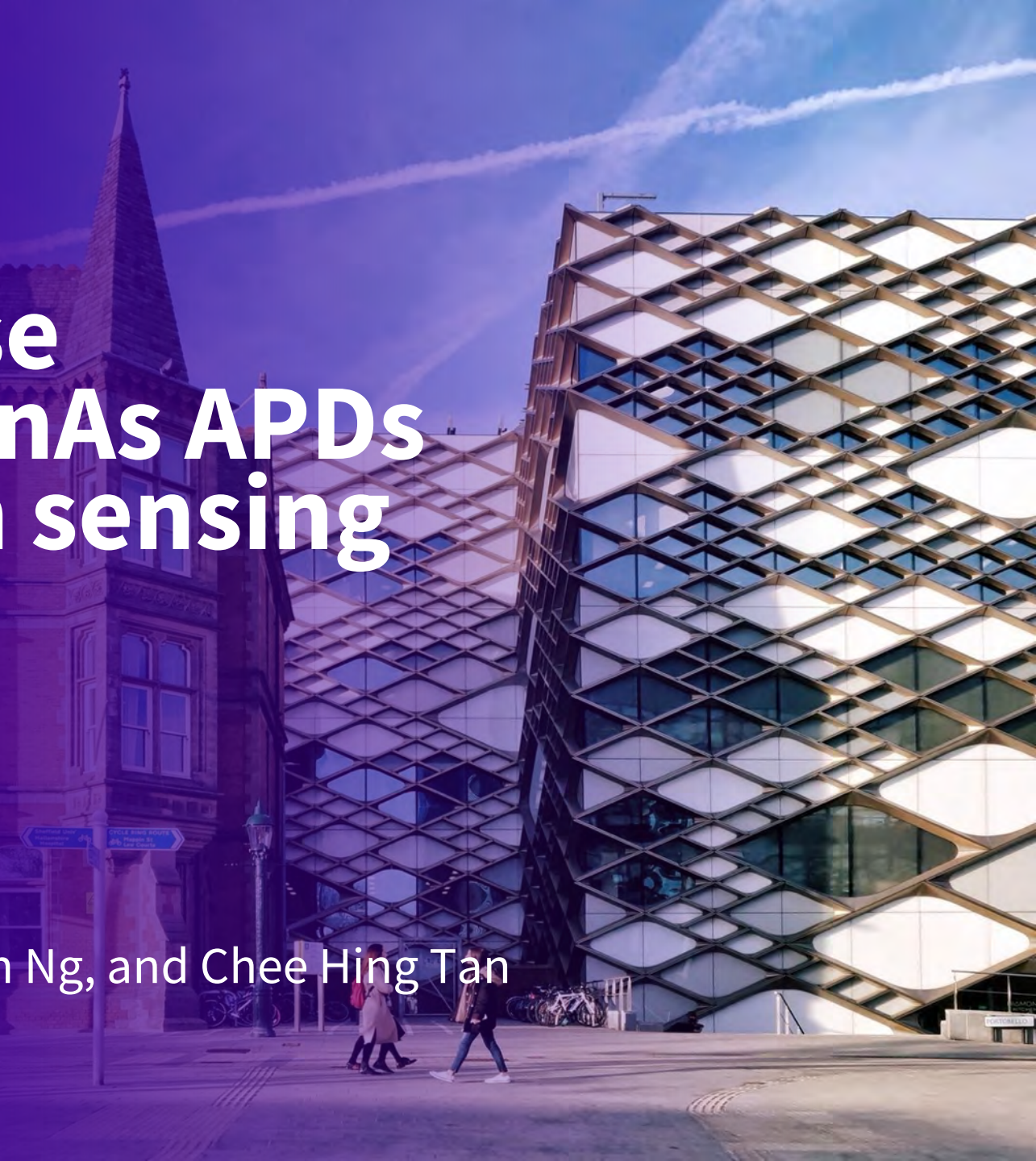
University of Sheffield

Sub 50 fw/√Hz noise equivalent power InAs APDs for 1550 & 2004 nm sensing



19th March 2024

CEOI Emerging Technologies Workshop

Jonathan Petticrew, Tarick Blain, Jo Shien Ng, and Chee Hing Tan

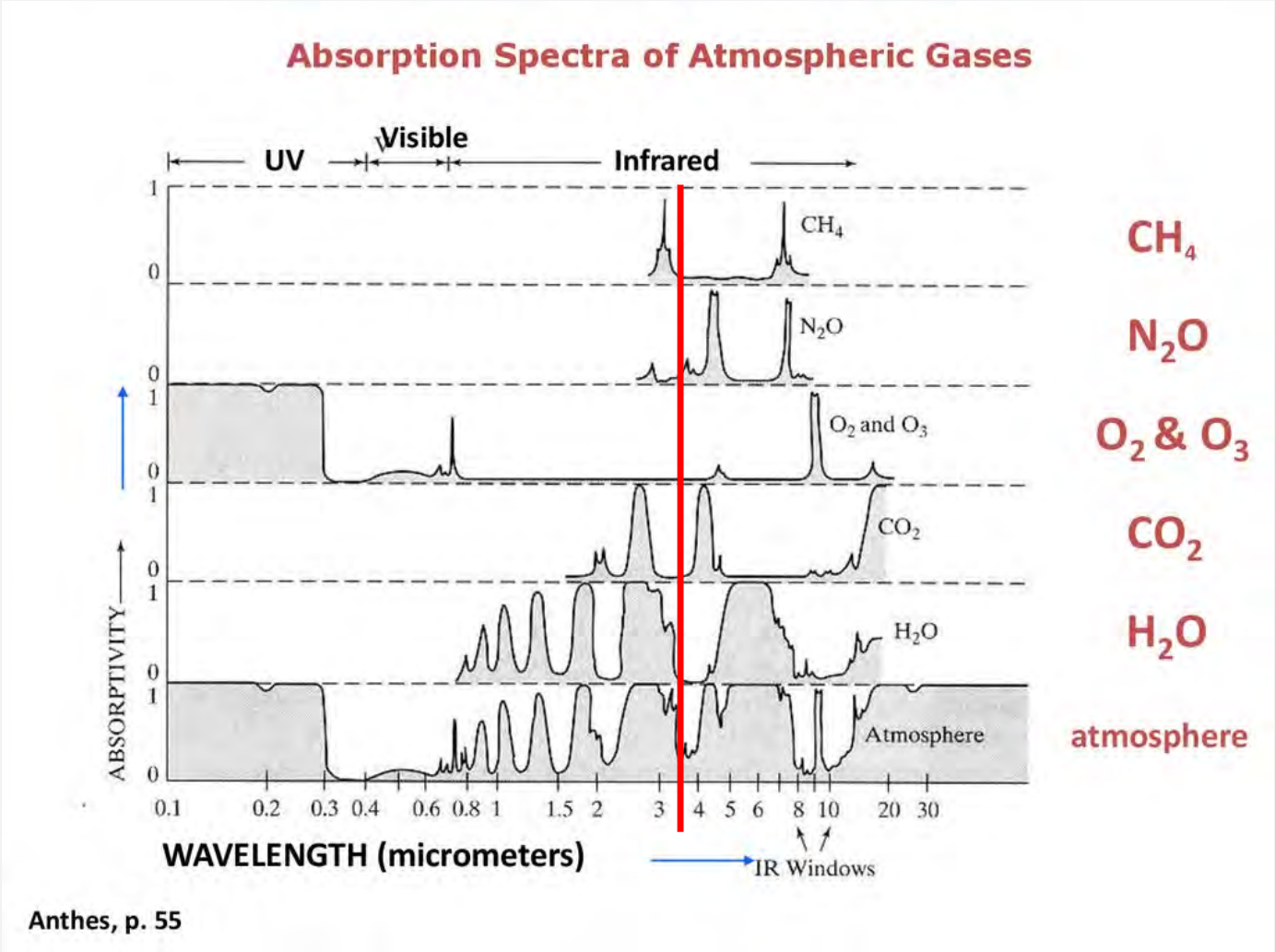
How to pick a detector?

- Wavelength range
- Material Characteristics
- Dark Signal?
- Signal to Noise Ratio

The ideal detector?

- Wavelength range
- Material Characteristics
- Dark Signal?
- Signal to Noise Ratio

Why InAs?

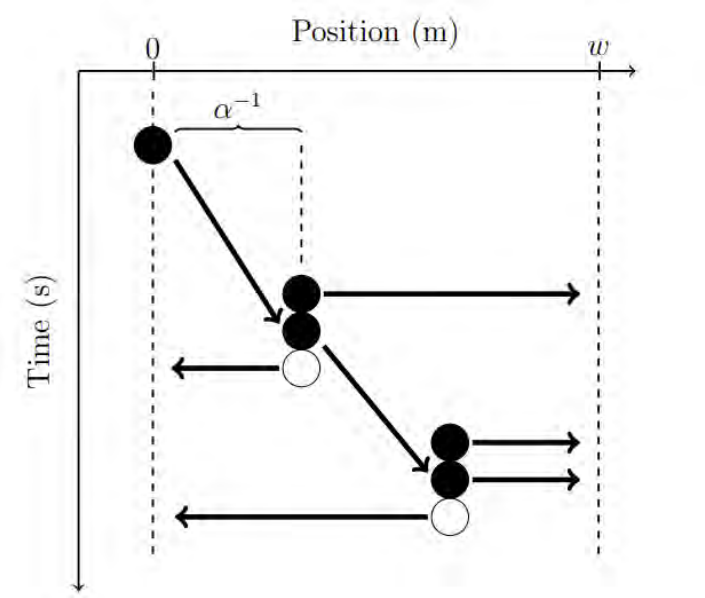


Anthes, p. 55

How to pick a detector?

- Wavelength range
- Material Characteristics
- Dark Signal?
- Signal to Noise Ratio

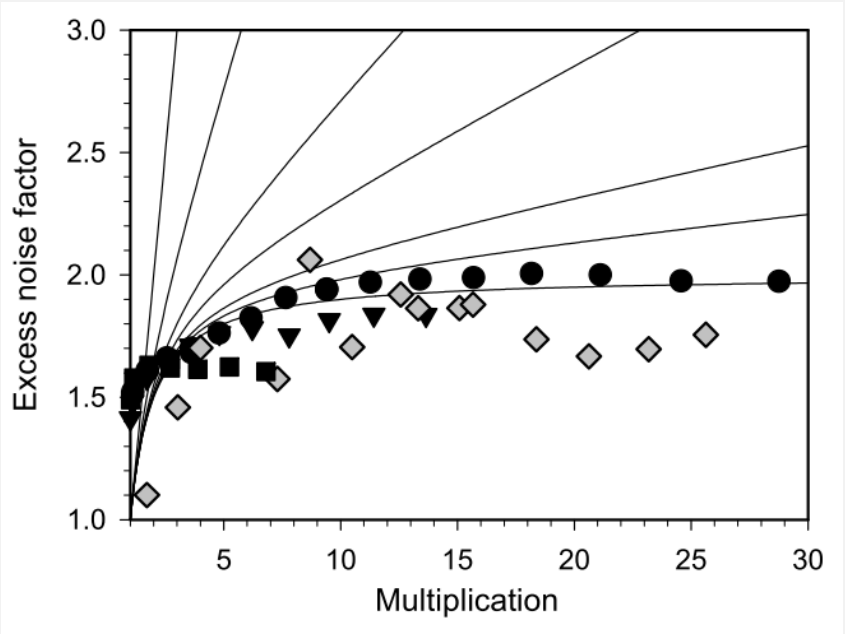
Why InAs?



Electron only impact ionization

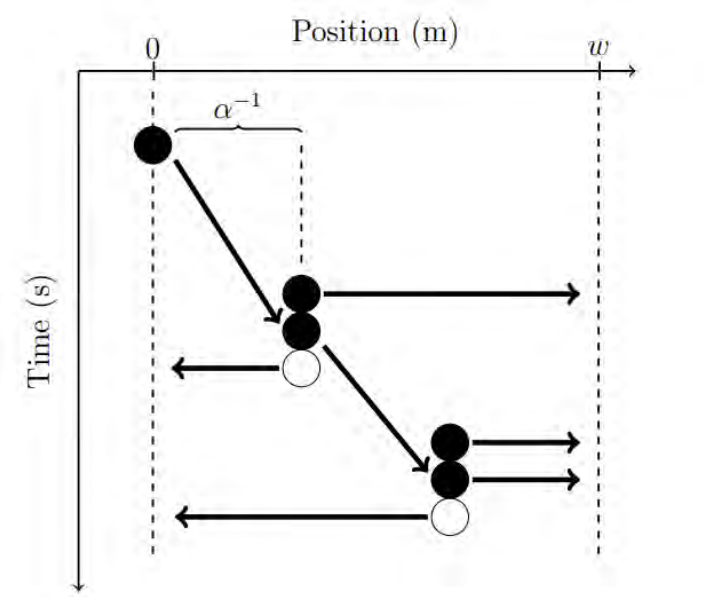
$$F = kM + (1 - k)\left(2 - \frac{1}{M}\right)$$

$$F_{k=0} = 2 - \frac{1}{M}$$

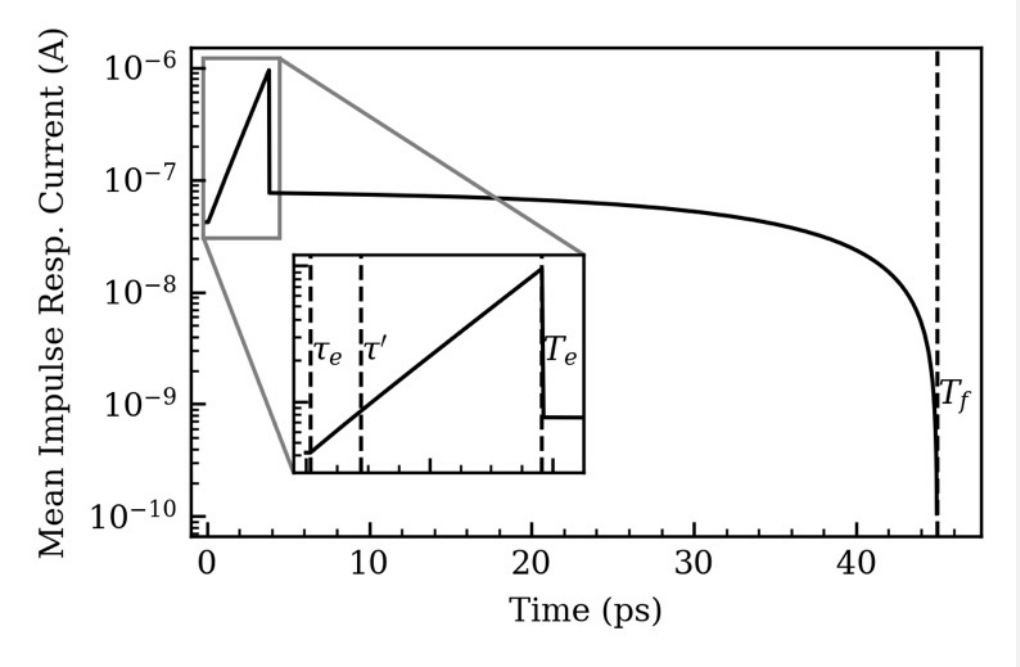


Marshall et al., IEEE Trans Electron Devices, **57**(10), 2010.

Why InAs?



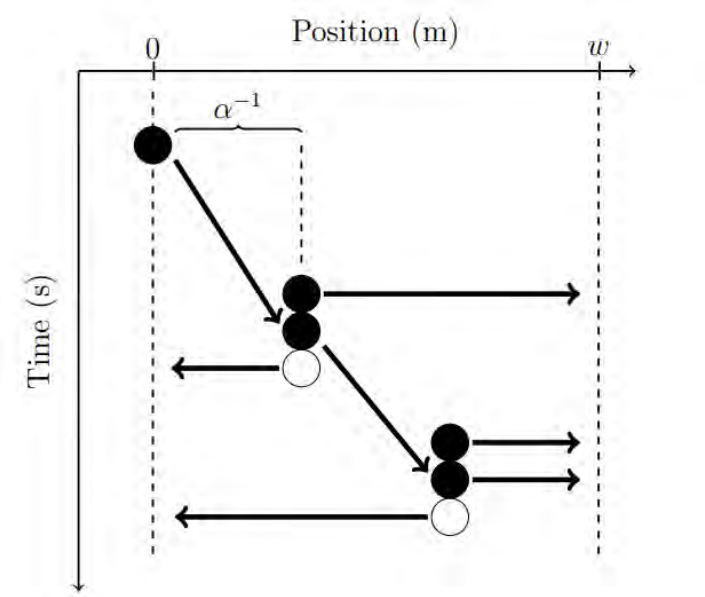
Electron only impact ionization



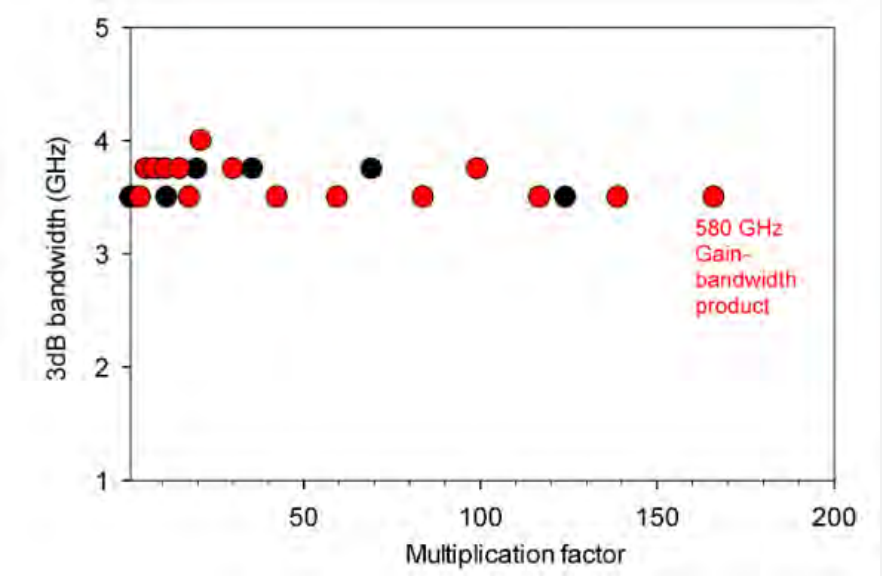
Short impulse response (example for a 3 µm InAs APD)

Shulyak et al., J. Lightwave Technology, **38**(4), 2020.

Why InAs?



Electron only impact ionization



Bandwidth limited by carrier transit time **NOT**
Avalanche multiplication

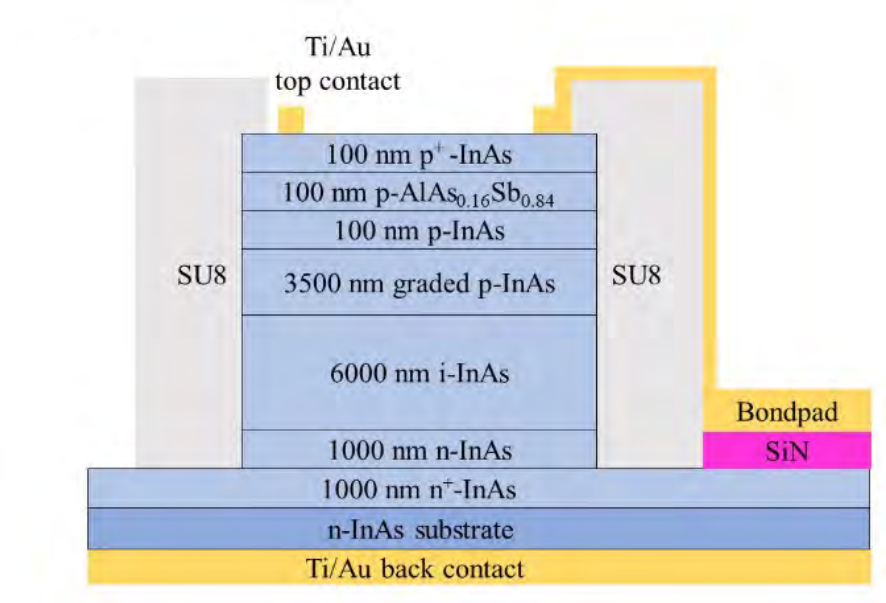
Marshall et al., Opt. Express., **19**(23), 2011

How to pick a detector?

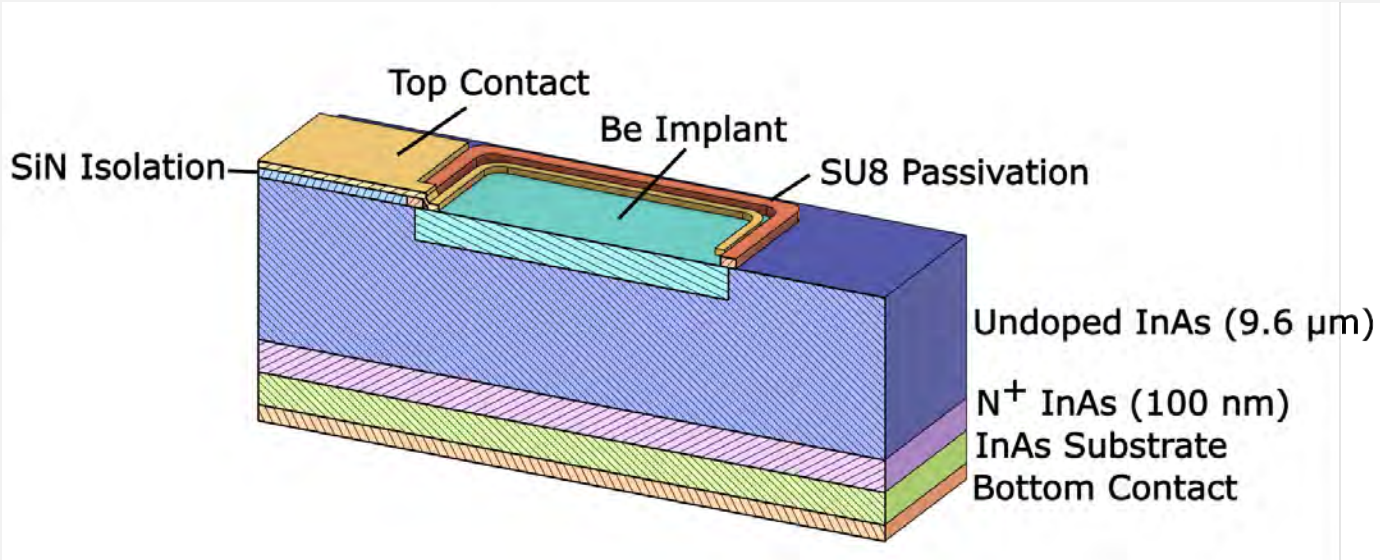
- Wavelength range
- Material Characteristics
- Dark Signal?
- Signal to Noise Ratio

What's different?

Typical – "Mesa"

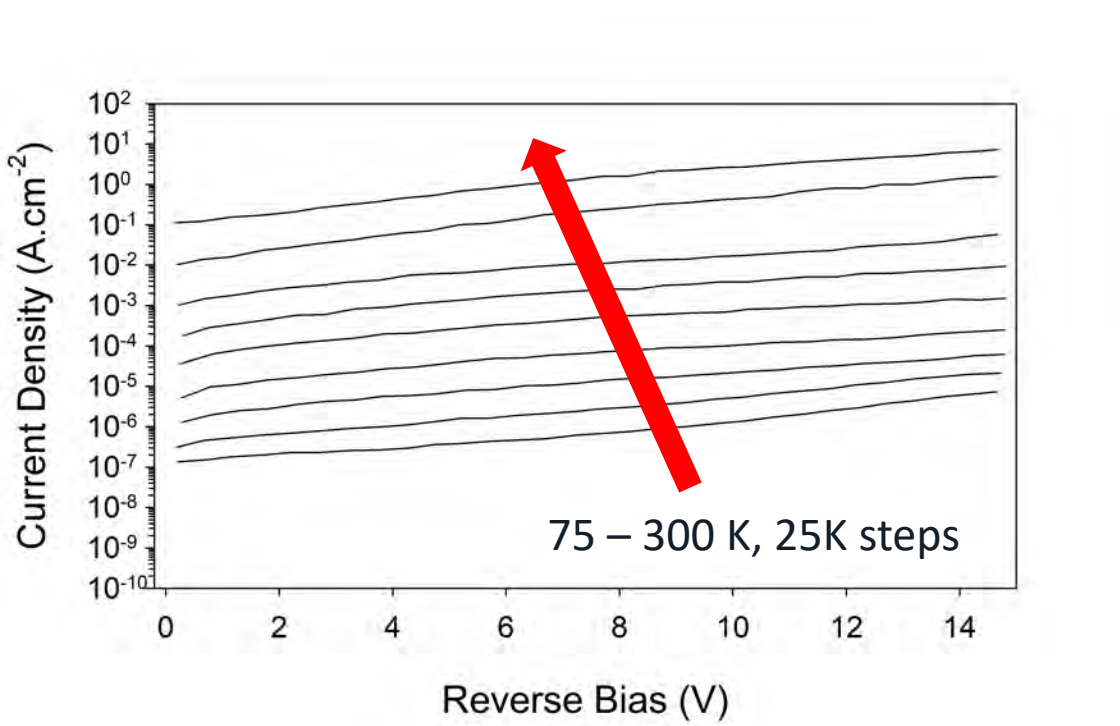


New – "Planar"



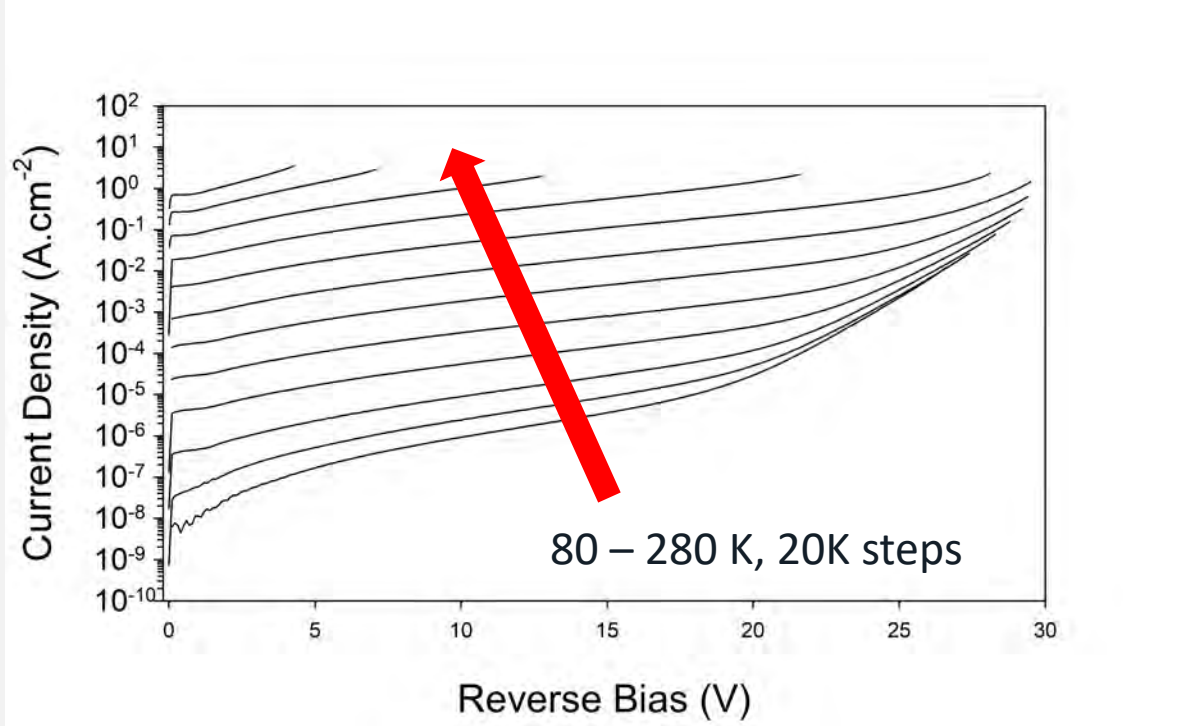
Dark Current

"Mesa"



110 µm Diameter
Ker et al.

"Planar"



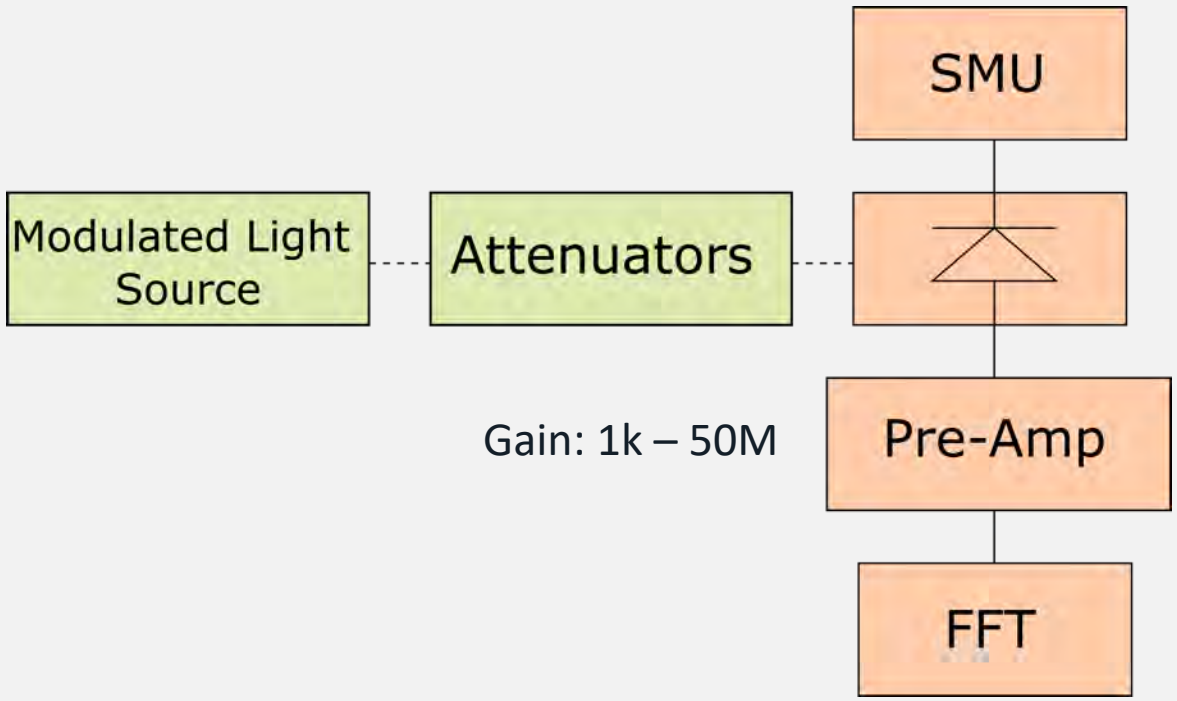
200 x 200 µm
(This work)

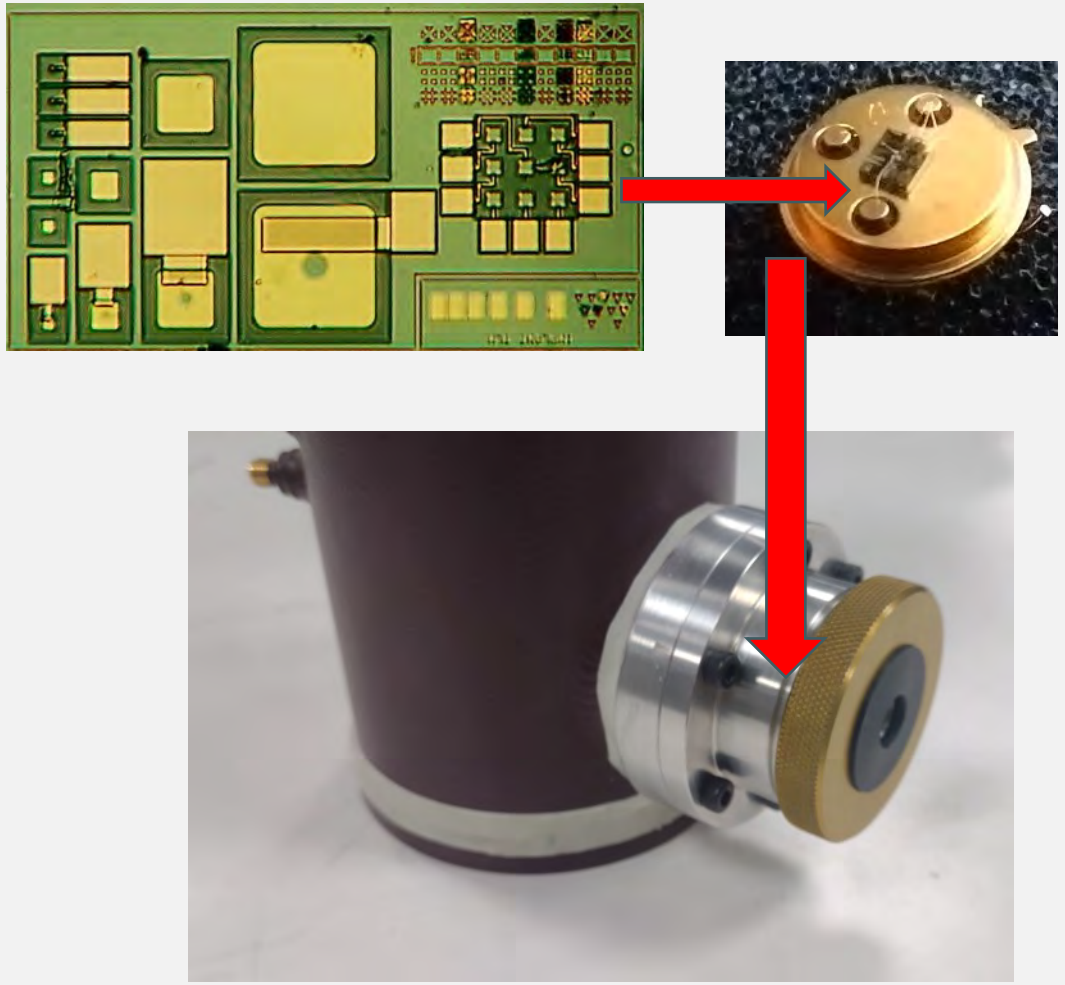
Ker et al., IEEE J. Quant. Electron., **47**(8), 2011.

How to pick a detector?

- Wavelength range
- Material Characteristics
- Dark Signal?
- Signal to Noise Ratio => Noise equivalent power

Measurement methods



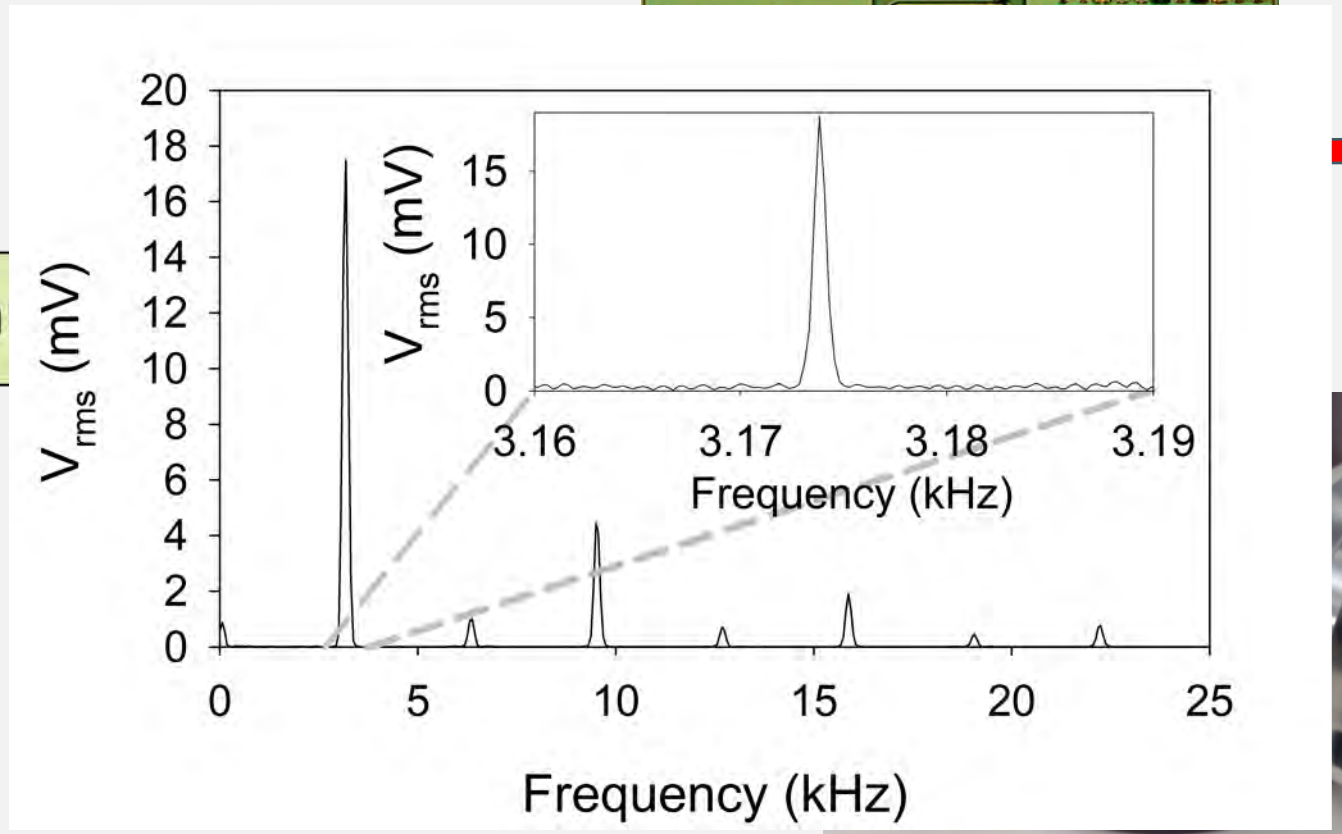


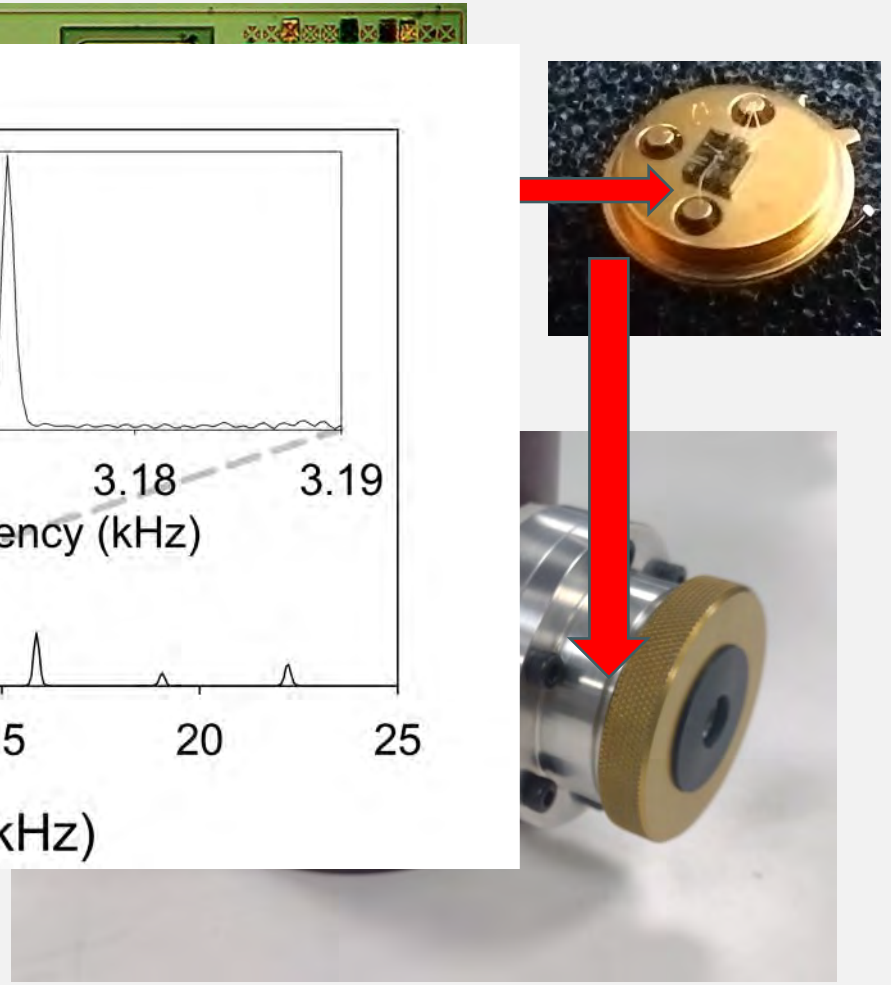
Measurement methods

Modulated Light Source

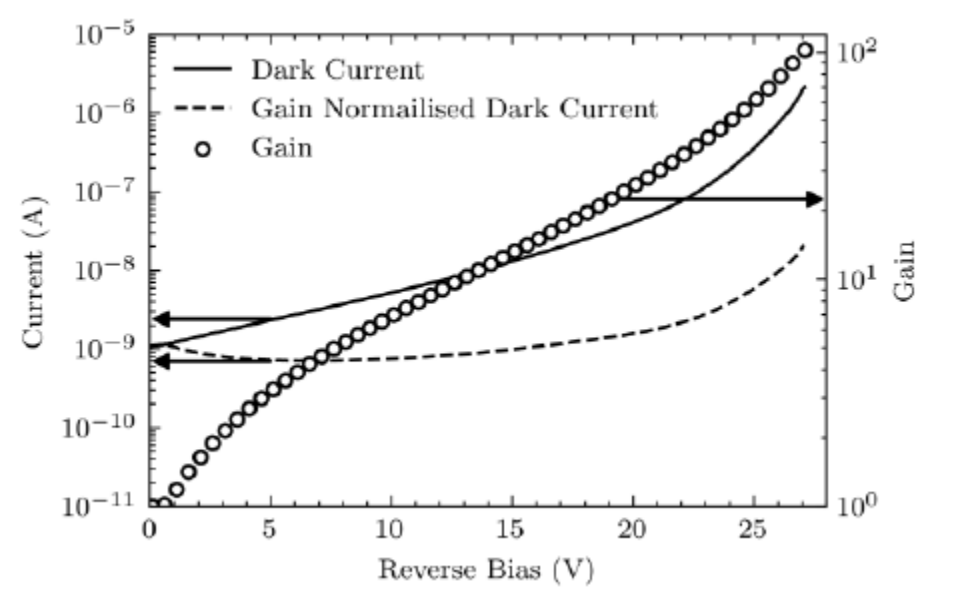
Atten

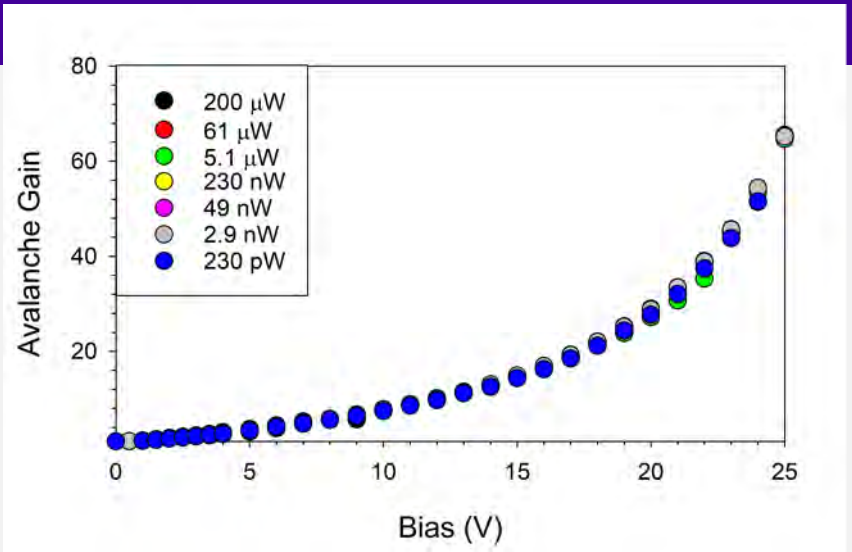
Gain:

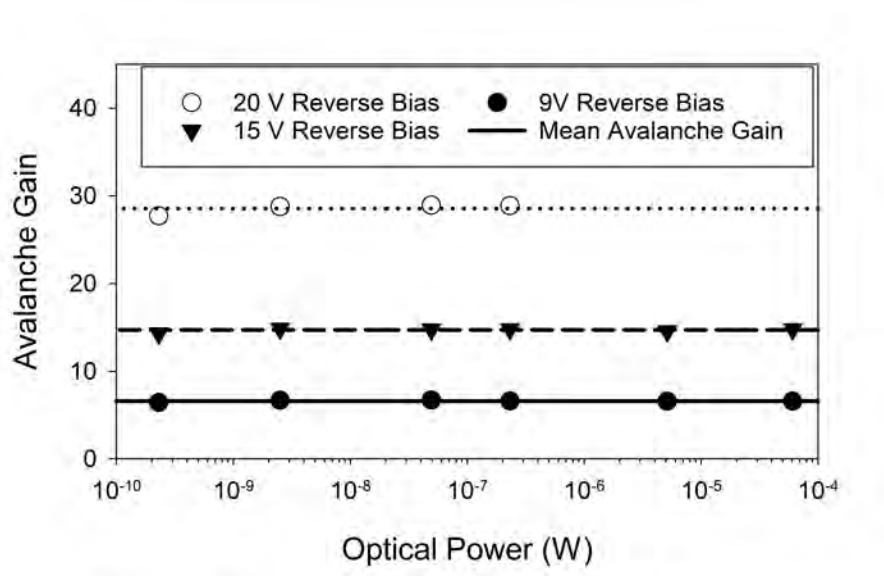




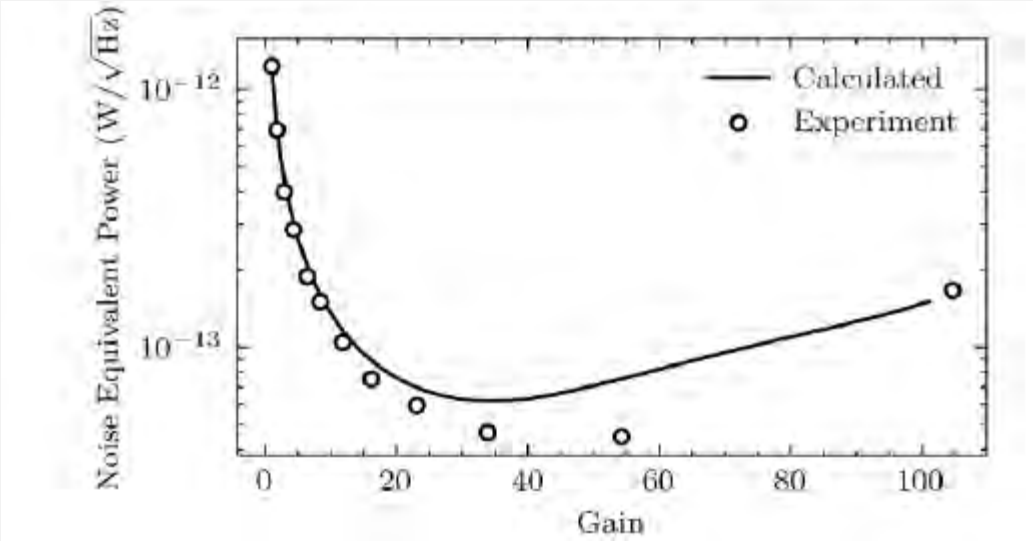
Avalanche Multiplication

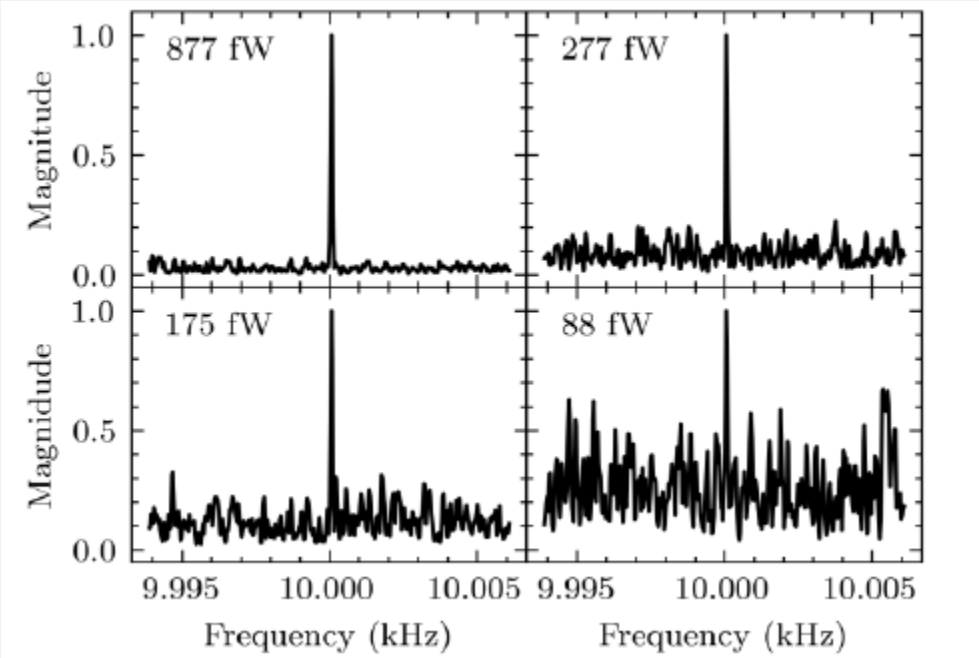




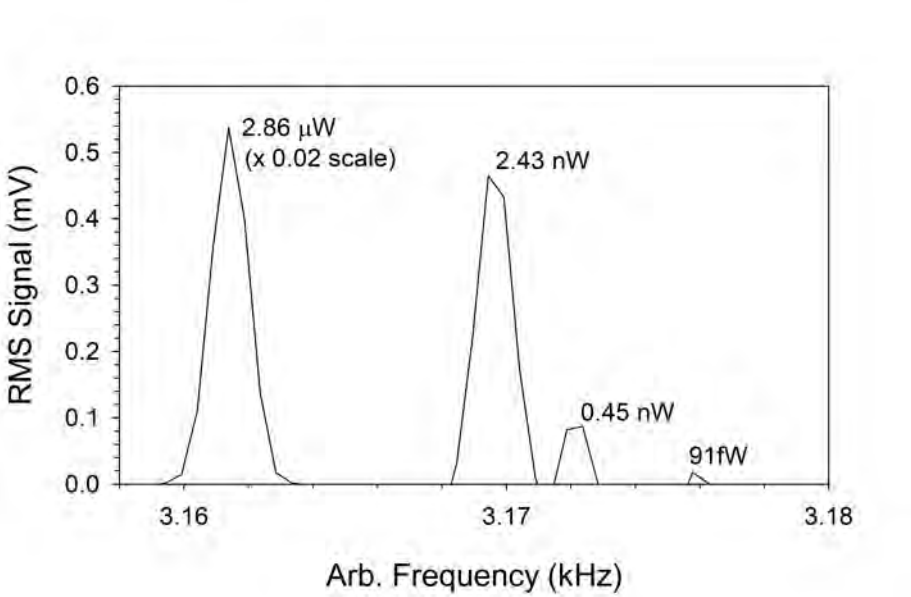


1550 nm


Noise Equivalent Power (W/√Hz)
10^{-12}
10^{-13}
Calculated
Experiment
0
20
40
60
80
100
Gain


Magnitude
Magnidude
1.0
0.5
0.0
877 fW
277 fW
175 fW
88 fW
9.995
10.000
10.005
Frequency (kHz)
Frequency (kHz)

2004 nm



Pre-amplifier Sensitivity	Signal Level	Optical Power
1 mA/V	26.9 mV	2.86 µW
50 nA/V	465 µV	2.43 pW
	87.1 µV	450 fW
	17.7 µV	91 fW
20 nA/V	23.2 µV	48 fW

Minimum NEP: 38.5 fW/√Hz

Conclusion

- Wavelength range:
  - Up to 3.5 µm detection
- Material Characteristics:
  - eAPD => Low variation in gain; narrow impulse responses; transit time limited gain bandwidth product
- Dark Signal
  - <30 nA for a 200 x 200 µm APD
- NEP & Low Photon detection
  - Highly linear avalanche gain vs optical power

	NEP minimum	Photons per pulse (@ rep. rate)
1550 nm	45 fW/√Hz	<70 (10 kHz)
2004 nm	38.6 fW/√Hz	80 (3.14 kHz)

So What?

Access to missions:

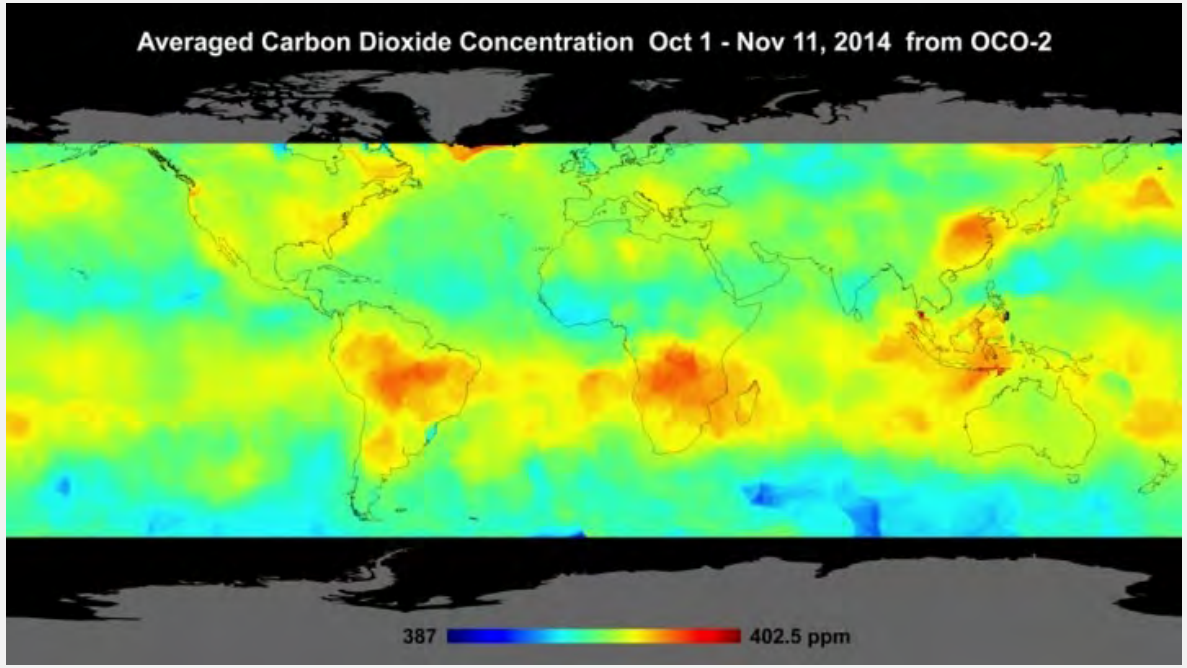
- Copernicus Sentinels (ESA); Climate change monitoring
- MERLIN; Methane sensing ~3000 nm Launching 2028
- CO2Image Satellite (DLR), Launching 2026

Commercial?

- Potential cost reduction vs HgCdTe detectors
- Improved supply chain resilience

Mission enablement:

- Disruptive sensor for <3.5 µm detection
- Alternative to existing HgCdTe detectors



Thanks!

J.D.Petticrew@sheffield.ac.uk