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Comparison of laser receivers for use at one micron wavelength

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VISION SYSTEMS

AGENDA

I. NASA applications/requirements

II. IPD device

III. APD device

IV. Summary

Space Borne Laser Altimeter Evolution ICESat/GLAS to LIST

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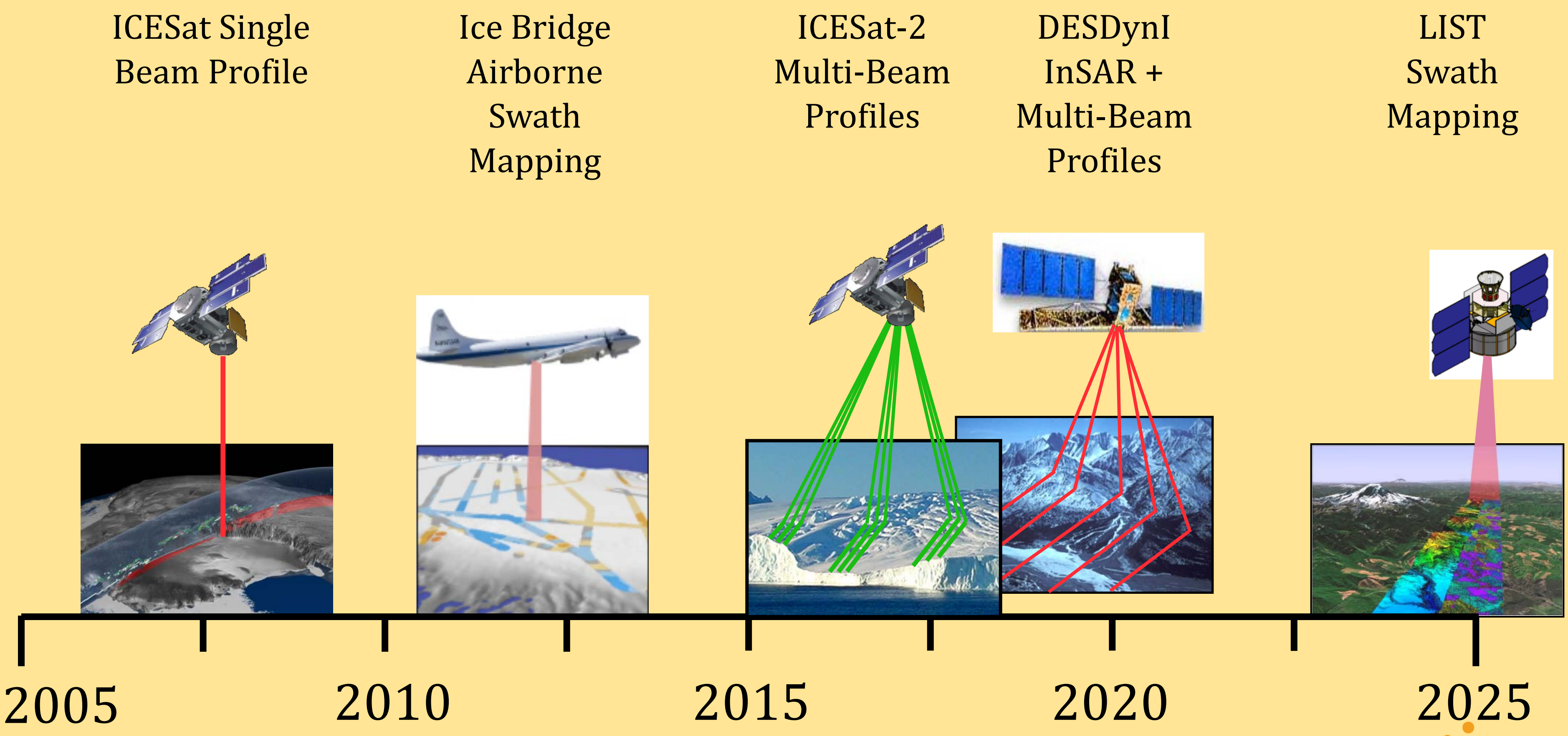

NRC Earth Science Decadal Survey Missions

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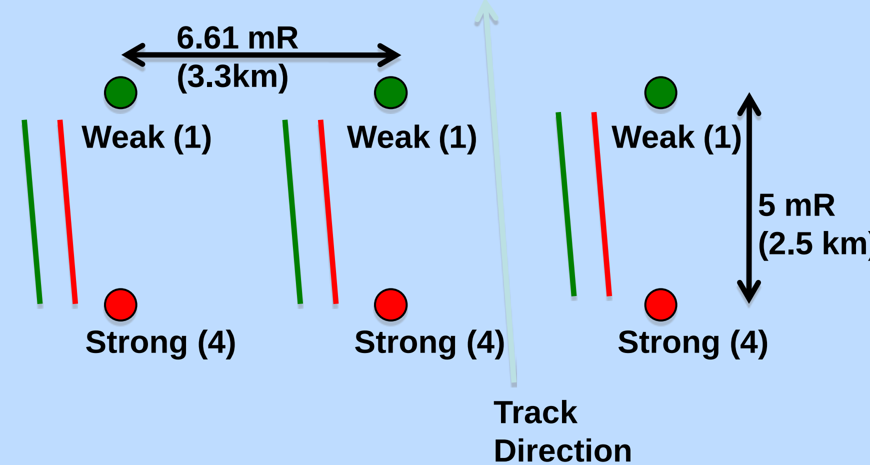
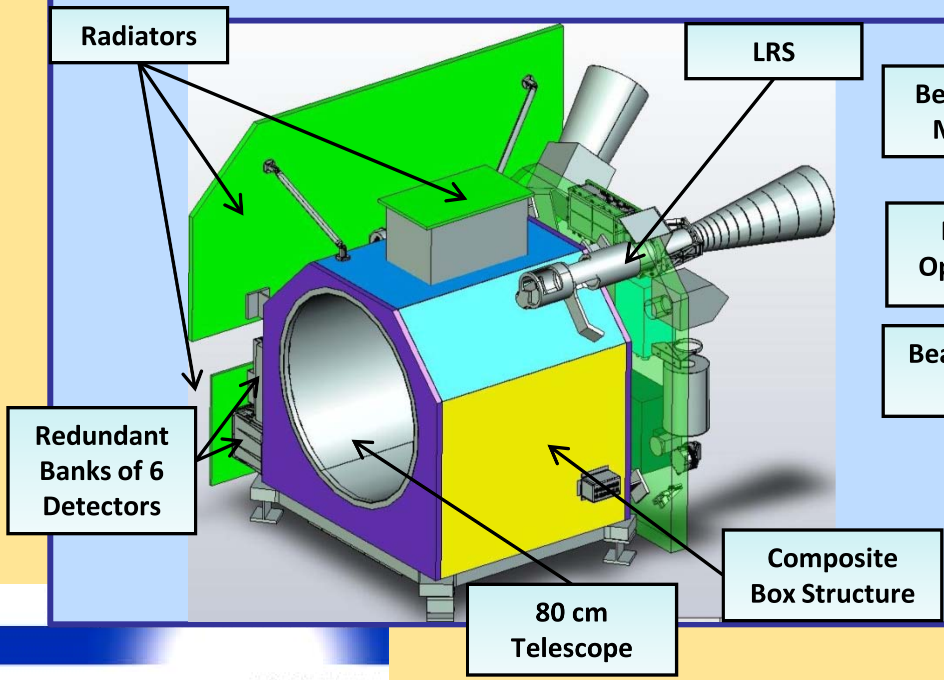
ICESat2/ATLAS Instrument Overview

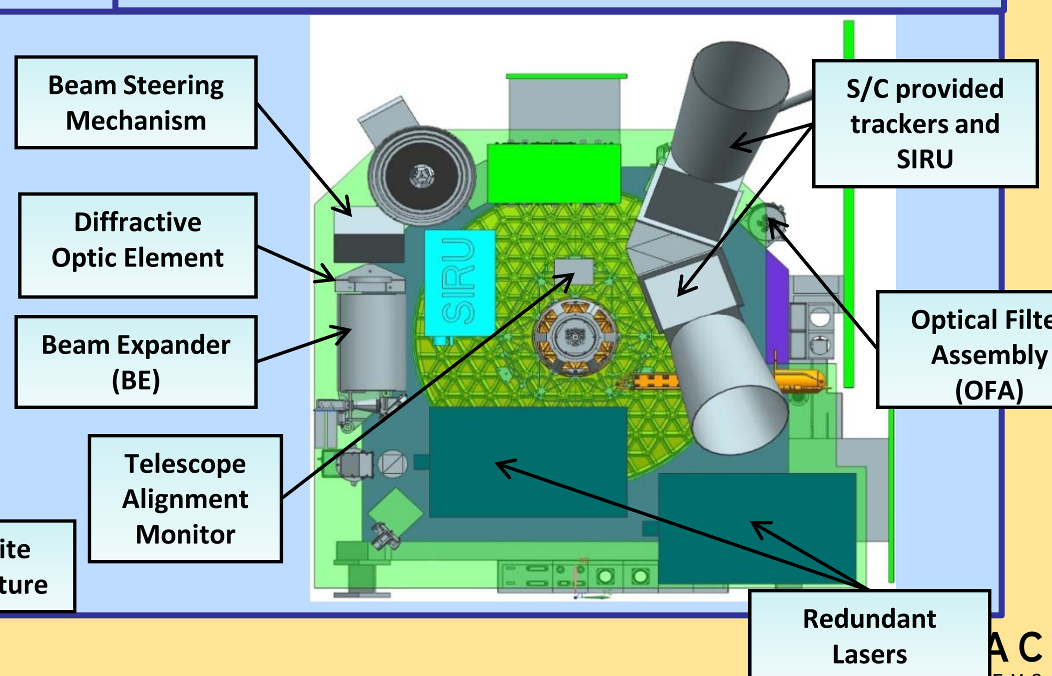
Multi-beam Micropulse Laser Altimeter

- Single laser beam split into 6 beams
- 10 m ground footprints
- 10 kHz rep. rate laser (~1mJ)
- Multiple detector pixels per spot
- On-board boresight alignment system
- Laser Reference System gives absolute laser pointing knowledge

Ground Track and Footprint







ICESat2/ATLAS baseline detector
Hamamatsu R-7900-16M

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- Successfully used on PAMELA ESA space mission
- Qty: 680 will fly on Alpha Magnetic Spectrometer ESA space mission.
- Quantum Efficiency >15%
- 350 ps timing jitter
- 1 GHz BW
- High reliability
- Negligible radiation damage

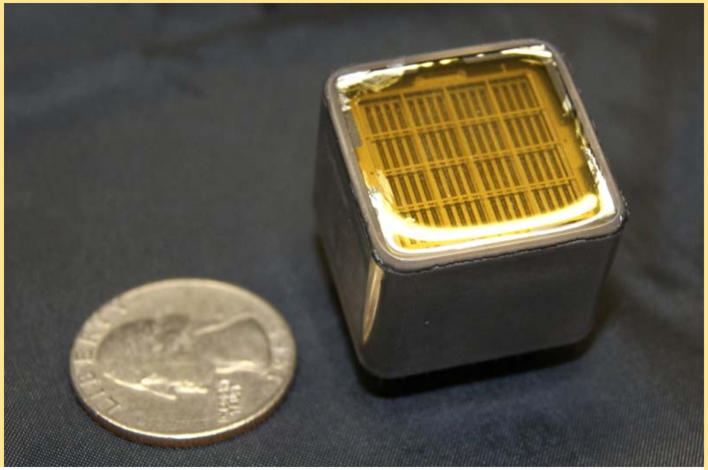
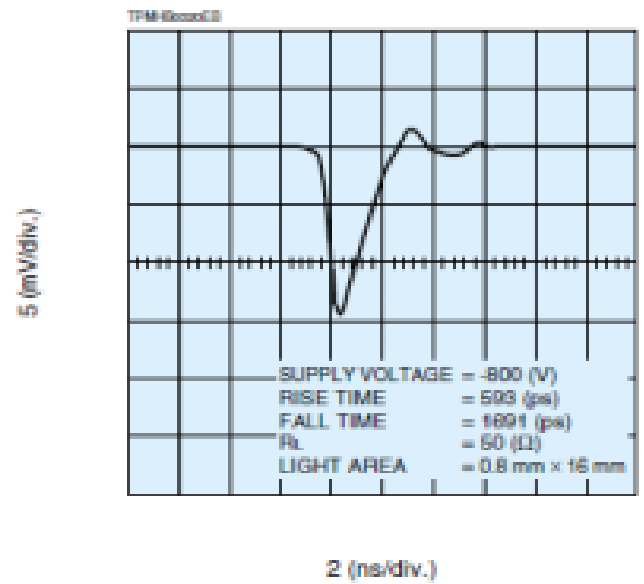


Figure 6: Typical Time Response



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Airborne Lidar Surface Topography Simulator (A-LISTs)

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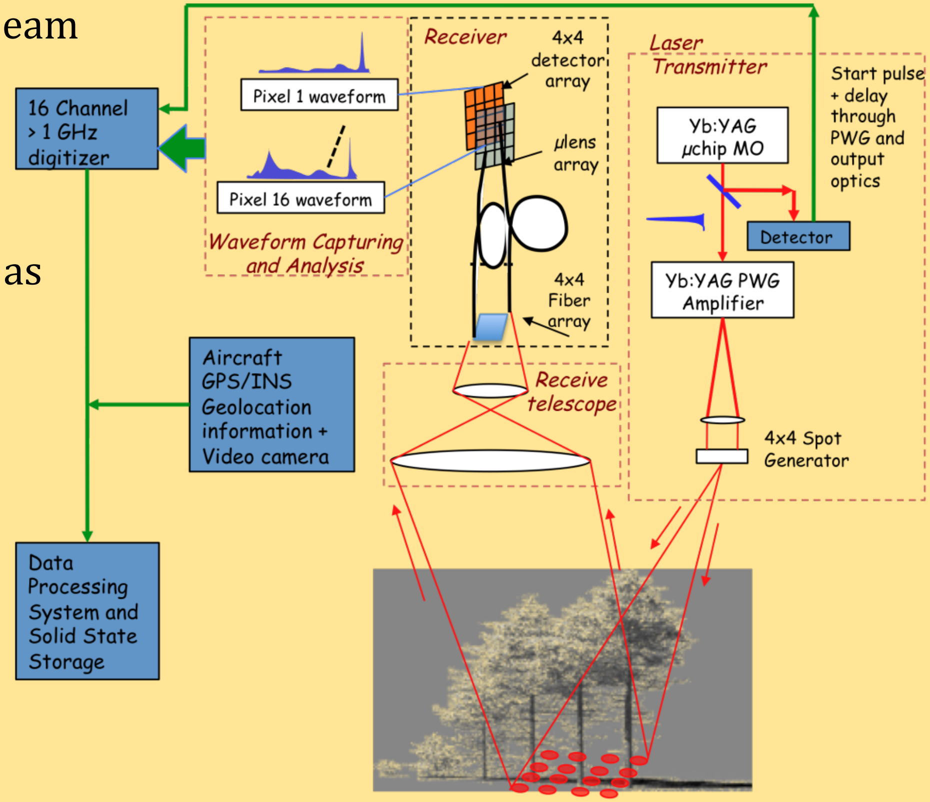
Objectives –

- Develop key technologies to meet the LIST mission requirements and scalability study for spaceborne mission.
    a. High efficiency, short pulse (< 1 ns) multi-beam laser transmitters
    b. Higher sensitivity array detectors, waveform capturing
    c. Similar spatial resolution (spot diameters) as LIST
- Advance TRL of critical subsystems (Laser & Detector) on airborne platform.
- Demonstrate LIST-type measurements over a variety of surface types, including those of vegetation canopy and substructures.



Approach

Develop and demonstrate a 16-channel airborne instrument – *Airborne Lidar Surface Topography Simulator (A-LISTs)* to demonstrate key subsystems and measurement techniques in support of the LIST mission.

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Need detector with high sensitivity
Key issue is achieving low-noise gain

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Received Signal photons (1, 10’s, 100’s) →

Absorber
at λ (1 micron)

InGaAs

InAlAs

InGaAsP

InAlAsP

“Thick” Silicon

Multipass Silicon

Signal electrons (1, 10’s, 100’s) →

Electron Gain mechanism

Transistor amplifier (too noisy)

Electron multiplier plate (dynode) in vacuum - PMT (low noise)

Electron bombardment in vacuum - IPD (~noiseless)

Electron multiplication in semiconductor “impact ionization” – APD (low noise to noiseless!)

Signal electrons (~1k’s to 1 M) →

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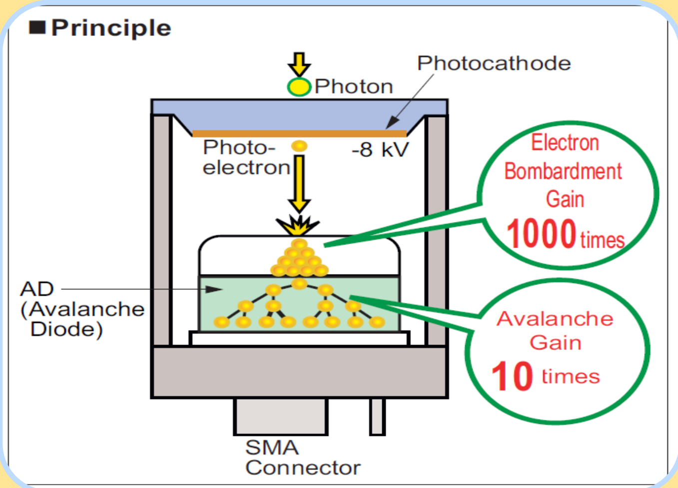
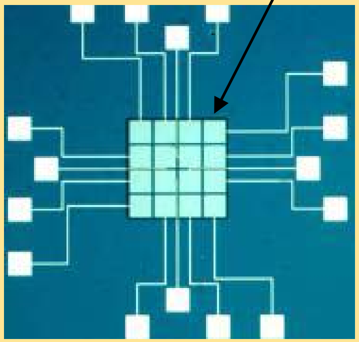
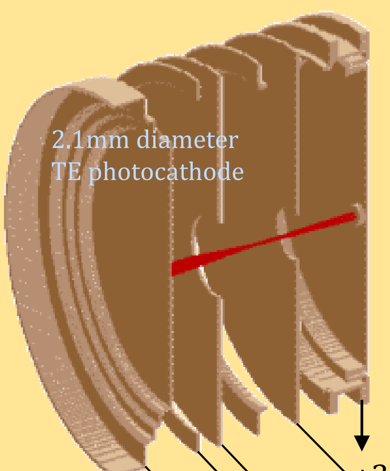
Intevac Multi-element IPD Design



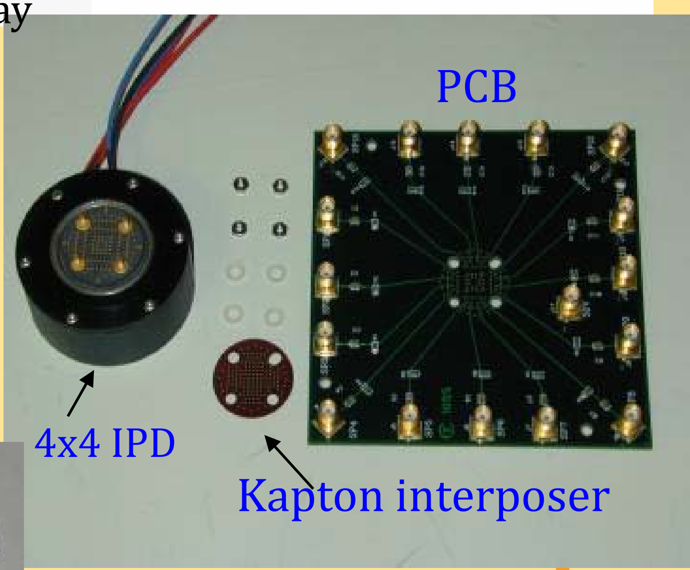
APD anode array

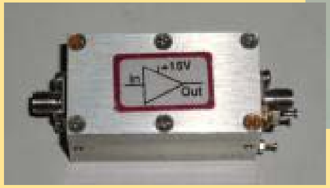
100µm square APD pixels
80% fill factor
(magnified by 1.59 to 170 um pixel at the photocathode)





+300V
-7780V
-8000V
-7997V





Low noise amplifier

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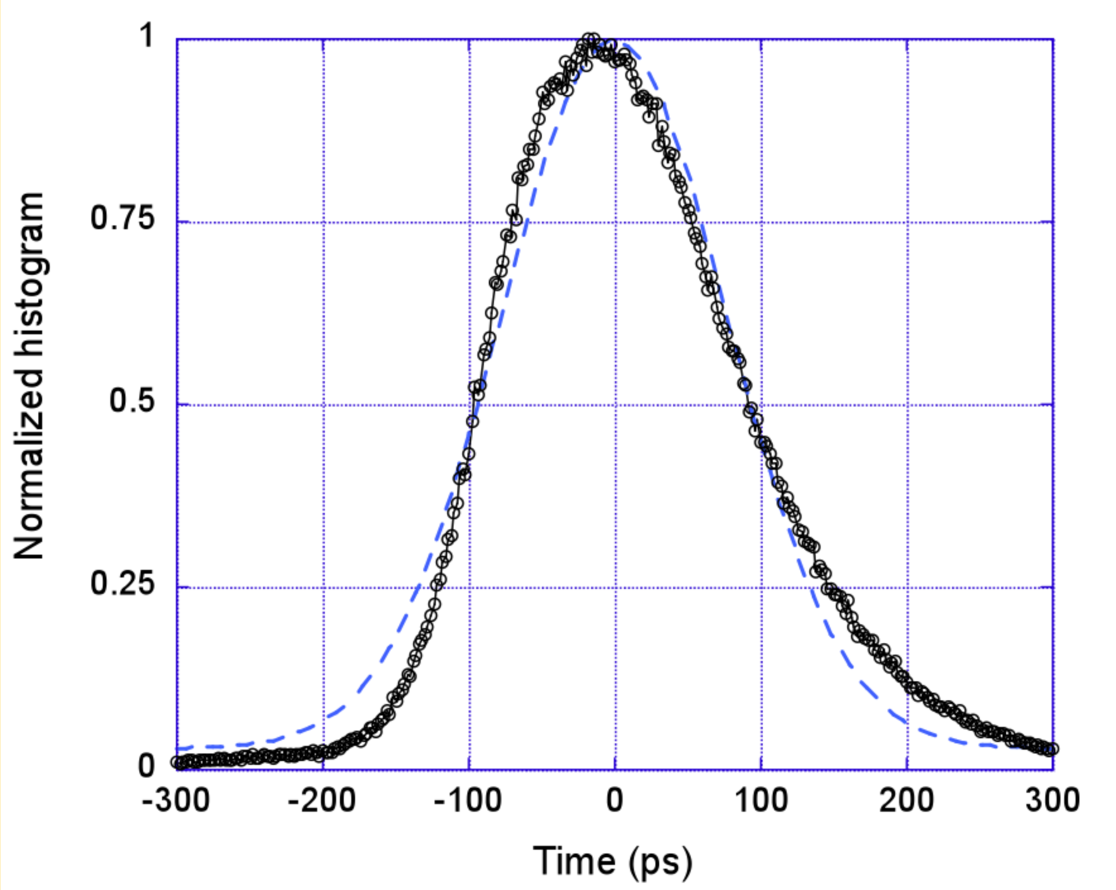
Single-photon timing jitter per pixel measurement



Results for IPD with 0.8 µm InGaAsP layer thickness.

FWHM = 188 ps.

Dashed line is Gaussian fit with σ = 78 ps.

Photon number (pulse height distribution) per pixel measurement vs. theory

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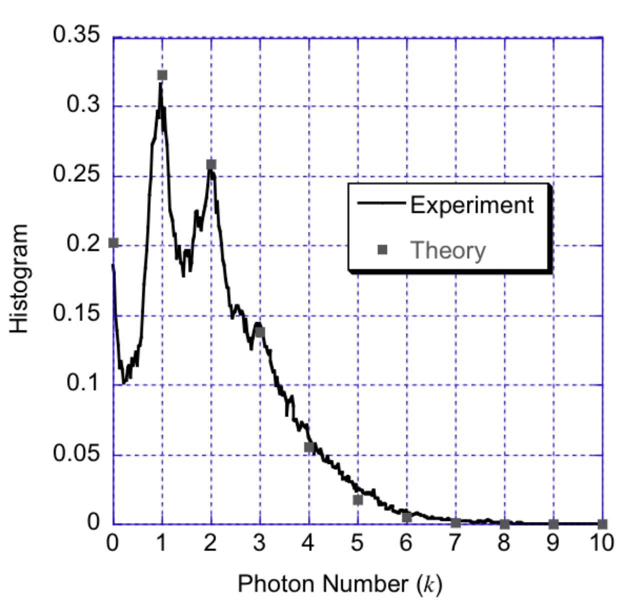

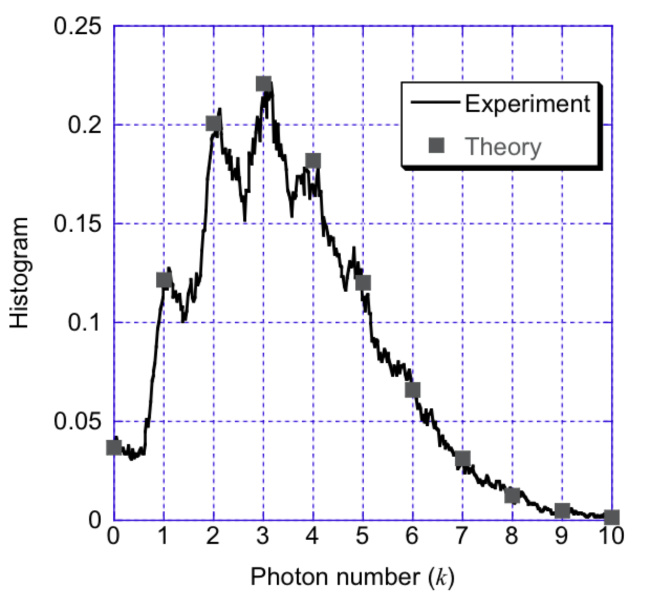

λ=1.6

λ=3.3

$$f(k,\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$$

Measured scaled histogram of the pulse height distribution and Poisson theory for (a) λ=1.6 and b) λ=3.3

16-Channel Intensified-Photodiode Detector

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- A 16-channel IPD detector was further developed for a NASA science airplane instrument with hopes for application to future NASA missions.
- The IPD physics allows for a large area with 1 GHz bandwidth and single-photon sensitivity.
- The photocathode thinning allows trading timing jitter (improvements) and quantum efficiency (reduction).
- 15% quantum efficiency at 1064 nm wavelength
- Timing jitter is 188 ps (FWHM) σ = 78 ps.
- Dark counts projected as 5 kcps at -20 C
- Photon number resolution is important to provide required dynamic range and to avoid ranging bias errors. Excellent agreement with theory.
- Reliability is paramount. Work is continuing on engineering both device and process reliability improvements.

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Noise Equivalent Power (NEP)

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- APD + TIA Amp NEP $$NEP = \frac{1}{R_{sp}}\left[2qI_dF + \frac{\alpha^2}{M^2}\right]^{1/2}$$

$$F = kM + \left(2 - \frac{1}{M}\right)(1-k)$$

R_{sp} (=QE*q) is the APD unity gain responsivity

M is the APD optical gain

F is the APD excess noise factor

k is the ratio of the hole and electron ionization coefficients

α is the Trans-Impedance Amplifier (TIA) noise current density

Critical parameters to reduce NEP	METHOD
– Low ionization coefficient ratio, k	Engineer the material (I2E)
– Low TIA noise α	Electronics design
– High quantum efficiency	Choice of absorber material
– Optimize gain (M)	

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Impact Ionization Engineering (I^2E)

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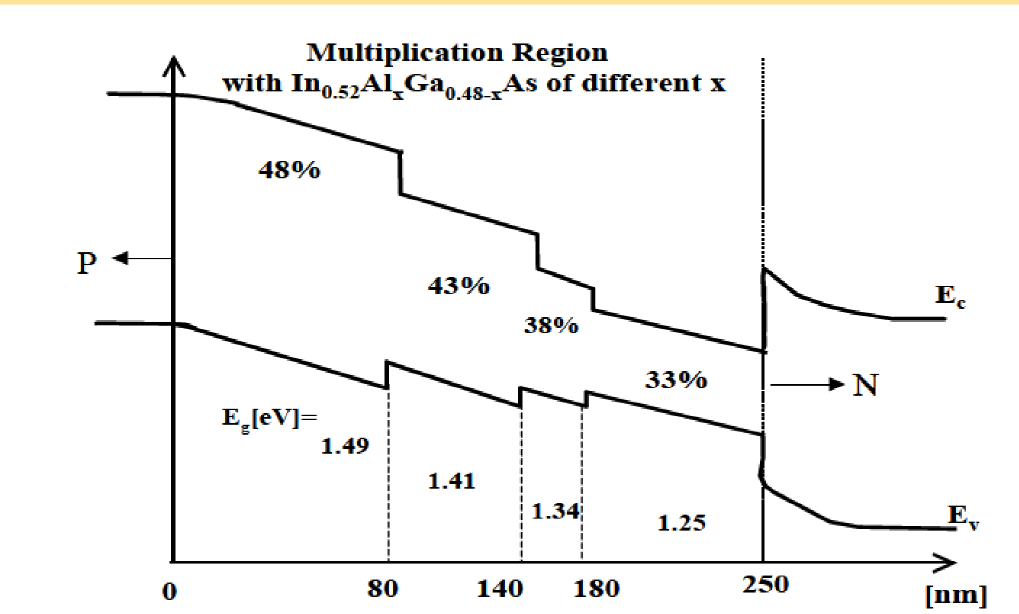
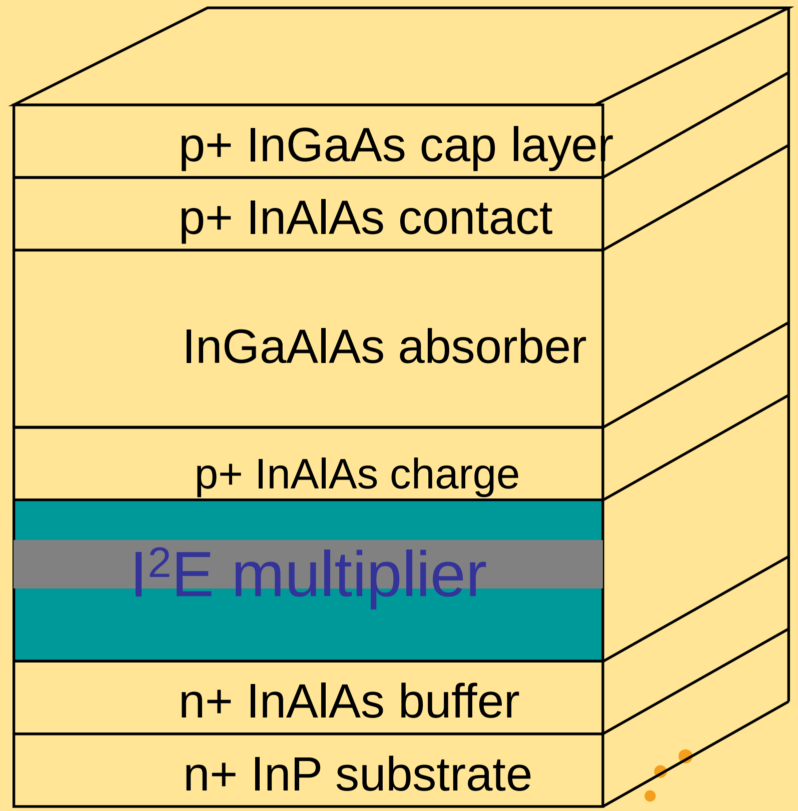
Multiple layers are used in the multiplication region. This allows localization of the multiplication process to make it more deterministic (i.e. less noisy).



Graph from S. Wang, et. al., IEEE Photonics Technology Letters, Vol.14, No. 12, pg1722, 2002



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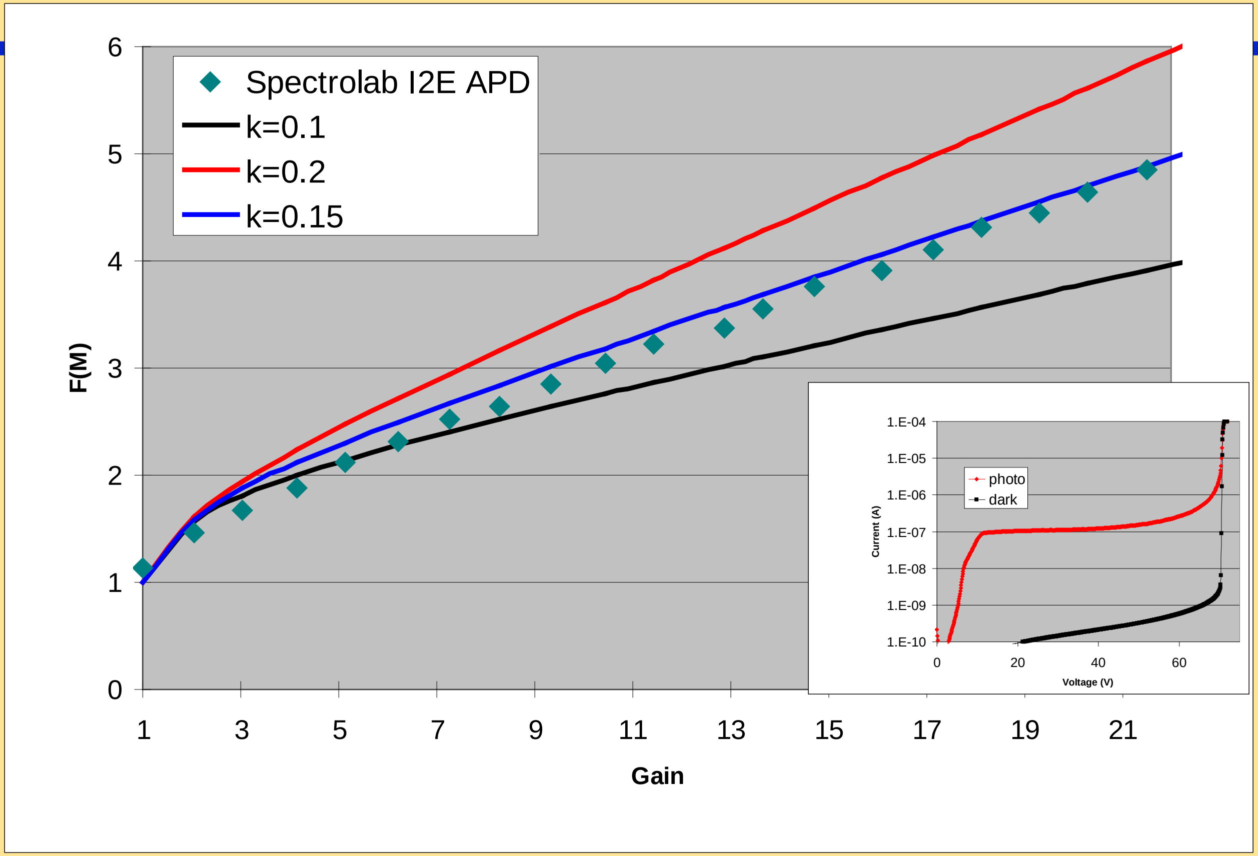
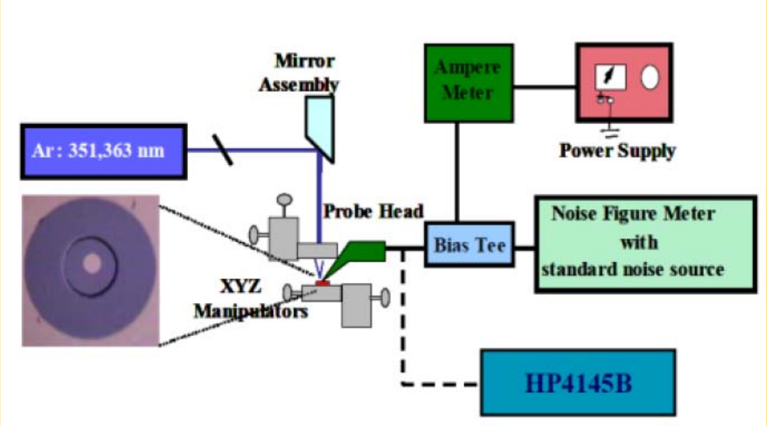
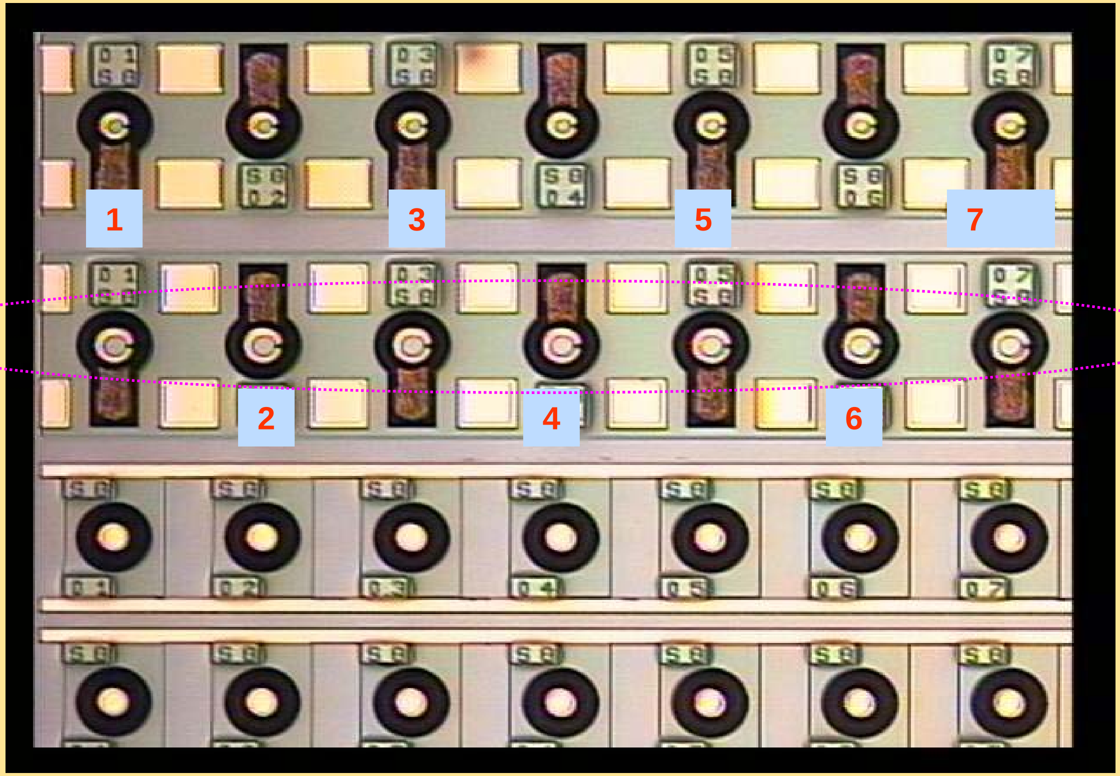
I^2E APD Excess noise





- Effective k value of 0.15 is reached
- I^2E APD shows low dark current and high optical gain

1×16 I^2E APD array



- APD arrays with a pitch of 250 µm
- 75 µm mesa diameter with ring contact
- Front side illumination
- Backside polished and Au deposited
- Backside illumination arrays available too

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Silicon APD vs. InAlAs APD vs. InGaAsP IPD photoreceiver comparison

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Receiver Parameter	Silicon APD + custom TIA	InAlAs APD + commercial TIA	IPD
Quantum efficiency at 1064 nm	40%	85%	15%
Active area diameter	700 micron (single detector)	75 micron (array element)	Single – 1 mm 4 x 4 array – 0.66 mm 164 micron pixel
Gain	100	50 (increase to >100)	20,000
Excess noise factor	2.6 @ Gain = 100	5 @ Gain=50	1.05
Bulk dark current	50 pA	100 pA	< aA (20 kcps)
Bandwidth	140 MHz	900 MHz	900 MHz
Radiation damage	No degradation	Not tested	Low
Responsivity	~300kV/W	~300kV/W	N/A
Transimpedance amplifier (TIA) noise	1.5 $pA/Hz^{1/2}$	6 $pA/Hz^{1/2}$	N/A
Noise equivalent power (NEP)	30 $fW/Hz^{1/2}$	180 $fW/Hz^{1/2}$	< 1 $fW/Hz^{1/2}$
Linear dynamic range	20 dB	20 dB	>80 dB
Power dissipation	< 0.2 Watts	< 0.2 Watts	< 0.1 W
Lifetime	>10 years in space (vacuum)	Not tested	Needs Improvement

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SUMMARY

- NASA airborne and spaceflight topographic lidar applications require high-bandwidth high-sensitivity laser receivers for use at one micron wavelength
- The IPD is close to a "perfect" detector with work remaining on device reliability.
- The InAlAs I2E APD developed by the ESTO ACT is the best room temperature APD with GHz bandwidth. A quantum well multiplier region may provide higher (low-noise) gain for further improvement.
- We plan to test both IPD-based and InAlAs I2E APD-based 16 channel receivers on the A-LISTS ESTO IIP.

ACKNOWLEDGMENT

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