Fabrication of Poly-Si on Locally Etched SiO_x as Passivating Contacts for c-Si Solar Cells

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Commercial TOPCon (rear)

< 5% of the world market share [1]

Commercial record $\eta \approx 25.09\%$ [2]

Lab-scale record $\eta \approx 26.0\%$ [3] using *p*-FZ

Polysilicon contacts - challenges

Lower surface passivation performance when:

- applied to random texture
- B-doped

[1] 2020 International Technology Roadmap for Photovoltaic (ITRPV).

[2] Scully, J. "LONGi Solar pushes n-type TOPCon cell to record 25.09% conversion efficiency," PV Tech, May 2021.

[3] Richter, A. et al. "Design rules for high-efficiency both-sides-contacted silicon solar cells with balanced charge carrier transport and recombination losses," Nature Energy. 2021.

Poly-Si contacts: processing alternatives

Tunneling-enabled contact

Pinhole-enabled contact
(thermally induced pinholes)

Pinhole-enabled contact
(room temperature,
chemically etched pinholes)

Dominant charge-carrier transport
Uniform transport across oxide

Dominant charge-carrier transport
Local transport across pinholes

Polysilicon on Locally Etched
Oxide passivating contacts
(PLEO)

Disadvantage

Performance that sensitively depends on oxide thickness [1],
undermining process yield

Etching of mesopores in c-Si using metal-assisted chemical etching (MACE)

- 0- RCA clean
- 1- Oxidation (2.2 nm)
- 2- *i* a-Si:H deposition

5- Ag removal

nanoparticle

3- Silver deposition
(electroless plating)

4- Metal-assisted etching
(HF:H₂O₂:H₂O solution)

6- *n* a-Si:H deposition

7- Crystallization,
dopant redistribution
& activation

Visualizing ~15 nm-wide mesopores via TEM

0- All steps up to Ag removal

1- Pt deposition

2- Focused Ion Beam preparation
(for cross-sectional TEM)

Pinholes can be etched in both planarized and textured surfaces

‘magnified’ mesopores

‘magnified’ mesopores

We speculate dilution of the etching solution reduces the etch rate by smaller particles due to their smaller etching front

[1] Tetzlaff et al. "A simple method for pinhole detection in carrier selective POLO-junctions for high efficiency silicon solar cells," *Sol. Ener. Mater. Sol. Cells*, 2017.

Passivation of PLEO contacts

$$J_{0,total} = f \times J_{0,pinhole} + (1 - f) \times J_{0,oxide}$$

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n PLEO on n-Cz DST

p PLEO on n-Cz DST

$$J_{0,total} = f \times J_{0,pinhole} + (1 - f) \times J_{0,oxide}$$

Passivation and contact resistivity of PLEO contacts

PLEO solar cells were fabricated using double-side textured & planarized *n*-Cz

Symmetric test structures already anticipated that our V_{OC} would be severely limited by the rear (*p* PLEO) passivation

J-V parameters

ID	V_{OC} [mV]	J_{SC} [mA cm ⁻²]	FF [%]	η [%]
DST	665	37.8	76.2	19.2
SDE	678	32	79.8	17.3

Mitigating Boron pile-up at the c-Si/SiO_x interface

Poorer passivation properties of *p*+ poly-Si passivating contacts have been attributed to Boron pile-up at the c-Si/SiO_x interface

Hypothesis: would an additional SiN_y interlayer serve as a Boron diffusion barrier, and thus enable high-performing *p*+ contacts?

If so, can we transfer the mesopore etching technique developed for PLEO to the PLENO concept?

PLEO

Polysilicon on **L**ocally **E**tched **O**xide

PLENO

Polysilicon on **L**ocally **E**tched **N**itride/**O**xide

p^+ poly-Si on $\text{SiN}_y/\text{SiO}_x$ symmetric structures achieve 738 mV and $2 \times 10^{-16} \text{ A/cm}^2$

Structure used in pad-to-pad resistance measurement

Pinhole formation procedure	iV_{oc} [mV]	J_0 [$\text{fA} \cdot \text{cm}^{-2}$]	Pad-to-pad resistance
None	734 ± 1	0.74 ± 0.41	Too resistive
Mesopore etching + 1% HF for 20 s	733.5 ± 0.5	1.2 ± 0.3	Ohmic, $\sim 4000 \Omega$
Mesopore etching + 10% HF for 5 s	737.5 ± 0.5	0.20 ± 0.15	Ohmic, $\sim 100 \Omega$

Polysilicon on Locally Etched Nitride/Oxide (PLENO)

Summary

- Proof-of-concept for **p** polysilicon on locally etched **oxide** (PLEO) contacts.
- Room temperature approach (via MACE) to engineer pinholes decouples charge-carrier transport across contact from passivation scheme of choice.
- 19 and 17% PLEO devices fabricated on double-side textured and saw-damage etched *n* Cz wafers, respectively.
- Preliminary work on **p** polysilicon on locally etched **nitride/oxide** (PLENO) contacts.
- 0.2 fA/cm² achieved with *p* PLENO; contact displays Ohmic behavior but still very resistive due to low pinhole density.

Acknowledgement

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William (Bill) Nemeth
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Matthew Page
San Theingi
Vincenzo LaSalvia
Dr. David L. Young
Dr. Paul Stradins

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NREL/PR-5900-80273