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3 MeV Proton Irradiation Study of Ultra-thin GaAs Solar Cells

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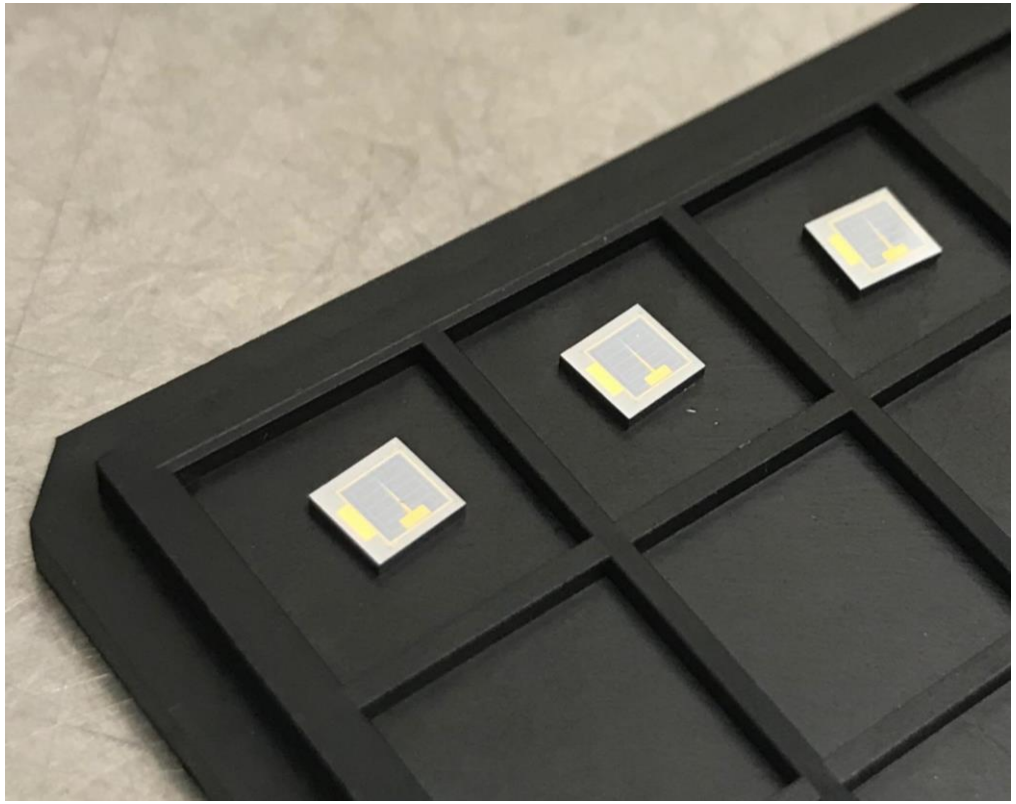
Overview

- Background
- Device design
- Fabrication process
- Results
  - Pre-exposure electrical characterisation
  - 3 MeV proton irradiation
- Conclusions
- Future work



Background

- Outside of the Earth’s protective atmosphere there are regions with high levels of damaging radiation
- Satellite mission lifetimes are limited by radiation damage of solar arrays
- Radiation tolerant solar cells could open up currently inaccessible orbits and space missions

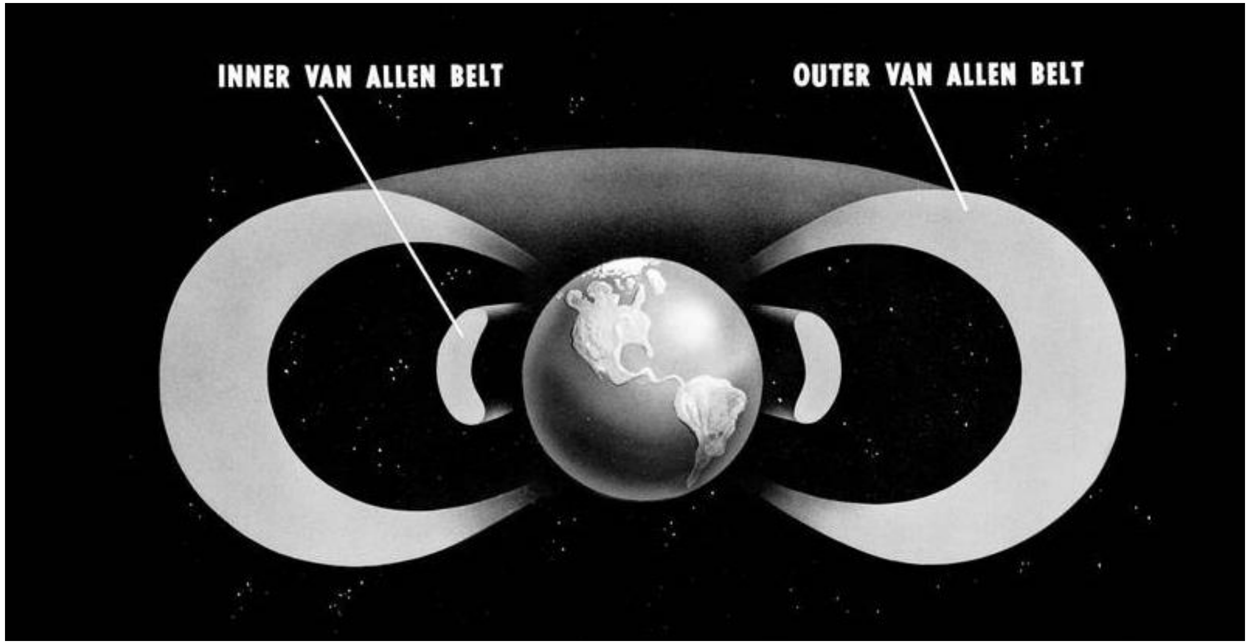
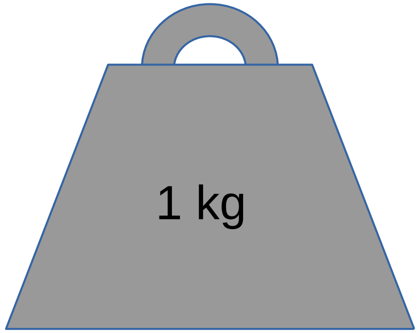


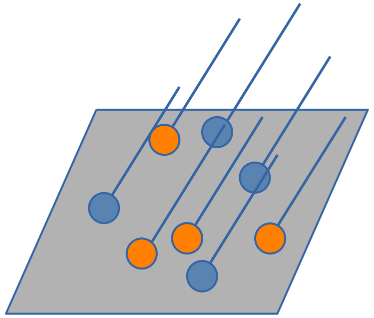
Image source: NASA

Background

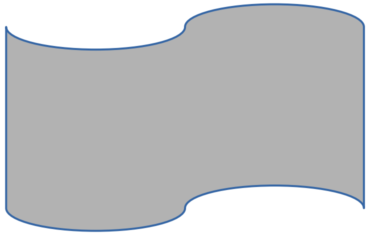
Key metrics/attributes of space photovoltaics:



High specific power



Radiation tolerance



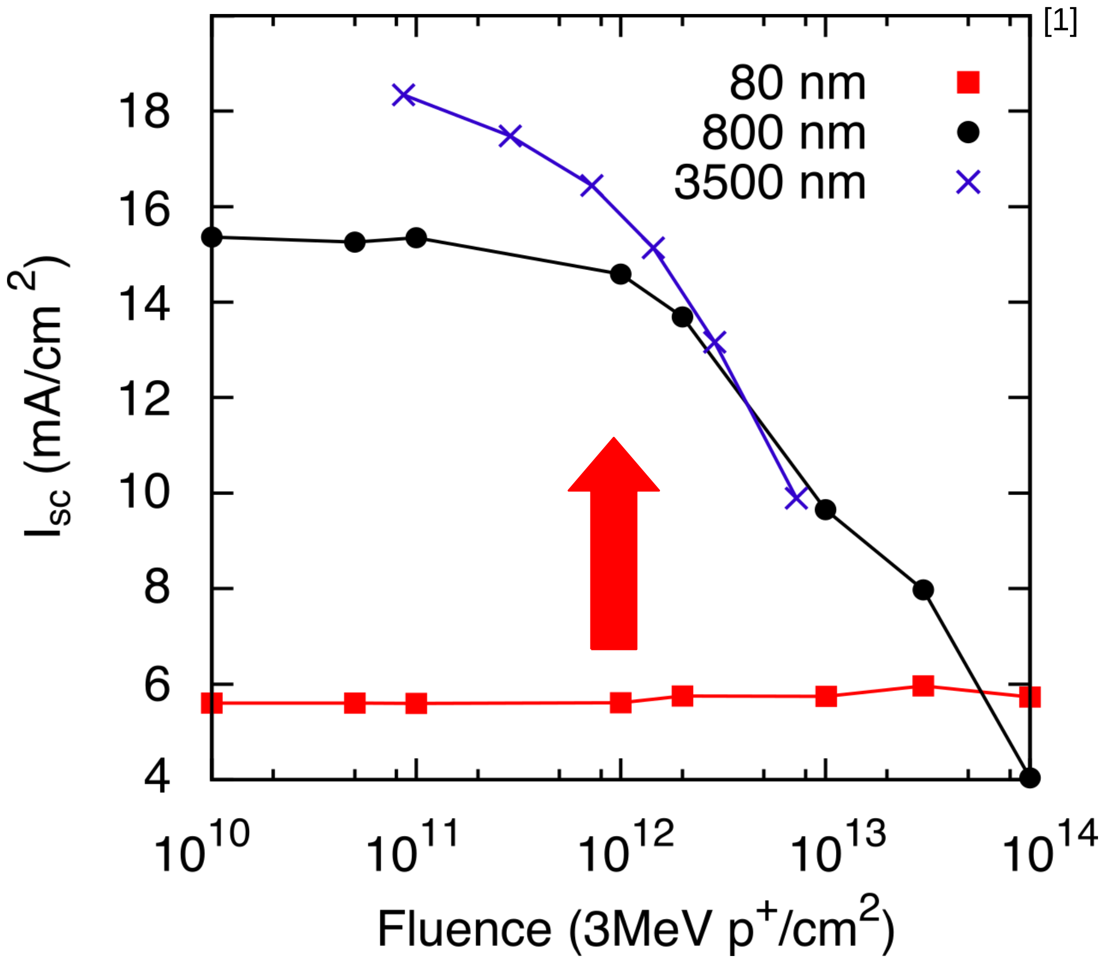
Flexible form factors

Background - Ultra-thin solar cells

- Ultra-thin (<100 nm absorber layer) solar cells have shown intrinsic radiation tolerance[1]
- High transmission losses need to be mitigated
- Previous studies have achieved 19.9% AM1.5 efficiency for a 205 nm GaAs absorber layer with an integrated light-trapping layer[2]

[1] L. C. Hirst *et al.*, “Intrinsic radiation tolerance of ultra-thin GaAs solar cells,” *Appl. Phys. Lett.*, 2016.
[2] H-L. Chen *et al.*, “A 19.9%-efficient ultrathin solar cell based on a 205-nm-thick GaAs absorber and a silver nanostructured backmirror,” *Nature Energy*, 2019.

Ultra-thin solar cells



Goal: Boost absorption while maintaining radiation tolerance through the use of a nanophotonic light-trapping layer

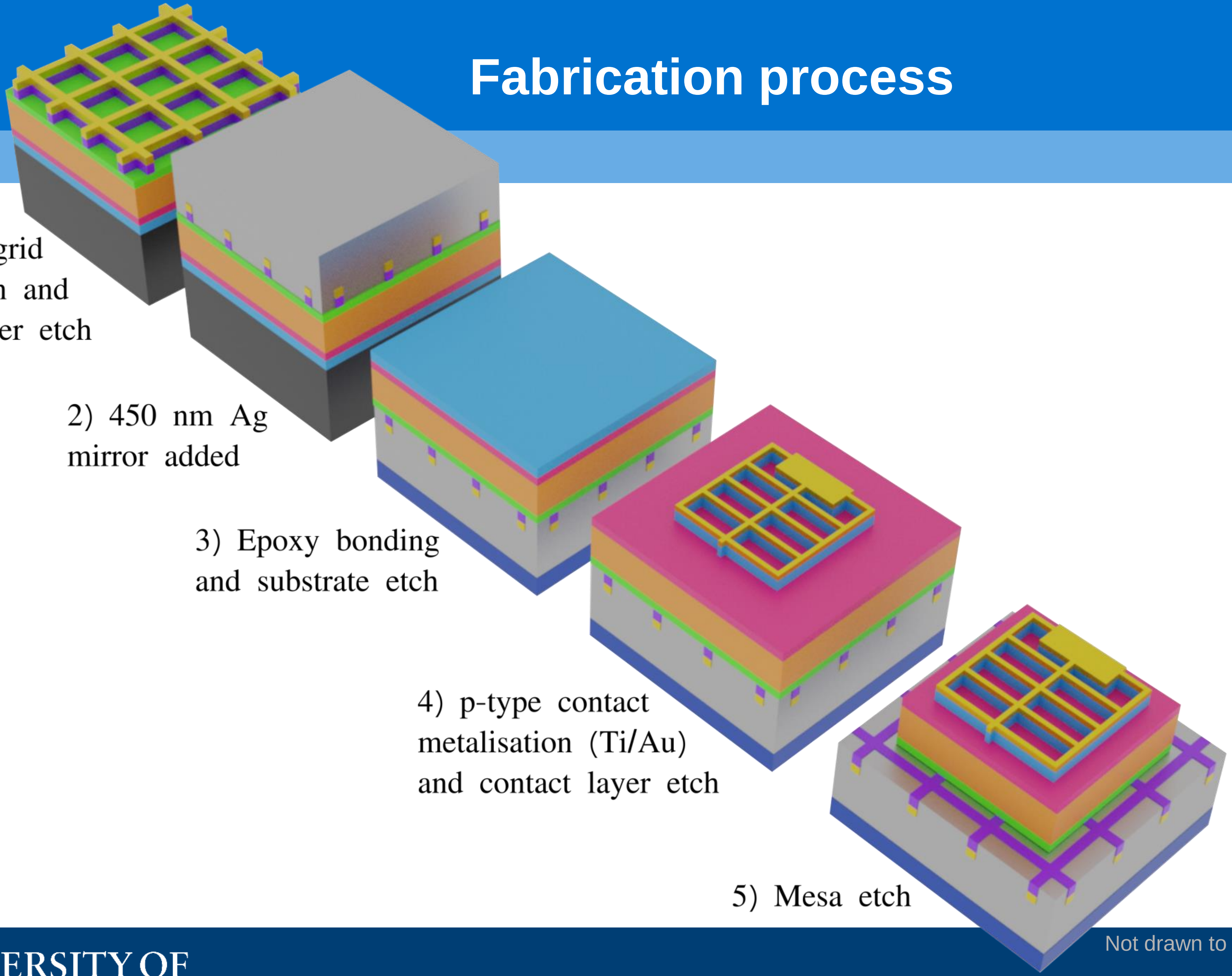
[1] L. C. Hirst *et al.*, “Intrinsic radiation tolerance of ultra-thin GaAs solar cells,” *Appl. Phys. Lett.*, 2016.
[3] M. Turowski *et al.*, “Simulating the Radiation Response of GaAs Solar Cells Using a Defect-Based TCAD Model,” *IEEE Trans. Nucl. Sci.*, 2013.

Device design

Table 1: Layer structure of ultra-thin cells as grown by molecular beam epitaxy

Layer	Material	Dopant	Doping density (cm^{-3})	Nominal thickness (nm)	Measured thickness (nm)
n-type contact	GaAs	Si	$5x10^{18}$	300	318
Hole barrier	$In_{0.47}AlP$	Si	$5x10^{18}$	20	17
n-type absorber	GaAs	Si	$1x10^{18}$	40	87
p-type absorber	GaAs	Be	$1x10^{18}$	40	
Electron barrier	$In_{0.49}GaP$	Be	$5x10^{18}$	20	19
p-type contact	GaAs	Be	$1x10^{19}$	25	25
Etch stop layer	InAlP	Be		150	145
Buffer	GaAs	Be		300	
Substrate	p-GaAs				

Fabrication process



1) n-type grid metalisation and contact layer etch

2) 450 nm Ag mirror added

3) Epoxy bonding and substrate etch

4) p-type contact metalisation (Ti/Au) and contact layer etch

5) Mesa etch

Not drawn to scale

Results - Pre-exposure electrical characterisation

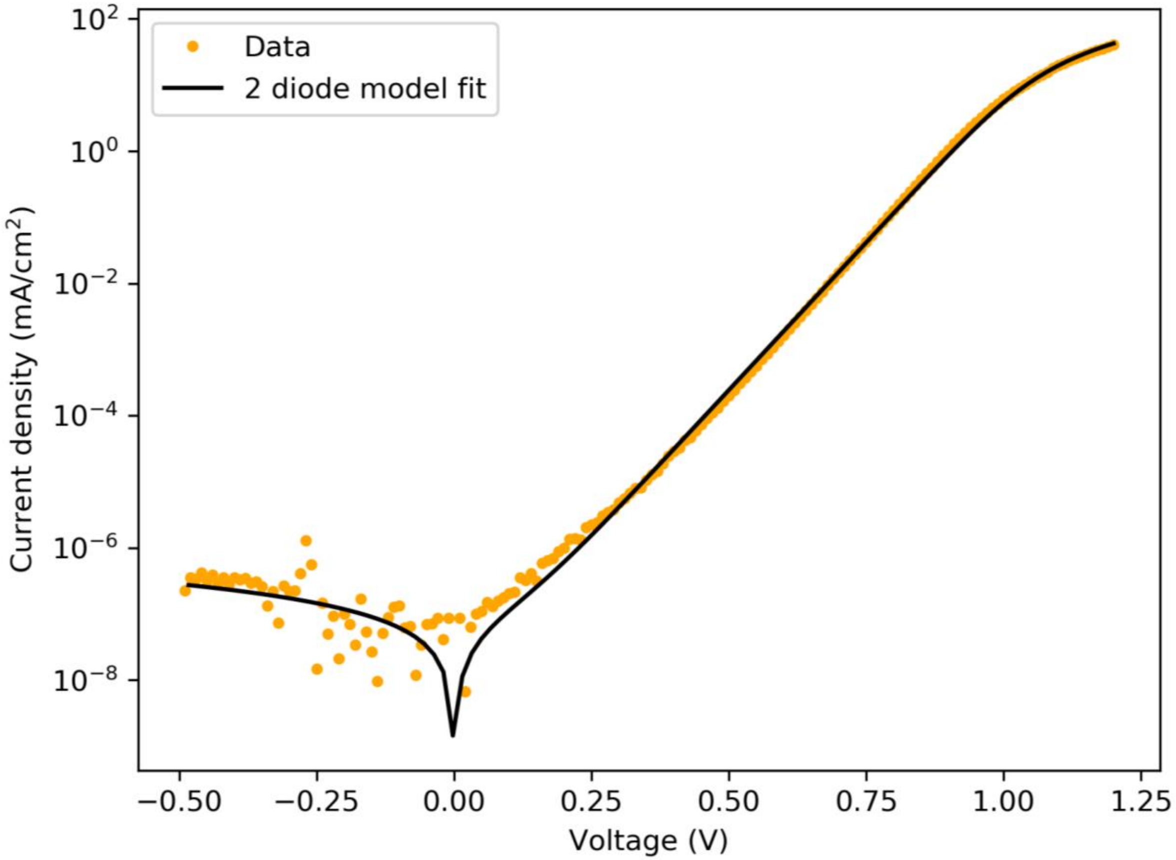


Table 2: comparing off wafer DIV parameters to literature

	Thickness (nm)	J_{02} (mA/cm^2)	R_{ser} (Ohm cm^2)	R_{par} (Ohm cm^2)
Chen [5]	205	4.3×10^{-8}	0.8	2.4×10^{3}
Hirst [1]	800	7.7×10^{-9}	0.99	8.9×10^{7}
	80	1.4×10^{-6}	13.23	3.8×10^{6}
This work	80	6.14×10^{-9}	4.54	4.14×10^{8}

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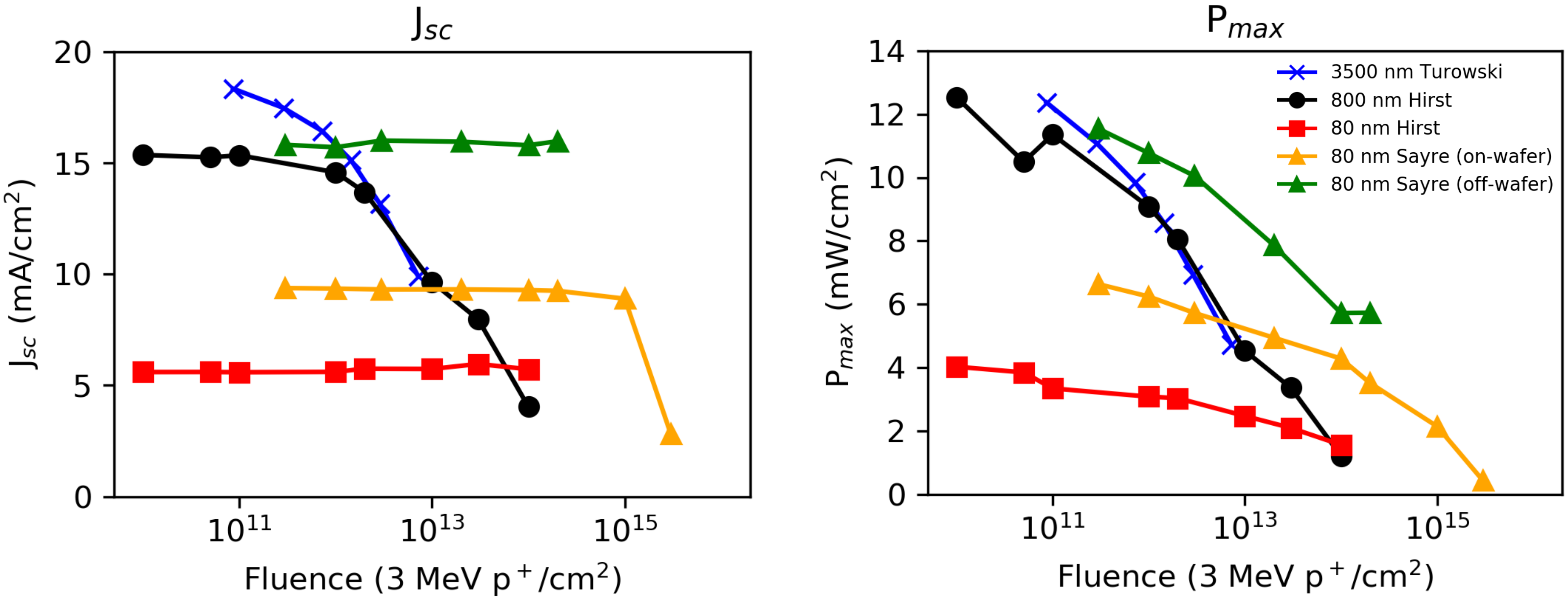
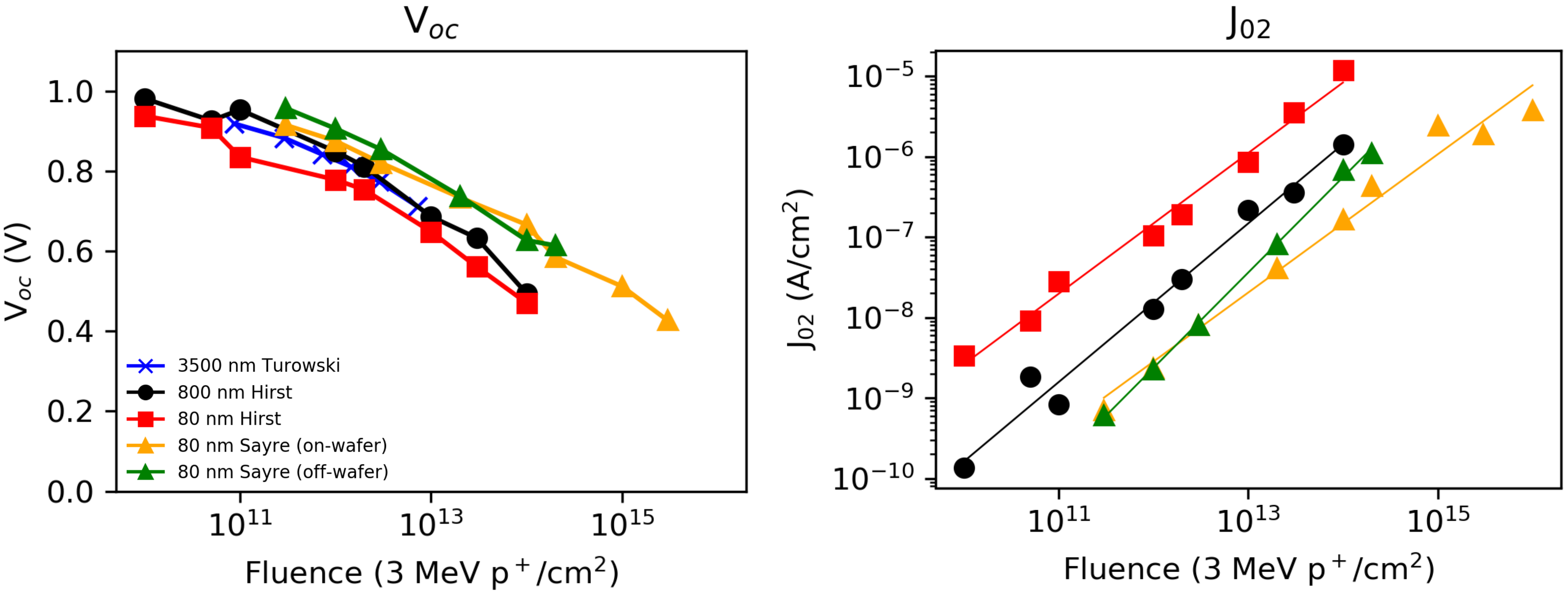
[4] S. Suckow, 2/3-Diode Fit (2014). http://nanohub.org/resources/14300.
[5] H-L. Chen *et al.*, "A19.9%-efficient ultrathin solar cell based on a 205-nm-thick GaAs absorber and a silver nanostructured backmirror," *Nature Energy*, Sep. 2019.

Results - 3 MeV proton irradiation



[3] M. Turowski *et al.*, “Simulating the Radiation Response of GaAs Solar Cells Using a Defect-Based TCAD Model,” *IEEE Trans. Nucl. Sci.*, 2013.
[1] L. C. Hirst *et al.*, “Intrinsic radiation tolerance of ultra-thin GaAs solar cells,” *Appl. Phys. Lett.*, 2016.

Results - 3 MeV proton irradiation



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[3] M. Turowski *et al.*, “Simulating the Radiation Response of GaAs Solar Cells Using a Defect-Based TCAD Model,” *IEEE Trans. Nucl. Sci.*, 2013.
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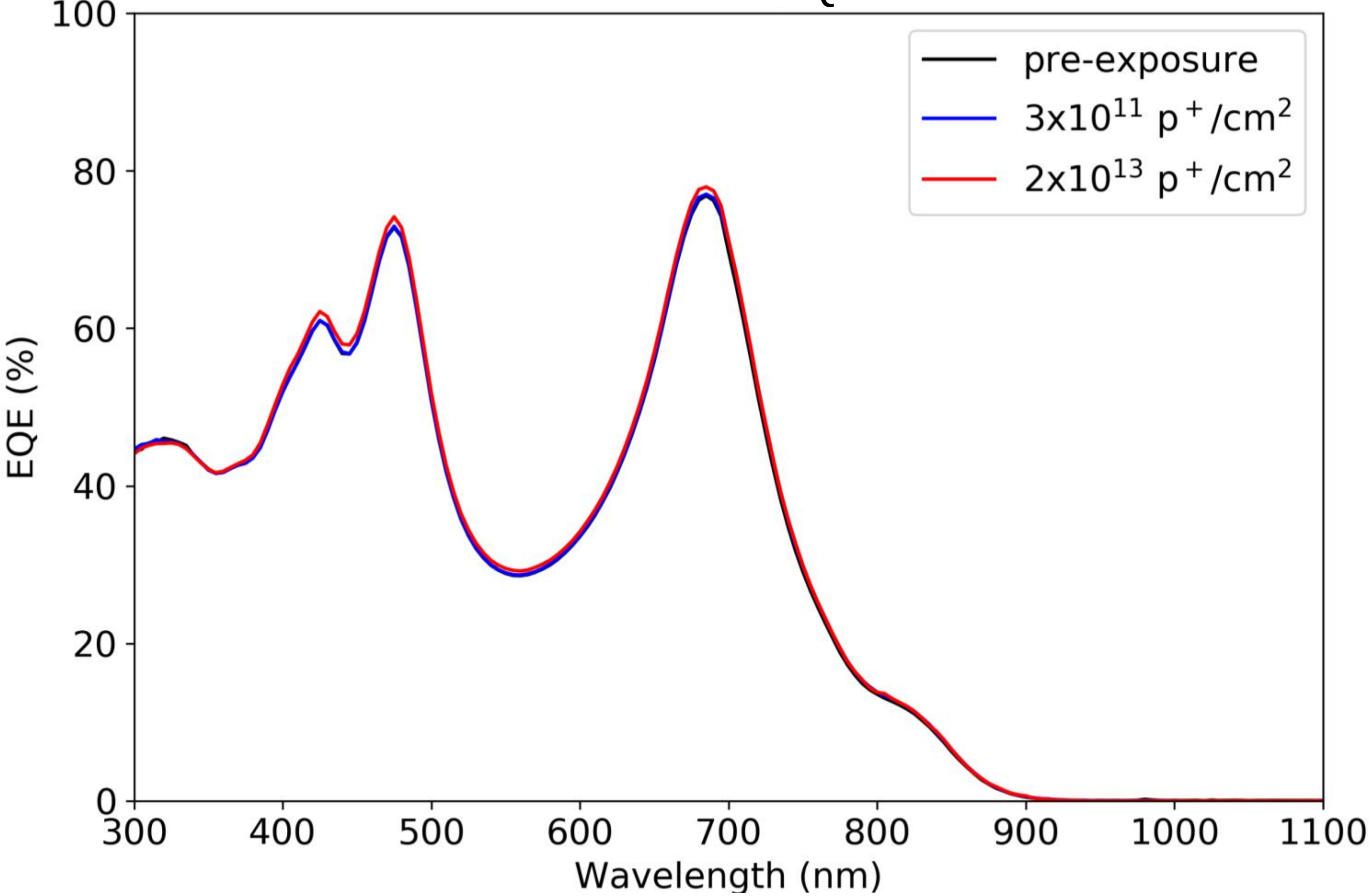
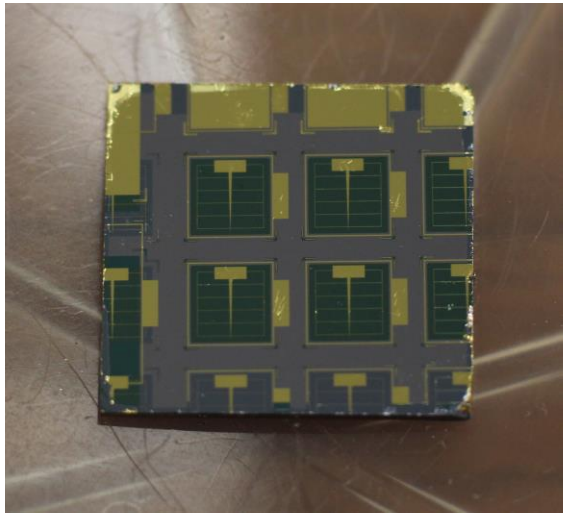
Results - 3 MeV proton irradiation

Off wafer EQE

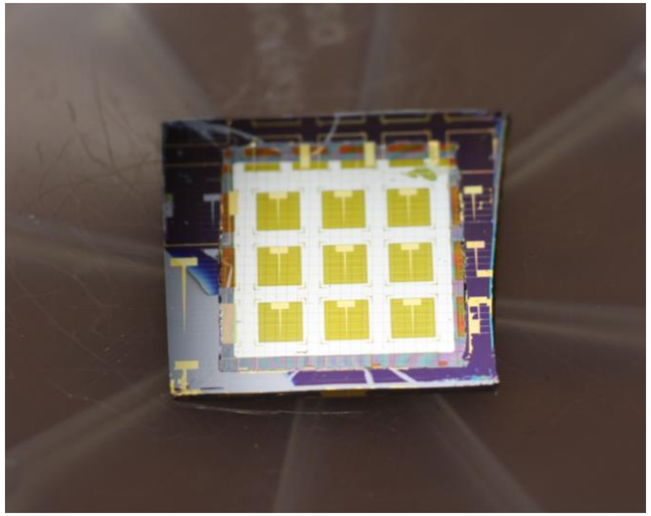


Conclusions

- High levels of radiation tolerance when exposed to high fluences of 3 MeV protons
- Excellent electrical performance: recombination currents and parasitic resistances
- Pathway to 16% AM0 efficiency with nanophotonic light-trapping layer[6]



On-wafer



Off-wafer with planar Ag mirror

[6] L. Sayre *et al.*, “Ultra-thin GaAs solar cells with nanophotonic metal-dielectric diffraction gratings fabricated with displacement Talbot lithography,” *Prog. Photovolt.*, 2022.

Future work

- Integrating nanophotonic light-trapping layer
- Anti-reflection coatings
- Optimisation of bonding process
- Further irradiations at different energies

Thank you for your attention!

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