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High-speed Light Peak optical link for high energy applications

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ABSTRACT

Optical links provide high speed data transmission with low mass fibers favorable for applications in high energy experiments. We report investigation of a compact Light Peak optical engine designed for data transmission at 4.8 Gbps. The module is assembled with bare die VCSEL, PIN diodes and a control IC aligned within a prism receptacle for light coupling to fiber ferrule. Radiation damage in the receptacle was examined with ^{60}Co gamma ray. Radiation induced single event effects in the optical engine were studied with protons, neutrons and X-ray tests.

1. Introduction

Optical links allow higher bandwidth and longer distance transmission in comparison to electrical links. The usage of fiber is favorable for low-mass requirements in high energy experiments. Commercial off-the-shell optical transceivers have been evaluated for radiation hardness in hadron collider environments (e.g. [1]). In this report, we present a study of an optical engine developed by the FOCI [2], as a Light Peak transceiver of USB 3.0 fiber cable for data transmission at 4.8 Gbps. The Light Peak project [3] aims for optical link applications of 10 Gbps or higher in personal computing and consumer electronic devices.

The optical engine is a compact assembly with a custom designed "*prism receptacle*" housing bare-die VCSEL and PIN diodes and an optical control IC (VO510 of Via Labs [4]) fabricated using 90 nm CMOS technology of TSMC [5]. In Section 2 we discuss the prism receptacle and the light coupling among VCSEL, PIN and fiber ferrule. The substrate assembly and the optical IC functions are described. In Section 3 we discuss radiation tests with the prism receptacle exposed to ^{60}Co gamma-ray, light degradation of VCSEL in 30 MeV protons at INER [6], and single event effects (SEE) in the optical engine irradiated with neutrons at LANSCE [7], and a laboratory X-ray source. This study leverages applications of commercial Light Peak device in radiation hazard environment. Results are summarized in Section 4.

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2. Optical engine components

The assembly of the optical engine is illustrated in Fig. 1. The components packaged within the prism receptacle include the GaAs-based 850 nm VCSEL and PIN diodes of 10 Gbps, and the optical IC for USB 3.0 control and optical-to-electrical (O/E) conversion, and vice versa. The VCSEL and the PIN are bare dies attached on the substrate circuit-board with wire-bonds to the optical IC. The prism receptacle is aligned and glued on top. The fibers are prepared separately with "*plug ferrule*" to join the lenses on the receptacle window.

2.1. Prism receptacle

The prism receptacle is the key component for light coupling between opto-electronics and fibers. It is made by precision plastic injection molding of polyetherimide (PEI). The design complies with the Light Peak specification for having two pairs of transceivers. The external dimension is 6.4 mm in width and 1.6 mm in thickness. The inner cavity dimension is 4.8 mm in width, 4.4 mm in length, and 0.4 mm in height. This can accommodate two pairs of VCSEL and PIN diodes and the VO510 optical IC with dimensions of 2.0×1.0 mm^2.

The plano-convex hyperbolic lenses on the prism receptacle couple the light among VCSELs, PINs and the plug ferrule with mounted fibers. The pictures of prism receptacle are shown in Fig. 2. The pitch between the lenses is 500 μm. The lenses are made in different diameters and step heights to accommodate the VCSELs and PINs of different chip heights and active apertures. The coupling of VCSEL light to the receptacle and fiber ferrule is

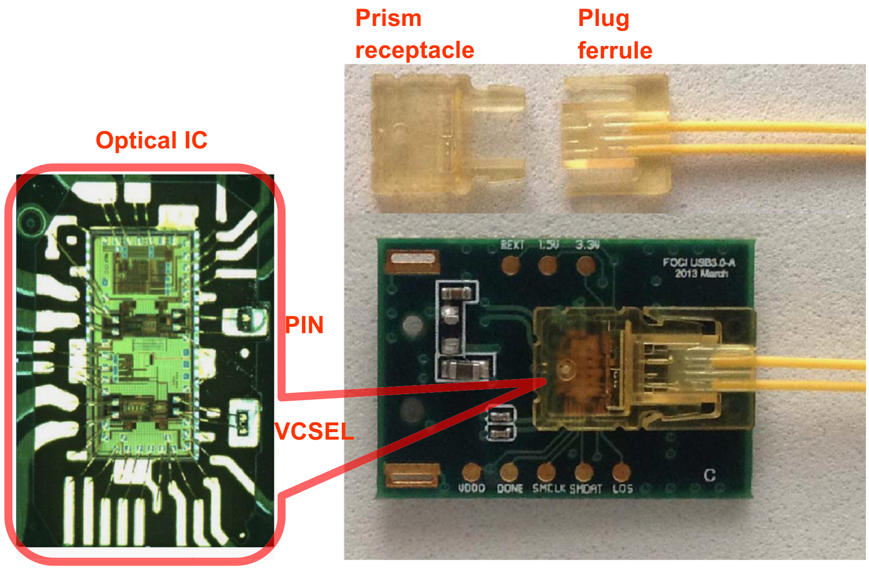

Fig. 1. The substrate of FOCI optical engine carrying the prism receptacle and opto-electronics including a pair of VCSEL and PIN, and the VO510 optical IC.

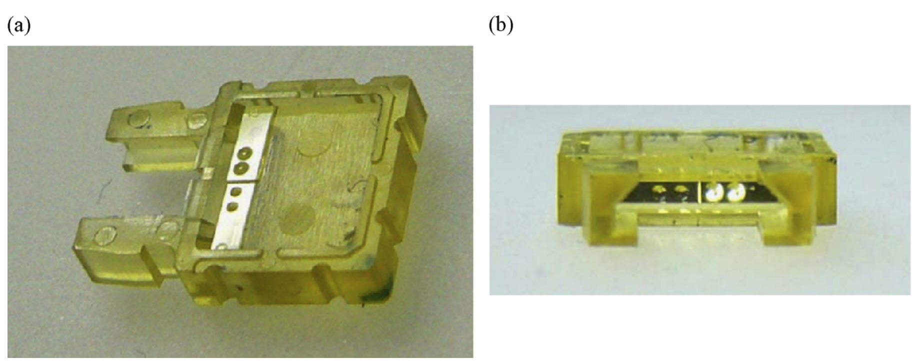

Fig. 2. Pictures showing (a) the surface within the prism receptacle with lenses for light coupling to opto-electronics, and (b) the external window connecting plug ferrule. The lenses are of different diameters and step heights for VCSEL and PIN diodes.

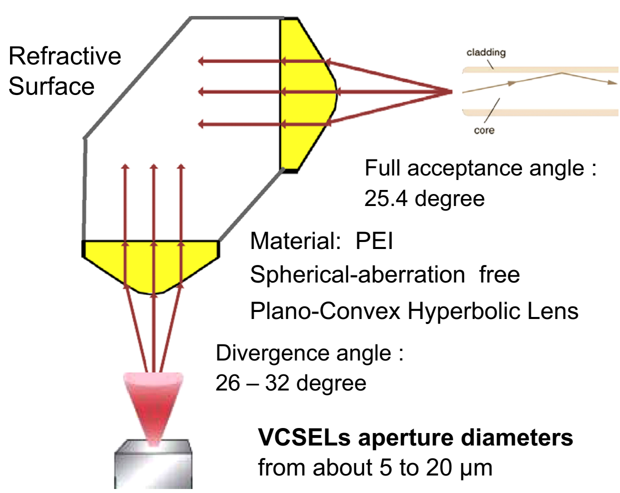

Fig. 3. The prism receptacle is illustrated for the refraction surface and lenses coupling VCSEL light to multi-mode fiber ferrule.

illustrated in Fig. 3. With the lens, the precision in alignment is relaxed to 5 μm [8] to yield uniform coupling efficiency of $>80\%$. The typical coupling loss in production modules is -3 dB.

The plug ferrule has multi-mode fibers fixed in alignment grooves. It is inserted along guiding slides and is held in position by locking clips on the receptacle.

2.2. Photonic integrated circuits and opto-electronics

The optical engine is powered at 5.0 V with a low current consumption of about 60 mA. The function diagram of the VO510 optical IC is illustrated in Fig. 4. The DC-to-DC converter provides bias voltages to the optical IC (3.3 V) and the VCSEL and PIN. The power-up sequence is configured with one-time programmable (OTP) non-volatile memory.

The transmitter circuits include a pre-amplifier and a VCSEL driver to convert electrical signals into discrete laser light levels. The VCSEL has a threshold current of 0.7 mA and a slope efficiency of 0.5 mW/mA. The bias current to the VCSEL is 5.4 mA. The coupling loss of the prism receptacle to fiber ferrules results in less power measured through the fiber, typically of about 1.7 mW. The extinction ratio of the two optical power levels of digital signals is 5 dB at room temperature.

The receiver has a PIN diode to detect laser light levels with the responsivity of 0.5 A/W. The modulated photocurrent to the transimpedance amplifier (TIA) is in a range of 0.16–0.75 mA.

2.3. Wave form tests

The tests of the optical engine were conducted with an interface board shown in Fig. 5, which provides 5 V power input and connections of electrical signals to oscilloscope or bit-error test modules. The waveform in 5 Gbps transmission was measured with a Anritsu BERTWave scope. The eye-diagram of the 850 nm VCSEL optical signal