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# The development of high gain InAs electron-APDs

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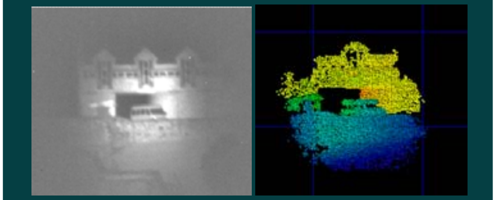
## Introduction

Avalanche photodiodes (APDs) are used to increase the sensitivity of light detecting systems. They are well established in visible and near IR applications, in particular telecommunications. For detection beyond 1.7µm only recently developed CdHgTe (CMT) ADPs are available; these present a costly option with limited availability. Over the last three years we have developed InAs APDs as a III-V based alternative.

All APDs contribute to system noise, however this can be minimised if only one carrier type, electrons or holes, undergoes avalanche gain. The relative gain of electrons and holes depends on the material properties. CMT was the only material shown to have ideal properties, however our work has shown that InAs also matches the theoretical ideal. This opens up ideal APD characteristics to a larger community through the more widely available III-V material system.

## Applications

Our work is focussed on focal plane array (FPA) applications for active and discriminative imaging, where low photon fluxes must be detected. CMT APD FPAs have been successfully used by SELEX in active and 3D imaging systems. InAs APD FPA's could offer similar performance with lower cost and higher operating temperature.



3D imaging from Baker et al. Proc. of SPIE Vol. 6940 69402L-4

Benefits of InAs APD FPAs:

- Use lower power sources for active imaging
- Reduce size and weight of optics
- Option of enhanced covertness by imaging beyond the 1.7µm cut-off of InGaAs cameras

Other applications include $CO_2$ monitoring at ~2µm

## Targets

Operating voltage < 10V, with gain > 10
Excess noise F = 2
Operating temperature > 200K
Quantum efficiency > 60%
High wafer uniformity

Potential advantages compared to emerging CMT e-APD FPAs are operating temperature and cost.

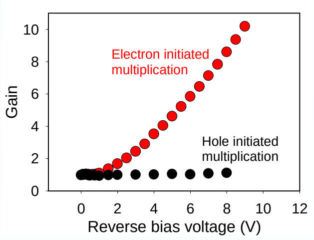
Minimal prior work makes realising the potential of InAs e-APDs technologically challenging.

EMRS DTC
Electro Magnetic Remote Sensing Defence Technology Centre

## Key InAs e-APD characteristics

### Only electrons contribute to gain

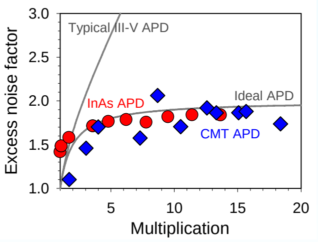
InAs and CMT are unique in exhibiting theoretically ideal APD characteristics where only one carrier type contributes to avalanche gain.



Ideal avalanche gain characteristics

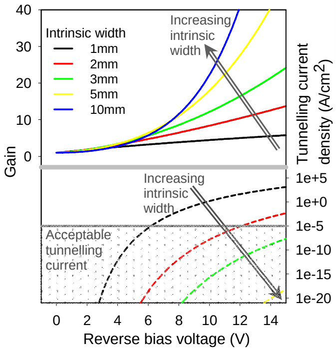
### Ideal theory matching low noise

Electron only avalanche multiplication results in the predicted extremely low excess noise, matching the theoretical optimum



### Unique low field multiplication in thick diodes gives increased gain and reduced tunnelling current

InAs e-APDs exhibit unique low field multiplication which redefines the established trade-off between reduced operating voltage and increased tunnelling current. Typically increasing tunnelling current defines the lower limit for operating voltage. However increasing the intrinsic region width of a p-i-n type InAs APD can increase gain and reduce tunnelling current and operating voltage. This can be exploited to achieve high gain at low operating voltages below 10V.



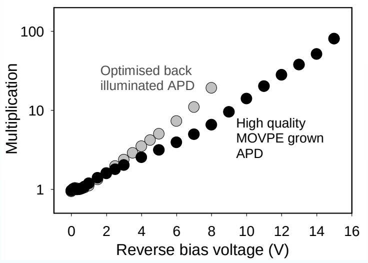
***Established APD trade-off***

- Reduce multiplication width
- Reduce operating bias
- Increase electric field
- Increase tunnelling current

***InAs APD trade-off***

- Increase multiplication width
- Reduce operating bias
- Reduce electric field
- Reduce tunnelling current

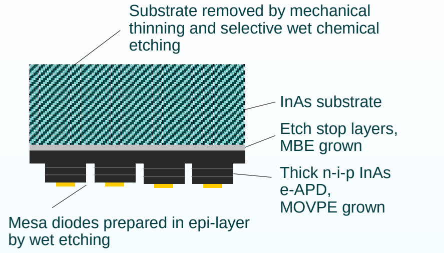
## Realising high gain InAs e-APDs



### Record high gain at low voltages

Realising the predicted high gain requires background doping levels below $1x10^{15}$ /cm$^3$, so the wide intrinsic layer can deplete. Achieving this and good material quality during the thick growths is challenging. MOVPE growth development enabled high gain InAs e-APDs.

Where material quality was high, gains > 100 were achieved at 300K. With further development InAs e-APDs could make excellent single photon detectors



Substrate removed by mechanical thinning and selective wet chemical etching

InAs substrate

Etch stop layers, MBE grown

Thick n-i-p InAs e-APD, MOVPE grown

Mesa diodes prepared in epi-layer by wet etching

### Structure optimised for substrate removal and back illumination

An MBE grown etch stop was combined with a thick diode structure grown by optimised MOVPE. Using new fabrication techniques developed during the program diodes were fabricated, the substrate was removed and high gain was demonstrated with back illumination for the first time in InAs e-APDs.

## Conclusions

InAs e-APDs are electrically unlike other III-V APDs. Their characteristics match the essentially ideal performance of CMT e-APDs, and make this available to the III-V community. Furthermore unique low field gain leads to a win-win trend towards higher gain and lower tunnelling which can be exploited in thick p-i-n type structures.

Development of growth and fabrication techniques has made it possible to start realising practical InAs e-APDs. The latest work further developed the theory and technology culminating in the demonstration of record high gains with FPA style back illumination after substrate removal.

## Future work

Further funding will be sought to continue the fabrication development required to eliminate surface leakage at low temperatures; using passivation or planar structures.

It is targeted to produce and distribute robust single element InAs e-APDs for testing by collaborators.