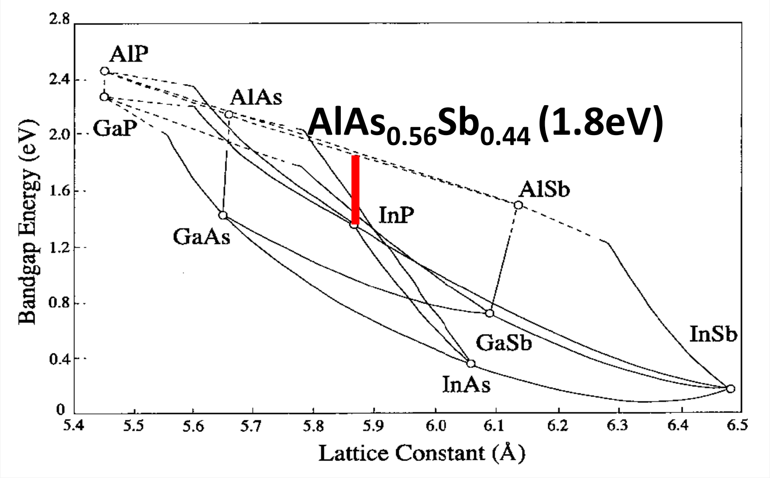
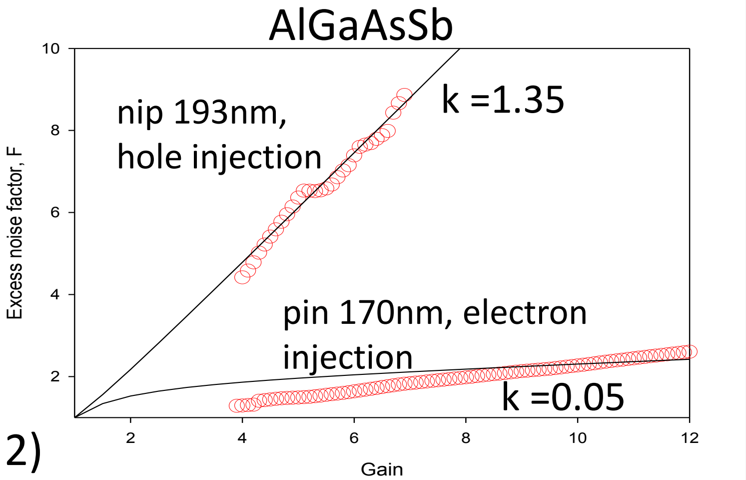
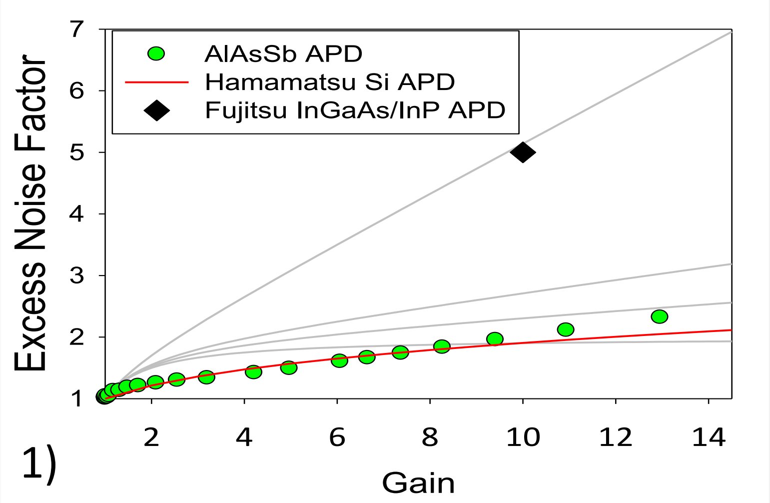
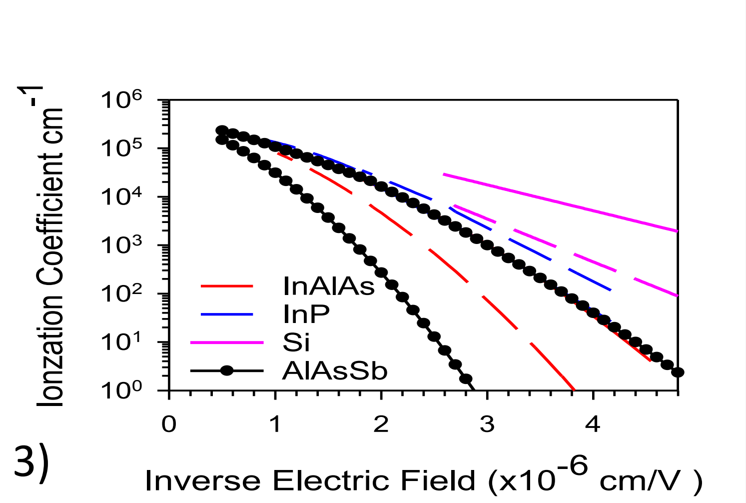
Al(Ga)AsSb





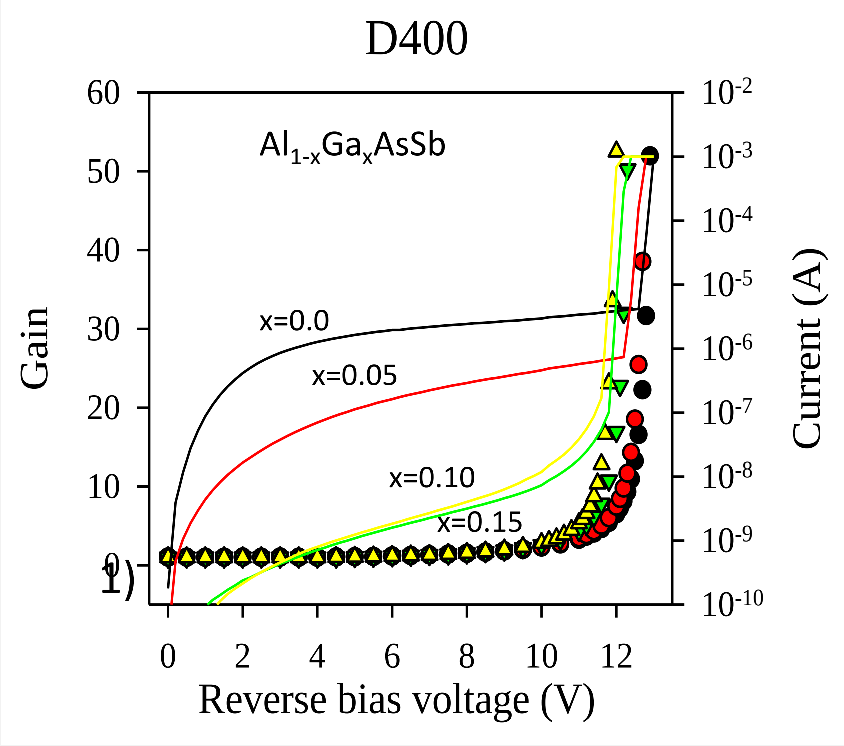


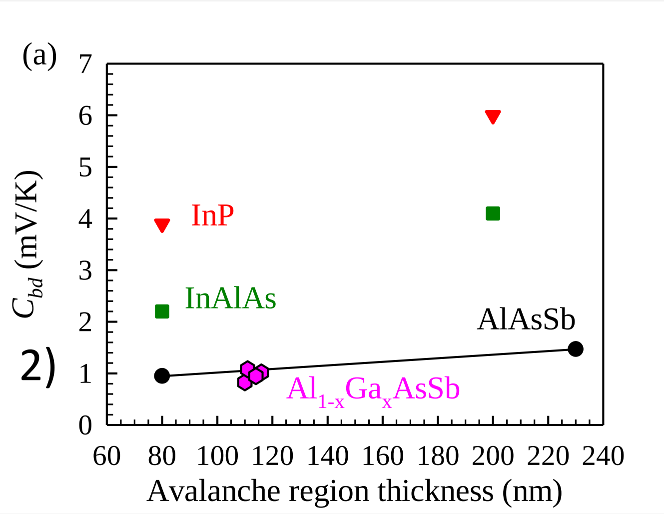


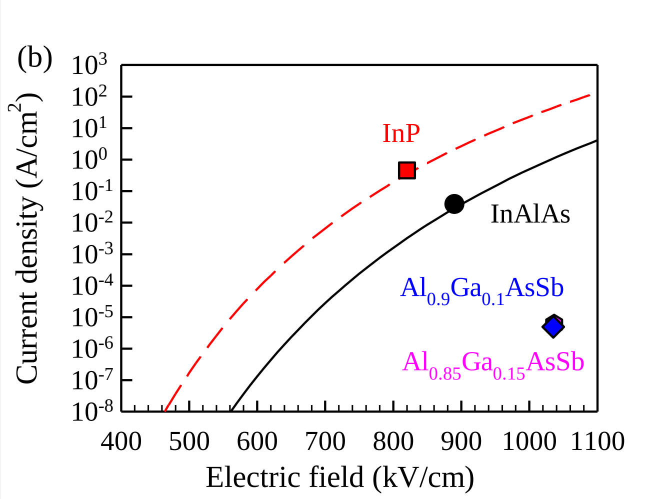
- Excess noise factors in AlAsSb and Al(GaAsSb) devices are comparable to Si APDs, due to very large ratio of electron to hole ionisation coefficient.
- Lattice matched to InP (substrate) and InGaAs (for 1550nm absorption)

1) Jingjing Xie at. al., IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 59, NO. 5, 1475, MAY 2012
2) Lucas Pinel et al, Vol. 26, No. 3 | 5 Feb 2018 | OPTICS EXPRESS 3568
3) Xin Yi et al, SCIENTIFIC REPORTS | (2018) 8:9107 | DOI:10.1038/s41598-018-27507-w

$Al_xGa_{1-x}AsSb$



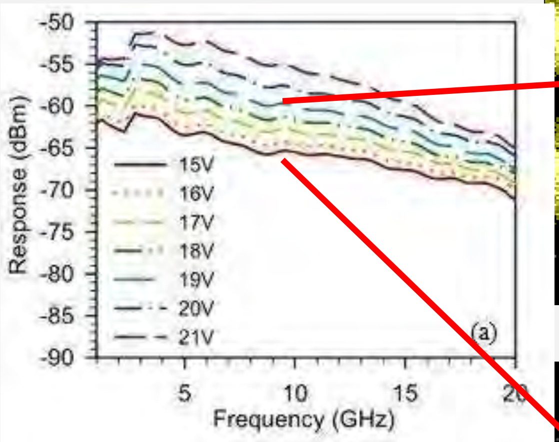




- Surface leakage current reduces with increasing Ga
- Weak temperature coefficients of breakdown voltage ~ 1mV/K
- Current density at $0.95V_{bd}$ is **100,000x < InP, 1,000x < InAlAs, w =100nm (not limited by tunnelling current)**.

1) Xinxin Zhou et al., IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 28, NO. 22, NOVEMBER 15, 2495, 2016
2) Xinxin Zhou et. al., Royal Society Open Science, 2017, DOI: 10.1098/rsos.170071

High Gain-Bandwidth Product




Research Article

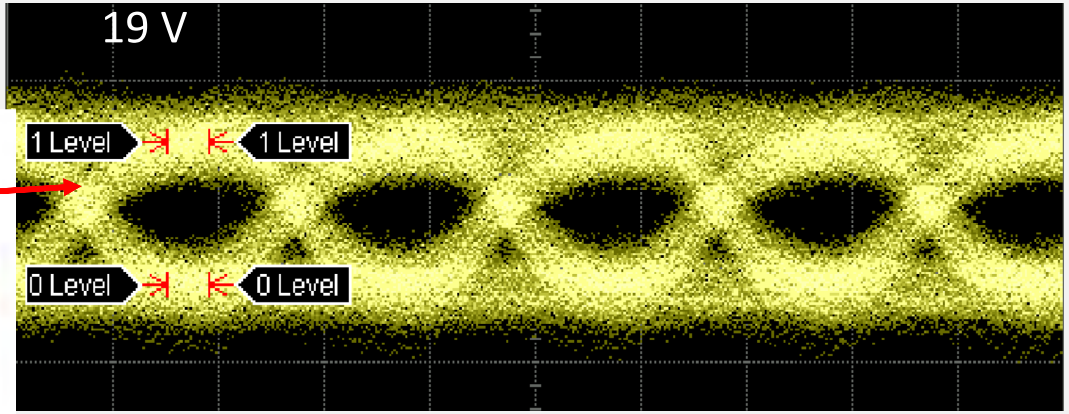
Vol. 24, No. 21 | 17 Oct 2016 | OPTICS EXPRESS 24242

Optics EXPRESS

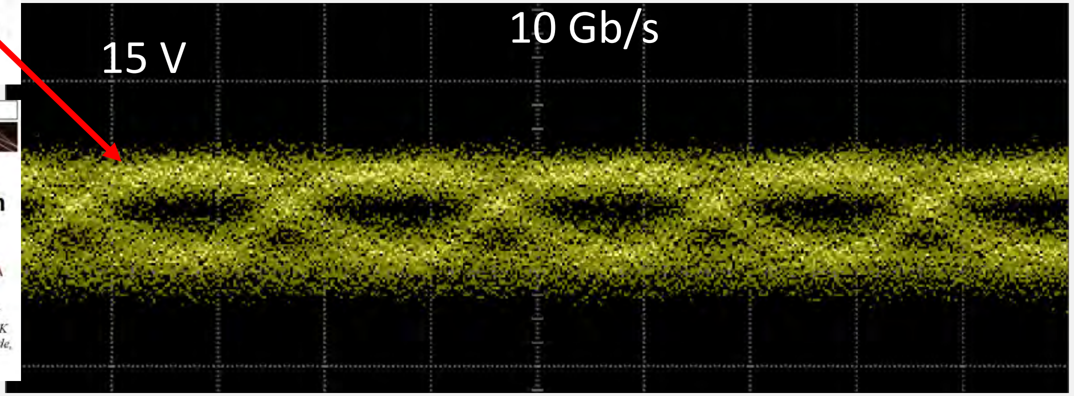
InGaAs/AlGaAsSb avalanche photodiode with high gain-bandwidth product

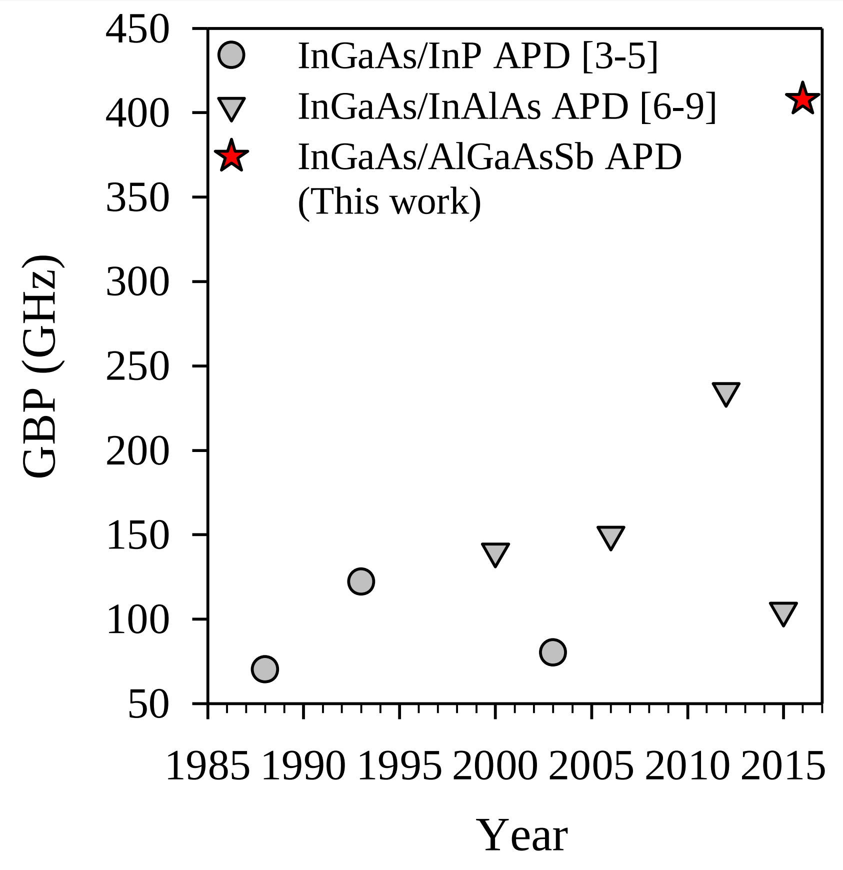
Shiyu Xie,[1,3] Xinxin Zhou,[1] Shiyong Zhang,[1] David J. Thomson,[2] Xia Chen,[2] Graham T. Reed,[2] Jo Shien Ng,[1] and Chee Hing Tan[1,*]

[1]Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield S3 7HQ, UK
[2]Optoelectronics Research Centre, University of Southampton, Highfield, Southampton SO17 1BJ, UK
[3]Present address: School of Physics and Astronomy, Cardiff University, Queen's Building, The Parade, Cardiff CF24 3AA, UK
[*]c.h.tan@sheffield.ac.uk



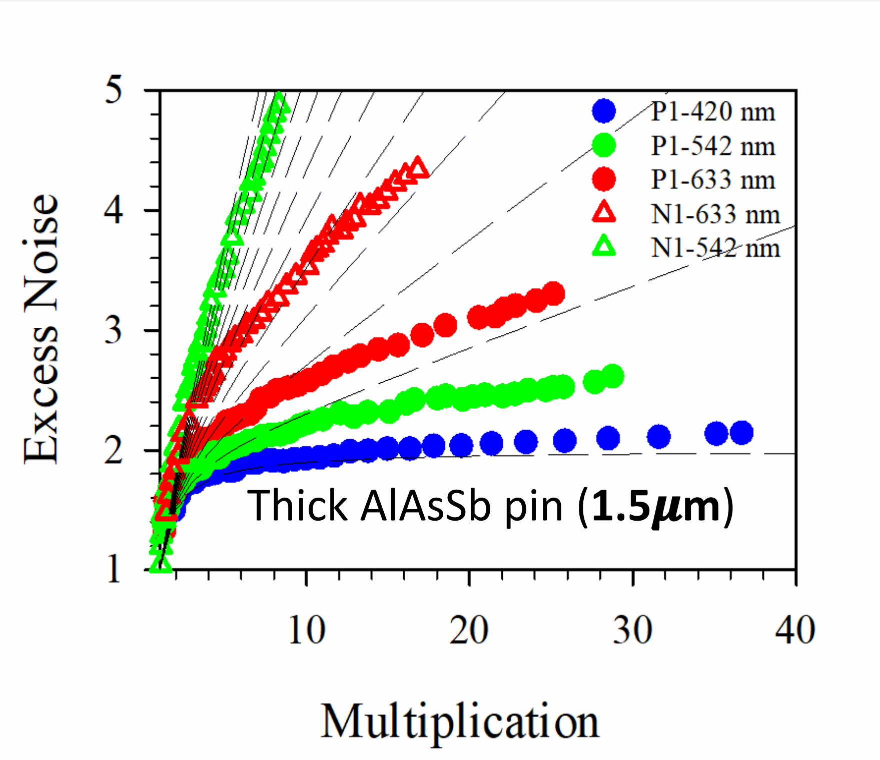
Shiyu Xie, Vol. 24, No. 21 | 17 Oct 2016 | OPTICS EXPRESS 24242

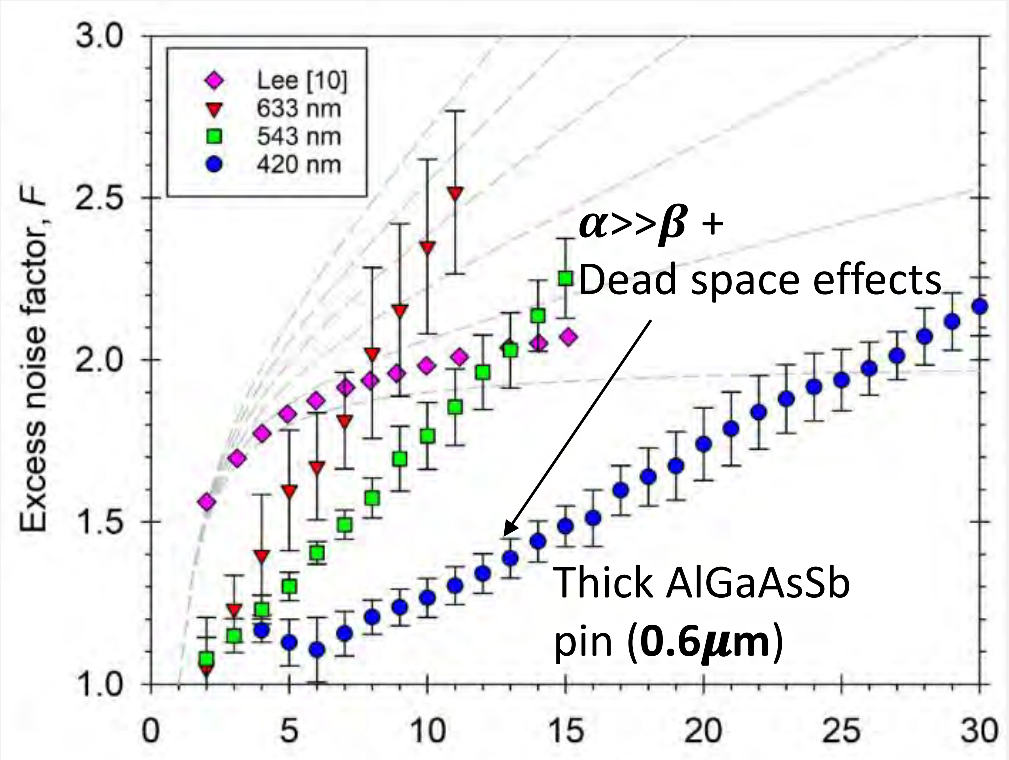




- Eye-opening due to avalanche gain at 19 V
- Gain-Bandwidth Product of ~ 424 GHz

Minimising excess noise





nature photonics
LETTERS
https://doi.org/10.1038/s41566-019-0477-4

Extremely low excess noise and high sensitivity $AlAs_{0.56}Sb_{0.44}$ avalanche photodiodes

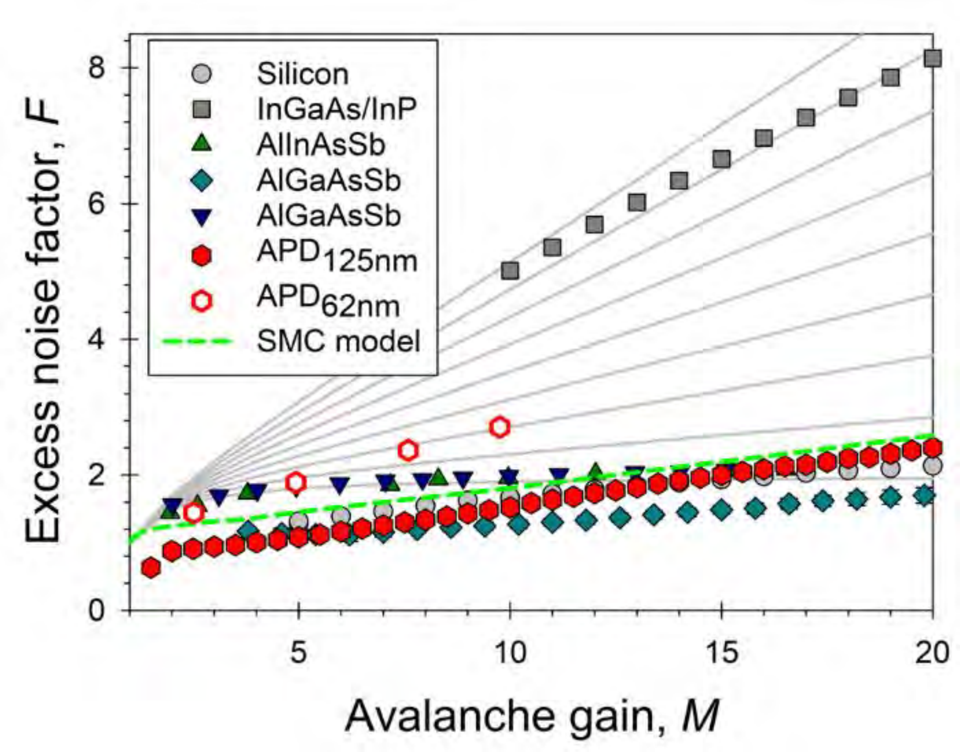
Xin Yi[1,4], Shiyu Xie[2,4*], Baolai Liang[3*], Leh W. Lim[1], Jeng S. Cheong[1], Mukul C. Debnath[3], Diana L. Huffaker[2], Chee H. Tan[1] and John P. R. David[1*]

IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 33, NO. 20, OCTOBER 15, 2021 1155

Low Excess Noise of $Al_{0.85}Ga_{0.15}As_{0.56}Sb_{0.44}$ Avalanche Photodiode From Pure Electron Injection

Jonathan Taylor-Mew, Vladimir Shulyak, Benjamin White, Chee Hing Tan, *Senior Member, IEEE*, and Jo Shien Ng, *Member, IEEE*

GaAsSb/AlGaAsSb APDs



Extremely low excess noise avalanche photodiode with GaAsSb absorption region and AlGaAsSb avalanche region

Cite as: Appl. Phys. Lett. **122**, 051103 (2023); doi: 10.1063/5.0139495
Submitted: 20 December 2022 · Accepted: 11 January 2023 ·
Published Online: 31 January 2023

View Online Export Citation CrossMark

Ye Cao, Tarick Blain, Jonathan D. Taylor-Mew, Longyan Li, Jo Shien Ng, and Chee Hing Tan[a)]

- Replace InGaAs absorption with GaAsSb to reduce conduction band energy barrier
- Simplify growth
- High gain ~130 at -49.6 V
- Extremely low excess noise factor F =1.52 at M =10 and F = 2.48 at M = 20

University of Sheffield

PART 3

State-of-art APD performance

PHLUX

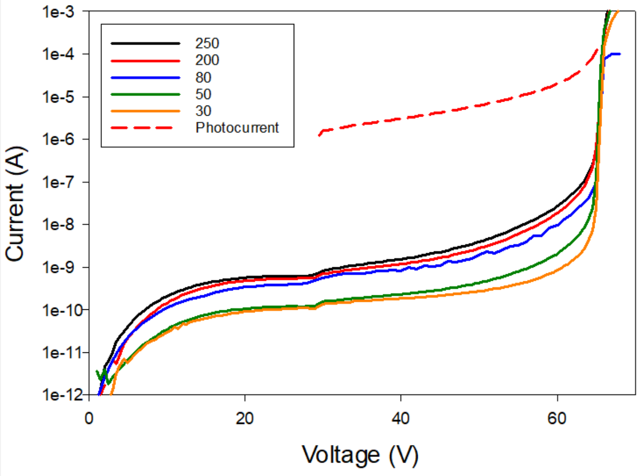
- Spinout (2020) from University of Sheffield
- Commercialising AlGaAsSb based APDs

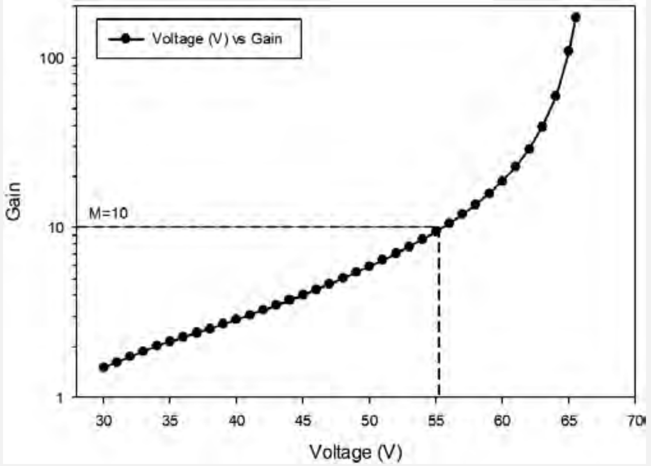
Website: phluxtechnology.com

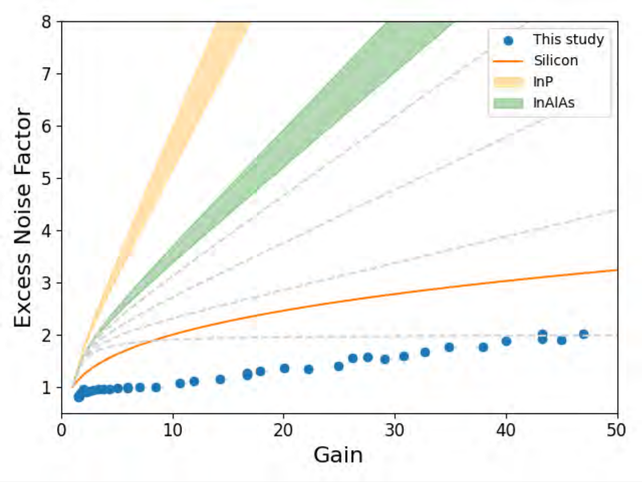
Email: info@phluxtechnology.com

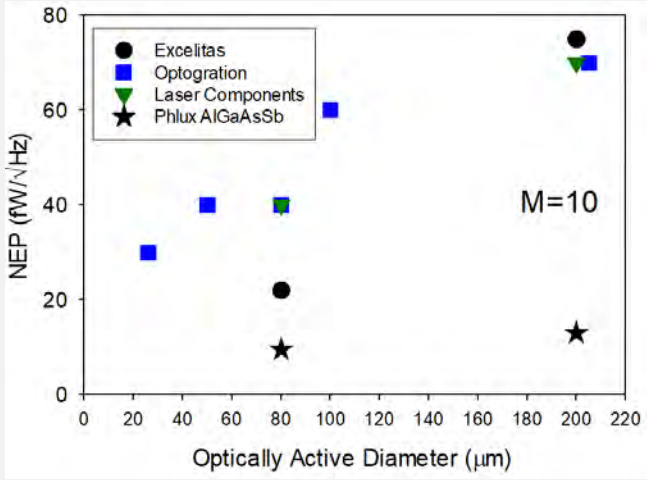
Email: ben.white@phluxtechnology.com

Phlux: Extremely low noise InGaAs/AlGaAsSb APDs (Jan 2023)

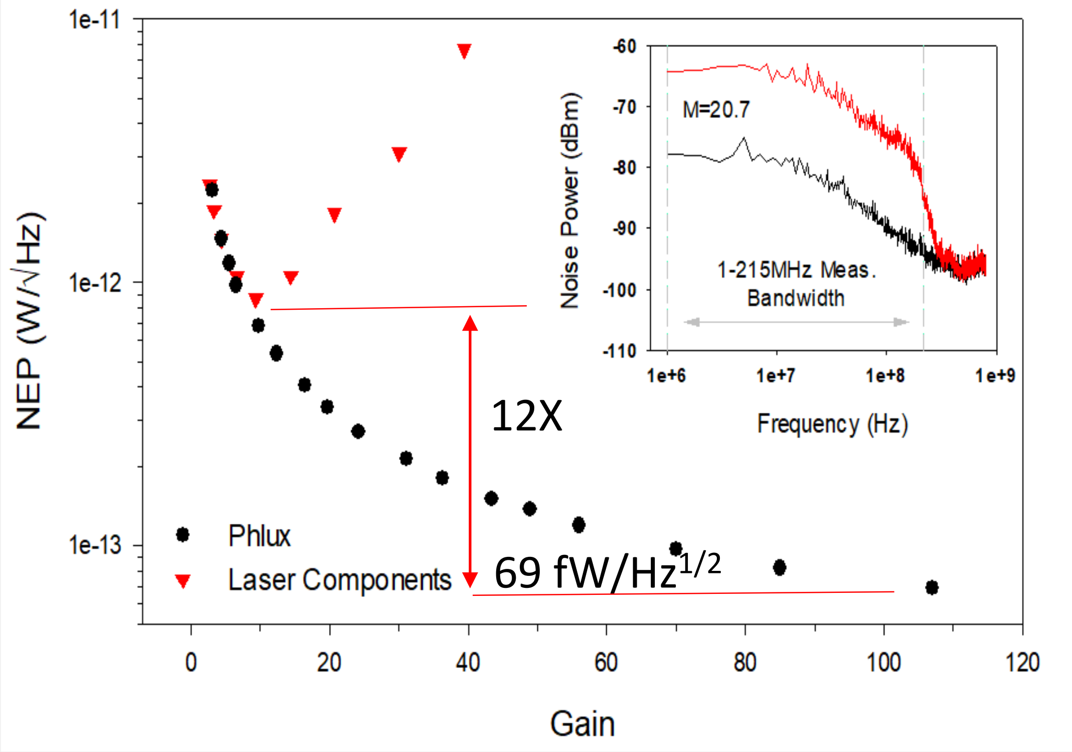




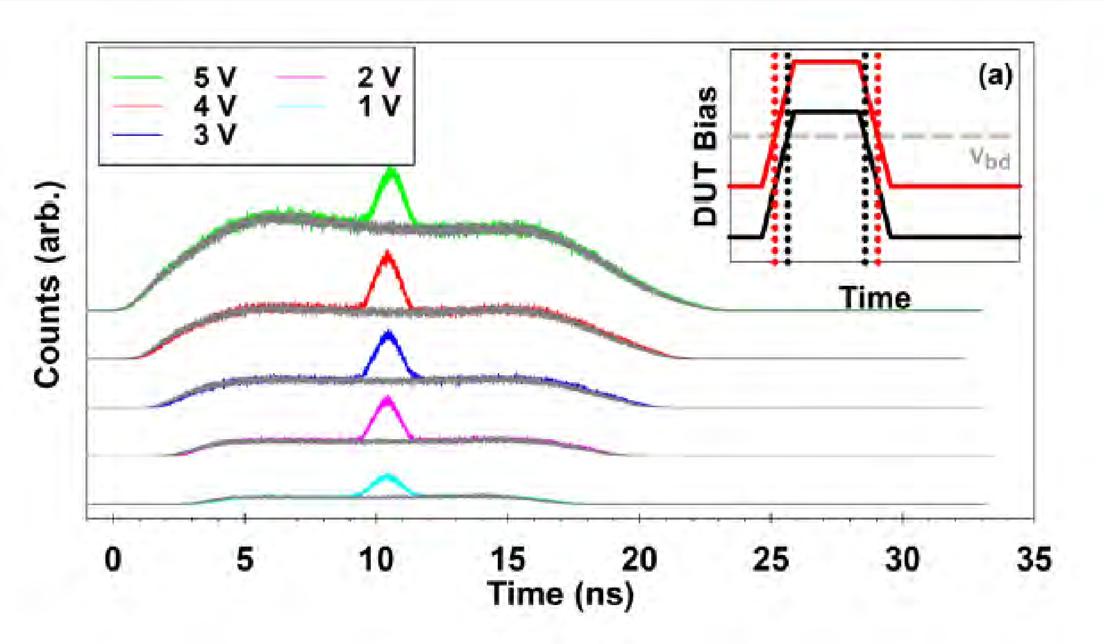


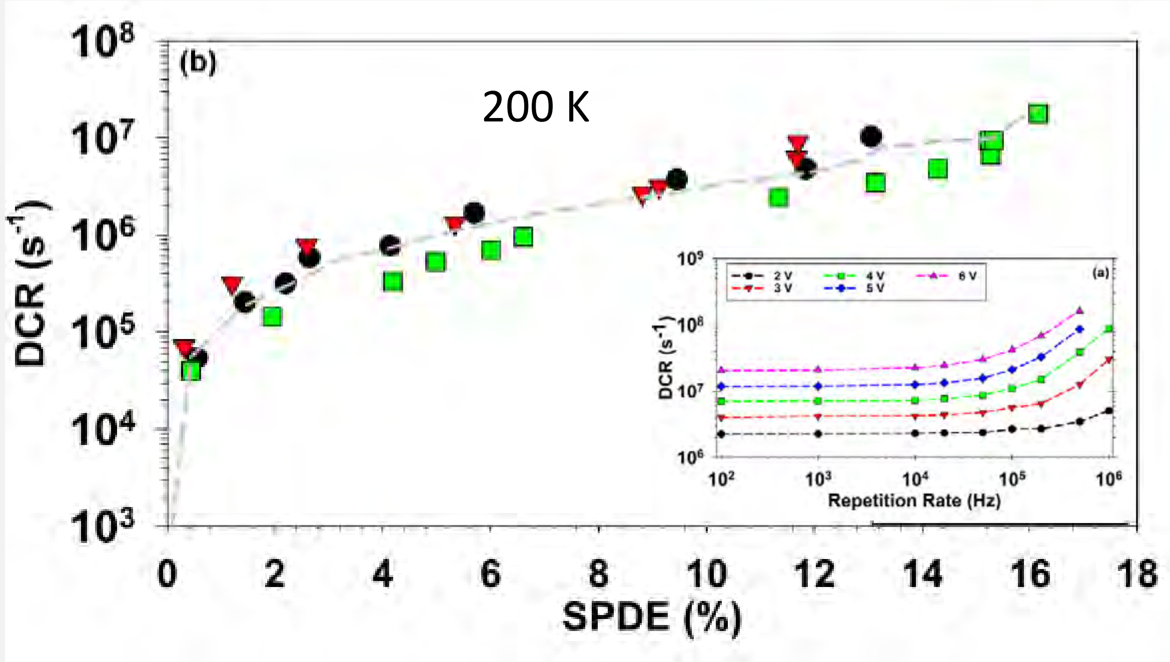


State-of-the-art performance Room temperature NEP



Single photon detection





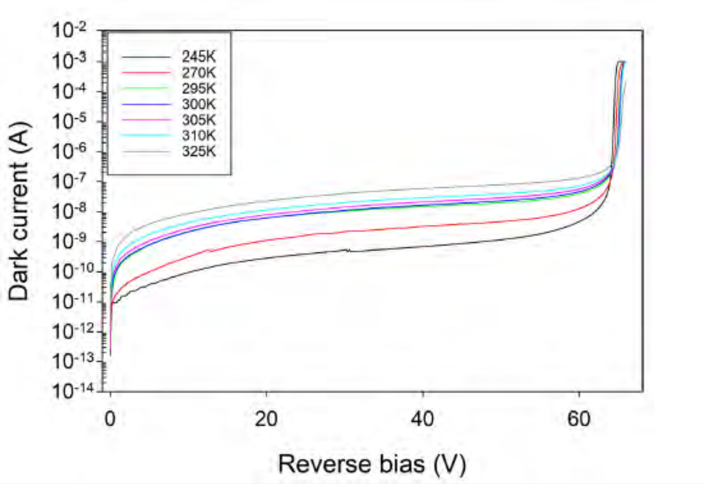
1994 IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 71, NO. 3, MARCH 2024

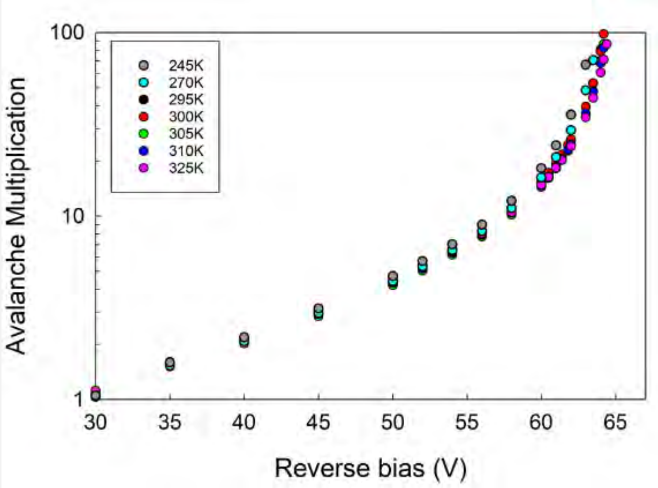
Development of InGaAs/AlGaAsSb Geiger Mode Avalanche Photodiodes

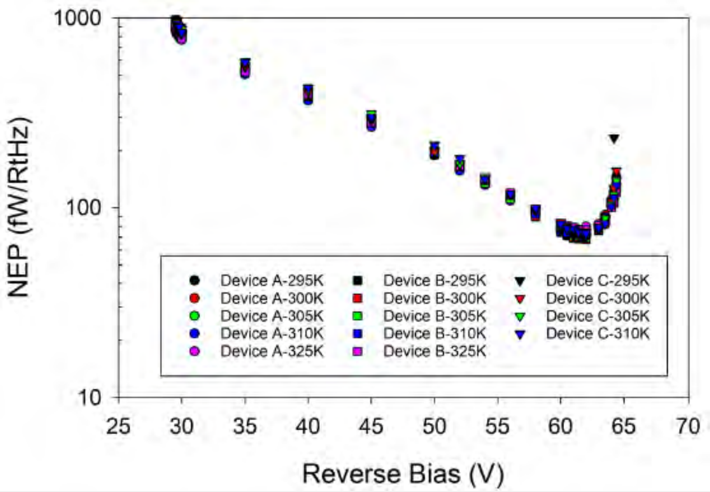
J. Taylor-Mew, X. Collins, B. White, C. H. Tan, *Senior Member, IEEE*, and J. S. Ng, *Member, IEEE*

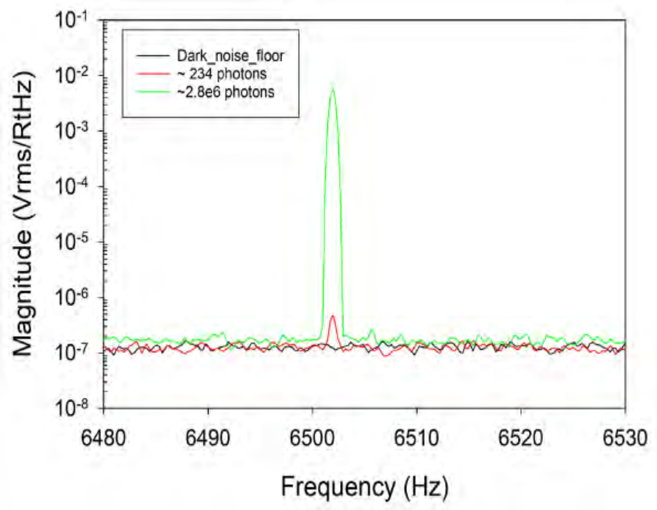
- Clear single photon pulses detected, with increasing overbias
- SPDE ~ 16% at 200 K (1st reported for AlGaAsSb)
- Hold–off time ~ 50 μs at 200 K
- Promising for single photon detection

NEP as a function of temperature (CEOI 15th EO Technology)









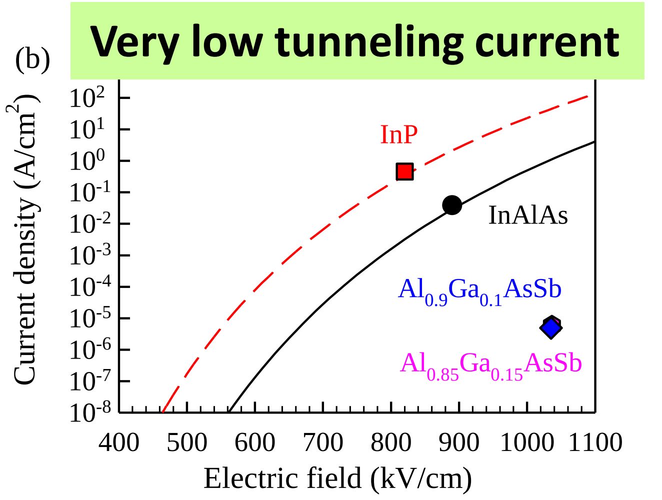
- Breakdown voltage only change by 13.4 mV/K
- Gain is more immune to temperature fluctuation
- When combined with an amplifier with noise of 1 pA/Hz$^{0.5}$, state of the art NEP ~76 fW/Hz$^{0.5}$ obtained.
- Capable of detecting fW optical power, even at 325 K

Device /Temp	295K (fW)	300K(fW)	305K(fW)	310K(fW)	325K(fW)
A	69.5	73.2	72.86	71.45	76.82
B	68.7	67.8	69.3	70.8	76.7
C	70.4	73.7	73.9	73.1	

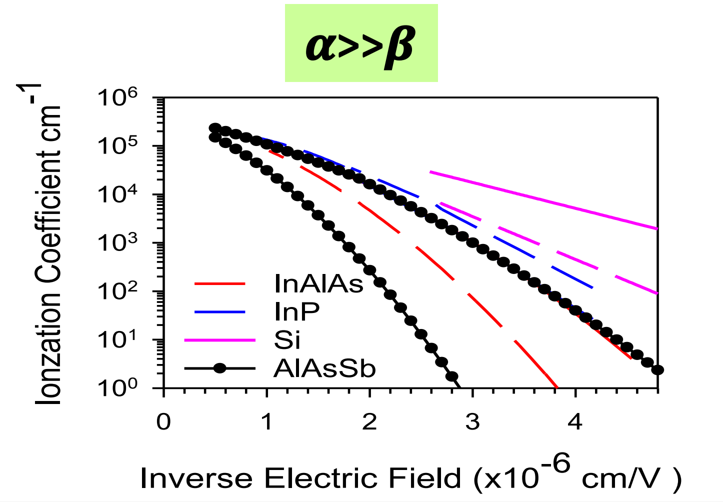
PART 4

Conclusions and Potential Impact

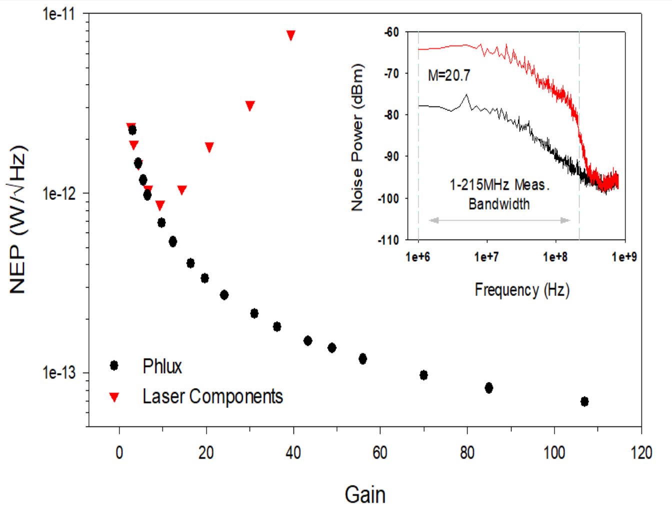
Low noise Al(Ga)AsSb APDs



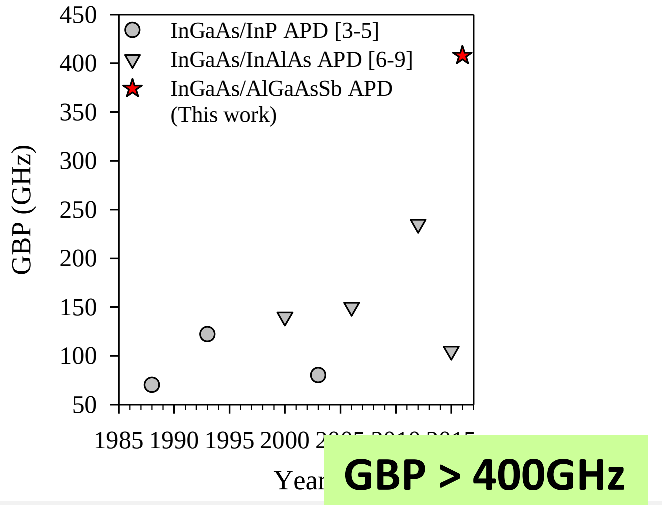
Very low tunneling current



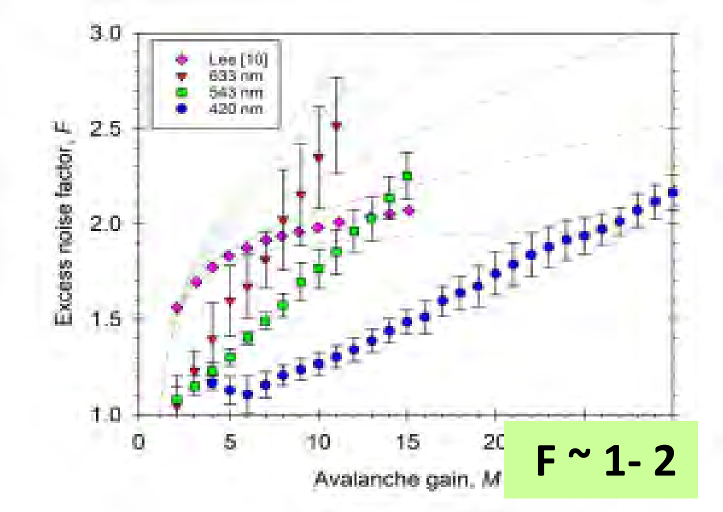
$\alpha >> \beta$



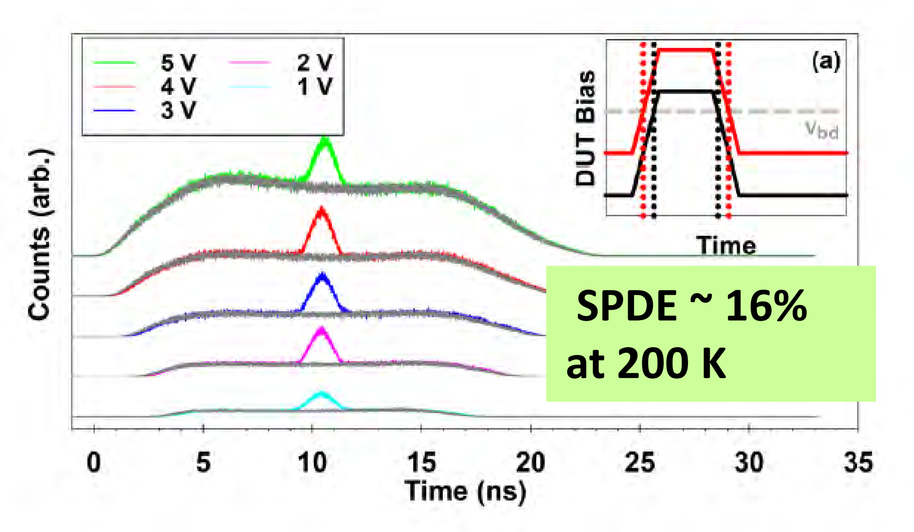
State-of-the-art InGaAs/AlGaAsSb APDs



GBP > 400GHz



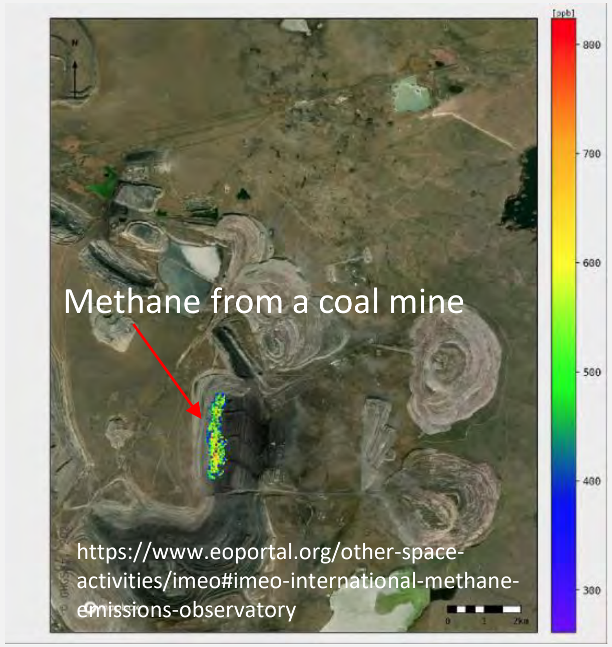
F ~ 1- 2



SPDE ~ 16% at 200 K

Predicted Impact

Missions: Gas sensing LIDAR
-CO_2 (1570 nm) and CH_4 (1650 nm).
-MERLIN (Methane Remote Sensing Lidar Mission).. Launch 15 Feb 2028
-Copernicus Anthropogenic CO2M (Carbon Dioxide Monitoring) Mission. ESA mission launch date TBC
-CO2Image.. Launch 2026



Methods envisaged:
-Differential LIDAR, lightweight uncooled APD with <100 photon sensitivity (fW)
-Switch between linear mode and photon counting to expand dynamic range
-Improved imaging through obscurant (fog) when using Time-of-flight single photon detection

Science:
-Improved large area monitoring of greenhouse gases, high sampling rate?
-Combined with optical free space communication? satellite to satellite, satellite to ground

Commercial:
-UK APD supplier: Phlux
-Cost reduction

PHLUX

THANK YOU

QUESTIONS??