.

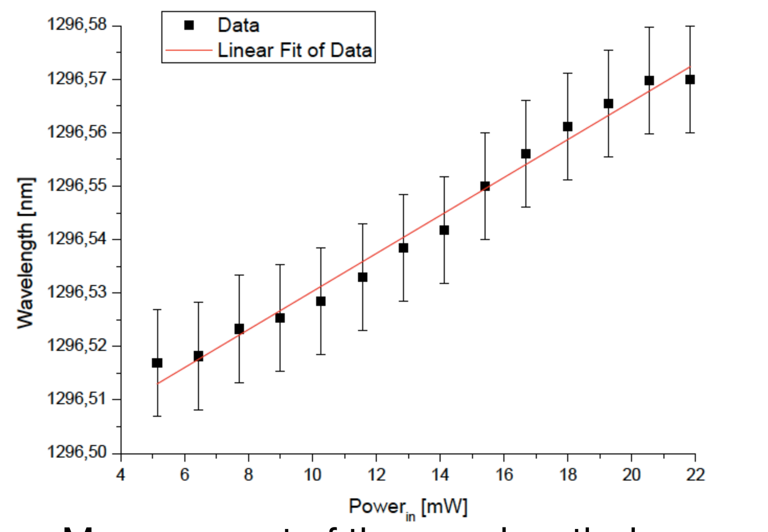


The setup is controlled via a PC running a labview program. The temperature regulation using a Peltier element and the measurements are automized.

Measured Results



Measurement of the wavelength dependency on the temperature.



Measurement of the wavelength dependency on the input power. The power has been varied by increasing the duty cycle of the driving signal step by step.

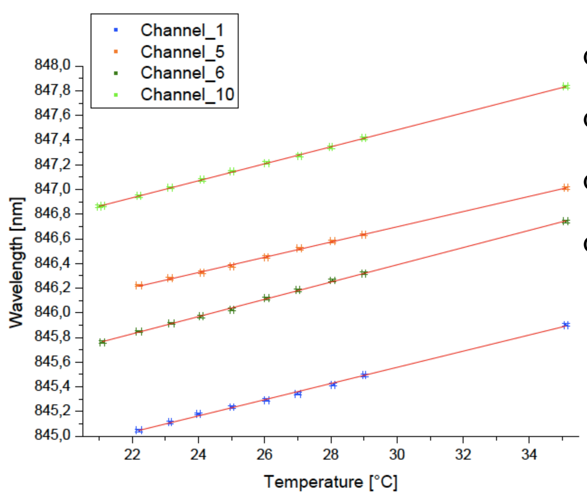
$$\frac{\Delta\lambda}{\Delta P} = 3.56 \pm 0.13 \frac{nm}{W}$$

$$\frac{\Delta\lambda}{\Delta T} = 0.0785 \pm 0.0007 \frac{nm}{K}$$

From these values one can determine the thermal resistance to be:

$$R_{th} = 45.2 \pm 1.7 \frac{K}{W}$$

Investigations for ATLAS Pixel Lasers



Channel 10 : $0.0688 \pm 0.0003 \frac{nm}{K}$

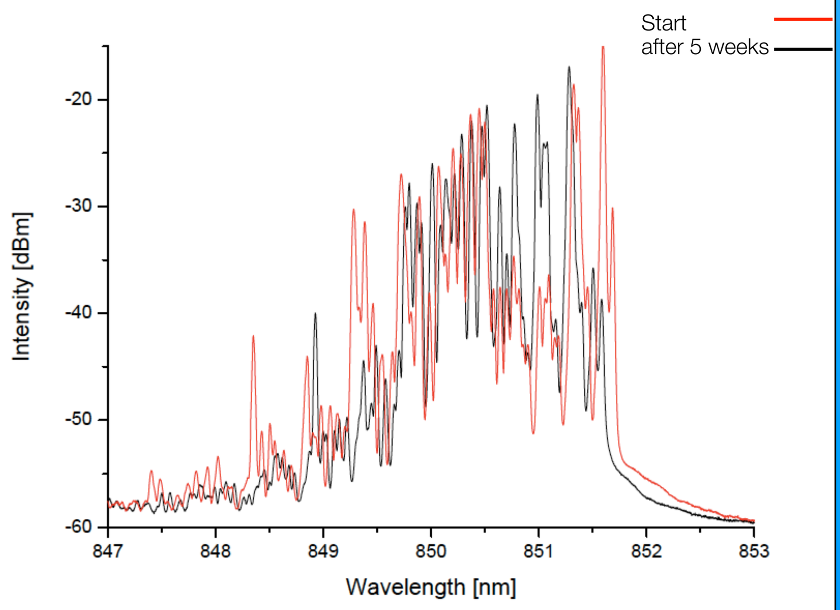
Channel 5 : $0.0618 \pm 0.0006 \frac{nm}{K}$

Channel 6 : $0.0699 \pm 0.0006 \frac{nm}{K}$

Channel 1 : $0.0656 \pm 0.0010 \frac{nm}{K}$

Wavelength shift vs. temperature for 4 channels of a laser array

Currently there are issues with the ATLAS Pixel and SCT off-detector lasers being located on small plug-in boards. The lasers degrade with operation time and die. A change in the optical spectrum is visible.



Investigations using the thermal resistance setup have been started to determine the laser characteristic and its change with time.
The temperature dependancy of the laser spectrum is shown as well as different spectra.

Outlook and References

- The measurement of thermal resistances aims for characterising different kinds of packaging to optimise the heat transfer between the VCSEL and the heat sink or cooling.
- Different kinds of VCSEL and materials will be invesigated to qualify the setup further.
- To investigate the laser issues in the present ATLAS subdetectors more device are under test and the measurement of the thermal resistance and from this the estimation on junction temperature and failure reason will be driven further.
- The usage of the optical spectrum analyser offers a good possibility to determine defects and damages of the laser devices itself.

References and Literature:

1. Accurate Thermal Impedance Measurements for Semiconductor Lasers by the Double Modes of Fiber Grating Laser, S.Y. Huang, Electronic Componente and Technology Conference 1996, Proceedings p. 635ff.
2. First High Fluence Irradiation Tests of Lasers for Upgraded CMS at SLHC, M. Axer, LHC Workshop 2005, CERN, http://lhc-workshop-2005.web.cern.ch/lhc-workshop-2005/ParallelSessionB/57-MarkusAxer.pdf
3. Thermal Impedance of VCSEL's with AlO –GaAs DBR's, M.H. MacDougal, IEEE Photonics Technology Letters, Vol. 10, No. 1, January 1998, p. 15