InGaAs Communication Photodiodes: From low to high power level designs

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Introduction

- **III-V opto-electronic components developed for several years mainly for optical fiber telecommunication networks**

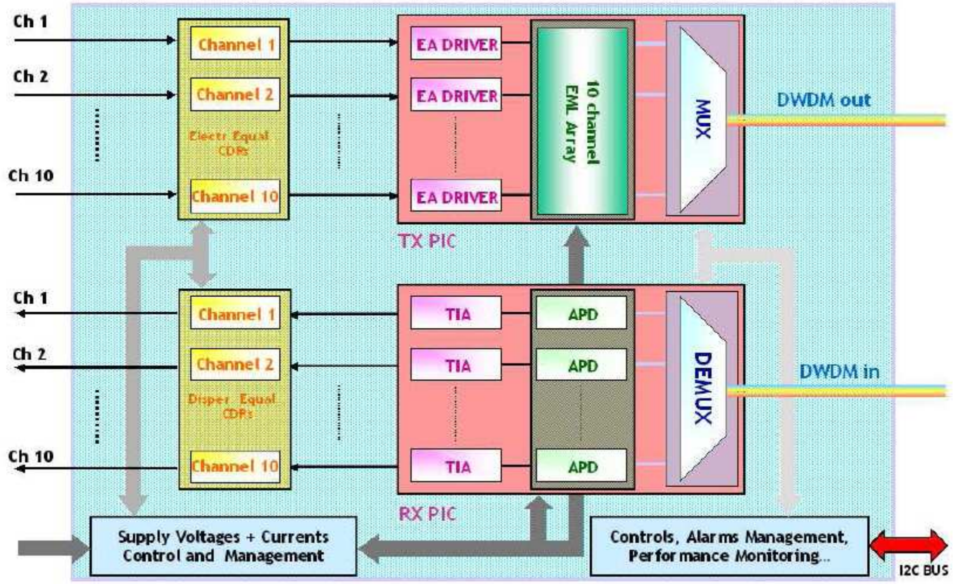
- **Following large scale applications in access networks (2.5G PON, 10G PON,…), several III-V technology achieved high maturity**
  - Reduce cost of components without compromising performances
  - Mature building blocks, large wafer sizes,…

- **InGaAs/InP photodiodes developed owing to the near-infrared sensitivity of $In_{0.53}Ga_{0.47}As$ grown lattice-matched onto InP:**
  - Best-in-class photodiodes for WDM applications (full use of C-band)
  - High reliability, yield,…

- **New applications (ranging/sensing, spectroscopy,…) are pushing new InGaAs photodiodes development, requiring new R&D**

Some Key Applications

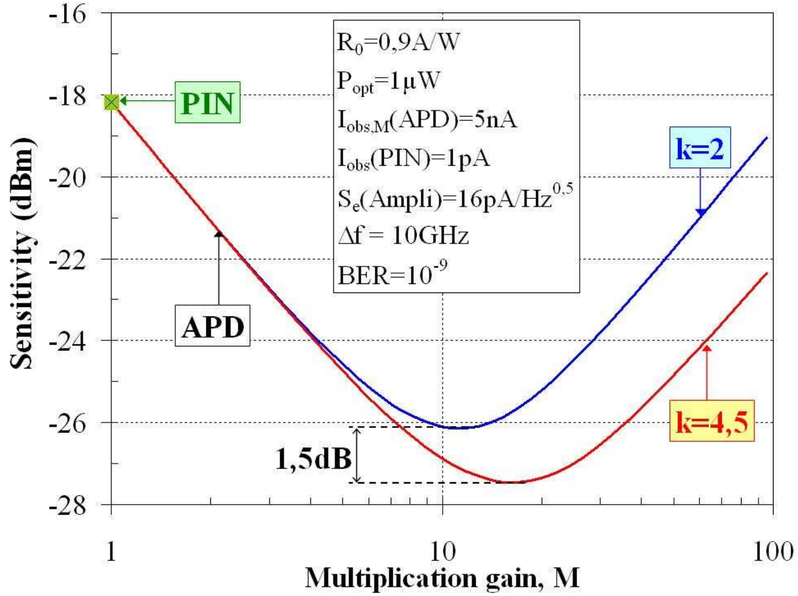
- **10-40Gb/s Avalanche photodiodes for:**
  - 10x10 (10x40) PIC to increase transmission reach without optical amplification
  - Increasing number of subscribers/terminals in 10GPON with very low noise APD

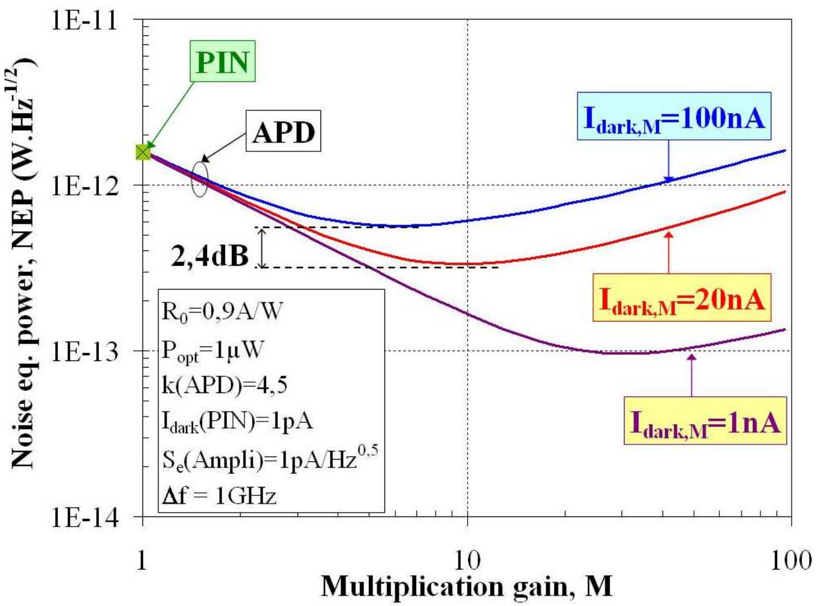


- **High power photodiodes for:**
  - 100Gb/s QPSK transmission with a coherent receiver (high power level local oscillator), 400Gb/s, multi-level modulation formats,…
  - Analog multichannel fiber optic links, Radar antennas,…

Low power light detection

- High sensitivity, low noise and often large bandwidth required
  ➔ APDs
- APDs for telecom networks
  - Longer transmission reach
  - Increased number of subscribers
  - Compact solution / low cost

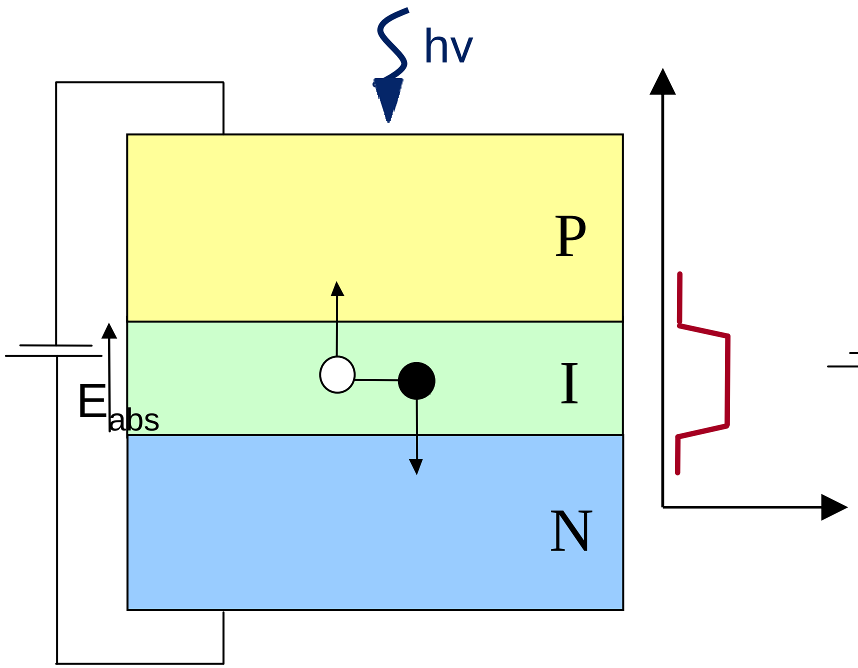


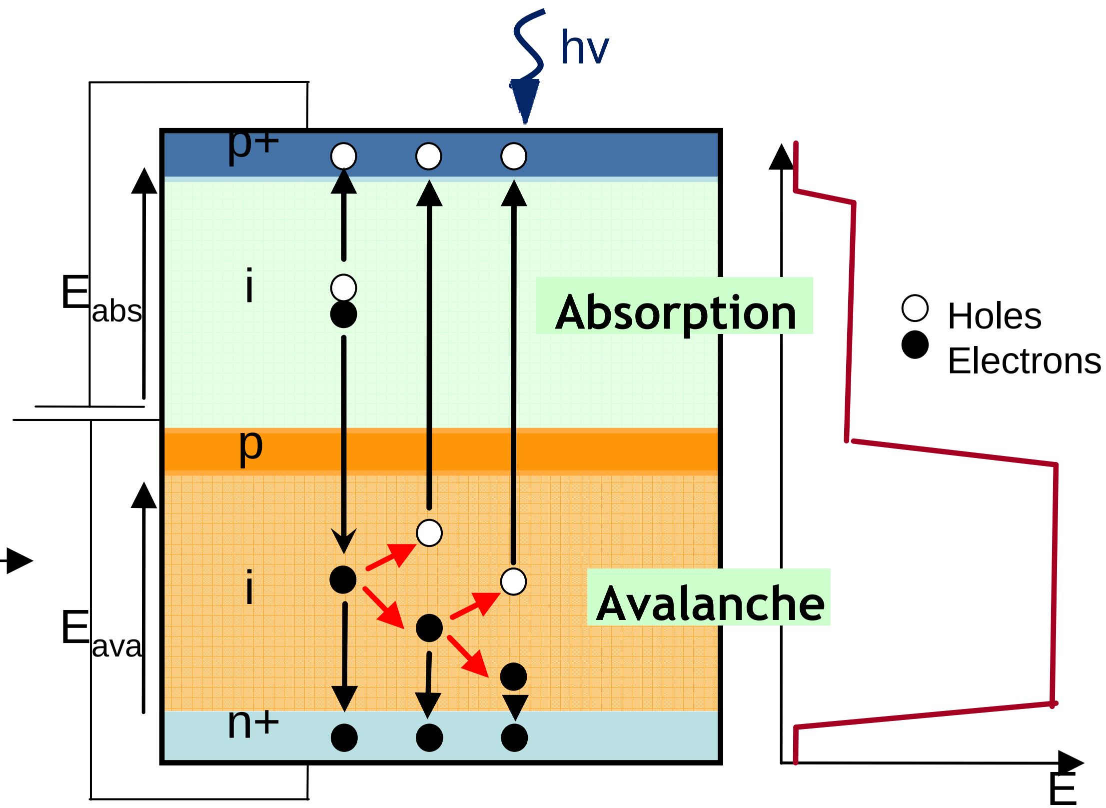


- APDs for ranging & sensing
  - Detect low level back-reflected photons
  - High spatial resolution

PIN and Avalanche photodiodes

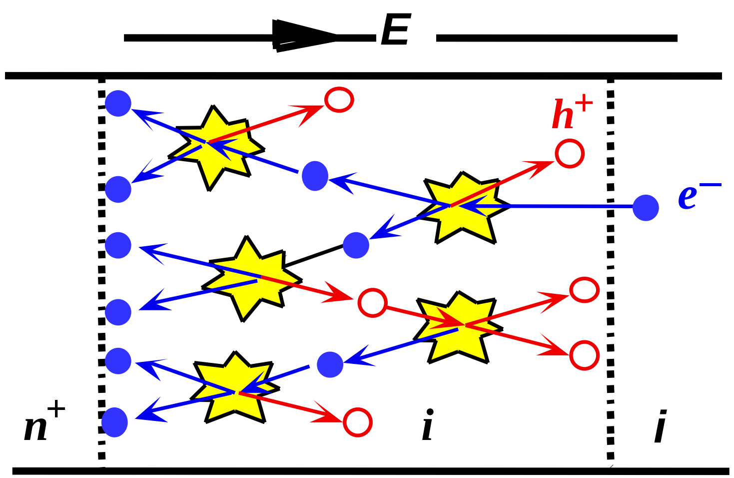
- **PIN structure**
  - Low bias operation
  - Low dark current & noise
- **APD structure**
  - Higher bias operation
  - Excess noise but improved S/N



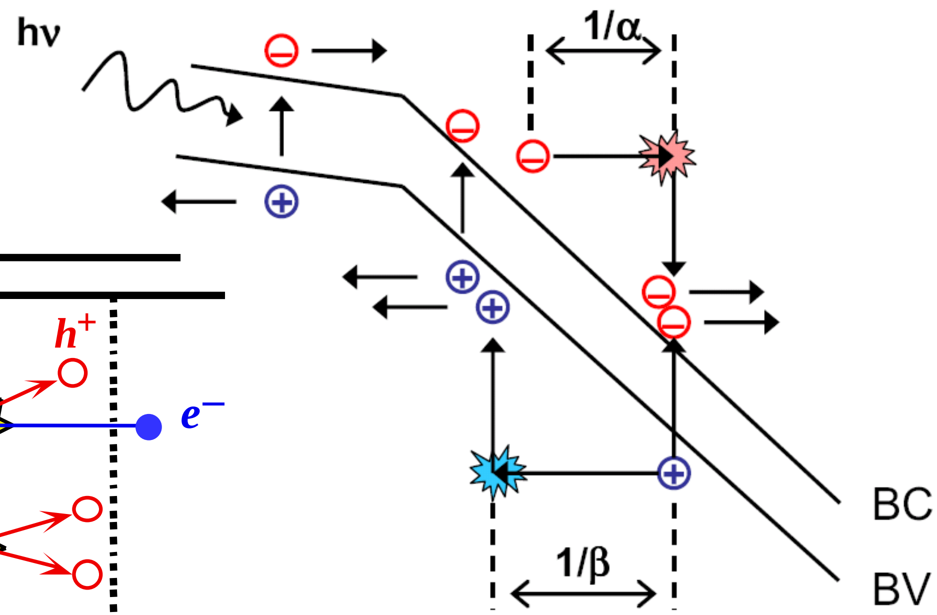


Avalanche mechanisms

- Impact ionisation process:
  - **Ionisation threshold depending on electric field intensity**
  - **Generation of secondary carriers**



Avalanche region

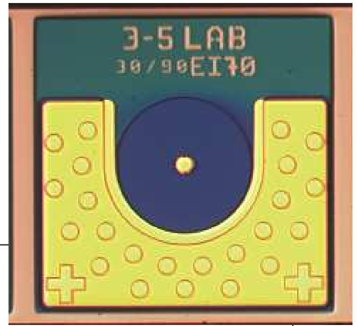


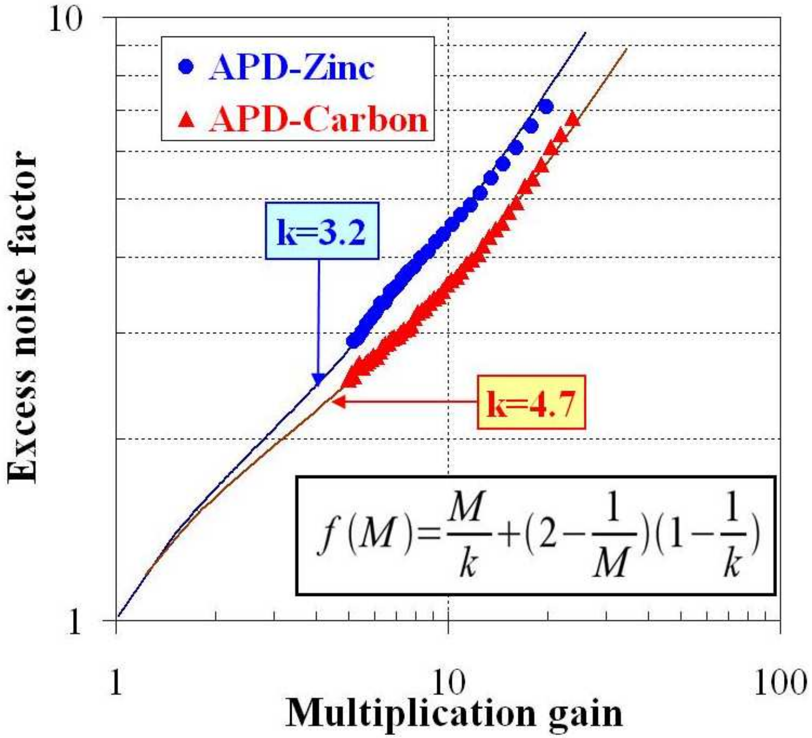
- α = electron ionisation coefficient
- β = hole ionisation coefficient
- k=α/β ionisation coefficients ratio (k>1)

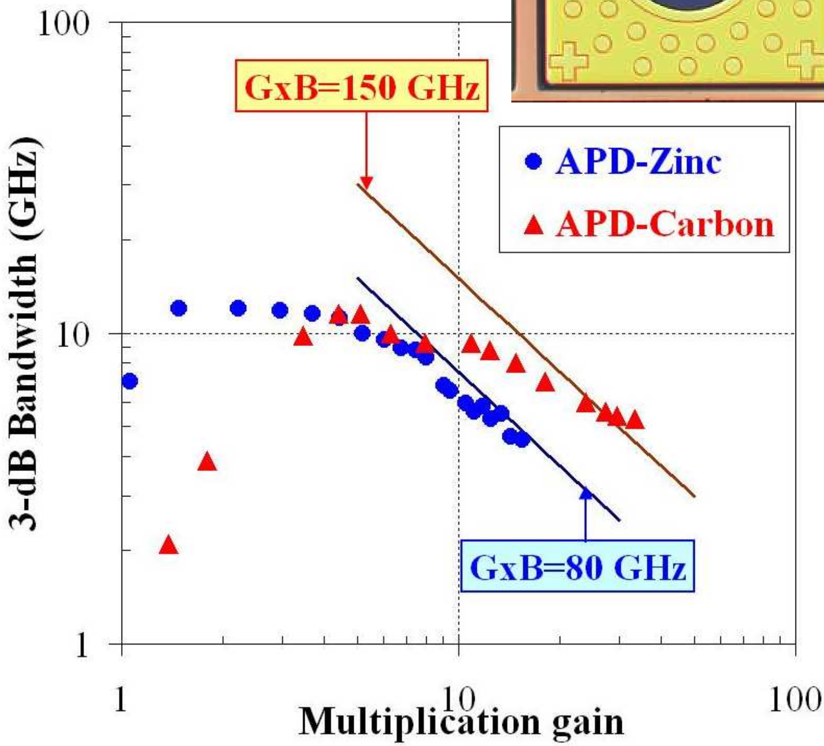
$$\alpha, \beta = A_{\alpha,\beta} \exp\left(-\frac{B_{\alpha,\beta}}{E}\right) \propto \frac{1}{lpm}$$

Charge doping impact on InGaAs/AlInAs APD characteristics

- **Uniform doping profile with abrupt tails using Carbon doping of the AlInAs charge layer**
  - Accurate electric field distribution along the APD structure
  - Low excess noise and high gain x bandwidth product

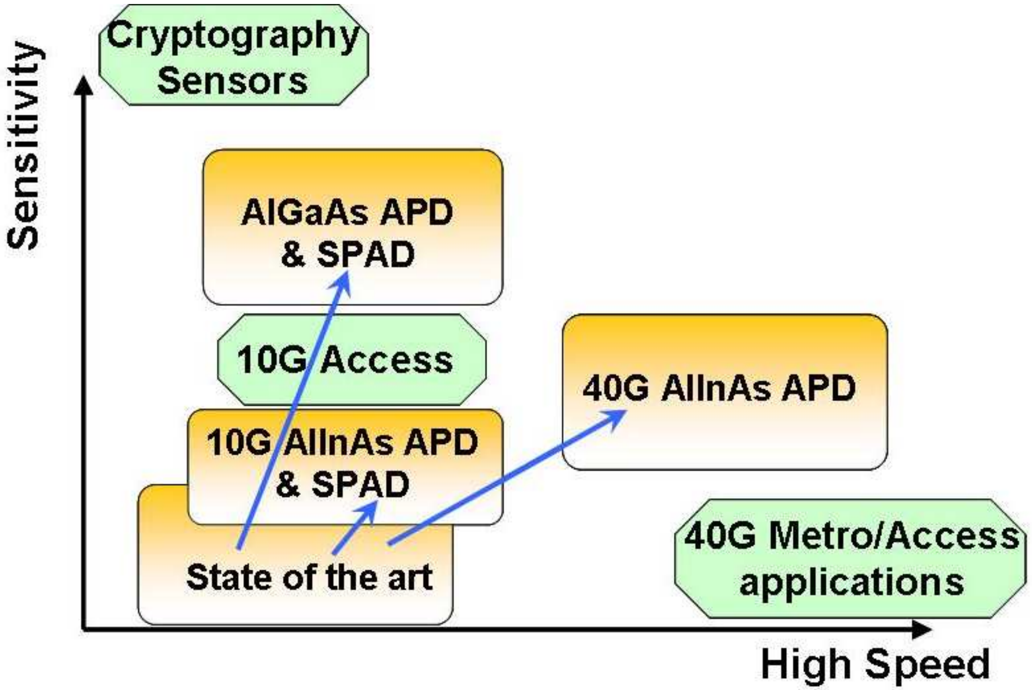






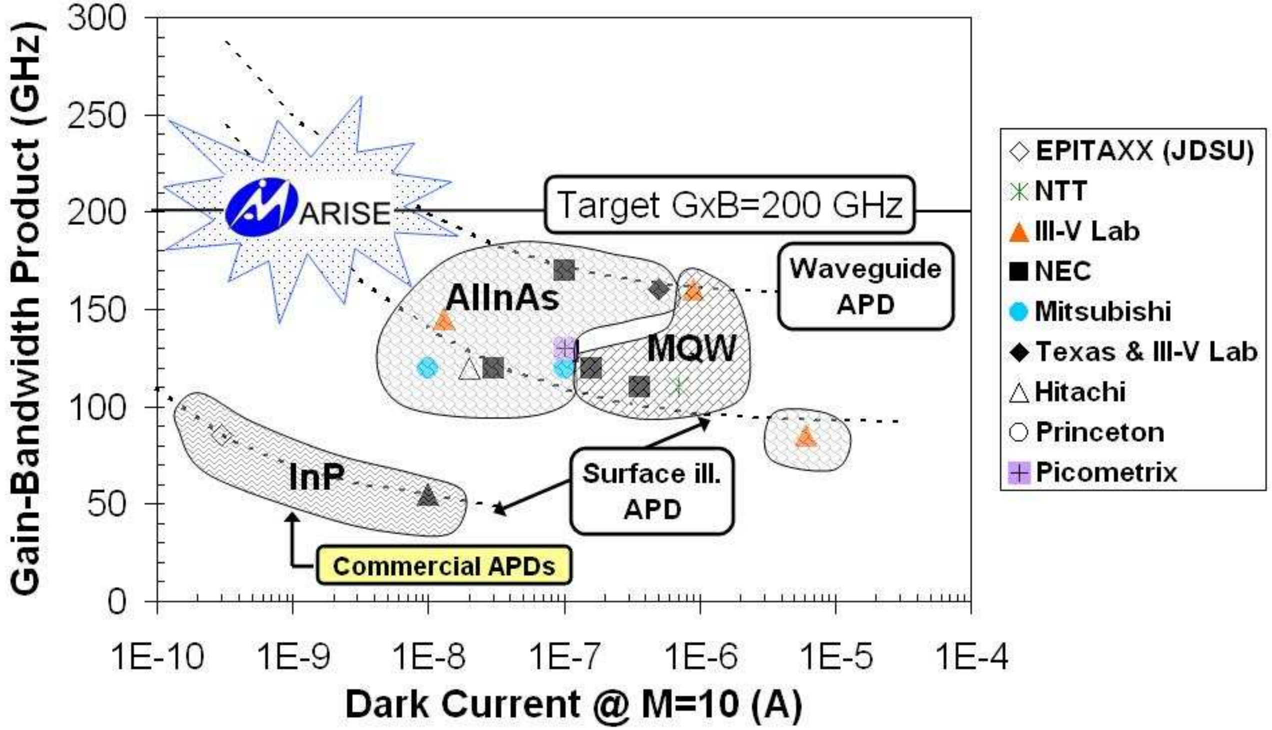
ICT-FP7 MARISE Project
3 years project, start: 05/2008

- **Objectives:**
  - Innovative APDs using two large bandgap III-V materials of interest: AlGaAs and AlInAs
  - Use recent breakthroughs in the impact ionisation characteristics in final APD devices
  - Exploit low noise properties of very thin avalanche layers to achieve high sensitivity
  - Several applications will be investigated: 10Gb/s access, core network avalanche receivers at 40Gb/s using waveguide structures and single photon operation for sensing



MARISE progress beyond state of the art

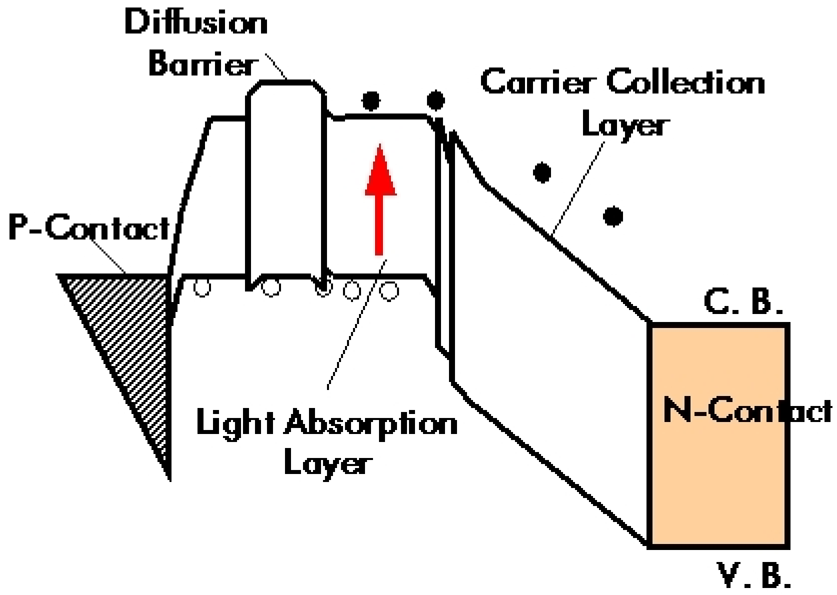
- **Three major objectives:**
  - **<u>Improved material</u>**: 1.3-1.55 µm AlInAs APD with GxB=160 GHz and Id<10nA at M=10
  - **<u>New structure</u>**: 1.55 µm AlInAs waveguide APD with GxB=200 GHz and f_{3dB}>30 GHz
  - **<u>New material</u>**: 1.3 µm AlGaAs/InGaAsN APD with targeted GxB>200 GHz

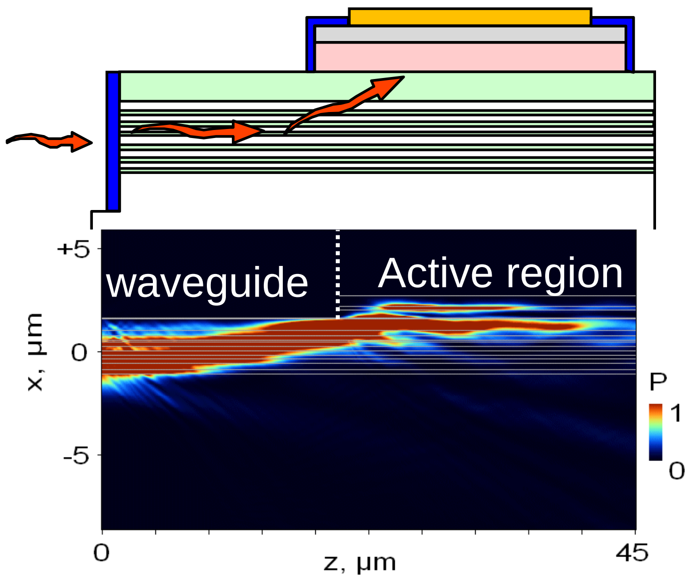


Towards lower dark current and higher gain-bandwidth product

InGaAs/InP high power UTC photodiodes

- **Advantages of UTC photodiodes**
  - Separation of absorption (p-doped) and drift (collector) regions
  - Use only electrons as active carriers (high speed operation)
  - Single carrier operation relaxes space charge effect (high power capabilities)

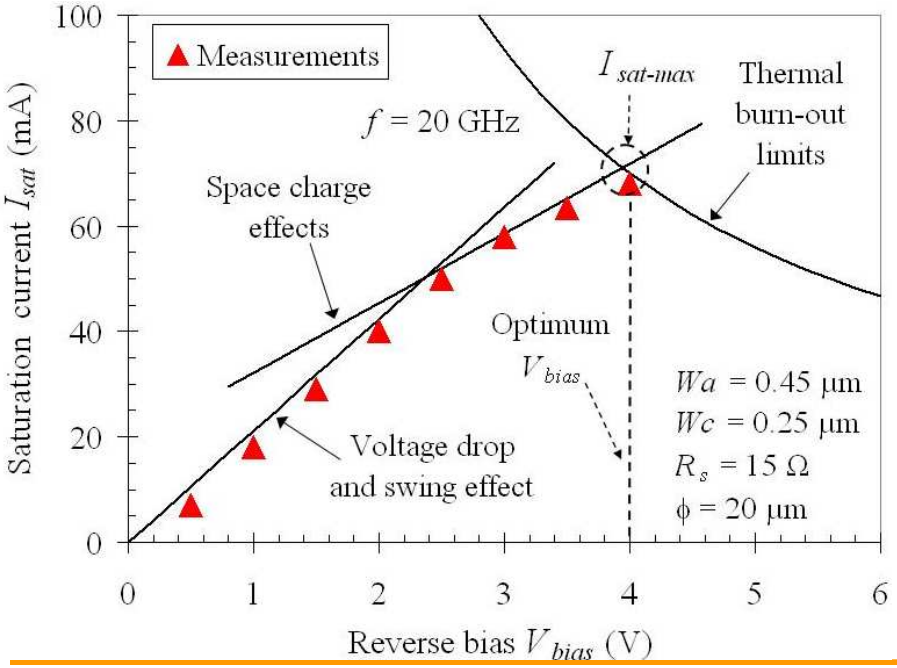


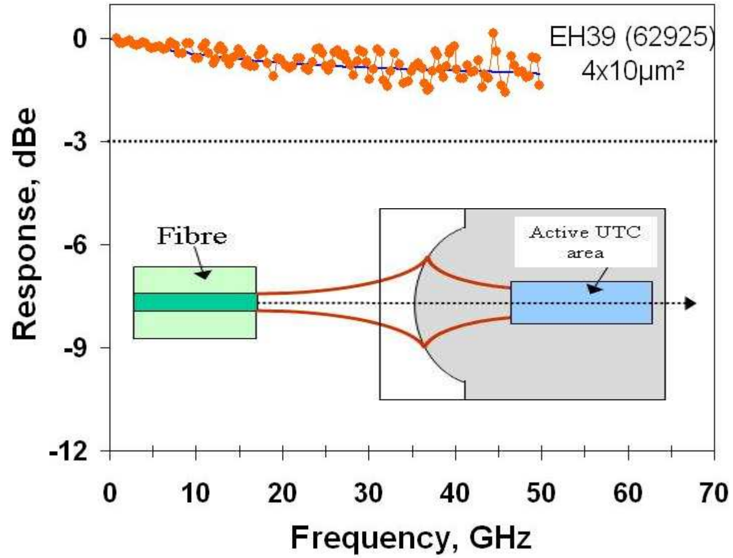


- **Edge evanescent UTC:**
  - Avoid direct illumination using planar diluted multimode waveguide
  - Progressive absorption of light (high power handling)

InGaAs/InP UTC performances

- **Monolithic integrated lens facet :**
  - Improved Responsivity and coupling tolerances (reduced imbalance)
- **Absorption/Collector design**
  - Very high speed operation

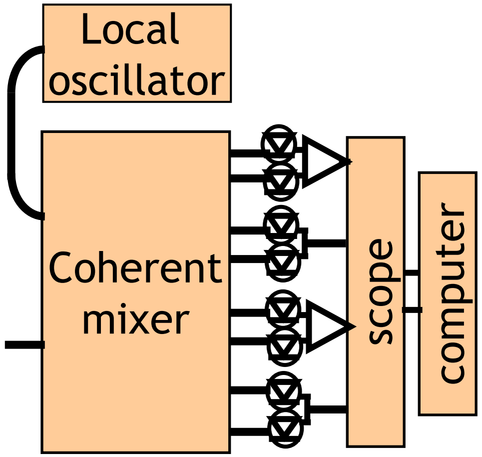


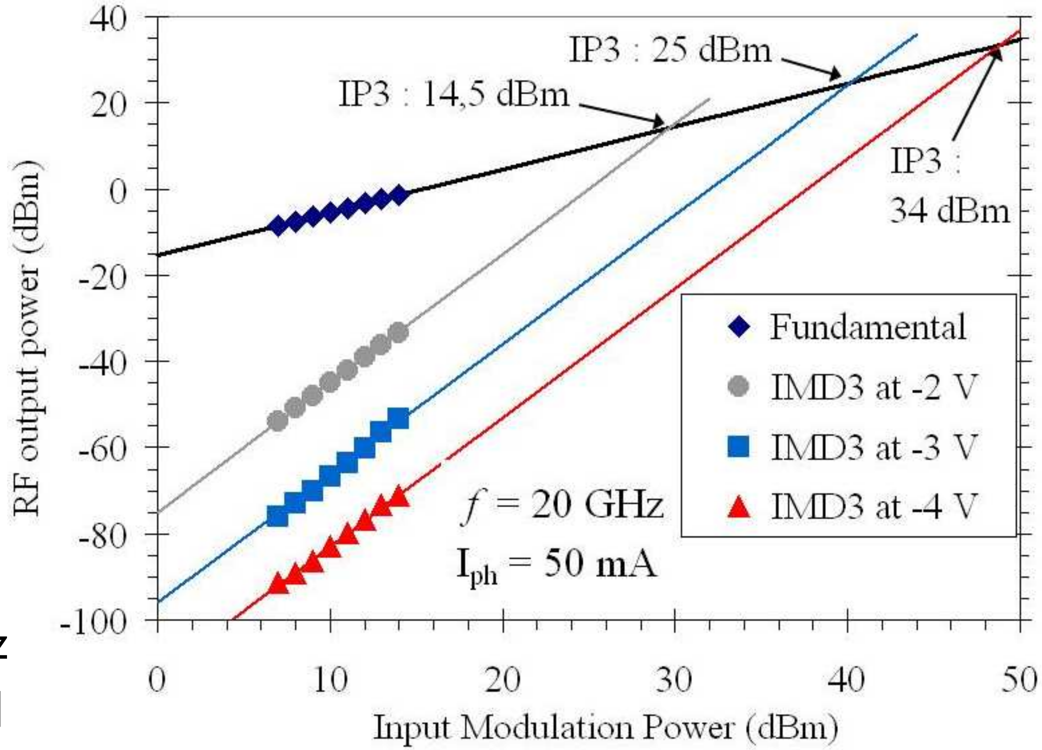


- **Saturation mechanisms at high I_{ph}:**
  - Voltage drop and swing (Rs)
  - Space charge effects (collector)
  - Thermal limitation

InGaAs/InP UTC linear operation for coherent detection

- **Highly linear UTC detector as required for linear front-end receiver and DSP (linear filtering to reduce CD and PMD)**

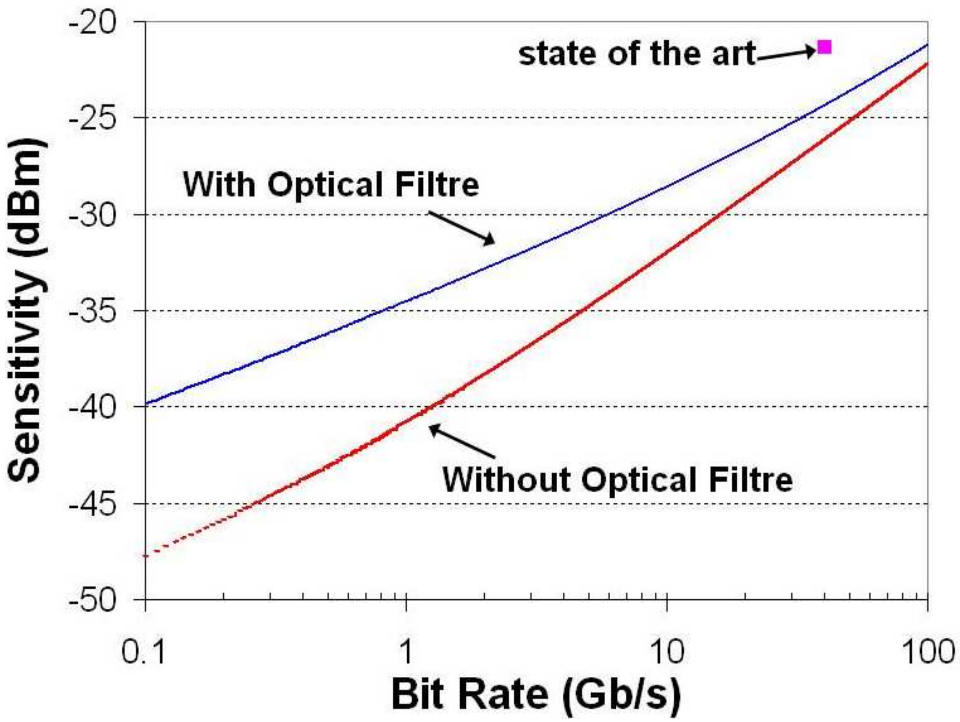


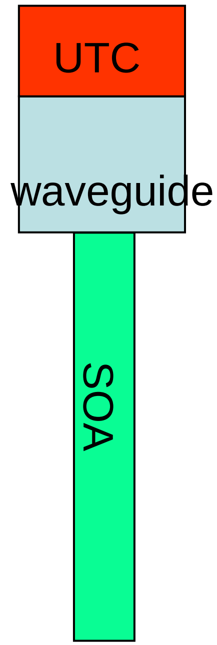


- **High linearity performances**
  - IP3=34dBm at Iph=50mA and 20GHz
- **Linearity still to be demonstrated on high speed waveguide UTC…**

Advanced SOA-PIN integration for high sensitivity 100Gb/s photoreceivers

- **SOA-PIN: Improved receiver signal to noise ratio with SOA integration**
  - Expected sensitivity improvement of ~ 5-10dB versus PIN-TIA
  - ASE filtering no longer necessary at 100Gb/s (< 0.5dB penalty)
  - Overcome gain-bandwidth product limitation of present APDs
  - Major bottleneck: TE/TM polarisation dependence





Conclusion

- **Rapid development in communication technologies:**
  - Increasing demand for InGaAs photodiodes
    - Higher sensitivity (GPON applications,…)
    - High power operation (coherent detection, microwave photonic links,…)
  - Various photodiodes designs as required for emerging systems/applications

- **Low power level light detection using InGaAs/AlInAs APDs:**
  - Record gain-bandwidth product and low excess noise for 10Gb/s access
  - APDs with very low dark current (ranging/sensing,…) and for 40Gb/s will need extra investigations on APD vertical structure design, improved material quality,…

- **High power InGaAs/InP UTCs**
  - Best in class power operation at microwave frequencies as required for coherent detection
  - Emerging SOA-PIN structures for improved 100Gb/s-400Gb/s link performances