Space Power Workshop

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Development of nanostructures and light management strategies for radiation hard multi-junction solar cells

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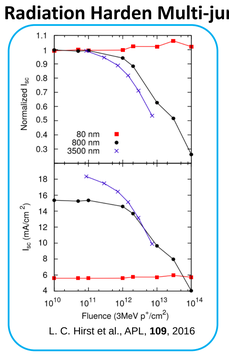
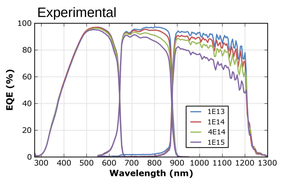
NPRL NANOPOWER RESEARCH LABS

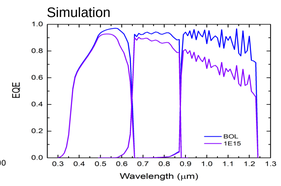
Graphical Abstract

Radiation Harden Multi-junction Space Cells



L. C. Hirst et al., APL, **109**, 2016

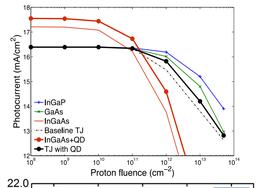




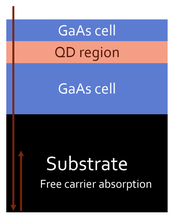
Bottom and middle junctions most susceptible to damage

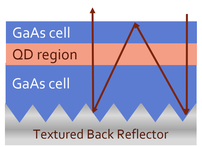
Thin cells maintain (lower) performance at EOL

Light management and nanostrucutres can boost overall performance

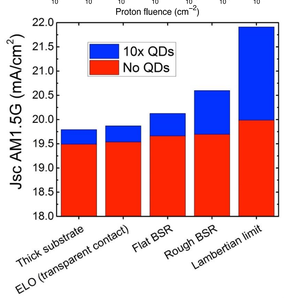


Boost Absorption in Cell Nanostructures

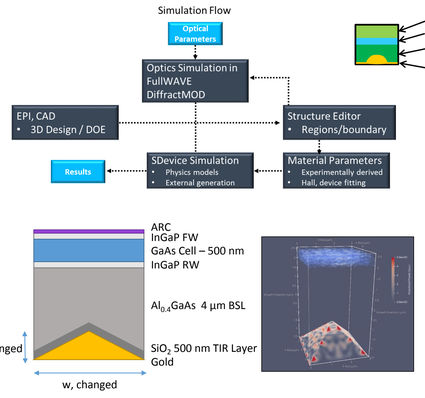




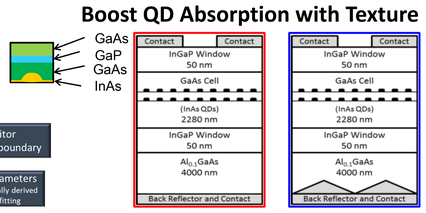
Growing more QD layers can degrade material quality, better to increase path length through dot region.

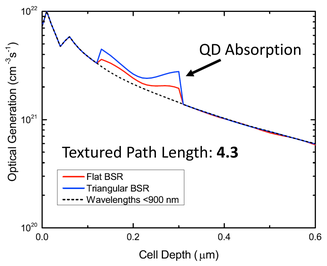


Back Surface Texturing Modeling

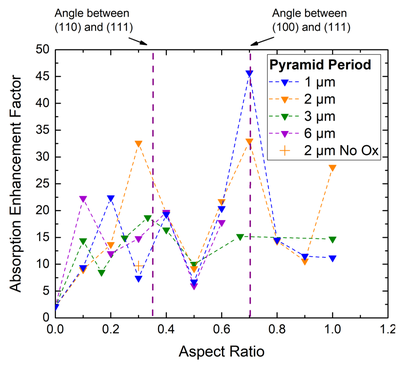


Boost QD Absorption with Texture

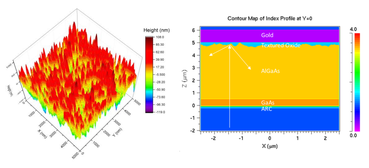




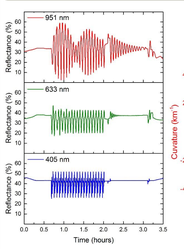
Path Length of 900 nm Light with Texture

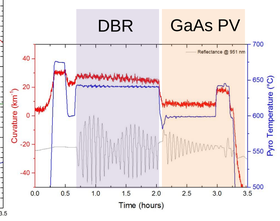


- Pyramidal structures: best case
- Peak OPL enhancement: >40
- Difficult to fabricate
- Random texture OPL: 10



MOCVD Growth





AIXTRON close-coupled showerhead

3x2", 1x3", or 1x4" capability

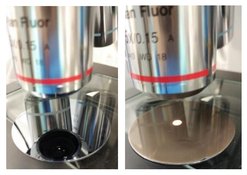
In situ reflectance, pyrometry, curvature

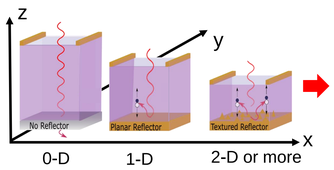
TBAs, AsH_3, PH_3, TMSb

TMAl, TTBAl, TMGa, TEGa, TMIn

DEZn, CCl_4, DETe, Si_2H_6

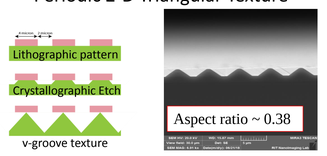
Light Scattering Structures





Higher dimensional scattering will increase OPL within GaAs solar cell.

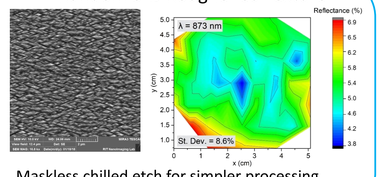
Periodic 2-D Triangular Texture



Requires UV photolithographic processing

- Vertical etch in $NH_4OH:H_2O_2:H_2O$ 1:1:75

Random 3-D Roughened Texture

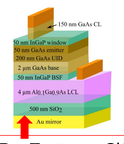


Maskless chilled etch for simpler processing

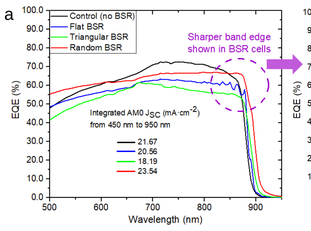
- Etched in $NH_4OH:H_2O_2:H_2O$ 1:4:40 at 2.5 °C

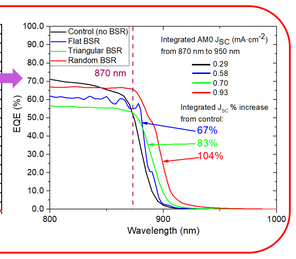
Single Junction with BSR and QDs

The textured BSR cells result in a flat band edge as a result of increased absorption.

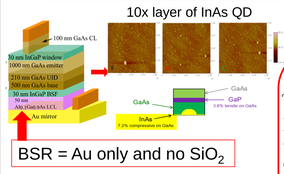


BSR = Texture + SiO_2

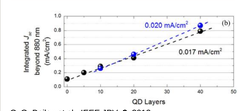




10x layer of InAs QD

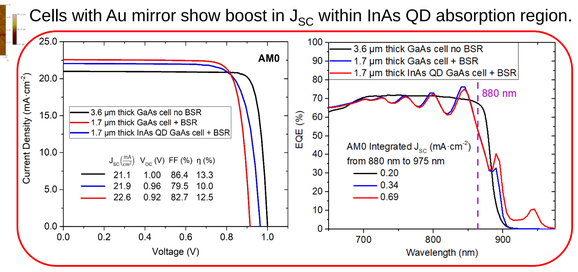


BSR = Au only and no SiO_2



C. G. Bailey et al., IEEE JPV, **2**, 2012

Cells with Au mirror show boost in J_{SC} within InAs QD absorption region.

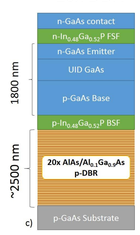


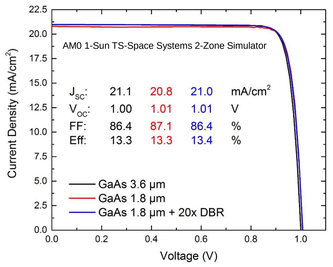
$$\text{OPL} = \frac{0.69\ \text{mA}\cdot\text{cm}^{-2} - 0.34\ \text{mA}\cdot\text{cm}^{-2}}{10\ \text{QD layers} * 0.02\ \left(\frac{\text{mA}\cdot\text{cm}^{-2}}{\text{QD layers in 1 pass}}\right)} = 1.75\ \text{passes}$$

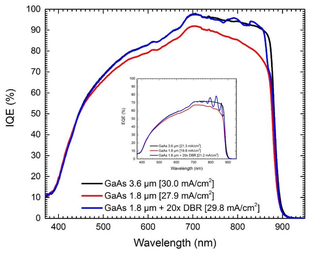
Adding SiO_2 dielectric interlayer could reduce parasitic loss at semiconductor-Au interface.

Single Junction with DBR

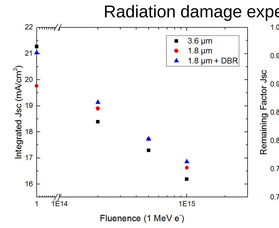
GaAs 1.8 μm + 20x DBR

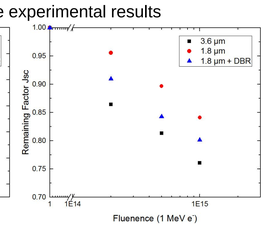




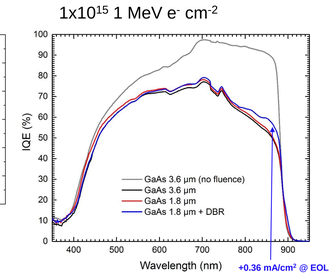


Radiation damage experimental results





1x10^{15} 1 MeV e$^-$ cm^{-2}



1.8 um + DBR device enhances performance in both remaining factor and absolute J_{SC} at EOL

Acknowledgements

STTR: FA9453-15-C-0404

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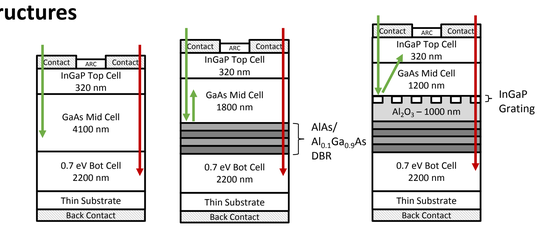
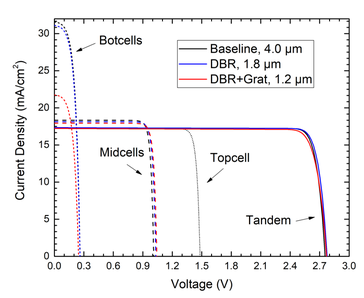
Anastasiia Fedorenko

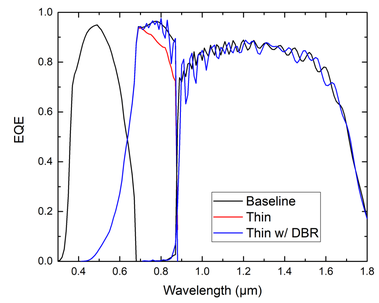
Multijunction Light Management Modeling

Simulated Structures

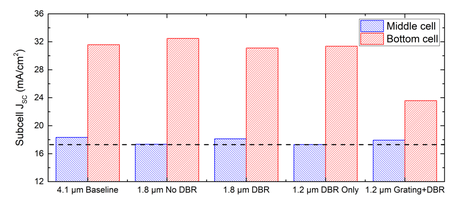


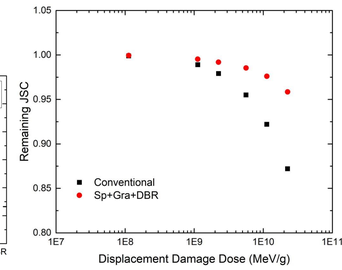
Simulated IV & EQE



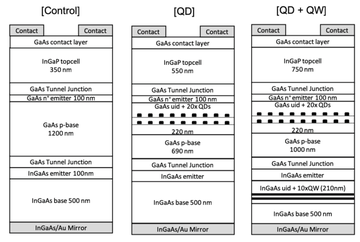


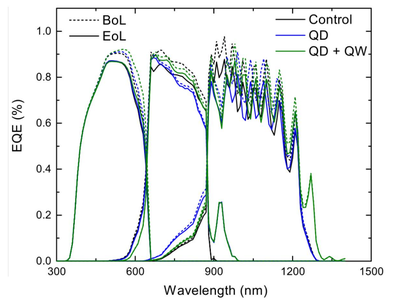
Current Matching With DBR - Subcell J_{SC}





Nanostructured Multijunction Modeling





Incorporation of nanostructures in both middle and bottom junction enhances EOL performance

Experimental Validation

S. R. Tatavarti et al., Sol. Mat., **185**, 2018

Conclusions

- Light management model allows for arbitrary 3D light management structures, integrates physics-based optical and electronic simulations.
- Developed maskless rear random texturing for GaAs with improved near-bandgap collection and rear reflector increasing OPL in nanostructures by 1.75x.
- Experimental validation of thin cell + DBR allows for thinned cells with improved 1x10^{15} 1 MeV e$^-$ cm^{-2} EOL J_{SC} by > 4% vs thick control.
- Multi-junction with light management structures and nanostructures can work in unison for further improvements via current matching and EOL design.