High-speed Light Peak optical link for high energy applications

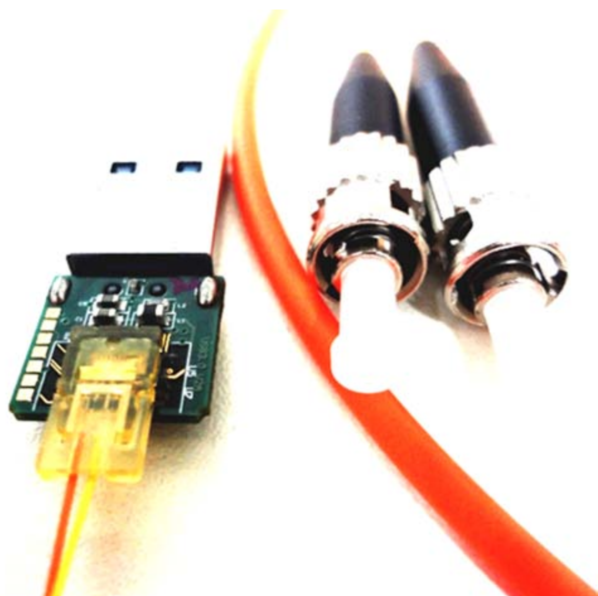
S. Hou, D.S. Su, P.K. Teng
Academia Sinica, Taipei, Taiwan

F. Chiang, J. Hou
FOCI Fiber Optic Comm., Inc., Hsinchu, Taiwan

T.K. Liu, J.B. Ye
Southern Methodist Univ., Dallas, TX, USA

C.H. Wang
Nat'l United Univ., Miaoli, Taiwan

Sep. 01- 05, 2013
Hiroshima



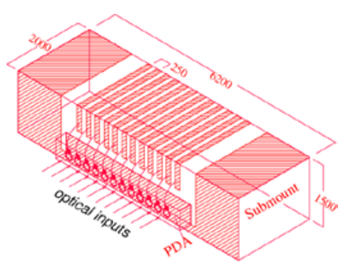
9th Hiroshima Symposium on the Development & Application of Semiconductor Tracking Detectors,

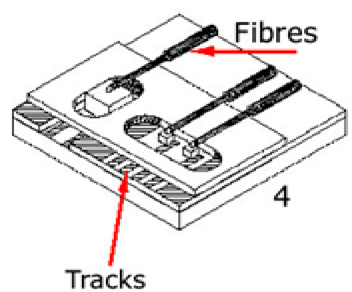
Outline

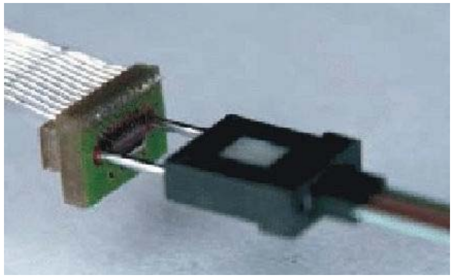
- **Light Peak optical link for HEP**
  - HEP developments vs Industrial products
  - FOCI light peak module : light coupler, driver
  - Advantages and requirements
  - Speed, Bit-Error-Rate
- **Radiation tests**
  - Beam test with 30 MeV proton at INER
  - Light coupler deterioration
  - Non-Ionizing-Energy-Loss to driver

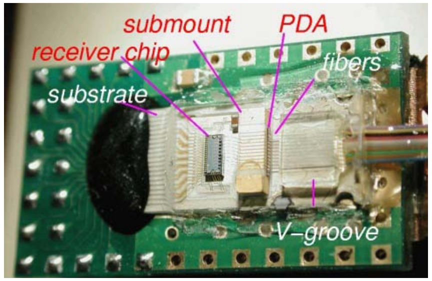
HEP optical modules

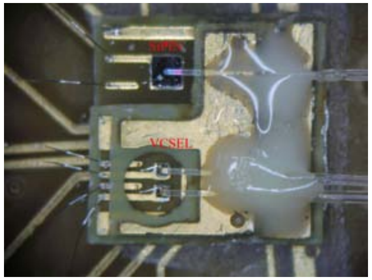
- **HEP applications: advantages over copper wiring**
  - low mass for inner tracking
  - zero cross-talk, long distance
- **HEP developments:** (modules by IPAS)
  - **CDF:** edge-emitting laser, 9 ch. parallel with ceramic 90° mount
  - **ATLAS SCT:** VCSEL with 45° fiber ends for coupling
  - **Difficulties:** light coupling to fiber,
    production yields, uniformity,





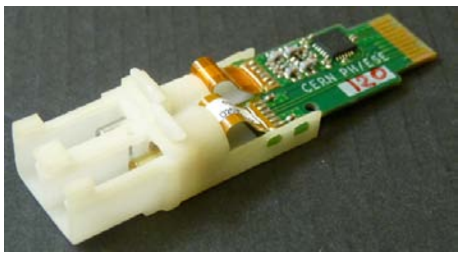






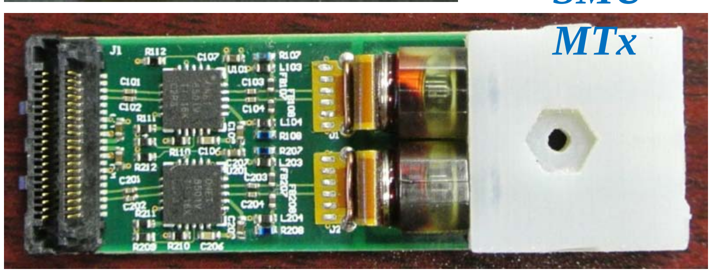
HEP transceivers vs Commercial products

- **IT industry: telecommunication and computing**
  - 10 Gb/s links with SFP+ transceivers for professional facilities
  - 4.8 Gb/s USB3 for personal computing and household electronics
- **Off-the-shell to HEP**
  - Laser, PIN are commonly rad-hard
  - TOSA/ROSA, relieved coupling issue
  - Driver/controller ASICs of old CMOS processes are not rad-hard
- **Outer detector transceivers with rad-hard drivers**
  - CERN Versatile links, 850 nm, MM, GBLD (IBM 130 nm)
  - SMU Multi-TX, 850nm, MM, LOCld (SOS .25 μm)

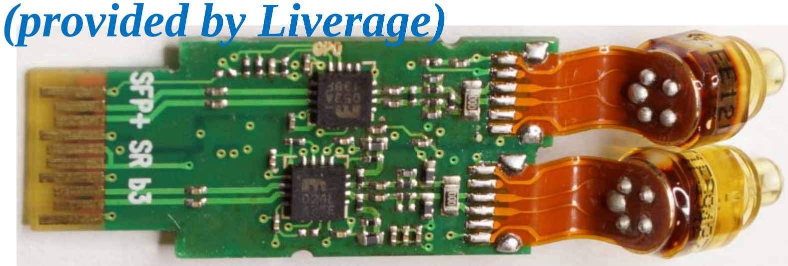


CERN VTRx

10 GB/s SFP+ (provided by Liverage)



SMU MTx



with Micrel drivers/controller

Total Ionizing Dose to Commercial

- QSFP, miniPOD, PPOD, ONET8501V, ONET1101L
  tested with X-ray or γ-ray, none meet the ATLAS LAr radiation requirement.
- Kintex 7, ONET8501
  tested with a neutrons in Los Alamos SEU rate of Kintex 7 is too high for LAr.

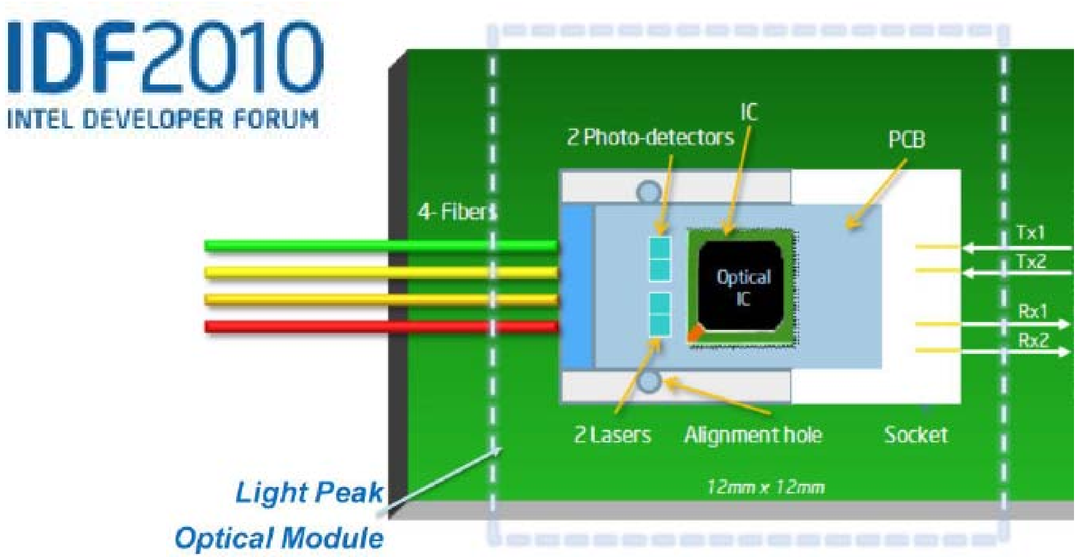
	Vendor	Part#	Gbps	# ch	Rad type	(krad/hr)	TID (krad)
QSFP	Avago	AFBR-79EIDZ	**10**	4	**^{60}Co γ**	10	75
miniPOD	Avago	AFBR-810FN1Z	**10**	1	**x-ray**	360	66
PPOD	Avago	AFBR-810EPZ	**10**	12	**x-ray**	360	150
VCSEL driver	TI	ONET8501V	**10**	1	**x-ray**	39	178
F-P laser driver	TI	ONET1101L	**10**	1	**x-ray**	9.6	464
					^{60}Co γ	10	< 900

	Vendor	Part#	# of ch	**Flux (n/cm^2/s)**	**Fluence (n/cm^2)**	# errors	σ (cm^2)
Kintex-7	Xilinx	XC7K325TFF G900	16 (2 tested)	**4.6E5**	**2.1E11**	4/4 (2 shared)	1.6E-11
VCSEL driver	TI	ONET8501V	1	**4.6E5**	**2.1E11**	0	< 5E-12

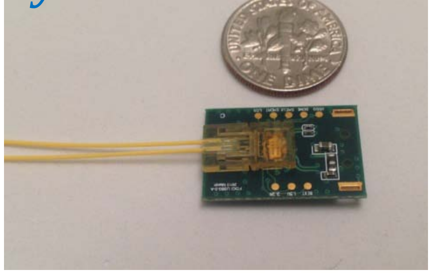
SMU, TWEPP2012

Light Peak Technology

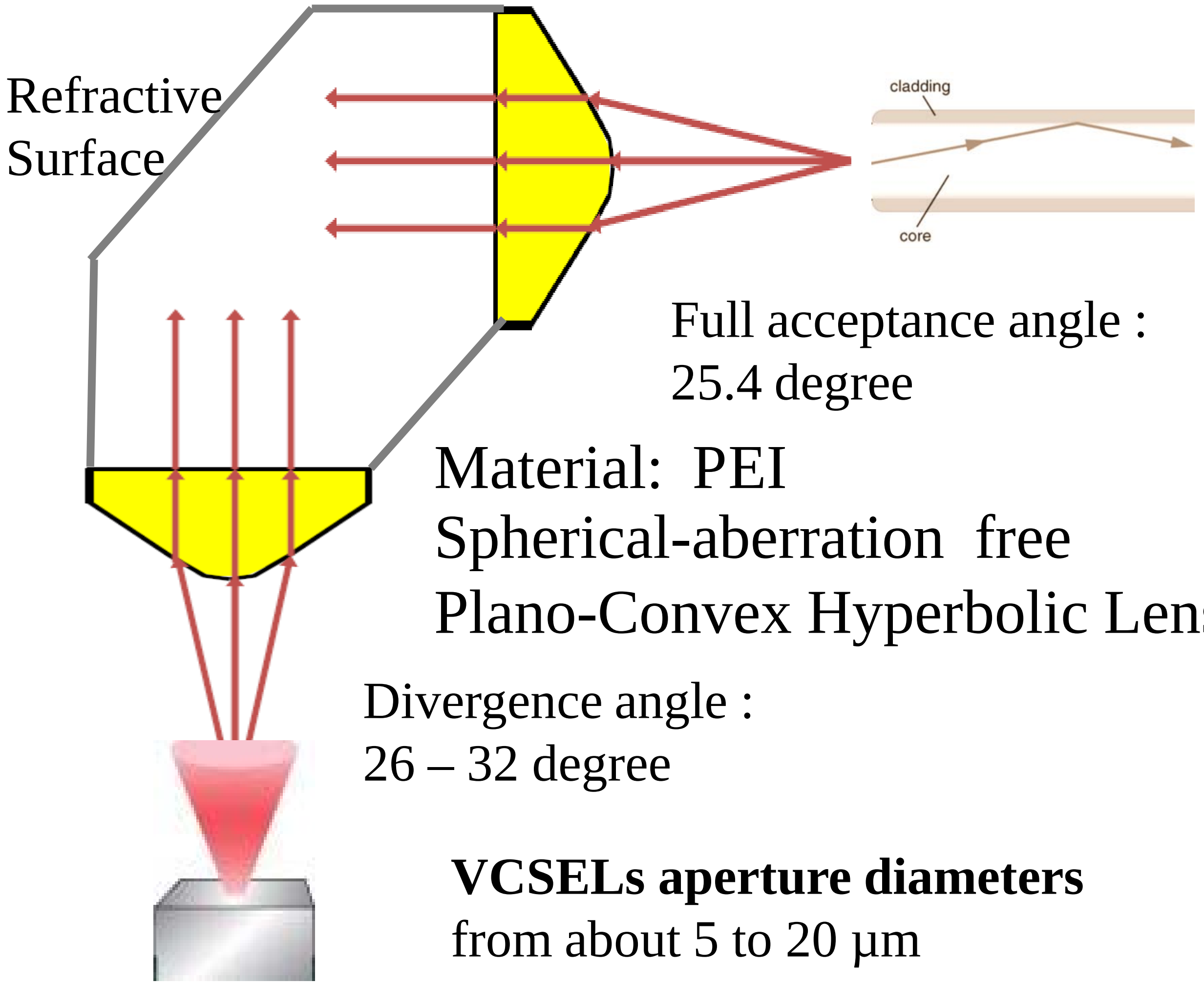
- **Light Peak, Intel** technology delivers high bandwidth starting at 10 Gb/s to mainstream computing and consumer electronics in a cost-effective manner
- **Multiple I/O protocols,** simultaneously over a single cable, enabling connection between peripherals, workstations, displays, disk drives, docking stations …



One Port Optical Module by FOCI



Light Peak Optical module



Full acceptance angle :
25.4 degree

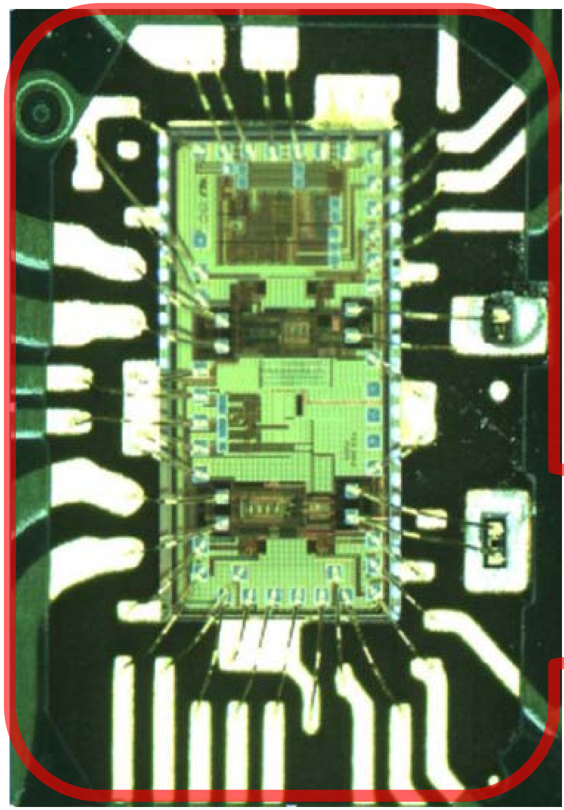
Material: PEI
Spherical-aberration free
Plano-Convex Hyperbolic Lens

Divergence angle :
26 – 32 degree

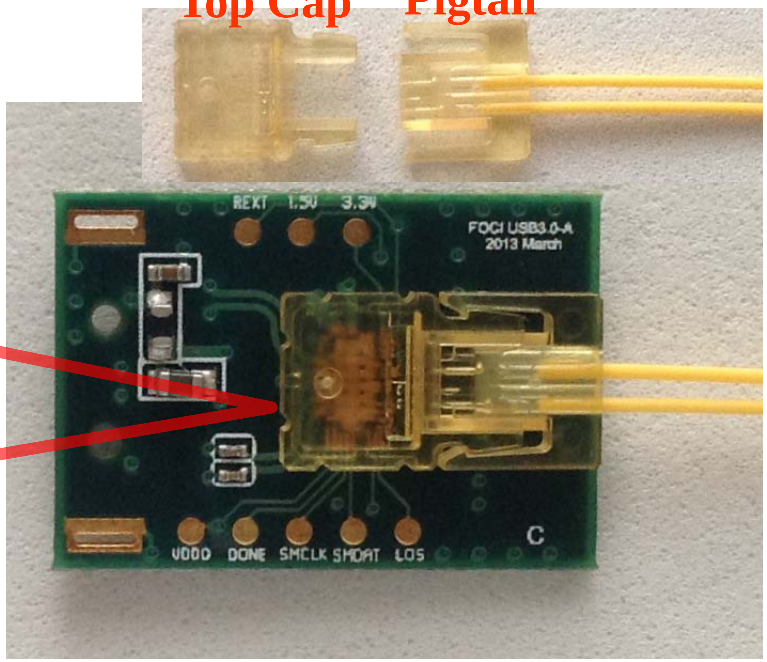
VCSELs aperture diameters
from about 5 to 20 µm

FOCI Light Peak module

Coupler mechanical precision is 5 μm
Lens improve light coupling efficiency and relaxed matching tolerance



Optical IC

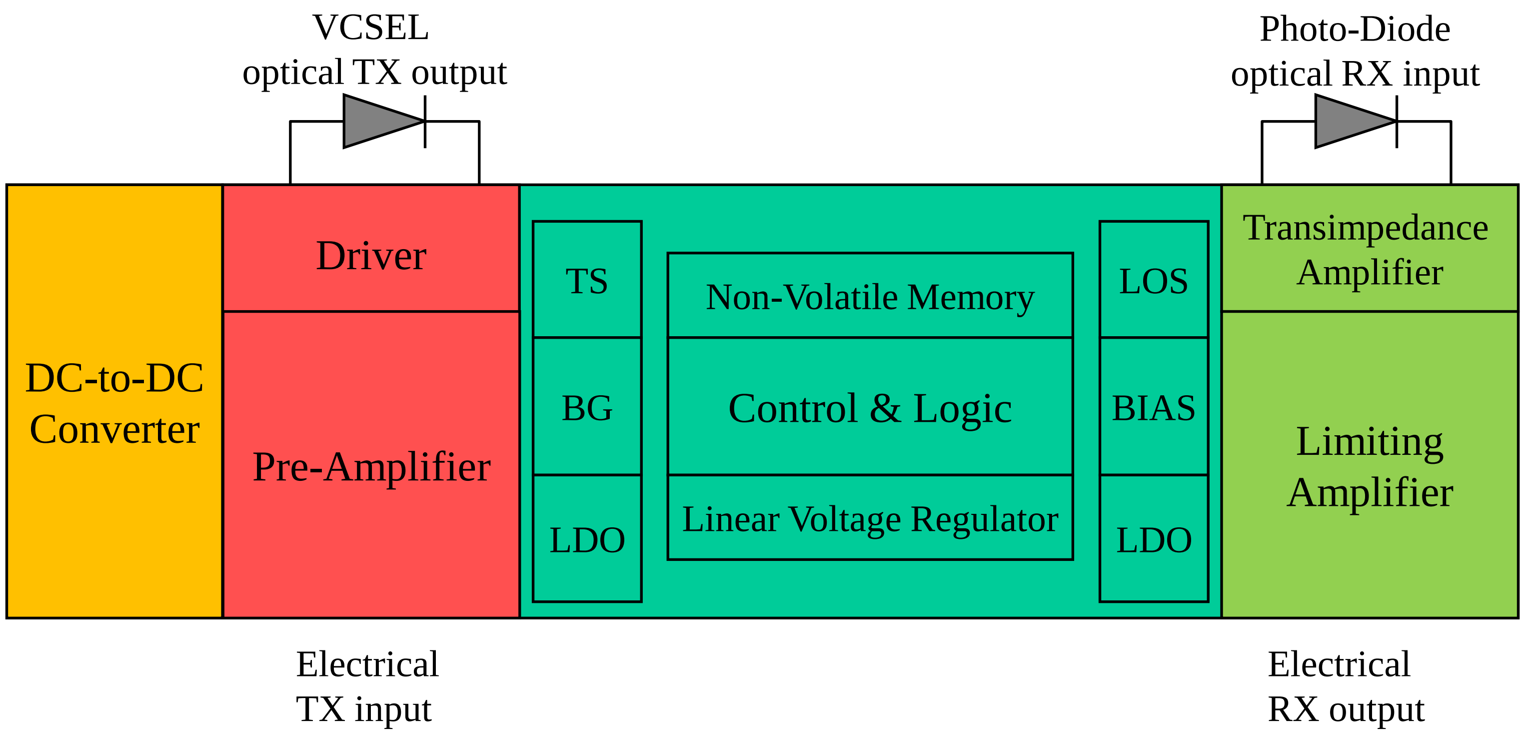


VIA Labs USB 3.0 Active Optical Cable Solution Demonstrated at CES 2012
*Collaboratively developed with FOCI, PCL, OpTarget and UMEC, the VIA Labs V0510 optical transceiver extends the reach of **USB 3.0** to over **100 meters***

FOCI module functional diagram

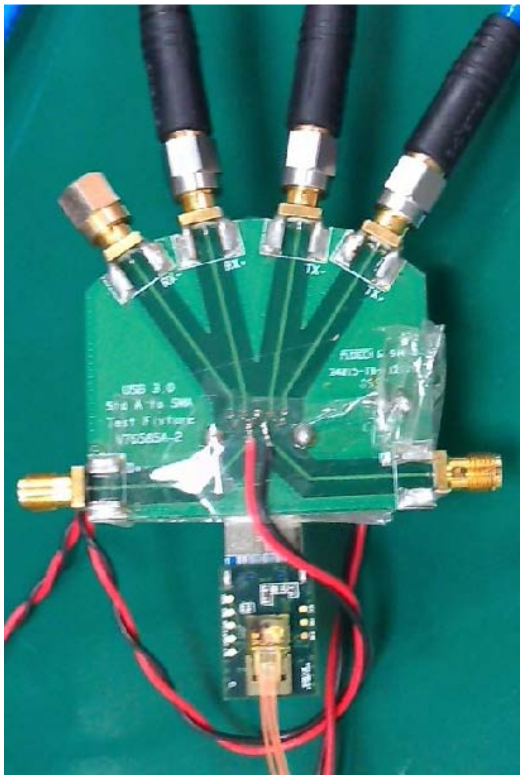
VCSEL/PIN: 850 nm bare die, 4.8 Gb/s or 10 Gb/s, >0 dBm (1mW)

Optical IC: **VIA Labs V0510**, TSMC 90nm technology
USB-3 protocol, ~60 mW, 4.8 Gb/s TX/RX driver+ regulator/controller

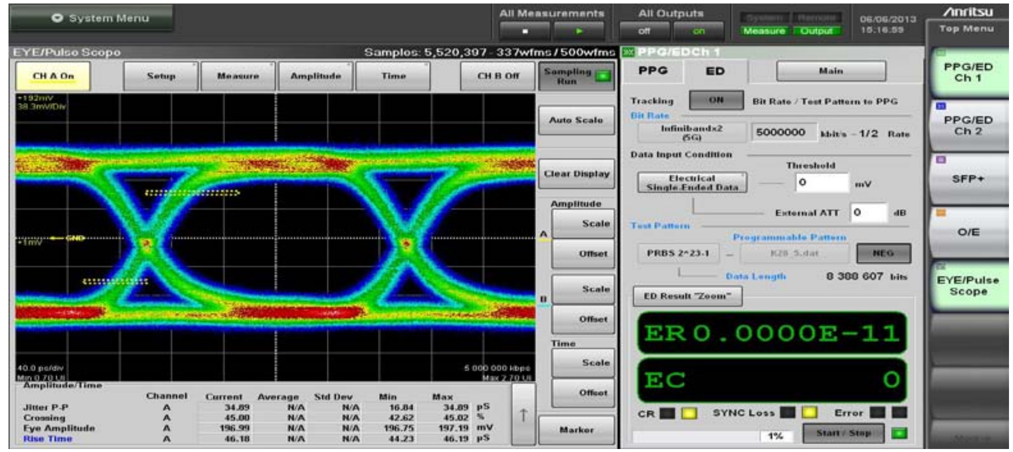


LOS: Lost Of Signal Detector
TS: Temperature Sensor
BG: Band Gap Reference
LDO: Low Drop Out voltage regulator

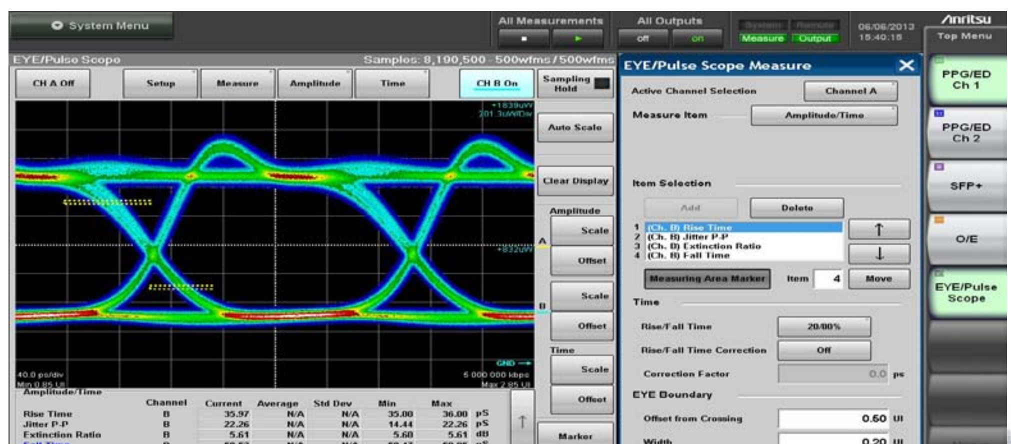
Bit Error Rate test



RX – Jitter P-P 34.89 ps, Crossing 45 %,
Eye Amplitude 197 mV, Rise Time 46.18 ps



TX – Rise Time 35.97 pS, Jitter P-P 22.26 ps
Extinction Ration 5.61, Fall Time 58.52 pS

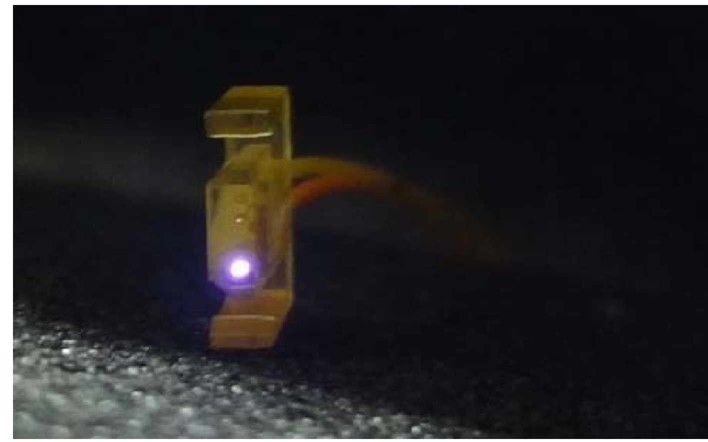


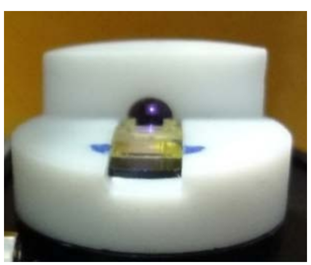
Radiation damage to coupler cap

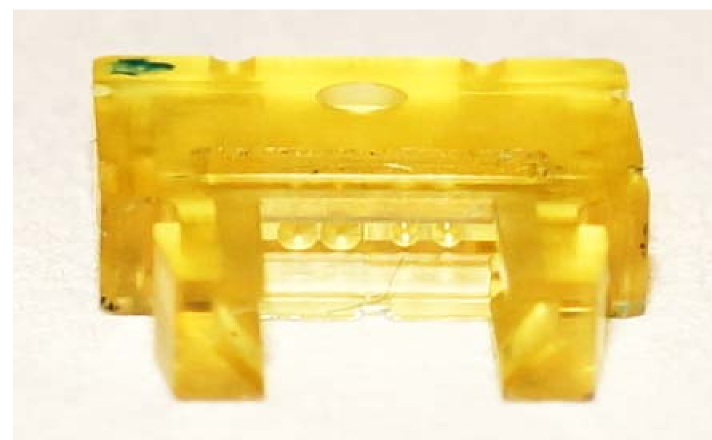
- **The light coupler cap**
  Spherical-aberration free Plano-Convex Hyperbolic Lens
  Material: PEI (polyetherimide), as for the TOSA/ROSA tip
  optical quality surface

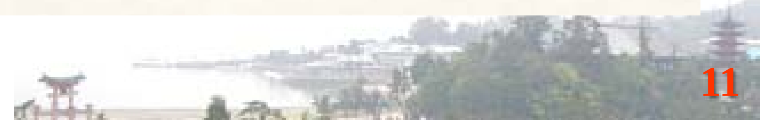
- **Deterioration by Total-Ionizing-Dose**
  Irradiated with Co^{60} Gamma ray
  at INER Taiwan
  flux: 3.5 kGy/hr, total: **117 kGy**

  ➔ NO LOSS !!
  for light transmission
  within the 2% systematic error



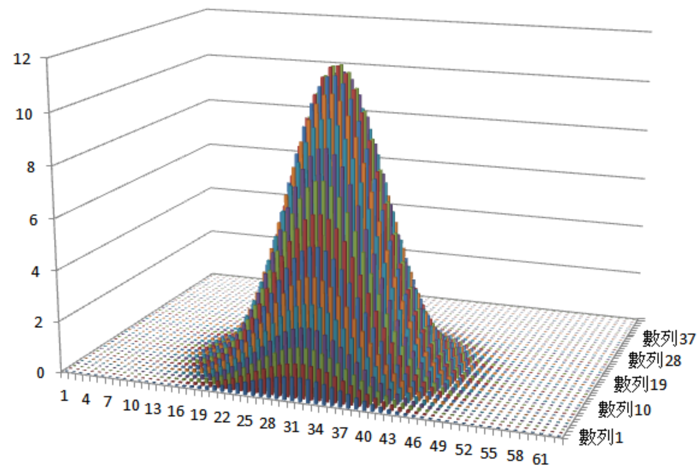




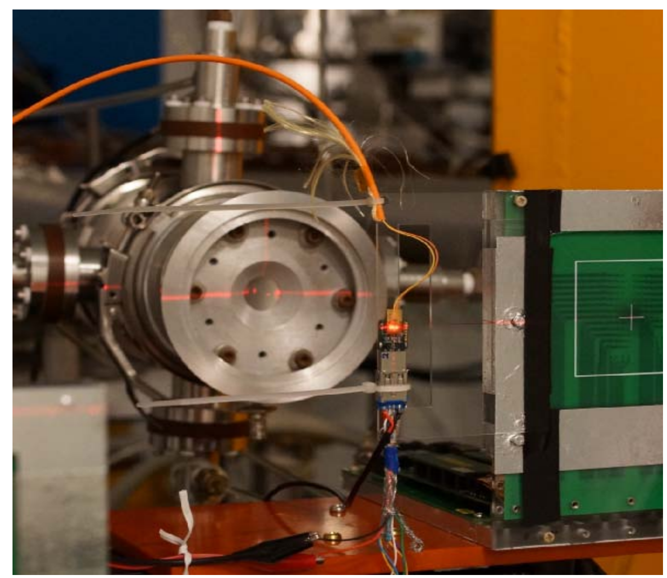


Non-Ionizing Energy Loss to VCSEL, Optical IC

- **Proton Irradiation**
  INER 30 MeV proton beam
  flux of 3.5×10^{10} p/cm^{2}s, to a total $\mathbf{1.2 \times 10^{14}}$
  equivalent to $\mathbf{8.9 \times 10^{14}}$ n(1MeV)/cm^{2}s
- **Beam profile**
  Strip and pad chambers for beam profile
  strip pitch 1 mm



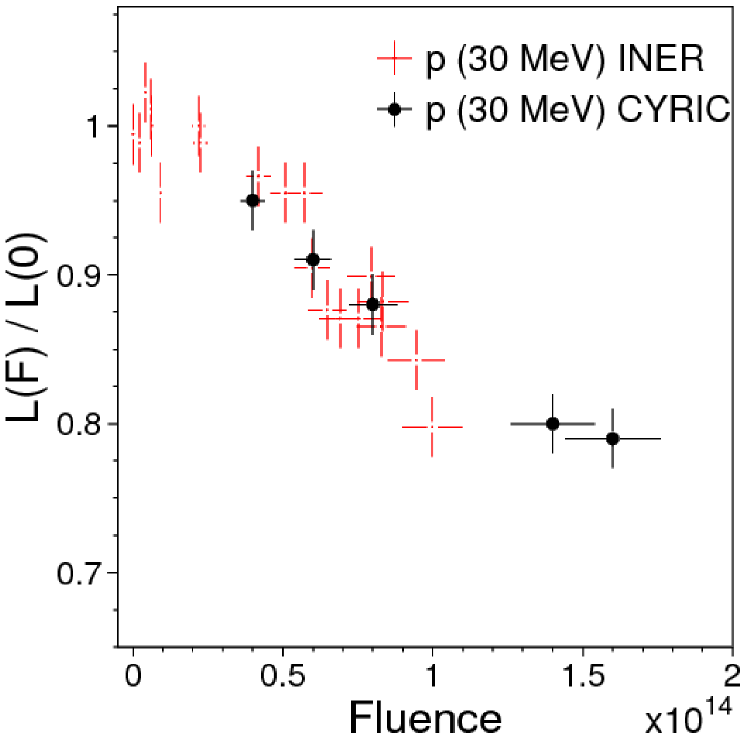
- **Irradiation measurement**
  FOCI module DC biased
  no signal input,
  VCSEL online monitored
  for mid-level DC light
  - **VCSEL light degradation**
  - **Optical IC function**



NIEL damage to VCSEL, Optical IC

- **VCSEL degradation**
  - VO510 DC biased, (1.5 V to TX driver)
  - Annealing during irradiation
  - Linear loss to fluence

  ➔ VECEL degraded to **80%** of the original after **$1x10^{14}$** p(30 MeV)/cm^2 consistent with bare VCSEL tests



● VCSEL die at 10 mA (Truelight)

+ VCSEL in FOCI, TX DC biased

- **Single Event effect to Optical IC**
  - Single Event Effect = $3x10^{-3}$ Hz @Beam flux = $3.5x10^9$ /cm^2s to controller circuits, observed by VCSEL DC light level hopping
  - Fatal damage to Optical IC after $1.2x10^{14}$ p(30 MeV)/cm^2

Summary

- Light Peak design on light coupling
  ➔ compactness, flexibility in packaging
  ➔ choice of die, chip etc
- Optical IC of latest CMOS technology
  ➔ radiation hardness to be confirmed
- New versions of FOCI modules
  dual TX/RX and new 10 Gb/s driver IC
  radiation hardness to be investigated