HgCdTe Avalanche Photodiode Detector with >2 um Cut-off Wavelength

ESA/ESTEC Contract 21751/08/N/EM

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Introduction

Objectives of Contract

- Design and manufacture a mercury cadmium telluride (MCT) avalanche photodiode (APD) detector that meets a set of performance criteria suitable for a LIDAR receiver
- Design and manufacture a suitable pre-amplifier circuit for the MCT APD such that the MCT APD/Pre-amplifier combination meets a set of performance criteria suitable for a LIDAR receiver
- Test and characterise the MCT-APD and pre-amplifier to an agreed test plan

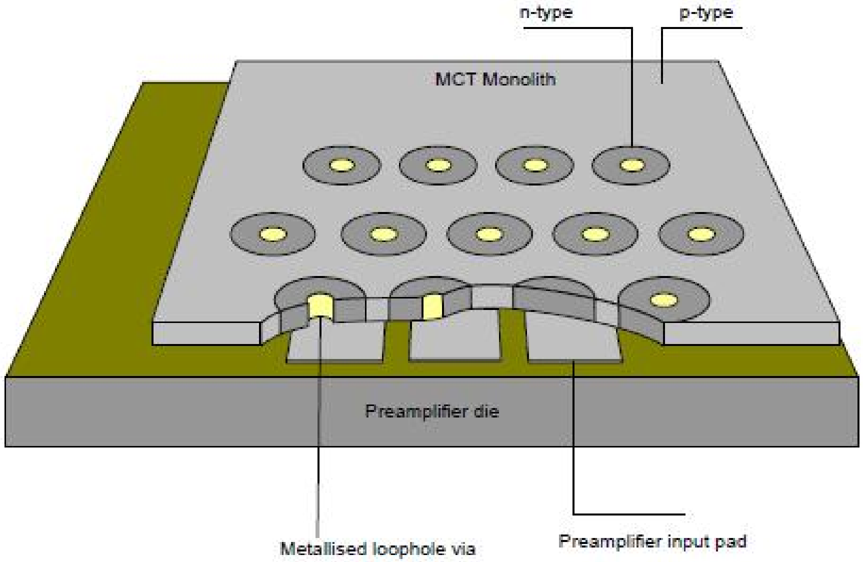
Why use MCT for Avalanche Photodiodes?

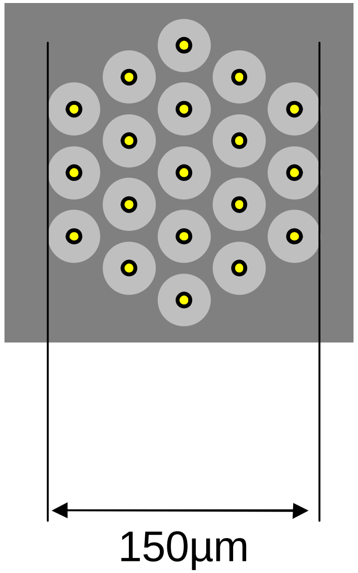
- Near-ideal single-carrier cascade avalanche
  - "almost noiseless" gain in the pixel
- Composition-tuneable bandgap – suitable for many IR wavelengths

Summary of Performance Demands

Parameter	Value
Operating wavelength	2051 nm
Detector quantum efficiency	> 70%
Active area diameter	> 150μm
Excess noise factor (F)	<1.5
Operating temperature	> 200 K
Input signal/dynamic range.	minimum: 8000 maximum: 2E6
Bandwidth	>20 MHz
NEP	< 100 fW/√Hz
Gain stability	0.1% rms.
Linearity	5% rms
Total ionizing dose	5 krad (Si) minimum
Proton irradiation	1E10 p/cm2

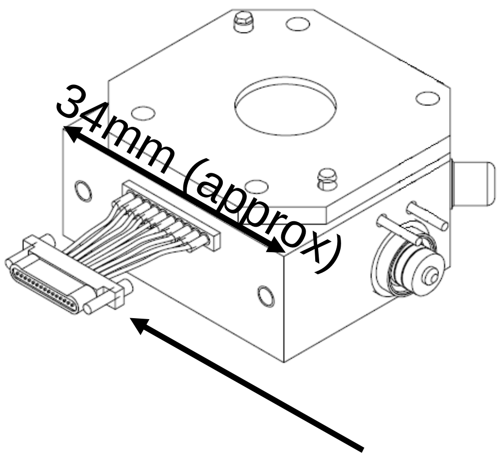
Approach: CMOS TIA hybridised directly with a standard "loophole" diode array





19 Elementary loophole diodes coupled in parallel to form 150um hexagonal pixel

Description and Overview



Encapsulated Detector

- **APD thermoelectrically cooled to 200K**
- **Standard “loophole” diode hybridisation**
- **Military-qualified encapsulation**

Construction: Encapsulated Detector

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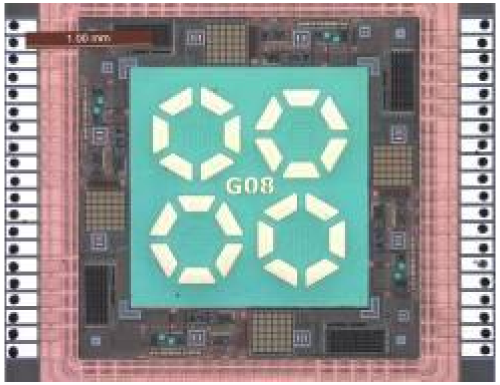
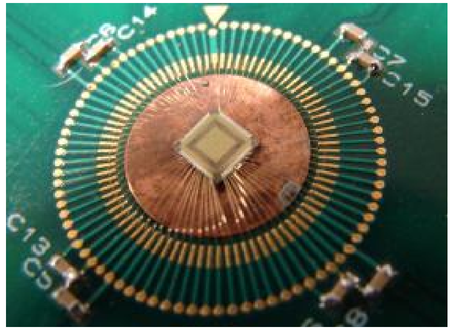
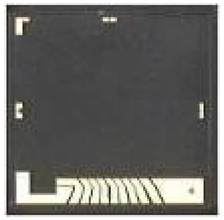
Hybrid





Preamp die

Metallised leadout



Device

Housing

Detector

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APD Performance Characteristics

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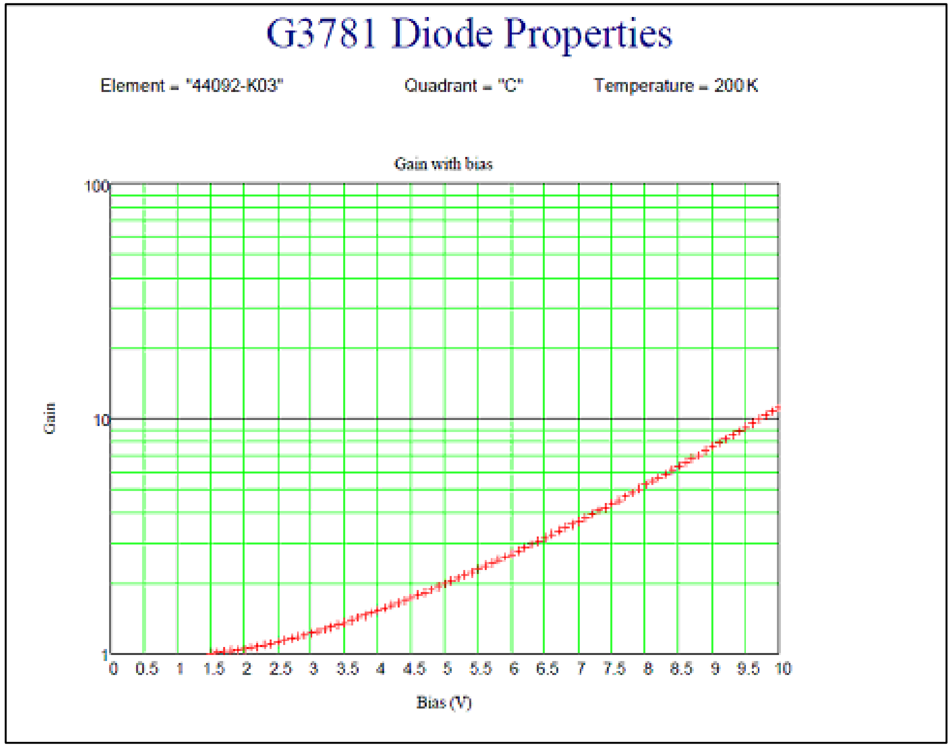
Performance Summary

Summary Conditions:

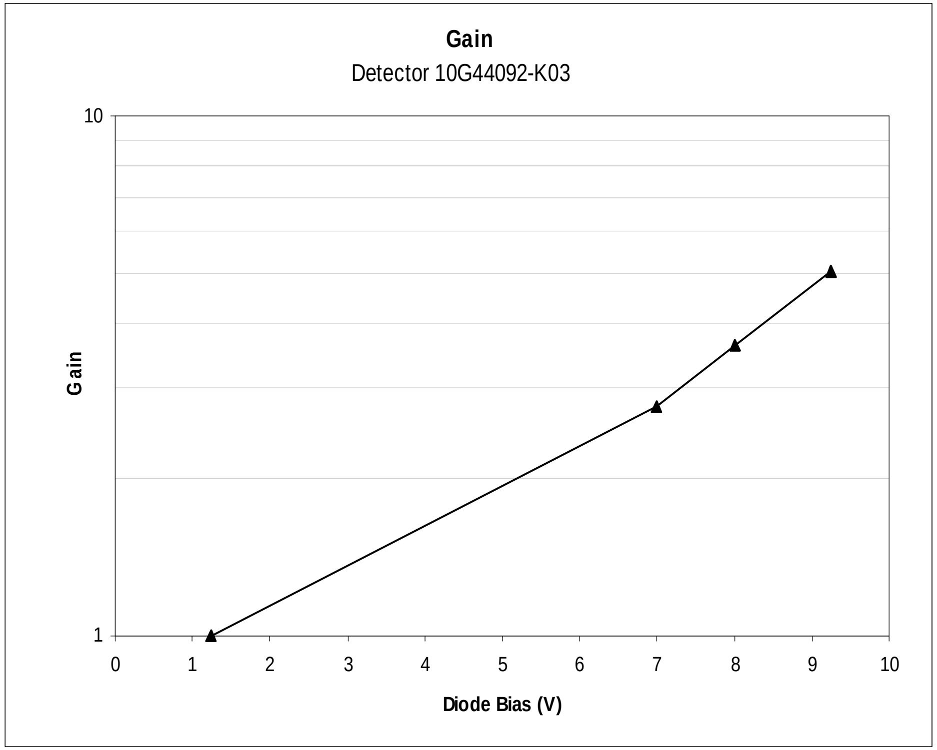
Low flux:	7.9kphotons/50ns/pixel from 1000K Blackbody Source
Avalanche Bias:	9.25 ± 0.05 Volts reverse bias
Signal Frequency:	500Hz (mechanical chopper)
Noise frequency:	500kHz (10kHz measurement bandwidth)

Device Identity	Low Flux Signal	Low Flux Noise	White Noise (No flux)	Low Flux QE*	NEP
	mV	**nV/√Hz**	**nV/√Hz**	**-**	**fW/√Hz**
4720-E05	6.84	73	54	1.02	63
4721-G08	6.02	164	70	0.93	87
44092-L01	7.11	112	54	0.89	58
44092-M01	6.63	114	65	0.87	74
44092-I02	9.65	245	150	0.94	120
44092-J02	7.90	161	82	0.83	83
44092-K01	**6.20**	**96**	**52**	**0.92**	**65**
44092-K03	**7.20**	**130**	**62**	**0.89**	**69**

Avalanche Gain



Individual Loophole Junction

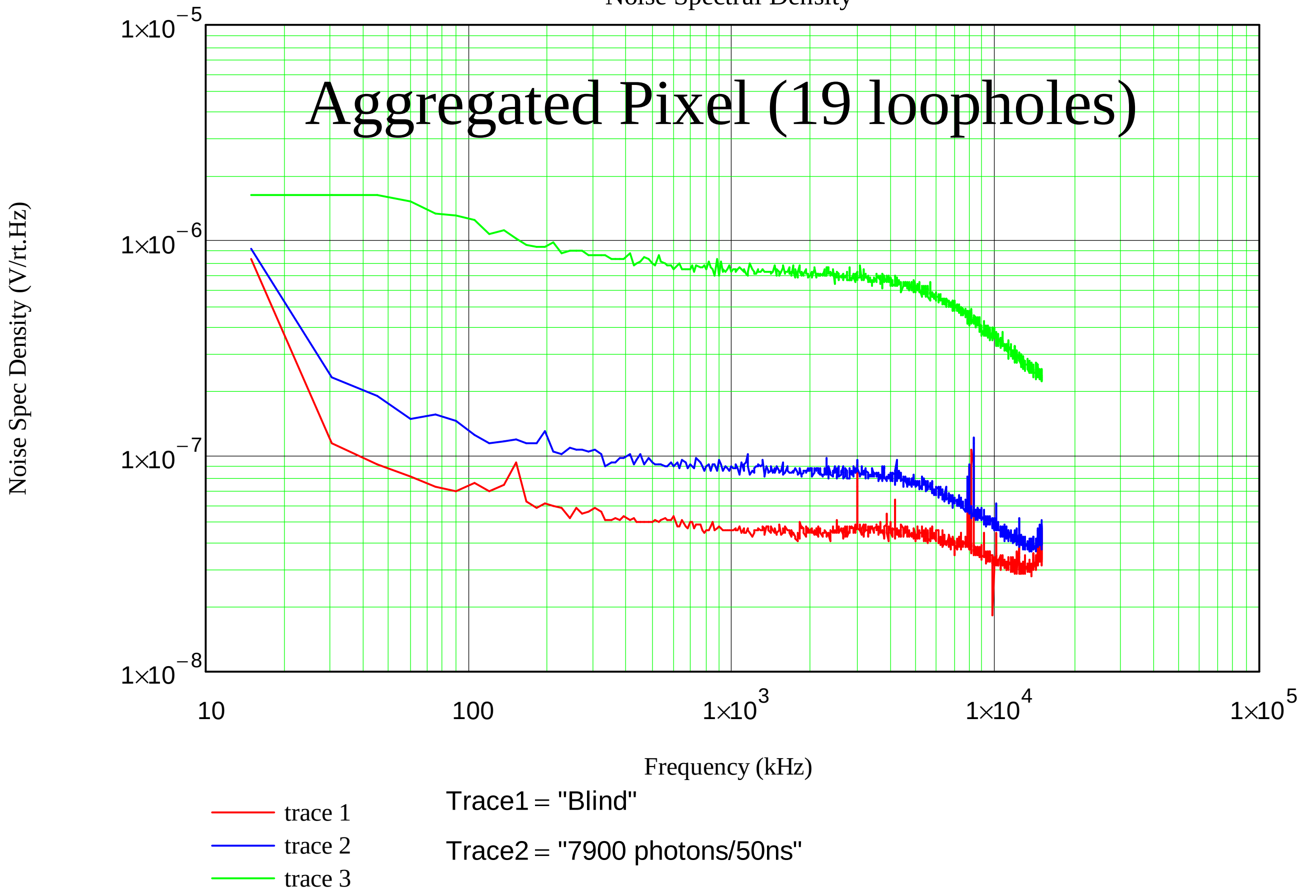


Aggregated Pixel (19 loopholes)

Output Noise

G3781 Diode Properties

Element = "4720-E05"   Quadrant = "B"   bandwidth = 10·kHz
Temperature = 200 K   bwQuery = "RBW 10 KHZ"

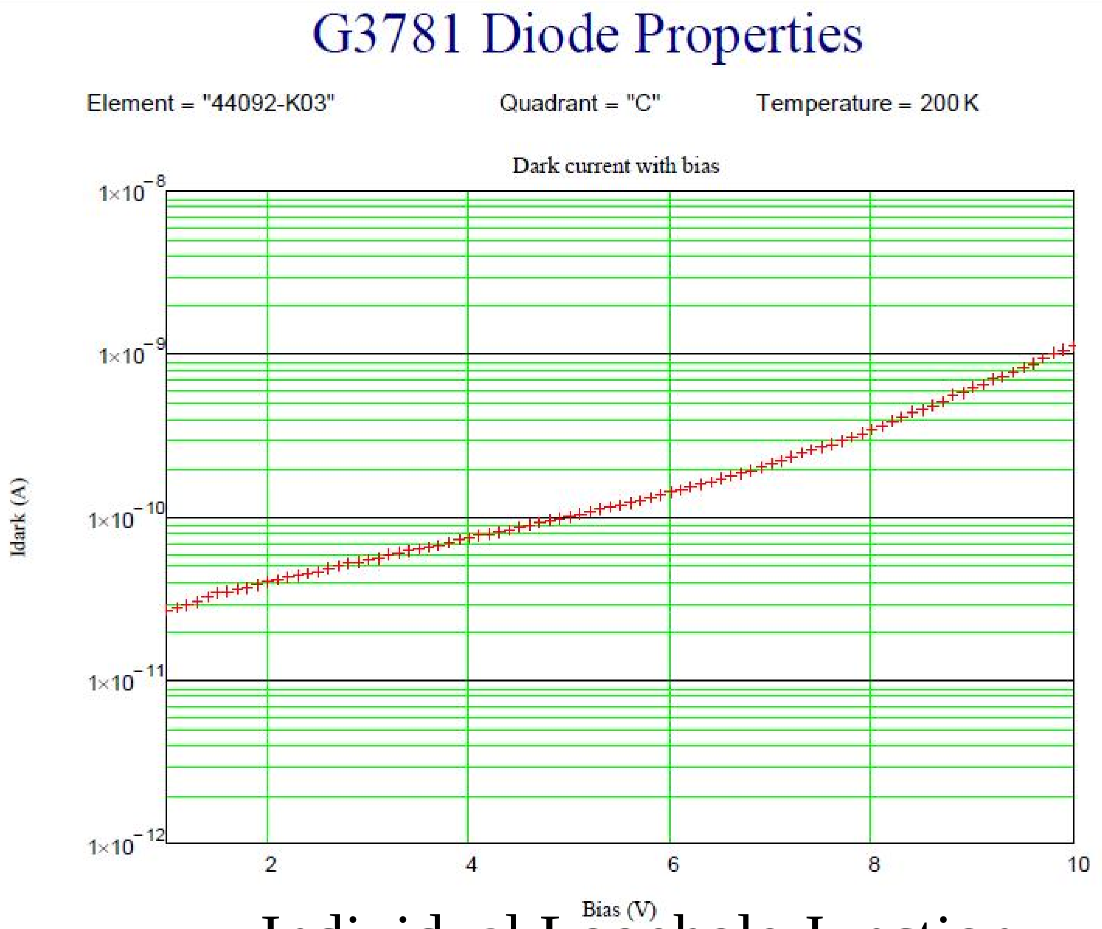


Trace1 = "Blind"

Trace2 = "7900 photons/50ns"

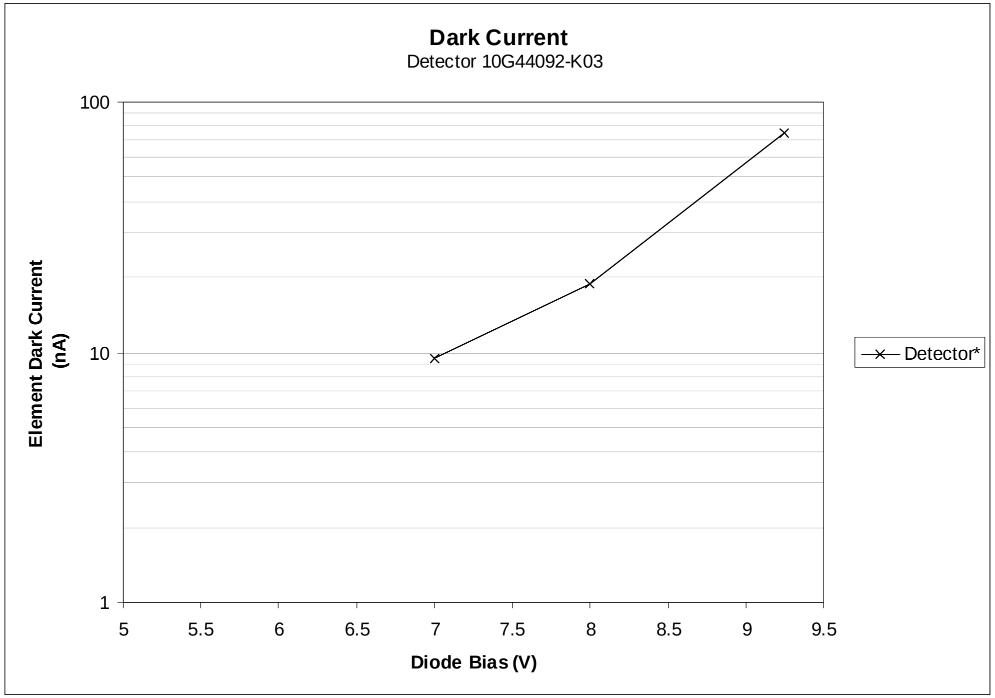
Trace3 = "1.4M photons/50ns"

Dark Current: Elementary Junction



Individual Loophole Junction

Dark Current: Whole Pixel



Aggregated Pixel (19 loopholes)

Element Dark Current at 9.3V bias (nA)	Before Radiation	After Radiation
4720-E05	38	47
4721-G08	160	160
44092-L01	170	170
44092-I02	880	860
44092-J02	500	430

Impact of Radiation Exposure

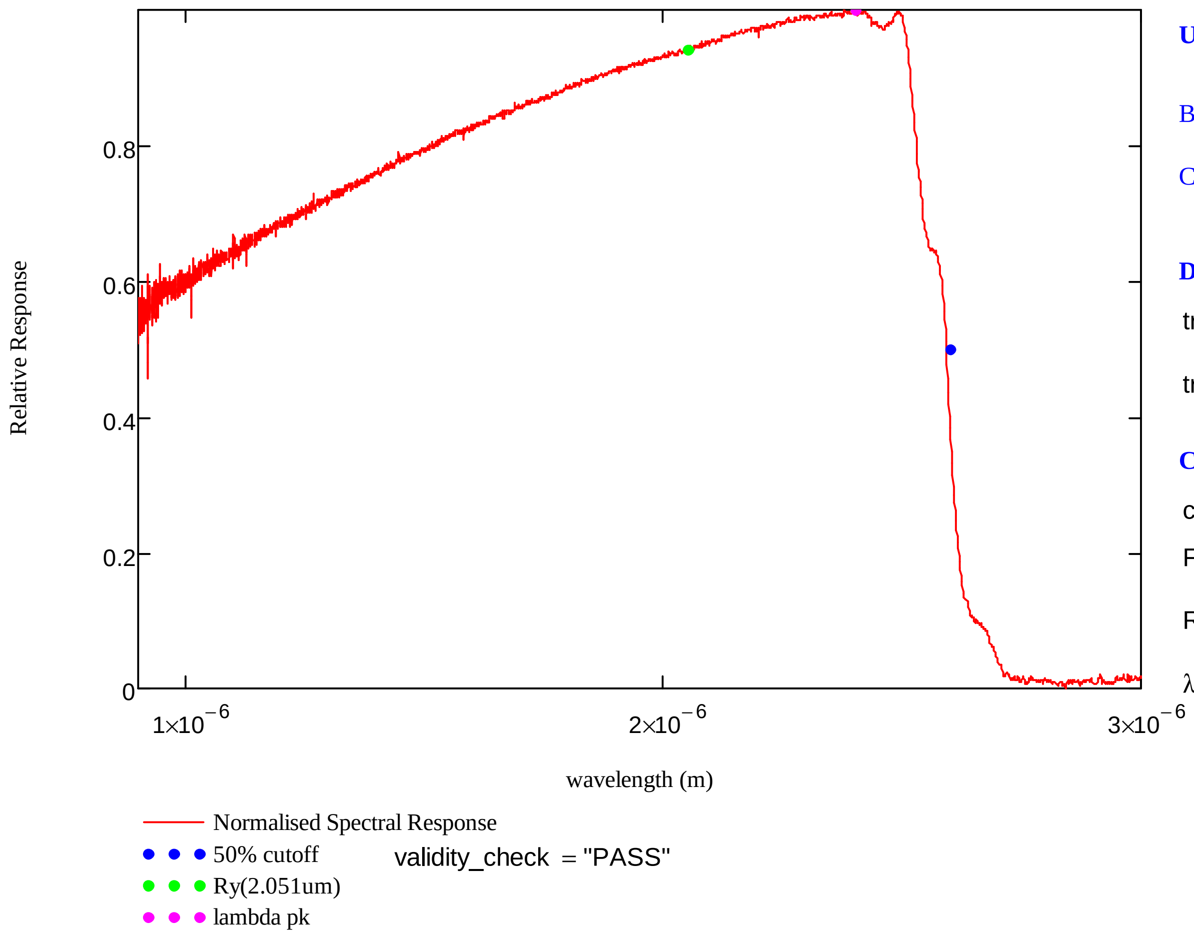
Aggregated Pixel (19 loopholes)

Spectral Response

G3781 Spectral Response

Array_ID = "44092-K01"

Quad = "B(Stack)"



validity_check = "PASS"

User Settings:

Blackbody Temp $T_{bb} = 1\times10^{3}\,K$

Chopper Temp $T_{ch} = 295\,K$

Data Truncation:

truncate_below = 0.9 µm

truncate_above = 3 µm

Calculated Values:

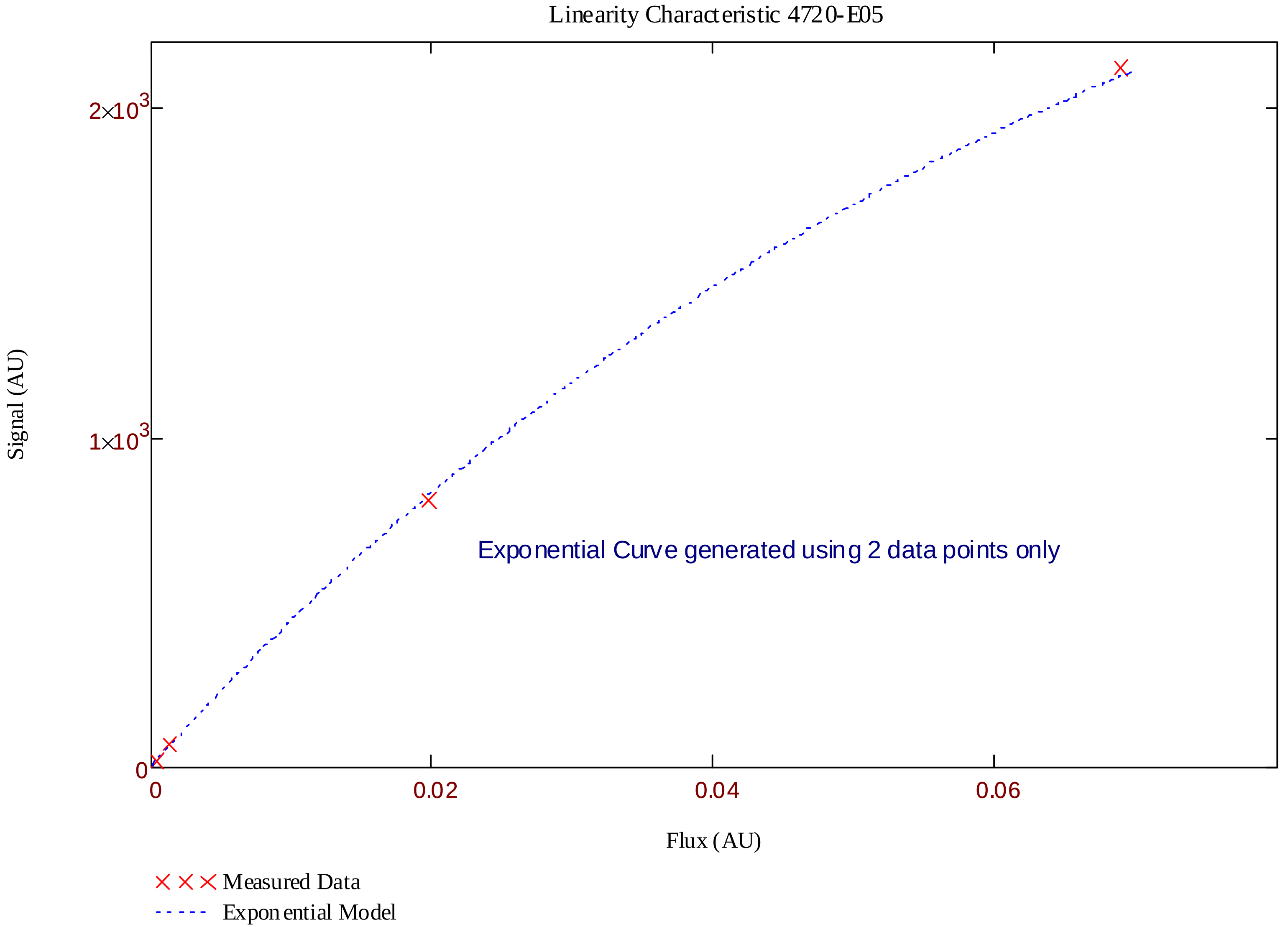
cutoff = 2.599 µm

$F_{bbPk} = 5.899$

Ry_normalised (2.051µm) = 0.942

$\lambda_{pk} = 2.402\,\mu m$

Linearity


Linearity Characteristic 4720-E05
Signal (AU)
2×10^3
1×10^3
0
0
0.02
0.04
0.06
Flux (AU)
Exponential Curve generated using 2 data points only
Measured Data
Exponential Model

Other Characteristics

Parameter	Value	Comments
Noise Factor (of avalanche gain, M)	1.45	At 200K, 9.3V reverse bias. Dependent on frequency. Best estimate from measurement data
Bandwidth	>20MHz at -3dB Max slew rate 55V/µs	At 200K Limited by preamplifier. Adjustable
TIA Input Dynamic Range	0-40µA	At 200K Inclusive of dark current contribution. Adjustable
TIA Output Dynamic Range	3.7V	At 200K
Supply voltages	6V positive supply -8V bias supply	Nominal values

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Radiation Testing

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Total Ionising Dose

Facility:	ESTEC Co-60, Noordwijk, Netherlands
Dose rate:	2.5 krads/hr (approx)
Condition:	Powered, biased, room temperature
Time between irradiation and test:	15 days

44092-L01 **5kRad (Si)**

	Before	After	Change	Units
Signal	7.11	6.22	12%	mV
Noise (Low Flux)	112	111	1%	nV/√Hz
Noise (Blind)	54	52	4%	nV/√Hz
Gain	6.64	5.85	12%	-
Cut-off	2.583	2.574	0.3%	µm
NEP	58	63	-	fW/√Hz

4720-E05 **10kRad (Si)**

	Before	After	Change	Units
Signal	6.84	6.24	9%	mV
Noise (Low Flux)	73	75	3%	nV/√Hz
Noise (Blind)	54	40	26%	nV/√Hz
Gain	5.56	5.29	5%	-
Cut-off	2.618	2.614	0.2%	µm
NEP	63	50	-	fW/√Hz

Proton

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Facility: PSI, Villigen, Switzerland
Dose rate: 1×10^{10} protons/cm², 3×10^{10} protons/cm² (10MeV eq.)
Condition: Unpowered, room temperature
Time between irradiation and test: 57 days

Device ID: 44092-I02

Dose: 1×10^{10} p+/cm², 10MeV eq.

	Before	After	Change	Units
Signal	9.65	12.8	32.9%	mV
Noise (Low Flux)	245	219	10.6%	nV/√Hz
Noise (Blind)	150	94	37.5%	nV/√Hz
Gain	8.49	11.3	33.3%	-
Cut-off	2.57	2.595	1.0%	µm
NEP	124	57	-	fW/√Hz

Device ID: 44092-J02

Dose: 3×10^{10} p+/cm², 10MeV eq.

	Before	After	Change	Units
Signal	7.9	11.2	42.1%	mV
Noise (Low Flux)	161	115	28.7%	nV/√Hz
Noise (Blind)	82	54	33.8%	nV/√Hz
Gain	7.9	11.0	39.0%	-
Cut-off	2.611	2.612	0.0%	µm
NEP	83	38	-	fW/√Hz

The study suggests that there have been no detrimental effects to EO performance or dark current. The change in performance is believed to be an artefact of measurement variability and drift.

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Conclusion

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Conclusions

- "Novel" approach of hybridising diode directly to TIA preamplifier has been successful
- Device is sensitive to primary wavelength (2.051µm) but also suited to other wavelengths (1.3µm to 2.2µm)
- The device exceeds the key performance criterion (NEP<100fW $\sqrt{Hz}$)
- Most other performance criteria achieved (though some not fully demonstrated)
- Manufacturing method for diode established. Viability of manufacturing demonstrated – yields sustainable
- Encapsulated detector designed (and available for breadboard activities)
- Exploitation of device in LIDAR system yet to be demonstrated