Optical transceiver in miniature form factor for radiation hazard applications

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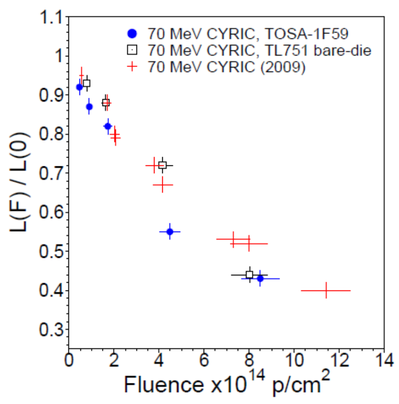
Introduction: optical links provides high speed data transmission with low mass fibers suitable for detector readout in collider experiments. Transceiver assembly in miniature form factor of ~2 mm in height is investigated for:

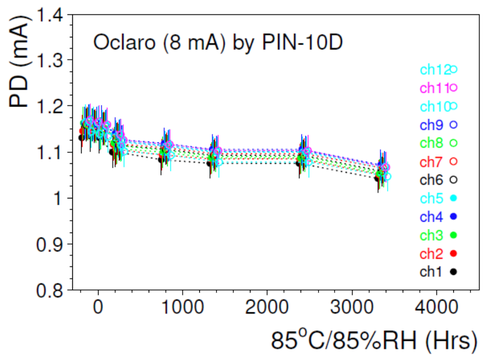
- VCSEL (vertical cavity surface emitting laser) of 850 nm GaAs, and the light coupling to multi-mode fiber;
- VLAD laser driver developed in rad-hard 65 nm TSMC process;
- Assembly with prism/lenses for light coupling;
- durability of opto-electronics and assembly, and radiation hardness.

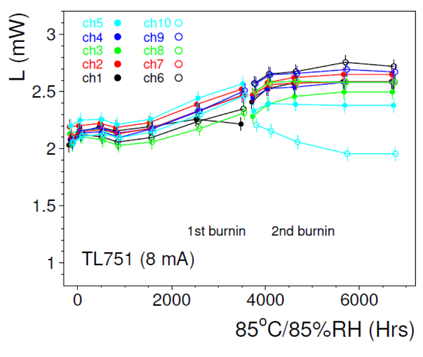
VCSELs of multi-mode ≥10 Gbps GaAs 850 nm types are investigated for radiation tolerate of up to 10^{15} (1 MeV) n/cm^2 [1]. Durability of various types is evaluated in burn-in at 85°C/85% to up to 5000 hours.



Light attenuation of irradiated VCSELs is approximately linear to proton fluences tested to 1×10^{15} (70 MeV) p/cm^2 [1].

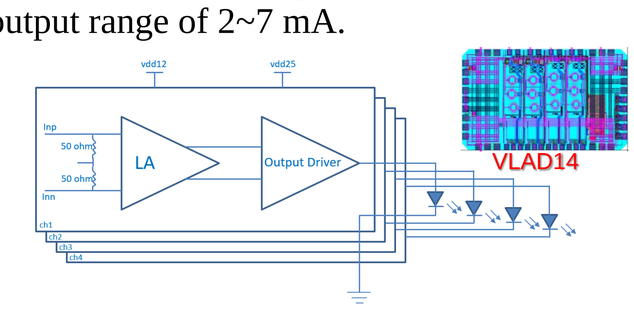
VCSELs in 85°C/85% RH chamber were biased at 8 mA DC. Light-power (measured after being cooled to room condition) versus the duration is plotted for two types of VCSELs showing different characteristics.

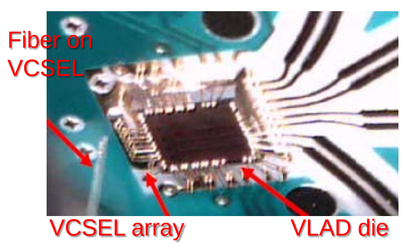


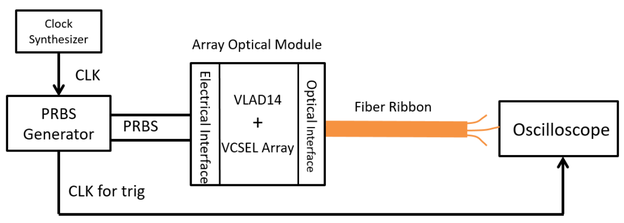


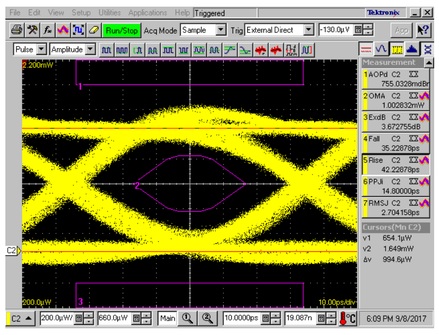
VCSEL sample for burn-in tests.

VLAD, VLAD14, two types of radiation tolerant 4-ch VCSEL array drivers are developed in TSMC 65nm process. Speed passes eye masks of up to 14 Gbps/ch with all channels active under radiation of total dose up to 350 Mrad (SiO_2) [2]. The power consumption is ~50 mW/ch with a output range of 2~7 mA.



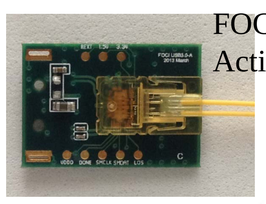




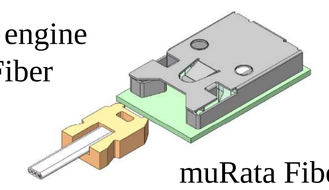


VLAD, VLAD14 design and test with the eye diagram obtained driving the II-VI 14 Gpbs VCSEL array.

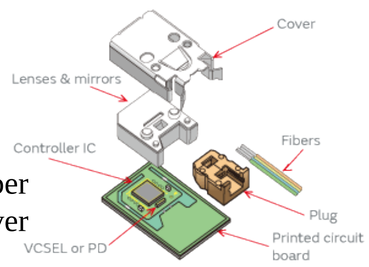
Miniature Form Factor: optical transceivers of commercial Light-peak, SFP+ and QSFP+ applications are packaged with Prism/Lenses housing VCSEL and driver, with a height of about 2 mm. The FOCI and muRata assemblies are shown. The light coupling mechanism is also illustrated.

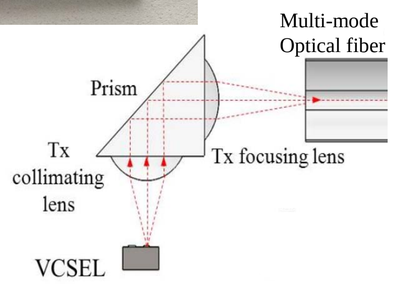


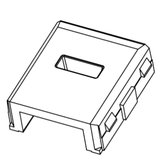
FOCI light-peak engine
Active-Optical-Fiber



muRata Fiber
Optical Transceiver



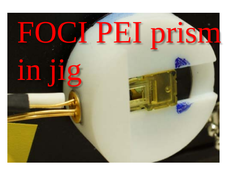


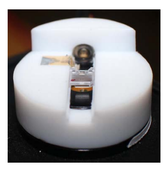


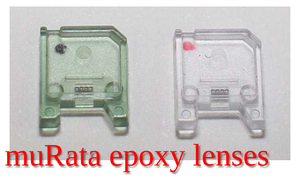
Forward Optics
4TX+4RX coupler to MT

Prism/Lenses were irradiated in Co^{60} γ-ray, with the FOCI prism made of PEI to 117 kGy, and the muRata Lenses of Epoxy to 300 kGy. The Epoxy is tanned by irradiation, however, both types show negligible loss for 850 nm light transmission within a 0.5% systematic error.

Laser light shines at the Prism Lens. The transmitted light reflected by a 45° mirror is measured by a power meter.

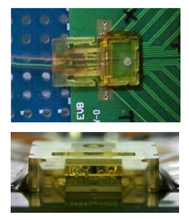


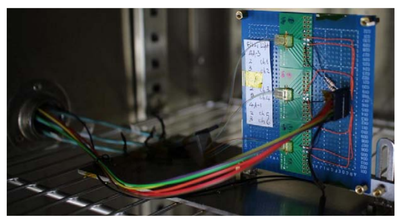


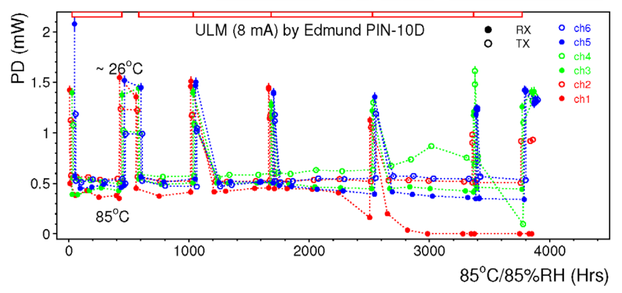


Durability of the FOCI prism assembly was tested at 85°C/85% RH. The assembly in die/wire bonds and UV-glue on PCB endured burn-in of 4000 hours, in a stable light coupling condition.

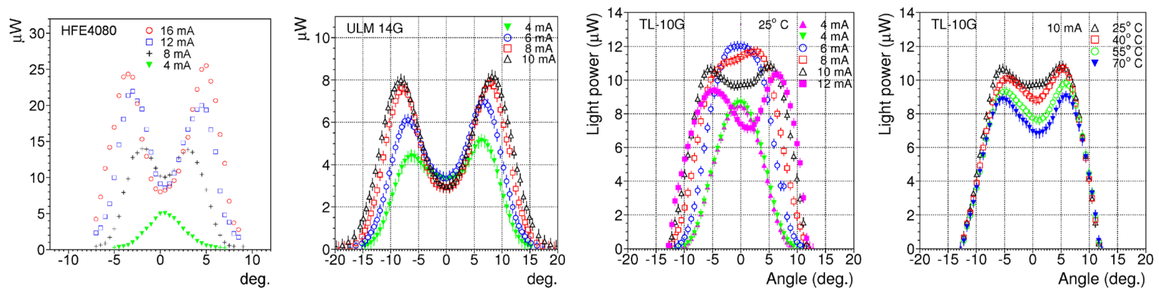
Aging tests of FOCI prism assemblies in a 85°C/85% RH chamber to 4000 hours. VCSELs were biased at 8 mA DC. Light power by coupling to FOCI Prism to fibers out of the chamber were measured continuously. Readings were also recorded when the chamber was cooled to room temperature of about 26°C. Some of the VCSELs deteriorated in the burn-in.



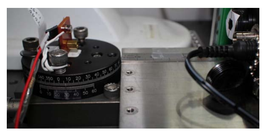




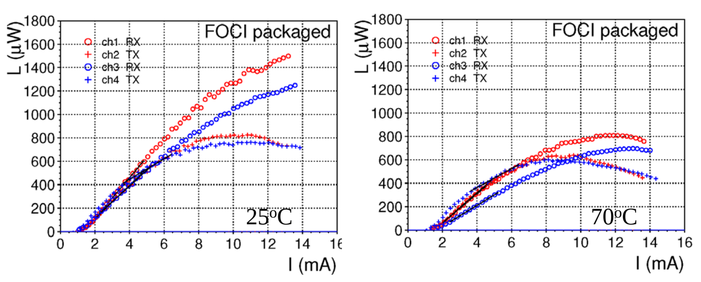
Light coupling: multimode 850 nm VCSEL has wide optical spectrum. Higher order modes shine in donut shape typically at an far-field angle of about 5°~8°. Plotted are the 1D spectra of types of 1.25 Gbps (HFE4080), 14 Gbps (ULM) and 10 Gbps (TL751). The Truelight VCSEL has the fundamental mode (centered) dominant at low current (<10 mA). The temperature effect is approximately linear in reduction to temperature.

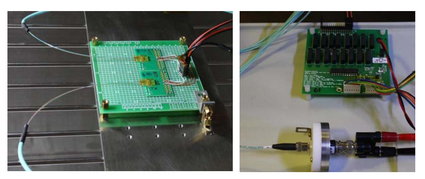


Far-field patterns of VCSELs at various DC currents. The Truelight 10 Gbps type was tested in a Chamber for temperature dependence with the light power scanned though a open window (picture).



Prototyping is most critical on light coupling of VCSEL to lens, and connection to fiber. The VCSEL light of higher modes are loss by angle in coupling. The L-I of a 14 Gbps VCSEL packaged in the FOCI prism is measured. This VCSEL has the far-field angle peaks around 8° at 6 mA, and grows wider with current. The TX channel having a large diameter lens to VCSEL shows linear L-I to 8 mA. The fraction of light degradation with temperature is compatible to the case of a bare-die. The RX lens is for coupling to PD. Trying on VCSEL shows severe loss with increasing temperature.





Light power of the FOCI packaged VCSEL is measured with the fiber connection to a PD in a jig.

L-I of VCSELs aligned to TX and RX lenses in a FOCI prism. Light power coupled to fibers are measured at 25°C and 70°C.

Summary: chip-on-board assembly of transceiver requires housing of opto-components and driver ASIC with light coupling to lenses that is available in miniature form factor of ~2 mm in height. Commercial assemblies are examined for feasibility in capacity of up to 4TX+4RX. Prototyping is necessary to evaluate the light coupling for the chosen range of VCSEL modulation.

[1] F.X. Chang et al., Nucl. Instr. and Meth. A 831 (2016) 349.
[2] D. Gau etal., JINST 12 C02065 (2017).