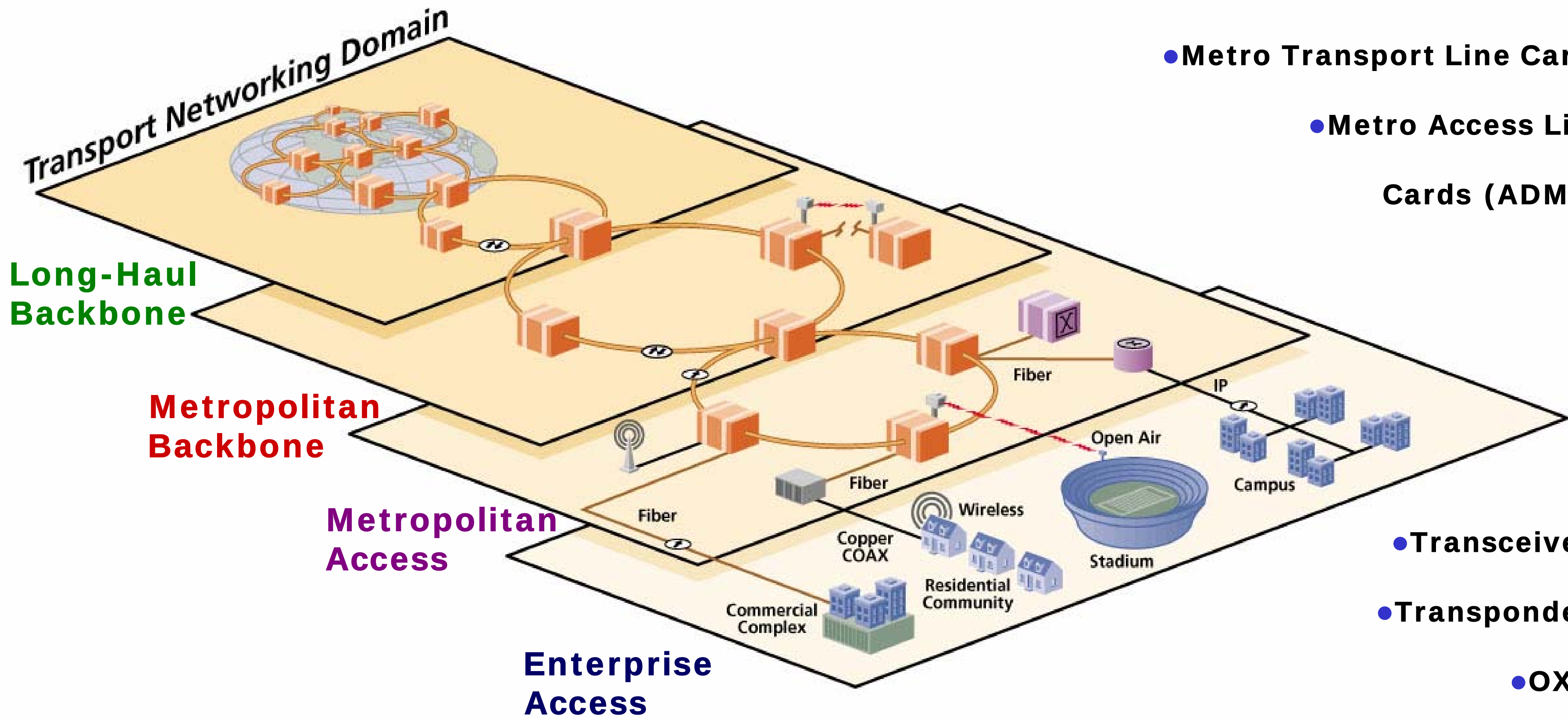
High Performance, Low Cost PIN, APD Receivers in Fiber Optical Networks and FTTx Applications

Hui Nie

4/23/2005

Receiver Applications



- Back Bone Core Nodes LR and VLR Interface Cards
- Metro Transport Line Cards
- Metro Access Line Cards (ADM's)
- Transceivers
- Transponders
- OXCs

- **FTTx Applications/Demands also heating up!**

TriQuint OPTOELECTRONICS

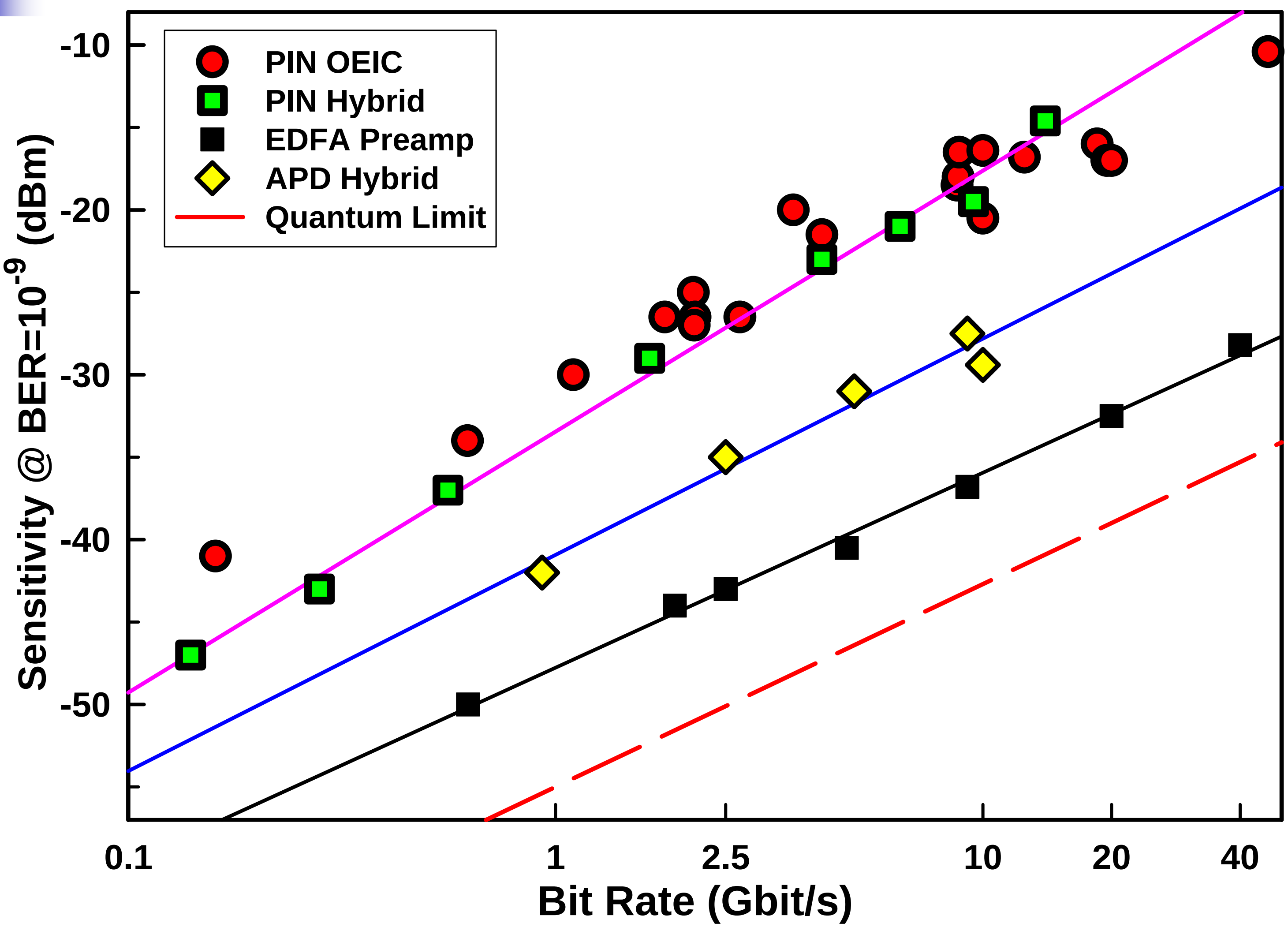
Photodetectors and Optical Receivers

- **Introduction**
- **Photodetectors Technologies**
  - Overviews
  - PIN Photodiodes
  - Avalanche Photodiodes (APDs)
  - APD Design Trade-offs
- **Photoreceivers Technologies**
  - Overviews
  - High Performance MSA Compliant Receivers & ROSAs
- PIN, APD ROSA in FTTx Applications

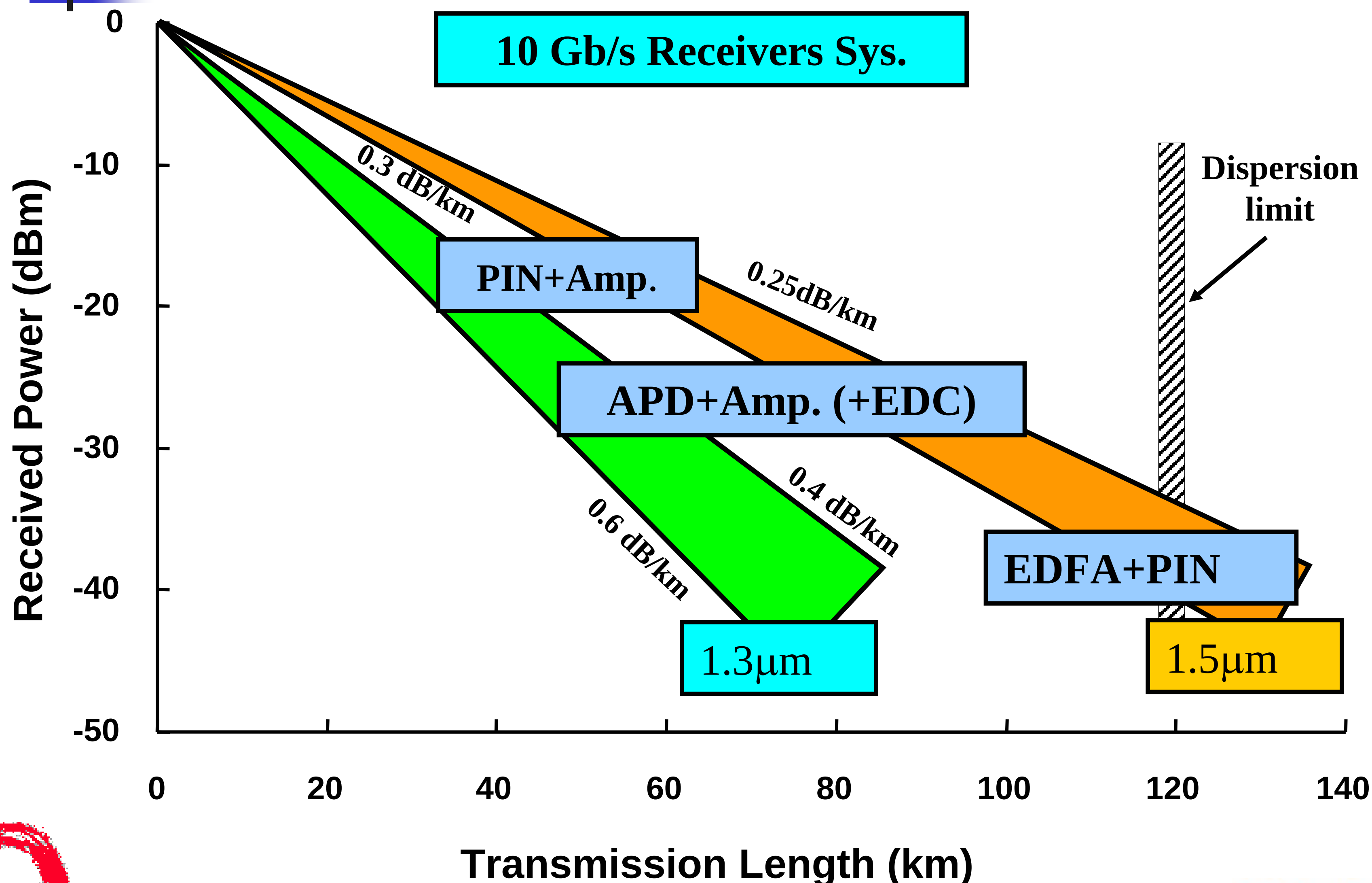
Photodiodes Technologies

- Overview
  - **Transit Time Bandwidth**
  - **RC Time Bandwidth**
- PINs
  - **Surface-Illuminated PINs**
  - **Waveguide PINs**
  - **Traveling-Wave PINs**
- APDs
  - **Etch-Regrowth Planar SACM APDs**
  - **Buried-Mesa APDs w/ Regrowth Guard Ring**
  - **Resonant-Cavity APD w/ Thin Multiplication Layer**
  - **Wafer-Fused SHIP APD**
  - **InGaAlAs/InAlAs Superlattice APD**
  - **Waveguide APD**

Photoreceiver Sensitivities v.s. Bit-Rate

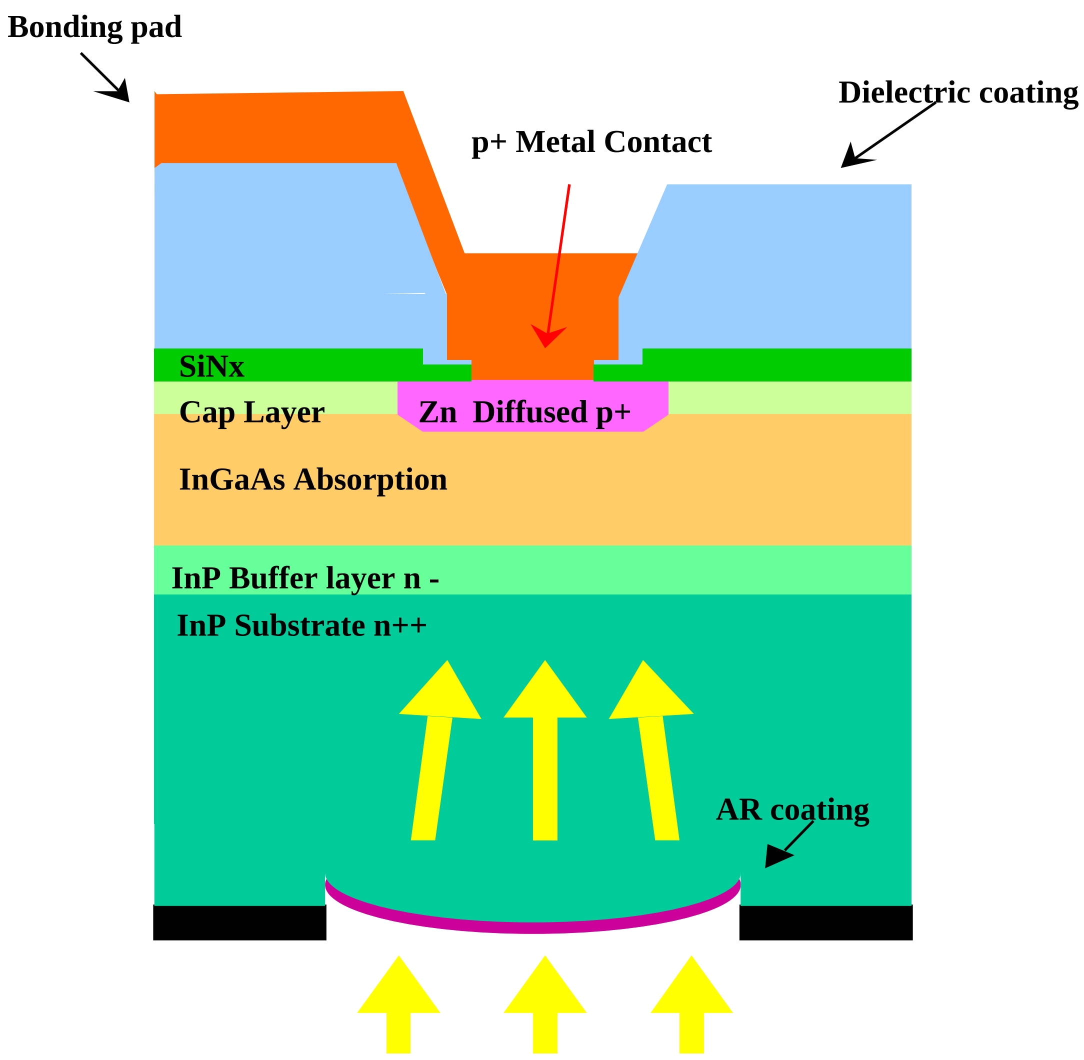


Receiver Systems & Applications (10Gb/s Systems)



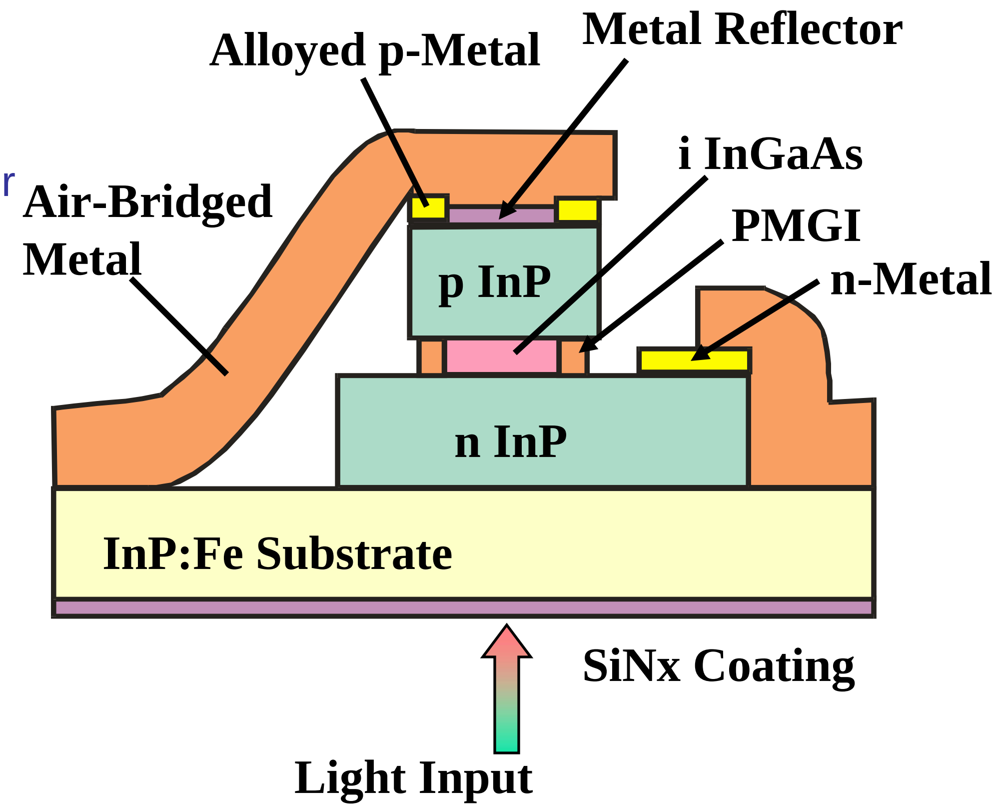
TriQuint OPTOELECTRONICS

Industry Standard Top-illuminated Planar PIN



High-Speed Surface-illuminated Mesa PINs

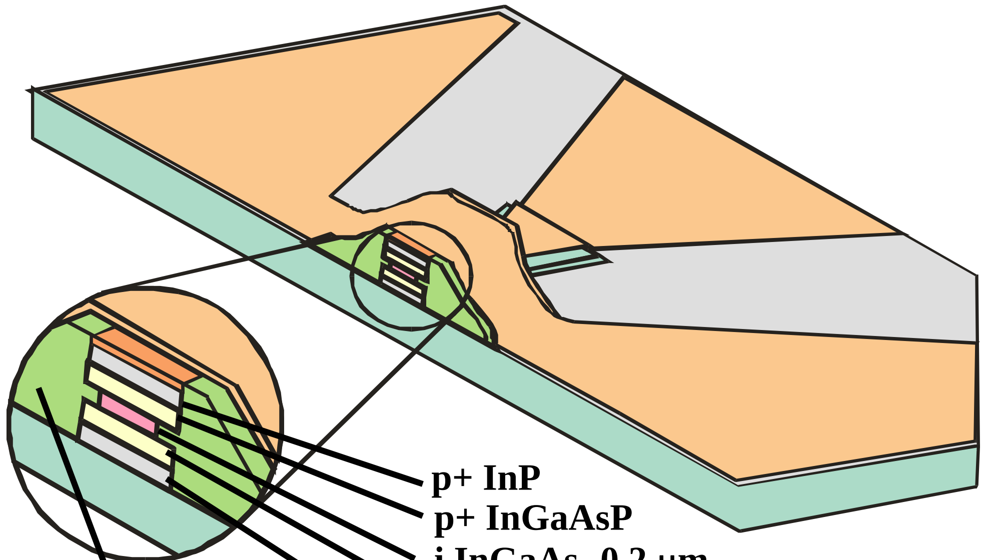
- InGaAs/InP Graded Double Heterostructure p-i-n
- Superlattice Interface Grading
- Small Mesa Size <10 μm^2
- < 0.2 μm InGaAs Absorption Layer
- Undercut, Mushroom Mesa to Minimize Parasitic Capacitance
- QE <25%@1.3 μm
- Hard to Manufacture
- Integrated Bias Circuit (Bias Tee and Matched Resistor)
- Possible Wafer-Fusion DBRs to Enhance QE



TriQuint OPTOELECTRONICS

Waveguide Photodetectors (WGPDs)

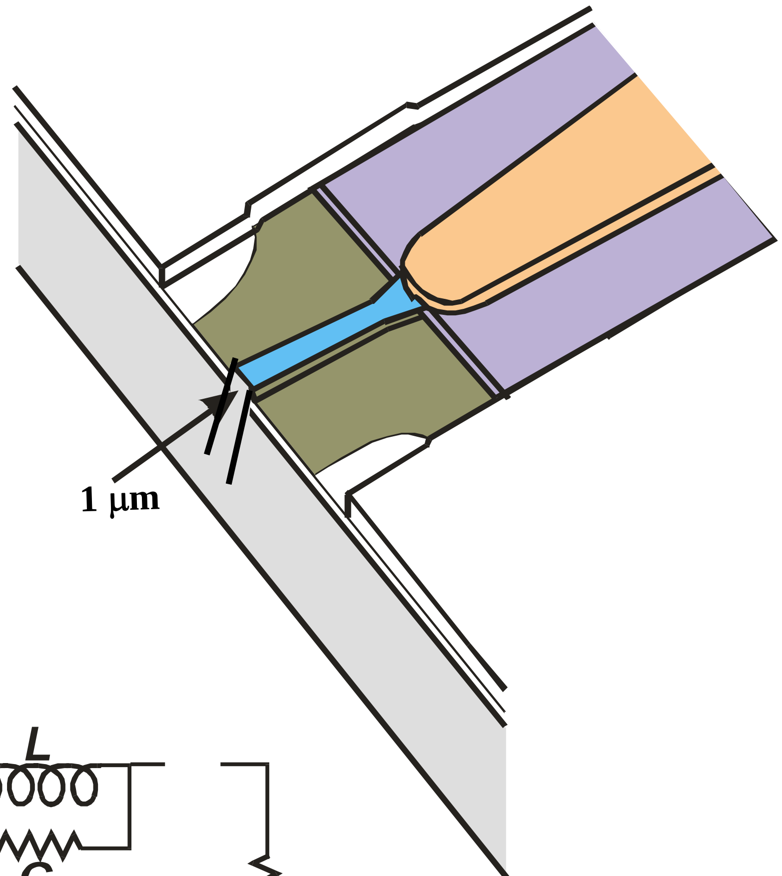
- Side-Illumination
- Optimize Bandwidth and QE Independently
- Multimode Ridge Waveguide
- Micro-Lenses Fiber Coupling, Small Spot Size
- External QE>70%
- Bandwidth>100GH
- Can be integrated OEIC Photoreceiver

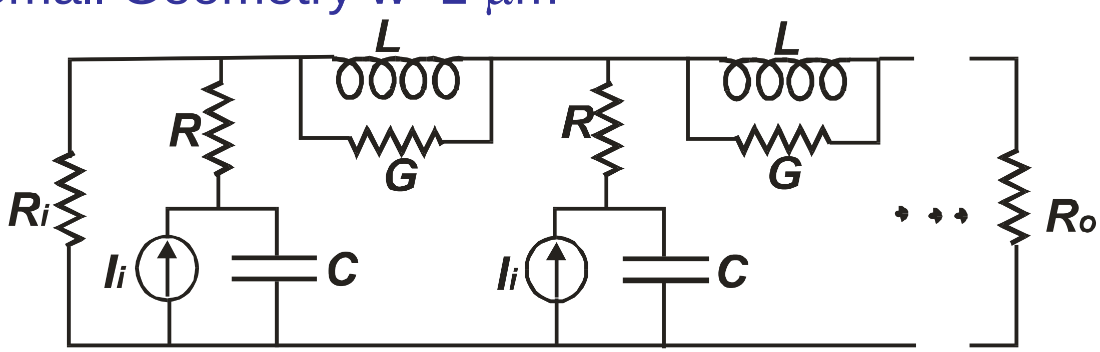


TriQuint OPTOELECTRONICS

Traveling-Wave Photodetectors (TWPDs)

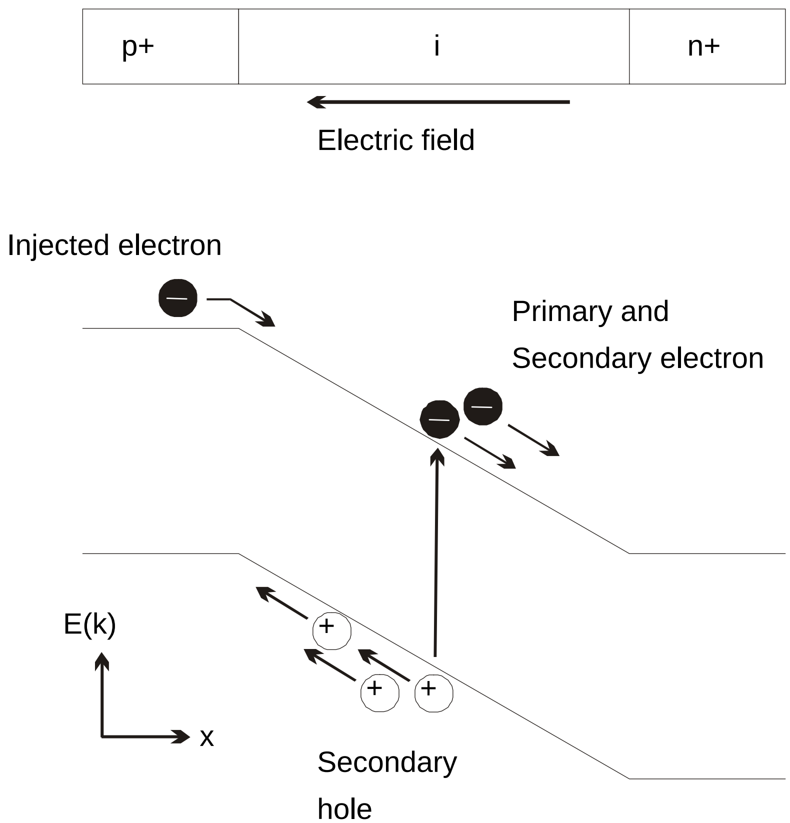
- Electrical Waveguide Concomitant with Optical Waveguide
- Match Between Electrical Wave and Optical Wave (50Ω)
- Eliminate RC Time Tradeoff
- Higher Saturation Power
- Bandwidth=172 GHz, QE~40%
- Small Geometry w=1 μm



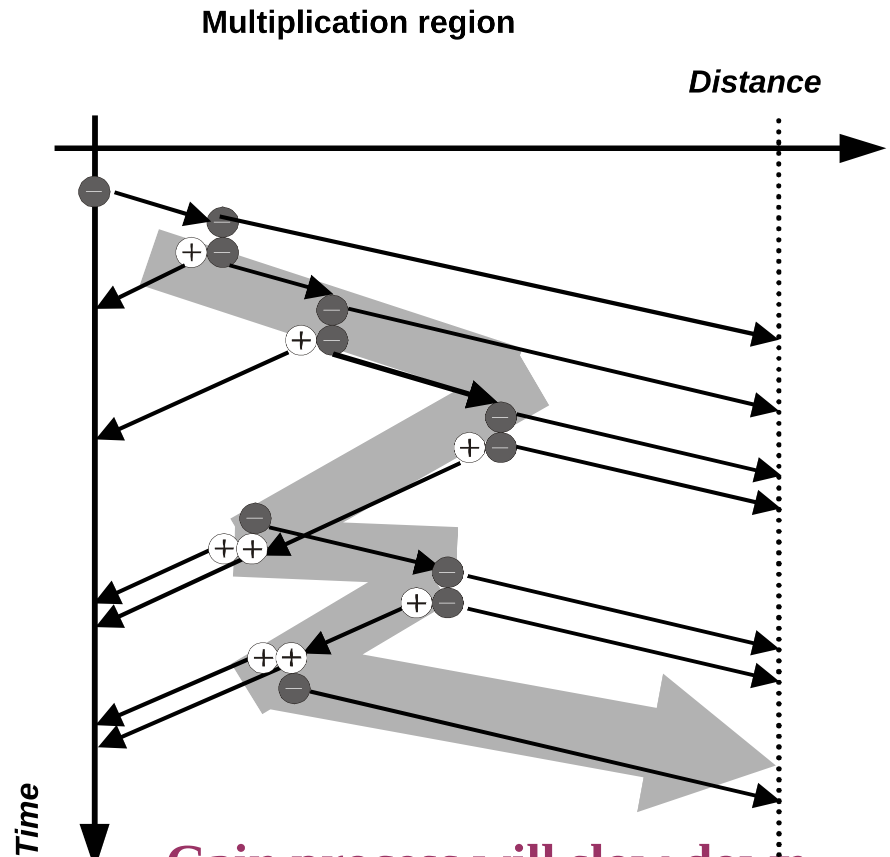


TriQuint OPTOELECTRONICS

Multiplication Process Enhance Performance



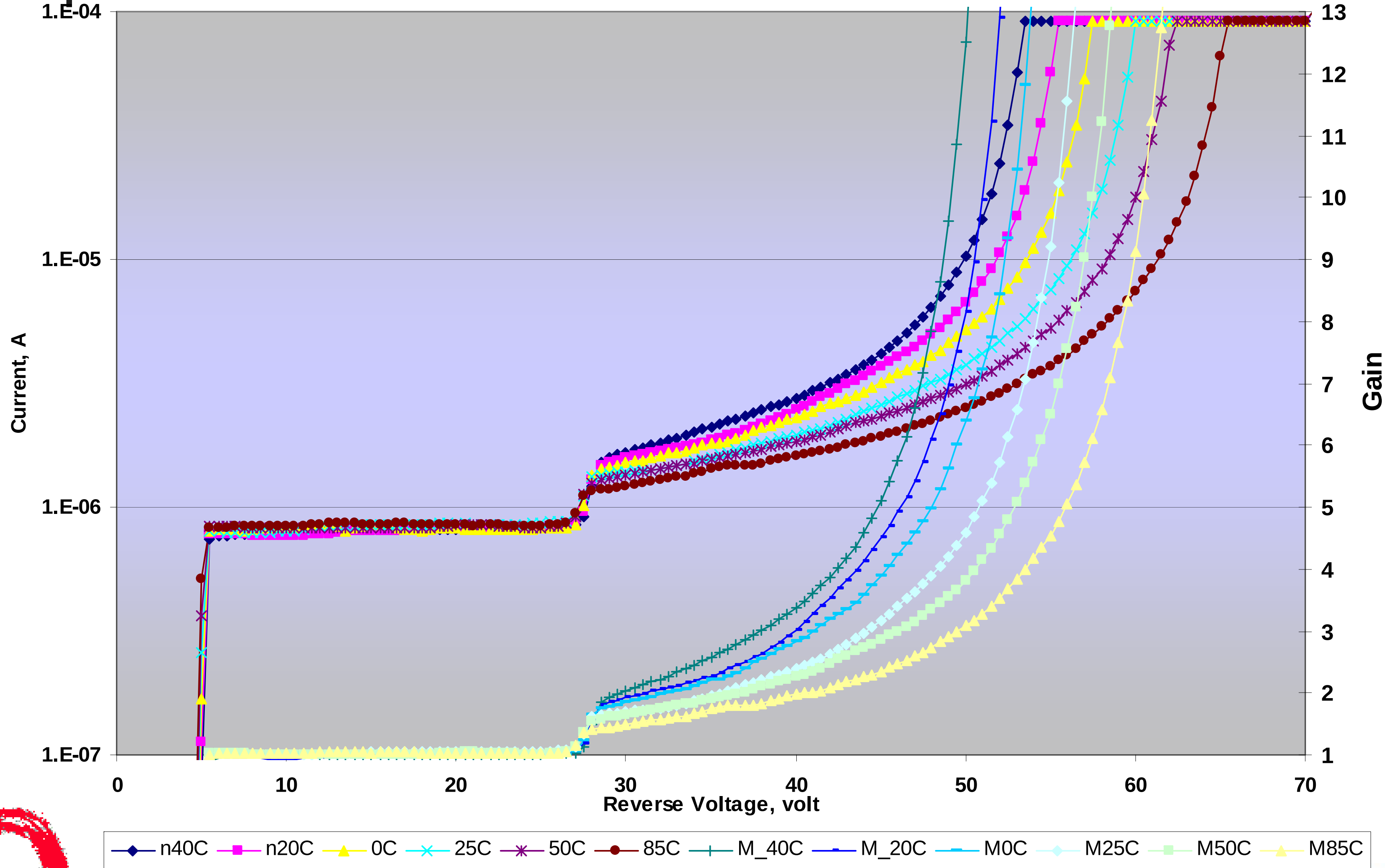
High Electrical Field near avalanche breakdown!



Gain process will slow down transit-time!
Figure of Merit:
Gain-Bandwidth Product

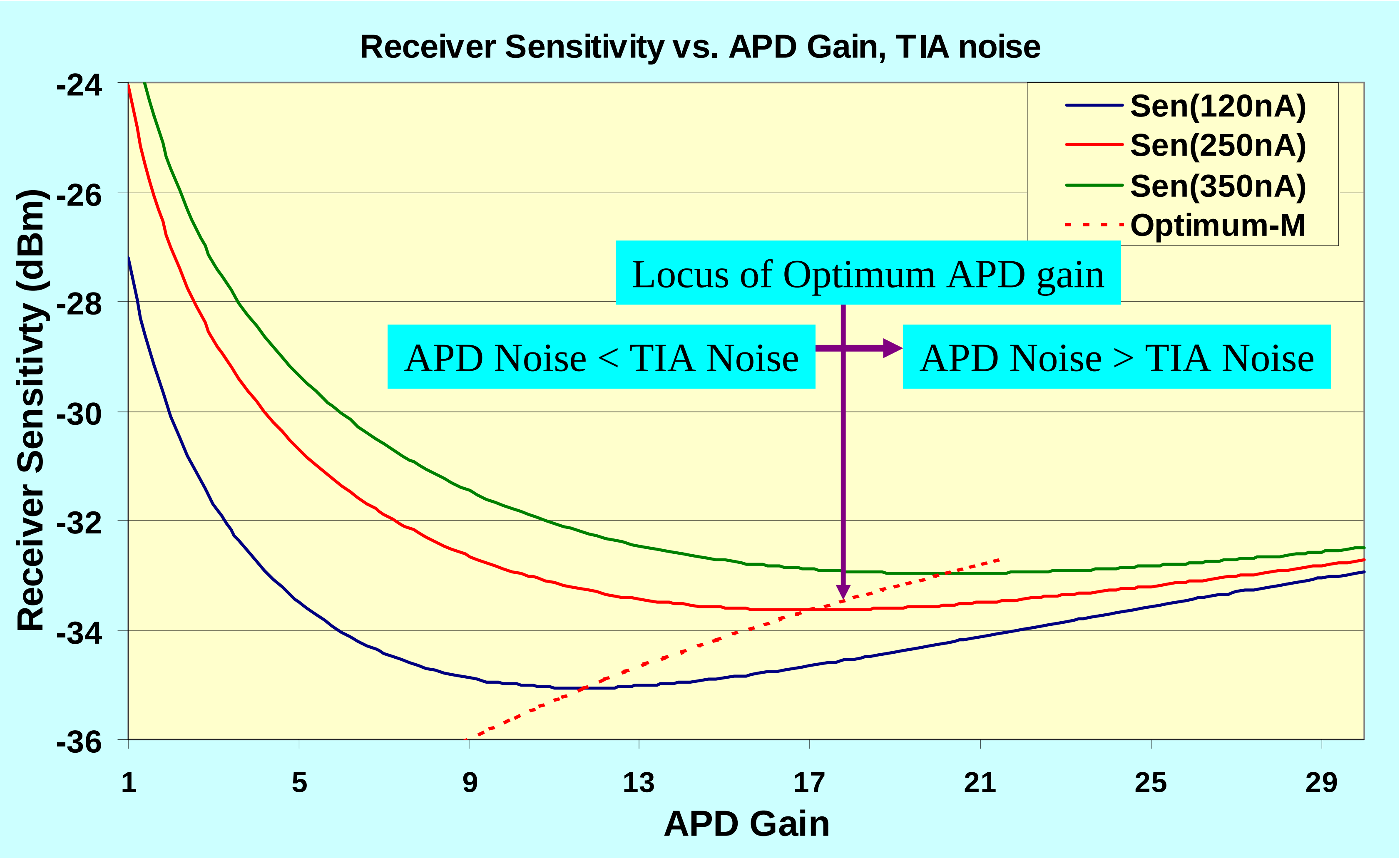
TriQuint OPTOELECTRONICS

APD Photocurrent & Gain vs. Temperature

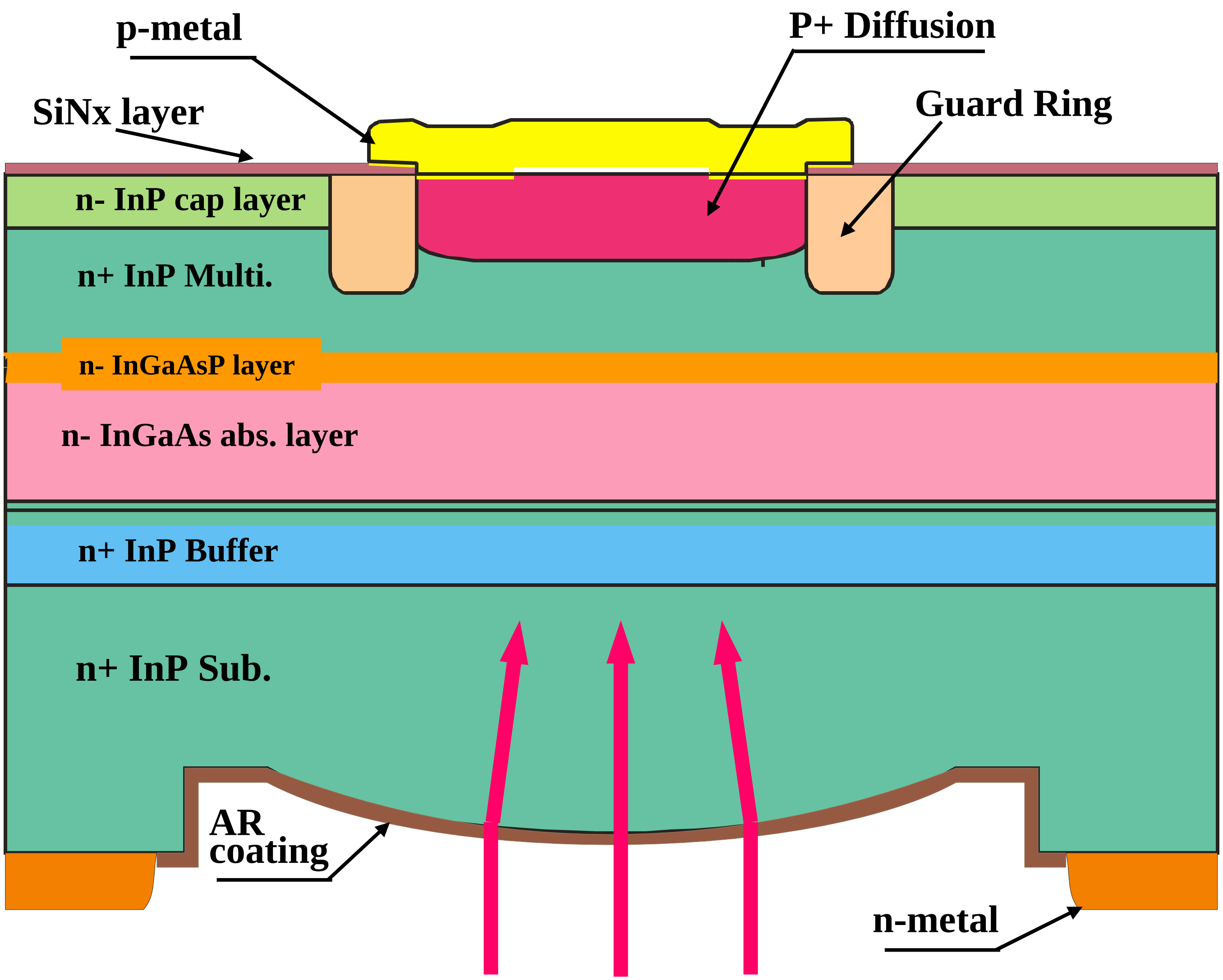


WOCC-2005

How does APD Enhance Rx Sensitivity?

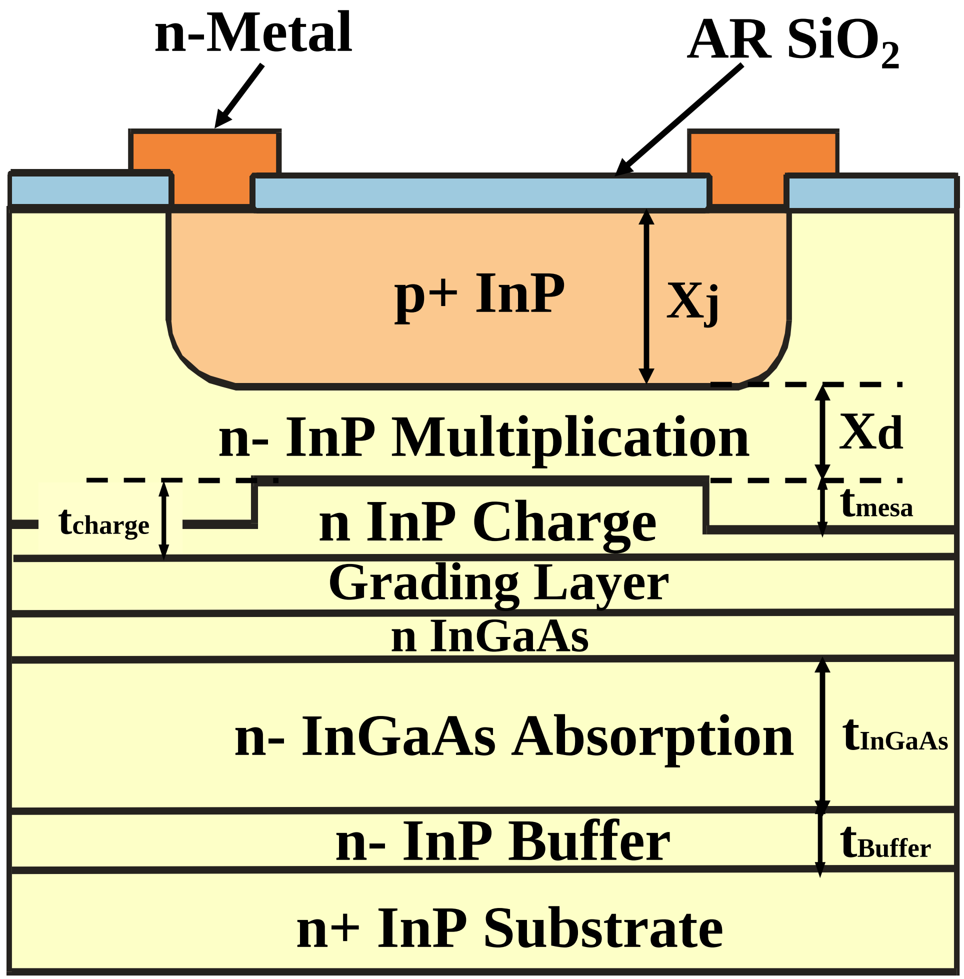


Planar Separate Absorption, Multiplication (SAM) APD Structure



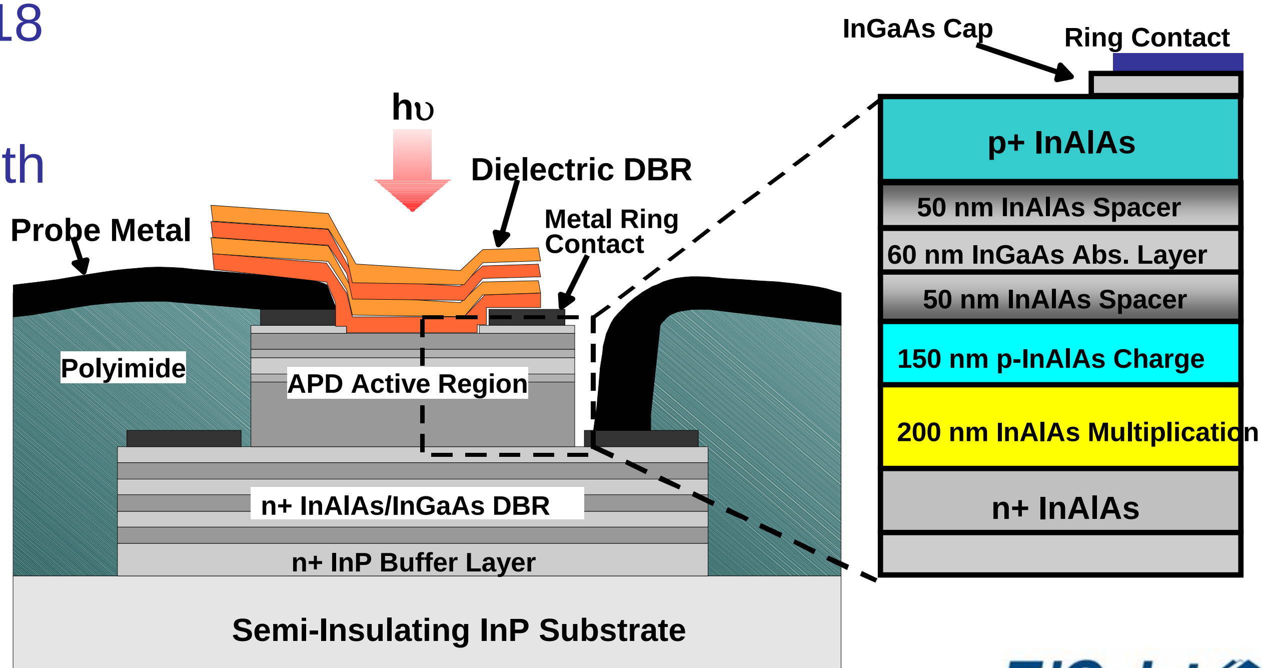
Planar SACM/SACGM APD

- InGaAs/InP Two-step MOCVD
- Planar Structure
- Etch and Regrowth Charge and Multiplication Region
- Diffusion controlled Multiplication Layer (single Diffusion or Well Etching-Diffusion)
- Xd ~ 0.2-0.4 μm
- GB product = 122 GHz
- Noise Ratio *k*~0.45
- No Implant



Resonant-Cavity InGaAs/InAlAS SACM APD

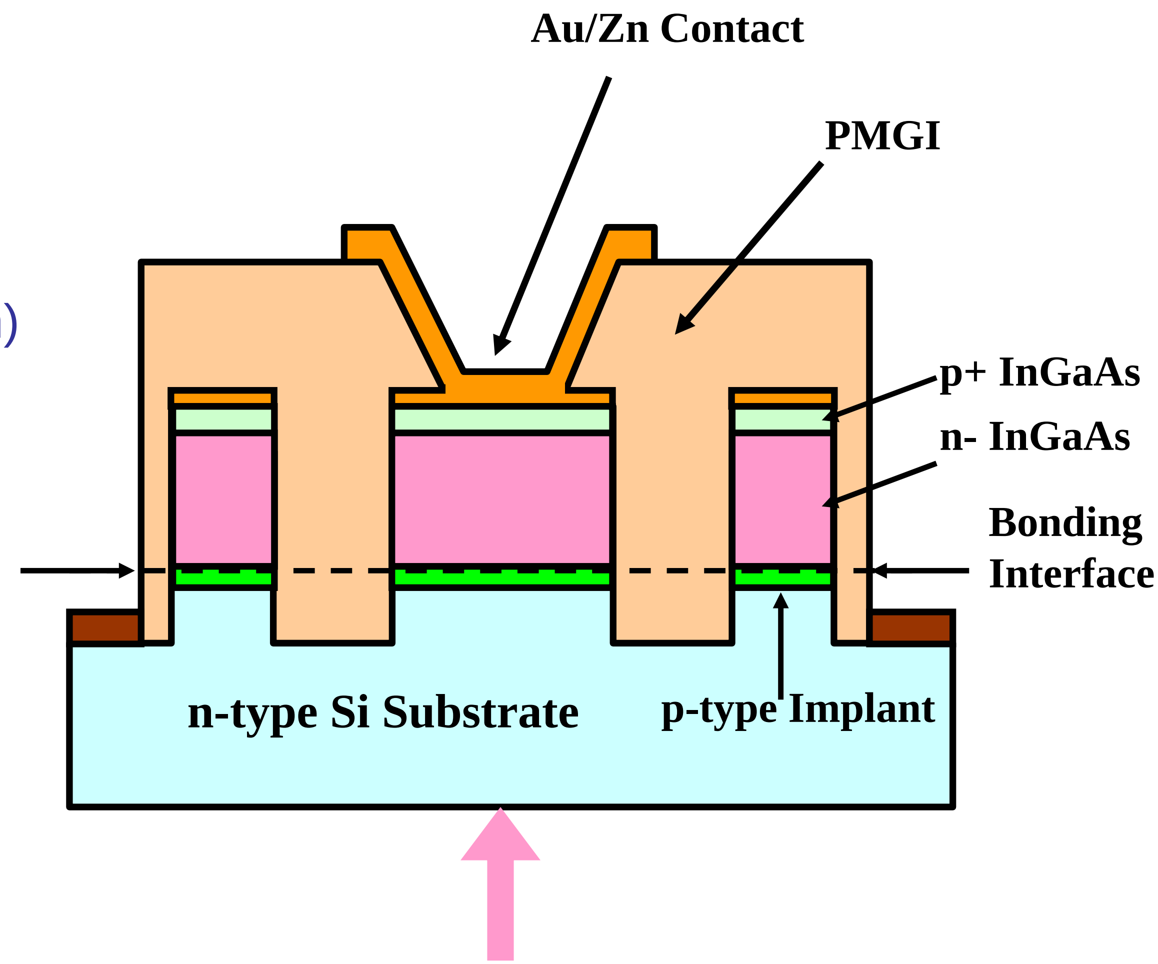
- Resonant-Cavity Structure
- High QE ~ 75%
- Mesa Isolated
- SACM Configuration
- Thin InAlAs Multiplication Region (200 nm)
- Lower Noise k ~ 0.18
- Bandwidth>20 GHz
- High Gain-Bandwidth Product



TriQuint OPTOELECTRONICS

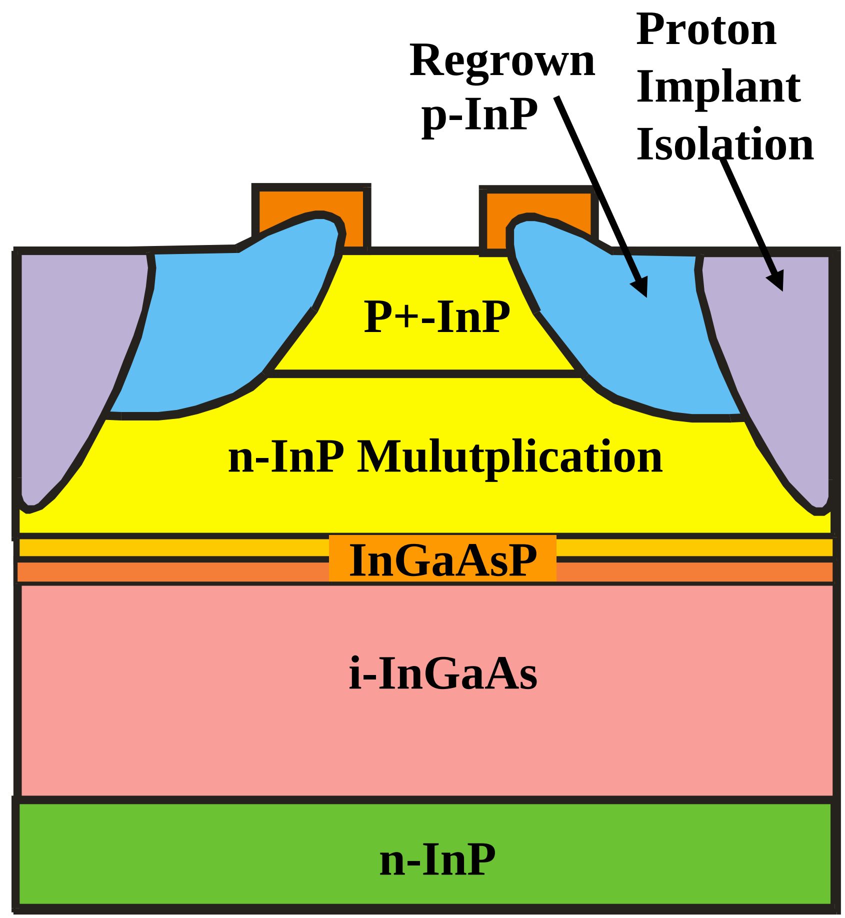
Wafer-Fused SHIP APD

- Silicon Heterointerface Photodetector (SHIP)
- Wafer-Fused Si Multiplication Region
- Mesa Isolated (20-30 µm)
- Backside Illumination
- Bandwidth= 13 GHz
- GainxBandwidth= 315 GHz
- Reliability Issue



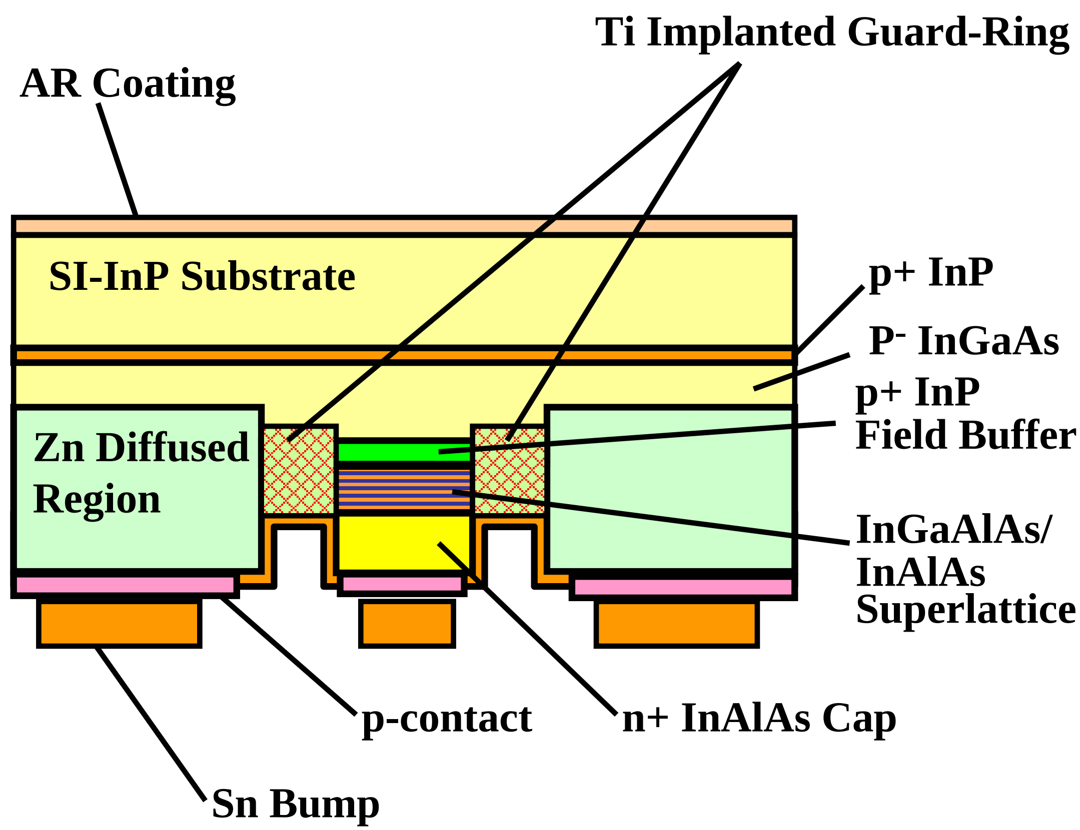
Buried Mesa APD with Regrown Guard-Ring

- Mesa Etch and Regrowth Isolation Layer (Patented)
- No Diffused Junctions and Multiple Implanted GRs
- Regrowth p-InP Guard Ring + Implanted Guard Ring
- Bandwidth< 4GHz for OC-48 Applications (2.5 GHz)
- GB Product=37 GHz
- Sensitivity= -33 dBm
- Excess Noise Factor=0.4



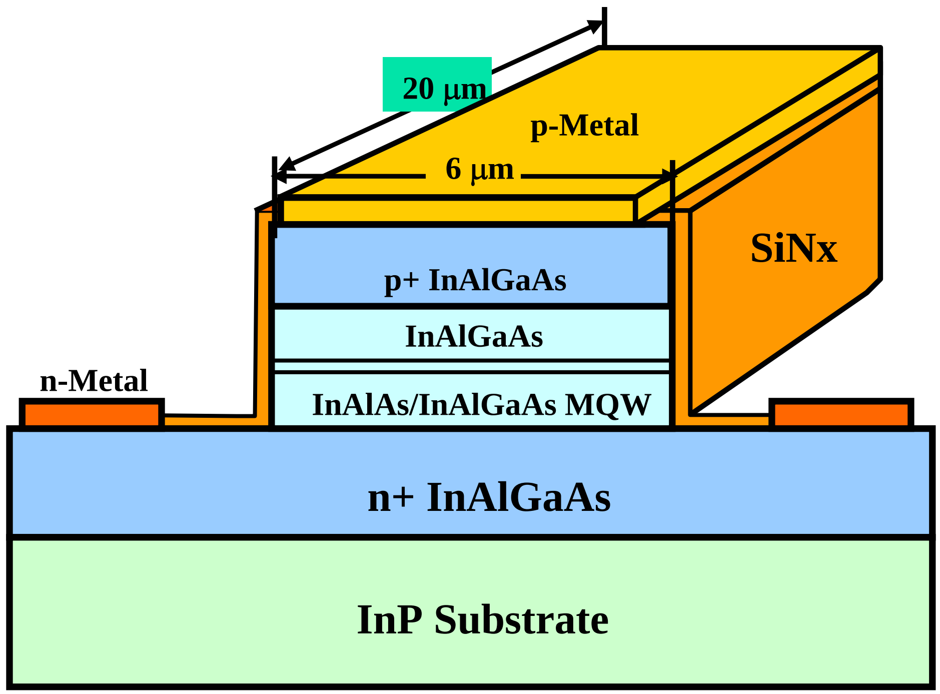
Planar InGaAlAs/InAlAs MQW APD

- SI InP Substrate
- Inverted Mesa Junction
- Ti Implanted Guard-Ring to Decrease p-concentration of Field-Buffer Layer
- Dark Current Increase Due to Implantation
- SiN_X Passivation
- p+ Zn Diffusion Isolation
- Contact Metal Deposition
- Flip-Chip Bonding
- Cd=0.15pF, Cp=0.06pF
- R_L=25 Ω to achieve Bandwidth=15.2GHz
- Id=0.36μA@ M=10
- GB Product = 120GHz



Waveguide APD

- Multimode Waveguide Structure
- Mesa Etch and SiNx Passivation
- InAlAs/InAlGaAs MWQ Multiplication Layer ~0.25 μm
- InGaAs Abs. Layer ~ 0.3 μm
- Top and Bottom InAlGaAs Cladding Layer ~ 0.8 μm
- Bandwidth= 20 GHz
- GB Product= 160 GHz
- Large Dark Current
  - 1 μA @ 90% V_B
- Edge Coupled w/ Lensed Fiber (3 μm Spot Size)



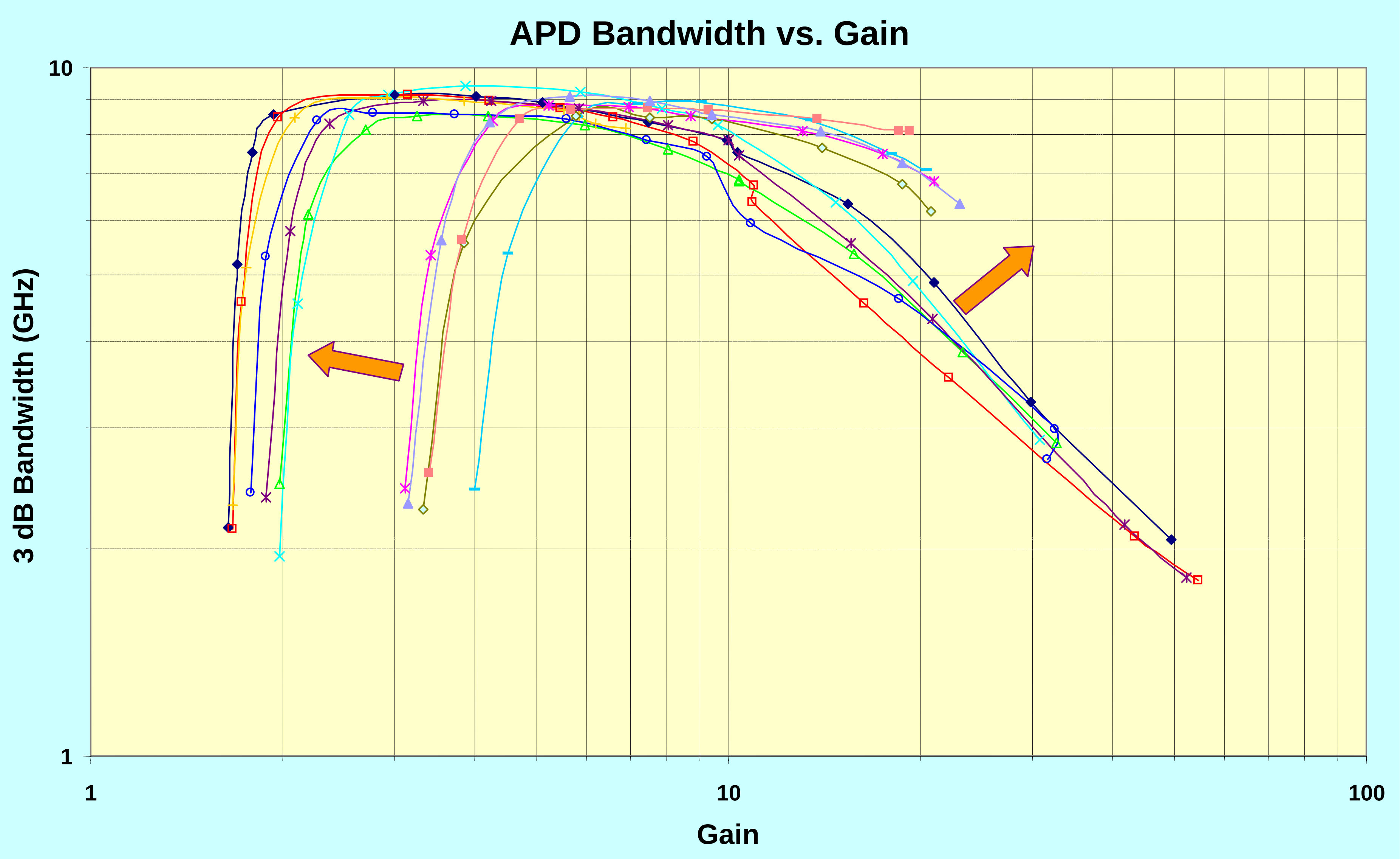
Real-World APD Device Specifications

- Quantum Efficiency, Responsivity
- Gain characteristics
- Bandwidth @ M=10,12 when P_{IN} is low (Sensitivity)
- Bandwidth @ M< 4 when P_{IN} is high (Overload)
- Primary Dark Current
- Excess Noise Factor
- Capacitance
- Breakdown Voltage

Performance of APD comes with price!

- Trade-off 1: Bandwidth~ Responsivity
  - InGaAs Absorption Layer Thickness
- Trade-off 2: RC Bandwidth ~ Transit Time Bandwidth
  - InGaAs, InP layer thickness
  - Device geometry
- Trade-off 3: BW@ M~10 ~ BW@ M~3
  - Multiplication layer doping
  - Diffusion junction depth control (Ehet control)
- Trade-off 4: Breakdown Voltage ~ Thickness, Doping
  - InGaAs, InP layer thickness
  - Multiplication layer doping

APD Design- Balance between Trade-offs

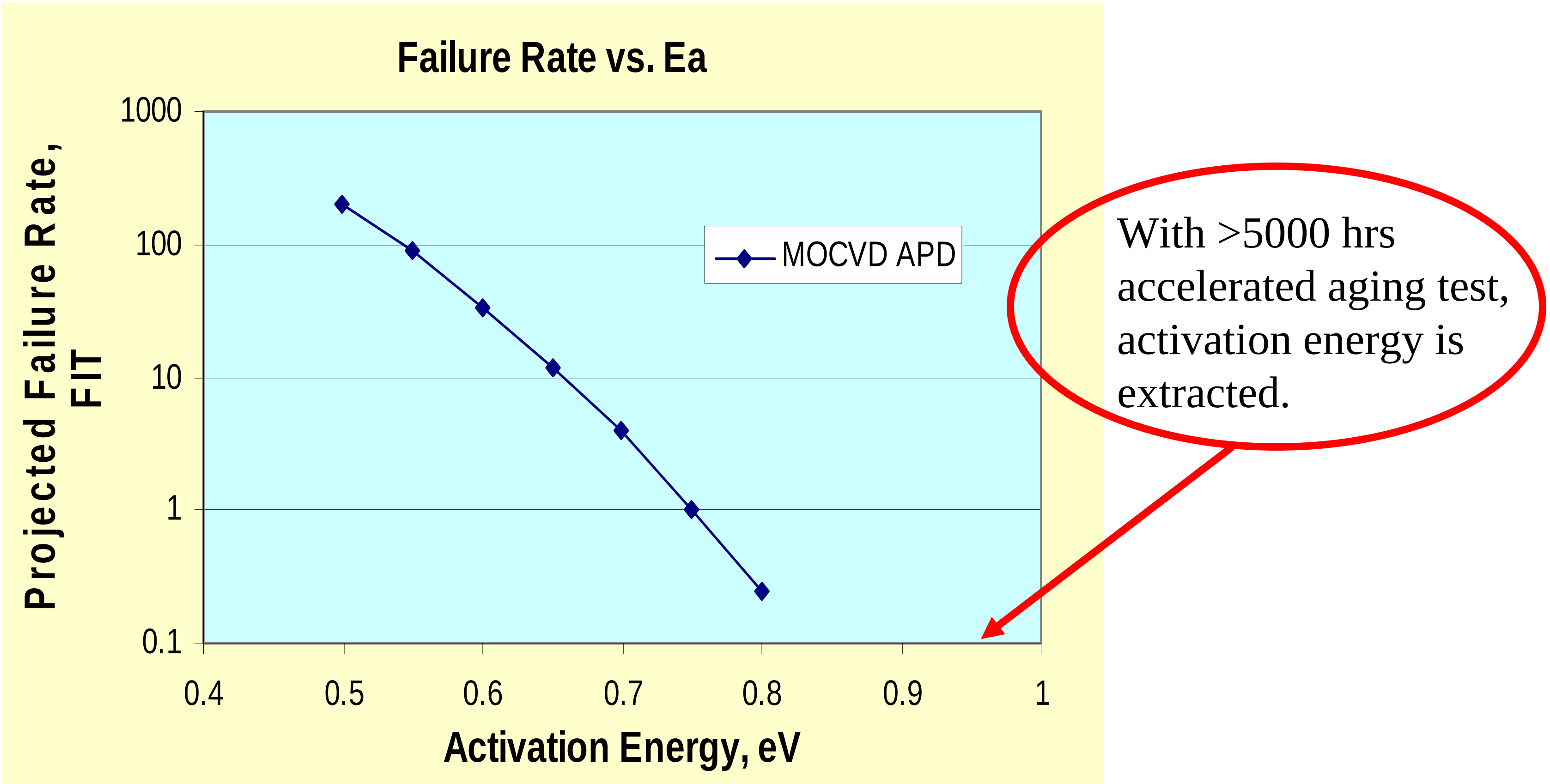


TriQuint OPTOELECTRONICS

TriQuint APD Chips

- Over than 15 years of design and volume manufacturing APDs used in commercial communication systems (AT&T Bell Labs -> Lucent -> Agere -> TriQuint -> CyOptics?)
- High quality, high yield and low cost MOCVD epi
- Reliability proven with > 5000 hrs aging and >15 years of field use
- High-speed automated wafer level electrical and optical probing systems
- Receiver performance demonstrated with high performance APD chips

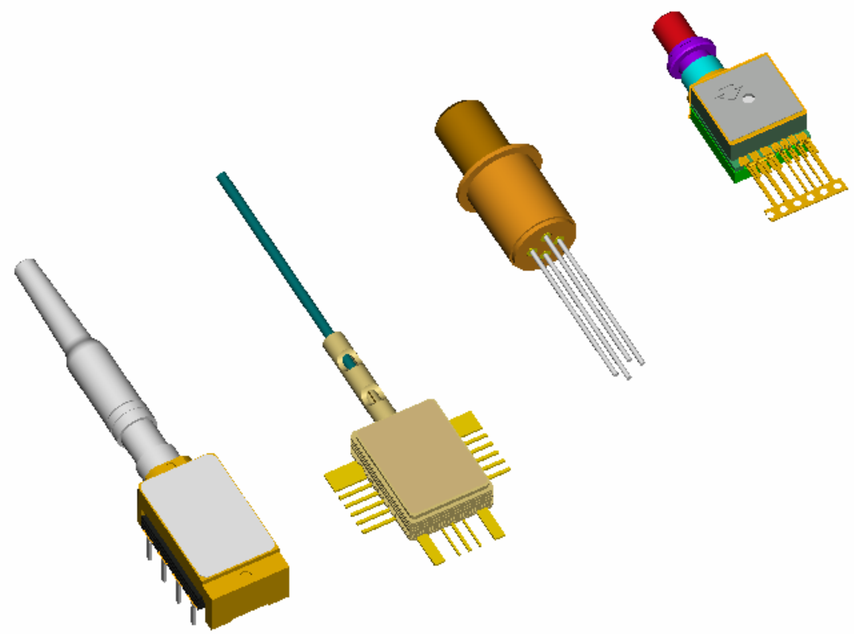
Failure Rates vs. Activation Energy



With the estimated Ea of 0.96 eV, these devices have very small FIT (< 1 FIT).

TriQuint Receiver Product Family

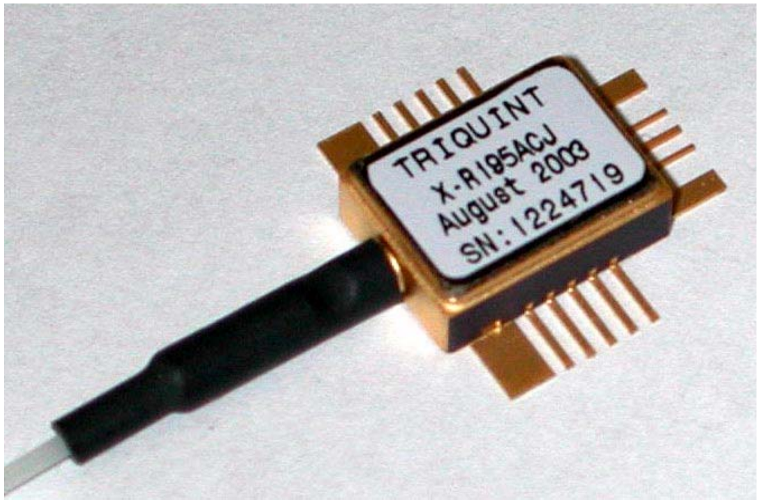
- Traditional butterfly package receiver
- MSA small-form-factor surface-mounted Receiver
- Ceramic packaged ROSA
- TO-can based ROSA



TriQuint OPTOELECTRONICS

APD & PIN MSA Receivers

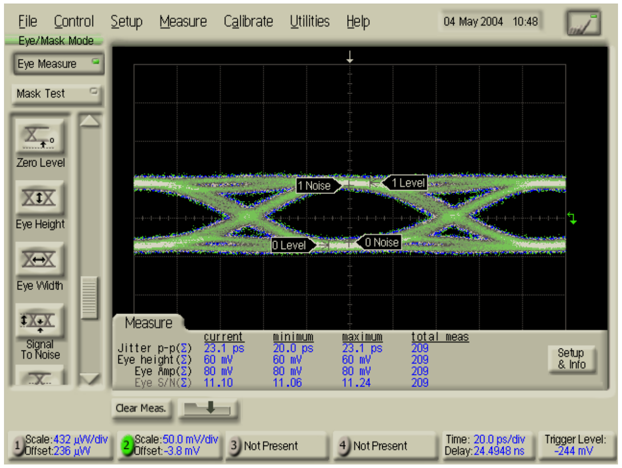
- **Key Advantages**
  - **MSA Small Form Factor**
  - **Surface Mount**
  - **High Sensitivity & Overload**
    - **R195A typical –26 dBm, -3dBm**
    - **R195P typical –19 dBm, +1 dBm**
  - **Small Group Delay Variations**
  - **Good Linearity**
    - **700mV Output Voltage Swing**
  - **Excellent OSNR Performance**



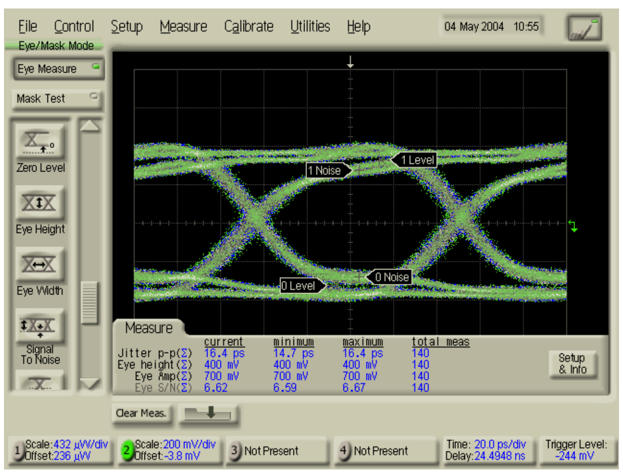
TriQuint OPTOELECTRONICS

MSA APD Receivers

Eye

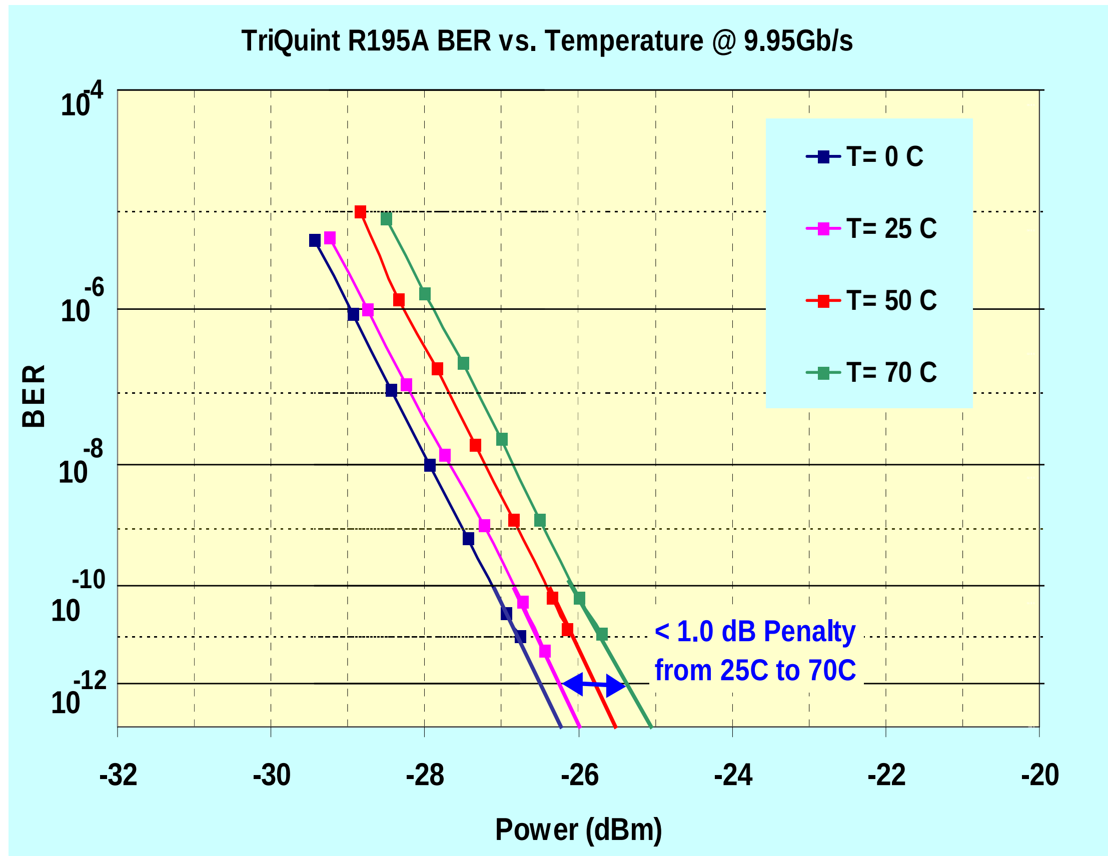


-26 dBm, M=10 **9.953 Gb/s, 1550 nm, 2E31 – 1 PRBS**



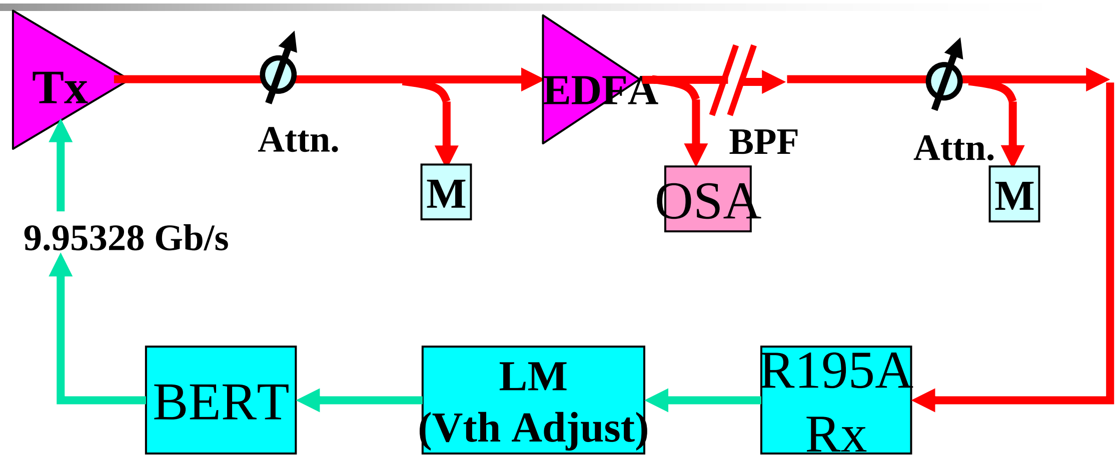
-3 dBm, M=3

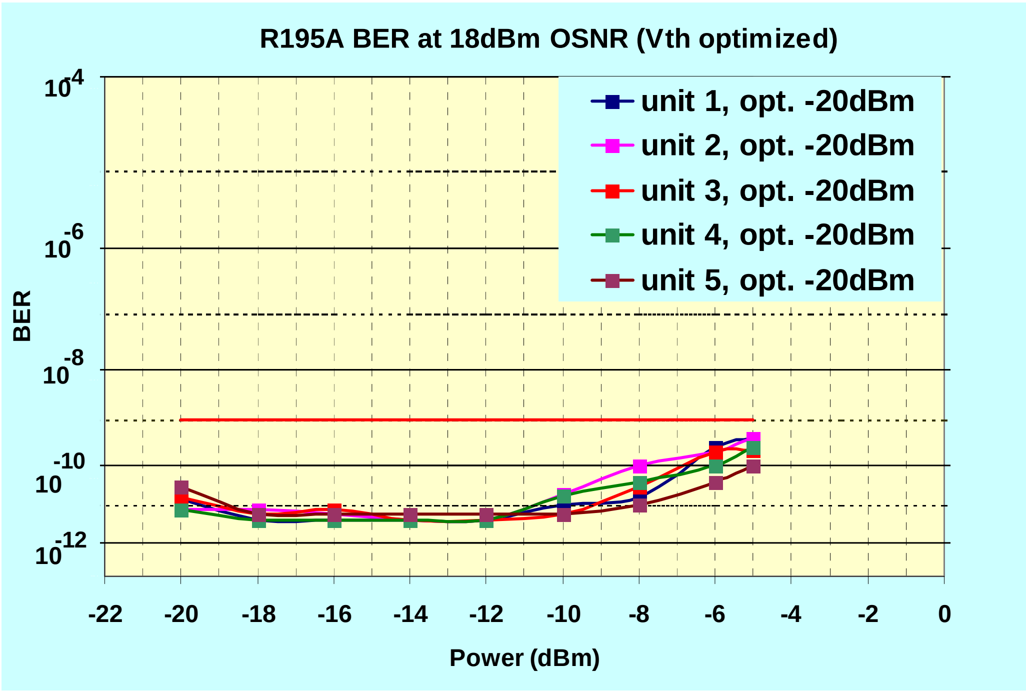
BER



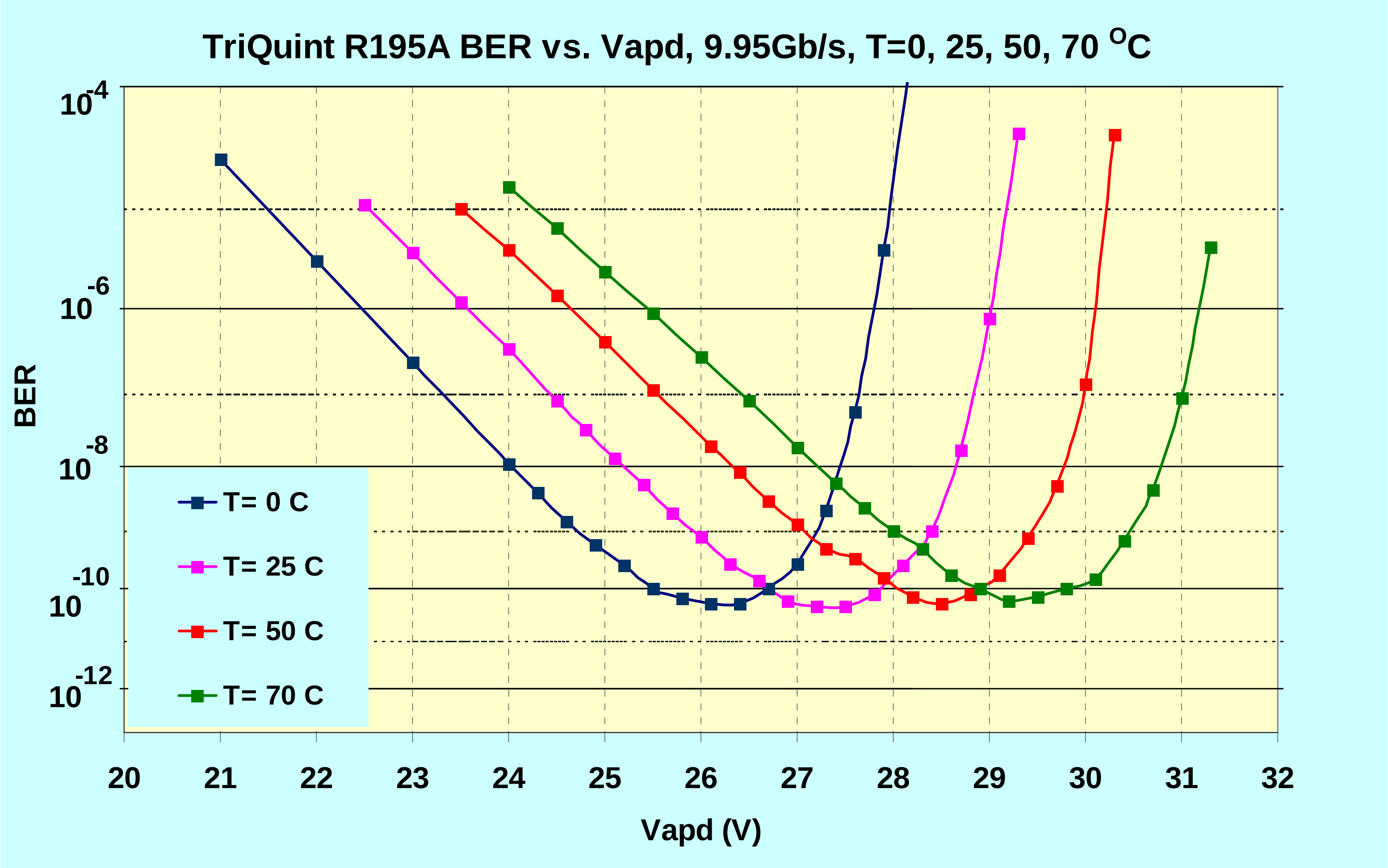
TriQuint OPTOELECTRONICS

10G APD Receiver OSNR Performance





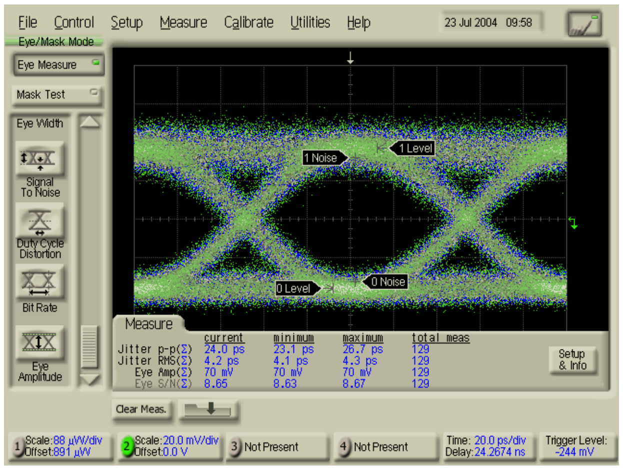
BER vs. Vpd over Temperature



*** For each temperature the optical power was adjusted to obtain a BER in the range of 4e-11 to 9e-11.**

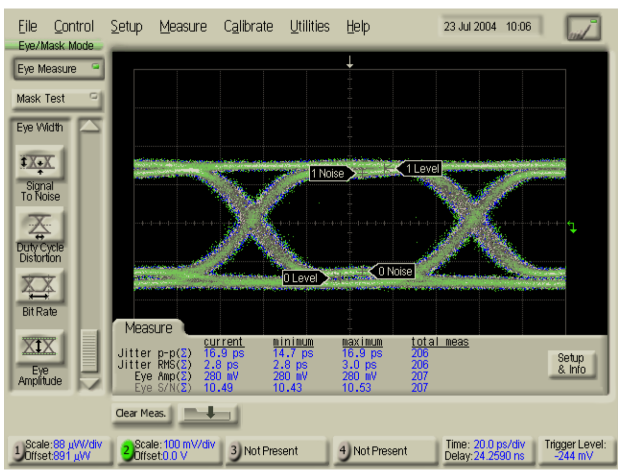
Next Generation MSA Receiver & ROSA

Eye



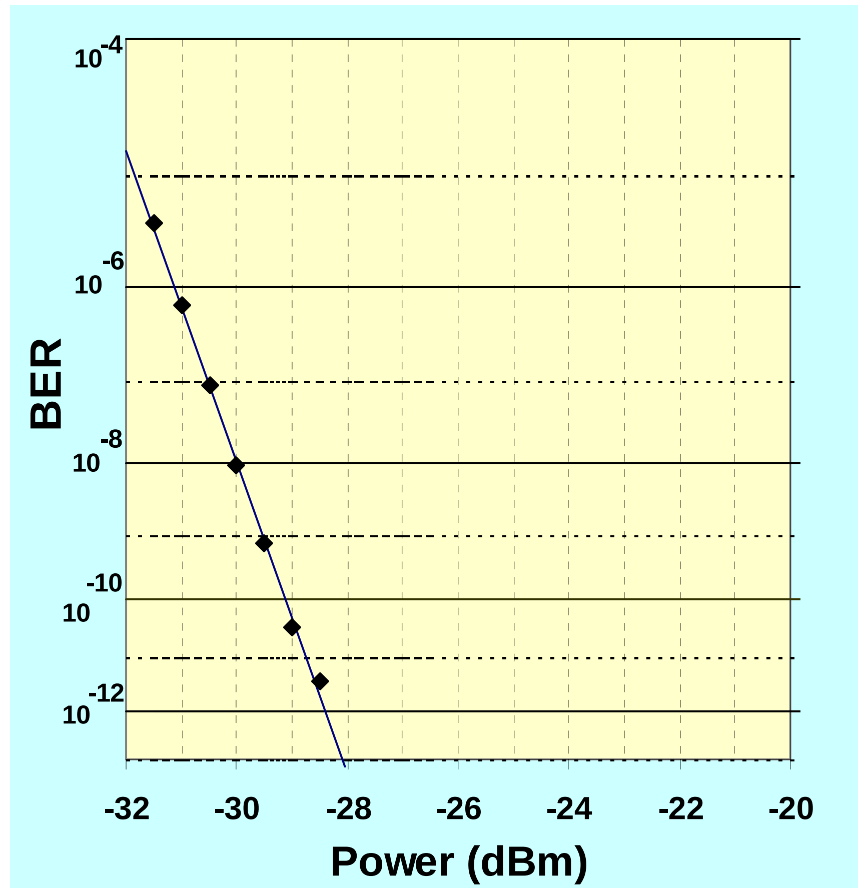
-28 dBm, M=9

9.953 Gb/s, 1550 nm, 2E31 – 1 PRBS

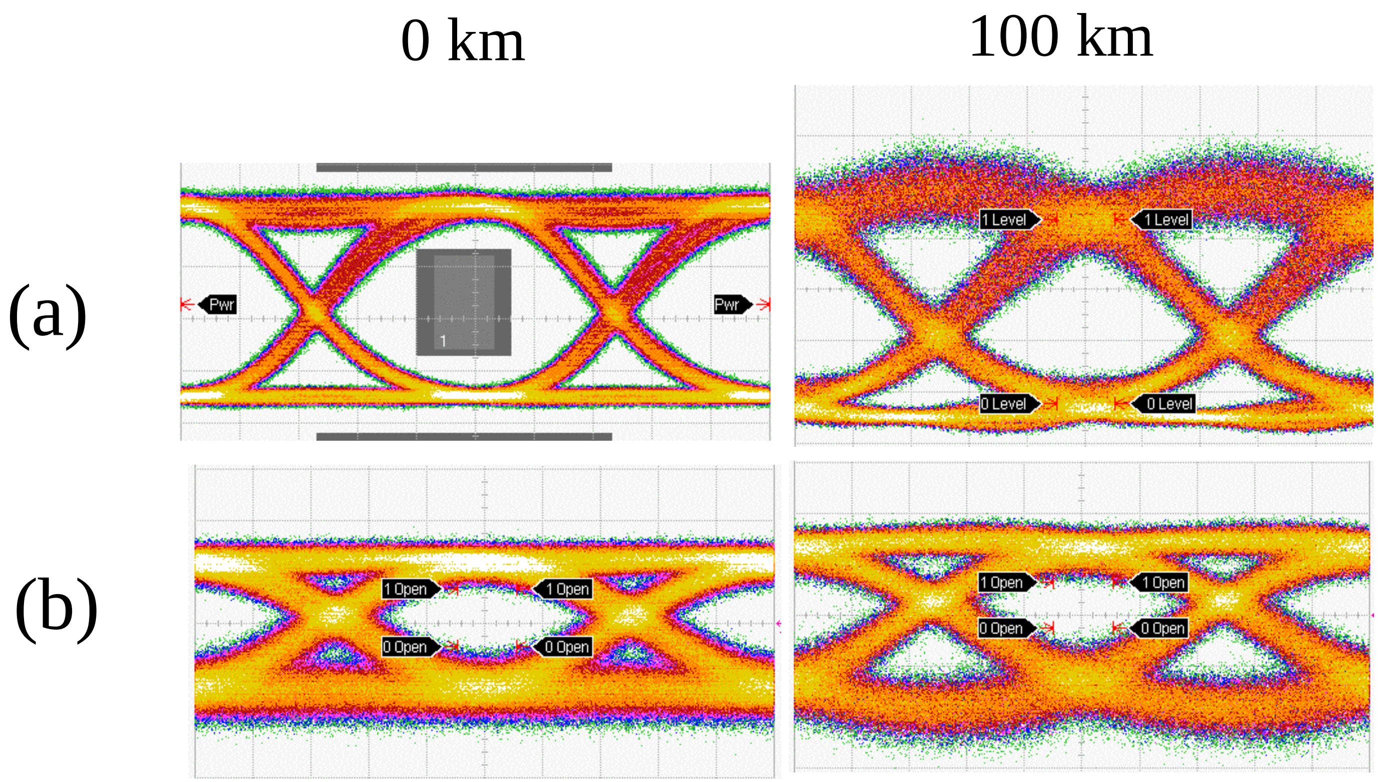


+1 dBm, M=3

BER

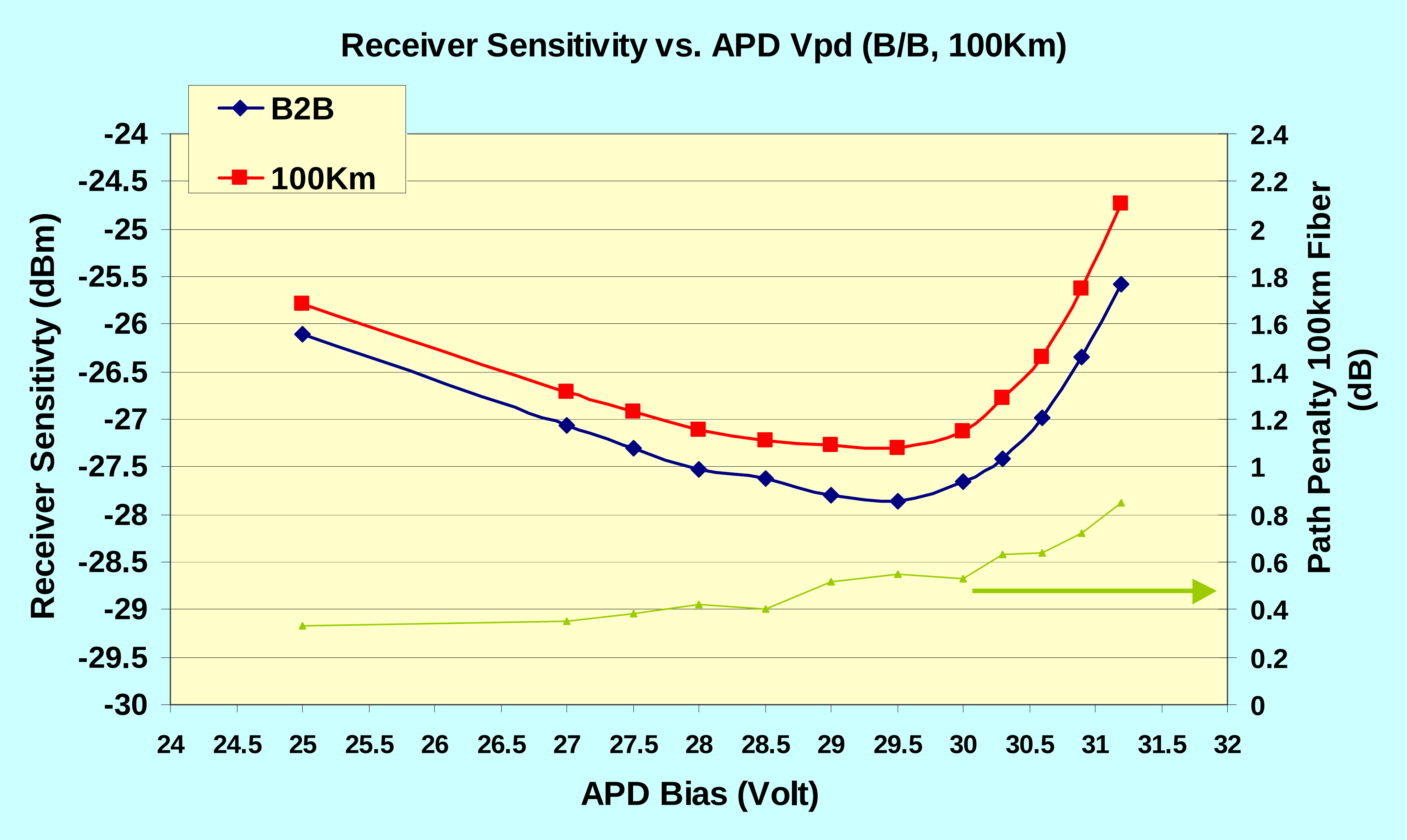


Fiber Transmission Experiments



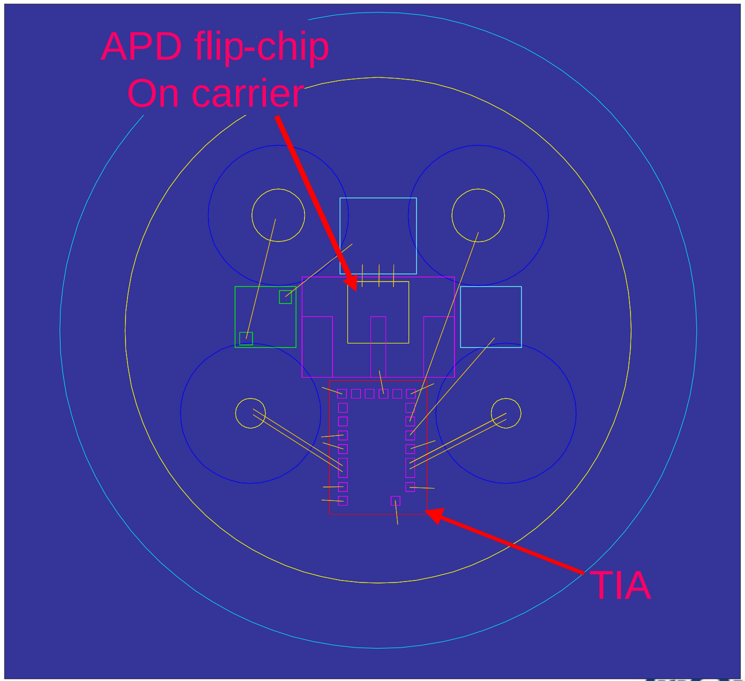
Eye diagrams back-to-back, and after 100 km transmission. (a) Optical. (b) Electrical.

Path Penalty after 100 km Fiber



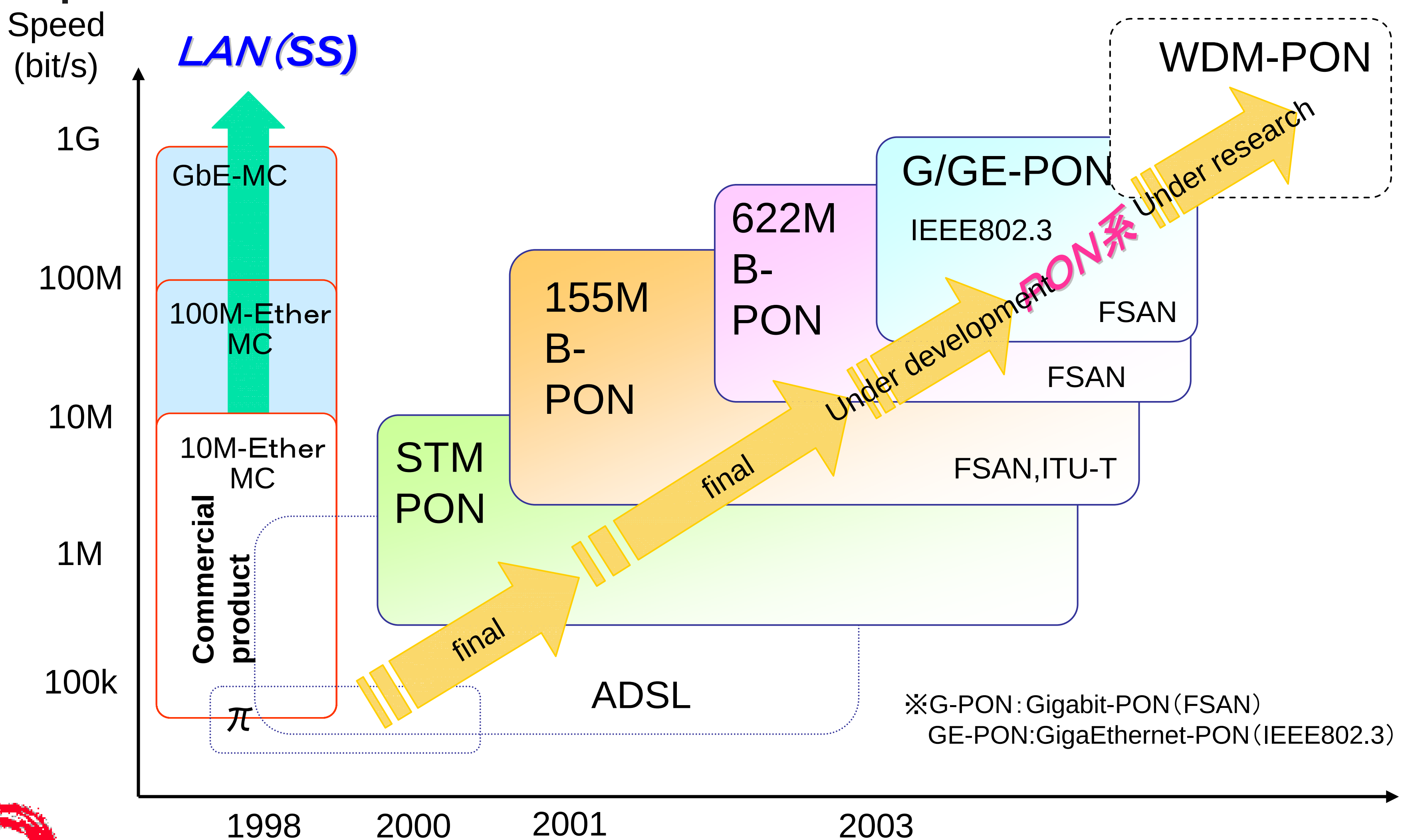
PIN & APD ROSAs

- Low cost, high performance
- XMD compatible
- 3.3V TIA
- Detector on carrier



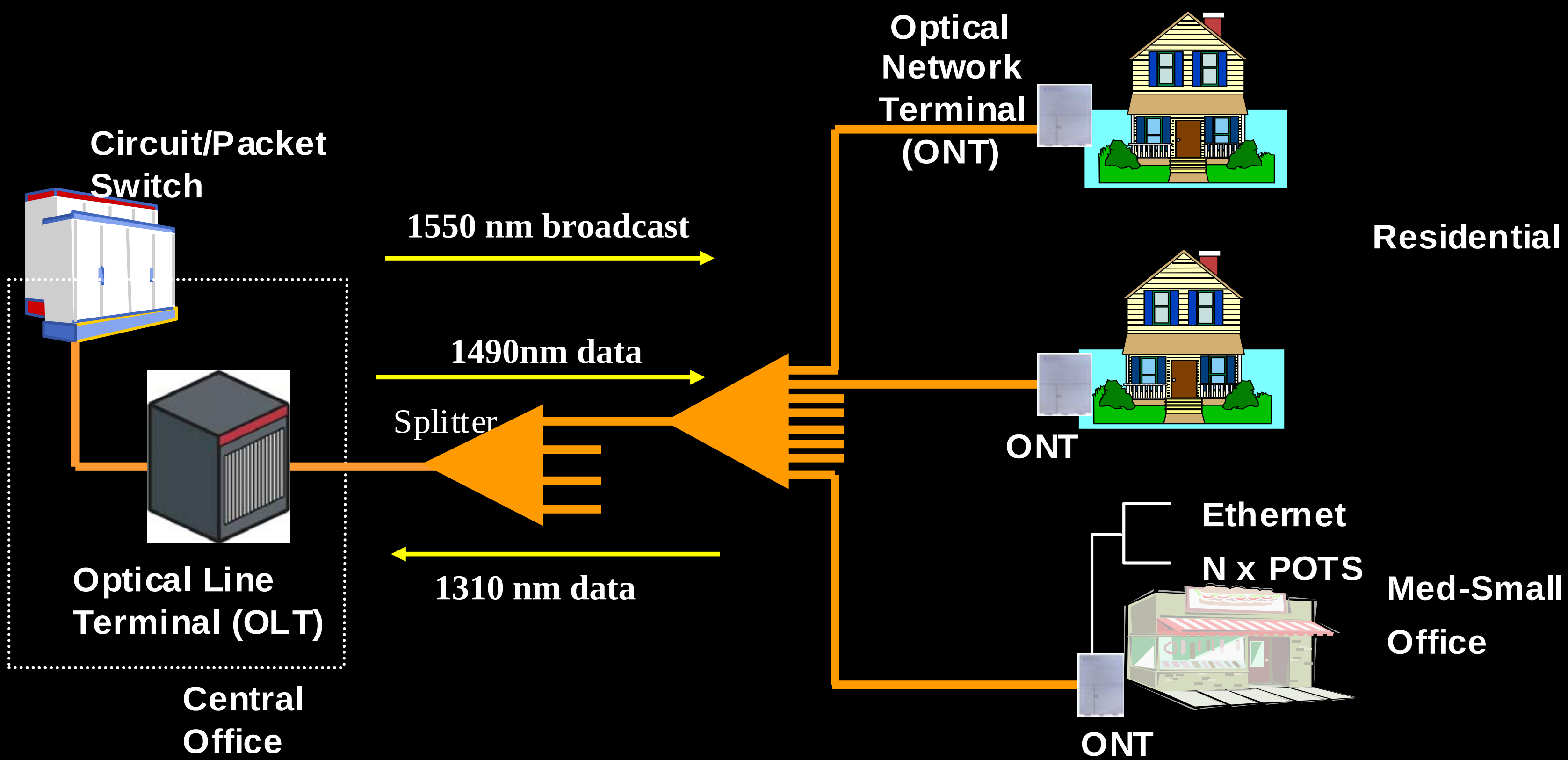
TriQuint OPTOELECTRONICS

Advancement in Access



※G-PON：Gigabit-PON（FSAN）
GE-PON:GigaEthernet-PON（IEEE802.3）

FTTP Architecture



PON (Passive Optical Network)
A single, shared optical fiber serving 32 customers.
"Passive" because no active electronics in access network, except for the end points.

FTTP Market

Market: North America: 1-2M home for 2005

- Verizon: About 150k Subscribers, 1M home passed. Plan to add 2M home by 2005
- SBC: Field trial on 2004, and plan add 300K home on 2005

Japan: 2-3M homes for 2005

- NTT: Plan spend $48B for 30M subscribers by 2010, add 1-2M subscribers on 2005
- Yahoo BB: Strong competitor with 2M subscribers in 2005 plan

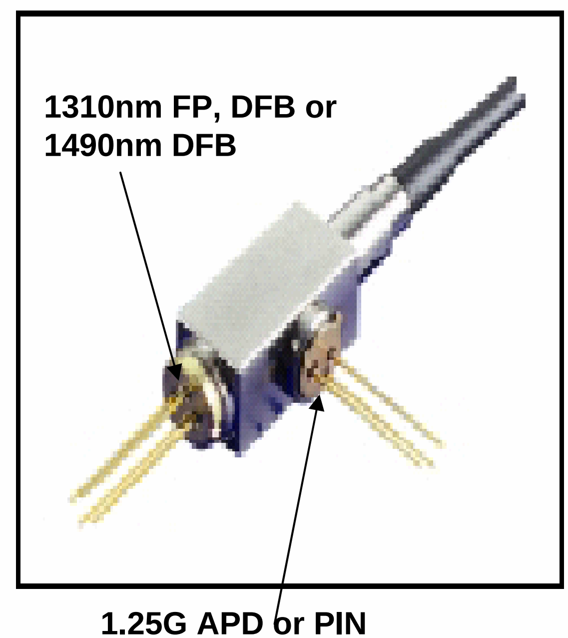
Korea: Plan to add 10M subscribers by 2007, but no detail plan yet

China: Still on earlier stage of deployment, a lot of trials

Europe: About 400K Subscribers, not high level growth can se

Equipment:

- Optical Network Terminal (ONT):
  - 1310 DFB or 1310nm FP for upstream
  - 1490nm PD 1550nm analog detector for receiver
- Optical Line Terminal (OLT):
  - 1490nm DFB for downstream data transmission
  - APD for receiving
- Cost, cost and cost while not sacrificing performance!



EPON & GPON Requirements

- EPON & GPON Different Requirements
  - PIN mostly in ONT side
  - APD mostly used in OLT side
  - APD will be more common due to split ratio increases

	EPON (IEEE 803.2ah)		GPON (ITU-T)
	1000BASE-PX10	1000BASE-PX20	G.984.2
Distance	10 Km	10 Km	20 Km
Attn Range	5-20dB @ upstream	5-20dB @ upstream	Class A: 5-20dB Class B: 10-25dB Class C: 15-30dB
Output Power	ONT: -1 ~ +4 dBm OLT: -3 ~ +2 dBm	ONT: -1 ~ +4 dBm OLT: +2 ~ +7 dBm	ONT: -2 ~ +3 dBm @ ClassB OLT: +1 ~ +6 dBm @ ClassB
Receive Power	ONT: -24 ~ -3 dBm OLT: -24 ~ +1 dBm	ONT: -24 ~ -3 dBm OLT: -27 ~ -6 dBm	ONT: -25 ~ -4 dBm @ ClassB OLT: -28 ~ -7 dBm @ ClassB

TriQuint OPTOELECTRONICS