Laser-Crystallised Thin-Film Polycrystalline Silicon Solar Cells

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UNSW AUSTRALIA

Never Stand Still | Faculty of Engineering | School of Photovoltaic and Renewable Energy Engineering

Australian Government
Australian Renewable Energy Agency

SUNTECH BE UNLIMITED

Contents

- Introduction – motivation for thin-film
- Thin-film PV technologies
- Diode laser crystallised thin-film pc-Si
  - Material and device preparation
  - Intermediate layers
  - Stability
  - Other current work
  - Near-term priorities for future work
  - Long-term priorities for future work

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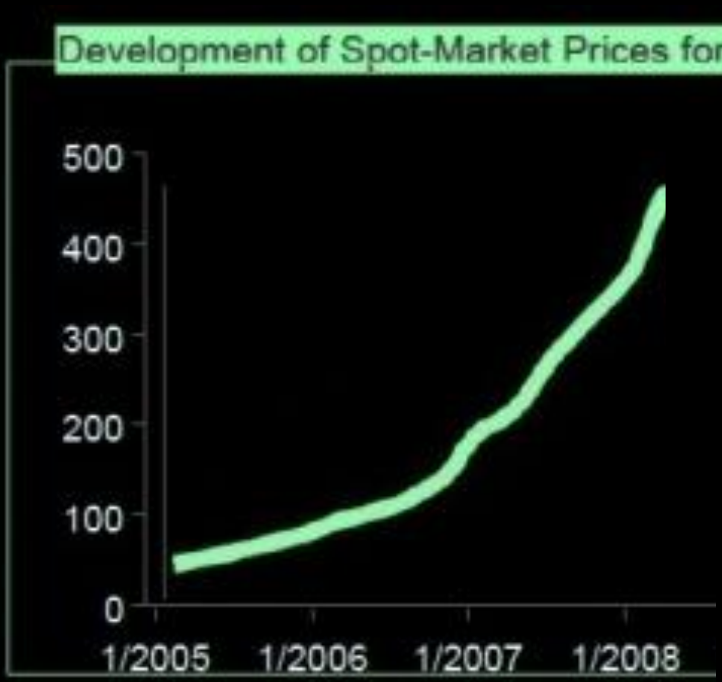
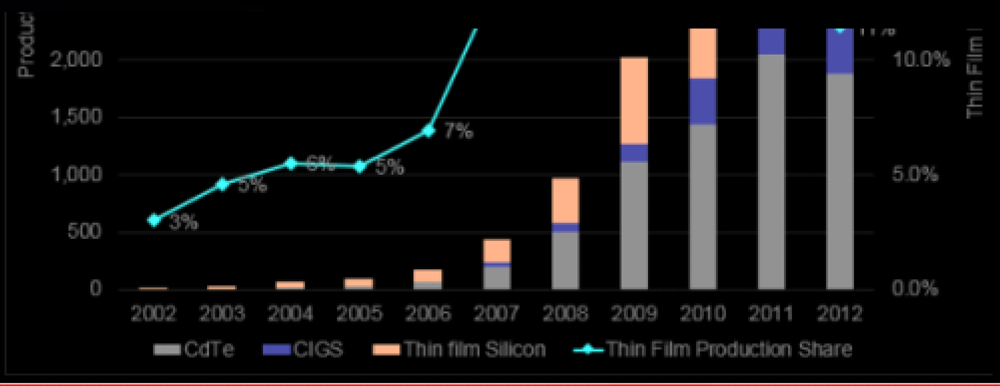
1. Introduction





GTM Research

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2. Thin-Film PV Technologies

- Commercial
  - CdTe
  - CIGS
  - a-Si/μc-Si
- Research
  - CZTS
  - OPV
  - Thin crystalline silicon
    - Wafer transfer
    - Thin polycrystalline

3. Thin Polycrystalline Si

- Solid Phase
  - SPC
  - AIC
- Liquid Phase
  - ZMR
  - EBC
  - LC
    - UV
    - Visible
    - IR

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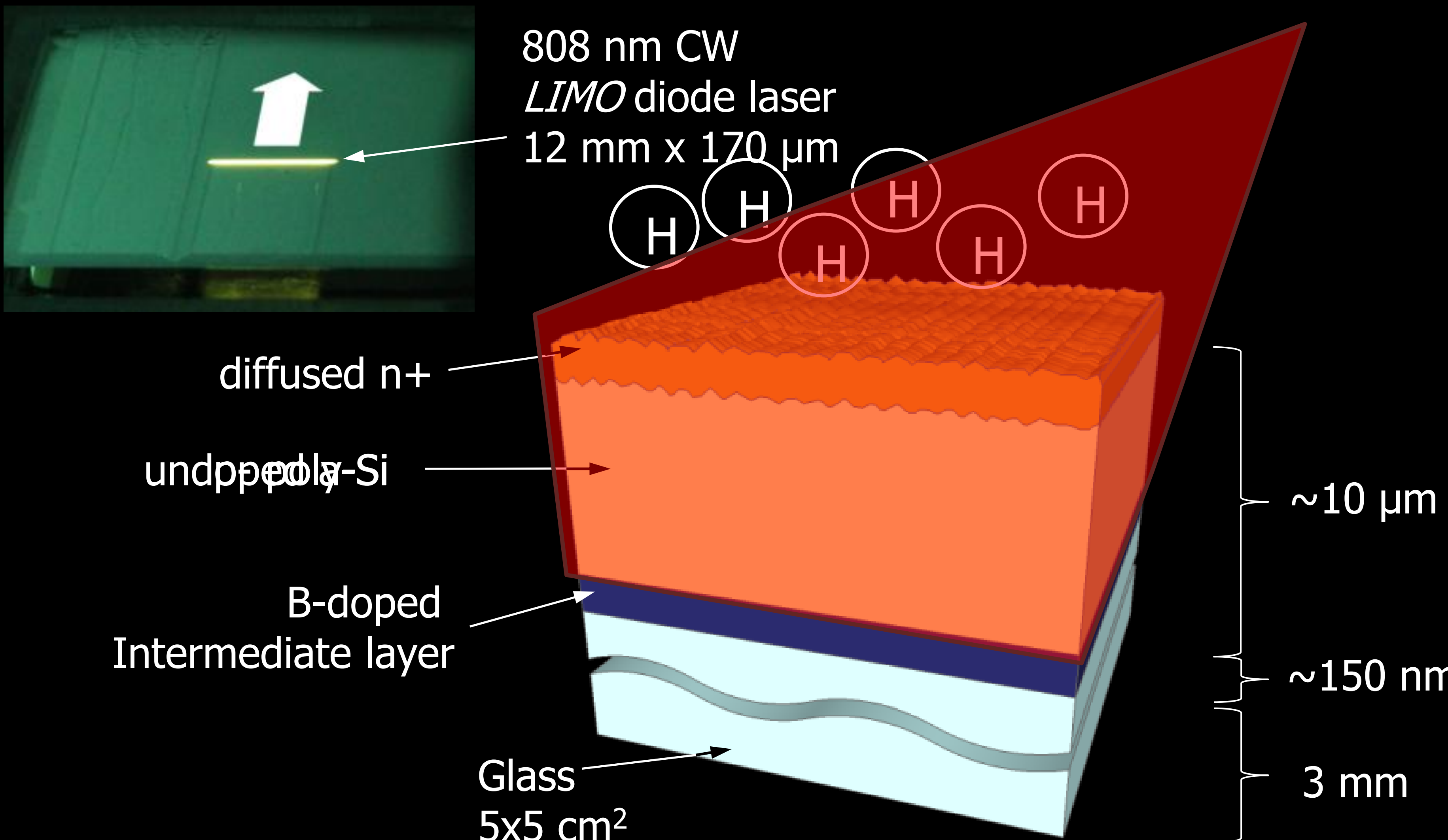
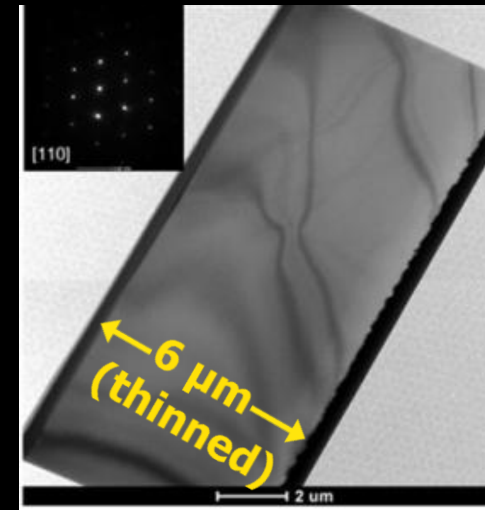
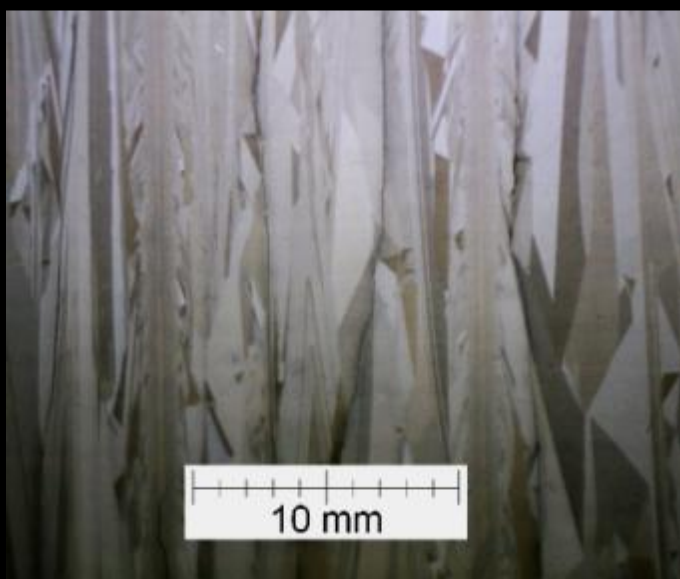
4. Material Preparation



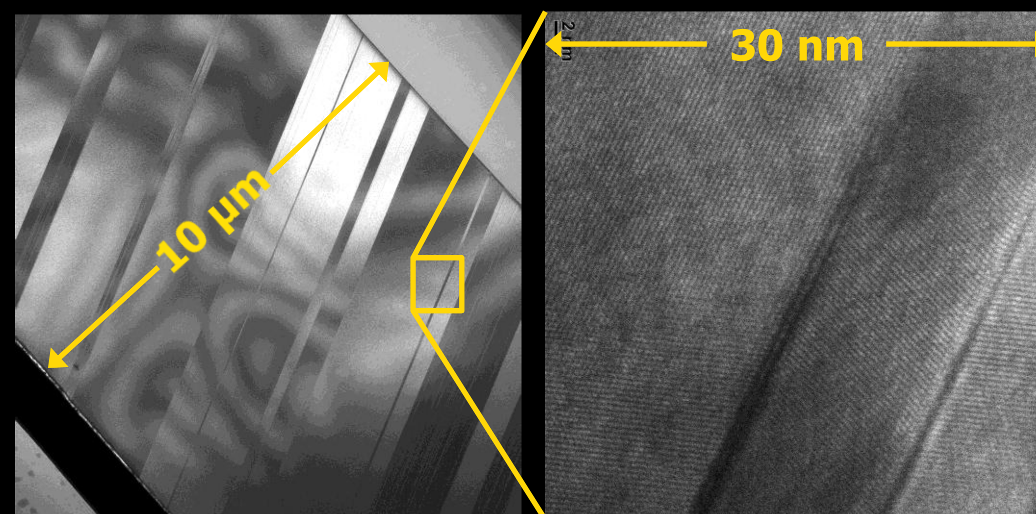
5. Grain structure

- Many Σ3 twin boundaries
- Defect density < 5e7 cm^{-2}
- Mobility of 300-450 at ~1e16 cm^{-3}



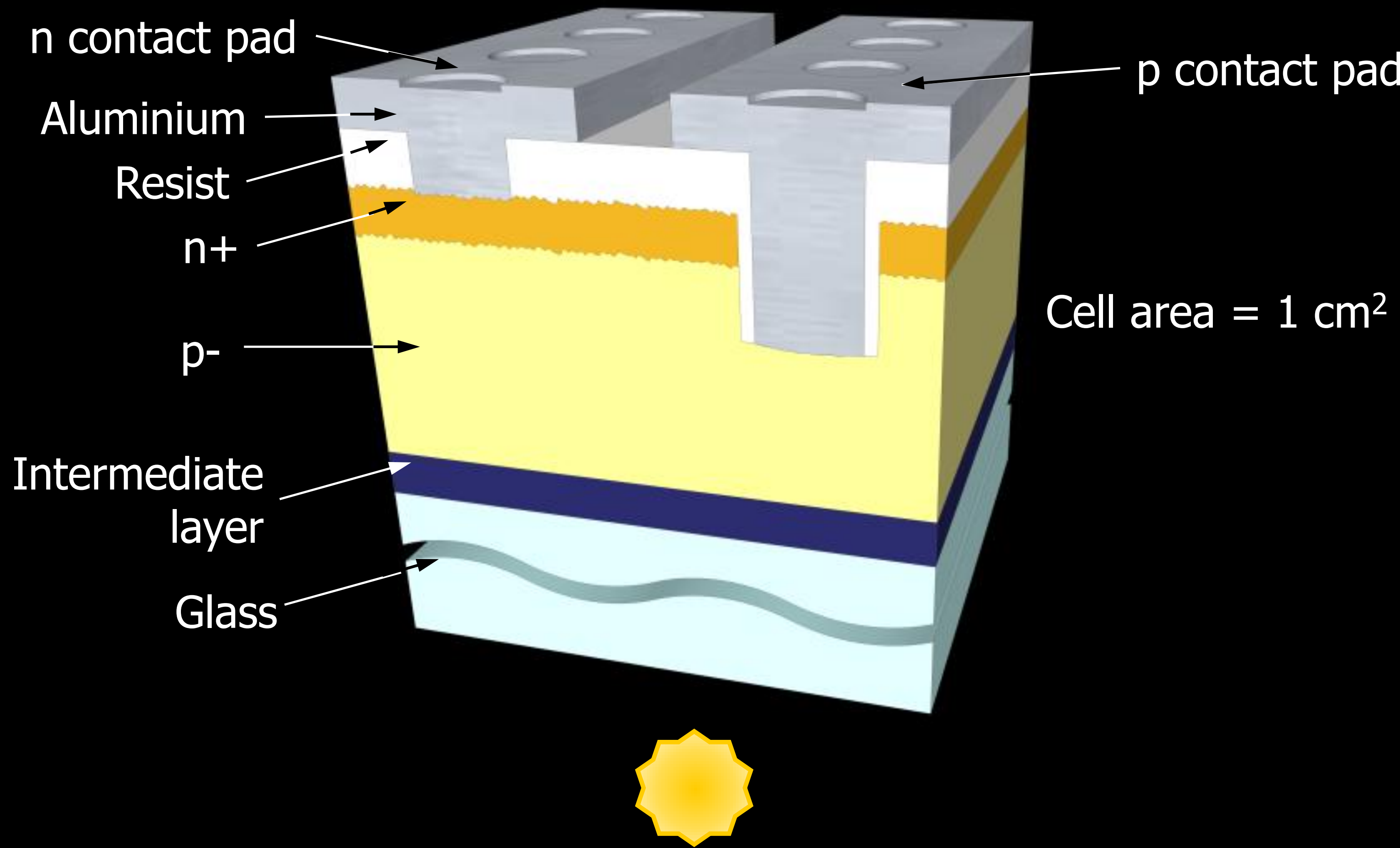


Optical microscope

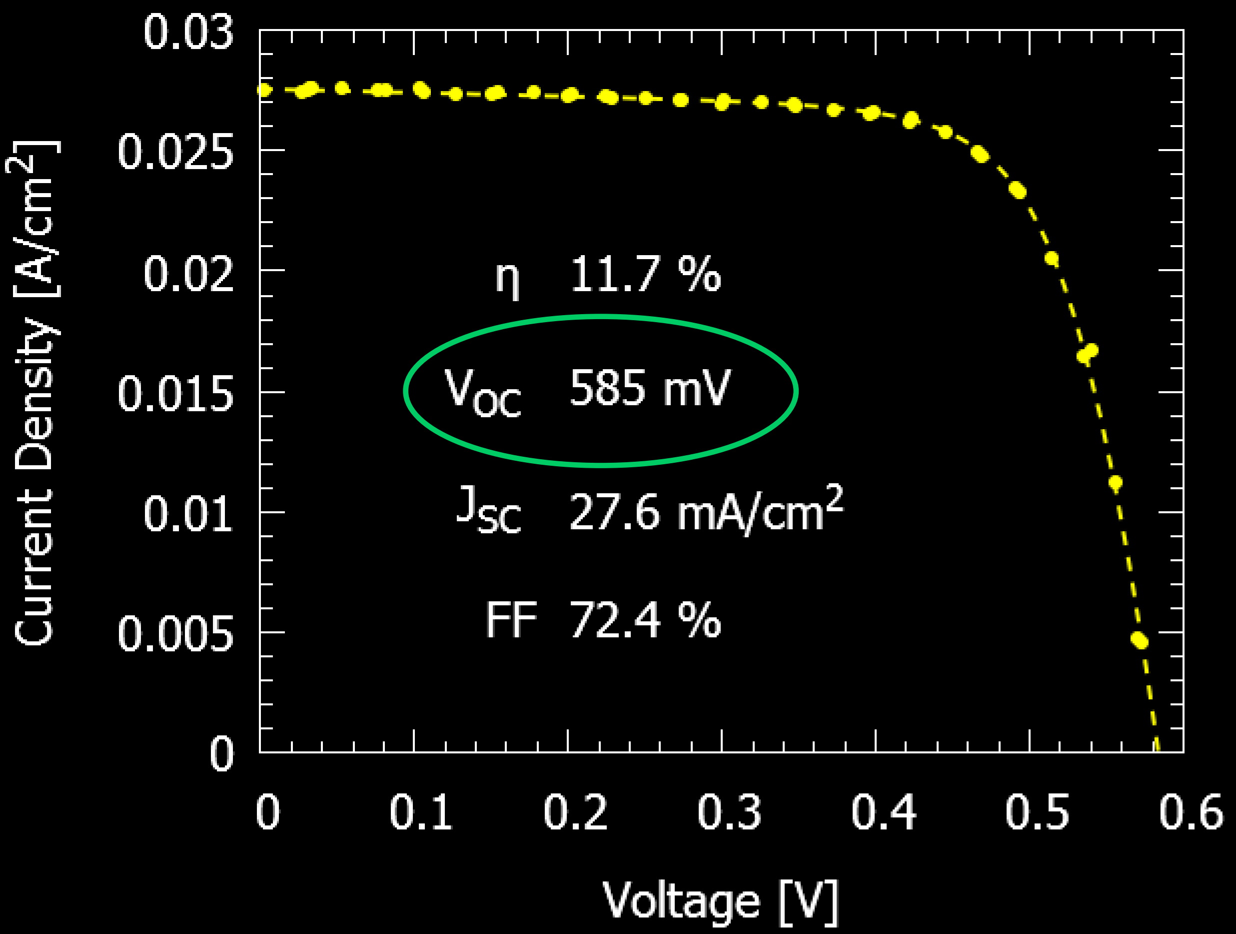


TEM

6. Device Fabrication

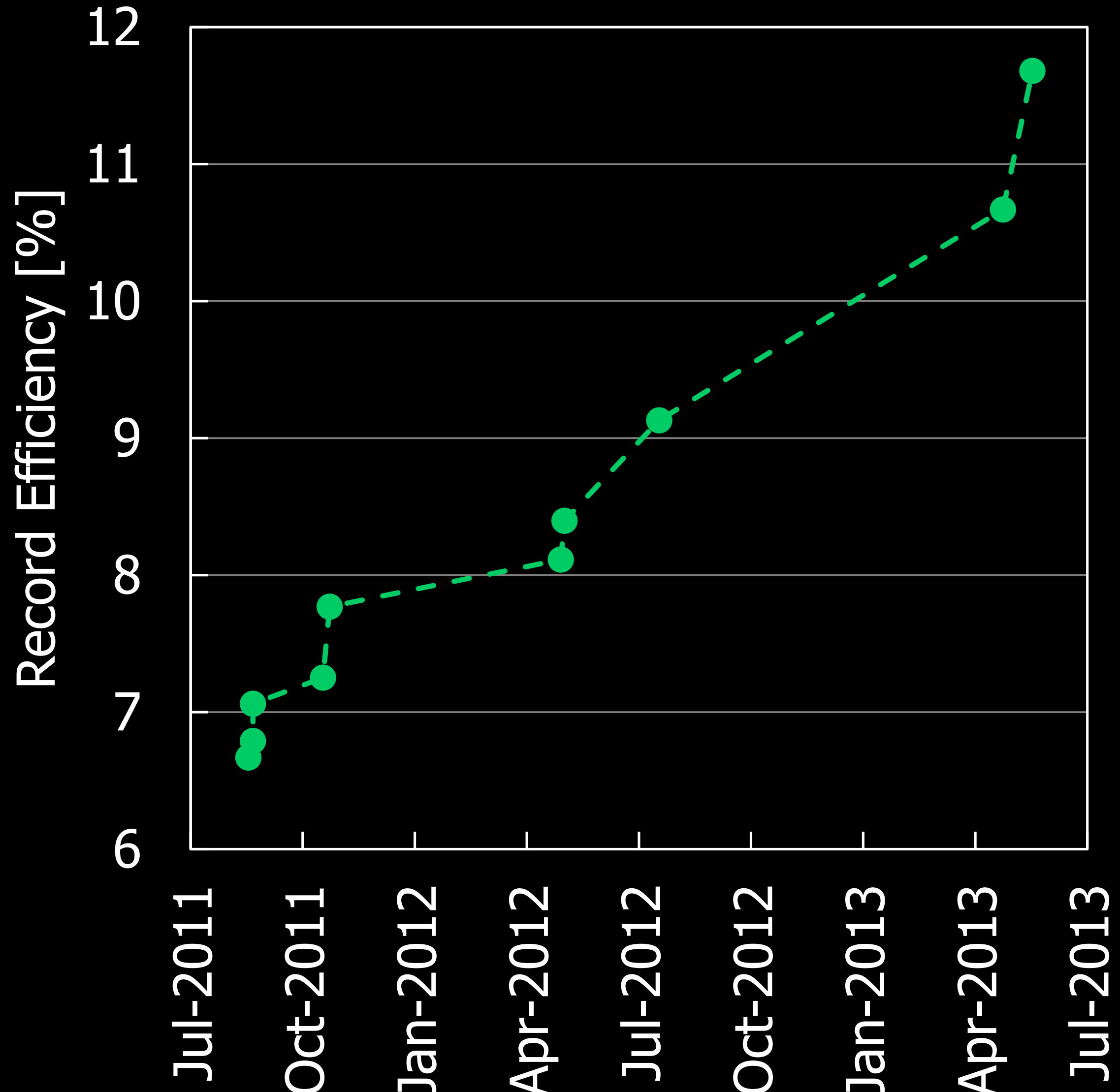


7. Light IV

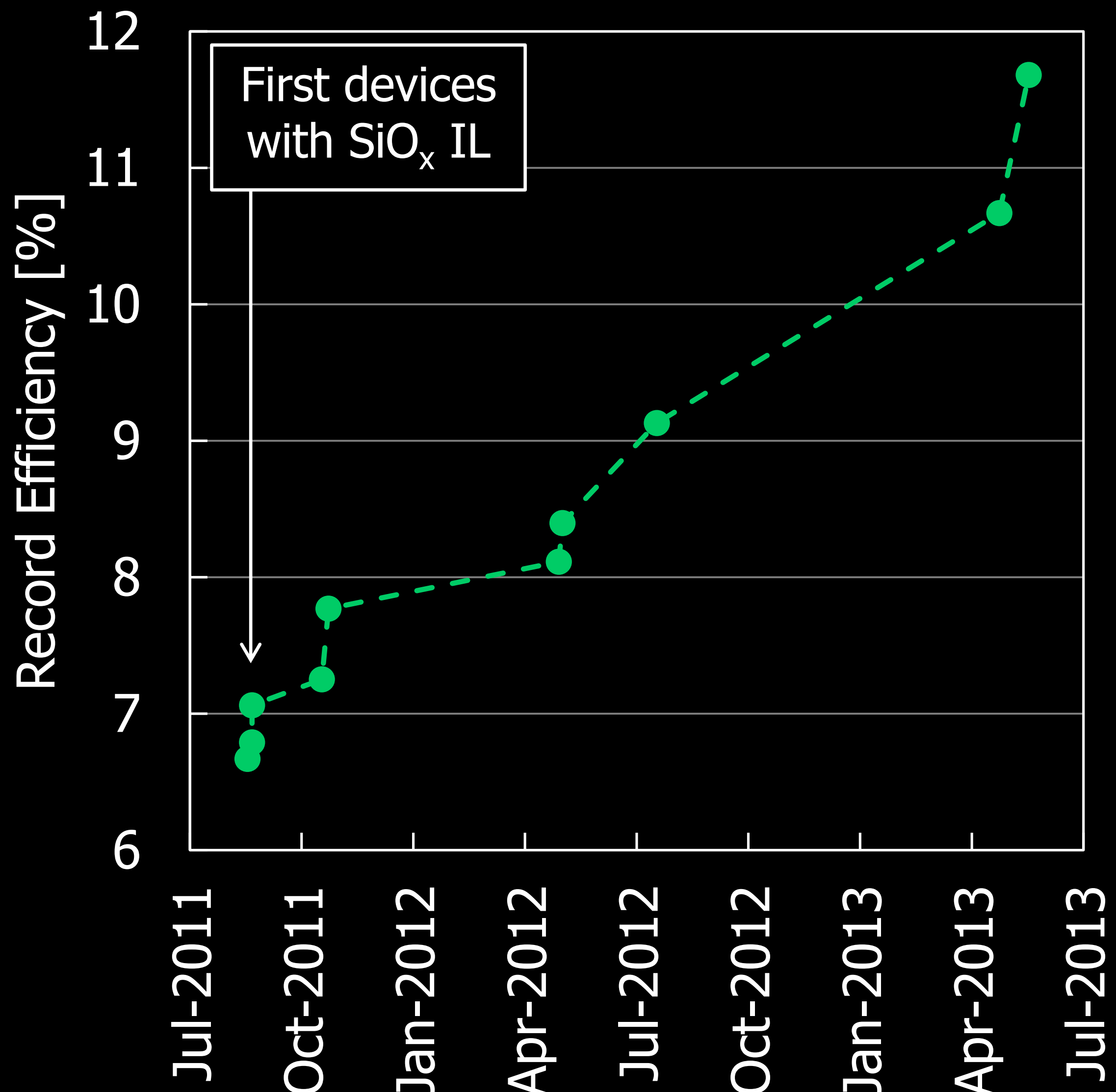


0.03
0.025
0.02
0.015
0.01
0.005
0
Current Density [A/cm2]
η 11.7 %
VOC 585 mV
JSC 27.6 mA/cm2
FF 72.4 %
0
0.1
0.2
0.3
0.4
0.5
0.6
Voltage [V]

8. Improvement path



8. Improvement path



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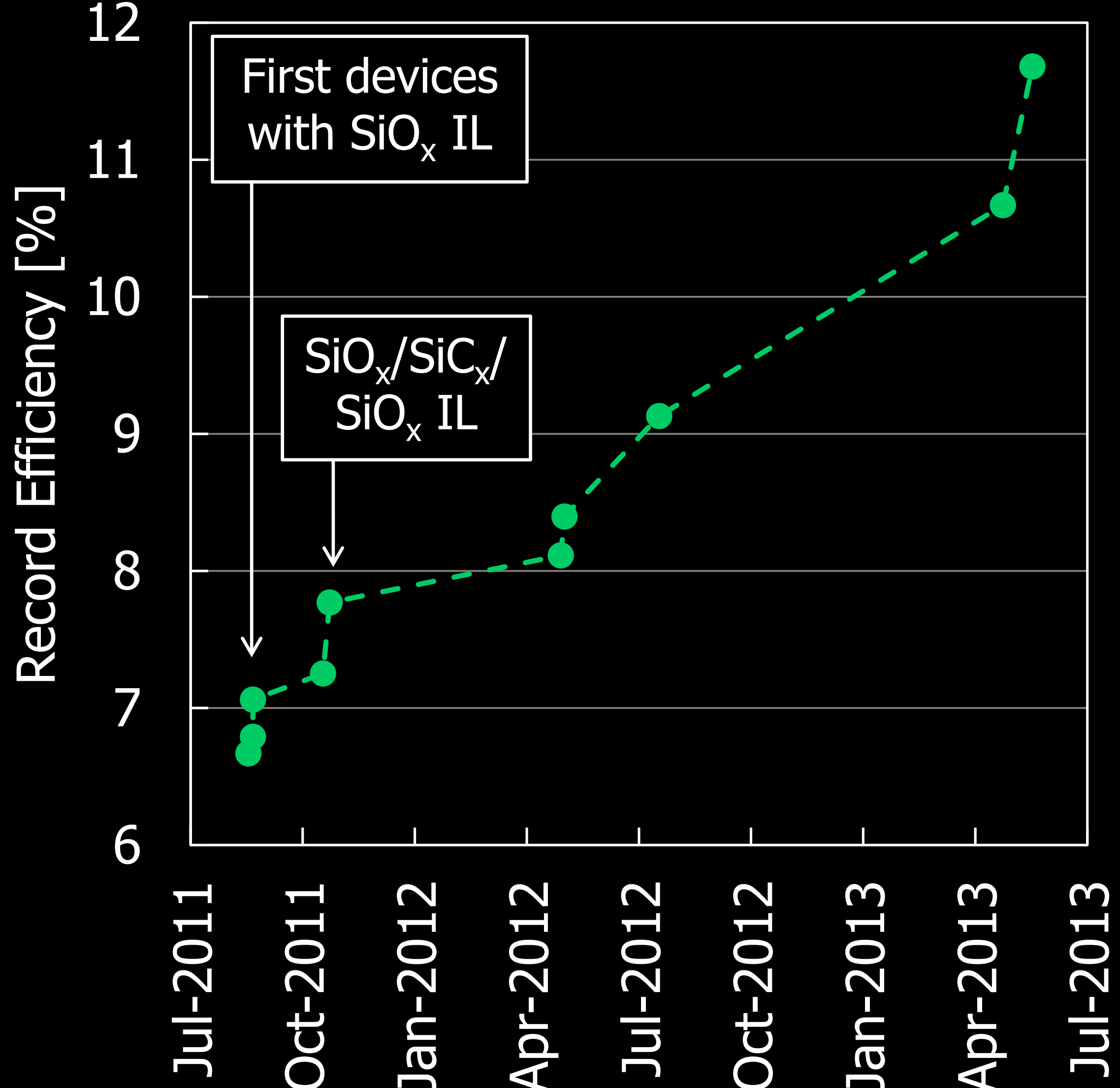

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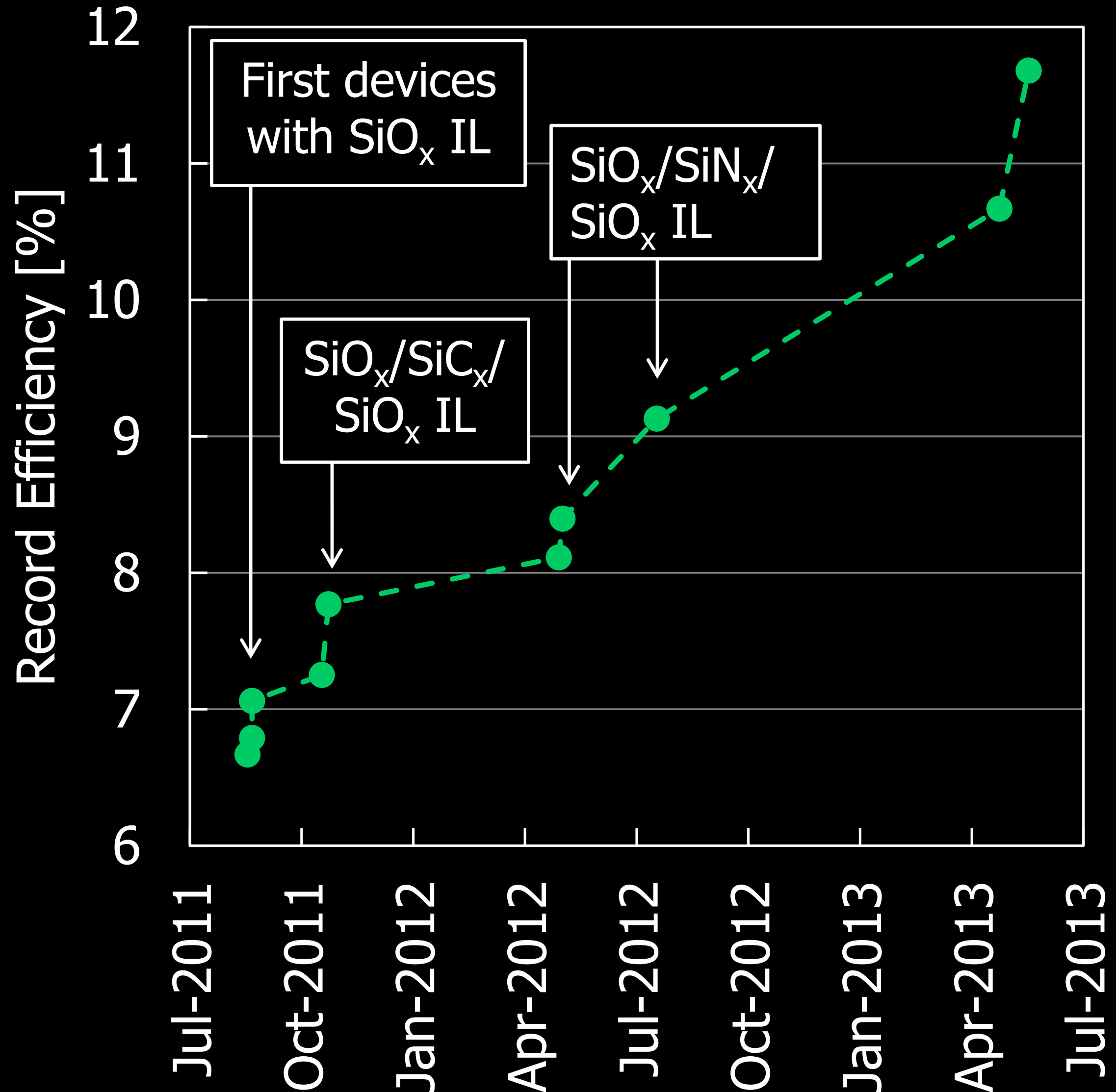

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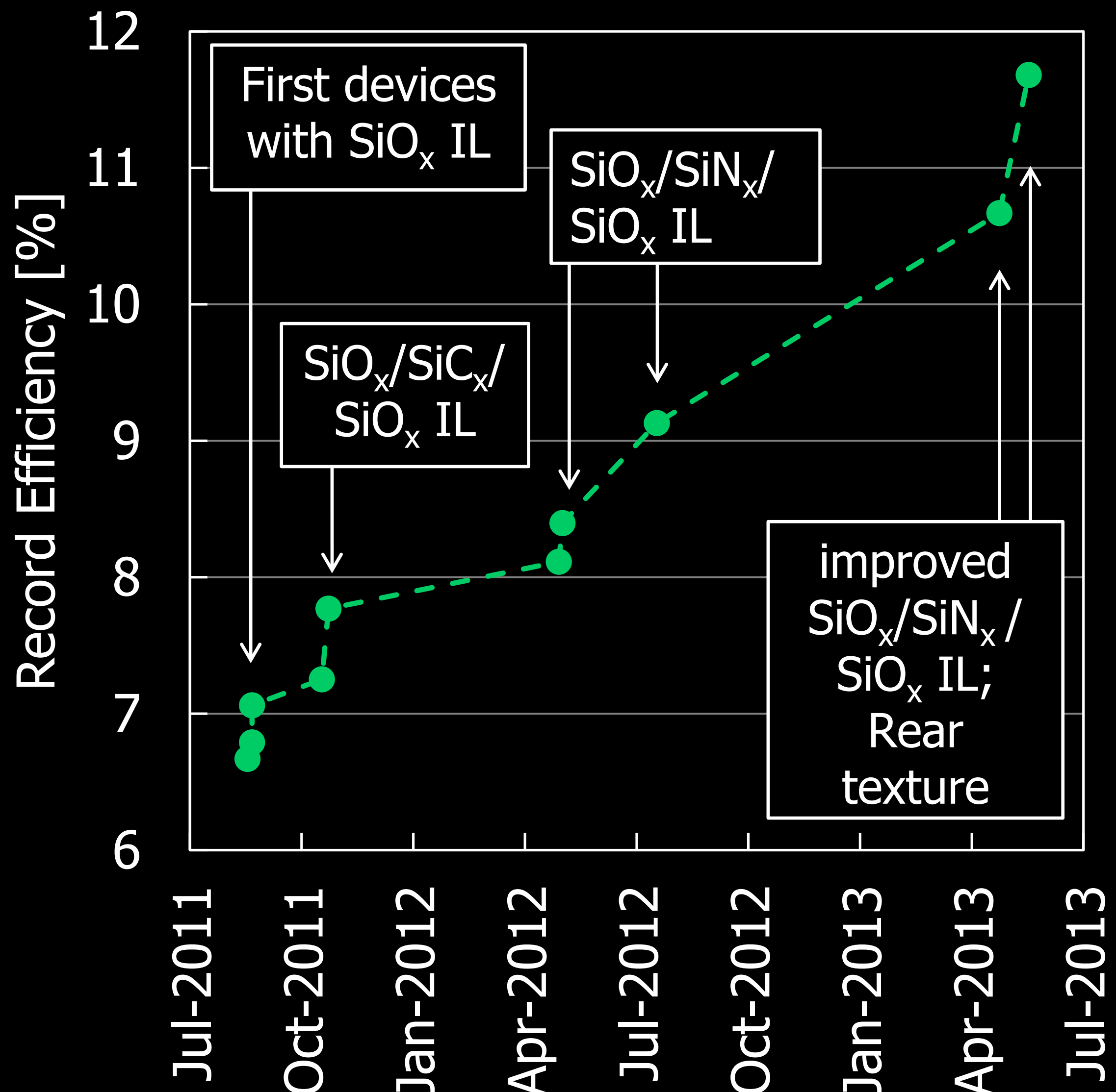

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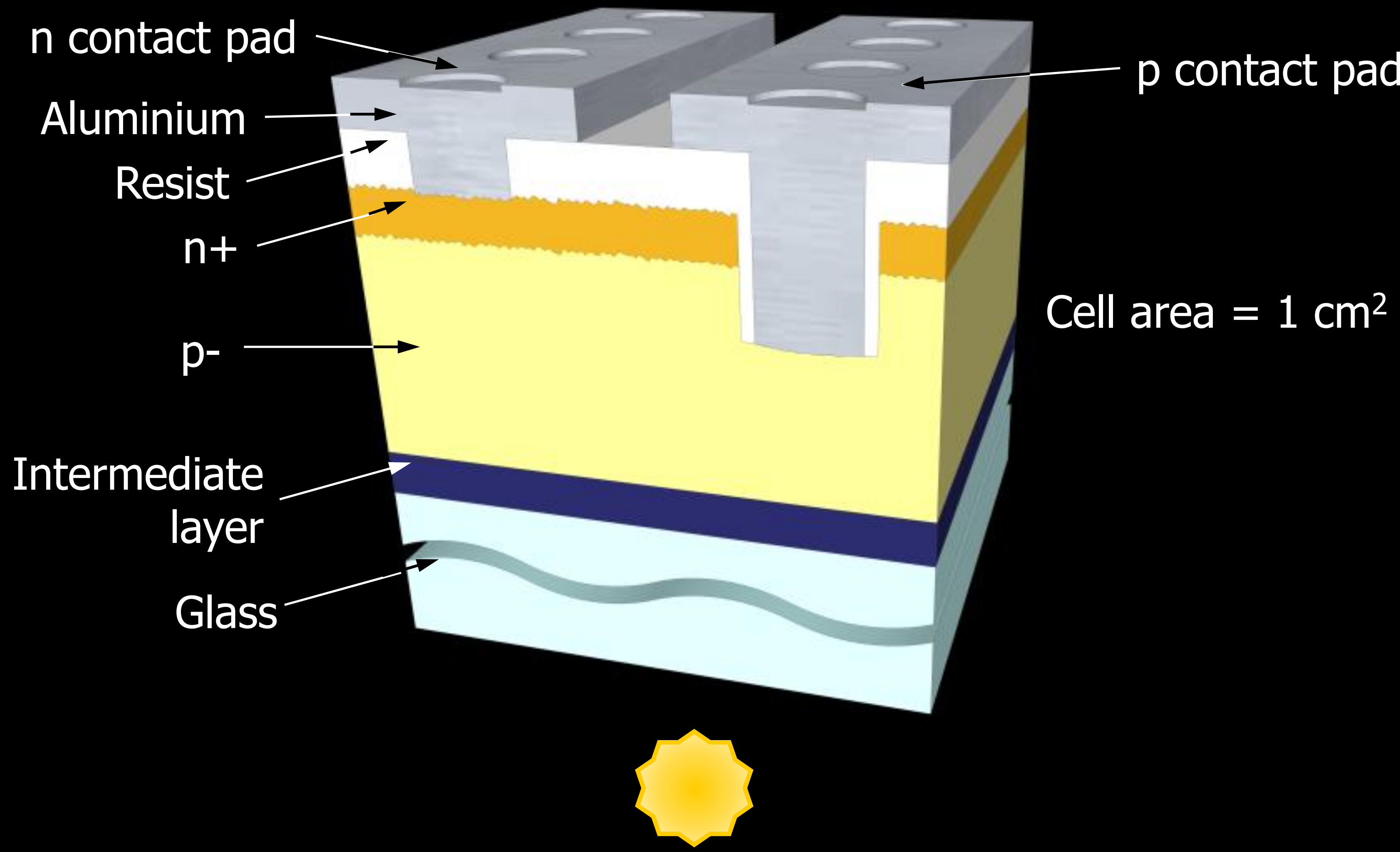
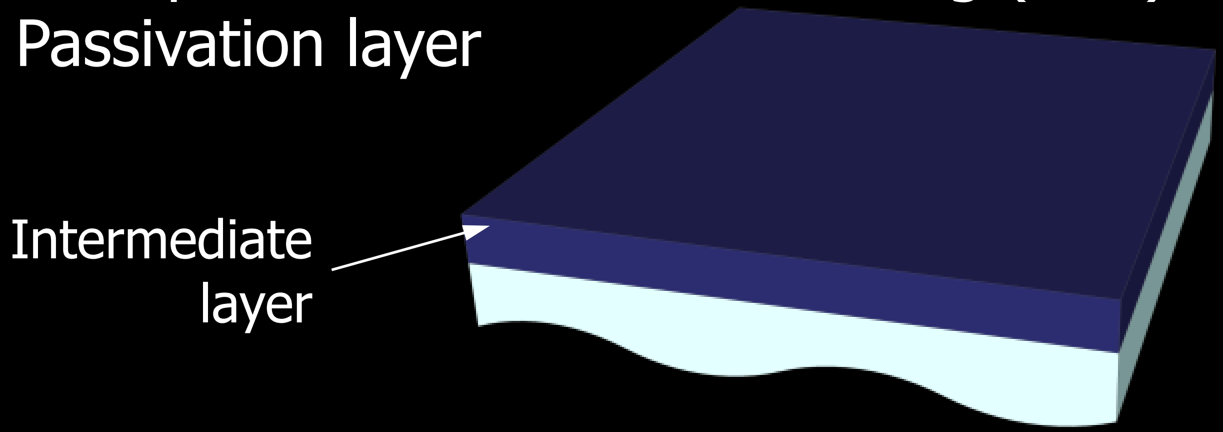
10. Intermediate Layer



10. Intermediate Layer

- Wetting layer
- Dopant source
- Contamination barrier
- Stable > 1414C
- Transparent anti-reflection coating (ARC)
- Passivation layer



11. Materials of Interest

- SiC_x
- SiN_x
- SiO_x

- Layers deposited by RF sputtering or PECVD
- 10-200 nm thick
- Either alone or in stacks

Intermediate Layer

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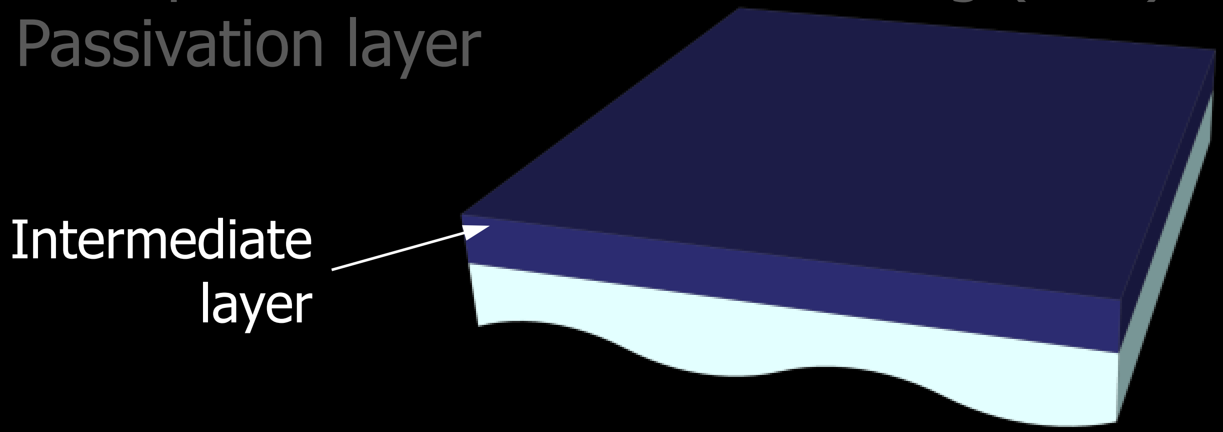
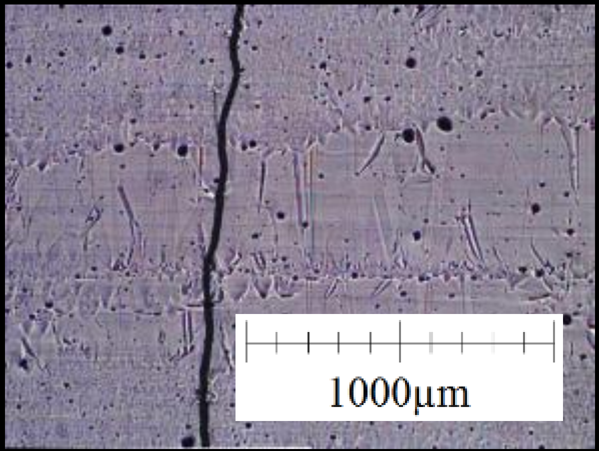


12. Wetting and crystallisation

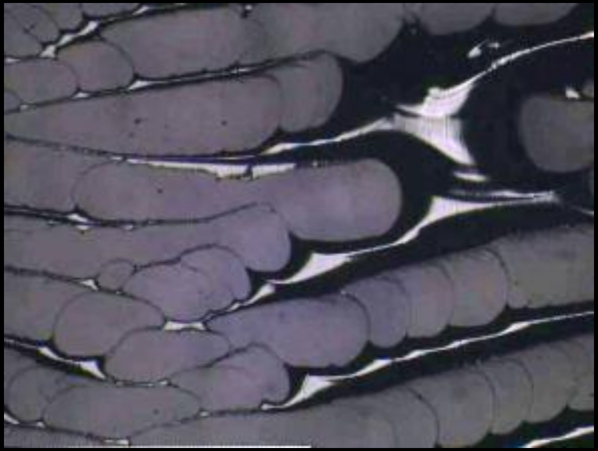
- Laser energy

Int. layer	Process range
None	13 J/cm²
SiO_x	194 J/cm²
SiN_x	220 J/cm²
SiO_x/SiC_x stack	246 J/cm²

Too low
(nc regions)



Too high
(dewetting)



Just right

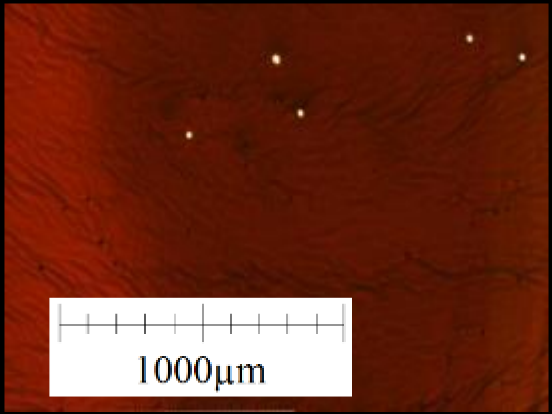
13. Wetting and crystallisation

- Laser energy

Int. layer	Process range
None	13 J/cm^2
SiO_x	194 J/cm^2
SiN_x	220 J/cm^2
SiO_x/SiC_x stack	246 J/cm^2

- SiN_x layers result in pinholes in Si at high laser energies

Transmission micrograph →



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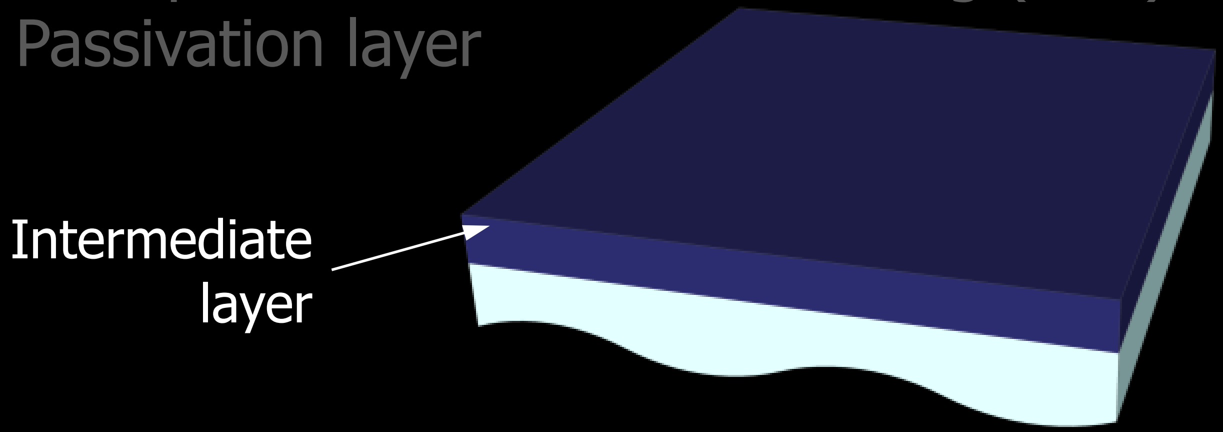
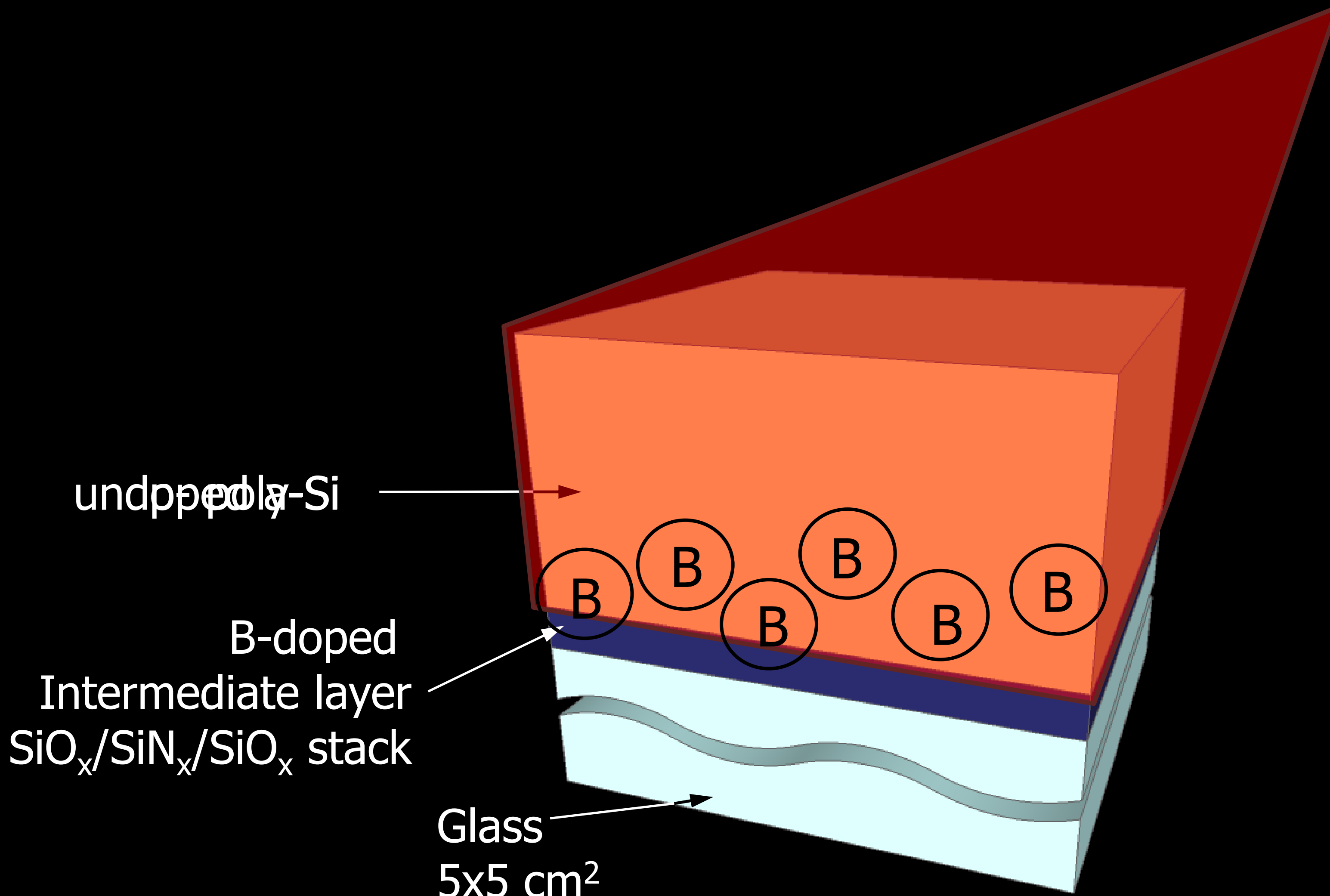
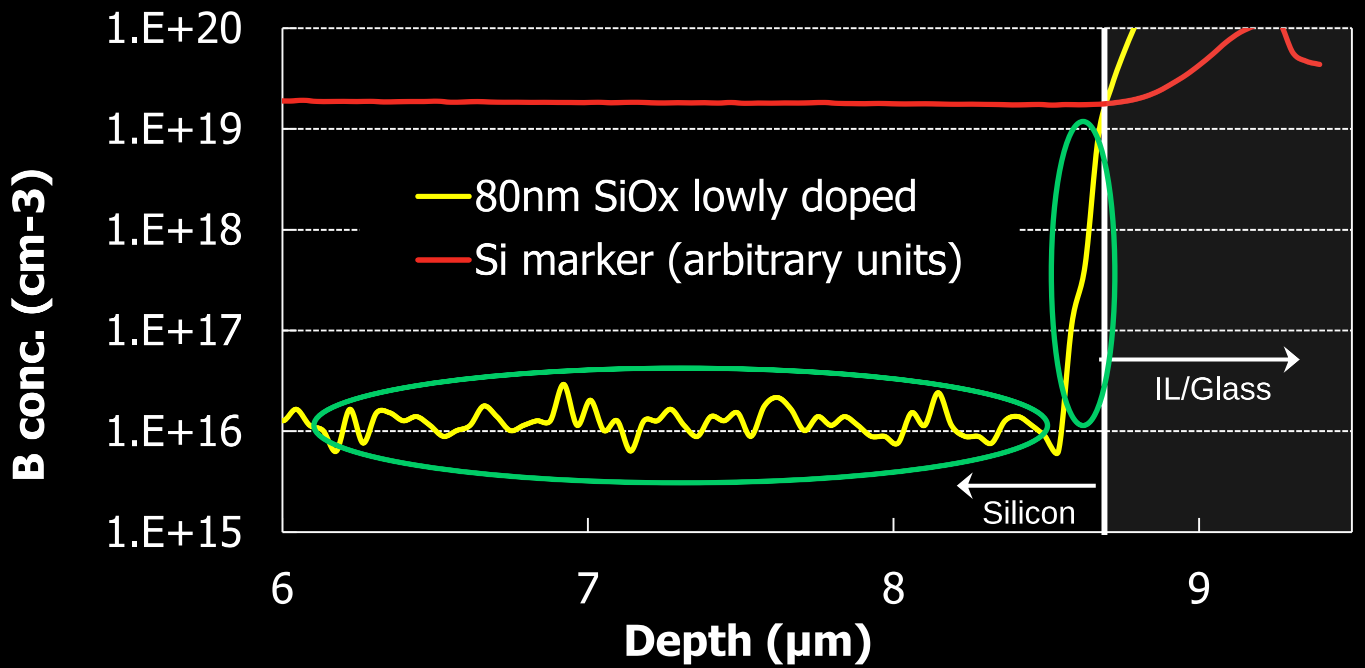


14. Dopant source



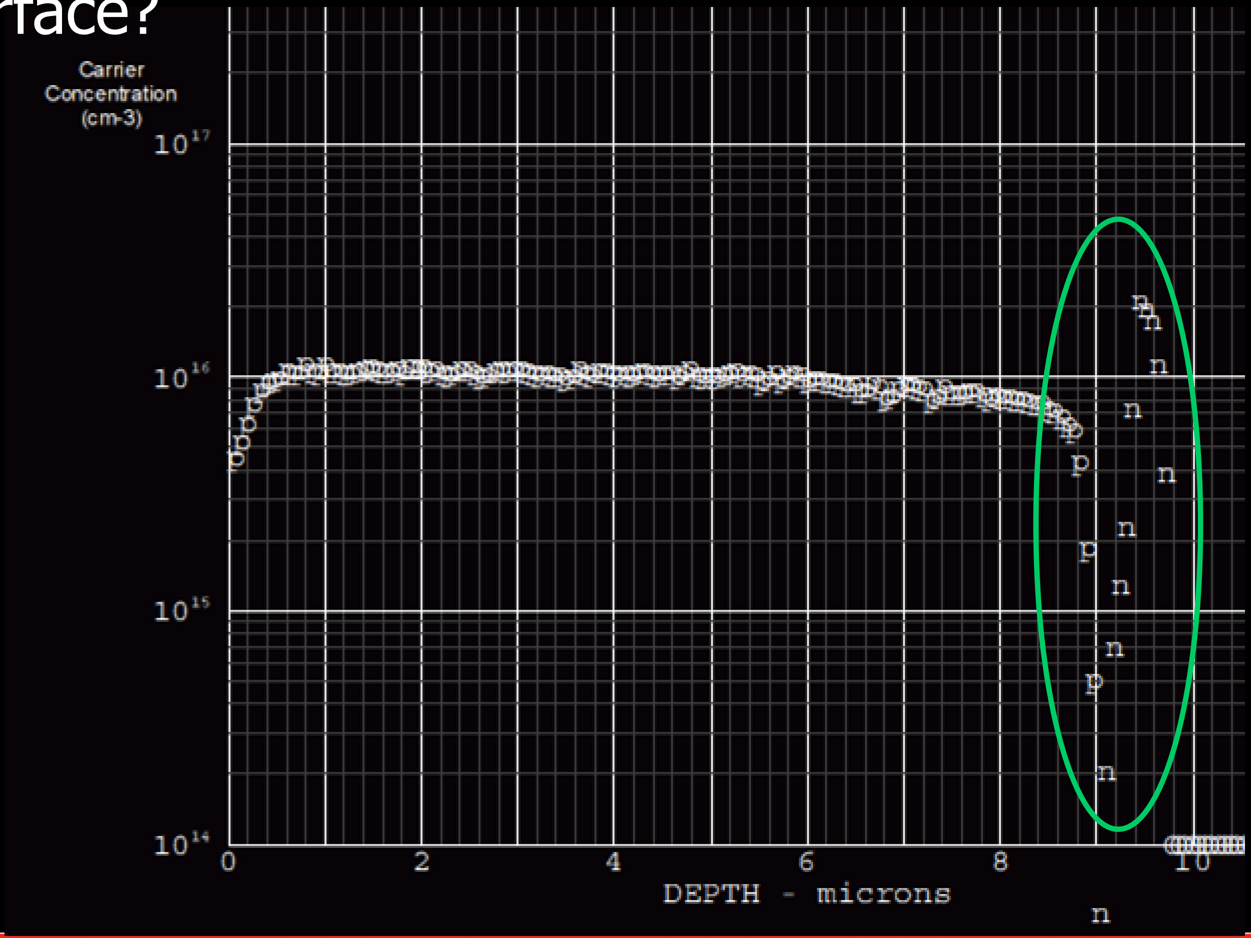
15. Dopant source

- Uniform region created during molten phase
- p+ region at interface?



16. Dopant source

- Spreading resistance shows no p+
- p+ region at interface?
- Inversion layer?



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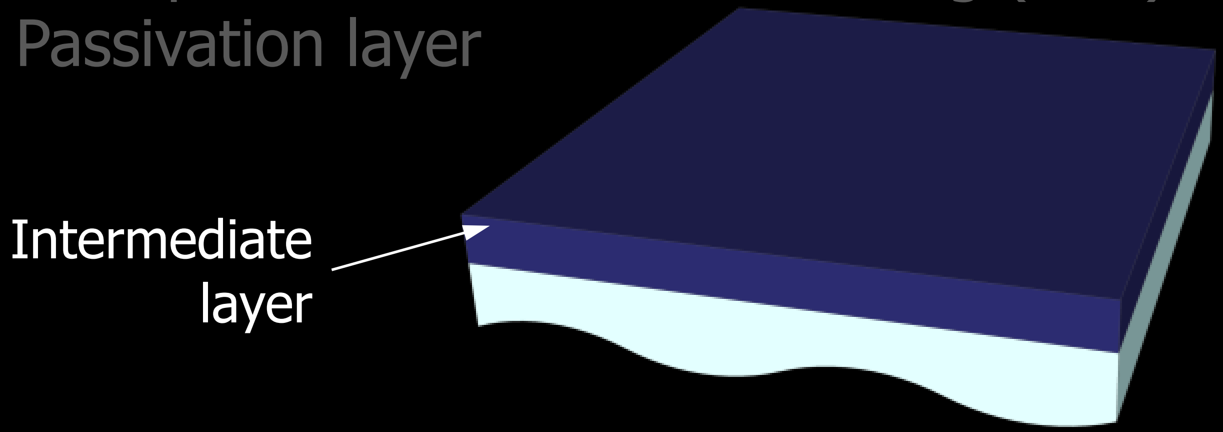
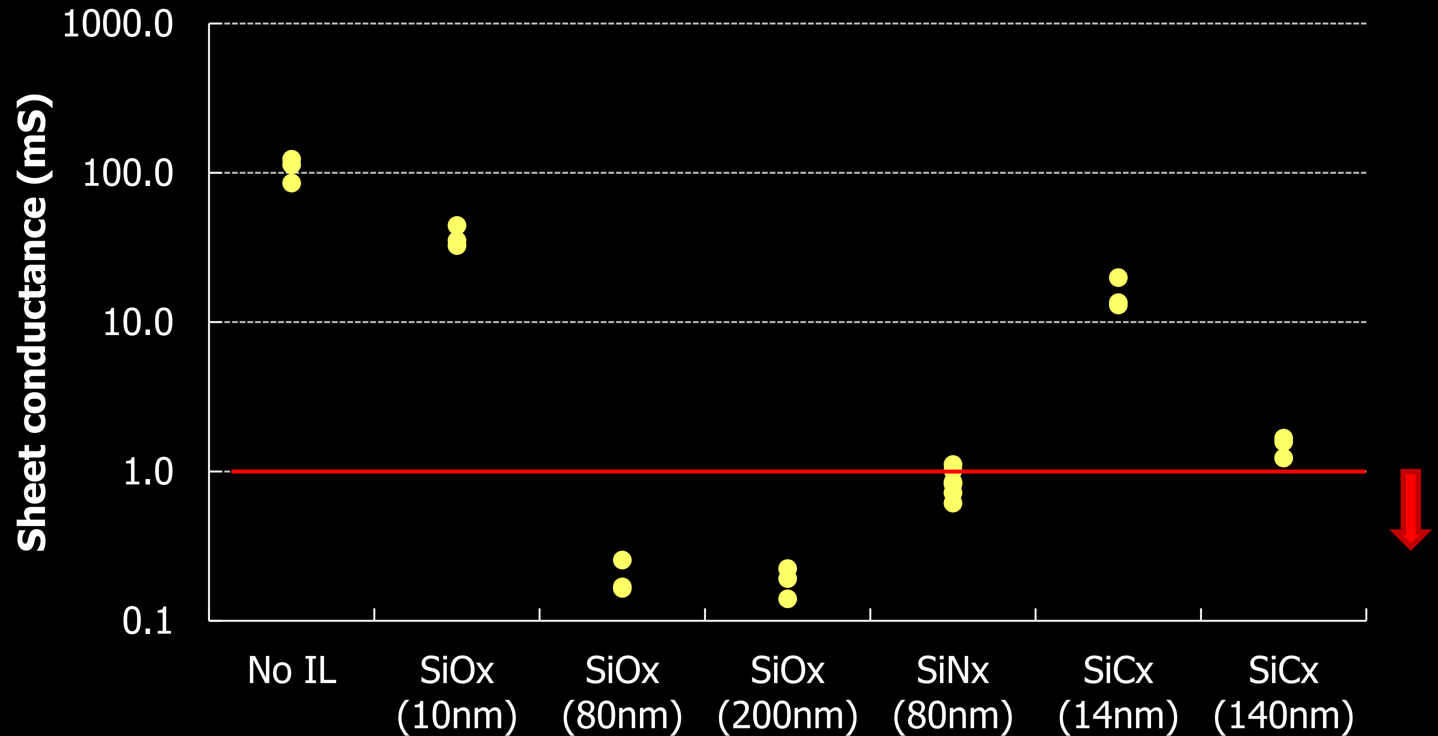


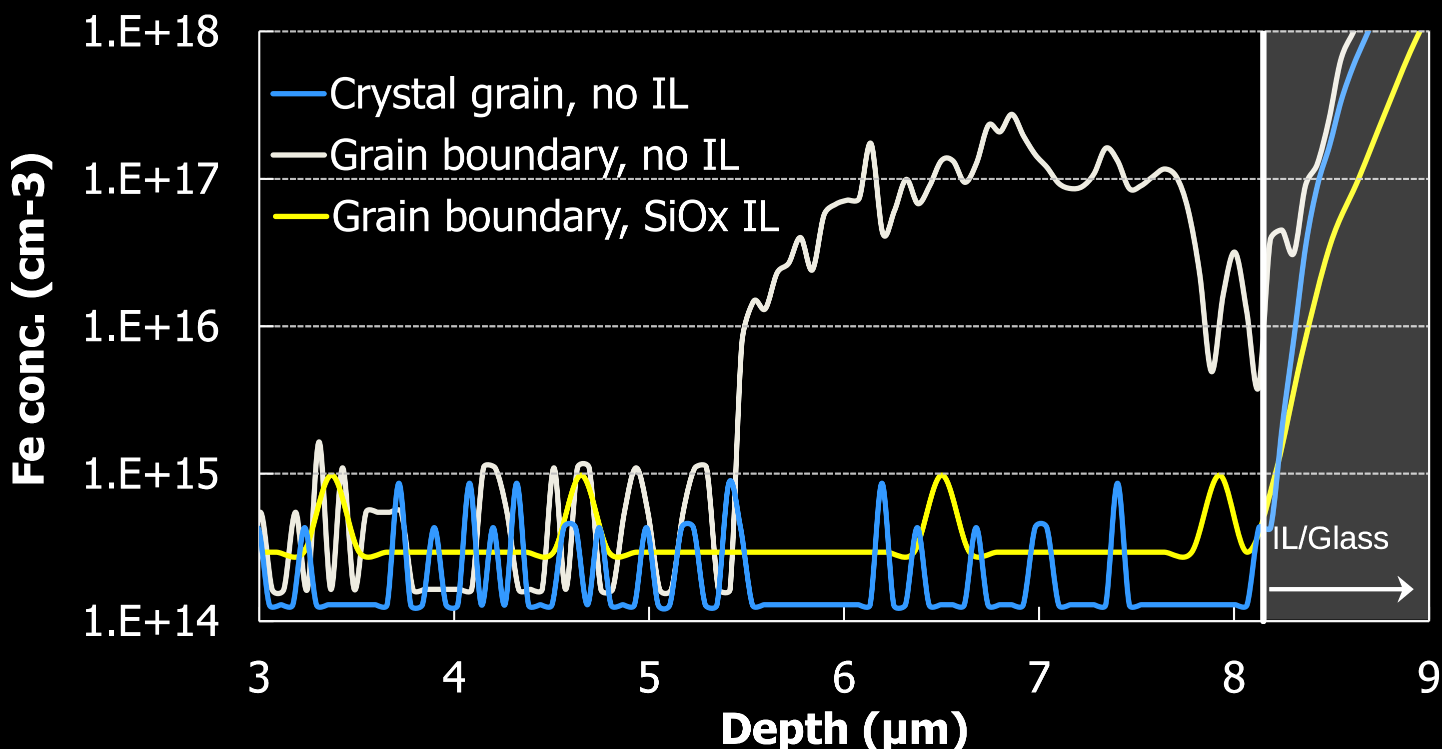
17. Contamination Barrier

- Problem is blocking B from glass!
- SiO_x best barrier
- Can use SiO_x/SiC_x or SiO_x/SiN_x stacks



18. Contamination Barrier

- Iron can also diffuse from glass
- Iron found at silicon grain boundary when no IL used
- No iron when SiOx IL used



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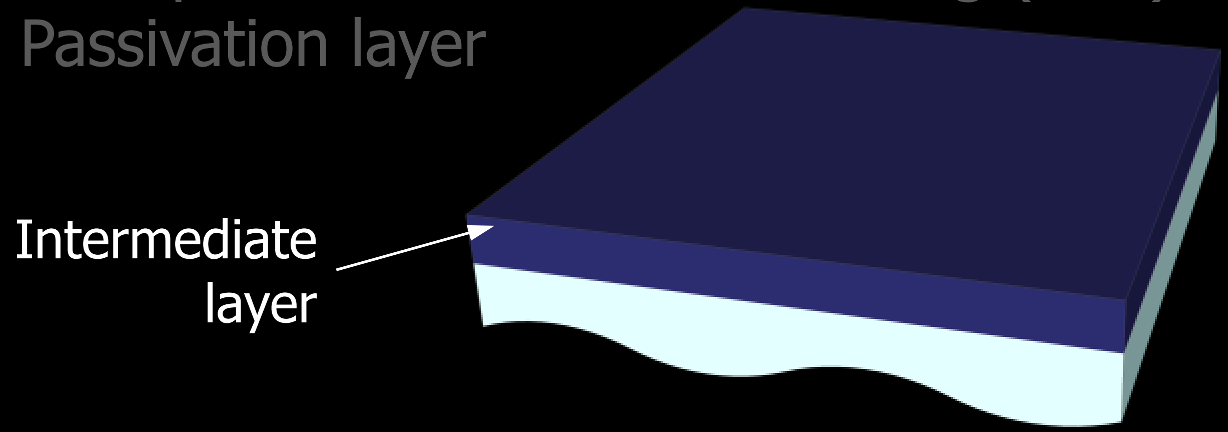
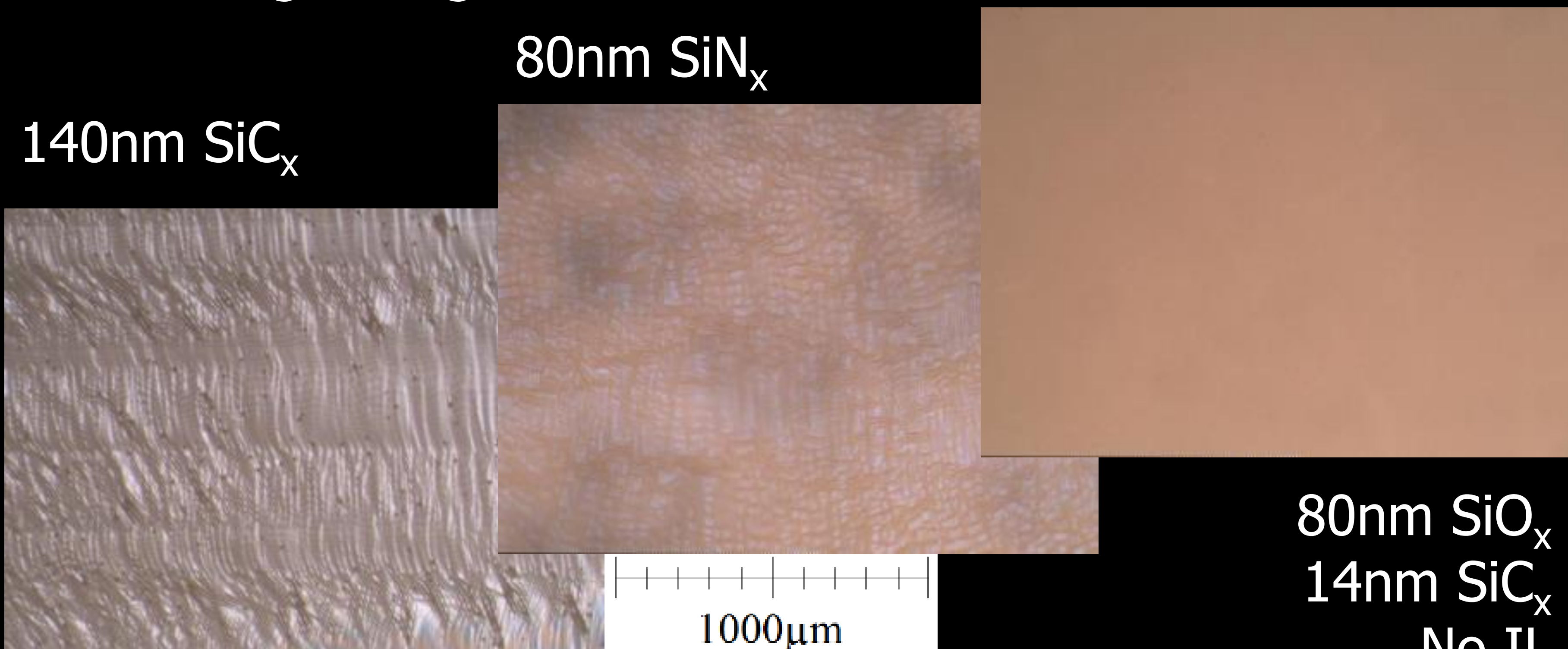


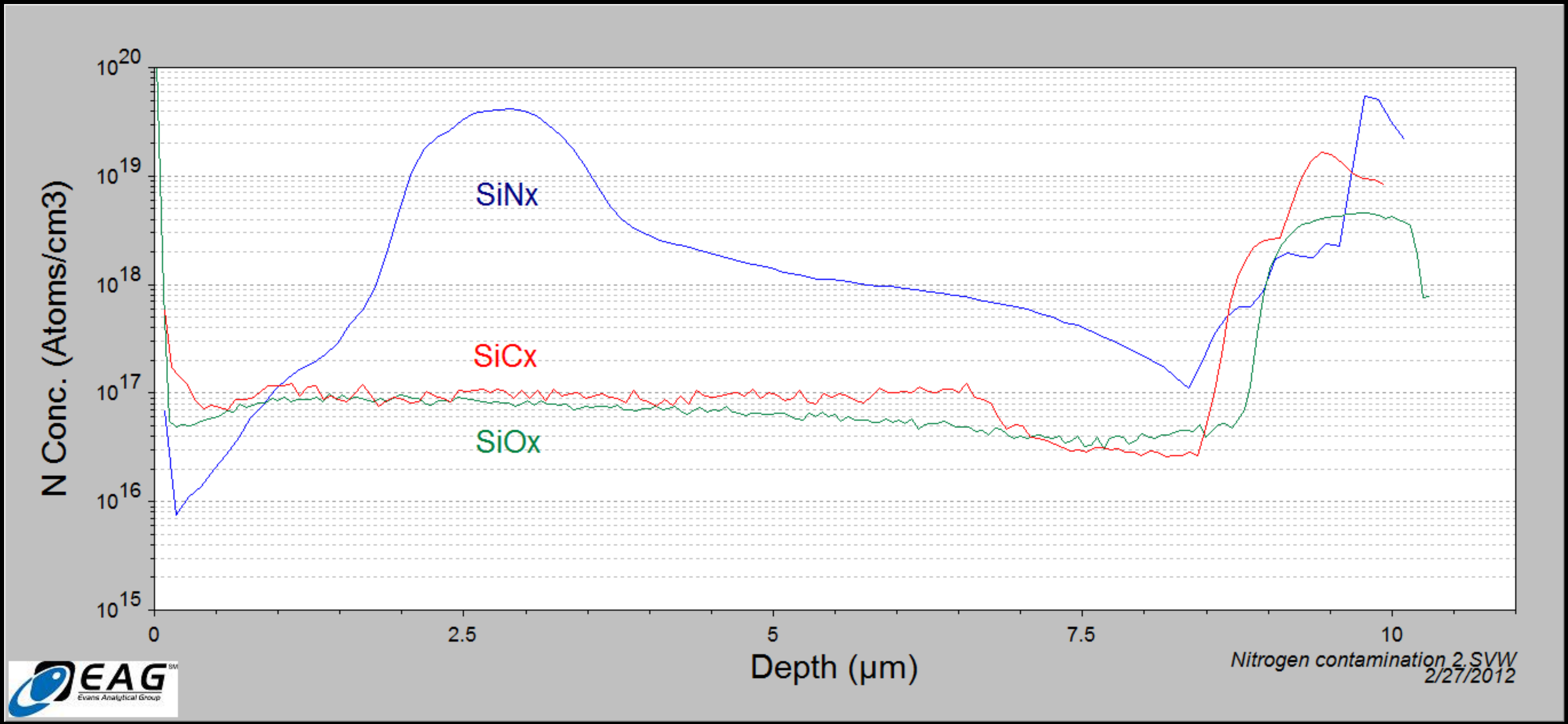
19. Stability

- Thick SiC_x or SiN_x layers cause wrinkling at the glass surface
- Visible in reflection micrographs at IL interface viewed through the glass



20. Stability

- Nitrogen from SiN_x layer diffuses into Si during crystallisation
- N conc in Si when SiC_x and SiO_x used likely from atmosphere
- No excess C from SiC_x or O from SiO_x



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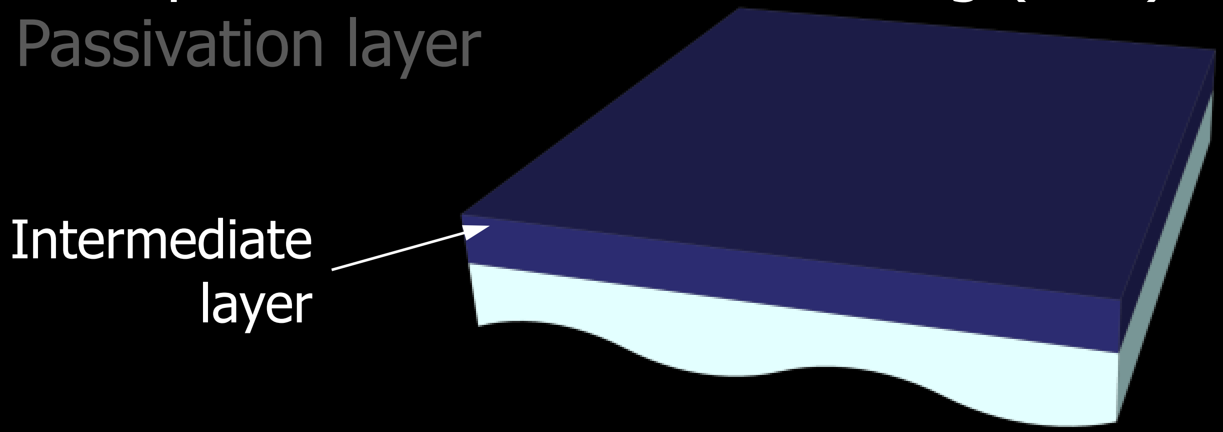
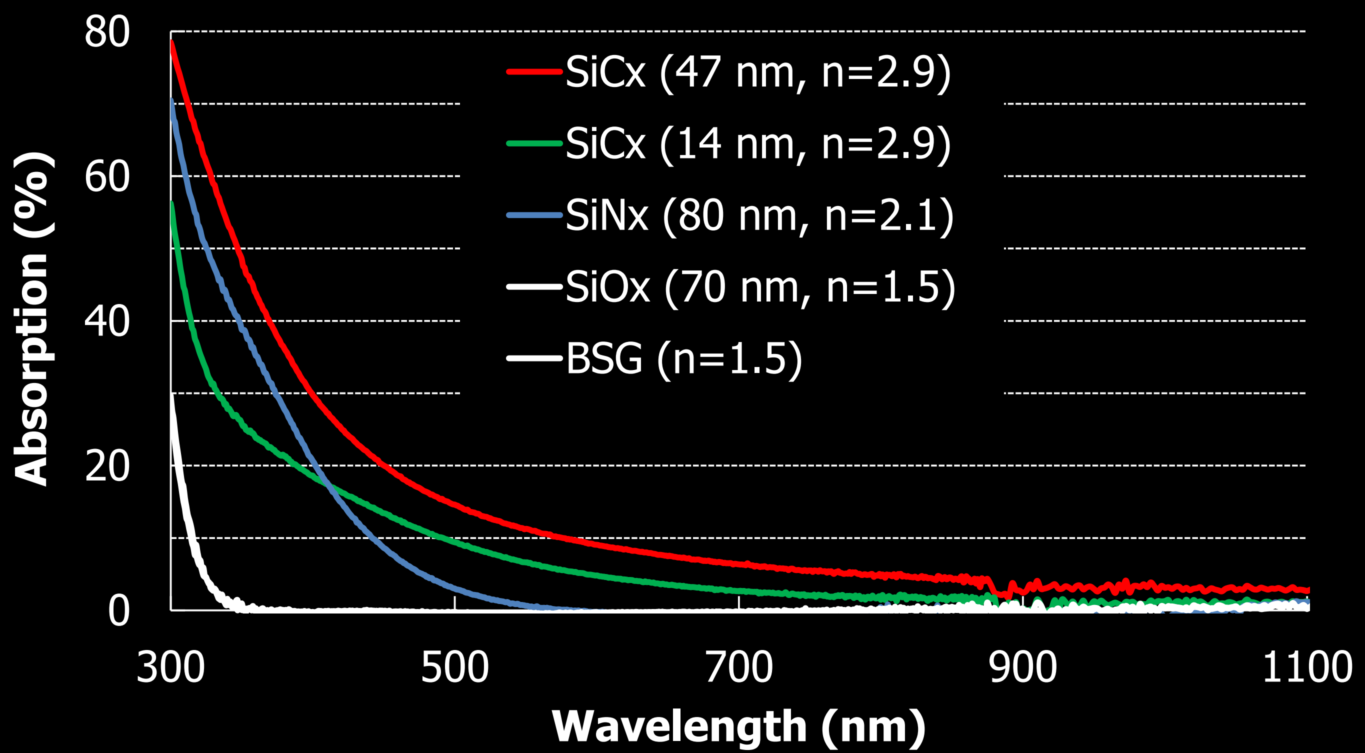


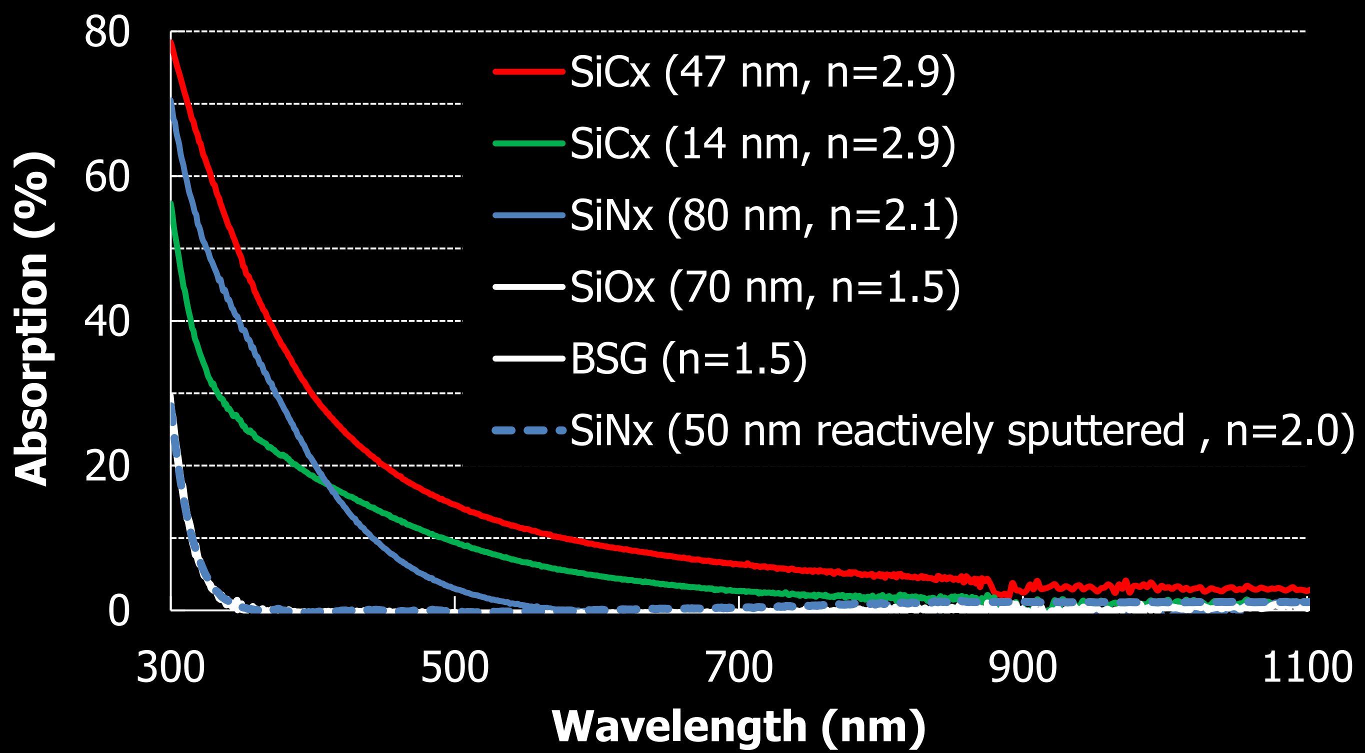
21. Transparent ARC

- Ideally, $n = 2.4$, $d = \frac{\lambda_{min}}{4n}$ and no absorption



22. Transparent ARC

- Ideally, $n = 2.4$, $d = \frac{\lambda_{min}}{4n}$ and no absorption



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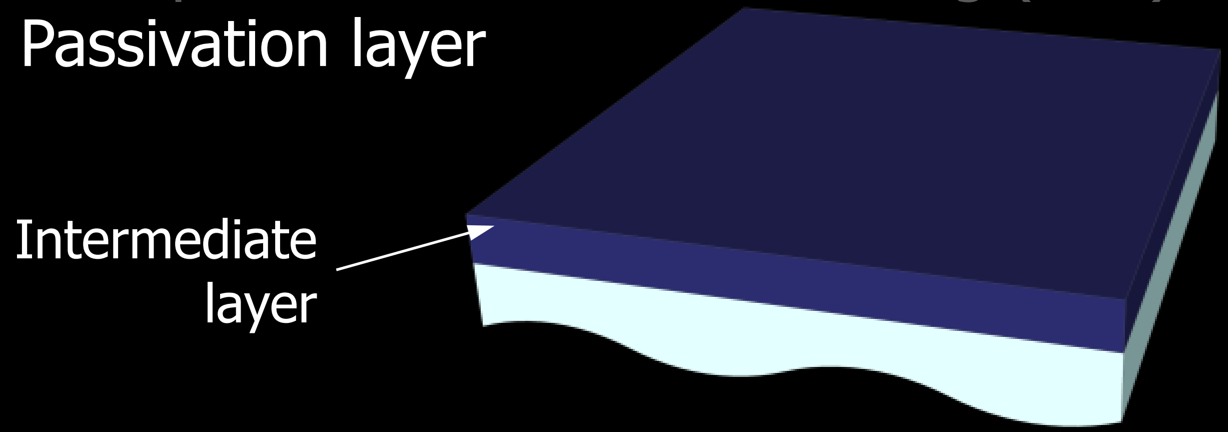
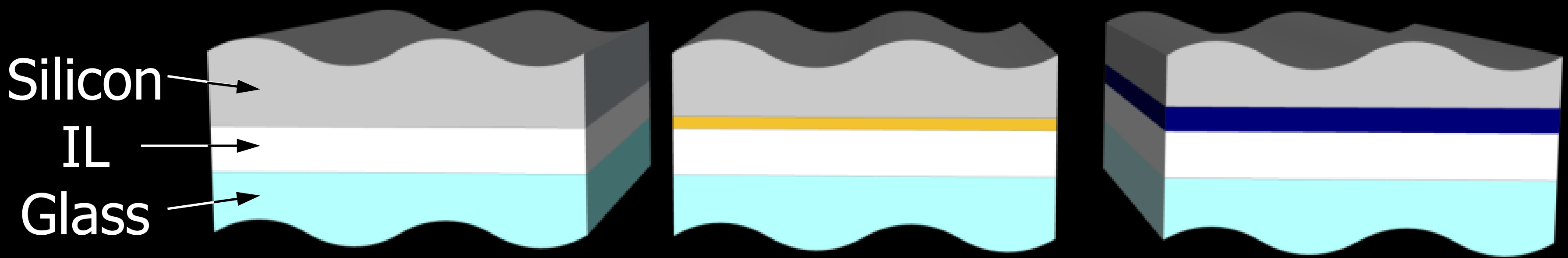


23. Passivation Layer

- Single- and double-layer stacks



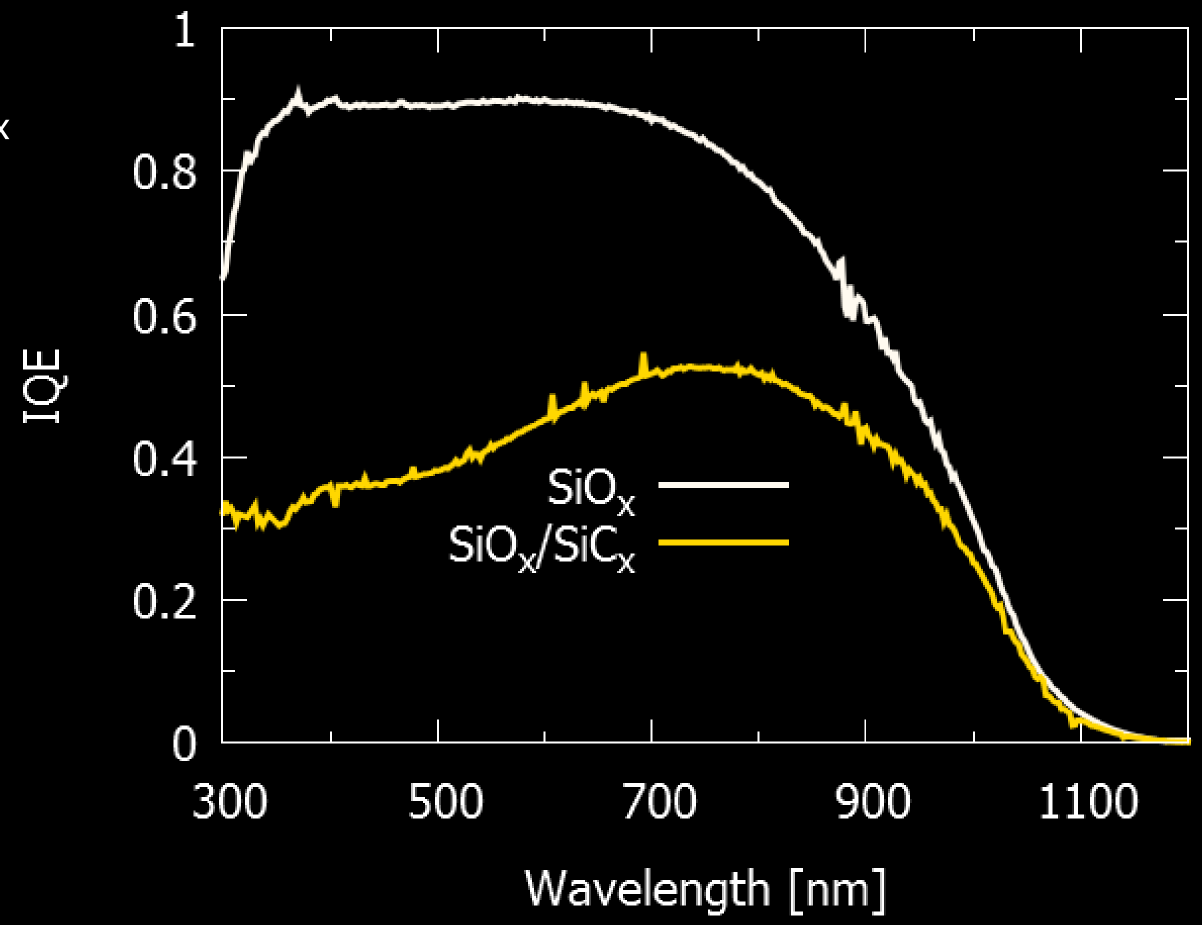
80nm SiO_x (n ≈ 1.5)

20 nm SiC_x (n=2.9)
80nm SiO_x

70 nm SiN_x (n=2.1)
80nm SiO_x

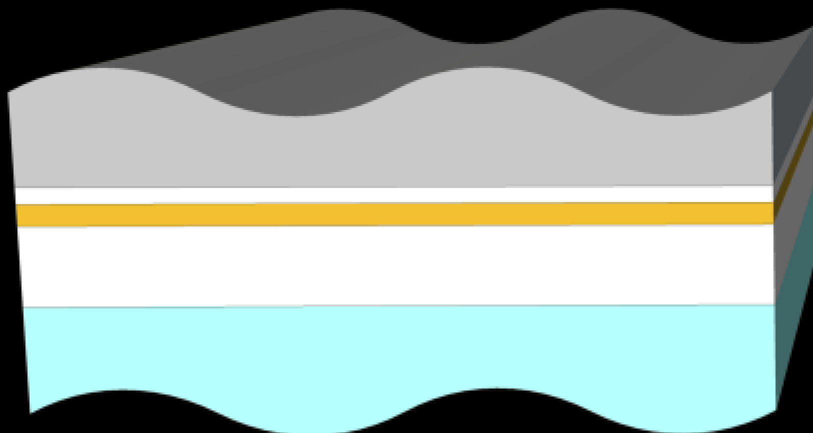
24. Passivation Layer

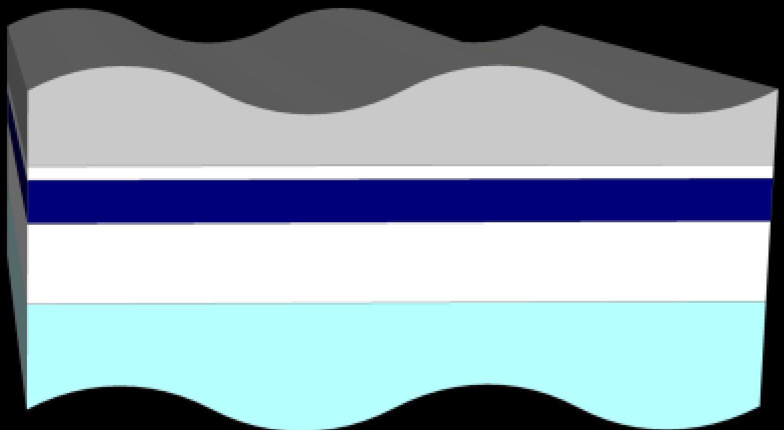
- Poor front surface for SiO_x/SiC_x



25. Passivation Layer

- triple-layer stacks



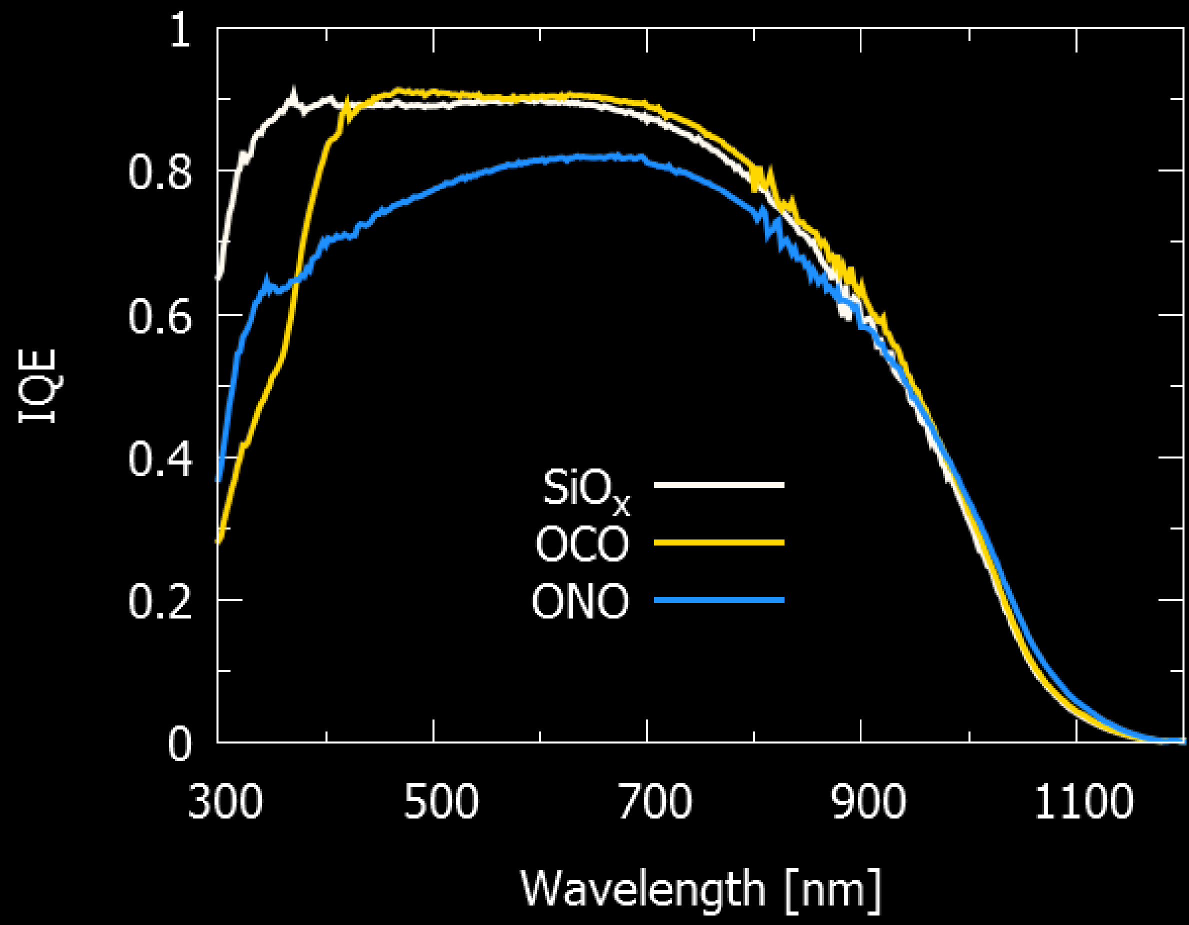


15 nm SiO_x
20 nm SiC_x
80nm SiO_x

15 nm SiO_x
70 nm SiN_x
80nm SiO_x

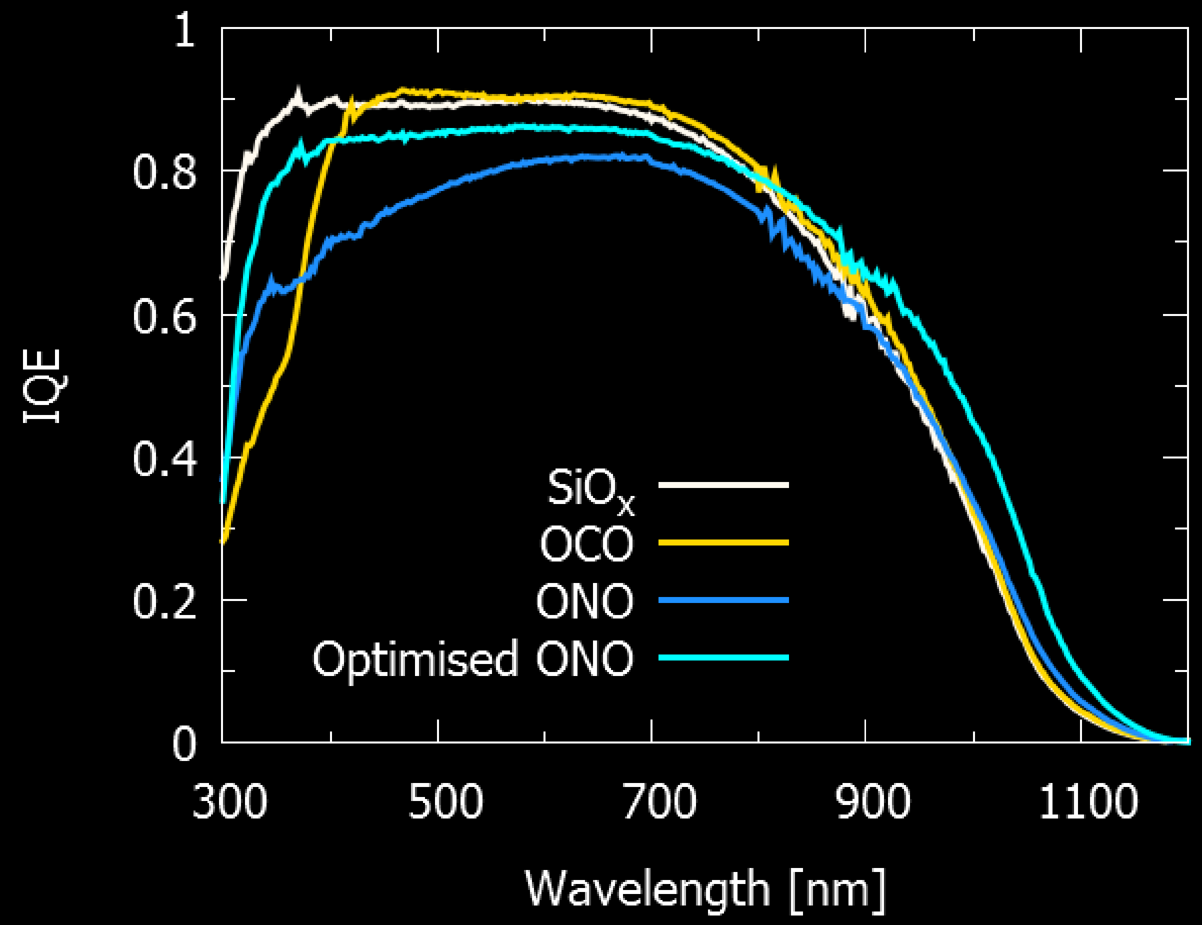
26. Passivation Layer

- Surface SiOx improves IQE
- ONO still not ideal

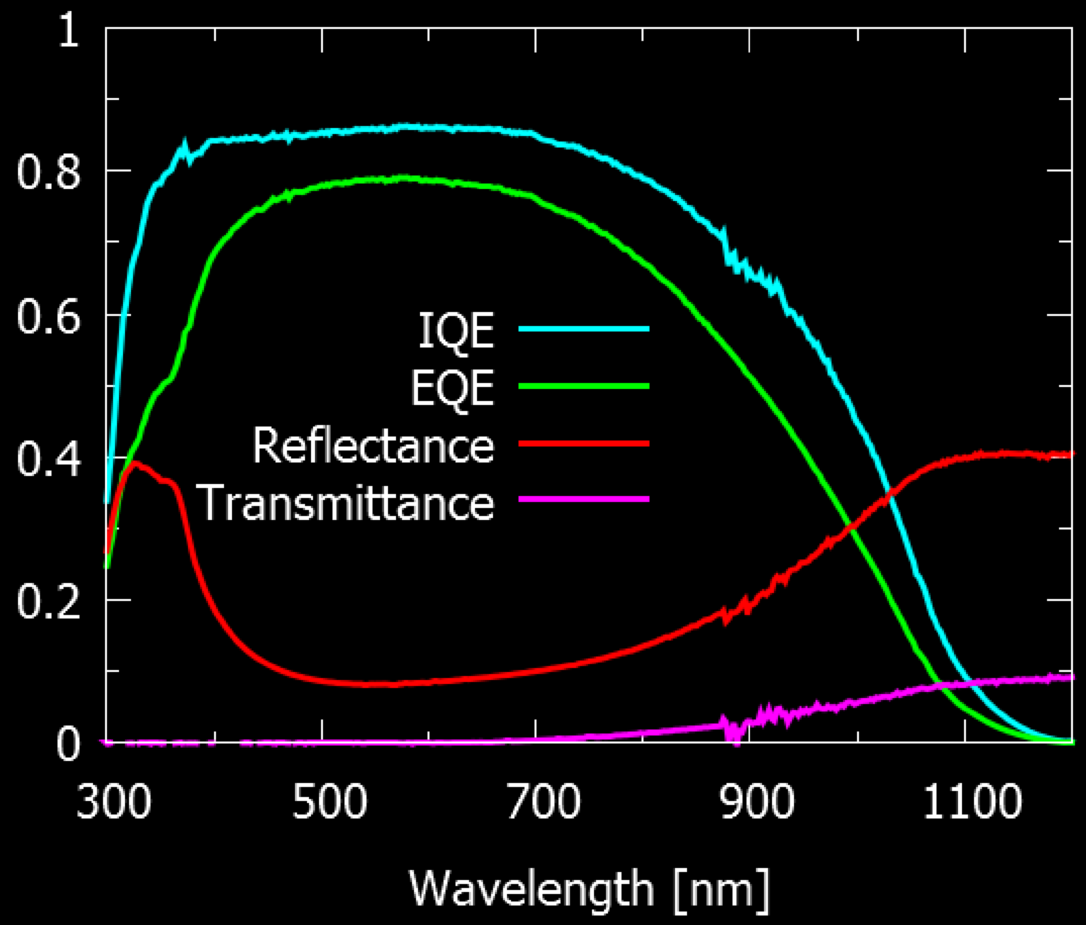


26. Passivation Layer

- Surface SiOx improves IQE
- ONO still not ideal
- Optimised ONO (with reactive sputtering) better



26. Passivation Layer



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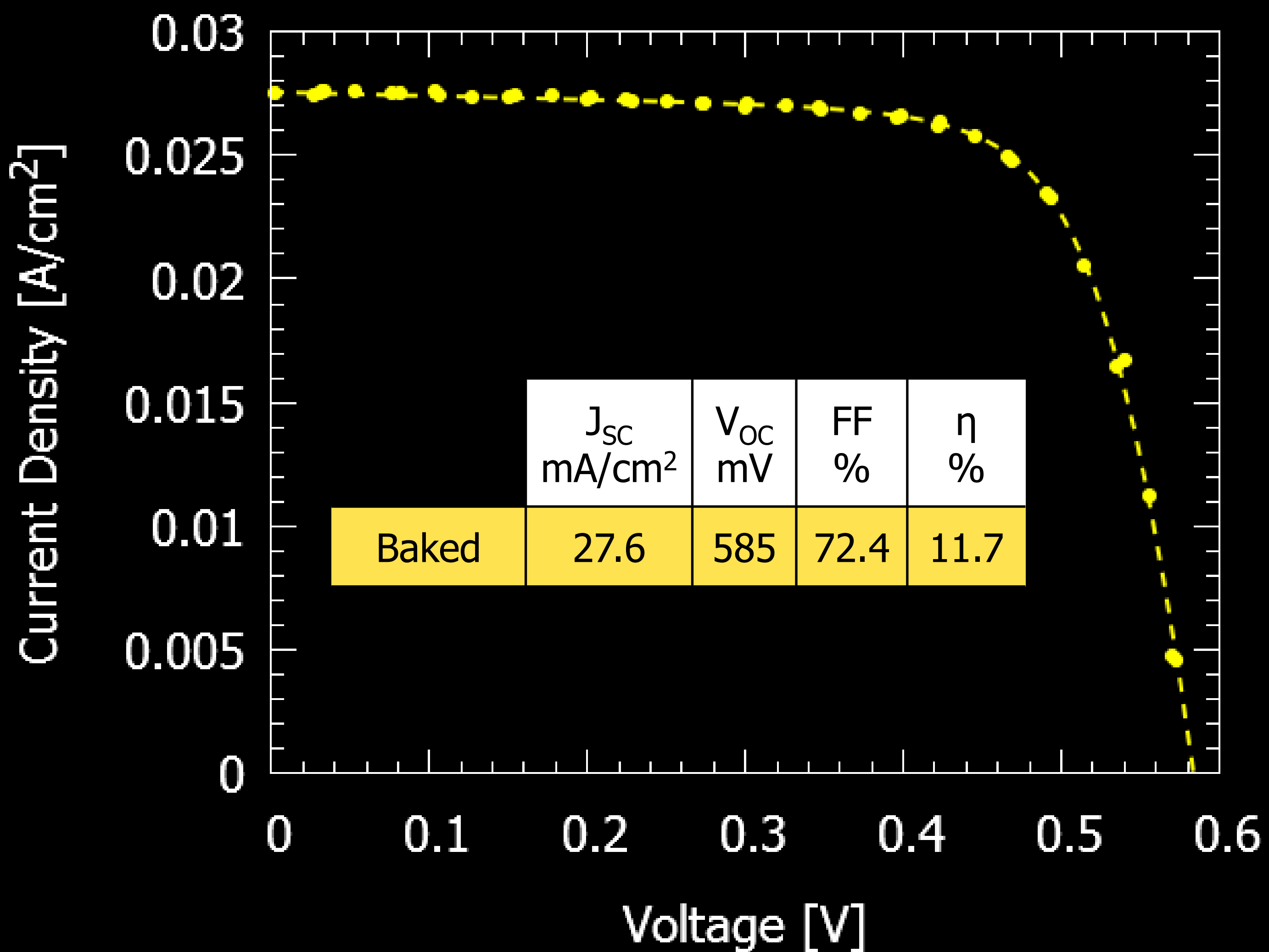
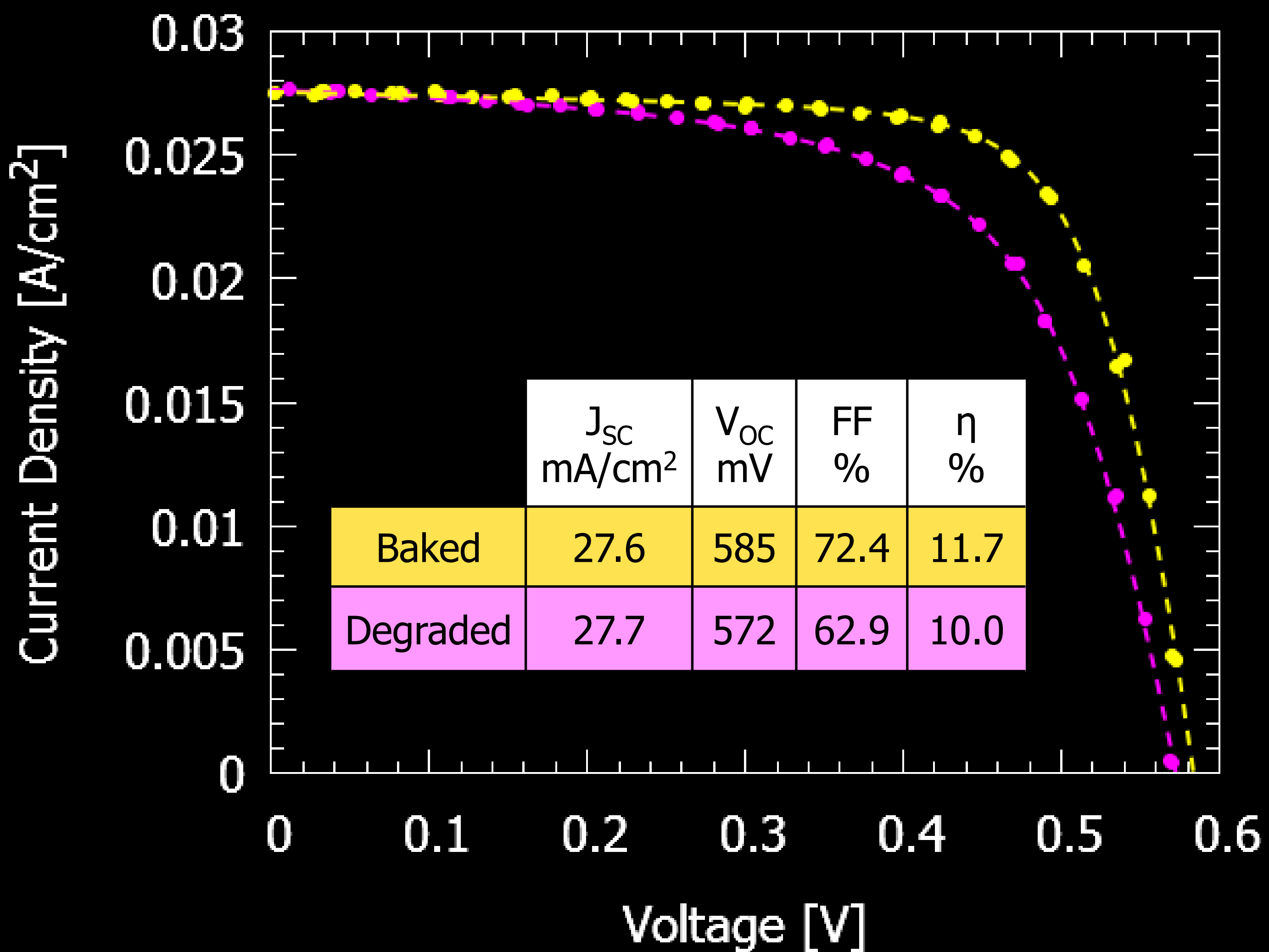
27. Stability



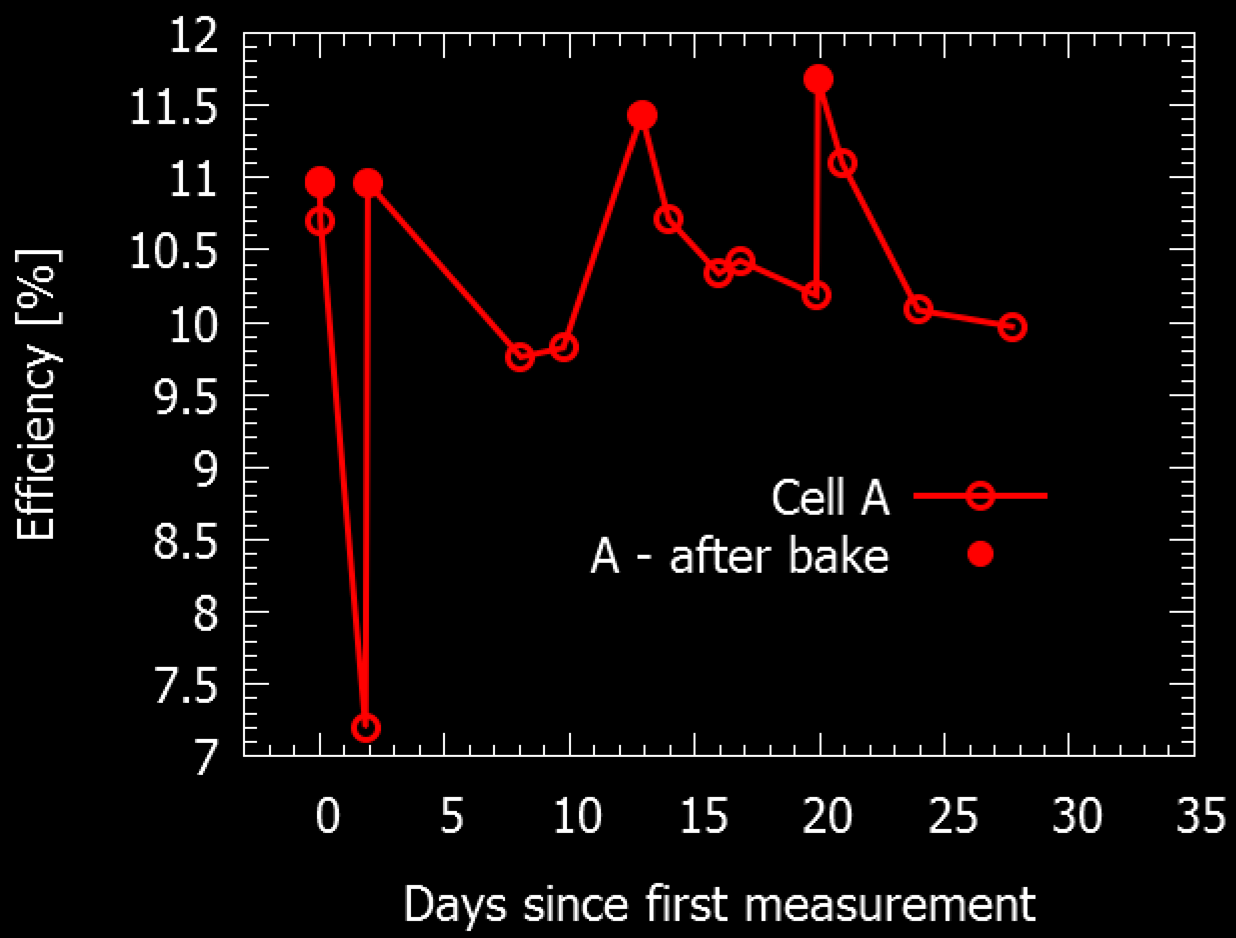
	J_{SC} mA/cm²	V_{OC} mV	FF %	η %
Baked	27.6	585	72.4	11.7

27. Stability



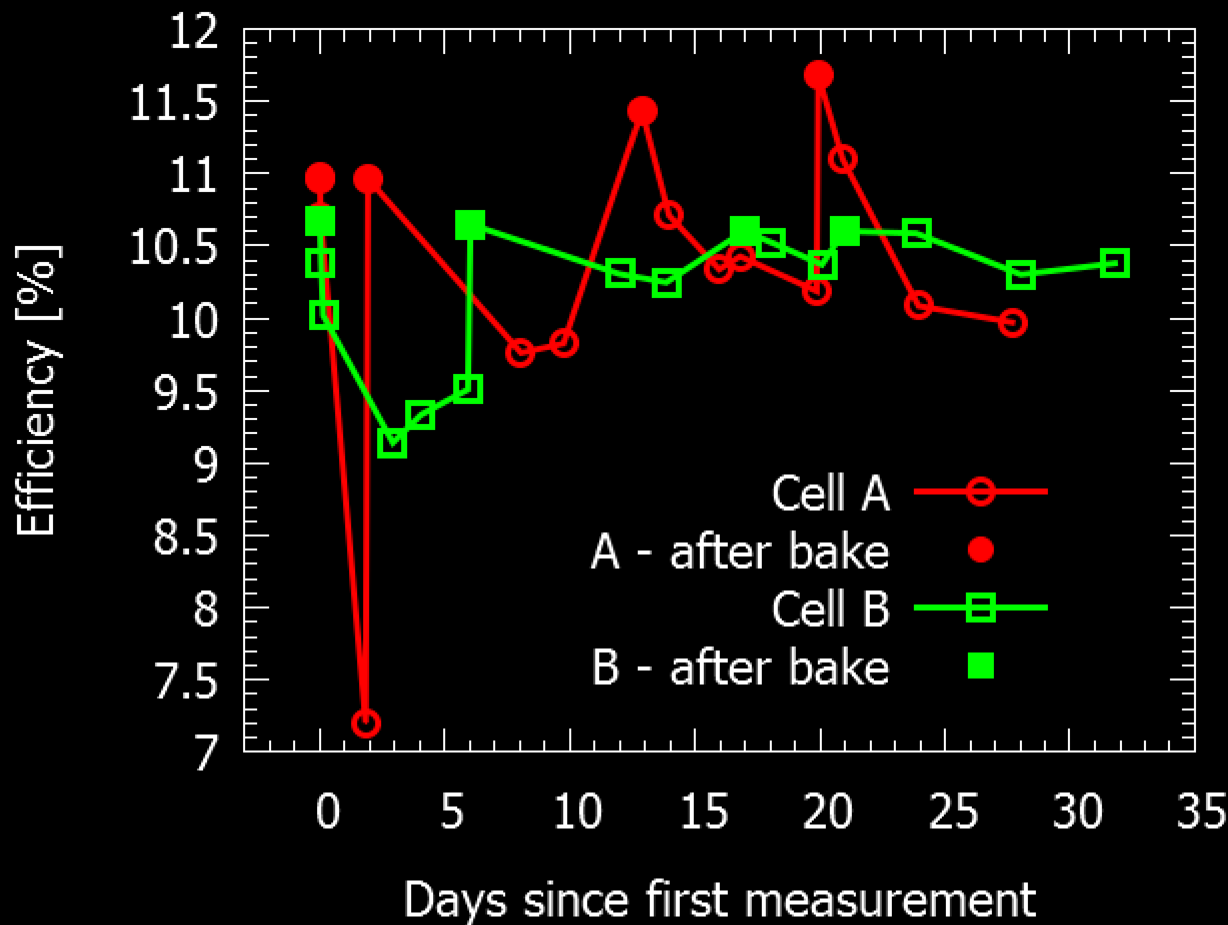
	J_{SC} mA/cm²	V_{OC} mV	FF %	η %
Baked	27.6	585	72.4	11.7
Degraded	27.7	572	62.9	10.0

28. Stability



- Occurs in dark

28. Stability

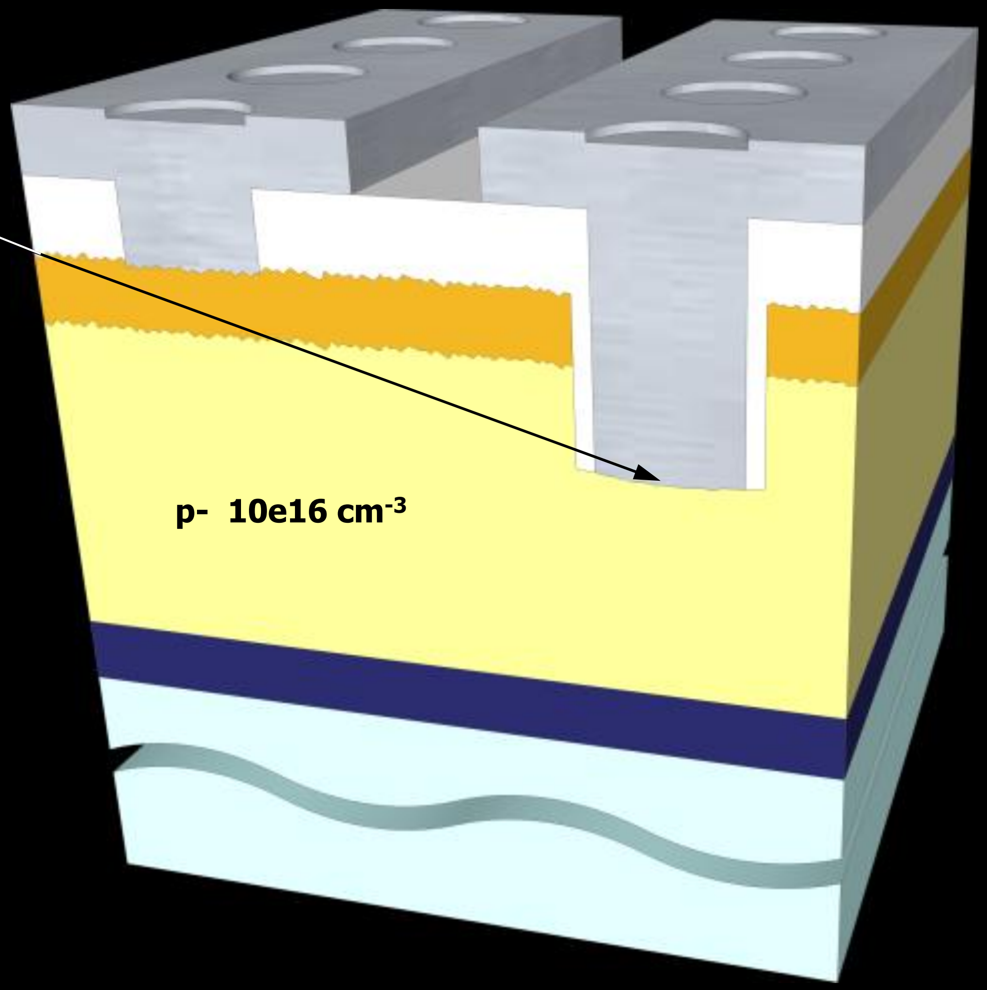


- Occurs in dark
- Related to absorber doping

- Best stabilised efficiency = 10.4%

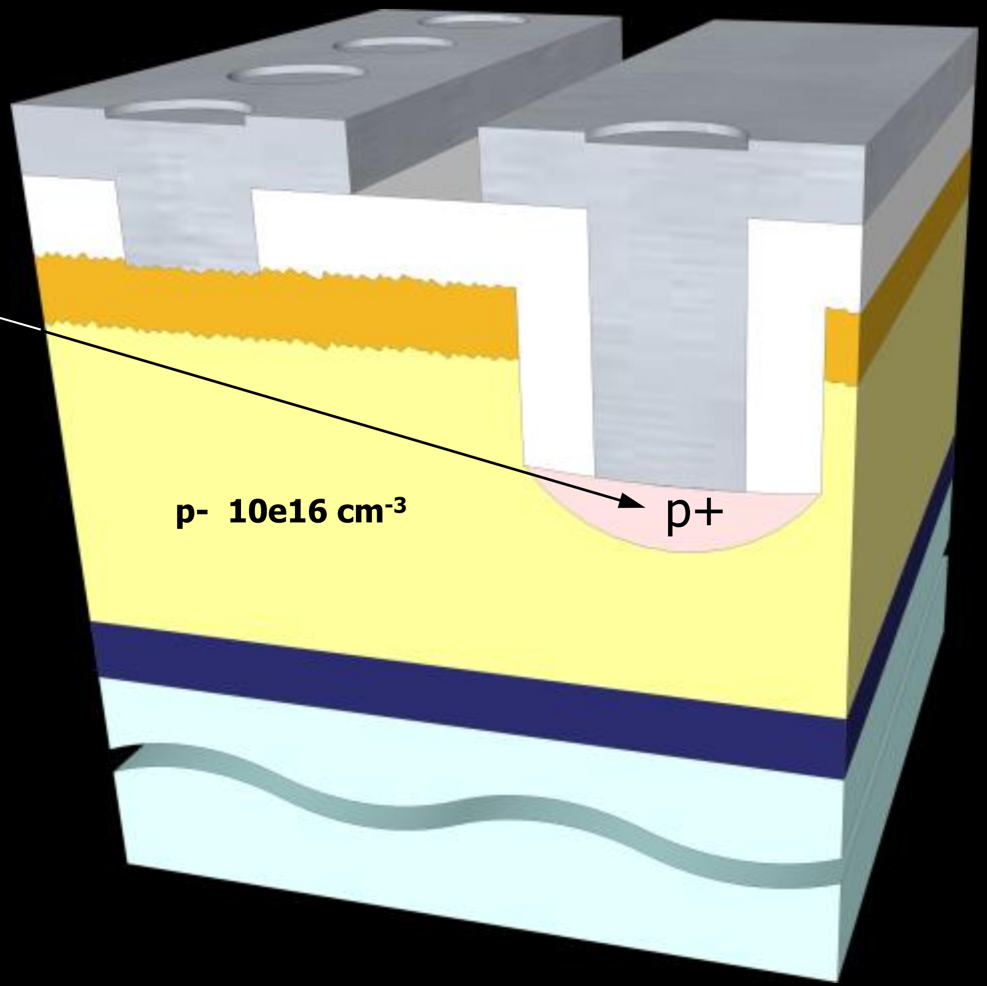
29. Selective p+ (Chaho Ahn)

- Degradation likely due to poor contact with lightly-doped absorber



29. Selective p+ (Chaho Ahn)

- Degradation likely due to poor contact with lightly-doped absorber
- Solution: selective p+ under absorber contact



30. Selective p+ (Chaho Ahn)

Cell	J_{SC} [mA/cm^2]	V_{OC} [mV]	FF [%]	η [%]
Baseline (initial)	23.6	524	62.3	7.7
Baseline (delayed)	23.9	434	46.4	4.7
Selective p+ (initial)	24.4	555	56.2	7.6
Selective p+ (delayed)	24.2	559	56.9	7.7

- Data for cells with SiO_x intermediate layer

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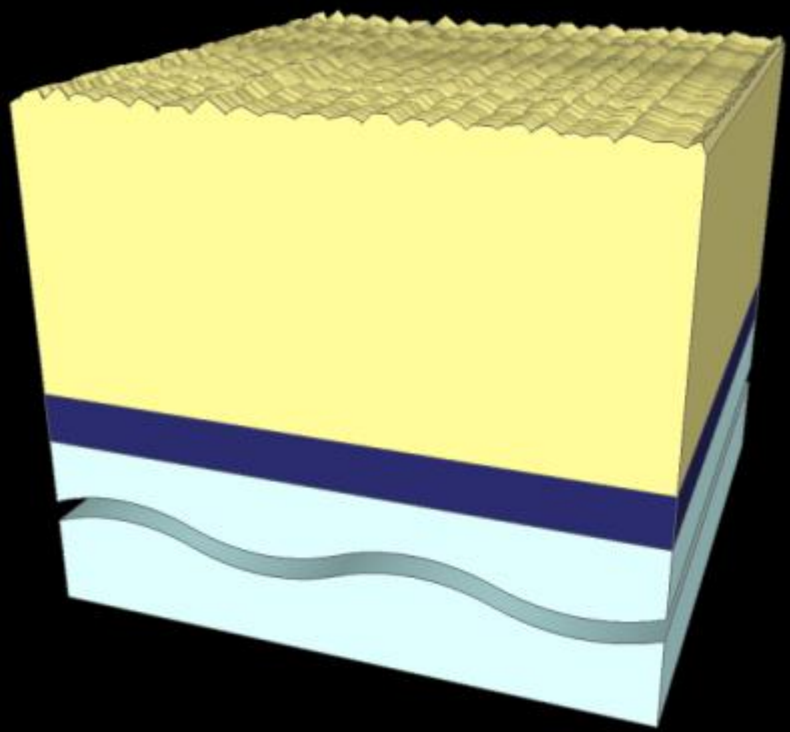
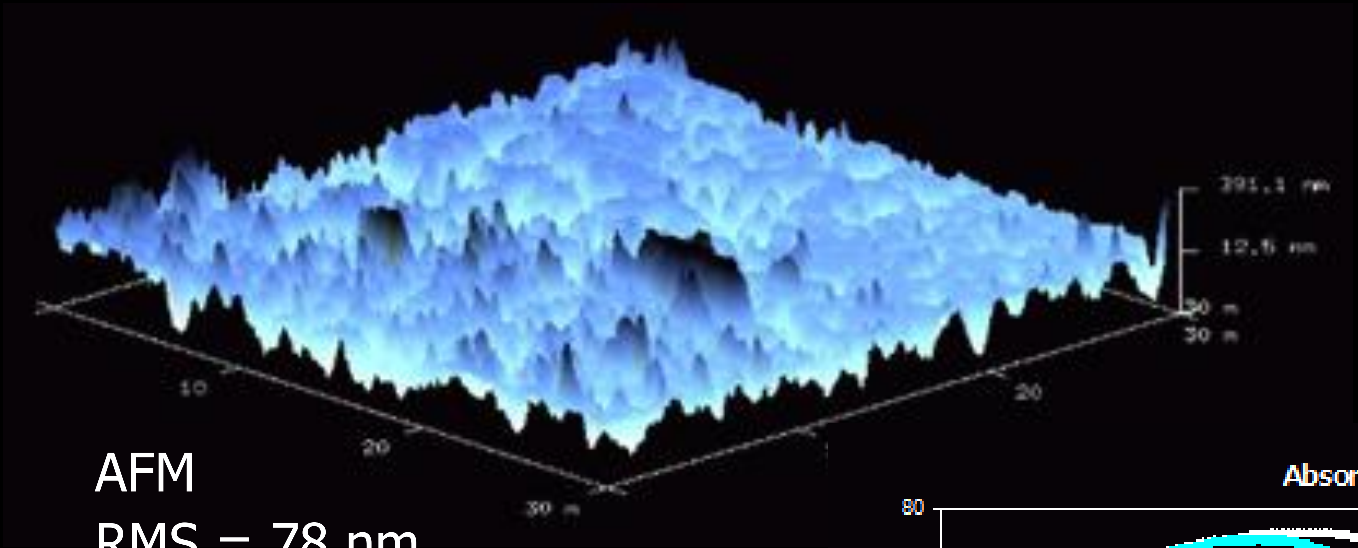
31. Rear Texture (Zamir Pakhuruddin)



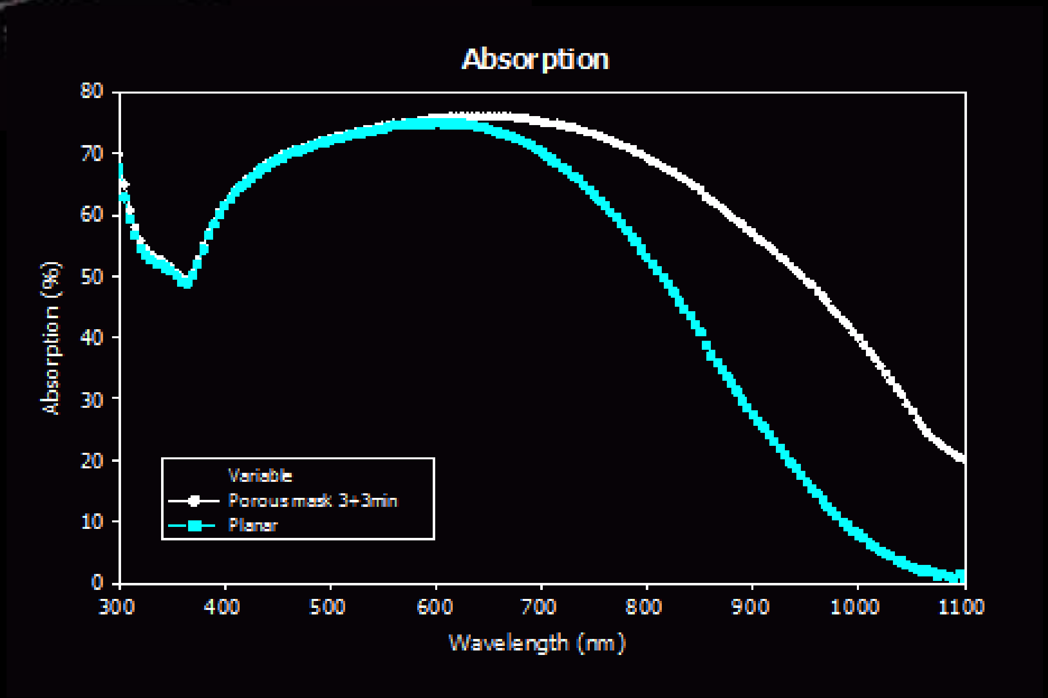
32. Rear Texture (Zamir Pakhuruddin)



AFM

RMS = 78 nm

Absorption without rear reflector or ARC



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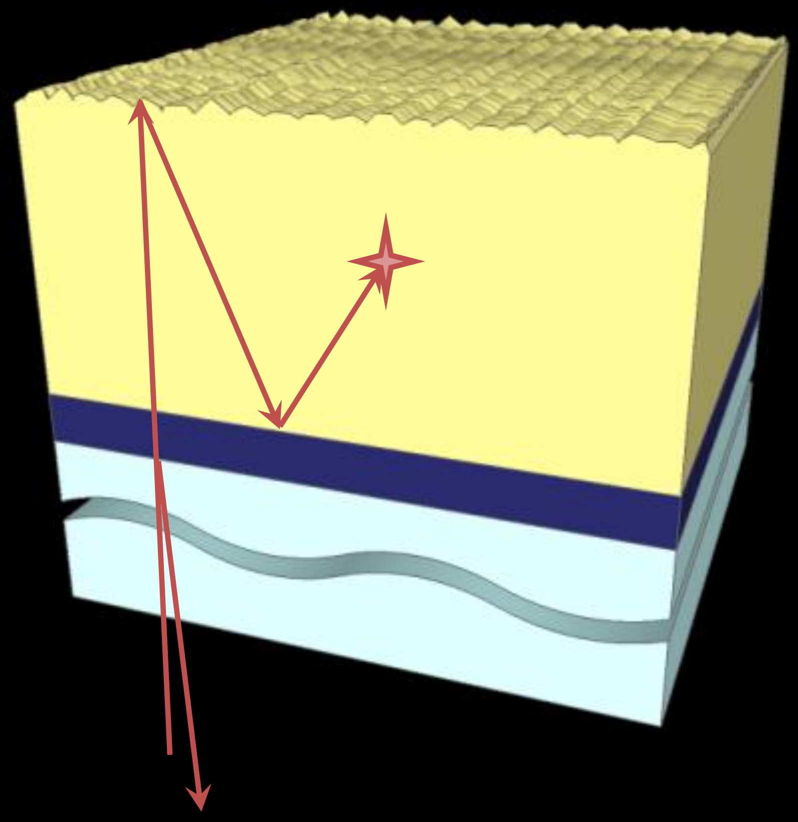

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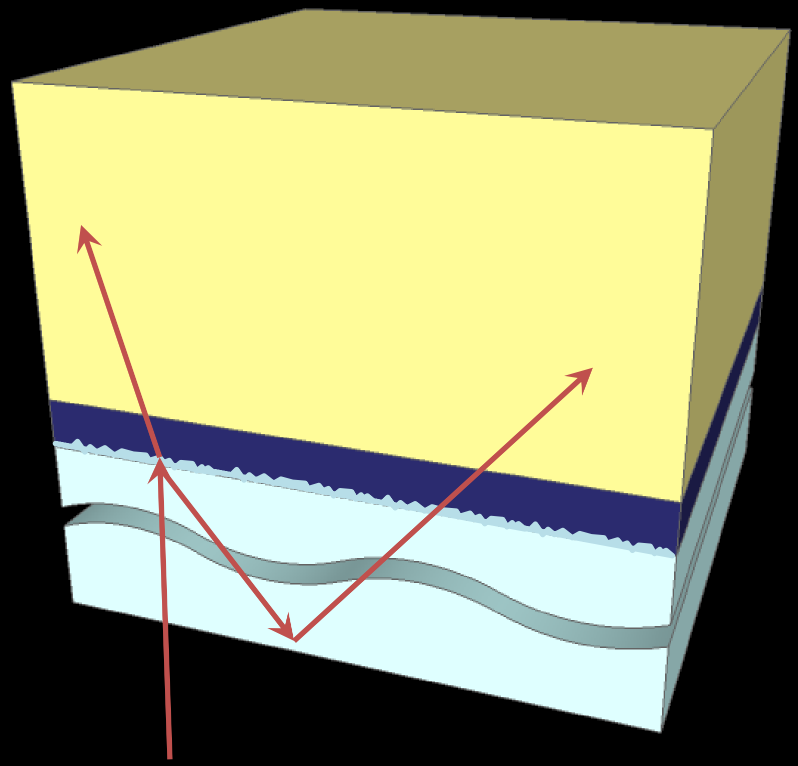
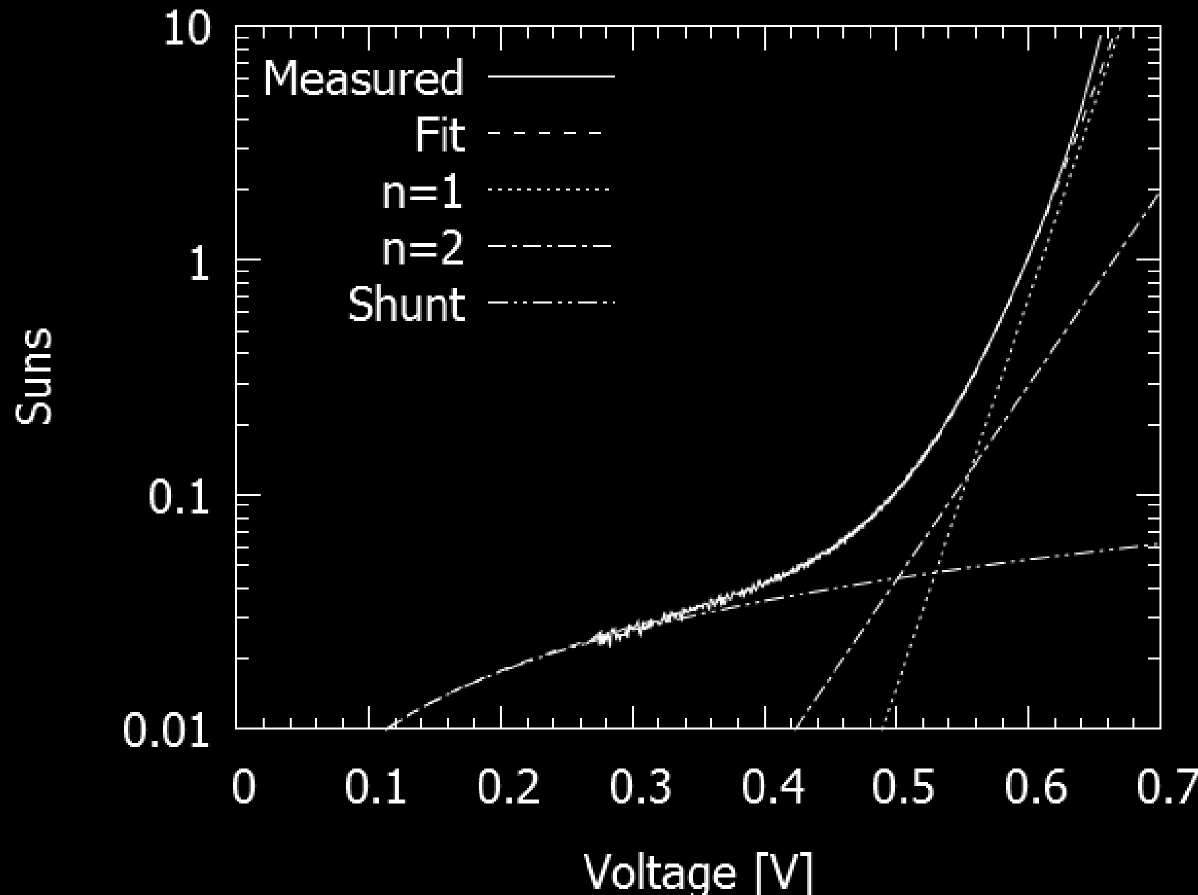
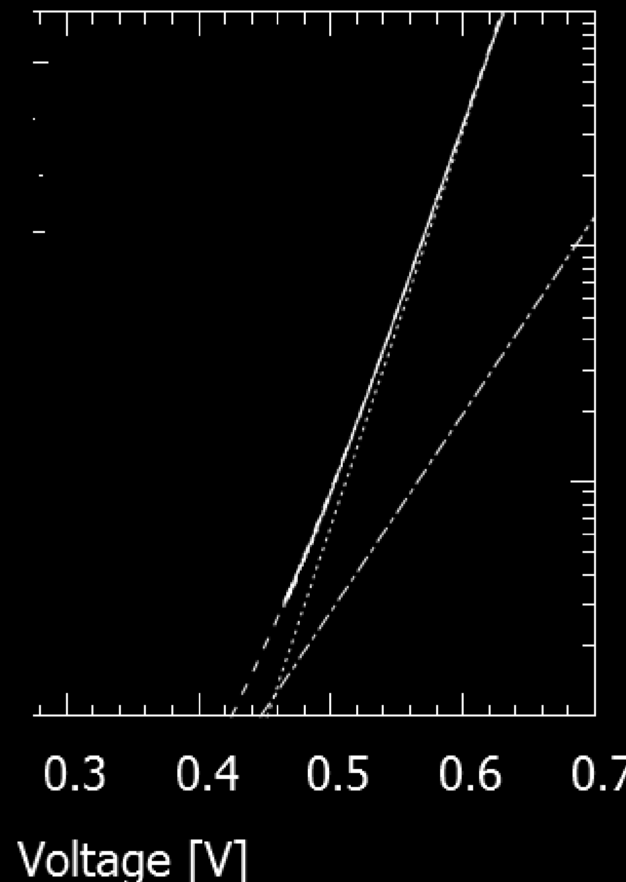


34. Suns-V_{OC}

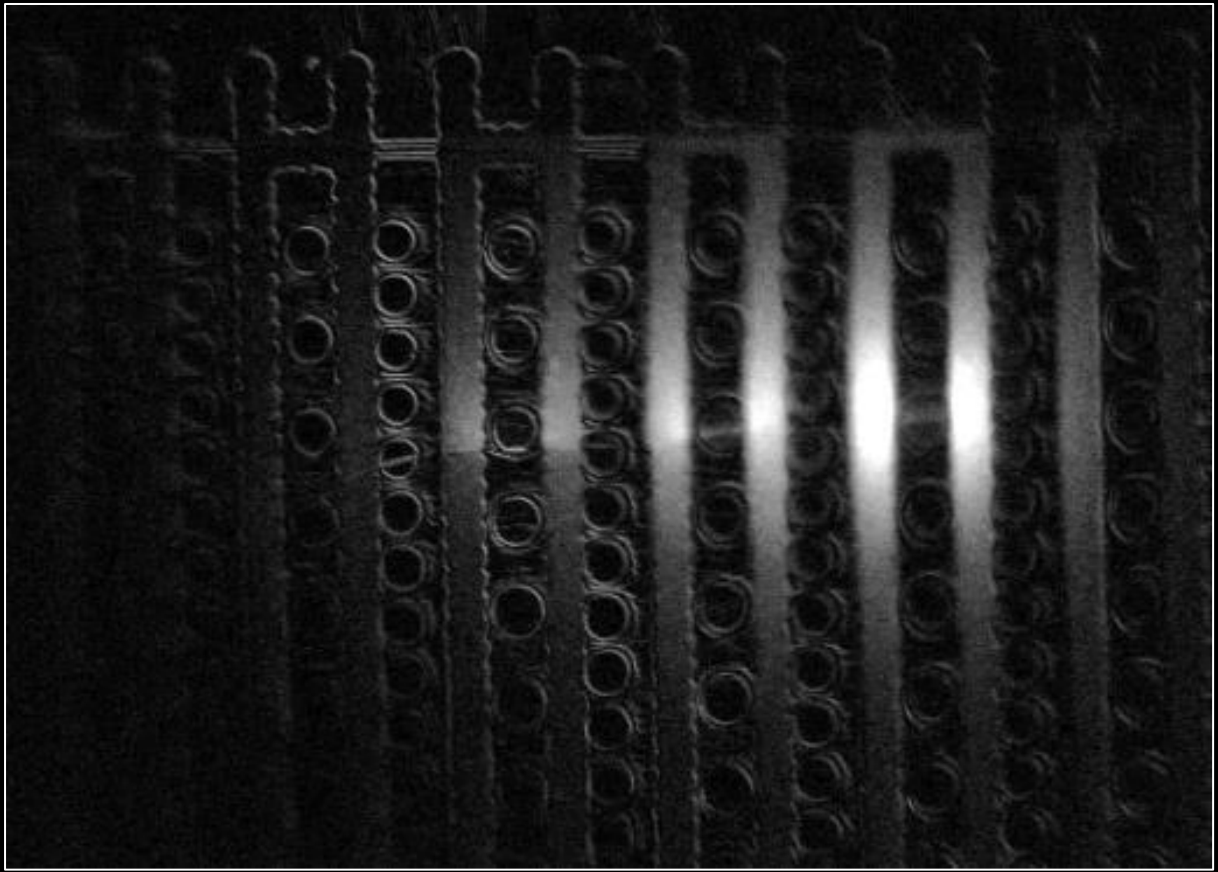




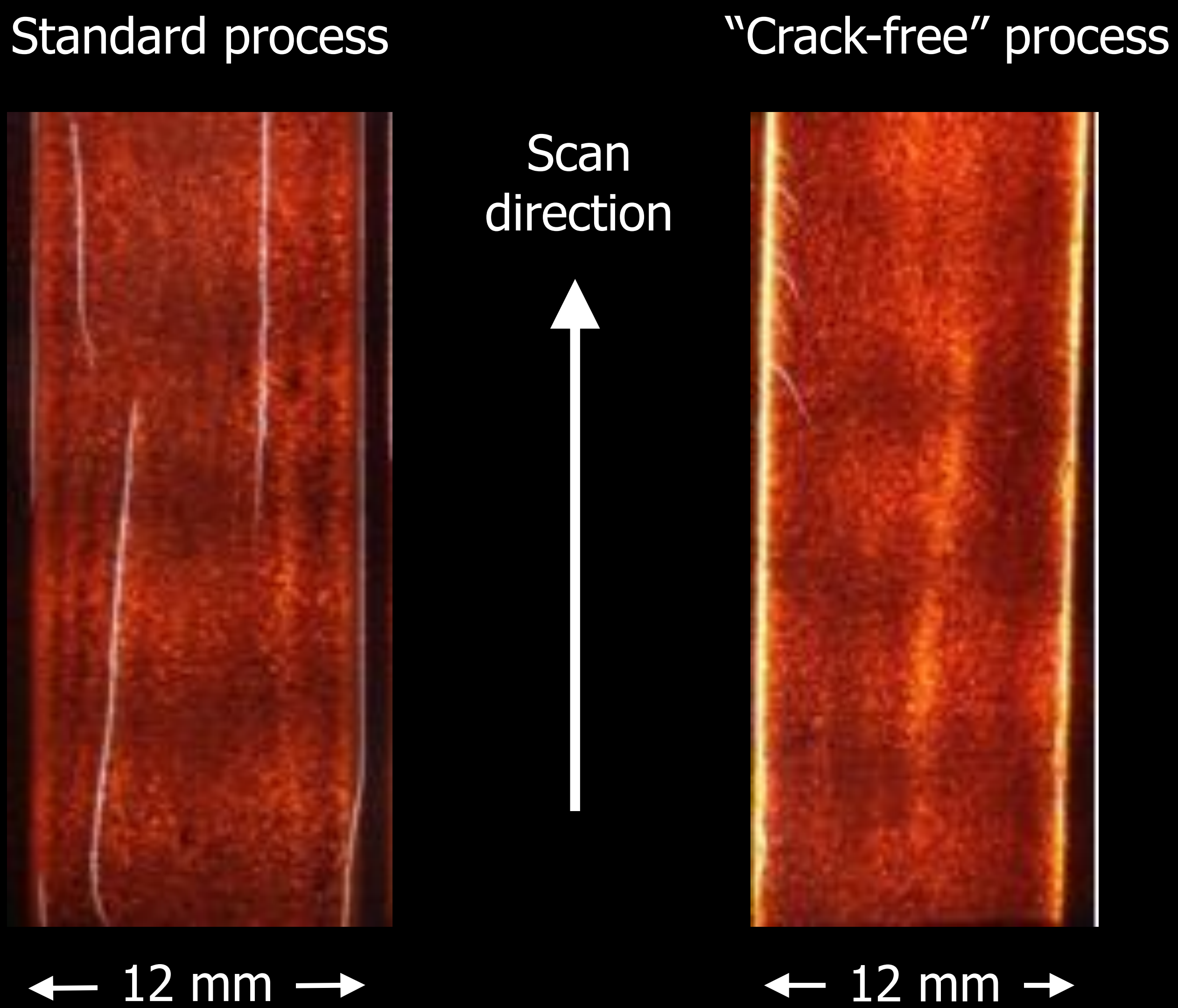
- Measured after metallisation
  - Significant R_{SH} ~ 500 Ohms.cm^2 and n = 2 influence

35. Dark Lock-In Thermography

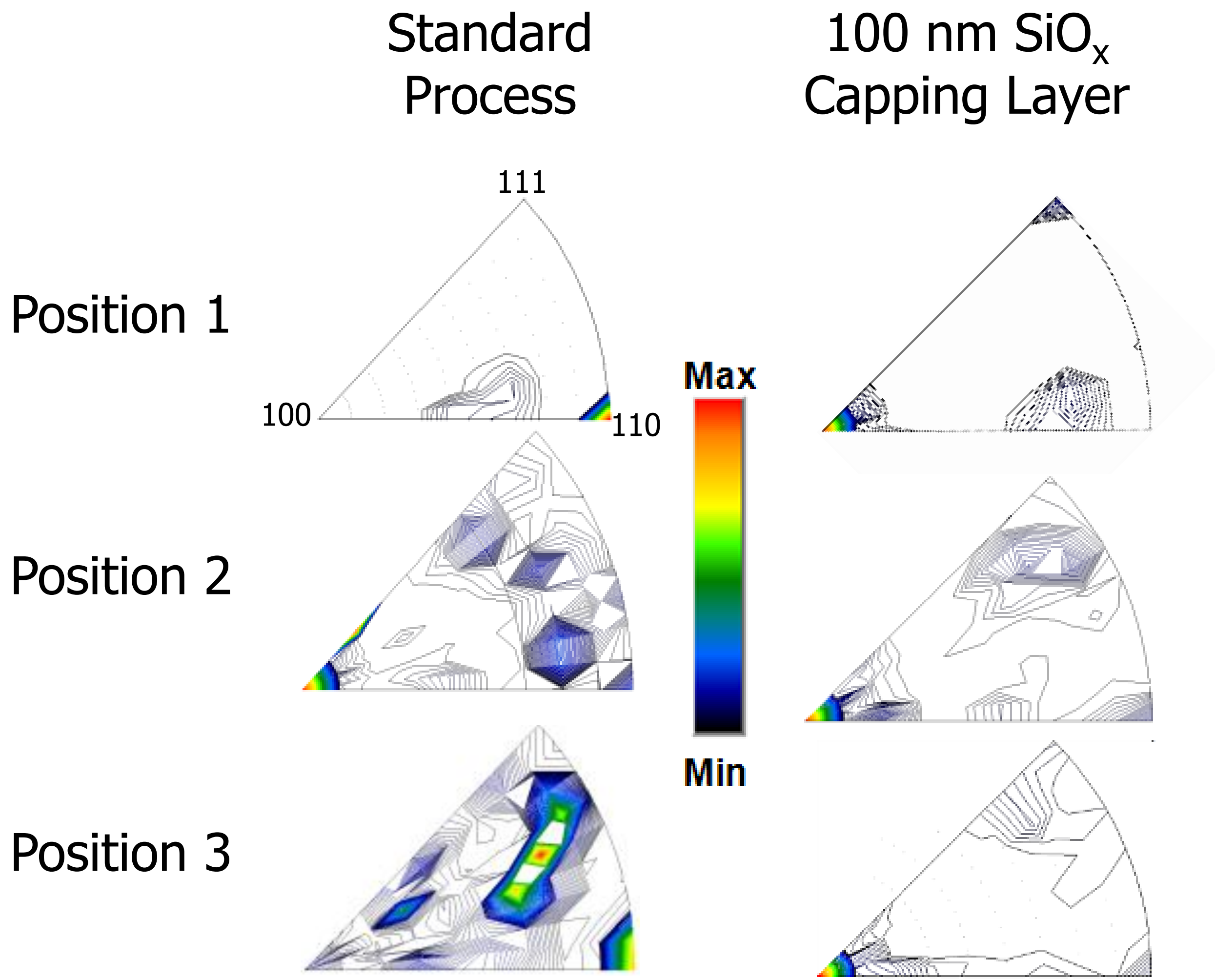
- DLIT shows hotspot at Si crack (shown for neighbouring cell)
- Same in forward and reverse bias
  - Ohmic shunt



36. Crack-free crystallisation (Jialiang Huang)



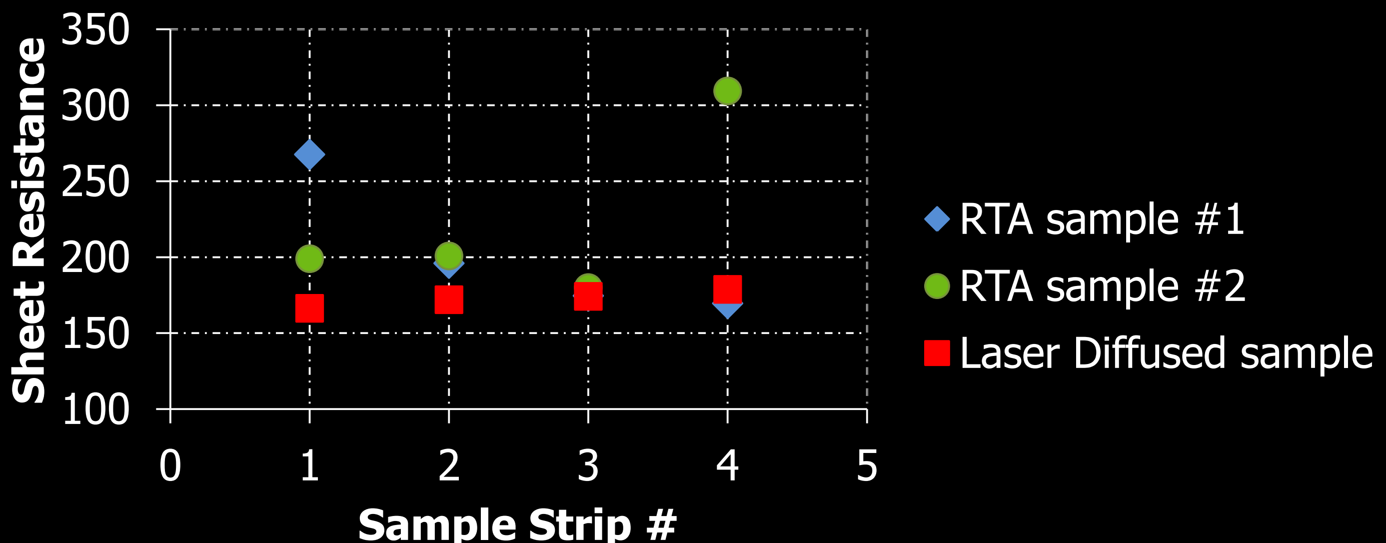
37. Grain orientation control (Jae Sung Yun)



Inverse pole orientation map

38. Laser diffusion (Miga Jung)

- RTP diffusion
  - ✗ Expensive
  - ✗ Slow
  - ✗ Causes glass softening
  - ✗ Exacerbates cracks
  - ✓ Large process window ?
- Laser diffusion
  - ✓ Cheap
  - ✓ Fast
  - ✓ No effect on glass
  - ✓ No effect on cracks
  - ✓ Process window ?



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- Introduction – motivation for thin-film
- Thin-film PV technologies
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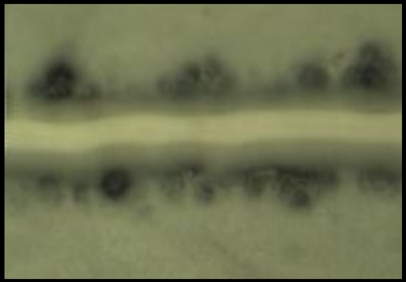
  - Material and device preparation
  - Intermediate layers
  - Stability
  - Other current work
  - Near-term priorities for future work
  - Long-term priorities for future work

39. Near-Term Priorities for Future Work

- Transfer processes to TETB
- Improve bulk passivation
- Improve surface passivation
- Identify and address device fabrication losses
  - E.g. Cell isolation scribes



- Investigate alternative junction formation
  - Heterojunction
  - Other?
- Plasmonic light-trapping?

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40. Simple economics

* Multi wafer spot price = \$0.84/wafer @ eff = 17% → \$0.20/W
* BSG ~ \$20/m² above standard glass @ eff = 12% → \$0.17/W
* Need to <u>increase eff</u> and/or <u>use standard glass</u>

41. Process sequence

- Typical TF-Si
- Clean
- Deposit
- Scribe
- Clean
- Deposit
- Scribe
- Deposit
- Scribe
- Module assembly

- Laser-crystallised TF-Si
- Clean
- Deposit
- Crystallise
- Coat
- Diffuse
- Etch
- Hydrogenate
- Scribe
- Coat
- Bake
- Inkjet
- Etch
- Expose
- Bake
- Inkjet
- Clean
- Bake
- Clean
- Deposit
- Scribe
- Bake
- Module Assembly

- Need to simplify contacting scheme

42. Conclusions

- Laser-crystallised poly-Si solar cell reaching 11.7% efficiency
  - Exceeds record for thin-film poly-Si
- Short-term, recoverable degradation
- Selective p+ metallisation makes stable cells
- Performance improvements mostly due to intermediate layer
- Many more opportunities for further improvement