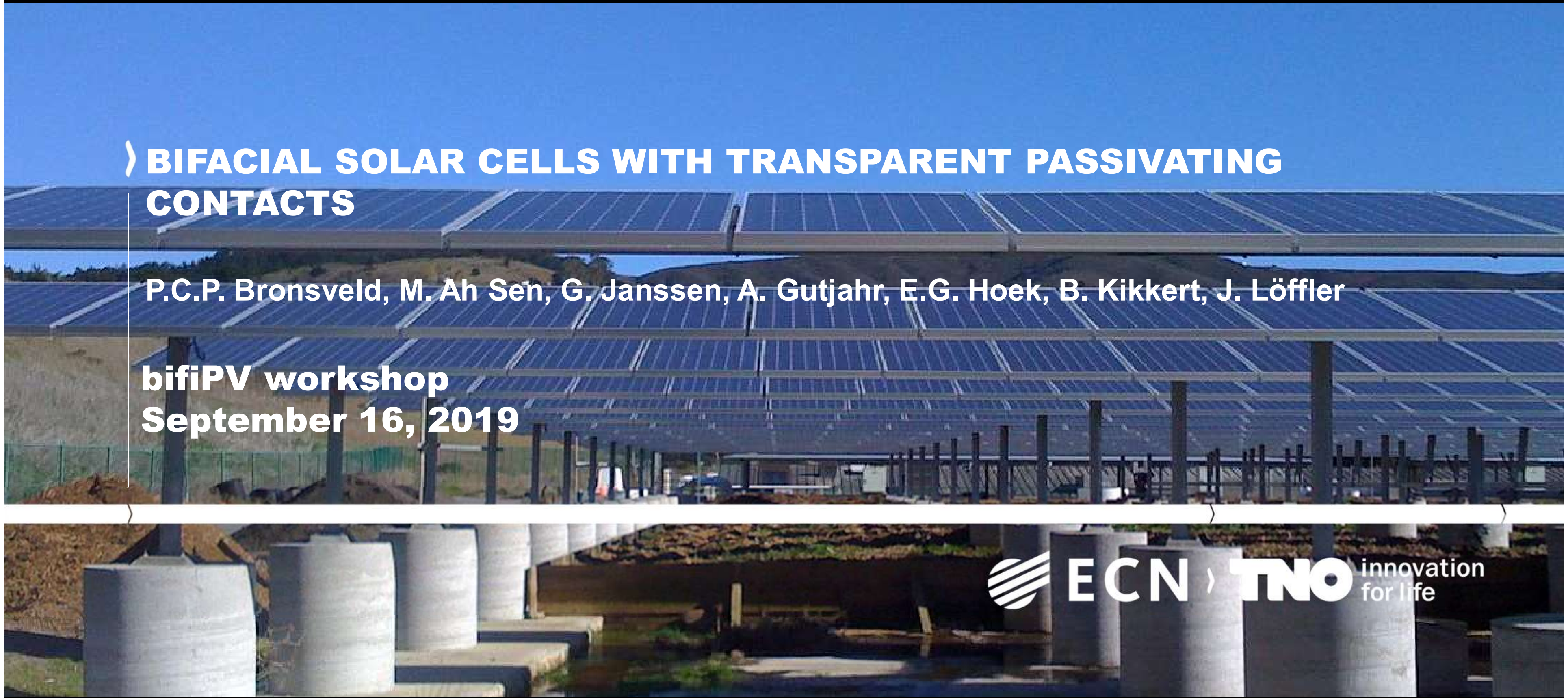

# BIFACIAL SOLAR CELLS WITH TRANSPARENT PASSIVATING CONTACTS

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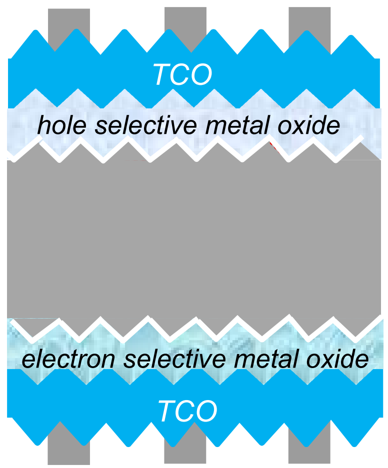
**bifiPV workshop**
**September 16, 2019**

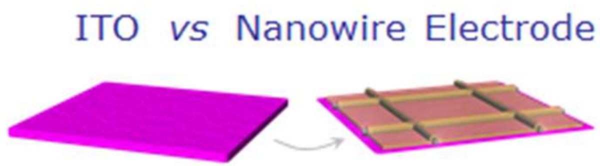
ECN › TNO innovation for life

*Picture: https://upload.wikimedia.org/wikipedia/commons/thumb/c/c6/Photovoltaic_mounting_system.jpg/1200px-Photovoltaic_mounting_system.jpg*

# TRANSPARENT PASSIVATING CONTACTS @ ECN.TNO

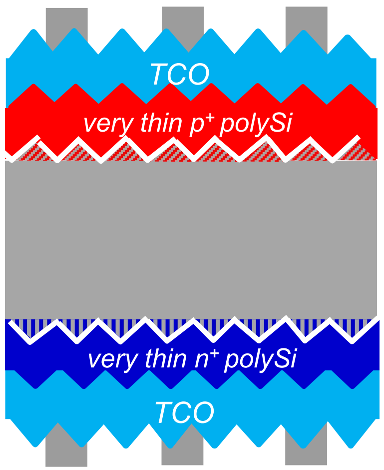



Part 1: transparent metal oxides



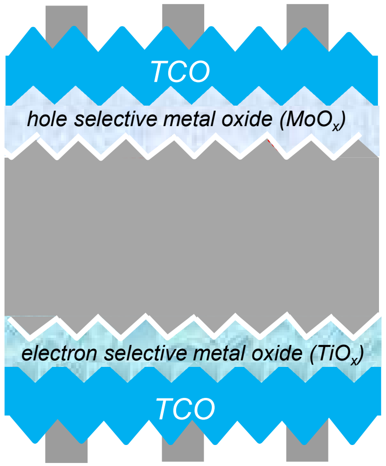

AMOLF

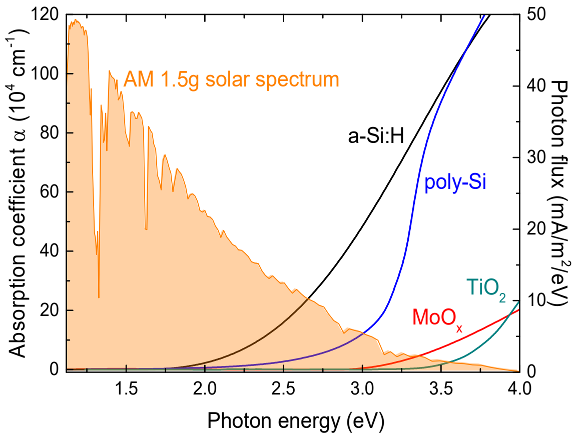
Intermezzo: Replace TCO with Ag NW grids

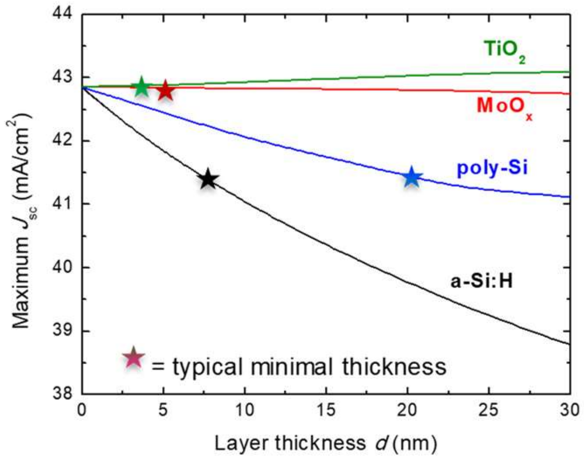



Part 2: very thin polySi contacts

# PART 1: TRANSPARENT METAL OXIDES



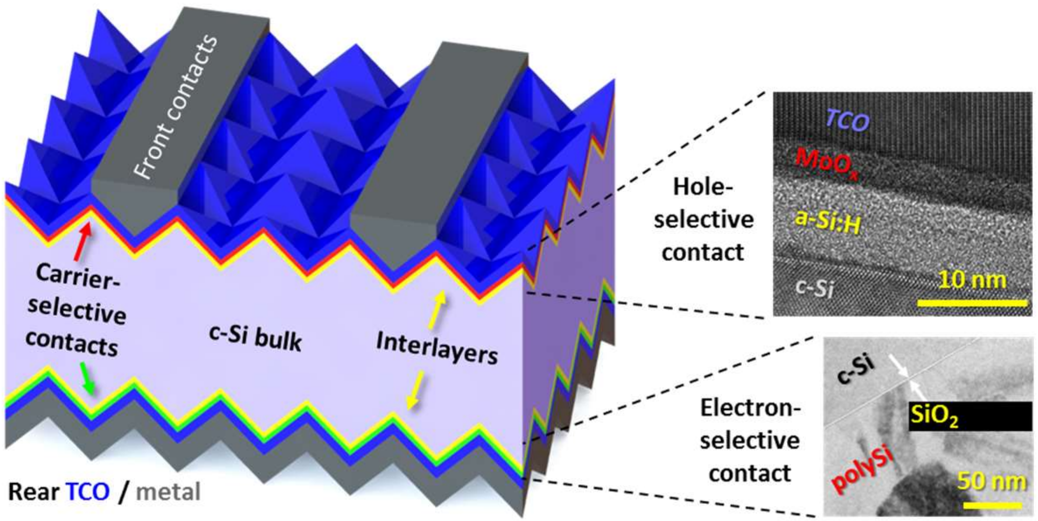



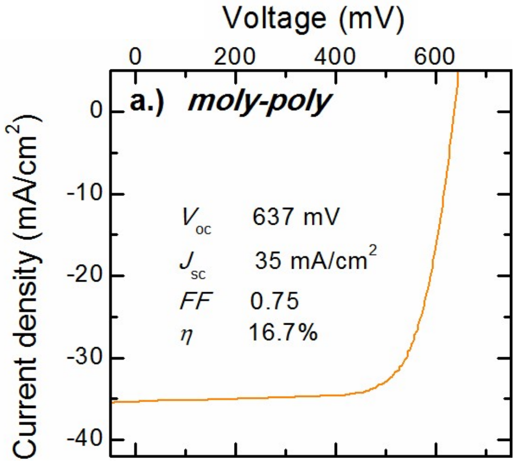

Practically zero parasitic current loss expected for optimal properties

Carrier selectivity based on WF offset w.r.t. bulk Si wafer (MOS junction)

# 'MOLY-POLY' SOLAR CELL

- Minimizing front side losses with a thermally stable rear
- Lab-scale moly-poly cell: 16.7% (Bullock *et al.*) , 4 $cm^2$
- Goal: **process for large-area moly-poly cell**

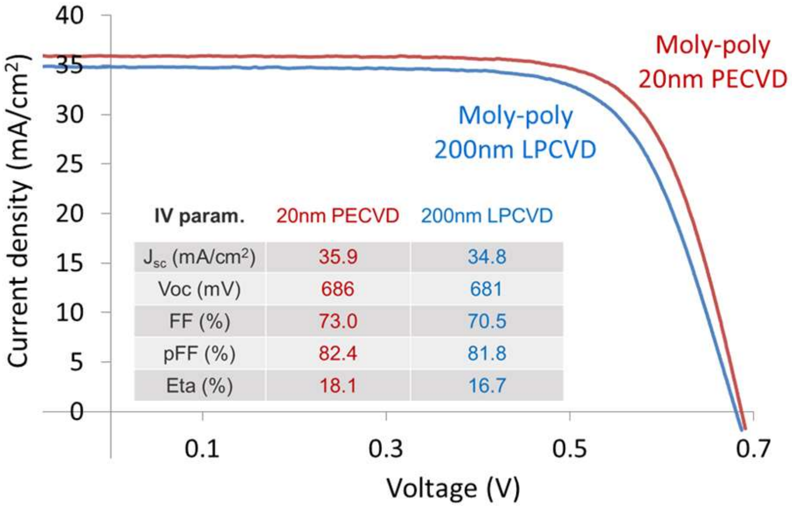



*J. Bullock et al., Energy Procedia (2015)*

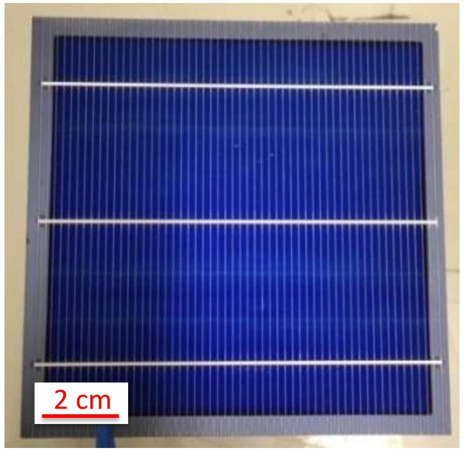
# 4 INCH MOLY-POLY WITH EVAPORATED $MOO_X$ ON A-SI:H

- First large area moly-poly cell (2017): **18.1% efficiency**
- Thermally evaporated MoOx on aSi:H(i) interlayer
- iVoc **732 mV** with ITO, $V_{OC}$ limited by $MoO_x$ reduction
- Jsc, FF mainly limited by metal print and ITO

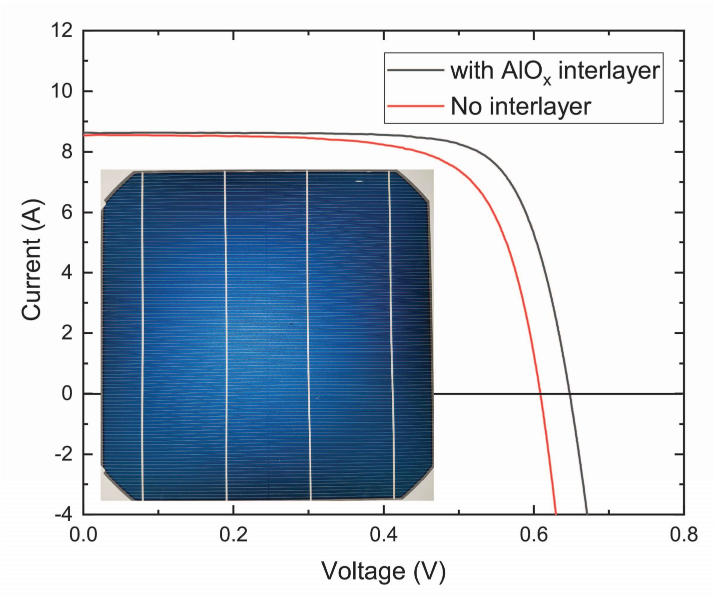



| IV param. | 20nm PECVD | 200nm LPCVD |
|---|---|---|
| $J_{sc}$ (mA/cm$^2$) | 35.9 | 34.8 |
| Voc (mV) | 686 | 681 |
| FF (%) | 73.0 | 70.5 |
| pFF (%) | 82.4 | 81.8 |
| Eta (%) | 18.1 | 16.7 |

Effective area (ITO mask):
9.2x9.2 cm$^2$

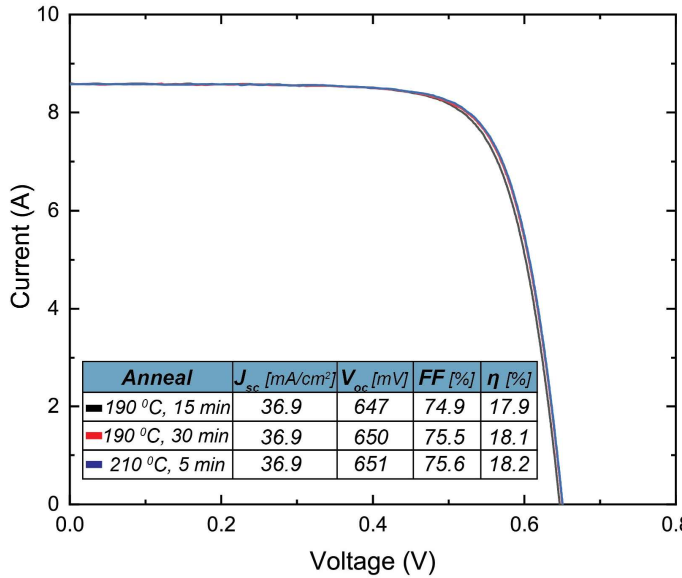


# 6 INCH THERMALLY STABLE MOLY-POLY: $MOO_X$ ON $ALO_X$




E-beam $MoO_x$ on ALD $AlO_x$ **18.2%** (2018)

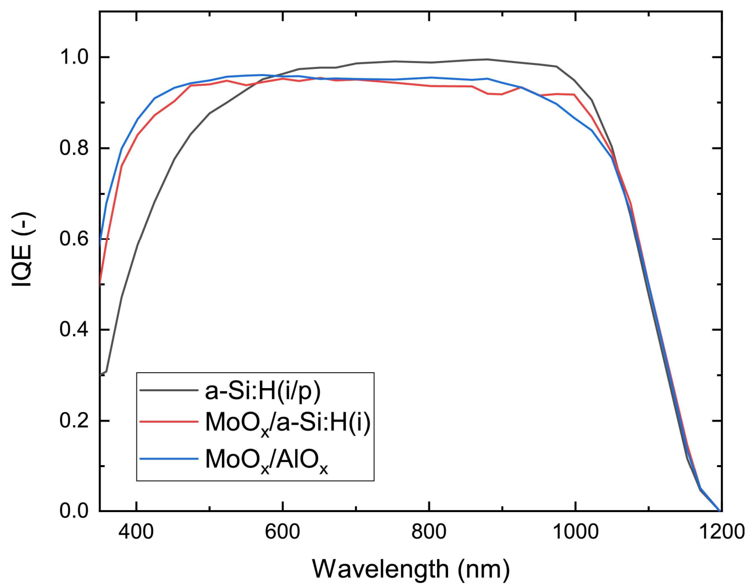
- Even more transparent in short wavelengths
- Simpler process (no SHJ cleans, no a-Si:H)
- Improvement of FF, zero selectivity loss
- Passivation better than without $AlO_x$

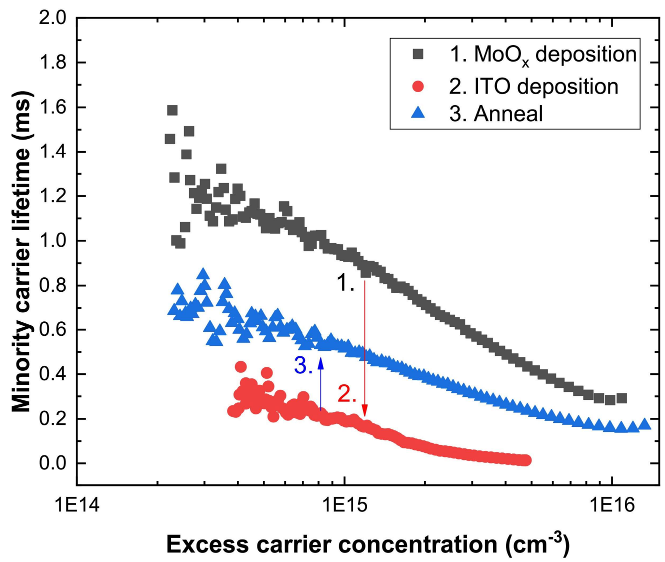


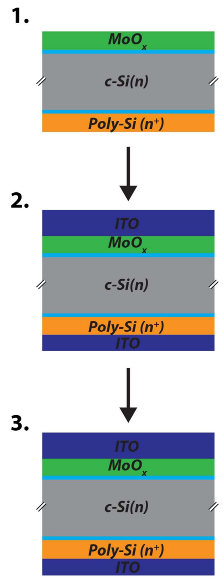

| *Anneal* | *$J_{sc}$ [mA/cm²]* | *$V_{oc}$ [mV]* | *FF [%]* | *η [%]* |
|---|---|---|---|---|
| *190 °C, 15 min* | *36.9* | *647* | *74.9* | *17.9* |
| *190 °C, 30 min* | *36.9* | *650* | *75.5* | *18.1* |
| *210 °C, 5 min* | *36.9* | *651* | *75.6* | *18.2* |

Thermally stable (improving) up to 210 °C

# OPEN ISSUES FOR MOLY-POLY CELLS WITH $ALO_x$ (2019)




## Work on increasing WF of $MoO_x$ (2019)

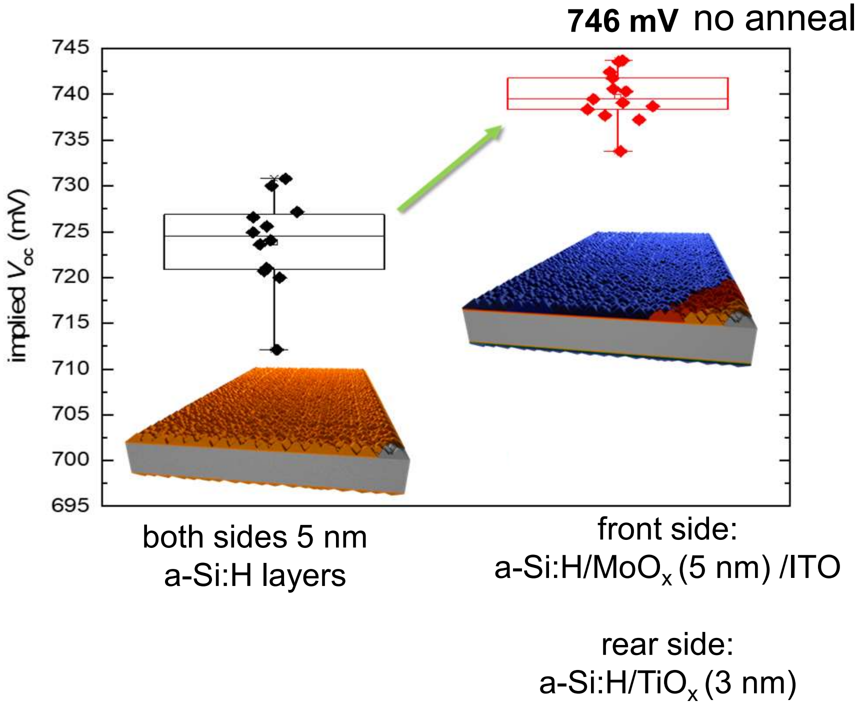
- Minimize subbandgap absorption (0.6 $mA/cm^2$)
- Secure zero selectivity loss (Janssen et al. EUPVSEC 2019)

## Increasing passivation of $AlO_x/MoO_x$ (2019)

- Improve initial passivation >>1ms
- Eliminate sputtering damage ($V_{OC}$ +60 mV)

## FIRST 6 INCH $MOO_X$-$TiO_X$ SOLAR CELLS (BOTH ON A-SI:H)

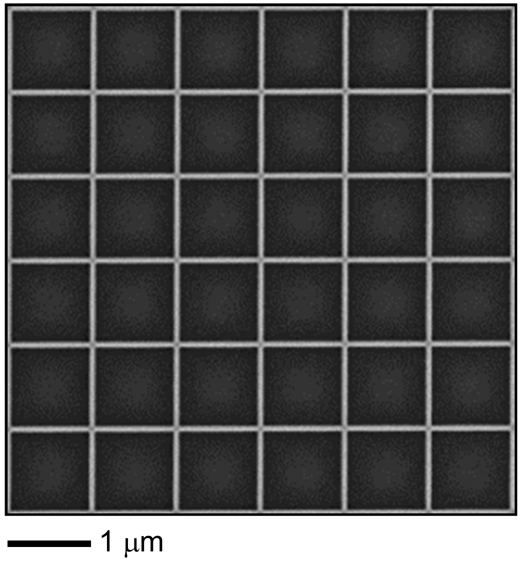
- First 6 inch $MoO_x$-$TiO_x$ cells
- Low damage metal oxide and TCO deposition: WF of layers will be optimized in new system (2020)
- Halffab with active layers and ITO: **high iVoc 746 mV, <u>without anneal</u>**



# INTERMEZZO: AG NANOWIRE NETWORKS (ON FLAT CELL)

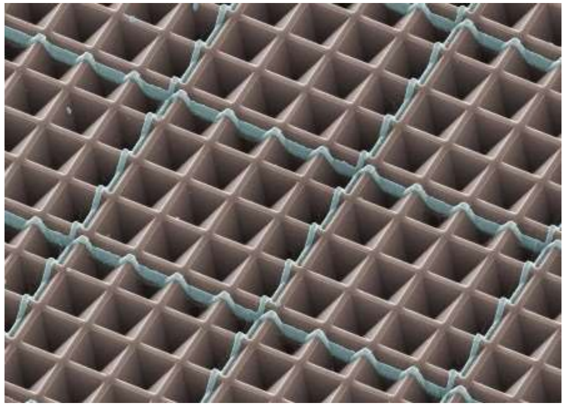
ITO *vs* Nanowire Electrode

| | 80 nm ITO | | Hybrid NW Electrode | |
|---|---|---|---|---|
| • Fill factor | 0.62 | → | 0.67 | +0.05 |
| • $J_{sc}$ | 32.7 | → | 34.1 | +1.4 mA cm$^{-2}$ |
| • Efficiency | 13.8 | → | 16.0 | +2.2% |

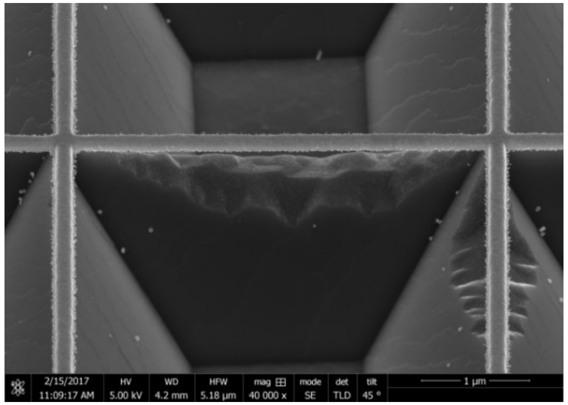




*Mark Knight, Paula Bronsveld*
Nano Energy **30**, 398 (2016)

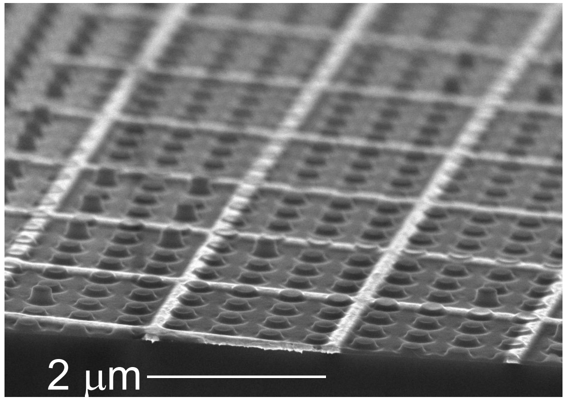
# INTEGRATING LIGHT MANAGEMENT



SCIL imprint on textured Si



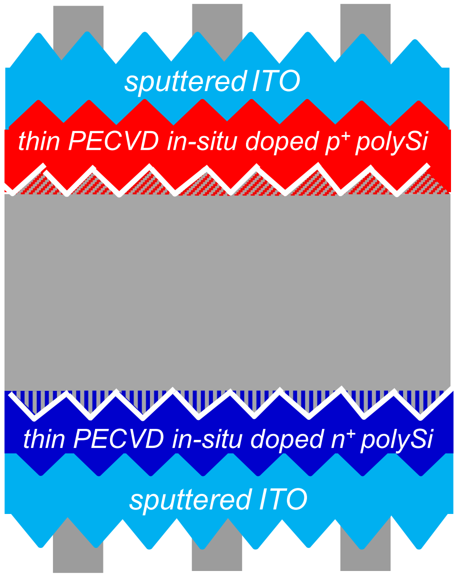

self aligned etching



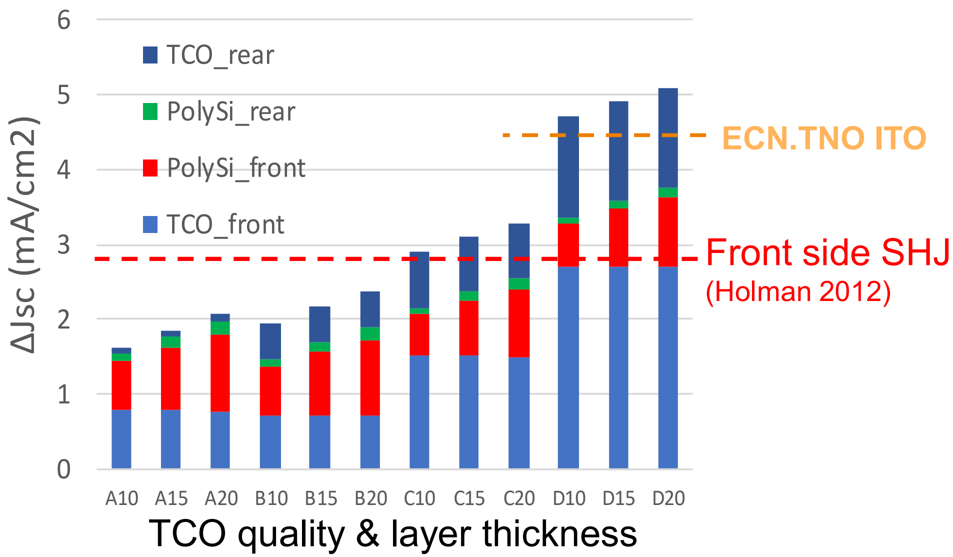

combined with Mie scatterers

New solar cell structures with these innovations are under development

# PART 2: VERY THIN POLYSI CONTACTS

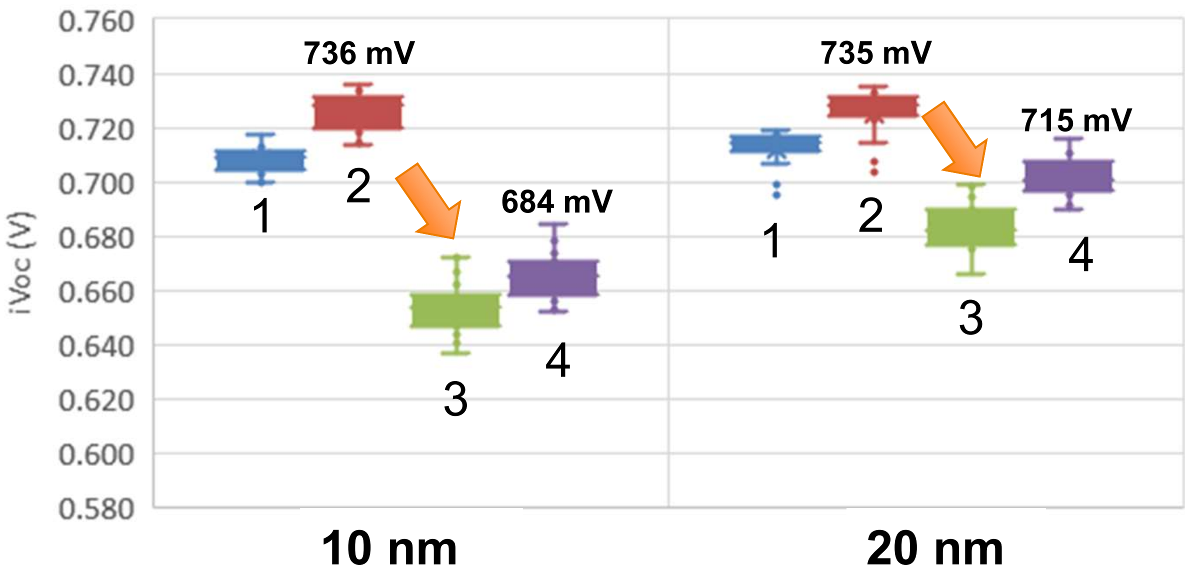



'poly-poly' solar cell



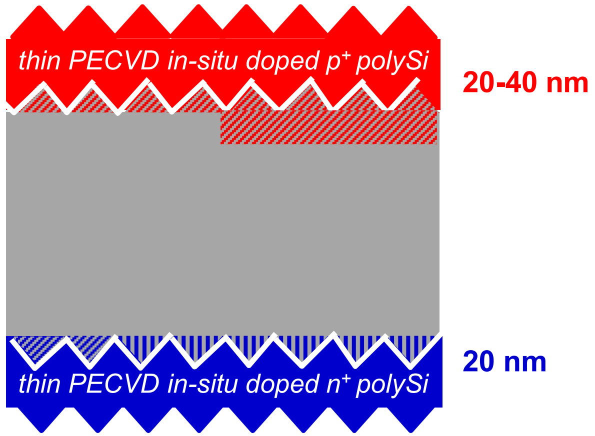

*Holman et al. IEEE J. of Photovoltaics 2 (2012) pp. 7*

# GOOD PASSIVATION REDUCED BY SPUTTERING DAMAGE

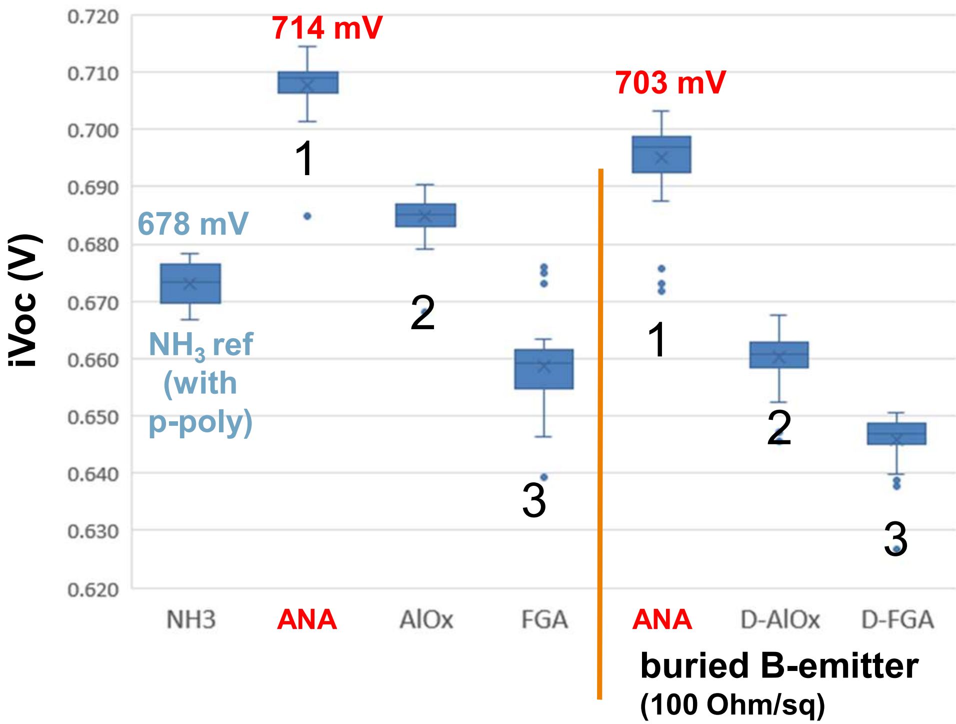




| | | | |
|---|---|---|---|
| 1. Textured 6” CZ samples<br>1.3 nm thermal oxide<br>$PH_3$ doped *n*+ polySi layers<br>annealed at 900 ºC | **2. Remote $NH_3$ plasma**<br>hydrogen treatment | 3. ITO sputtering damage | 4. 190 ºC anneal 20 min |

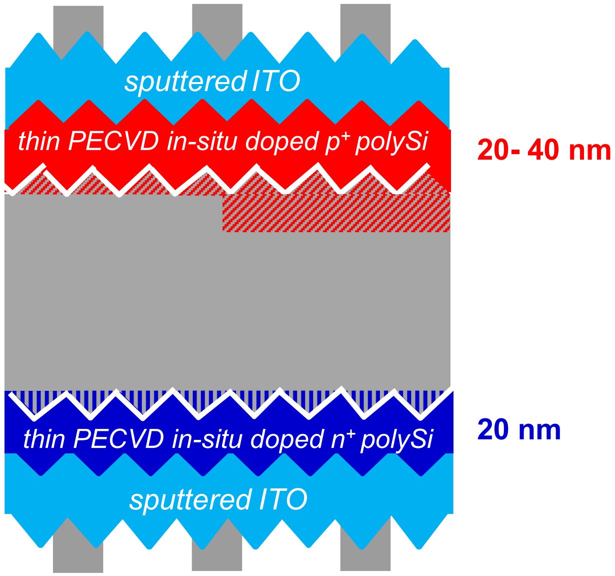
# 'ANA' GIVES GOOD PASSIVATION ALSO FOR P-POLYSI

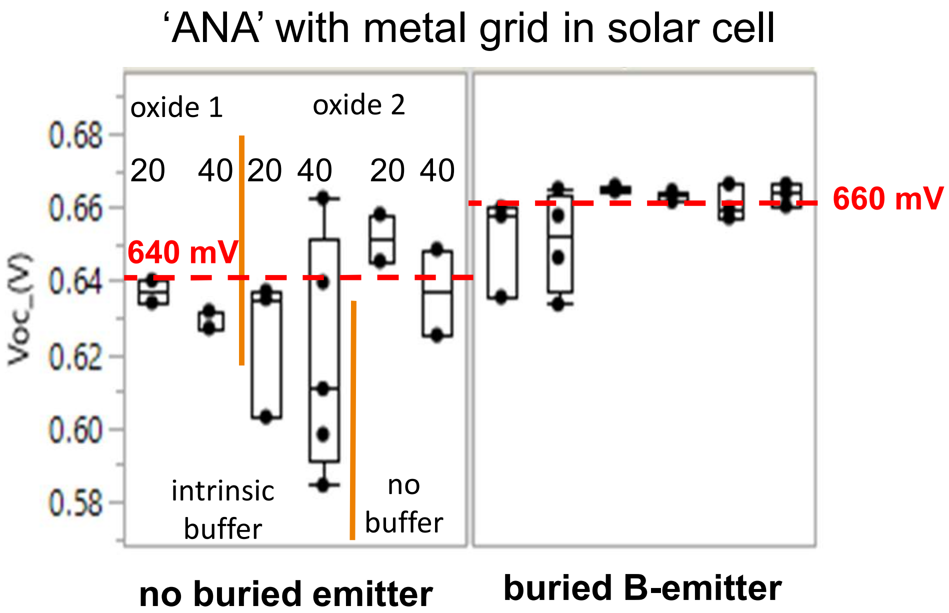



| NH$_3$ plasma ref | AlOx SiNx AlOx | AlOx | FGA @ 600 C |
|---|---|---|---|
| | 1 | 2 | 3 |

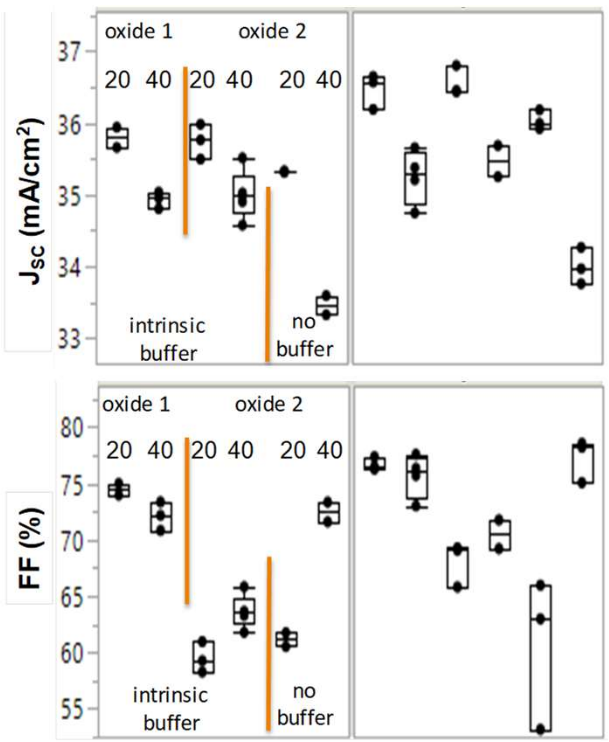


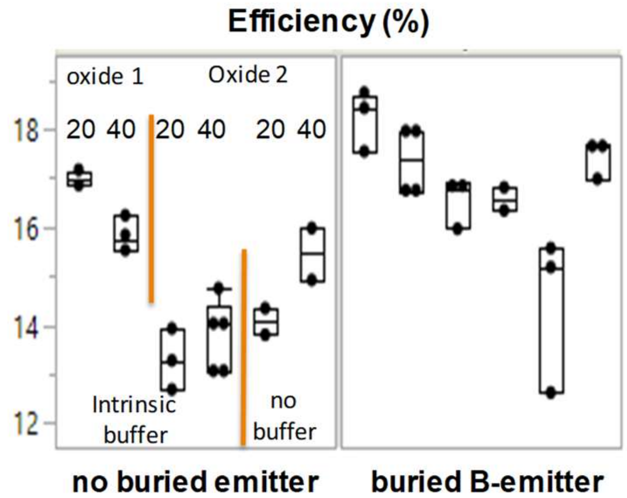
# SPUTTERING DAMAGE ERASES POSITIVE EFFECTS ☹



# $J_{SC}$ AND FF TRENDS DOMINATE EFFICIENCY TREND




**Efficiency limited mainly by TCO properties**

**Low transparency ($J_{SC}$< 38.5 mA/cm²)**
**High $R_{sheet}$ (FF < 78.5%)**
**Irreparable damage ($V_{OC}$ drops to 640-660 mV)**

## SUMMARY

- **Transparent metal oxide contacts on textured 6 inch wafers**
  - 2017: 4 inch moly-poly with high iVoc 732 mV
  - 2018: First 6 inch Moly-poly efficiency 18.2%, thermally stable up to 210°C
  - 2018: 6 inch $MoO_x$-$TiO_x$ half-fabs with iVoc 746 mV (working cells) with soft deposition
  - 2019: improving passivation and WF for $AlO_x$/$MoO_x$: modelling of effects
  - Outlook: AlOx/moly-poly in soft deposition tool and integration of 2019 findings →high efficiency!

- **Soft Ag NW grids effective increase in efficiency (higher conductivity, minor reduction $J_{SC}$)**
  - Work ongoing to integrate NW grids and light management

- **Poly-Poly cells with 10-40 nm thick in-situ doped polySi layers deposited by PECVD**
  - Can compete with SHJ cells because of lower parasitic absorption (and HT advantage)
  - 10 and 20 nm n+ polySi with $NH_3$ anneal*:* 736 & 735 mV
  - Poly-poly halffabs with ‘ANA’ hydrogenation: 702-714 mV
  - Voc drops to 640-660 mV in cell due to sputtering damage

- **All cells were very much limited by non-optimal TCO and strong sputtering damage**
  - Development of high quality, low damage TCO or TCE (NW grids) needed for success of these contacts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