National Aeronautics and Space Administration

Early Stage Technology Workshop

Astrophysics and Heliophysics

March 3-4, 2015

Low Noise, Large-Area, High Speed, InGaAs Quad Photoreceivers and Linear Arrays, for 1 to 2 Micron Short Wave Infrared Sensing Applications

March 3, 2015

Discovery Semiconductors, Inc.
Abhay Joshi (President & CEO), Shubhashish Datta, and Mike Lange

TECHNOLOGY DRIVES EXPLORATION

Company/Research Overview

- Discovery Semiconductors, Inc. Ewing, New Jersey
- Date formed: January 1993
- Number of employees: 20
- Revenue Breakdown
  - Government: 20%
  - Commercial: 80%
  - Customers include NASA, Boeing, Lockheed Martin, Harris, Raytheon, Northrop Grumman, L3, …
- Type of Business: C-Corp
- Minority owned

Overview: Low Noise Large-Area Quad Photoreceiver

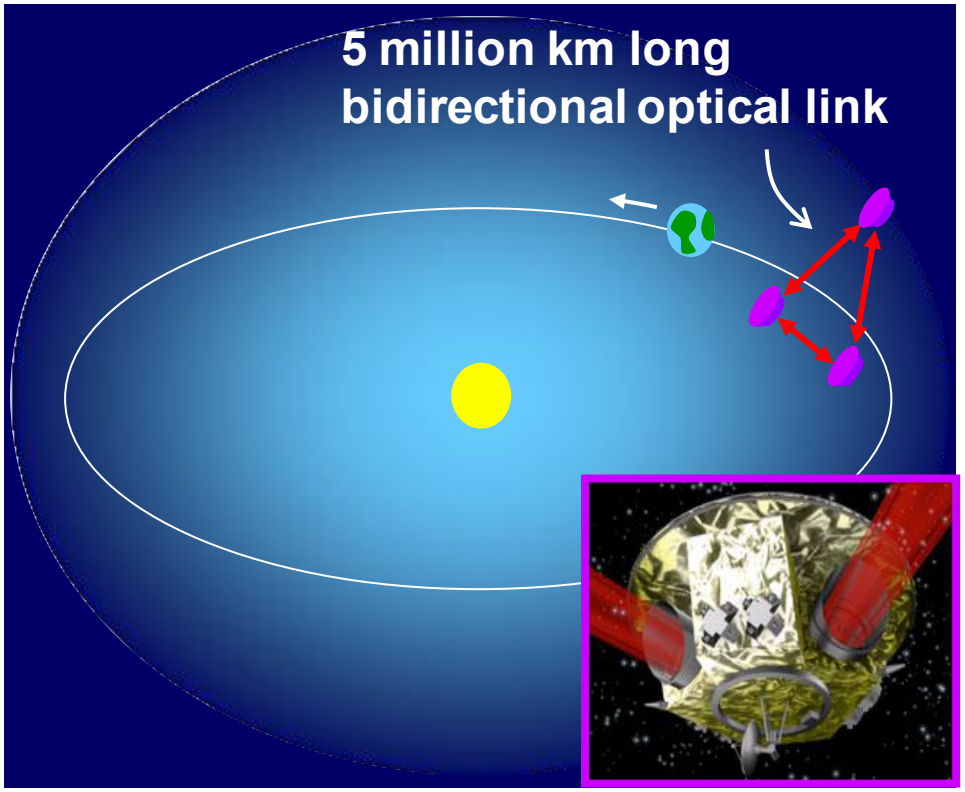
- Funding Agency: NASA Goddard Space Flight Center
  - SBIR Phase I Contract NNX09CD48P
  - SBIR Phase II Contract NNX10CA59C
  - Program Manager: Dr. Jeffrey Livas
- Description: High-sensitivity front-end optical sensor with quadrant geometry for position and/or direction sensing in free-space optical links and long baseline interferometry
- Current TRL level: 4-5
- What is unique about this technology?
  - Lowest Noise Large-Area Quad Photoreceiver in the world
  - Rad-hard by Design

Application of Quad Photoreceivers

Detection of gravity waves through ultra-sensitive laser interferometry in space.

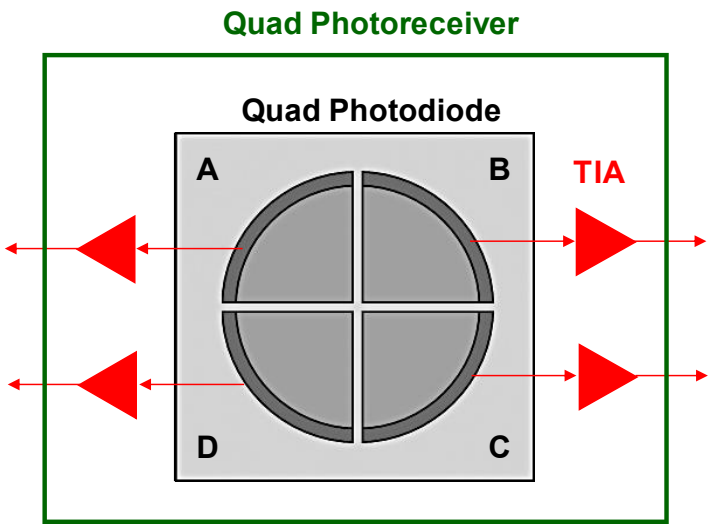
Front-end Quad Detector Requirements:

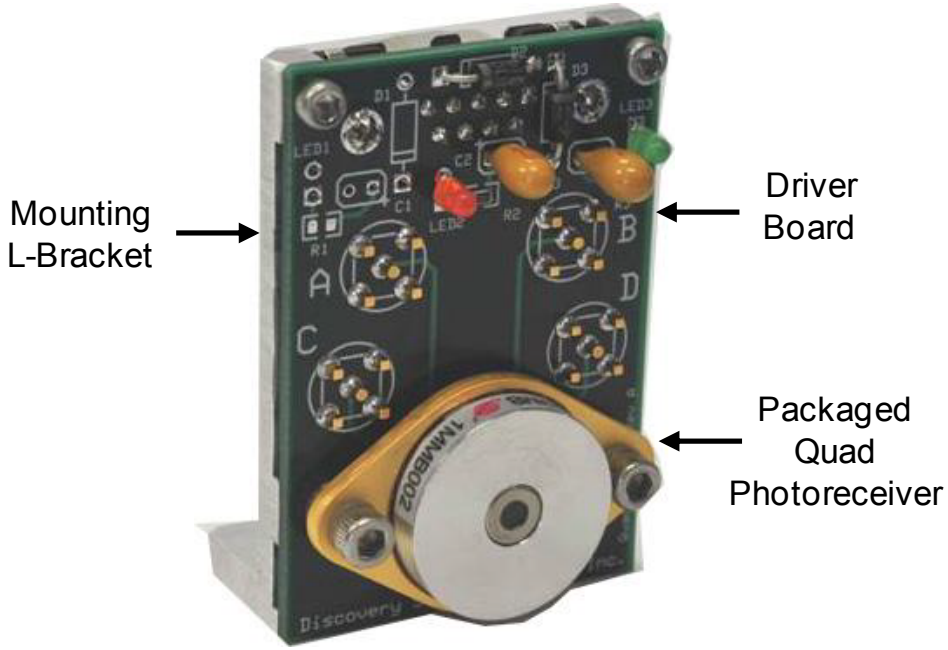
- Coherent Optical Heterodyne Detection at 1064 nm Wavelength
- Intermediate Frequency Range due to Doppler shift = 2 MHz to 20 MHz
- Optical LO Power > 100 μW per quadrant
- Equivalent Input Noise < 4.7 pA/√Hz for shot noise limited operation
- Direction sensing accuracy <100 nrad with 100x telescope



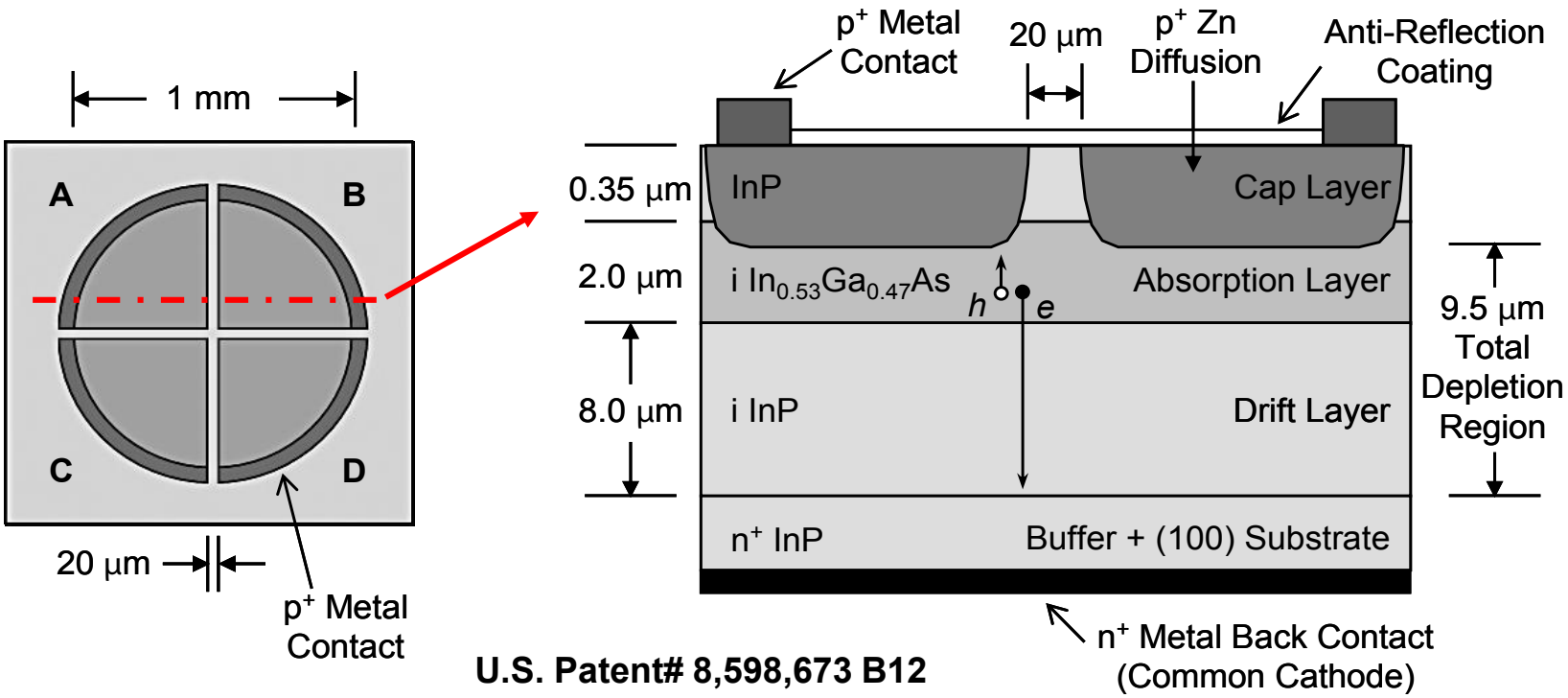
Low Noise, Large Area Quad Photoreceivers

- Large Active Area Diameter ⇨ Large Link Gain / Optical Collection Efficiency
- Small Photodiode Capacitance ⇨ Low Photoreceiver Noise ⇨ High SNR (Sensitivity)
- Small Crosstalk ⇨ High Position / Direction Sensing Resolution
- Rad-hard by Design for Space Qualification





Low Capacitance Quad Photodiode Structure

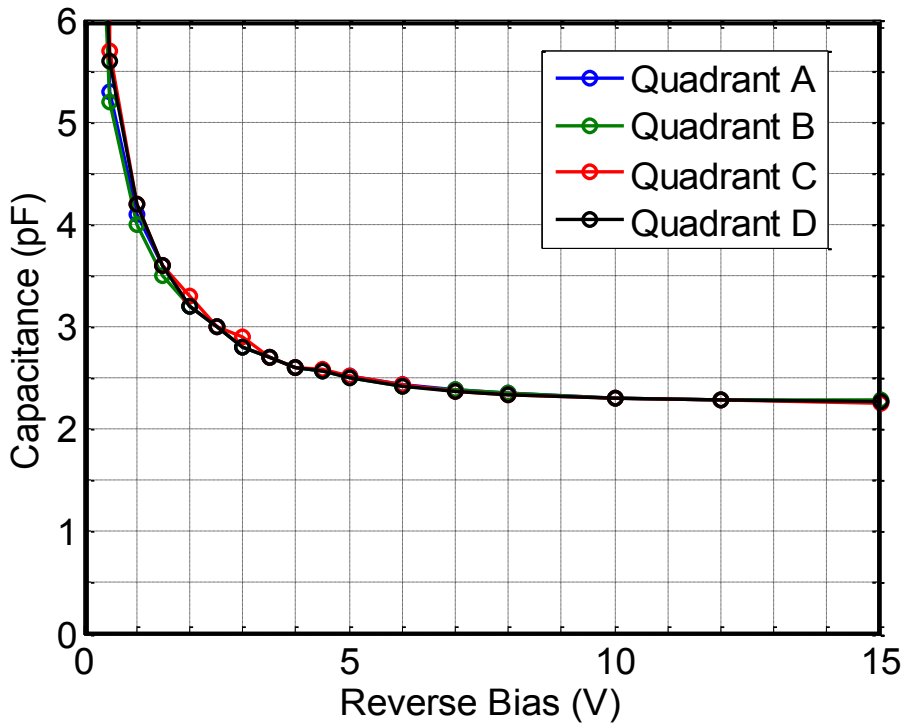


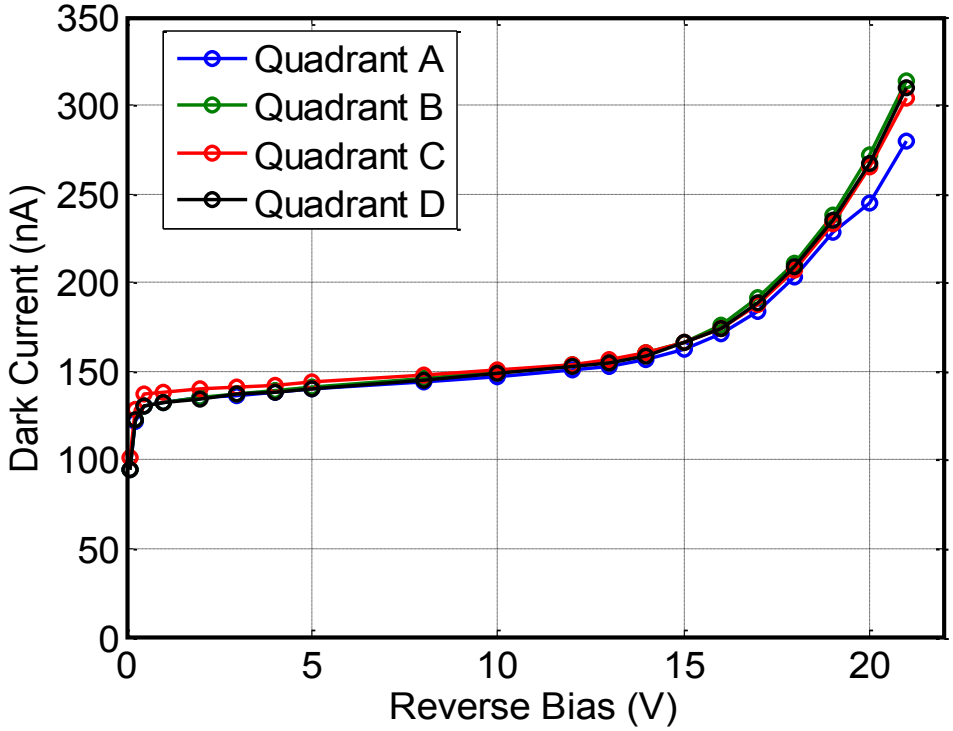
U.S. Patent# 8,598,673 B12

Dual-Depletion Region (DDR) Photodiode Structure

- 2 µm thick InGaAs Absorption Layer needed for ~0.7 A/W responsivity at 1064 nm wavelength
- Use InP Drift Layer to reduce junction capacitance and balance transit times of slow holes and fast electrons
- Thin low-bandgap InGaAs layer ⇨ low G-R and tunneling current + rad-hard by design

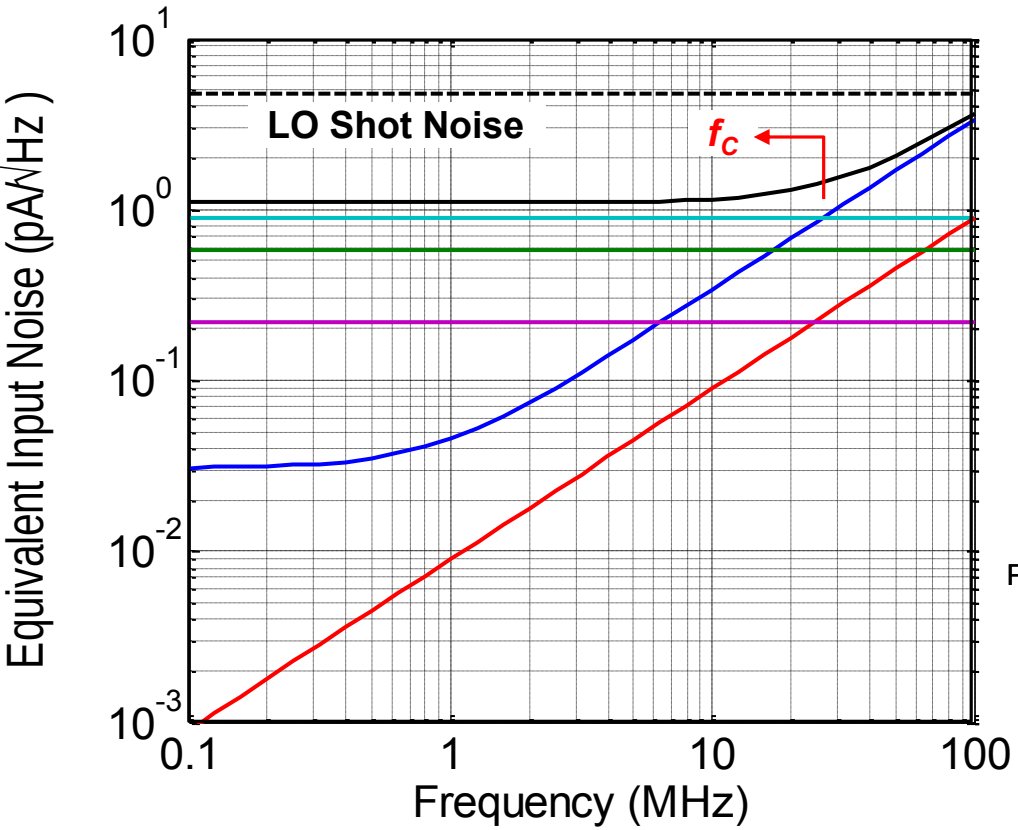
1 mm Diameter Quad Photodiode Results

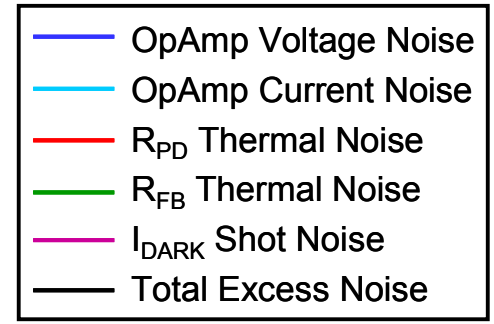


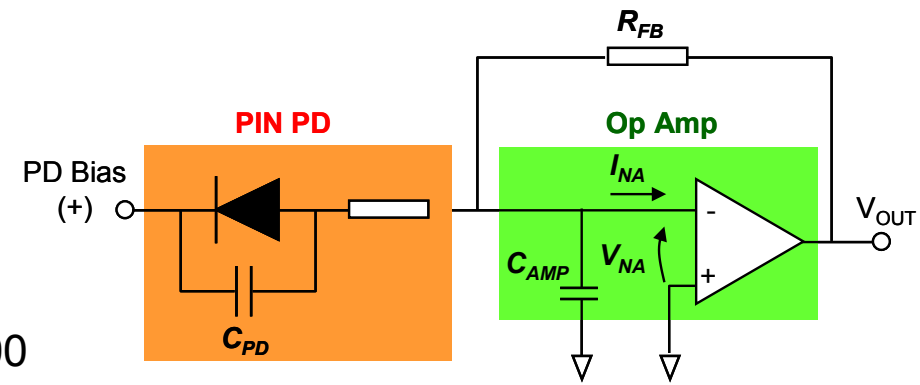


- Capacitance = 12.7 pF/mm^2 @ 5V bias
- ~10 μm thick epitaxial growth of intrinsic InP/InGaAs with 10^{14} cm^{-3} background doping

Quad PIN-TIA Photoreceiver Design







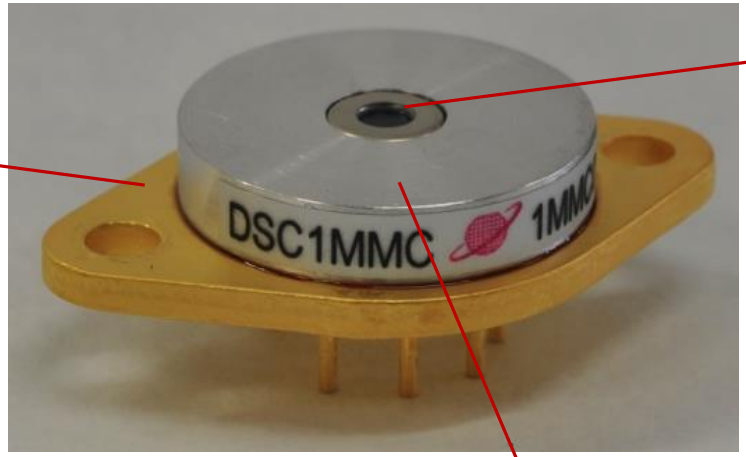
$$(I)_{NEQ}(f) \approx \begin{cases} \sqrt{\dfrac{4k_BT}{R_{FB}} + I_{NA}^2} & f < f_C \\ 2\pi f\left(C_{PD} + C_{AMP}\right)V_{NA} & f > f_C \end{cases}$$

R_{FB} = 49 kΩ

OpAmp: Intersil EL5135

- I_{NA} = 0.9 pA/√Hz
- V_{NA} = 1.5 nV/√Hz
- C_{AMP} = 1 pF

Packaged Quad PIN-TIA Photoreceiver



Sapphire window with ARC @1064 nm

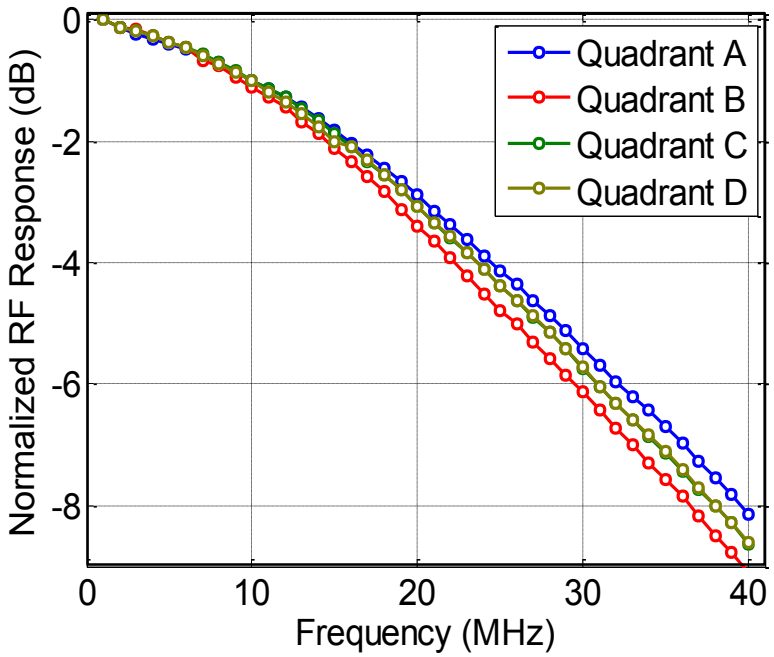
TO-3 Can Header

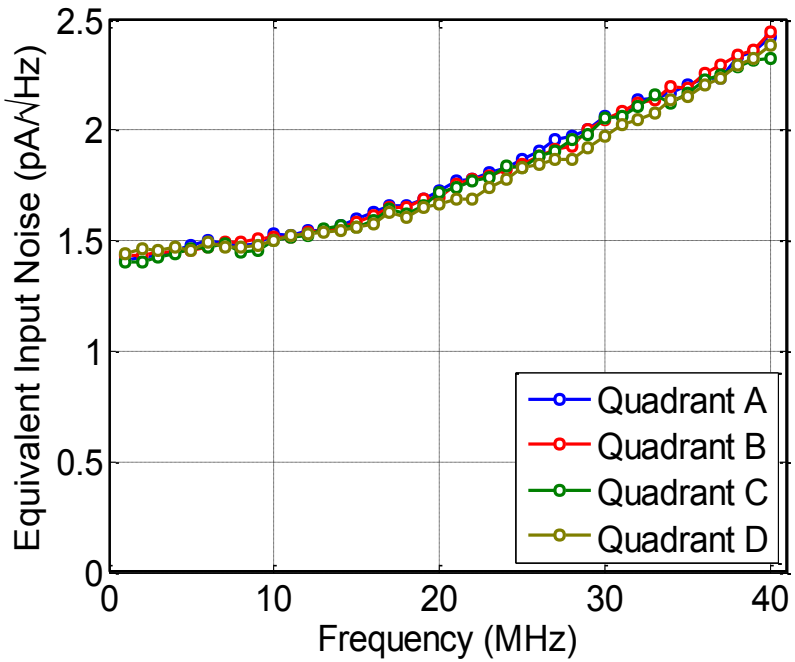
1 mm Thick Aluminum Cap

Receptacles for quad photoreceiver module pins

- Anti-reflection coated windows to boost collection efficiency at 1064 nm wavelength
- Rad-hard by design: 1 mm Thick Al Cap covers TIA and passive components

RF Response and Noise Results





Parameter		Quadrant A	Quadrant B	Quadrant C	Quadrant D
3 dB Bandwidth		20 MHz	19 MHz	20 MHz	20 MHz
Conversion Gain @ 1 MHz and 1550 nm wavelength		41.4 kV/W	42.0 kV/W	42.0 kV/W	41.5 kV/W
Input Equivalent Noise	1 MHz	1.4 pA/√Hz	1.4 pA/√Hz	1.4 pA/√Hz	1.4 pA/√Hz
	20 MHz	1.7 pA/√Hz	1.7 pA/√Hz	1.7 pA/√Hz	1.7 pA/√Hz

Non-Proprietary

Current Development Status of Technology

- Commercial products available for bench-top lab use
- For space applications, radiation testing needs to be done

What will it cost to advance this technology?

ROM: 3 Million USD to get space qualified

Why should NASA, Industry, and other government agencies invest in this technology?

Low noise high-sensitivity optical front-end detector is vital for any free-space sensing and communication link.

Target Technology Market Applications

NASA Applications

- Long baseline laser interferometry
- 3D Wind Profiling
- Planetary Mapping

Military Applications

- Covert Targeting and Tracking
- Free-space communication links

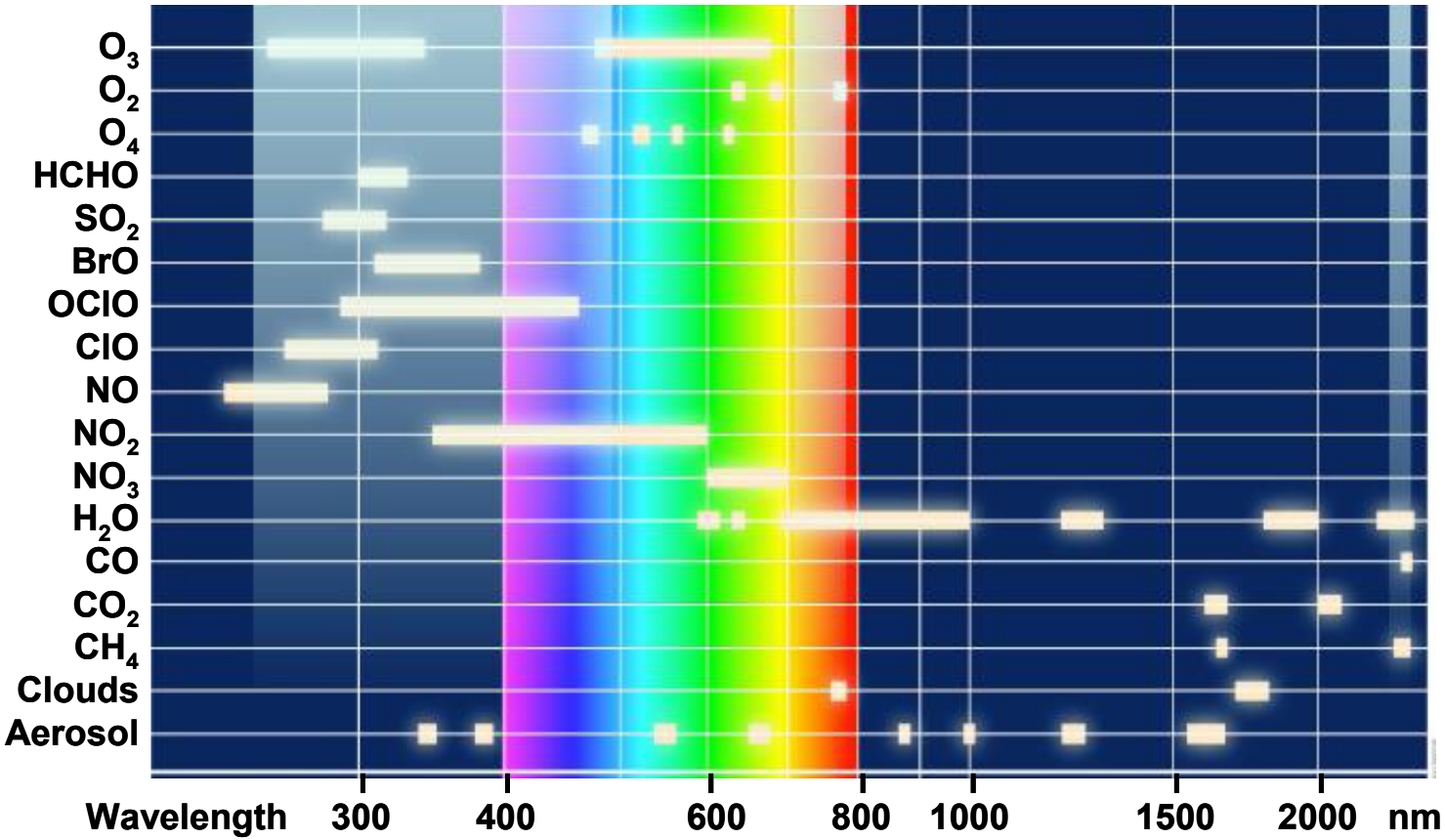
Commercial Applications

- Airport Wind Monitoring
- Airline Clear Air Turbulence
- Free-space (ground, airborne, and space) communication links
- Wind Mapping for Wind Farms
- Biomedical Imaging & Spectroscopy

Overview: 1 to 2 Micron High Speed Photodiode Arrays

- Funding Agency: NASA Goddard Space Flight Center
  - SBIR Phase I Contract NNX10CD60P
  - SBIR Phase II Contract NNX11CA91C
  - Program Manager: Dr. Sachidananda Babu
- Description: Photodiodes and Photodiode Arrays for high speed optical sensing applications at 1 - 2 micron wavelength
- Current TRL level: 4
- What is unique about this technology?
  - Fastest optical detectors for 1 - 2 micron wavelength
  - Uncooled operation
  - Rad-hard by Design

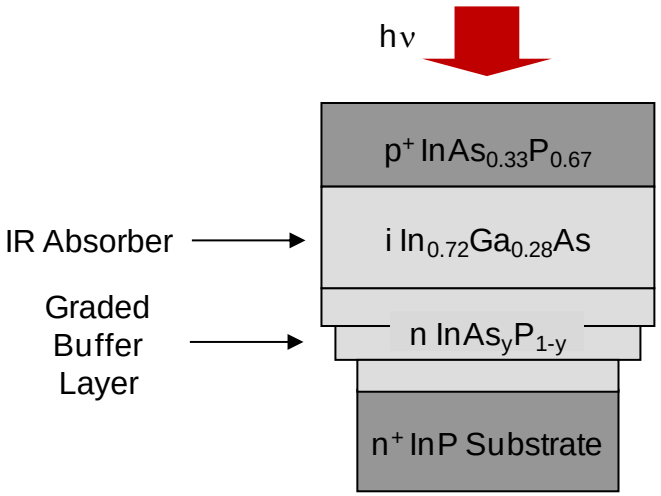
Application of High Speed UV-to-SWIR Optical Sensor

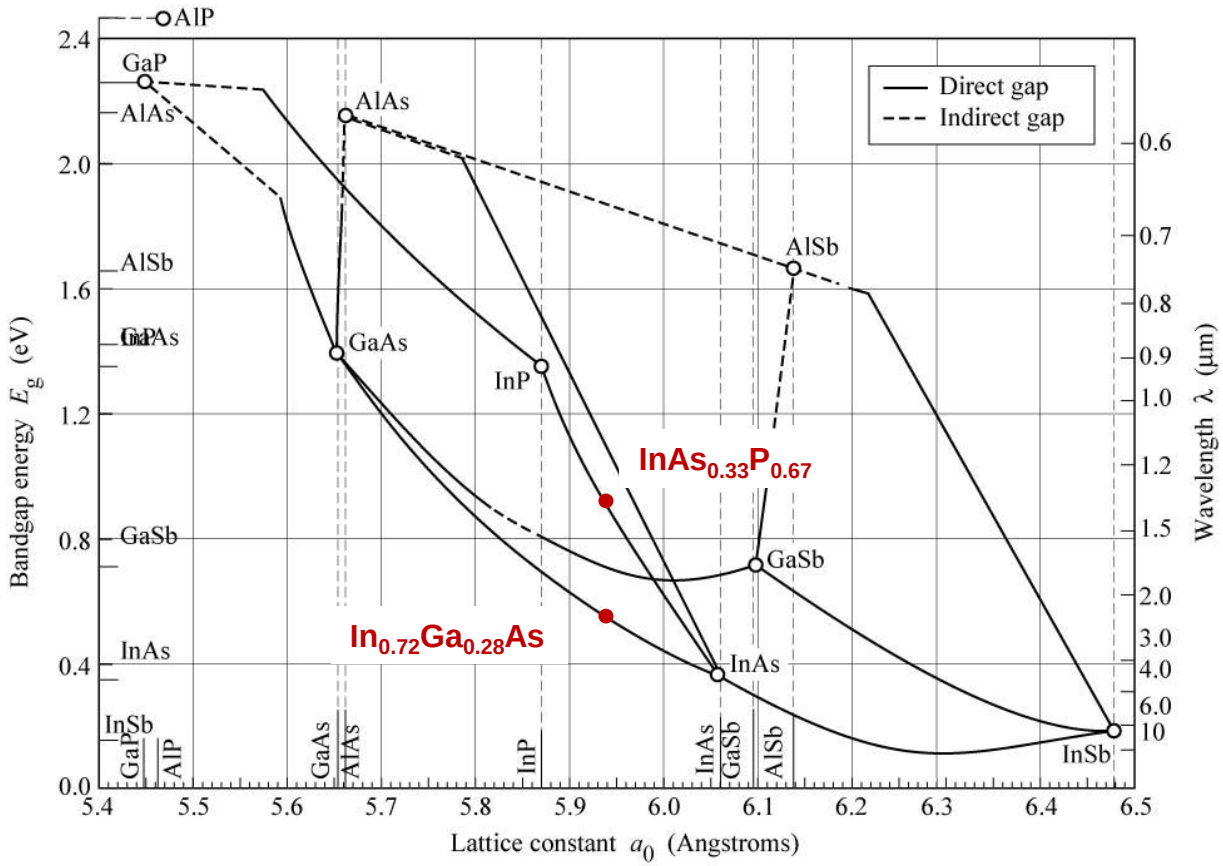


- Spectroscopy: Planetary exploration, Greenhouse gas detection, Oceanography, …
- Fast photodetector → Short integration in High-Speed ROICs → Higher SNR
- Enables pulsed active LIDAR sensors

Non-Proprietary

1 to 2 Micron InGaAs Photodiode Structure

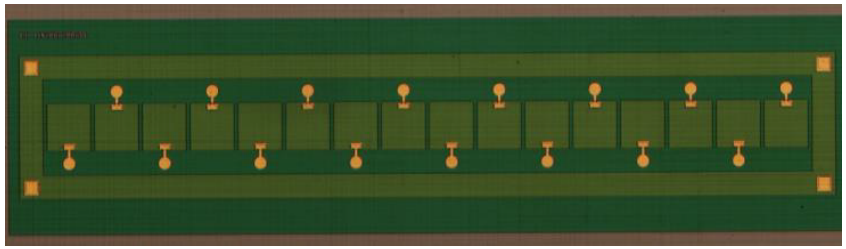


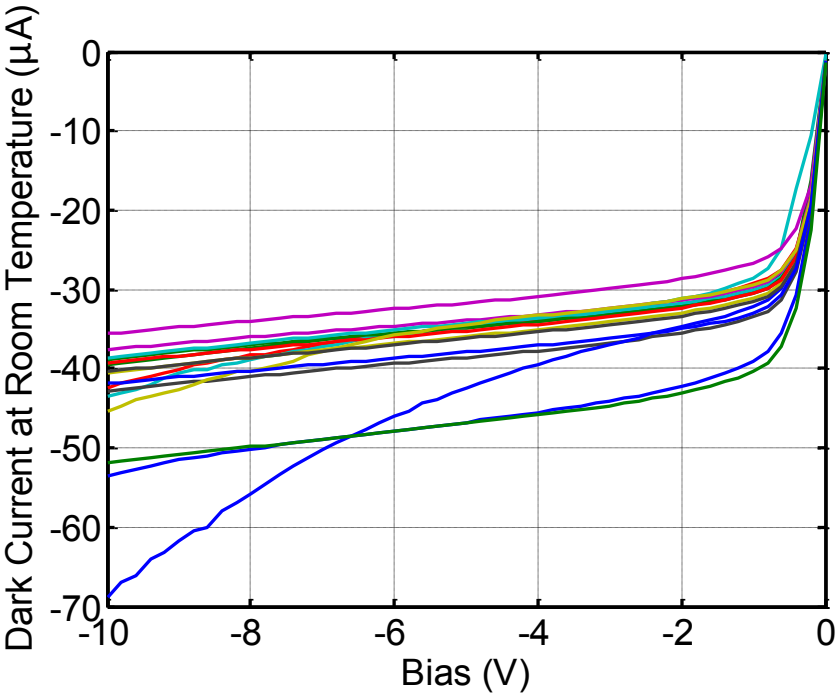


- $In_{0.72}Ga_{0.28}As$ has ~1.2% lattice mismatch with InP substrate
- Graded InAsP buffer layer needed to minimize dislocation defect density in absorber layer

Linear 1 to 2 Micron Photodiode Arrays: Dark Current

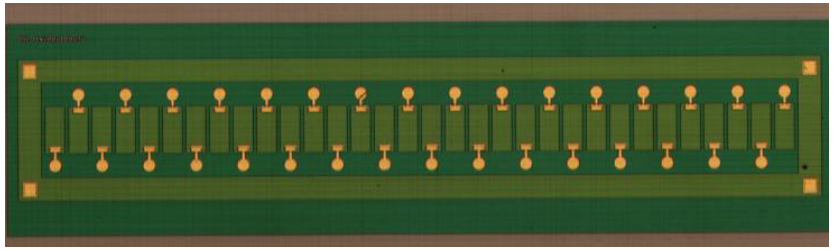
16-element 200 µm x 200 µm PD array

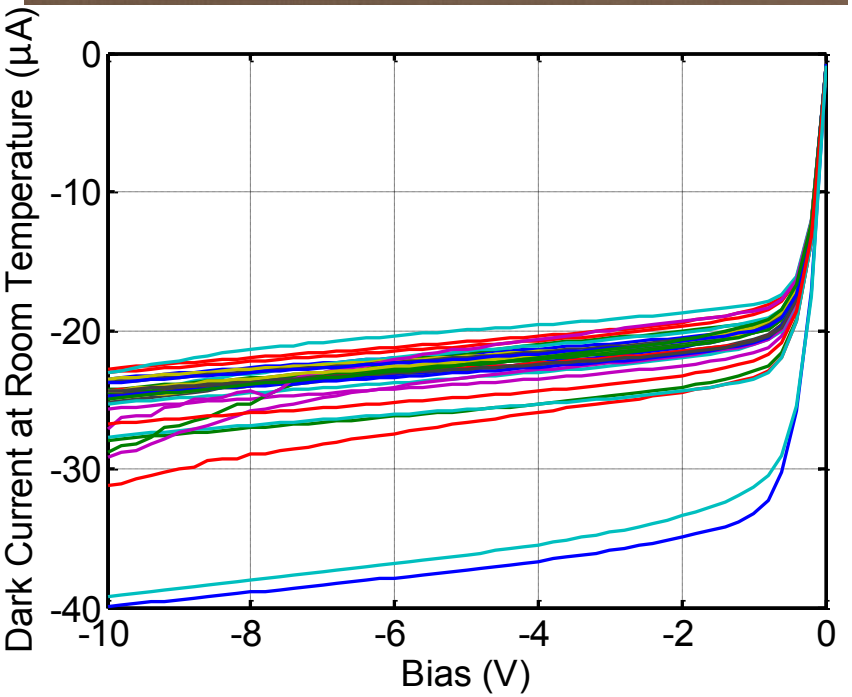




- Capacitance @ 5V Reverse Bias = 4 pF
- RC-Limited -3dB Bandwidth = 0.8 GHz

32-element 100 µm x 200 µm PD array

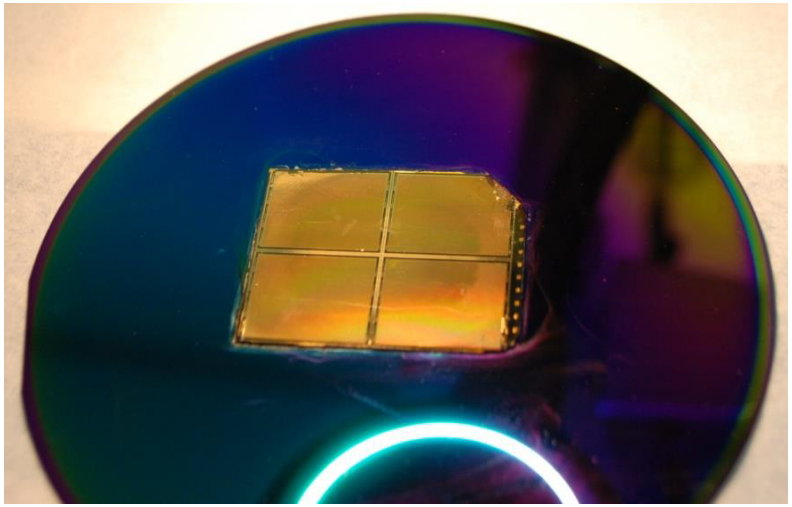


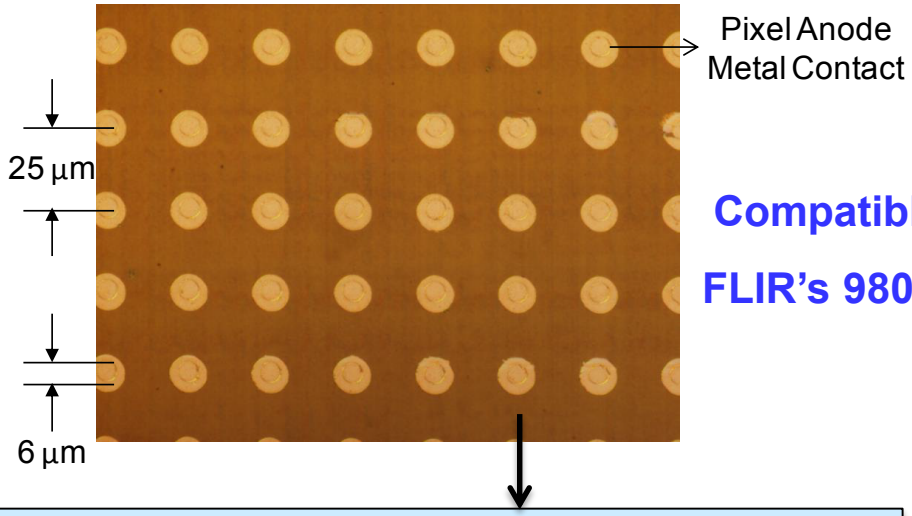


- Capacitance @ 5V Reverse Bias = 2.5 pF
- RC-Limited -3dB Bandwidth = 1.3 GHz

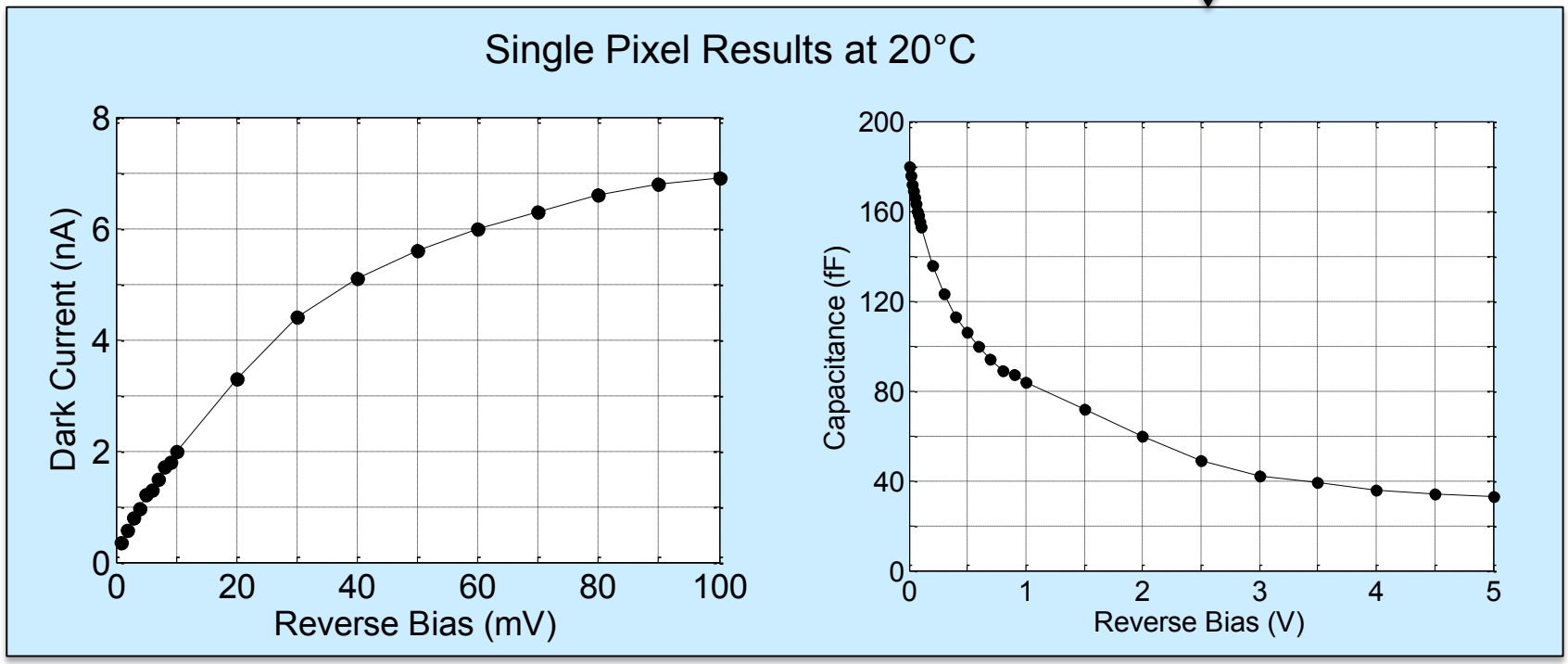
Non-Proprietary

512 x 640 1 to 2 Micron 2D Photodiode Array



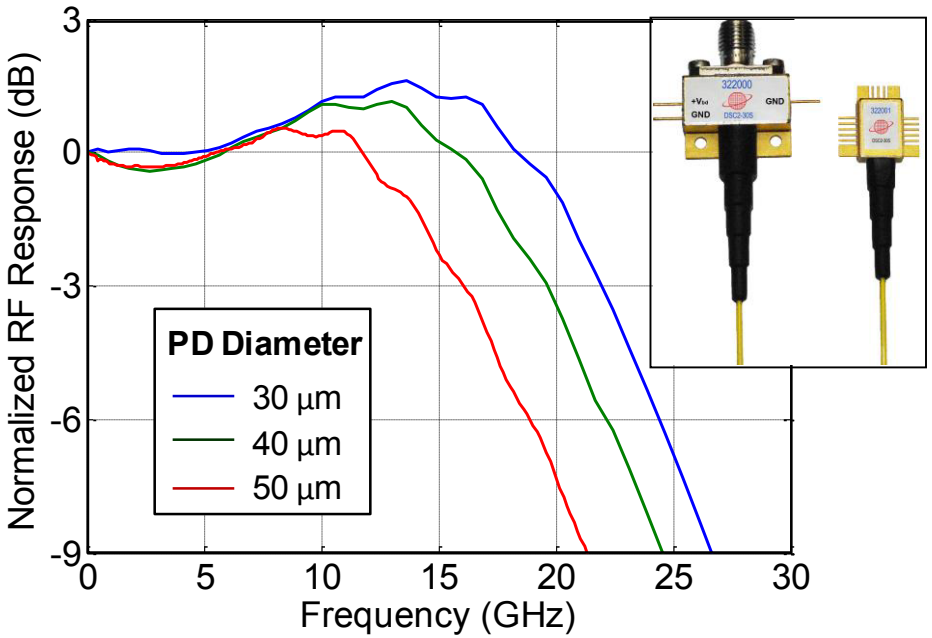


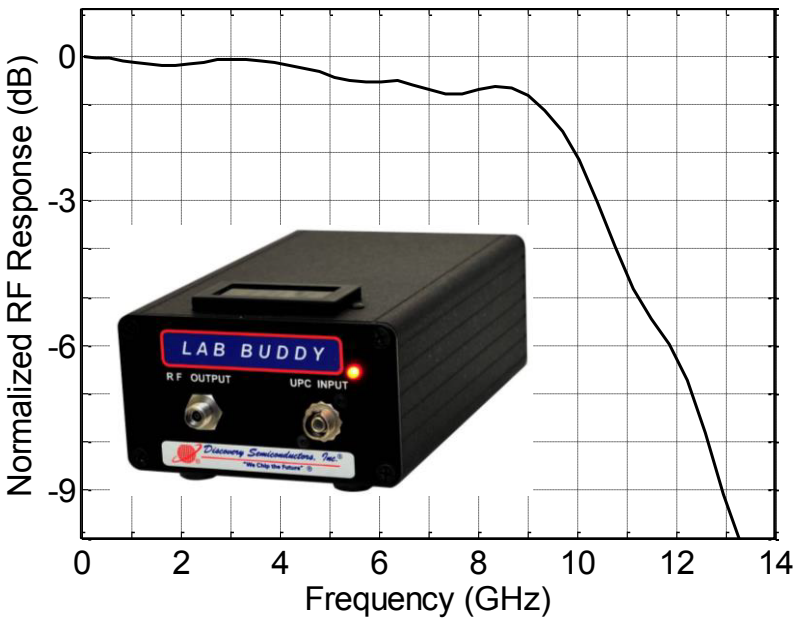
Compatible with FLIR's 9803 ROIC

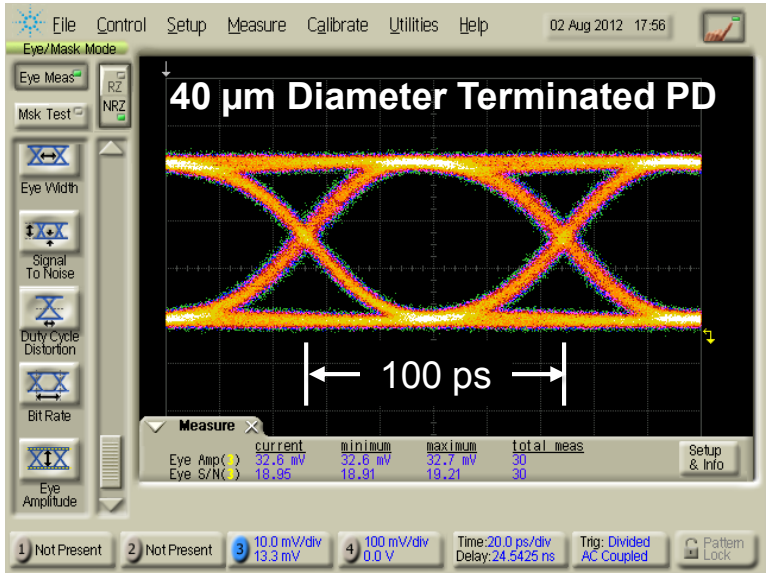


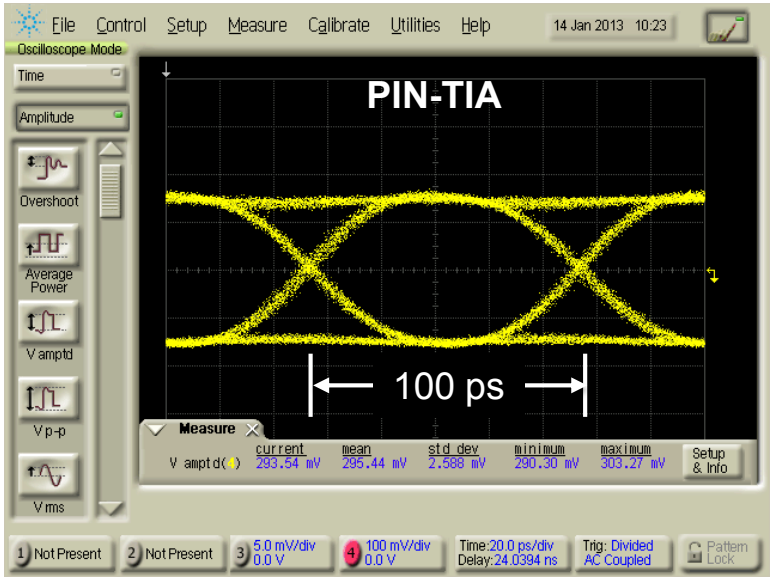
Non-Proprietary

Ultra-Fast 1 to 2 Micron Photodiodes and PIN-TIA Photoreceiver









Current Development Status of Technology

- Commercial products available for bench-top lab use
- For space applications, radiation testing needs to be done

What will it cost to advance this technology?

ROM: 5 Million USD to get space qualified

Why should NASA, Industry, and other government agencies invest in this technology?

Improved speed of optical detectors, in conjunction with high speed ROICs, will allow for operation at 250K to 300K temperature

Target Technology Market Applications

NASA Applications

- Ozone and Greenhouse Gas Monitoring
- Weather Observation
- Sensors for Planetary Missions

Military Applications

- Bio-Chemical Agent Detection
- Missile Identification and Tracking
- Imagers for Tanks, Humvees, etc.
- Border Surveillance

Commercial Applications

- Pollution Monitoring for Automobiles, Refineries, …
- Biomedical Imaging & Spectroscopy
- Jet Engine Development
- Industrial Process Control for Pharmaceutical, Food Processing, and Petrochemical Industries
- Crop Monitoring
- Mineral Detection

Contacts

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Website: www.discoverysemi.com

Summary of Key Points

Discovery Semiconductors has an established track record of building high quality photodetectors for aerospace applications in its 4000 square ft, Class 100 cleanroom

Low Noise Large Area Quad Photoreceivers Delivered to NASA

- Two 1mm diameter Quad Photoreceivers in TO-3 can package
- Four 1mm Packaged Quad Photoreceivers with Driver Boards

1 to 2 Micron Photodiode Arrays Delivered to NASA

- Four 512 × 640 2D photodiode arrays
- Two 200 × 200 μm 16-Element linear PD arrays
- Two 200 × 100 μm 32-Element linear PD arrays