https://indico.ihep.ac.cn/event/22089/sessions/14189/#20241026

Radiation tolerance of opto-electronics and Ge-doped MM fiber

- **850 nm MultiMode technology**
  speed to 25 Gbps/ch
  fabrication to miniature Chip-on-Board
- **Opto-electronics NIEL/TID radhard**
- **Ge-dope MM fiber TID**
  RIA (Radiation Induced Attenuation)

suen@sinica.edu.tw
侯書雲 Suen Hou
2024.10.26 10:20



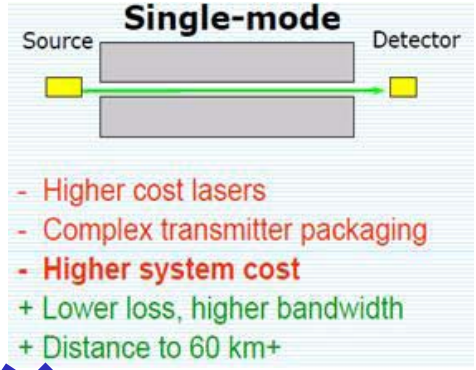

Fiber optical loss

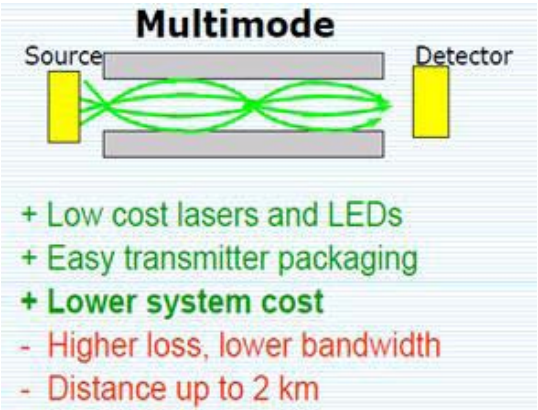
Silica glass fiber:

Low-mass, high bandwidth, little loss over long distance

− Absorption Scattering losses (Rayleigh, Raman…)

− Bending losses (micro bending)



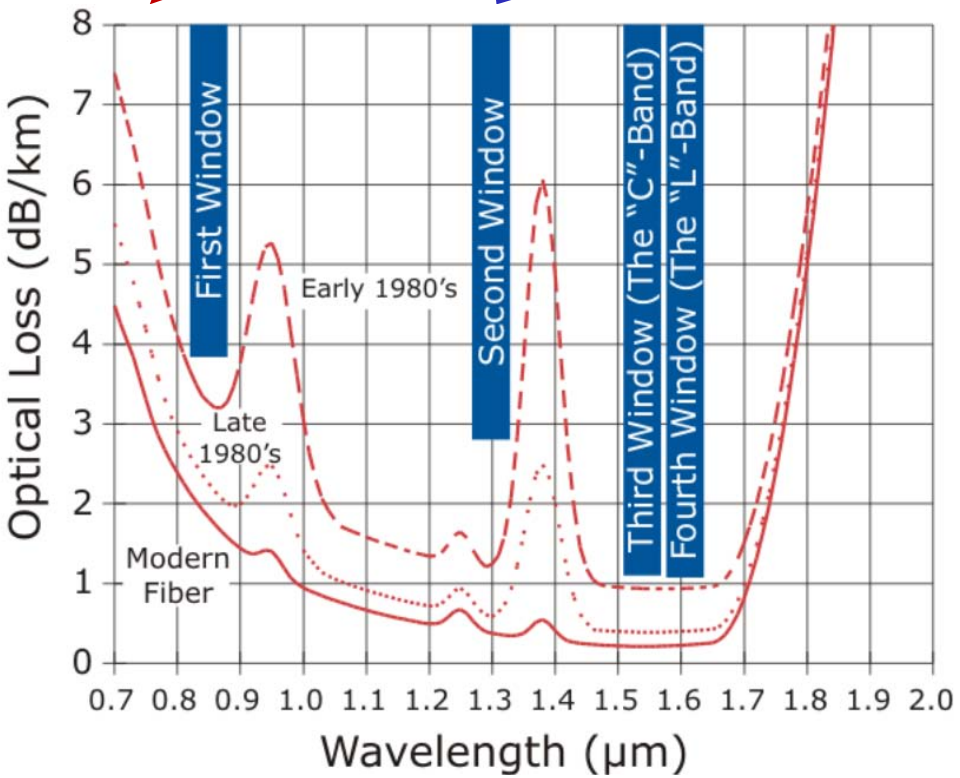


1st generation, ~1975, 0.8 μm fiber-MM, Laser GaAs

2nd generation, ~1980, 1.3 μm, fiber MM SM, InGaAsP FP-laser

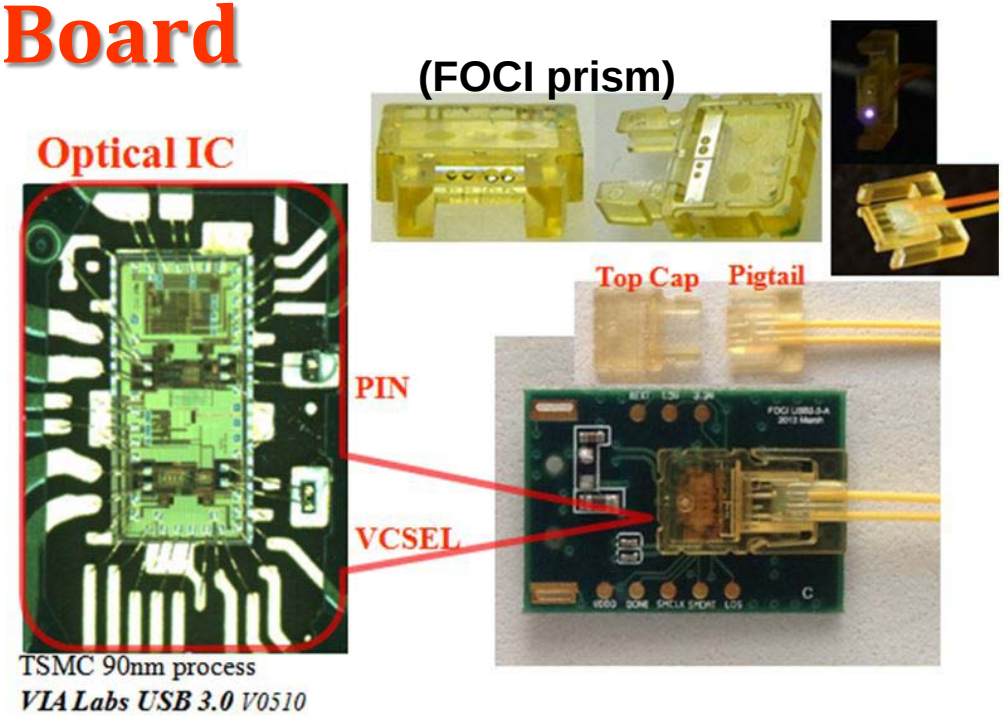
3rd generation, ~1985, 1.55 μm, fiber SM InGaAsP DFB-laser

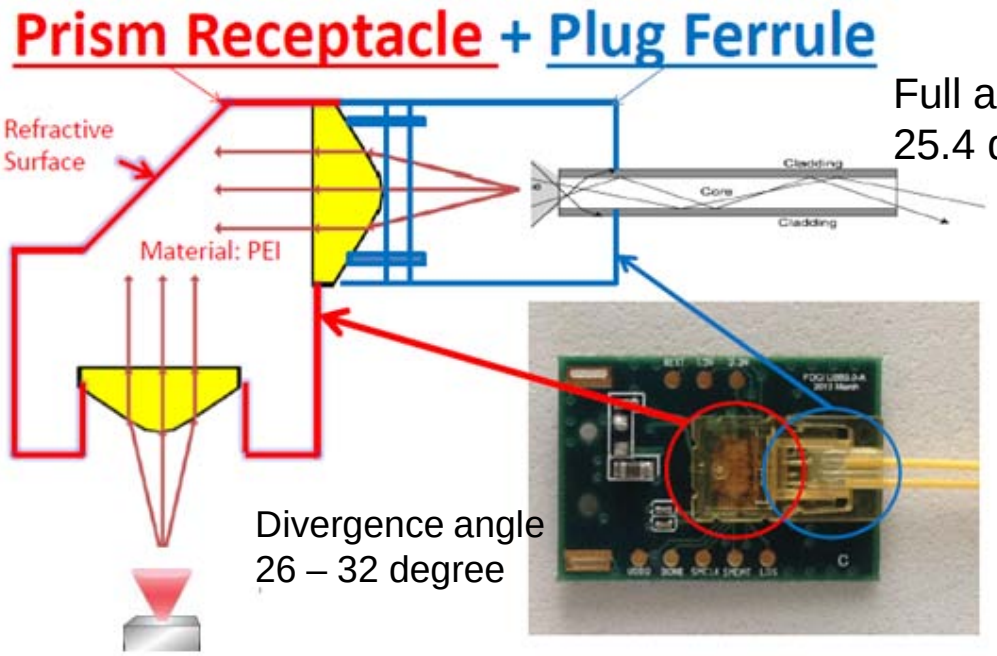
4th generation, 1996, 1.55μm WDM



Commercial Chip-on-Board

- **Light Peak USB 3 transceiver**
  10 Gbps for consumer electronics
- **Lens/Prism :**
  precision PEI molding





Spherical-aberration free
Plano-Convex
Hyperbolic Lens

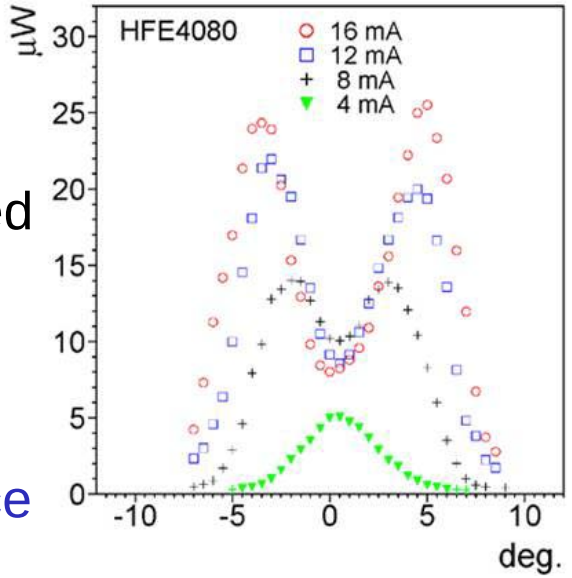
Full acceptance angle
25.4 degree

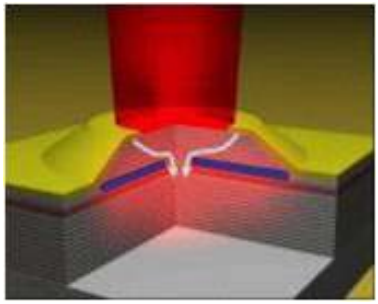
VCSELs aperture
from t Ø 5 to 20 µm

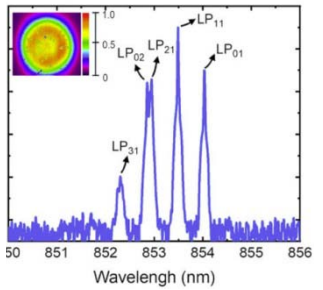
Divergence angle
26 – 32 degree

Light Coupling efficiency

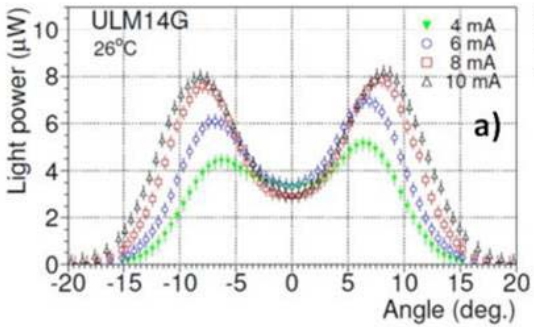
- **VCSEL far-field distribution**
  at low current, 0th mode is centralized
  higher modes pop-up in outer-rings
  wider angles
- **Coupling to Lens**
  loss to reflection, angular acceptance

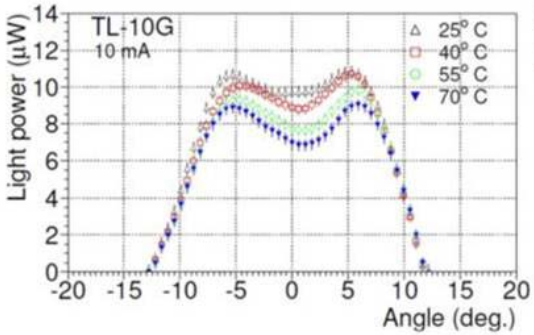




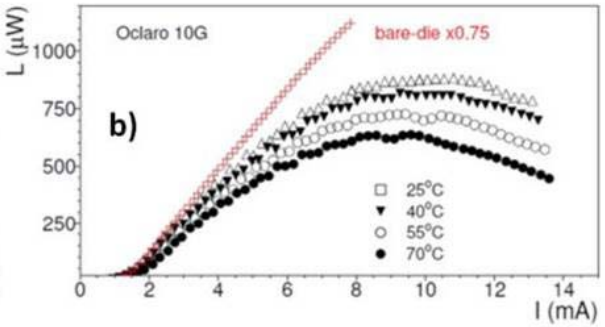


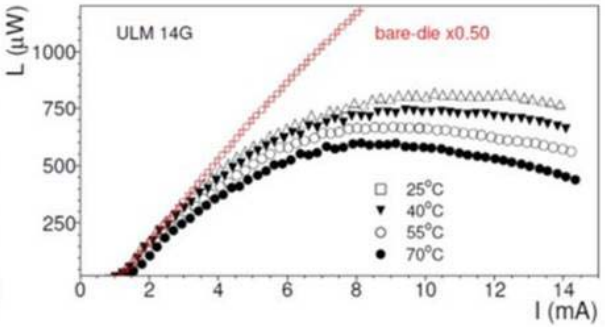
Far-field angle vs I, T





L-I, FOCI lens coupled

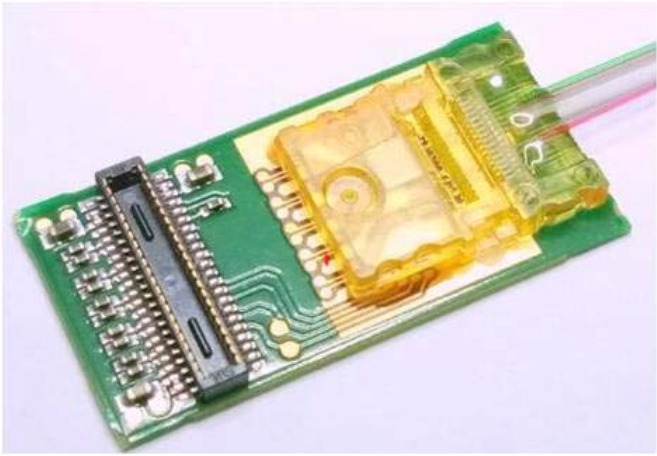




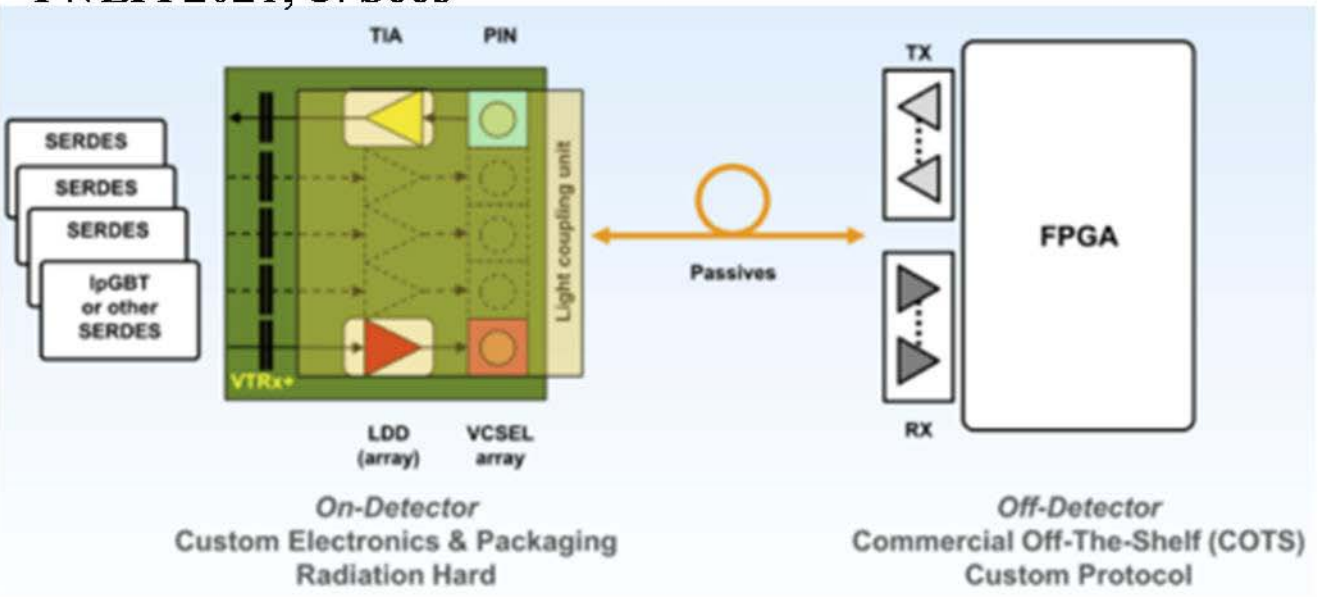
VCSEL+Lens in Oven

The CERN Phase-II VTRx+ (FOCI 上詮)

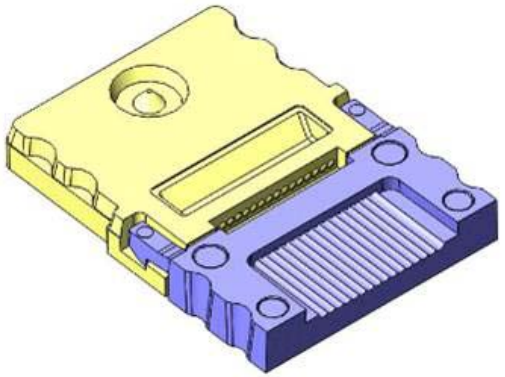
- CERN Versatile Link+ group ➔ one module for all
- 10x20 mm^2 height 2.5mm, 4.5mm
- 4TX+1RX, 10Gbps TX, 2.56 Gbps RX
- VCSEL array laser driver LQD, TSMC 65nm
- Optical Receiver GBTIA TSMC 65nm
- production 65K pcs
- Lens is the TW Orange-tek



TWEPP2021, C. Soos

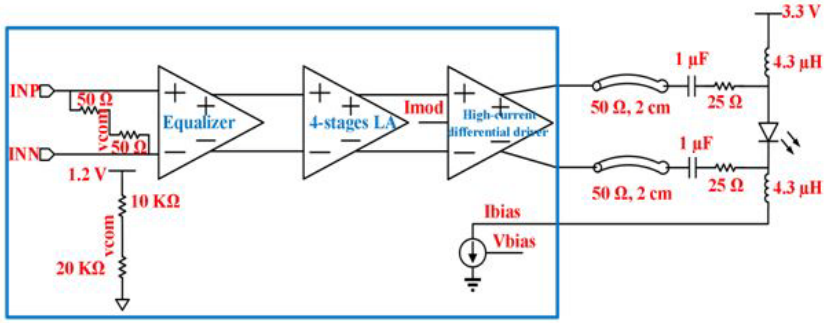


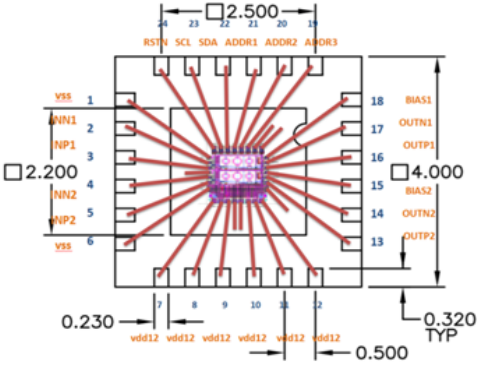
Orange-tek
OT-12, OT-13

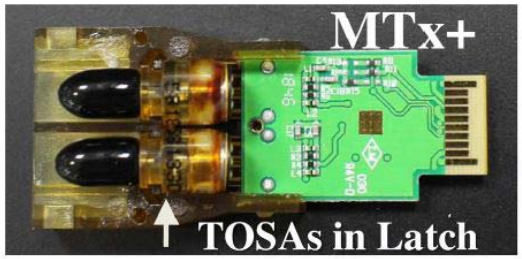


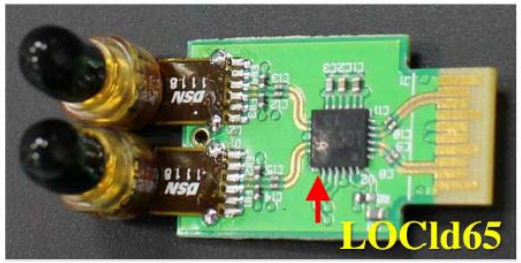
AS+SMU+前鼎(APAC) : 25 Gbps Transmitter

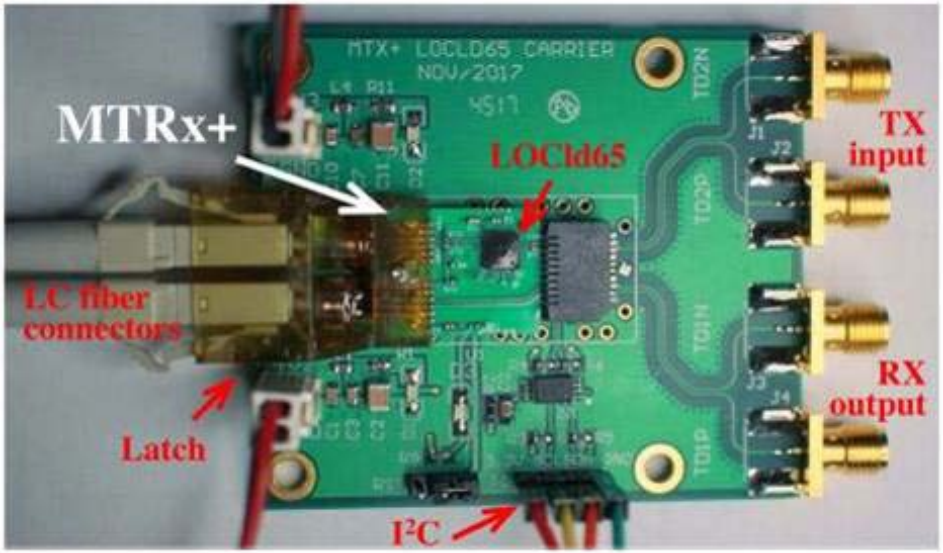
- 25 Gbps components, PCB megtron, connectors
- Driver, LOCld65, TSMC 65nm

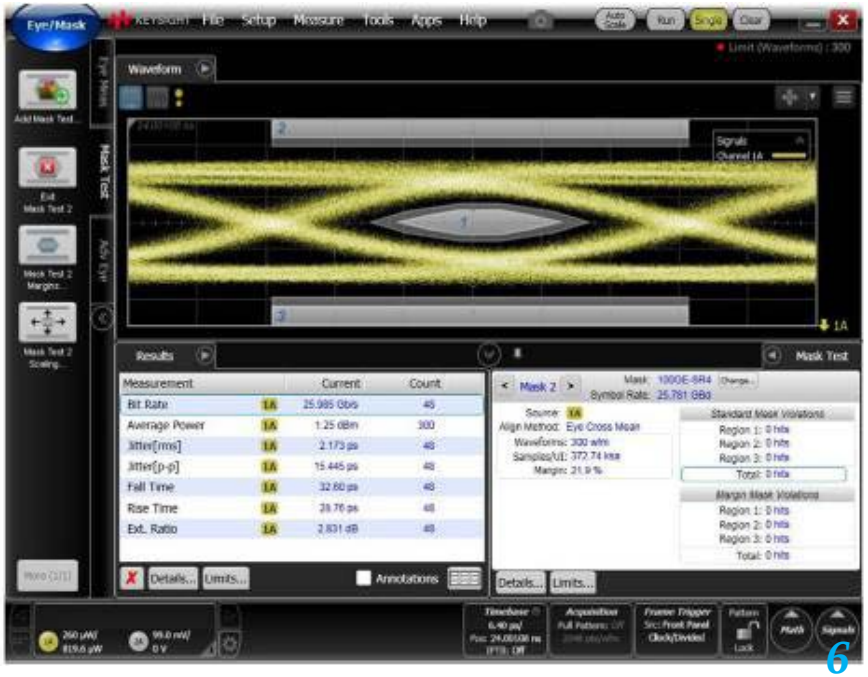




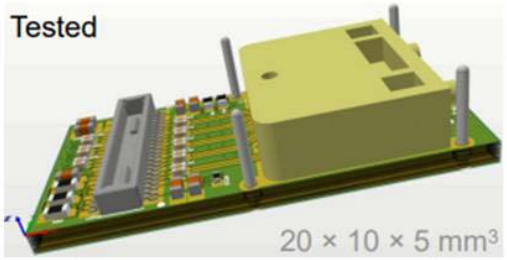




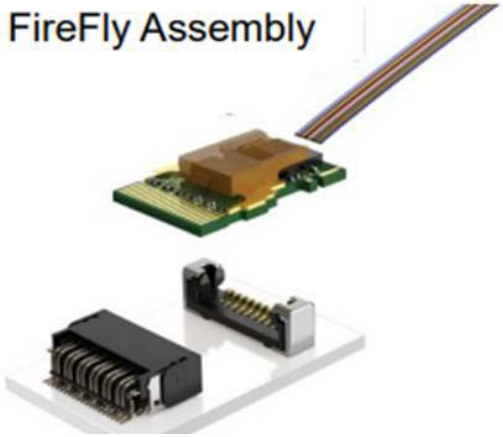




AS+SMU+前鼎 QTRx Transceiver

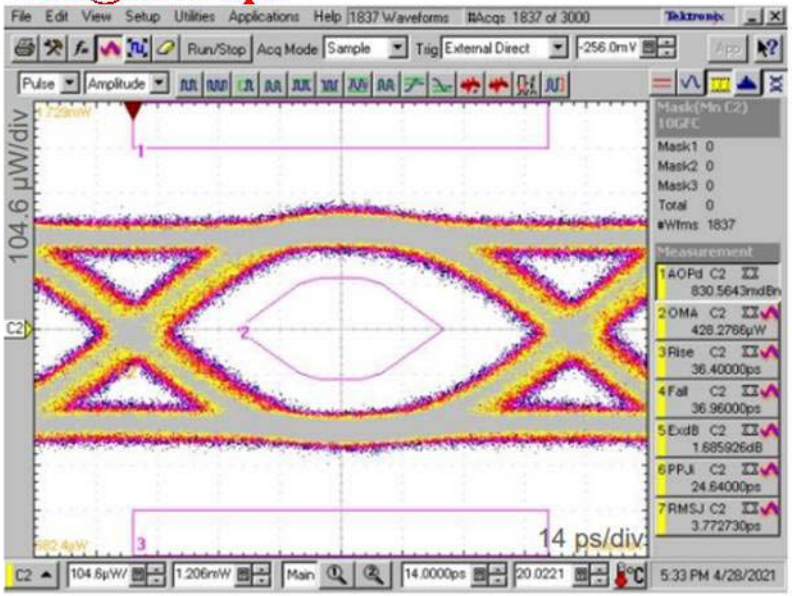


- 4TX+4RX, tested @10G, will do 25 Gbps
- VCSEL, PD, PCB all 25 Gbps qualified
- Driver, QLDD, QTIA, TSMC 65nm

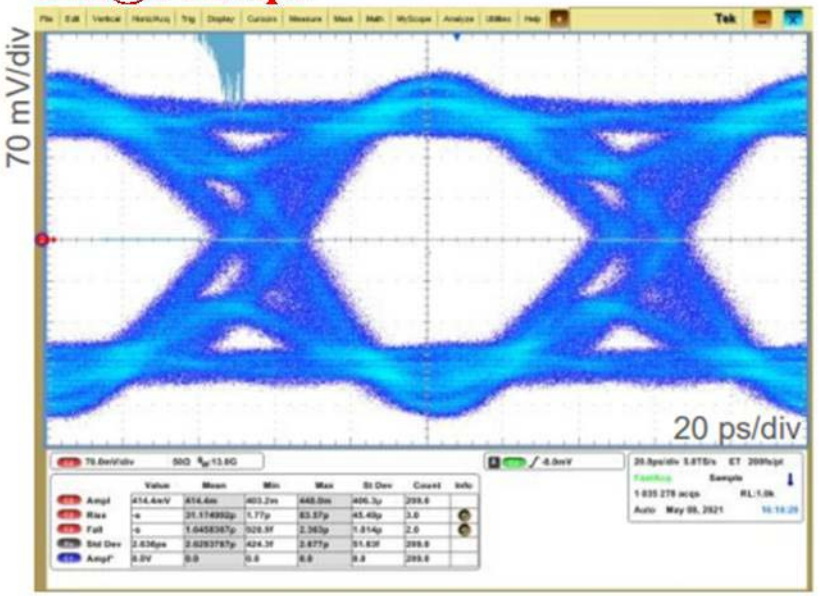


QTRx	QLDD	QTIA	
Data rate	10 Gbps	2.56 Gbps	10 Gbps
Power supply	1.2 V and 2.5 V		
Sensitivity (BER =1E-12)	80 mV	-17 dBm	-8 dBm
Rise /fall time	37 ps	40 ps	50 ps
Total jitter (BER =1E-12)	-	38.5 ps	52.4 ps
Power consumption /ch	124 mW	120 mW with CP	

TX@10Gbps

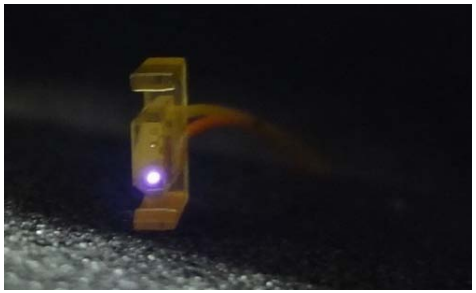


RX@10Gbps

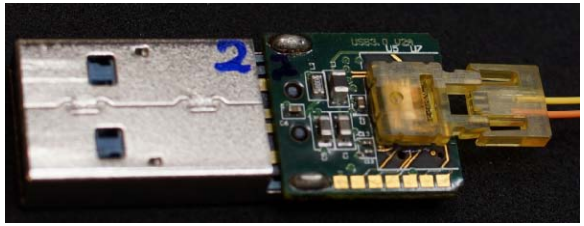


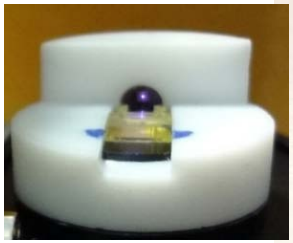
Radiation damage to PEI, epoxy Lens

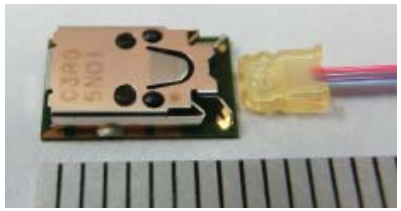
- **The light coupler cap**
  Spherical-aberration free Plano-Convex Hyperbolic Lens
  Material: PEI (polyetherimide), as for the TOSA/ROSA tip
  optical quality surface

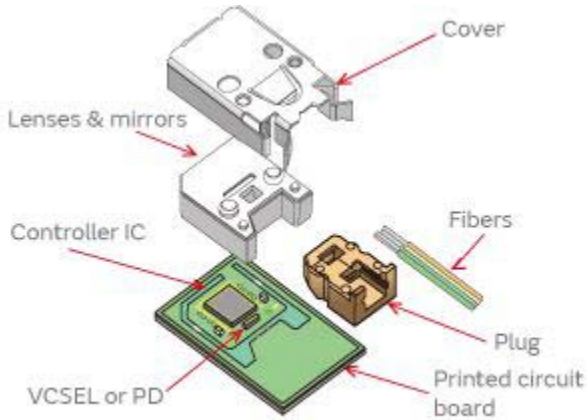


- **Deterioration by Total-Ionizing-Dose**
  Irradiated with Co^{60} Gamma ray
  at INER Taiwan
  flux: 3.5 kGy/hr, total: **117 kGy**
  ➔ **NO LOSS !!**
  for light transmission
  within the 2% systematic error









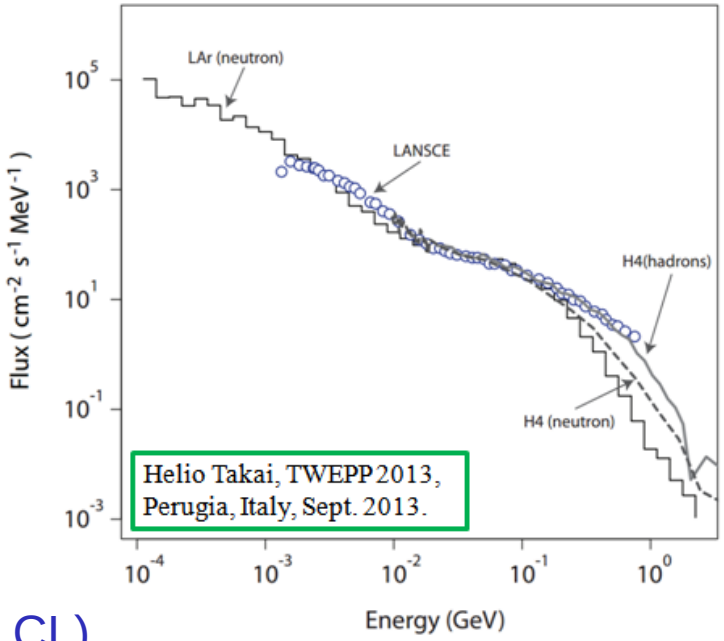
Internal structure of the FOT MMC3 series proc

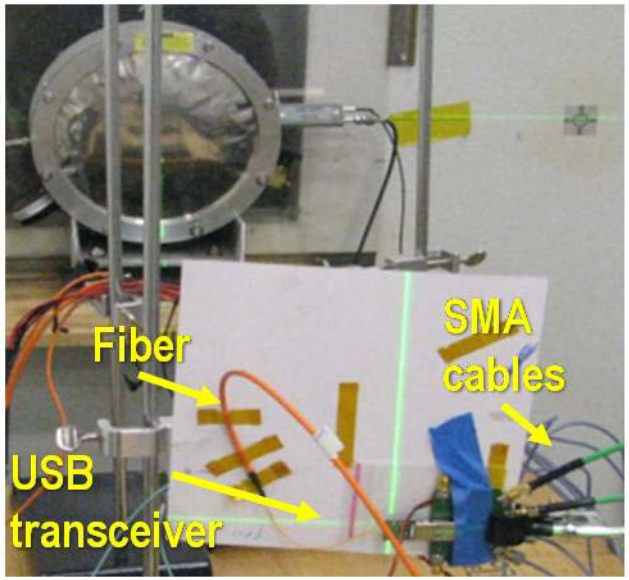
LANSCE neutron test

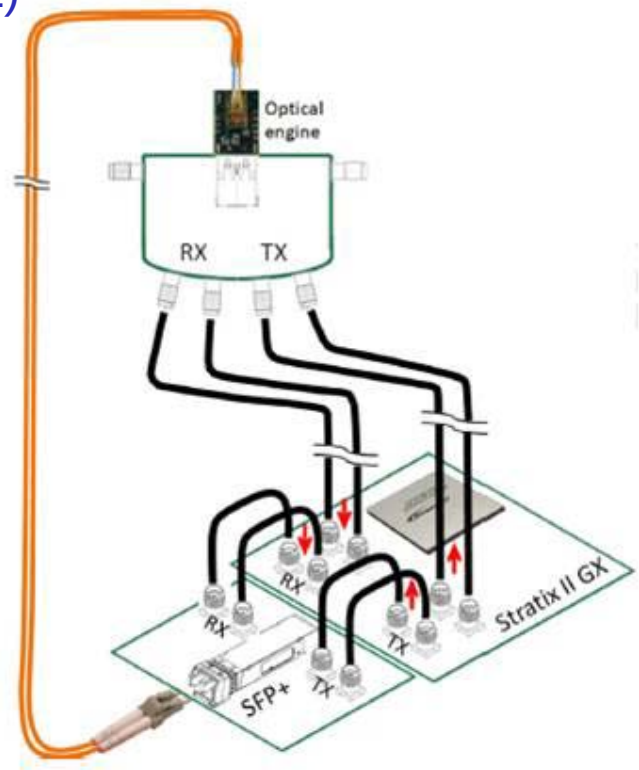
- Beam profile similar to ATLAS
- **USB transceiver in Bit-Err-Rate**
  Straitix II GX, PRBS 2^7-1 bit pattern
  TX path, RX path tested separately

  neutron flux 2.9×10^5 n/cm^{2}s
  over 1.5 days to 3.8×10^{10} n/cm^2

  TX: 0 error, upper limit 1.0×10^{-10} cm^2/ch (95% CL)
  RX: 11 errors SEE cross section 2.9×10^{-10} cm^2/ch

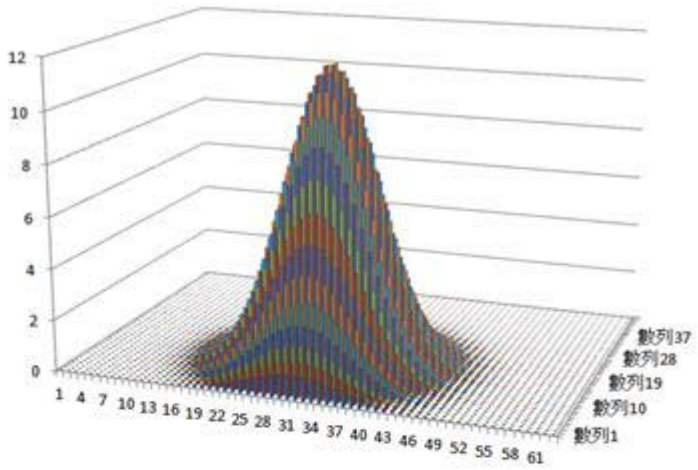




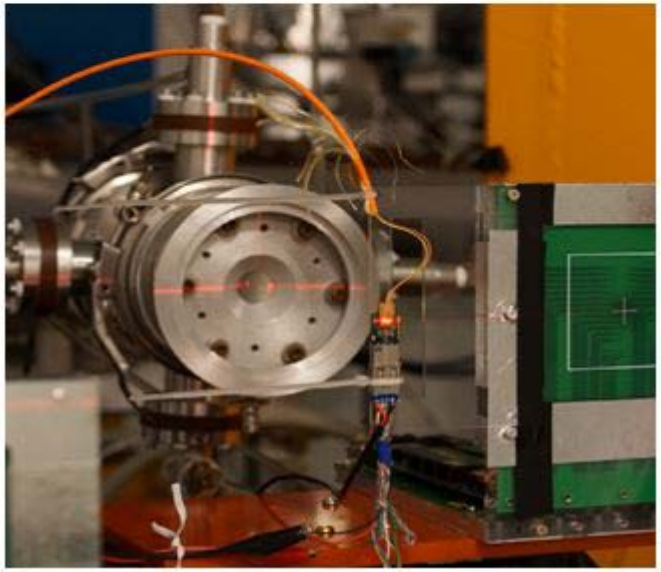


Non-Ionizing Energy Loss to VCSEL, Optical IC

- **Proton Irradiation**
  INER 30 MeV proton cyclotron
  flux of **$2x10^{12}$** p/cm^{2}s, to a total **$1.2x10^{14}$**
  equivalent to **$4.8x10^{14}$** 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**



VCSEL rad-hard degradation, annealing

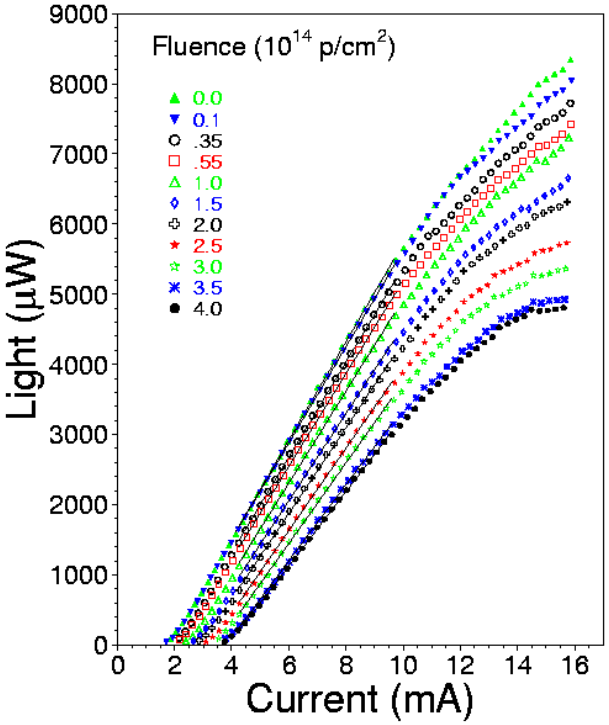
Indiana IUCF Cyclotron 200 MeV proton

VCSEL light degradation ➔ linear to fluence
rad-hard fiber connected to readout, independent of flux rate

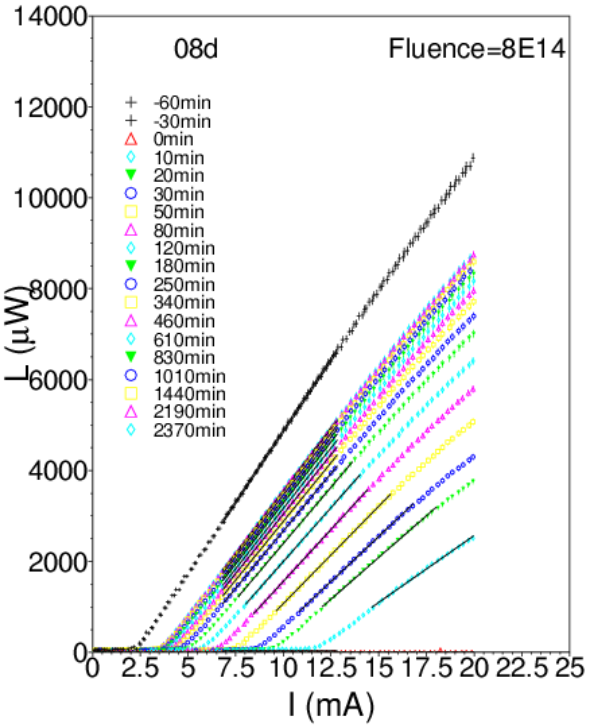
Fast annealing by charge injection
at operation current (10 nA) applied

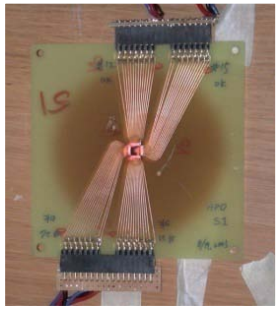
1st generation Oxide VCSEL
1 Gbps Truelight

L-I of VCSEL (oxide)
vs. **online** Fluence



L-I of VCSEL (oxide)
vs. **Annealing** time





NIEL to GaAs diodes

850 nm VCSELs, 1 Gbps

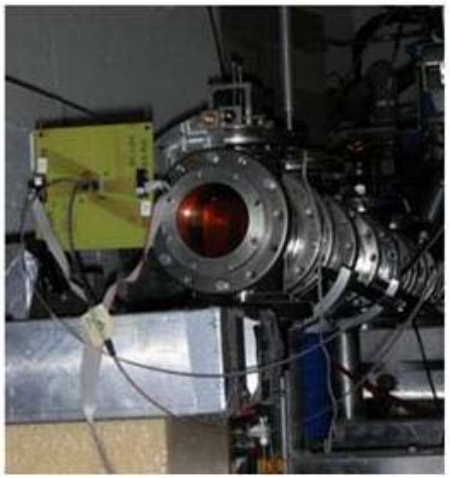
NIEL damage

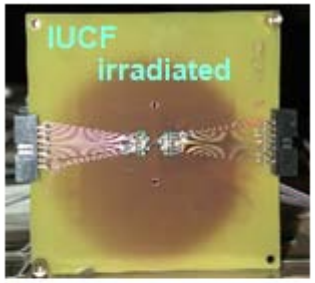
→ light degradation linear to fluence

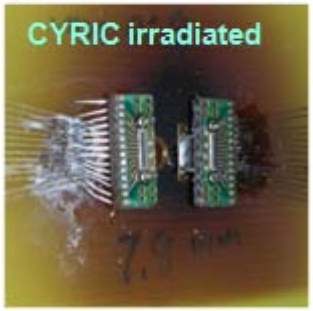
Higher proton momentum

→ less damage to GaAs components (contrary to theoretical calculations)

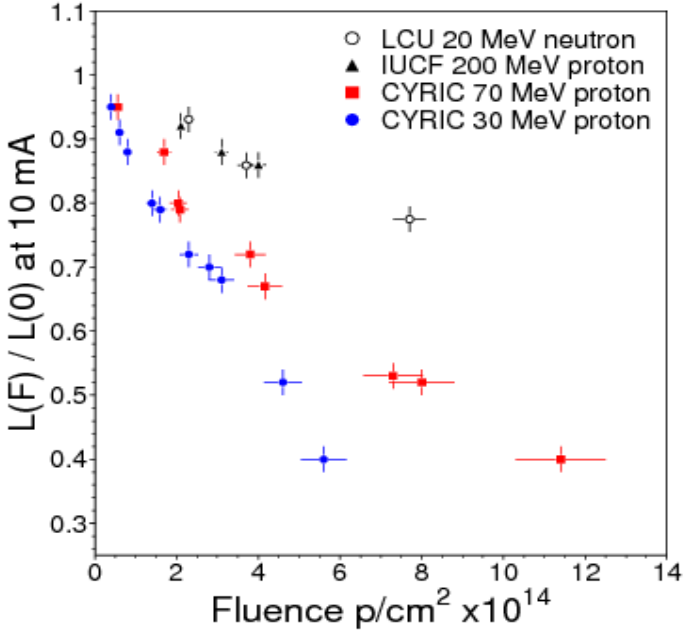
IUCF beam area





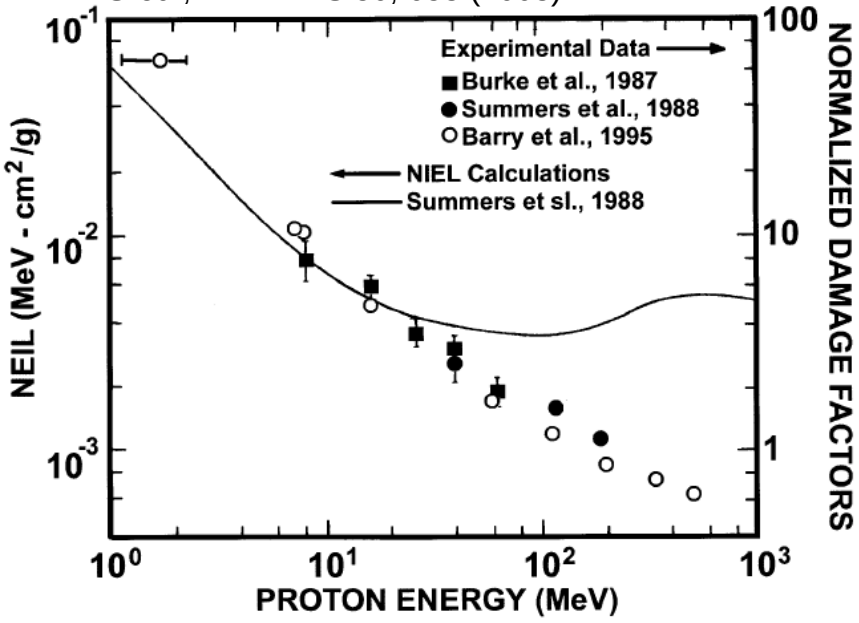


VCSEL (GaAs) light degradation



GaAs solar cell measurements

Srour, IEEE TNS 50, 653 (2003)



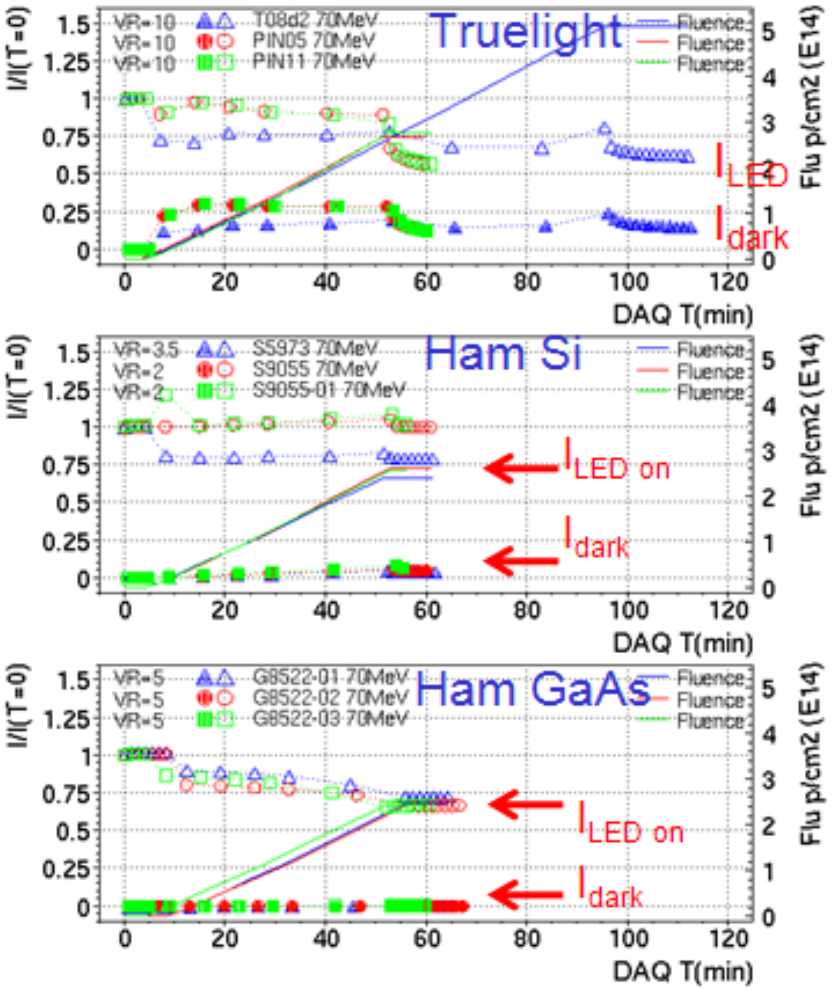
PIN proton damage

Degradation of responsivity (I/L) proton 2E14

	V_R Vol	fc GHz	diam. µm	I/L A/W	30 MeV I/L ratio	30 MeV Dark nA	70 MeV I/L ratio	70 MeV Dark nA
Truelight	**-10**		**100**	**0.55**	**45%**	**70**	**45%**	**50**
S9055	-2	1.5	200	0.32	100%	40	100%	20
S9055-01	-2	2.0	100	0.20	100%	15	100%	10
S5973	-3	1.5	400	0.53	70%	100	80%	50
G8500-01	-5	3.0	40	0.11	45%	0	80%	0
G8500-02	-5	1.9	80	0.25	40%	0	72%	0
G8500-03	-5	1.5	120	0.40	35%	0	72%	0

- PIN rad-hardness
  diameter, thickness ➔
  A/W, speed & rad-hard
- Proton energy dependence
  Si PIN : compatible with
  30 MeV and 70 MeV protons
  GaAs PIN : twice damage by 30 MeV
  than 70 MeV protons

70 MeV proton

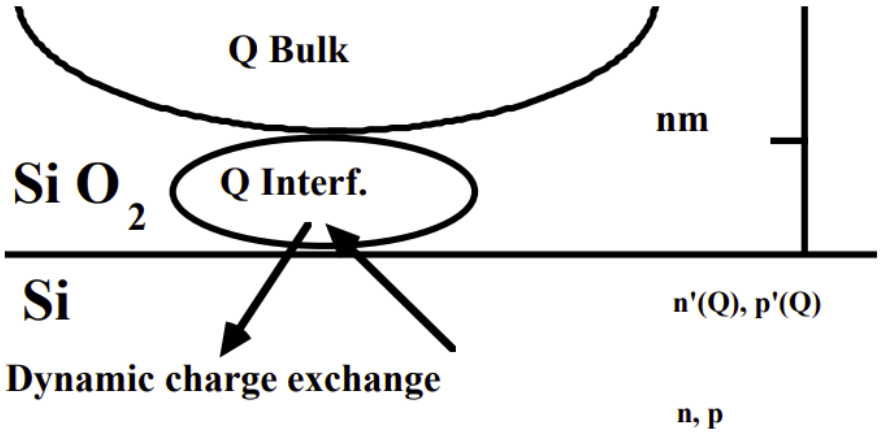


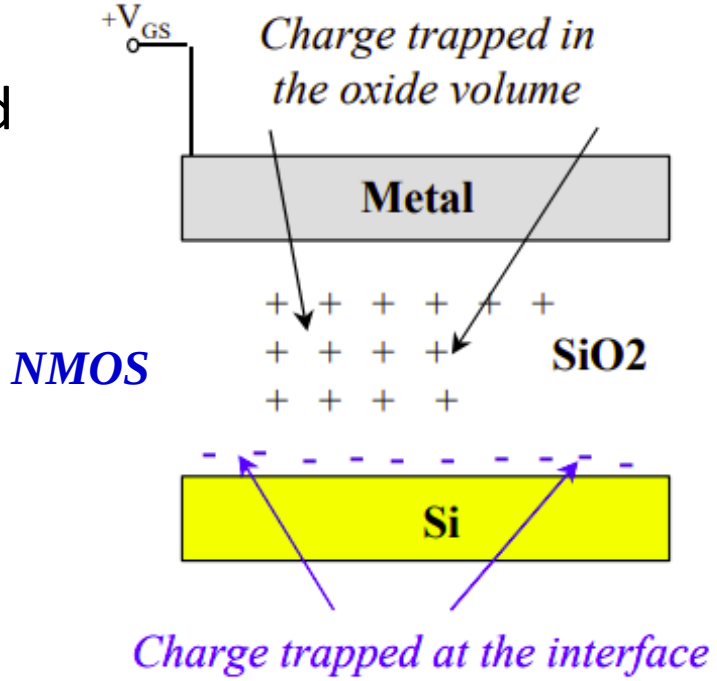
[J. Gasiot CERN Training]

TID effects on CMOS

Total Ionizing Dose (TID) induces charge-trapping at **Si-SiO2 interface**
Dependence : total dose, dose rate, annealing

- new interface states formed.
- interface state density vs. energy changed
- interface state density changes with time
- construction after irradiation
- static and dynamic electrical response of the Si-SiO2 altered



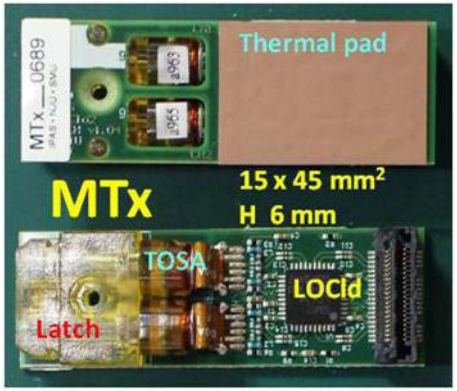


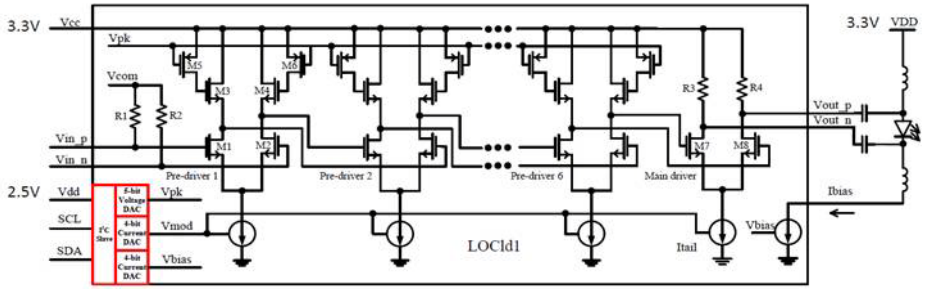
Threshold voltage degradation as a function of the total Dose

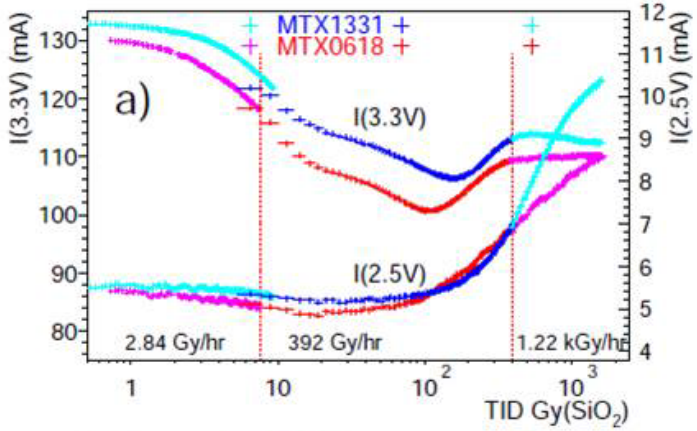
X-ray TID on MTX LOCld of ATLAS LAr

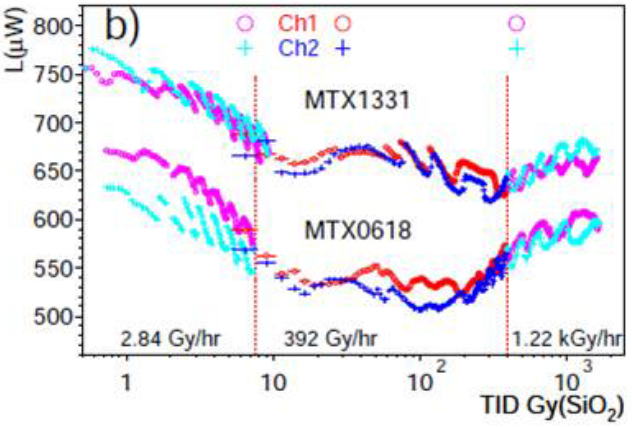
X-ray, 3 dose-rates in 280 min to 1.62 kGy(SiO_2)

LOCld laser driver shows degradation



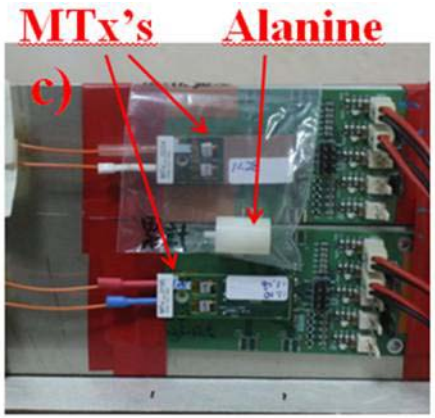


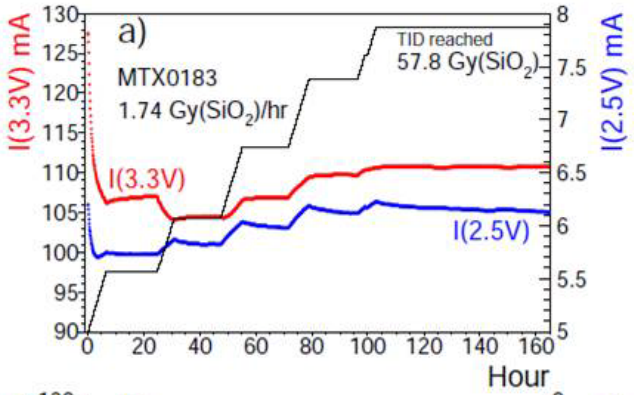


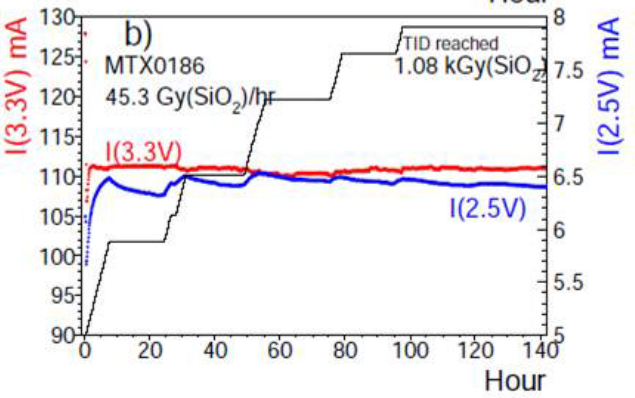


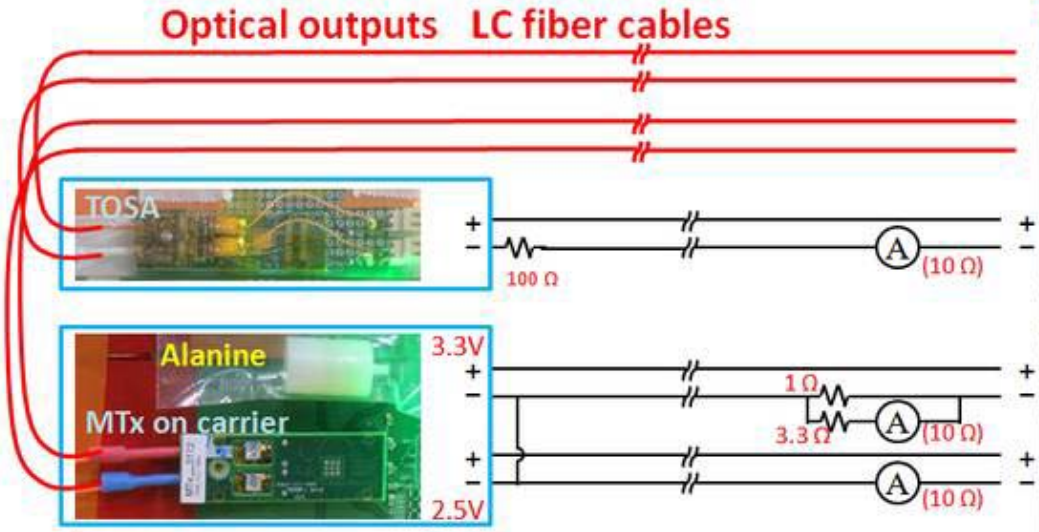
Co-60 TID on MTX LOCld

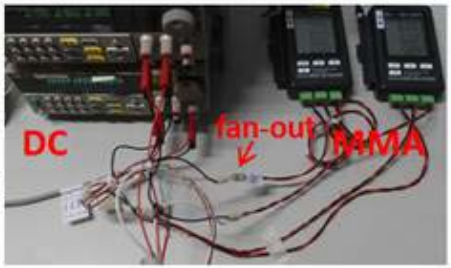
Co-60 varying dose-rates 0.14 to 45 Gy/hr
Irradiation in daytime, annealing overnight
Dose calibration using Alanine





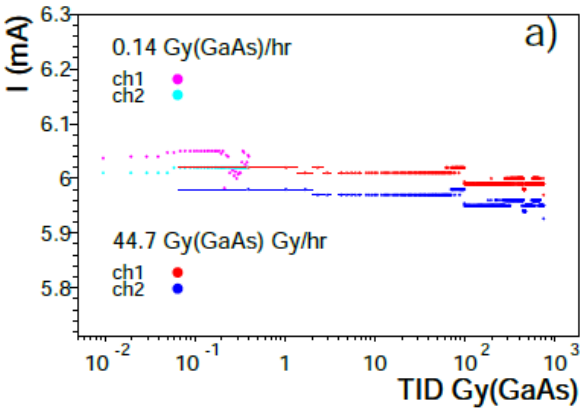


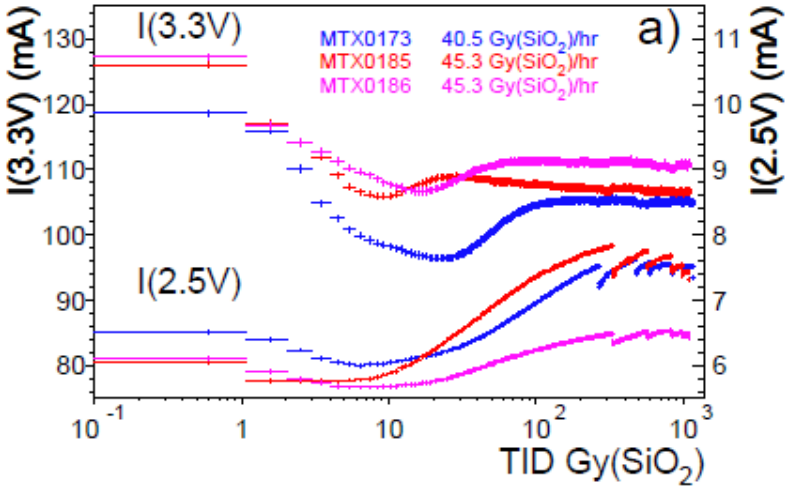


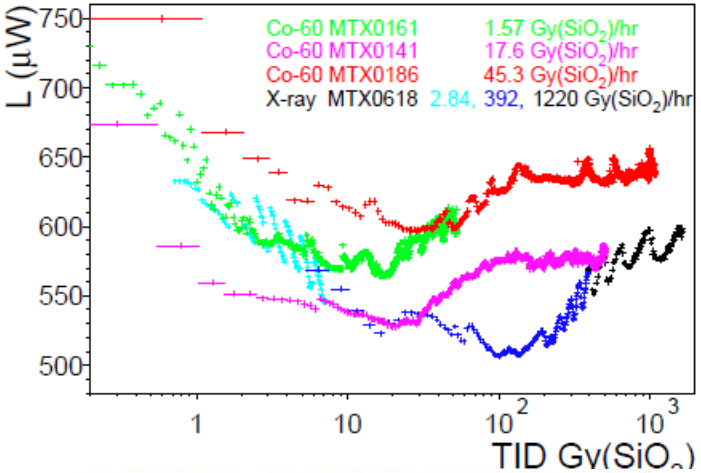


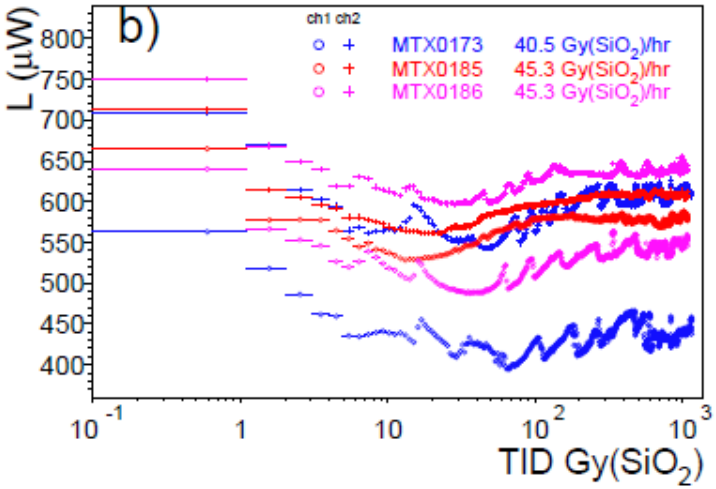
Co-60 TID on MTX LOCld

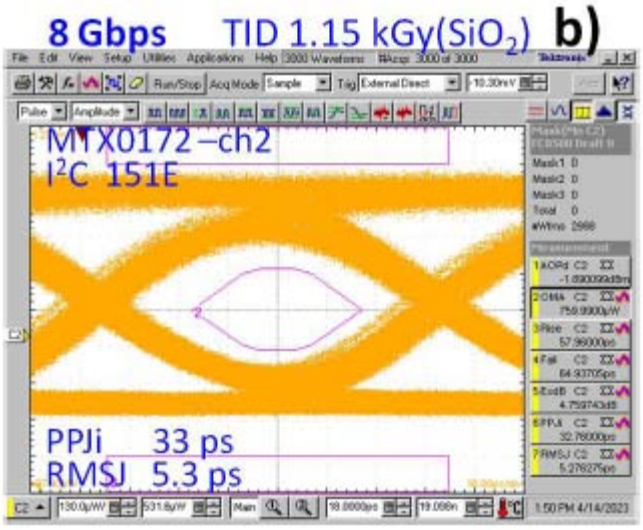
Co-60 lower rate to X-ray, mio
VCSEL not effected by TID
CMOS current drops ~ 10-100 Gy(SiO_2)





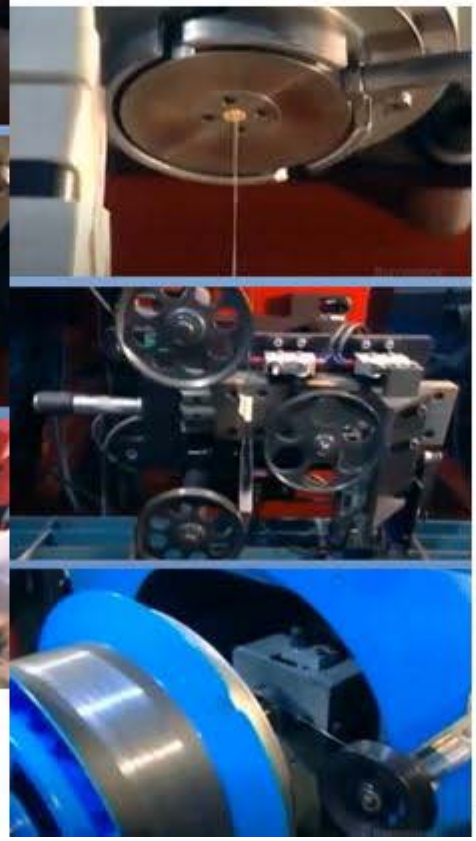




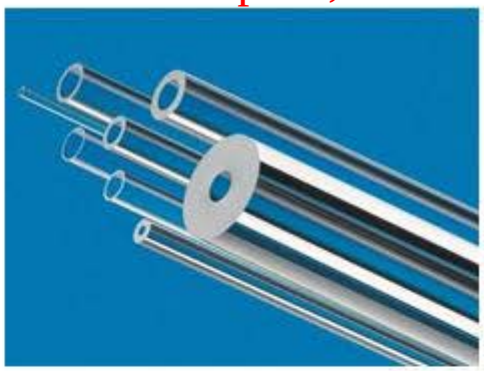


Optical fiber making

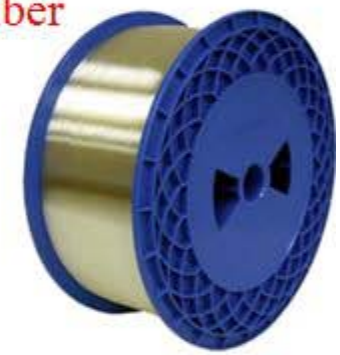
PCVD plasma chemical vapor Deposition
MCVD modified chemical vapor deposition
OVD outside vapor deposition
VAD vapor axial deposition



Fused Silica Tubes,
pure SiO_2
for Fiber Optics,



Bare Fiber
Reel

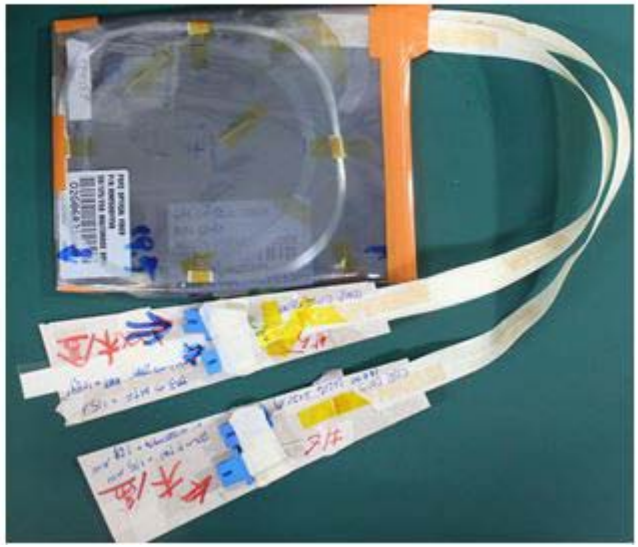


Fiber Cable

Looking for testing 武漢 YOFC
长飞光纤 Ge-doped, Rad-hard fibers

Co-60 irradiation facility

Bare fiber sample
in bag, with SC connectors
in water bath, const ^{o}C



Ge-doped MM fiber, Co-60 test

Fiber Radiation Induced Attenuation (RIA)

$$RIA = (IL(0) - IL(t))/Length$$

$$IL(dB) = 10 \times \log10 (P_T/P_R)$$

IL insertion loss

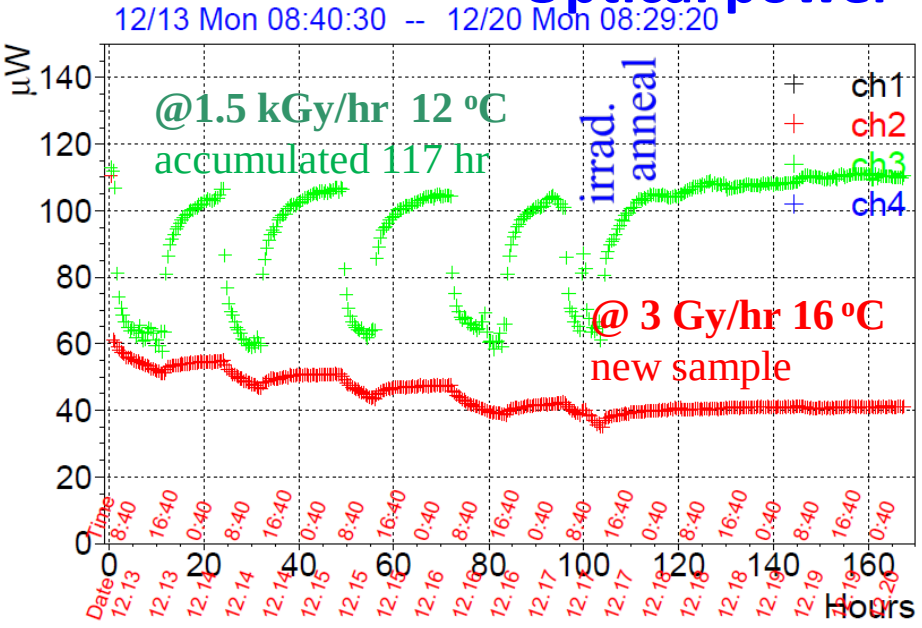
P_T transmitter, P_R received

Dependences : **Dose rate, Temperature**

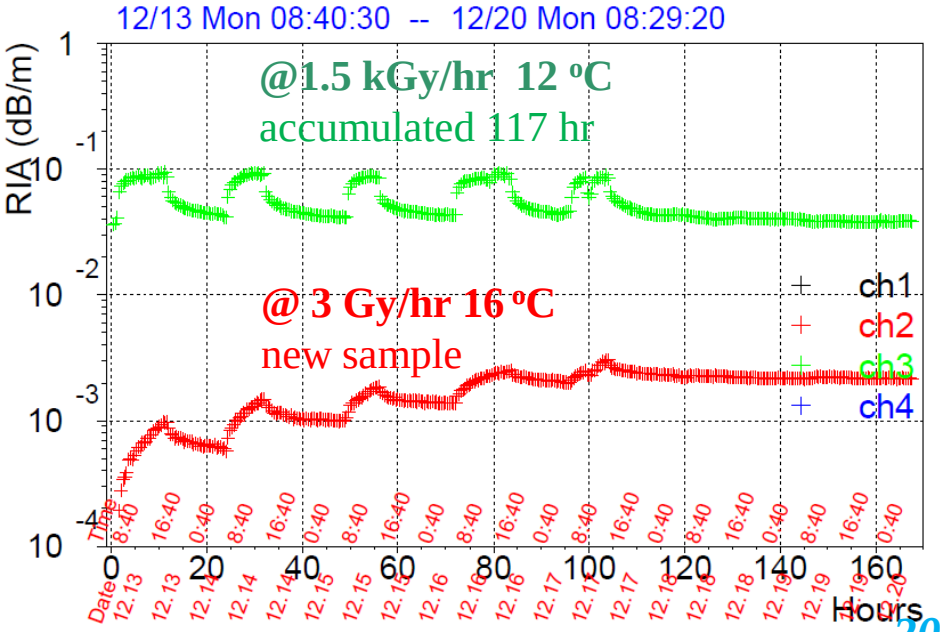
Fibers tested at Dose rate 1.5kGy/hr

Irrad ~8hr daytime, anneal overnight, over 1 week

Optical power

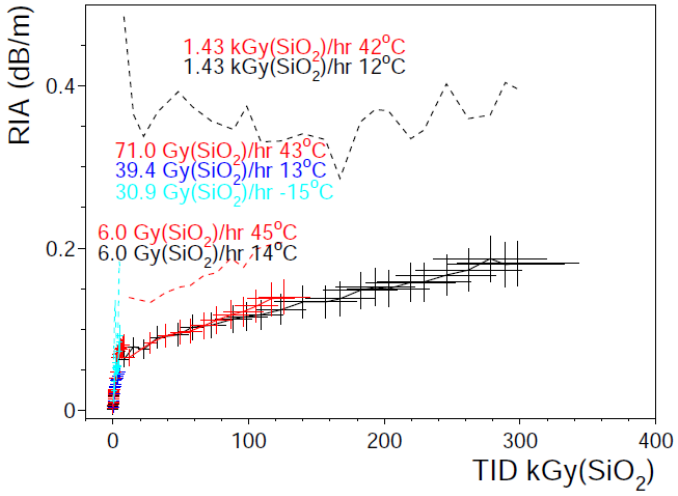


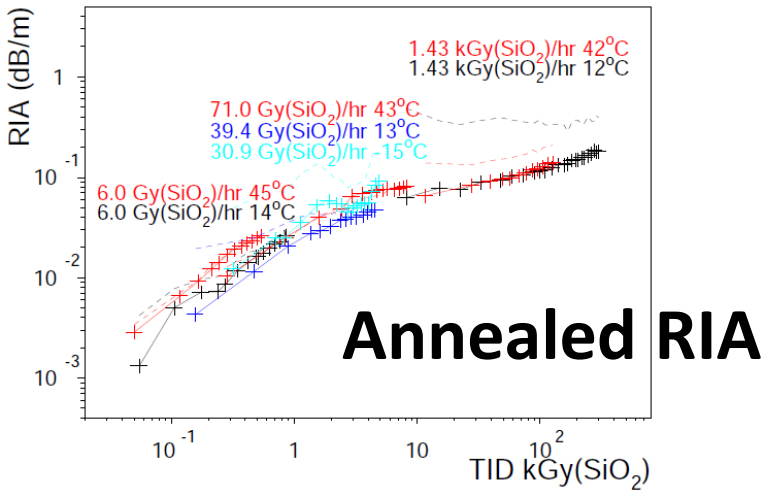
RIA



Ge-doped MM fiber (POFC 0.2 dB/m 300 kGy)

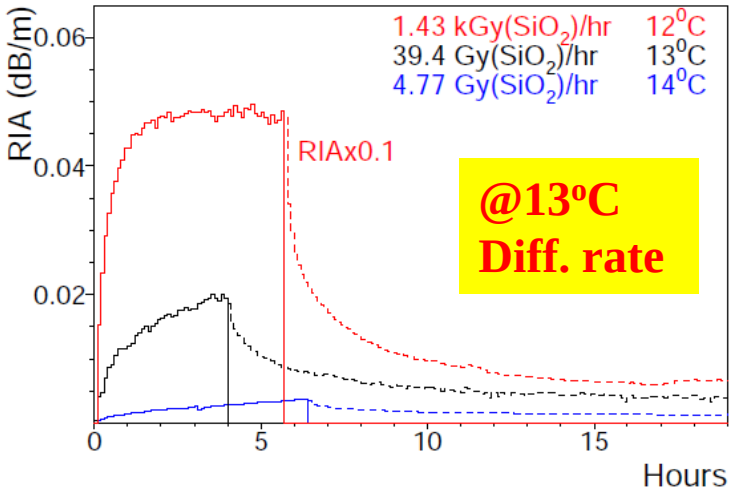
Dashed lines: Instant RIA, at daily max dose
Points: RIA after 10 hr annealing

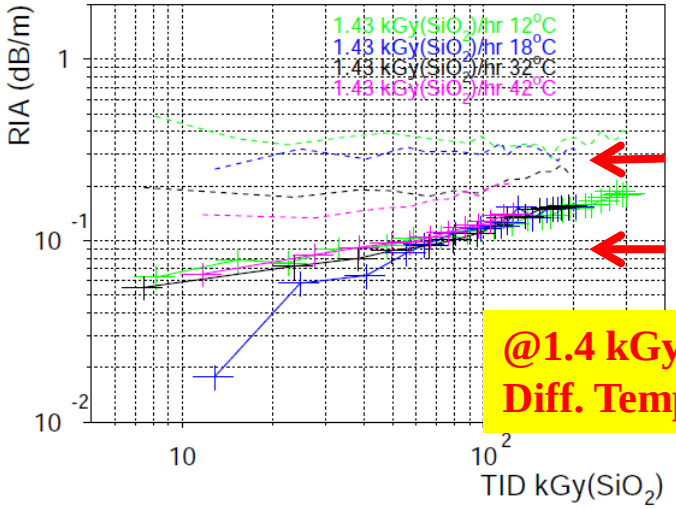




Annealed RIA

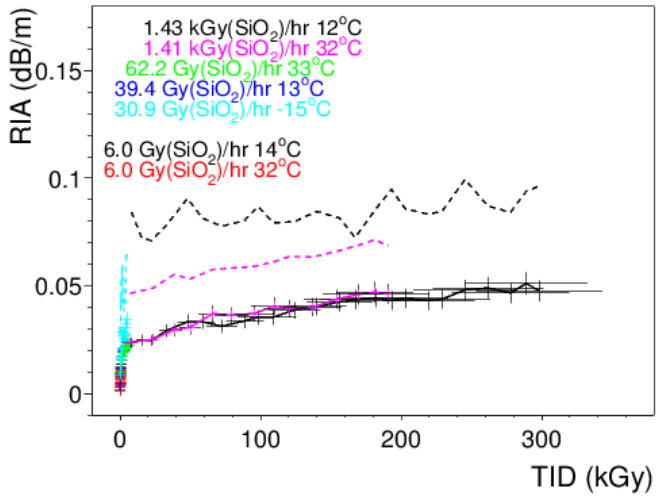
- **Dose Rate :** higher rate → higher instant RIA
- **Temperature :** lower T → higher instant RIA

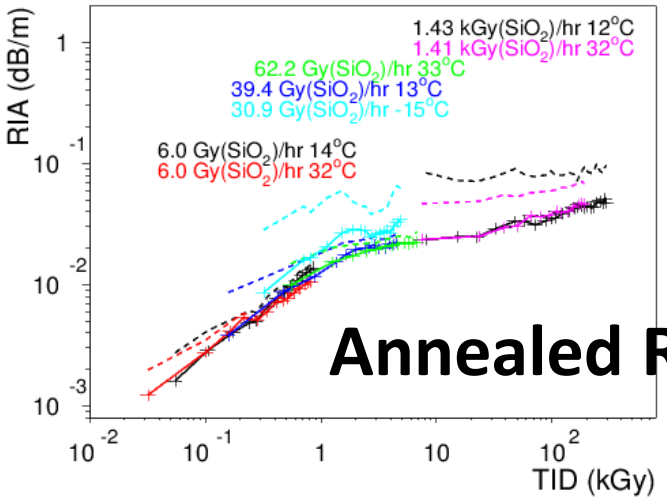




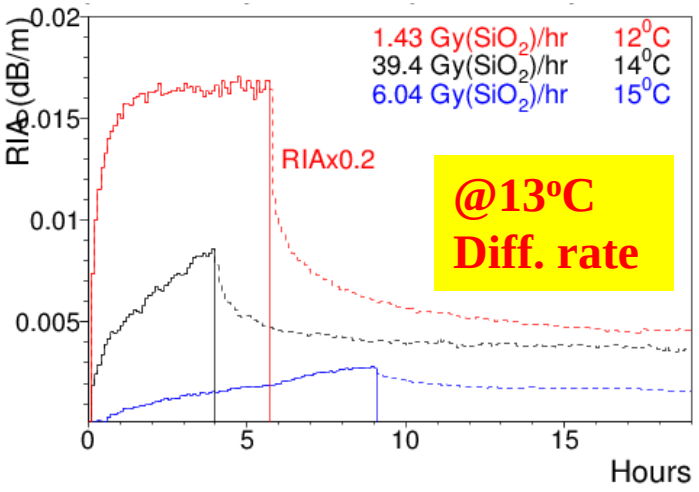
Ge-doped MM fiber (Co. 0.04 dB/m 300 kGy)

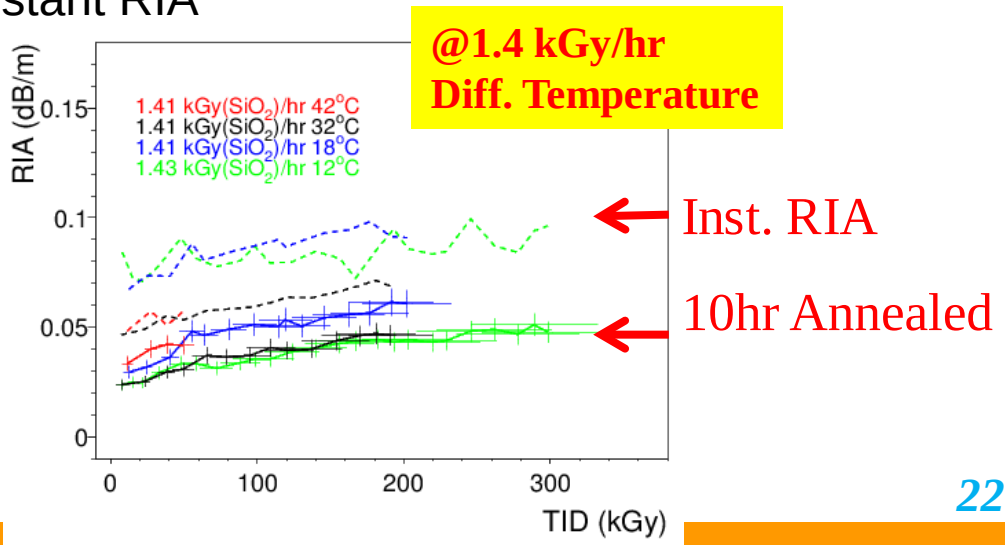
Dashed lines: Instant RIA, at daily max dose
Points: RIA after 10 hr annealing





- **Dose Rate :** higher rate → higher instant RIA
- **Temperature :** lower T → higher instant RIA





Summary

- **Opto COB assembly is mature >10 Gbps**

  PCB: 10 GHz FR4, 25 GHz, Megtron,
  Electric connectors: SFP, QSFP, Hirose, Firefly
  Optical coupling: LC, MT, mini-pigtails

- **Radiation hardness**

  Ge-doped MM fiber, good to 0.04 dB/m 300 kGy
  NIEL on VCSEL, PD
  TID, SEE on ASIC