Progress of 2-μm Detectors for Application to Lidar Remote Sensing

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Outline

- Overview
- Objective
- Applications
- Detector Characterization at Langley
- Custom-Designed Detector Validation
- Summary

Overview

- Detector with high gain and low noise is a detector of choice for laser remote sensing applications and no commercial detector was available at 2-μm wavelength range.
- NASA Langley Research Center's detector group worked in collaboration with Astro-Power, Inc./University of Delaware to develop custom-designed 2-micron phototransistors using Liquid Phase Epitaxy (LPE) technique.
- These phototransistors have very high gain, but also have longer recovery time, which may cause problem for CO_2 DIAL applications.
- Raytheon achieved high gain, high speed, and ultra low excess noise factor around 1 from the Avalanche Photodiode.
- Therefore, NASA Langley acquired HgCdTe avalanche photodiodes (APD) from Raytheon, characterized and applied in atmospheric testing at 2-μm.

Objective

Develop, test, and implement new technology 2 μm detectors for application to laser remote sensing from ground, aircraft, and space.

2-μm Detector Applications

- Detectors with responsivity at broad wavelengths are needed to span a wide wavelength range for the following applications
  - ❖ CO_2, O_3, H_2O, and CH_4
  - ❖ aerosols and clouds
  - ❖ detection of a large number of species in the visible-near infrared using active and passive remote sensing techniques, and
  - ❖ enable new science and lower-cost missions through compact instruments

2-μm Detectors Development and Characterization

Single element custom-designed phototransistors and avalanche photodiodes have been developed at Astropower/University of Delaware and Raytheon Vision Systems; and characterized them at NASA Langley Research Center

Measured the phototransistor's responsivity and noise

- Determined device performances, such as detectivity and noise equivalent power
- Demonstrated high responsivity 2650 A/W corresponding to an internal gain of 2737
- High detectivity (D*) 3.9×10^{11} cm.Hz$^{1/2}$/W that is equivalent to a noise equivalent power of 4.6×10^{-14} W/Hz$^{1/2}$.

Evaluated the APD's spectral response

- Determined high quantum efficiency and high gain

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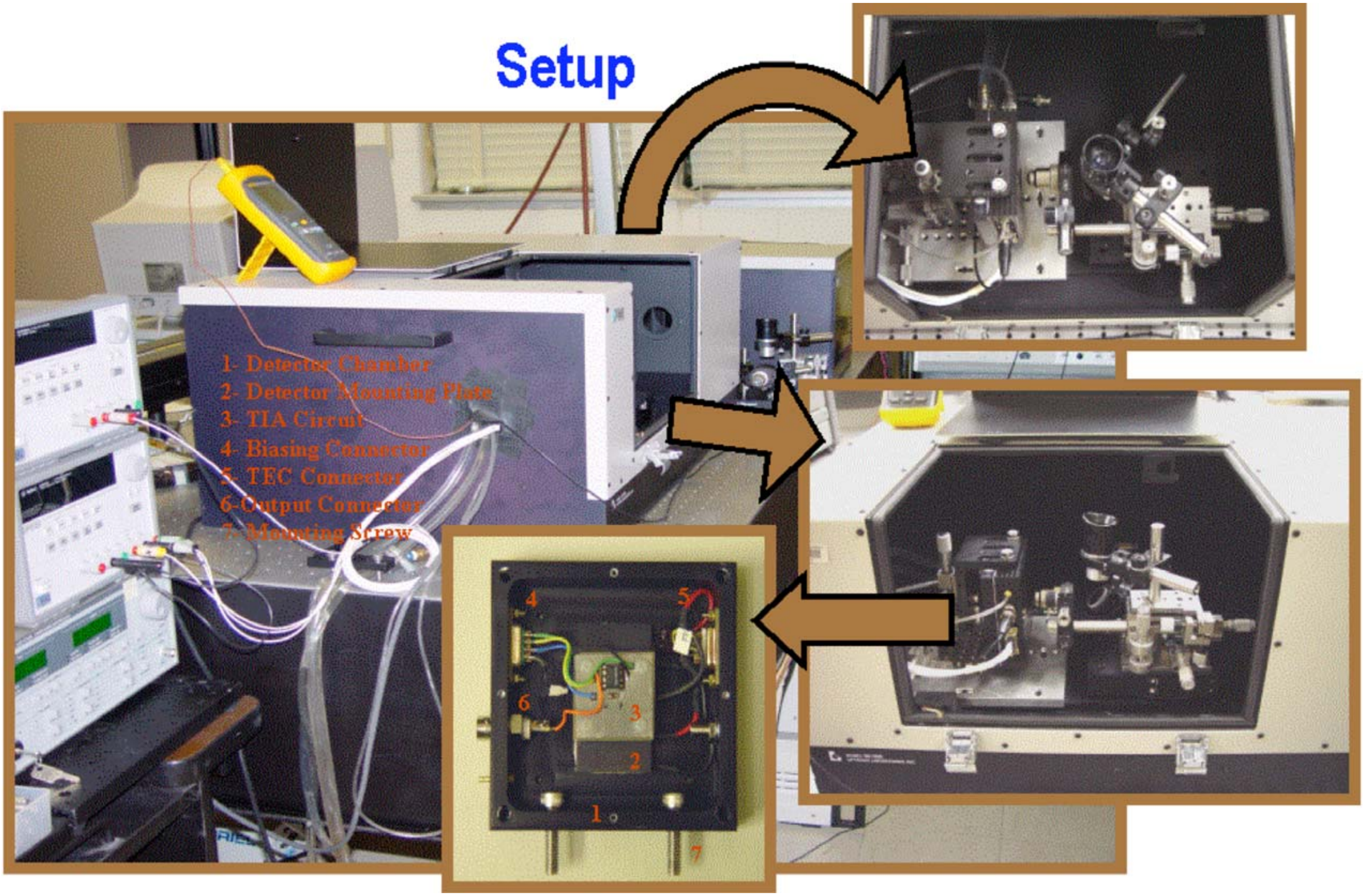
Detector Calibration

Setup

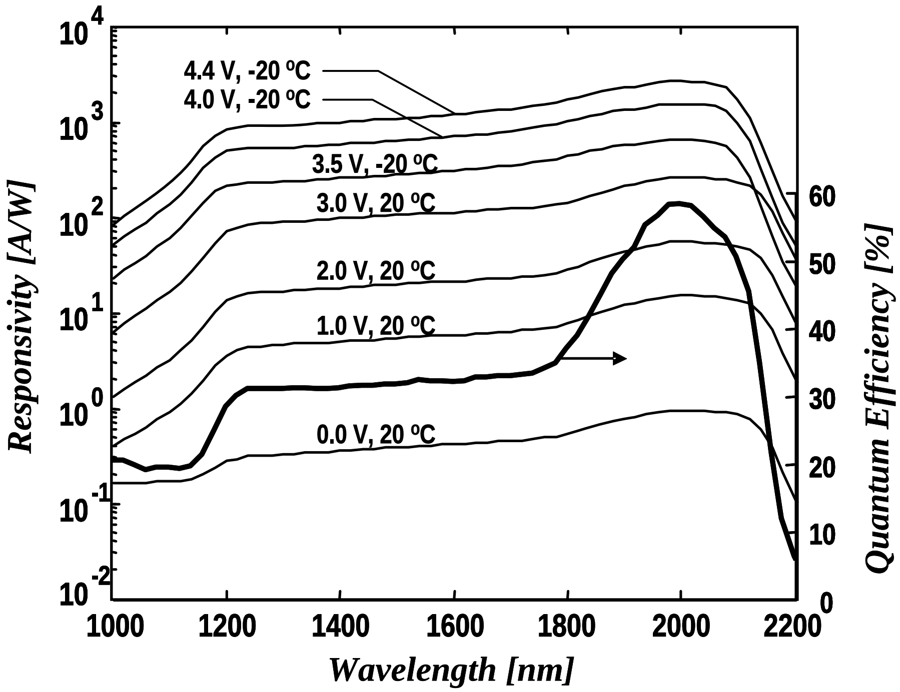


Custom-Designed Detector Calibration

2 μm InGaAsSb Phototransistor Characteristics

Custom-designed 2 μm Detector Technology

- PbS Reference Detector
- 20 nm Spectral Resolution
- -20 to 20 °C Temperature
- Different Bias Voltages
- Calculated Quantum Efficiency for 0 V at 20 °C



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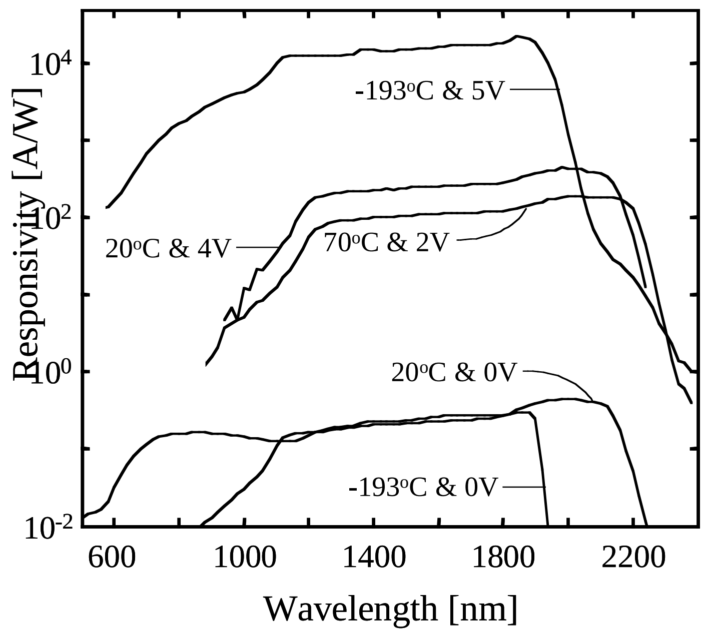
Custom-Designed Detector Calibration

2 μm InGaAsSb Phototransistor Characteristics

Custom-designed 2 μm Detector Technology

- *InGaAsSb detector peak positions shifted due to temperature variation*

- PbS Reference Detector
- 20 nm Spectral Resolution
- -193 to 70 °C Temperature
- Different Bias Voltages (0 V to 5 V)



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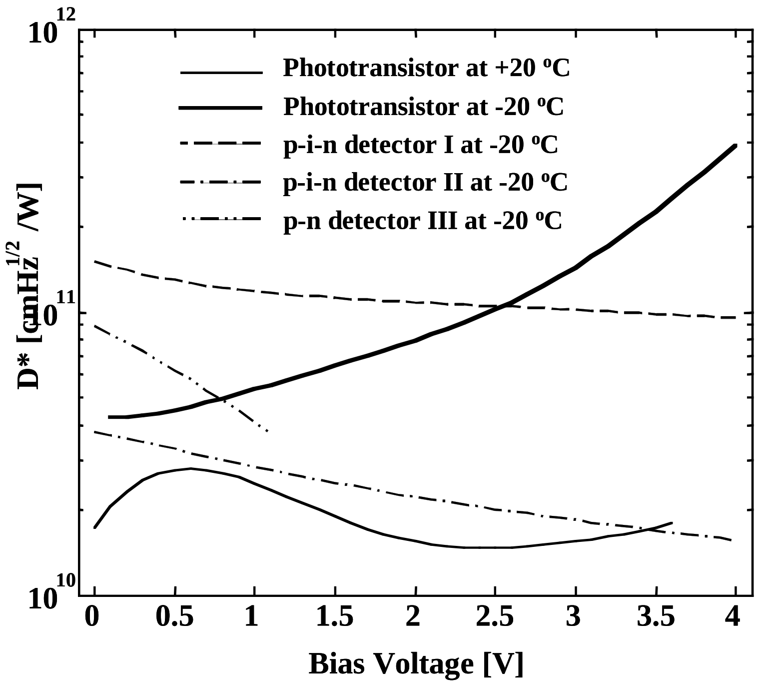
Detector Performance Comparison

Existing and Custom-Designed Phototransistor Characteristics

Detectivity (D)*

- With suitable bias voltage and 2-micron radiation, InGaAsSb Phototransistor has the best detectivity, compared to InGaAs (I & II) and HgCdTe (III) technologies.



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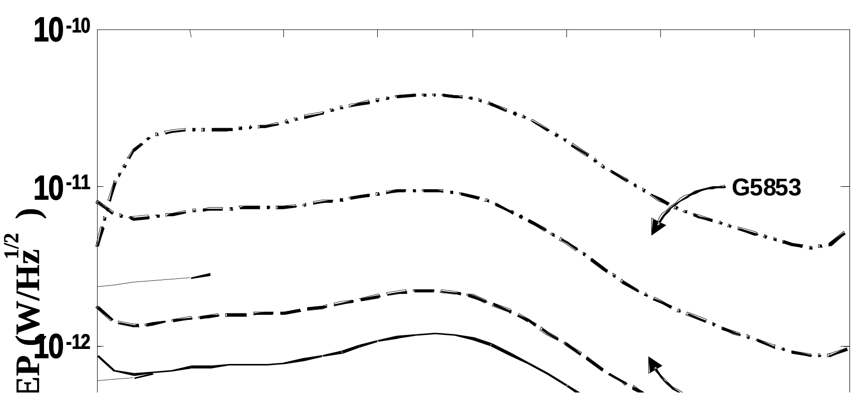
Detector Performance Comparison

Existing and Custom-Designed Phototransistor Characteristics

Noise-Equivalent-Power (NEP)

- With suitable bias voltage, InGaAsSb Phototransistor has the lowest NEP, compared to InGaAs (G5852: 2.3-cutoff) and InGaAs (G5853: 2.6-cutoff) technologies.



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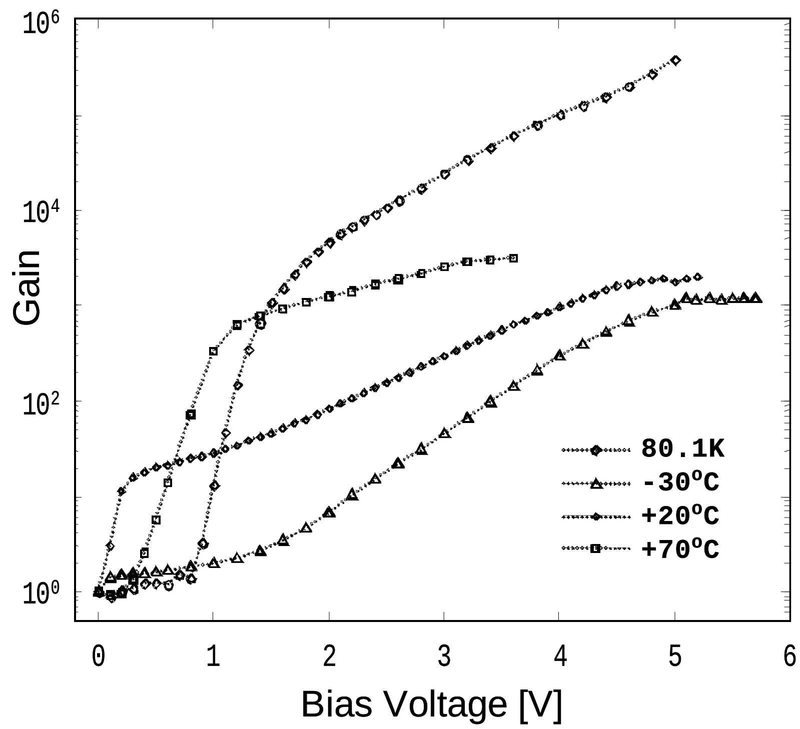
Detector Performance Comparison

Determination of Custom-designed 2 μm Phototransistor's Gain

❖ *InGaAsSb phototransistor gain variation at different bias voltage for fixed incident radiation @2.0 μm*

Gain

- Different Temperature.
- Bias Voltages (0.0- to 5.8-volts).



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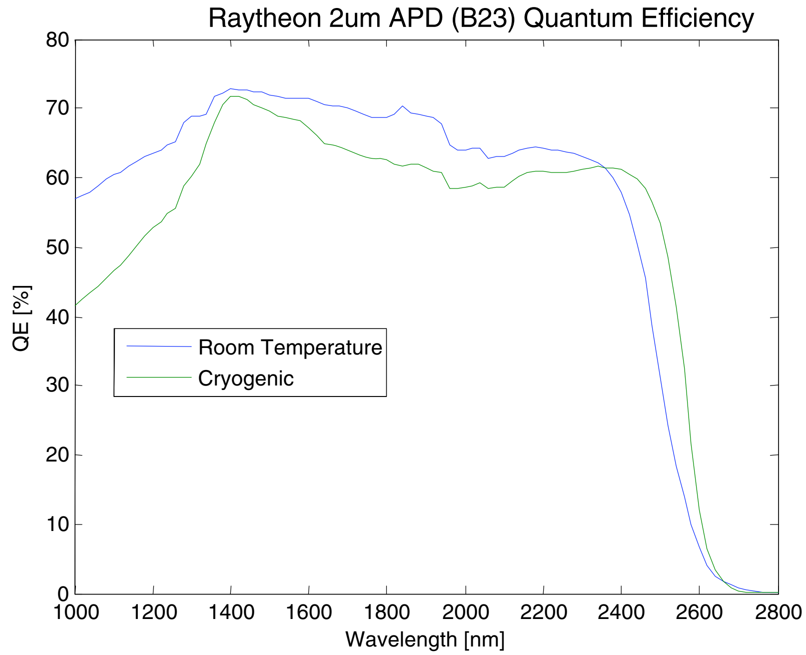
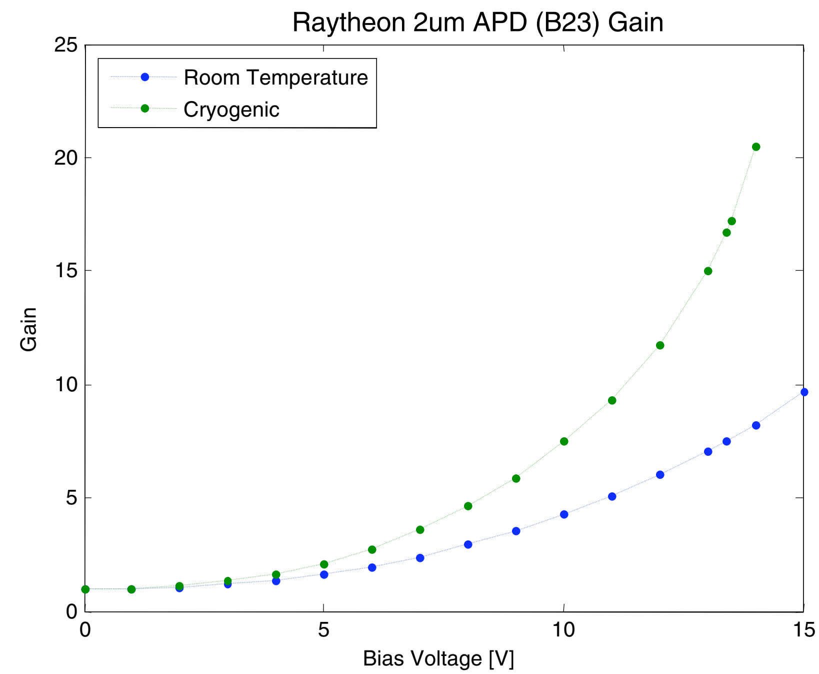
2 μm Avalanche Photodiode Performance

- QE at Room and Cryogenic Temperatures with 0 V Bias Voltage
- Gain at Room and Cryogenic Temperatures with different Bias Voltages

Quantum Efficiency



Gain



Note: APD was not AR coated, QE will exceed >80% with AR coating

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2 μm Avalanche Photodiode Performance

Summary Table of the 2 μm APD

Detector Parameters	NASA APD requirements	Achieved results at LaRC
Detector Type	Avalanche Photodiode	Avalanche Photodiode
Detector Material	HgCdTe	HgCdTe
Spectral Range	1.0 - 2.4 micron	1.0 - 2.6 micron
Detector Diameter	200-micron	200-micron
Quantum Efficiency	> 70% @ 2.05 micron	65% @ Room Temp 58% @ Cryogenic Temp.
NEP	< 2×10^{-14} W/sqrt (Hz)	------------
Multiplication Gain	50	9 @ 15.0 V @ Room Temp 21 @ 13.4 V @Cryogenic
Excess Noise Factor	< 2.0	-------------
Detector plus Amplifier Bandwidth	5 MHz	-------------

Note: APD was not AR coated, QE will exceed >80% with AR coating; NEP, excess noise factor, and bandwidth are not evaluated

Custom-Designed Detector Validation

Validated phototransistors at National Center for Atmospheric Research (NCAR), Boulder, Colorado, by integrating them into Lidar System operating at 1.543-μm and also at NASA Langley Research Center operating at 2.0-μm

Results:

- Phototransistor was optimized for 2-μm detection, but its performance is nearly similar to the InGaAs APD at 1.5-μm.

- Lidar tests were performed at 2.0-μm wavelength and results are promising

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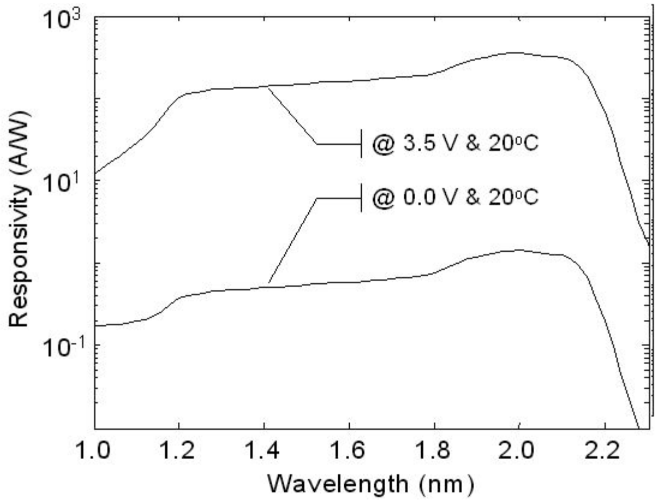
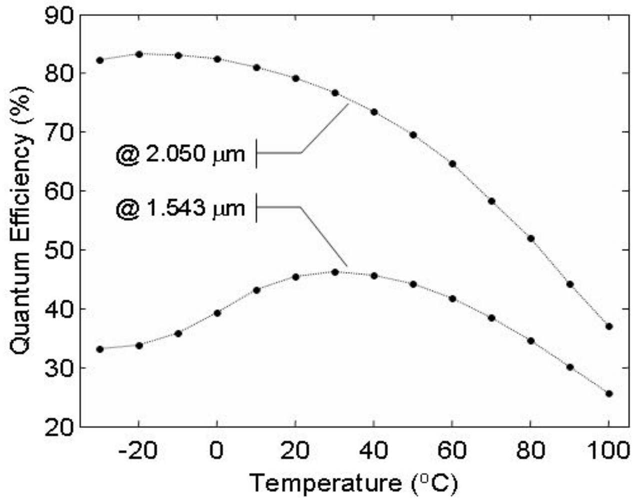
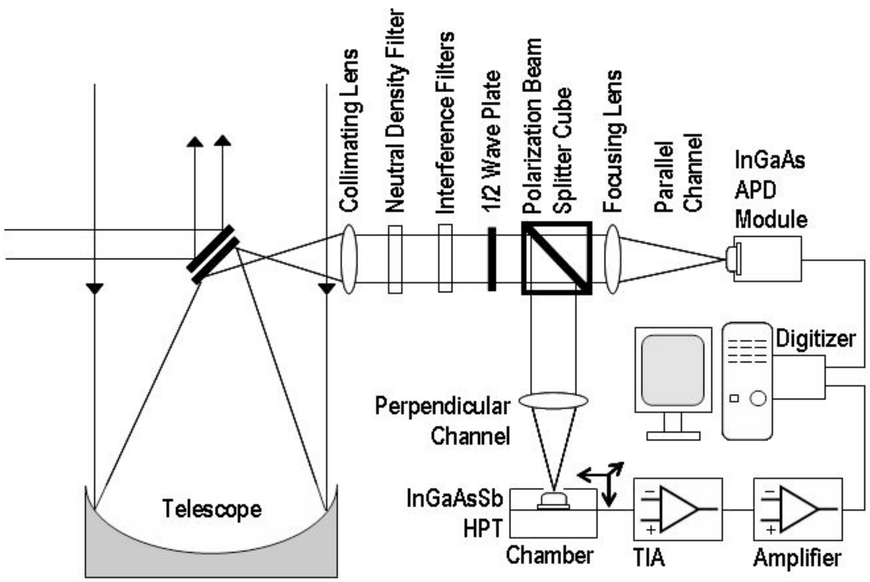
Spectral Response & Quantum Efficiency of Phototransistor

- NCAR Lidar operates at 1.5 μm wavelength.
- LaRC Lidar operates at 2.0 μm wavelength
- Lidar serves as a useful test-bed for comparing the phototransistor profile with that of the InGaAs APD
- This comparison validates the application of the phototransistor for lidar instruments





Phototransistor Validation Setup at NCAR



Courtesy: Schematic of the Lidar detection system at NCAR, Boulder, Colorado, with the phototransistor installed into the receiver's perpendicular polarization channel.

Transmitter: 170mJ/pulse
4 ns pulse width
Receiver: 40 cm Newtonian Telescope

- **Obtained lidar backscatter signals through the phototransistor and the InGaAs APD simultaneously**
- **Splitted backscatter signal into two equivalently energetic beams and focused them onto two independent detectors**

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Atmospheric Return at 1.5-μm

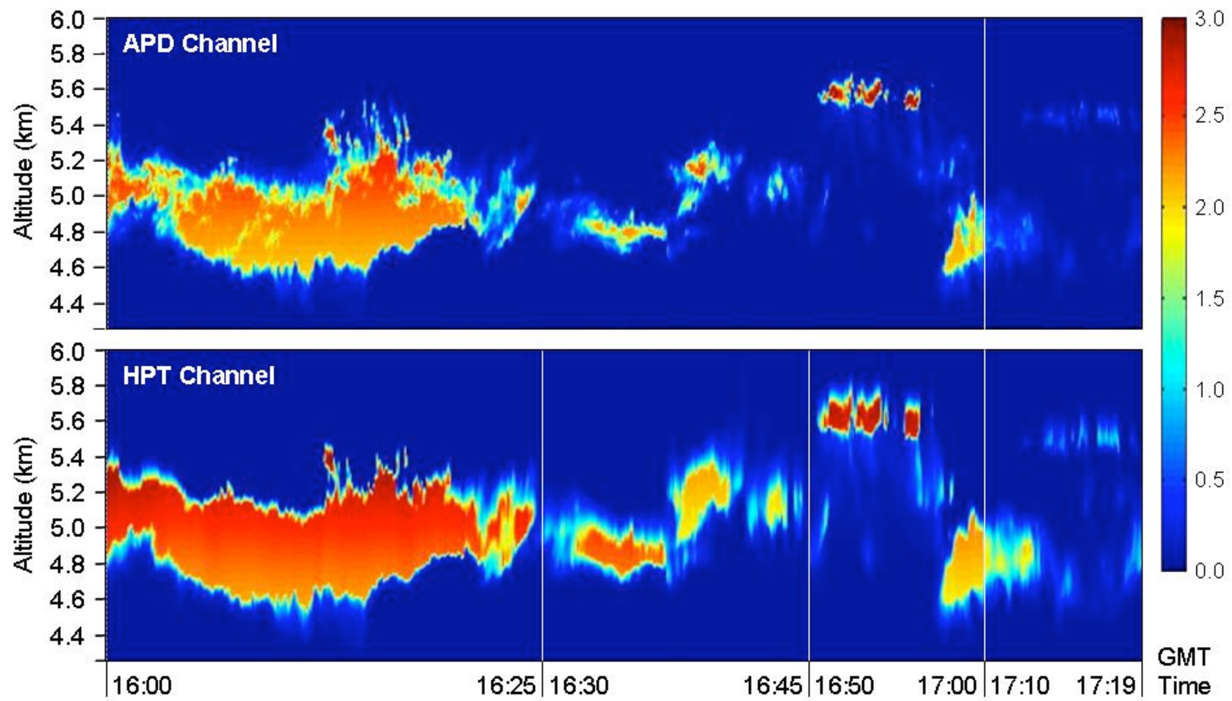
- Color image of the far-field temporal variation of the return signals
- Monitoring an optically thin cloud between 4.6 and 5.8 km altitude

16:00-16:25; The HPT operating at 20°C with 155 mJ/pulse laser energy.

16:30-16:45; Temperature =10°C.

16:50-17:00; Temperature = 30°C.

17:10-17:19; Laser energy reduced to 50% applying a neutral density filter to the transmitted beam (20°C).



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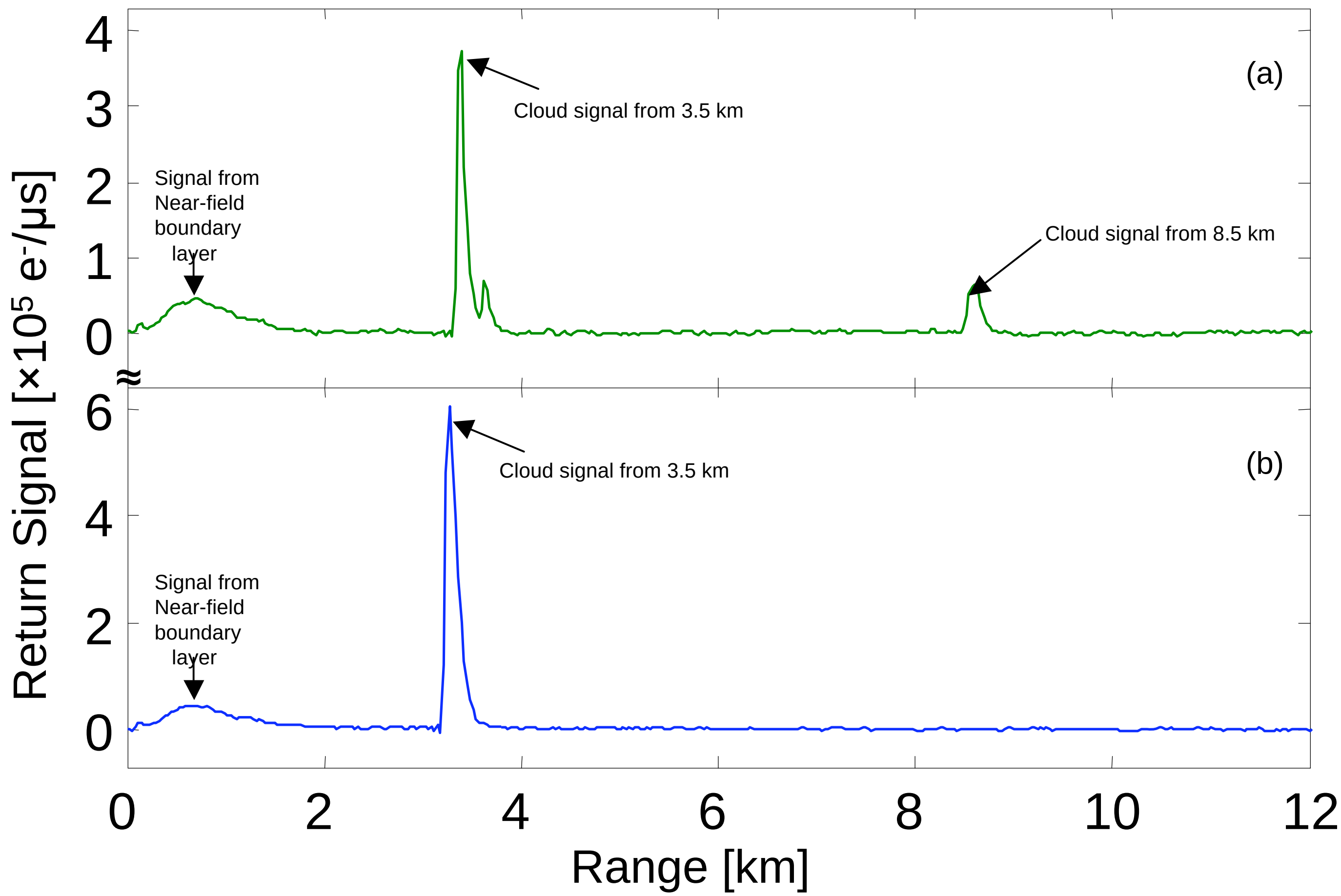
Return Signals from Targets

Acquired return signals from clouds using 2-µm wavelength



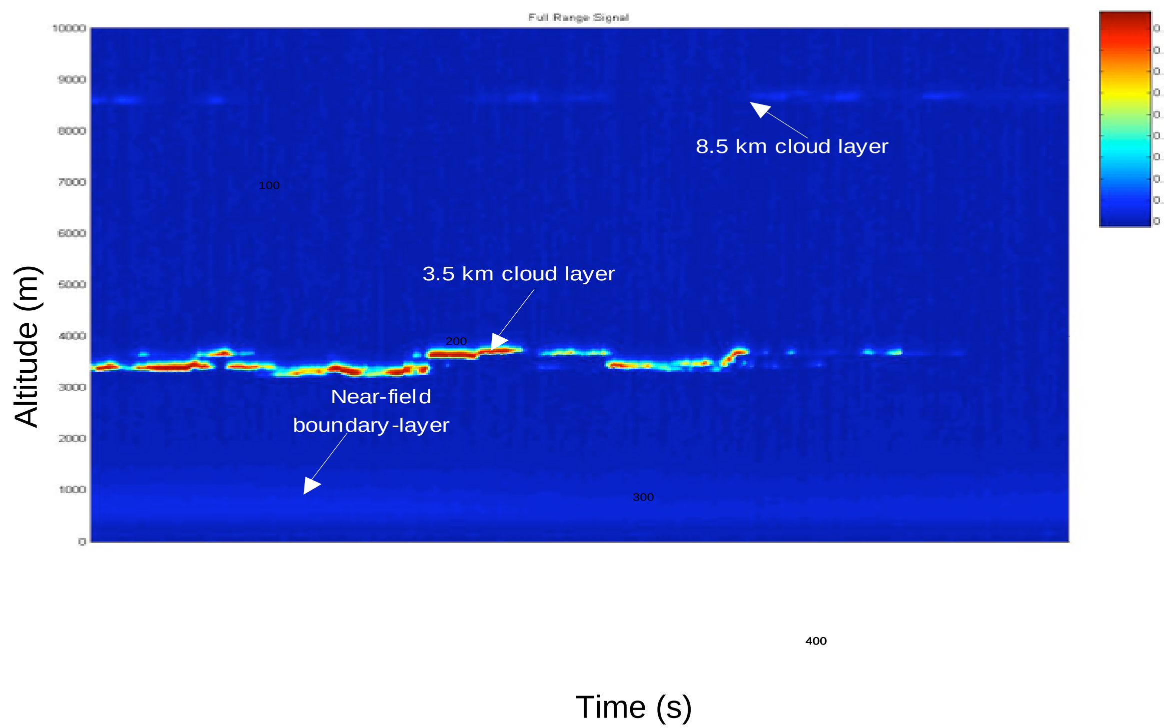
Returns signals recorded at different times. (a) Thin clouds located at about 3.5 km and 8.5 km and (b) Thin cloud located at about 3.5 km

Atmospheric Return at 2-µm

- Atmospheric images were obtained using phototransistor at 2-micron
- The system was pointed at thin discrete clouds at about 3.5-8.5 km altitudes

➢ The color image from two layers of clouds and boundary-layer

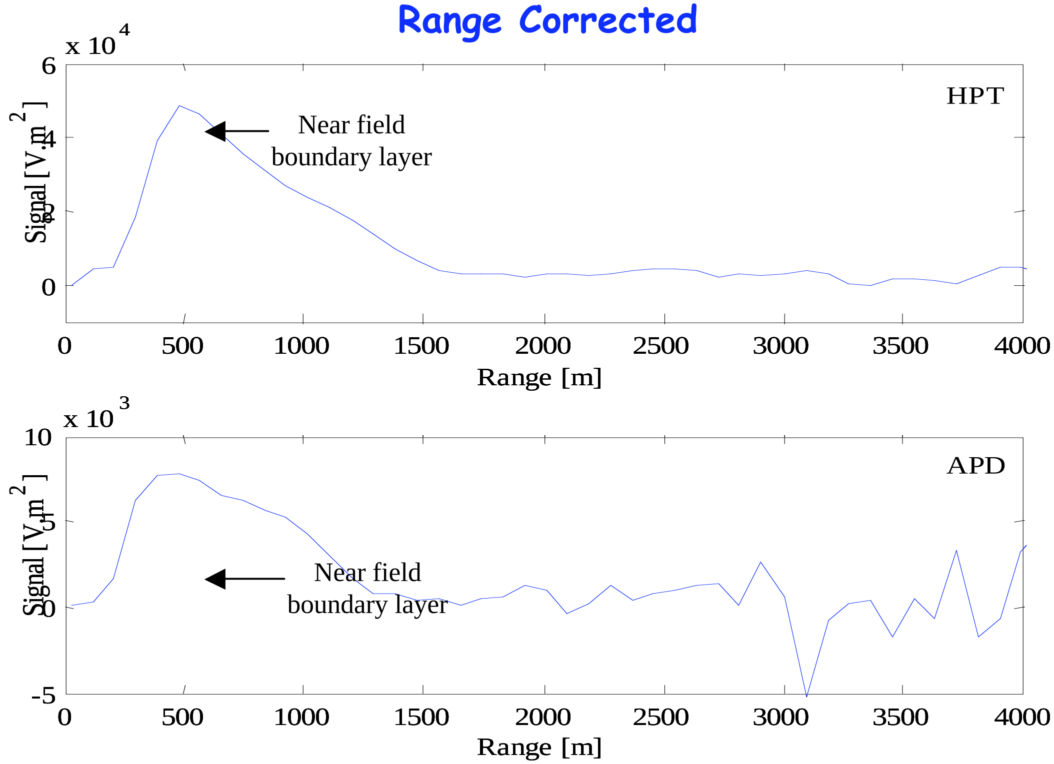
➢ The time scale spans between 0 to 550 sec, which corresponds to the phototransistor operating time at a temperature of 20 °C.



Comparison of Atmospheric Returns using 2 μm APD from Raytheon and HPT from Astropower

Atmospheric return signals using 2-μm HPT (Top trace) and HgCdTe APD (Bottom trace)

Range Corrected



Note: APD was not optimized for acquiring maximum signal, preliminary results show that APD has good sensitivity without optimization

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Summary

- Custom-designed phototransistors have been developed at Astropower/UD and characterized at NASA Langley Research Center under LRRP.

- Phototransistor shows comparable performance with respect to InGaAs APD operating at 1.5 μm wavelength under lidar testing
  - Results indicated an acceptable performance of the phototransistor device, in terms of detecting 5 km range atmospheric structures.

- Evaluated the phototransistor's performances at 2.0-μm wavelength
  - Measurements included detecting atmospheric structure consisting of thin clouds in the mid-altitude and near-field boundary layer.

- Preliminary results indicate that HgCdTe APD has some sensitivity with respect to phototransistor operating at 2.0-μm wavelength.

Acknowledgment

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