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Loss Analysis and Performance Optimization Pathways of 729-mV V_{oc} Si Solar Cells with Poly-Si on Locally-Etched Dielectric Passivating Contacts

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INTRODUCTION

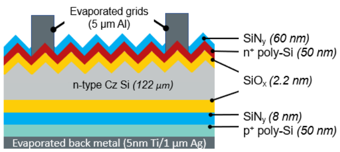


Fig. 1. Schematic diagram of the passivated contact solar cell with poly-Si on locally-etched dielectrics (pinholes omitted for clarity)

- *Passivated contact solar cells fabricated with pinholes in ultra-thin SiO_2 and SiO_2/SiN_x layers using metal-assisted chemical etching (MACE) on planar or textured surfaces, at room temperature*
- *Electron-selective n^+ Poly-Si on Locally Etched Oxide (SiO_x):(PLEO)*
- *Hole-selective p^+ Poly-Si on Locally Etched Nitride Oxide (SiN_y/SiO_x): PLENO.*

Ref: C. L. Anderson et al., Adv. Energy Mater. 13 (11), 2203579.

* C. L. Anderson fabricated and characterized the solar cells at NREL

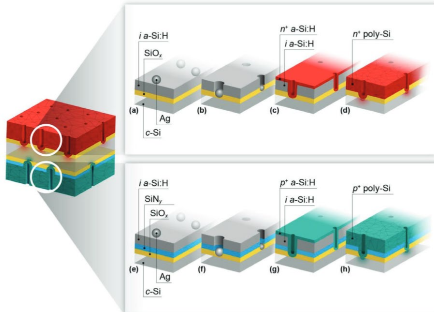


Fig. 2. Idealized processing steps for the fabrication of electron-selective n^+ poly-Si on locally-etched SiO_x (PLEO) and hole-selective p^+ poly-Si on locally-etched SiN_y/SiO_x (PLENO) passivating contacts.

DEVICE SIMULATION USING QUOKKA3

Table I: Parameters for simulation

Passivation	
$J_{0\ (no\ metal,front)}$	5.8 fA/cm^2
$J_{0\ (metal,front)}$	13 fA/cm^2
$J_{0(no\ metal,rear)}$	0.6 fA/cm^2
$J_{0(metal,rear)}$	10 fA/cm^2
Bulk lifetime	2750 µs
Metal Contacts	
Width of fingers	20 um
Pitch of Fingers	1.19 mm
TiAg for rear contact	0.005 µm Ti + 1 µm Ag

Note: The parameters have been derived from various characterizations such as Jo measurements and minority carrier lifetime measurements using Sinton WCT, profilometer for width and height of metal contacts and PL imaging.

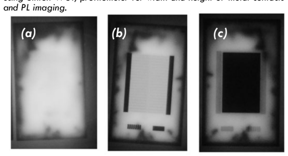
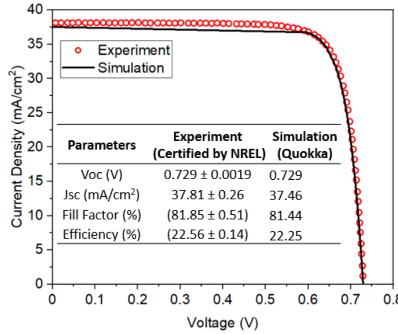


Fig. 3. Photoluminescence (PL) image of (a) before metallization (b) after metallization: front side (c) after metallization: rear side.



Parameters	Experiment (Certified by NREL)	Simulation (Quokka)
Voc (V)	0.729 ± 0.0019	0.729
Jsc (mA/cm²)	37.81 ± 0.26	37.46
Fill Factor (%)	(81.85 ± 0.51)	81.44
Efficiency (%)	(22.56 ± 0.14)	22.25

Fig. 4. Comparison of J-V for experimental result (certified at NREL) with simulation results using Quokka3.

LOSS ANALYSIS

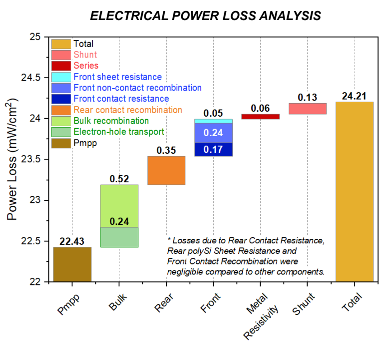


Fig. 5. Detailed electrical power loss analysis using Quokka3 of the passivated contact solar cell with poly-Si on locally-etched dielectrics.

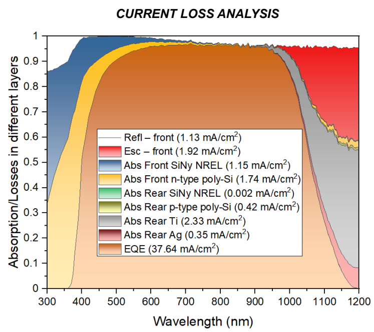
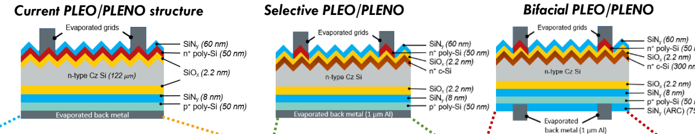


Fig. 6. Optical loss of current density using Sunsolve of the passivated contact solar cell with poly-Si on locally-etched dielectrics (Shading loss ~1.56% has not been shown here but included in electrical simulation by Quokka 3).

PATHWAY TO ACHIEVE HIGHER EFFICIENCY



Experiment: Drawbacks

V_{oc} = 0.729 V; J_{sc} = 37.46 mA/cm^2; FF = 81.44 %; η = 22.25%

- High bulk recombination .
- High rear contact recombination.
- High current loss due to parasitic absorption in front poly and rear Ti.

Step 1: Improving parameters

V_{oc} = 0.745 V; J_{sc} = 37.64 mA/cm^2; FF = 82.78 %; η = 23.21 %

- Improve bulk lifetime (~20 ms for practical reasons like availability).
- Better rear passivation (5fA/cm²).
- Use of Al as rear metal contact instead of Ti/Ag.

Step 2: Selective n-polySi

V_{oc} = 0.746 V; J_{sc} = 39.14 mA/cm^2; FF = 81.54 %; η = 23.77 %

- At front, n-Poly Si only below the metal contact.
- For detailed method please refer K. Chen et al., IEEE J. Photovolt., 12 (3) , pp. 678-689, 2022.

Step 3: Bifacial

V_{oc} = 0.760 V; J_{sc} = 42.43 mA/cm^2; FF = 77.04 %; η = 24.84 %

- Metal grids aligned at both sides
- Illuminated from both sides in simulation.
- Rear illumination: 10% of AM1.5.
- Rear SiNx ARC is non-absorbing (Simeon C et al., Prog. Photovolt.: Res. Appl. 19(4), pp.406-416, (2011)).

EFFECT OF PARAMETER VARIATION IN DETAIL

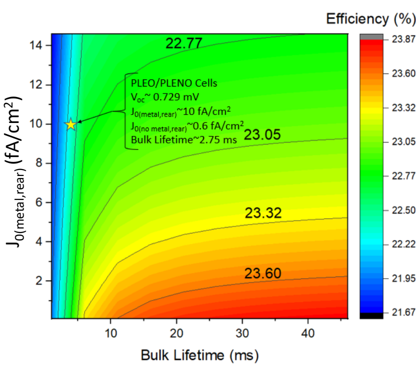


Fig. 6. Variation of efficiency with bulk lifetime and $J_{o(metal,rear)}$ for PLEO/PLENO passivated contact solar cells.

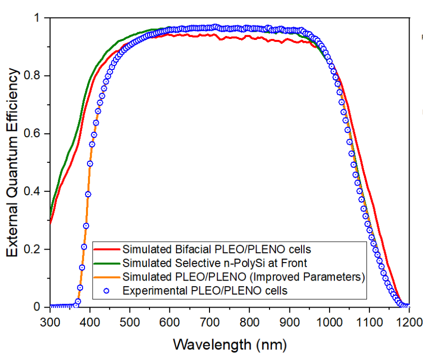


Fig. 7. Comparison of External Quantum Efficiency for different structures.

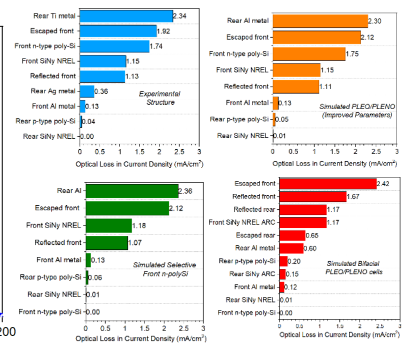


Fig. 8. Comparison of optical loss in current density for different structures.

SUMMARY

- ***Experimentally 22.5% efficient passivated contact solar cells have been fabricated with deliberate introduction of pinholes using MACE method***
- ***Increasing bulk lifetime to 20 ms and decreasing $J_{o(metal,\ rear)}$ can reduce electrical power loss***
- ***Current loss analysis shows high absorption in rear Ti metal layer and front n-polySi***
- ***Solutions have been proposed by improving the parameters, removing front n-polySi in non-contact regions and reducing rear metal contact in bifacial PLEO/PLENO structure to achieve η~25%***
- ***In future, front SiN will also be changed as it is also absorbing in nature***

ACKNOWLEDGEMENTS

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