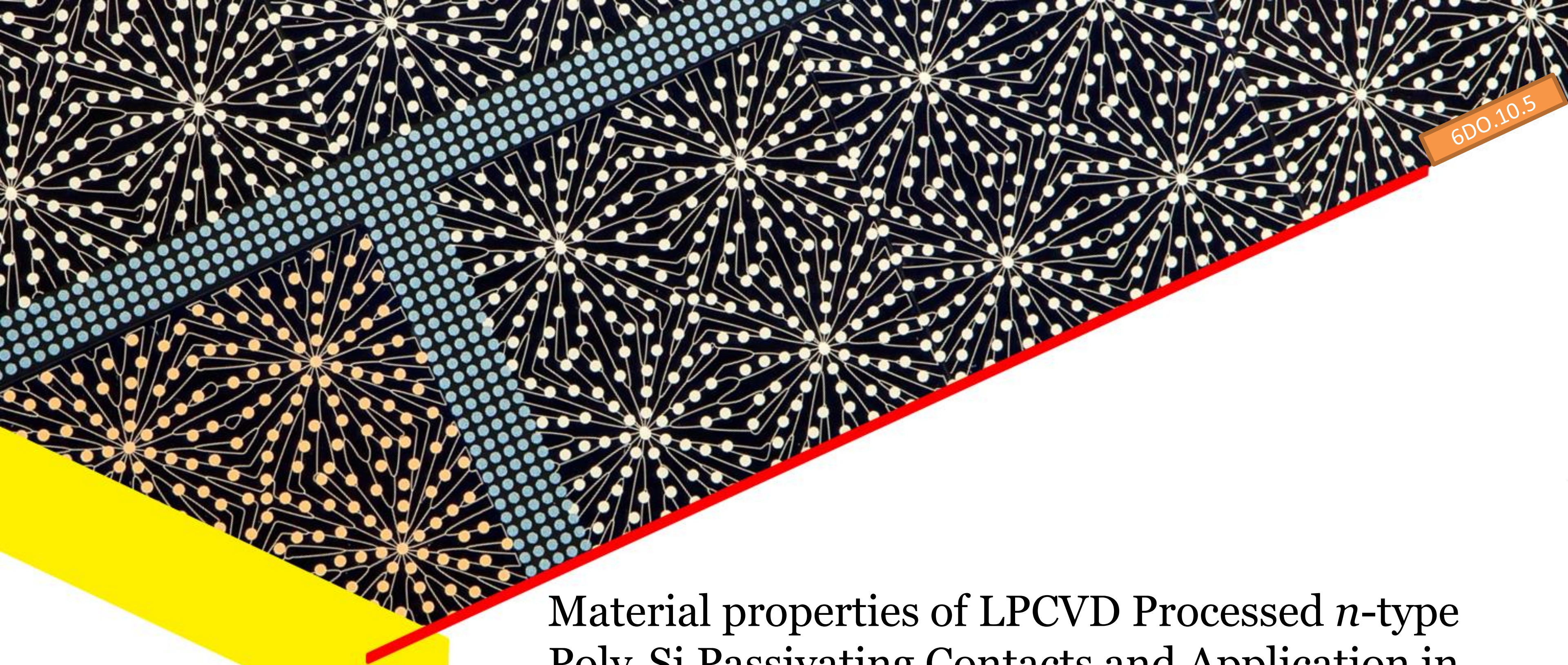



# Material properties of LPCVD Processed *n*-type Poly-Si Passivating Contacts and Application in PERPoly Industrial Bifacial Solar Cells

**EUPVSEC 2017**, Amsterdam
September 28th, 2017

**Maciej K. Stodolny et al.**
ECN Solar Energy

ECN

TEMPRESS AMTECH GROUP

UNIVERSITY OF TWENTE. TU/e TUDelft Delft University of Technology

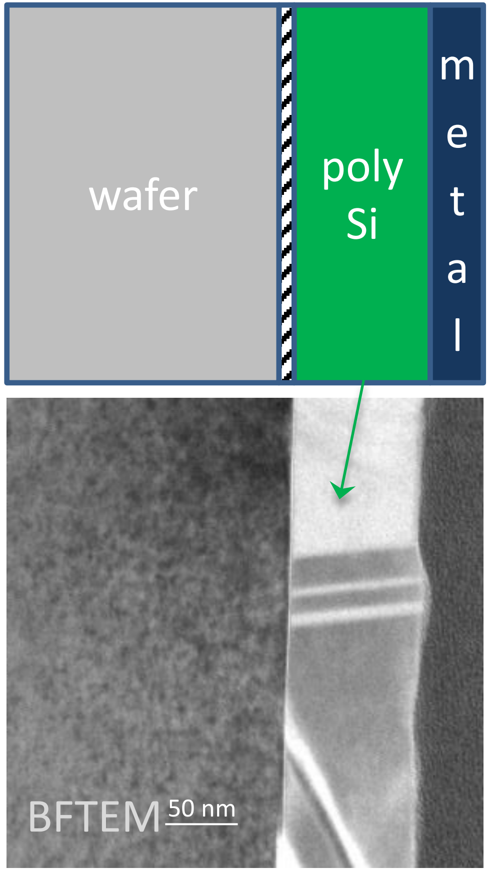
**Talk 2DO.3.2**

# Poly-Si passivating contact

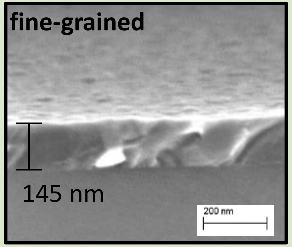
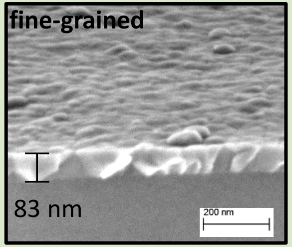
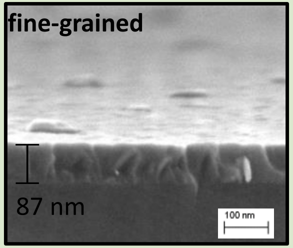
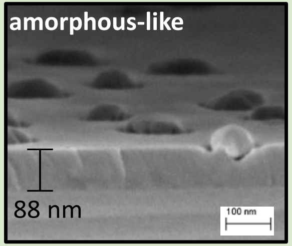
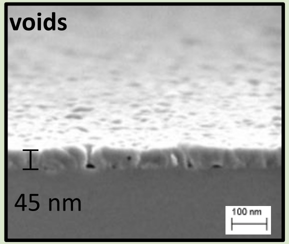
- Thin oxide layer
  - low recombination velocity after hydrogenation
  - tunable charge transport and diffusion barrier

- LPCVD poly-Si layer doped by e.g. $POCl_3$ diffusion
  - reduces minority carriers at interface
  - good conductance for majority carriers

- Application as rear passivating contact in n-PERT solar cells with FT metallization

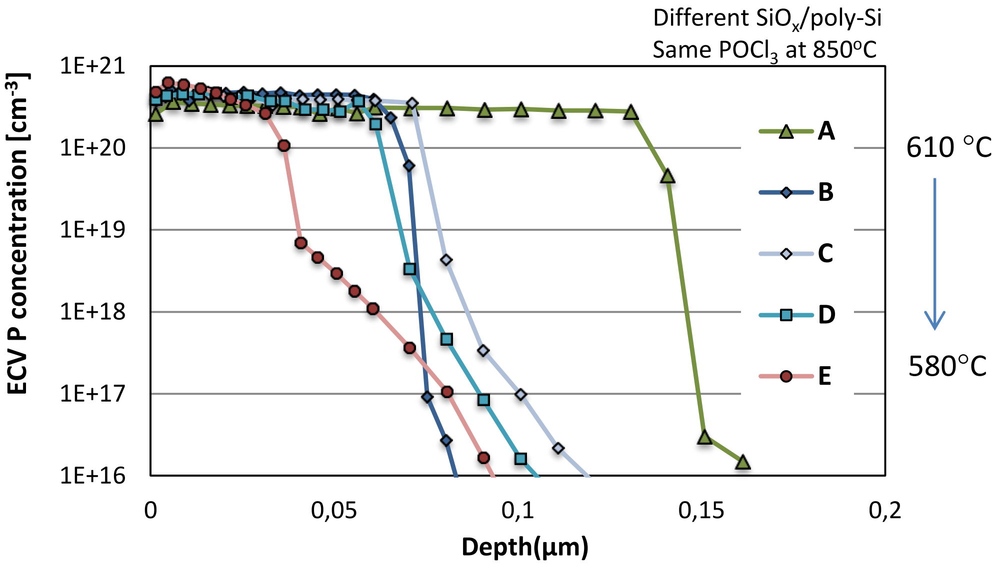


# LPCVD Poly-Si structural properties

| polySi type | A | B | C | D | E |
|---|---|---|---|---|---|
| **Temperature (°C)** | 610 | 610 | 595 | 580 | 580 |
| **$SiH_4$ flow** | high | low | medium | high | low |
| SEM image<br>after $POCl_3$ doping and phosphosilicate glass removal |  |  |  |  |  |

- Growth rate increases (linearly) with T and $SiH_4$ flow rates
  - For T> 595°C: fine-grained poly-Si layers, columnar and voids-free
  - For T≤ 580°C: amorphous-like layers with crystalline precipitates

# Poly-Si electronic/doping properties

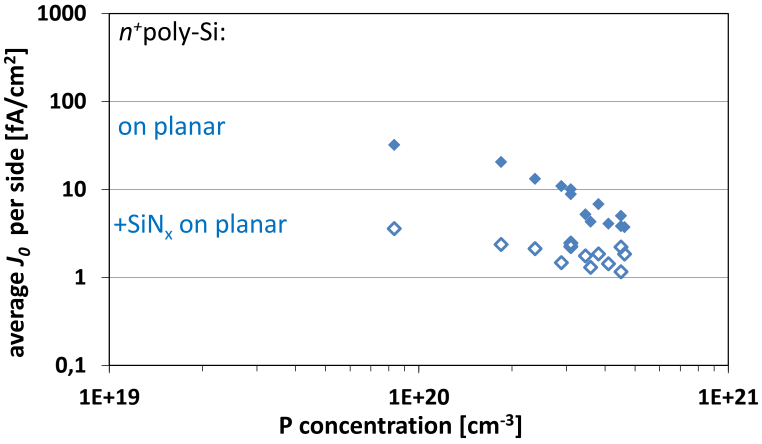


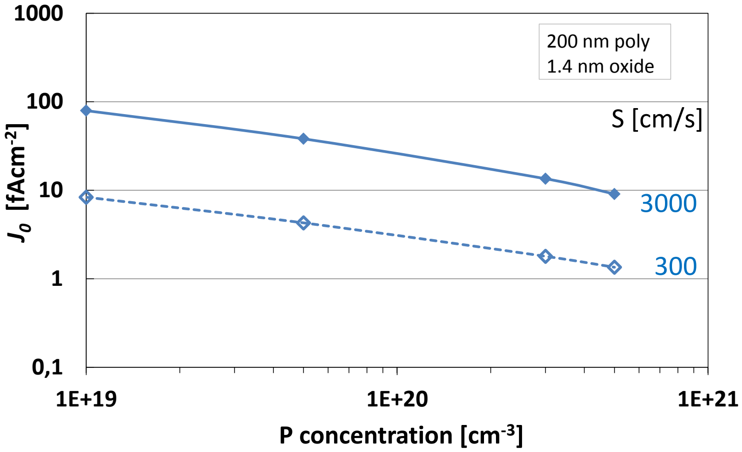

- Doping profiles correlate with deposition parameters of $SiO_x$ / poly-Si

  → P in-diffusion depends on poly-Si morphology and Th.Ox effective thickness

# Poly-Si passivation properties

Modelling of $n^+$poly-Si $J_0$ G. Janssen 2AO.4.6

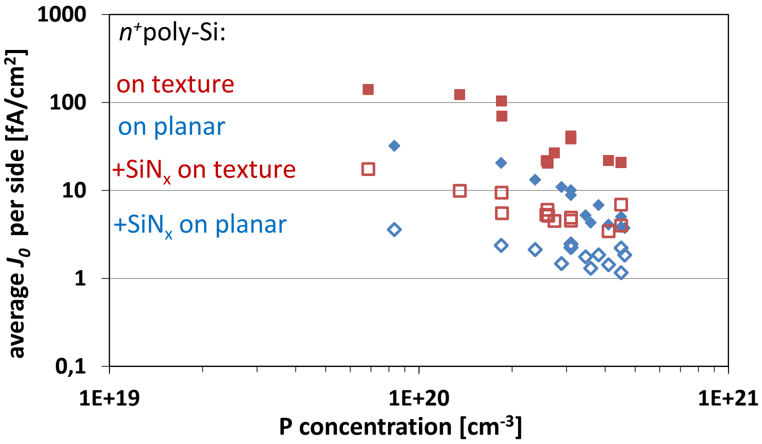


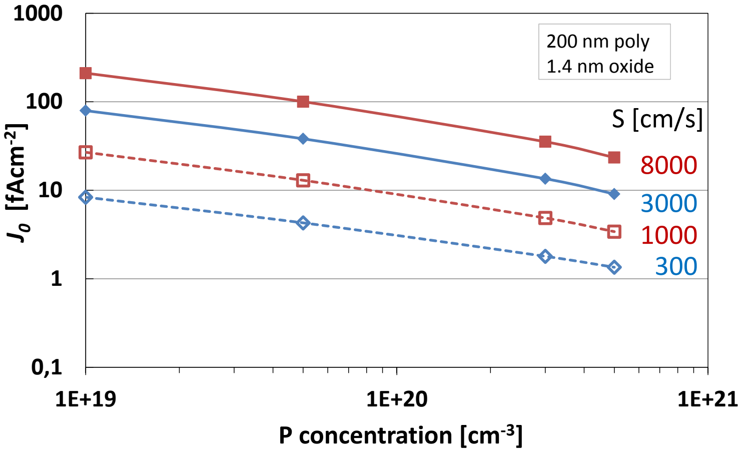




- $J_0$ improves with higher doping concentration (field-effect passivation ↑)
- $SiN_x$ reduces $J_0$ by hydrogenation of interface defects (chemical passivation ↑)

# Poly-Si passivation properties

Modelling of $n^+$poly-Si $J_0$ G. Janssen 2AO.4.6



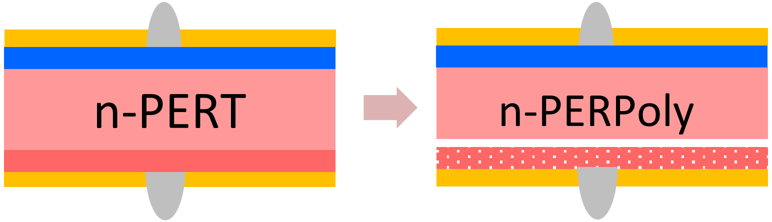




- $J_0$ improves with higher doping concentration (field-effect passivation ↑)
- $SiN_x$ reduces $J_0$ by hydrogenation of interface defects (chemical passivation ↑)

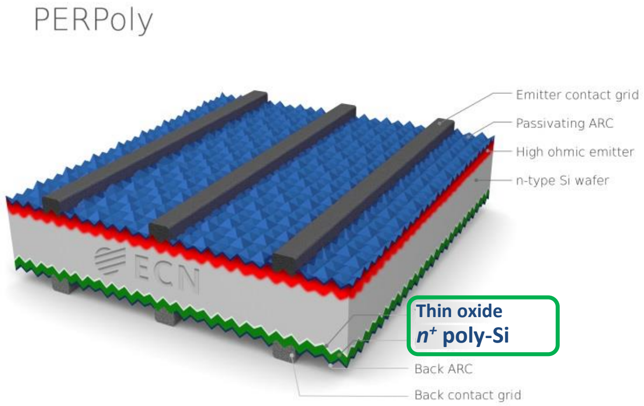
➔ Excellent passivation on planar (~1 fA/cm²) and textured surfaces (~3 fA/cm²)

# ECN's vision: Industrial passivating contact solar cell

- n-PERT + $n^+$poly-Si rear ➔ PERPoly cell
  **PERPoly** - **P**assivated **E**mitter and **R**ear **Poly**silicon




M.K. Stodolny et al., SOLMAT 158 (2016) 24-28

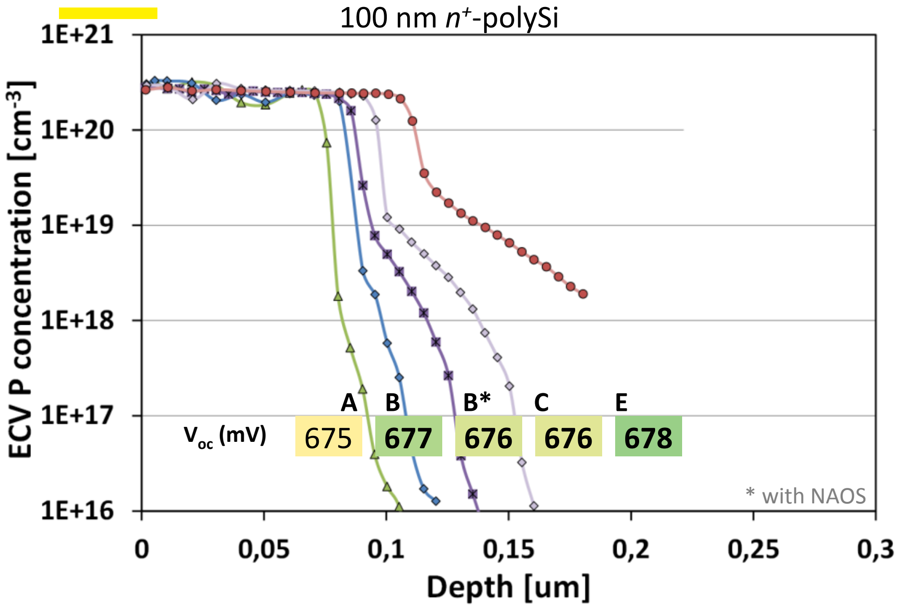


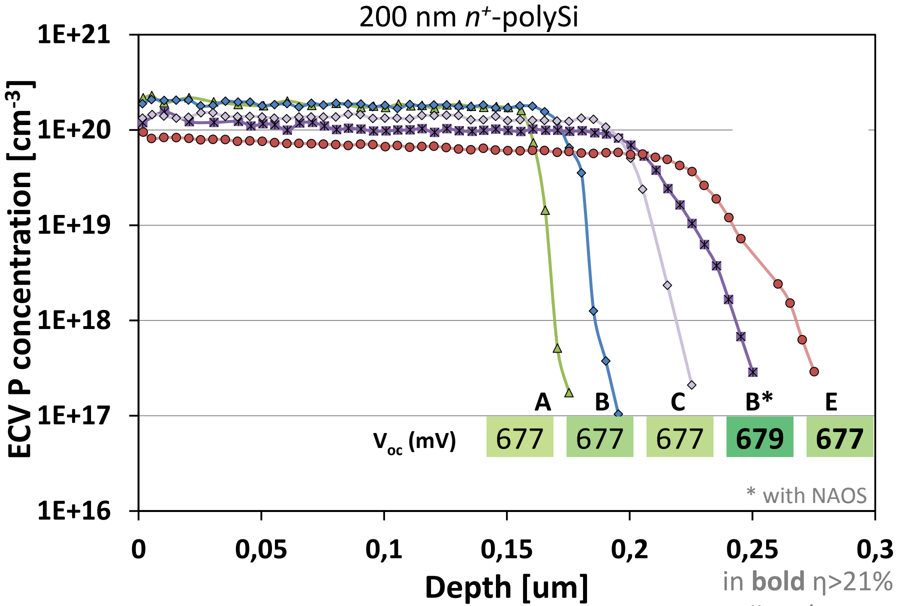


Properties:

- 23% potential with Fire-Through contacts
- 6 inch Cz material
- Industrial, high throughput tools
- Bifacial → additional energy yield

# Influence of $n^+$-polySi on PERPoly cells

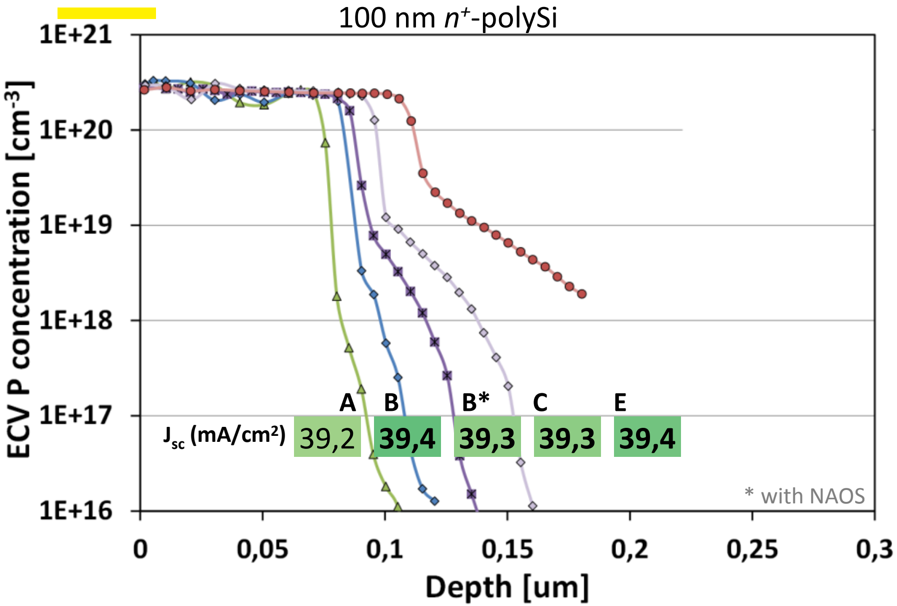


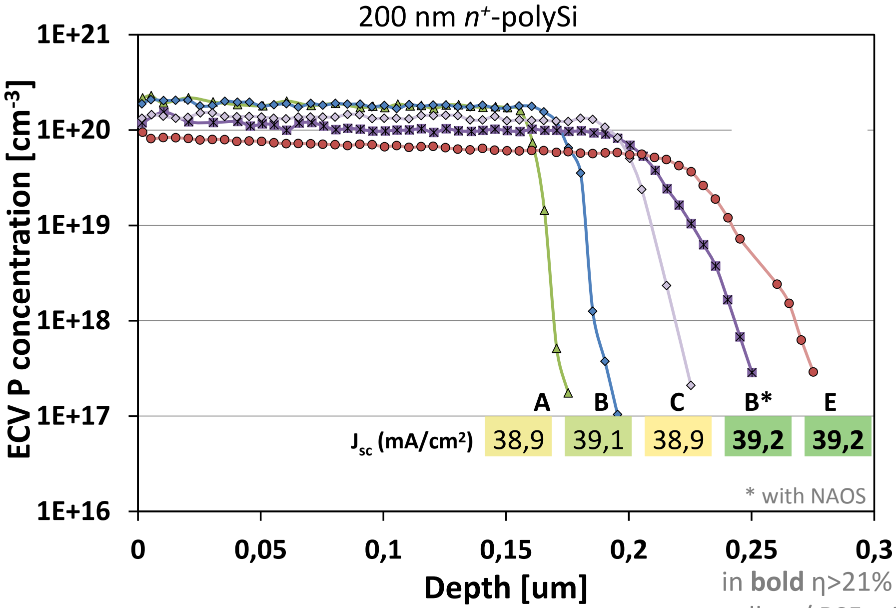




in **bold** η>21% cells w/ BSF tail

- $V_{oc}$: high and stable for 100 and 200 nm poly-Si layers
  → broad processing window with FT metallization (w/ P-tail)

# Influence of $n^+$-polySi on PERPoly cells

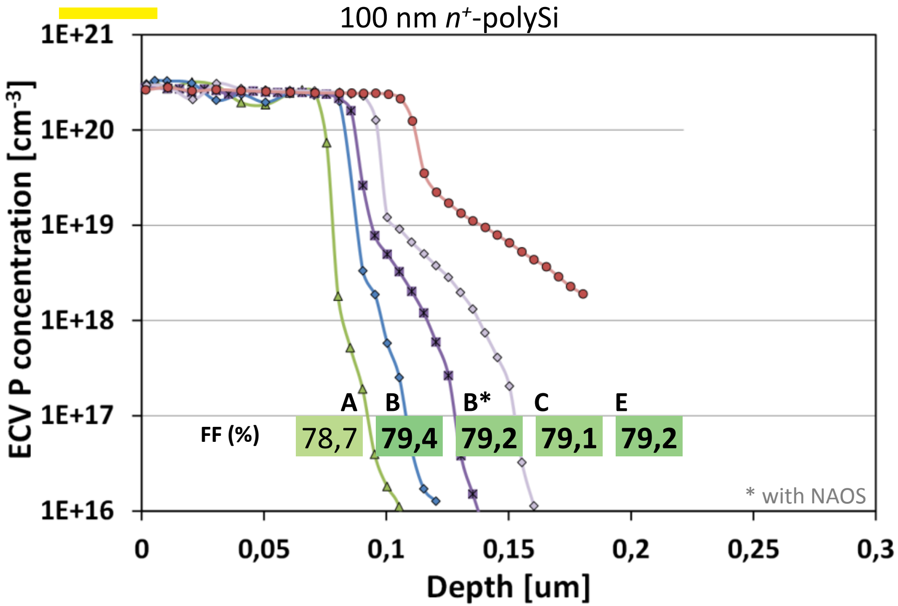


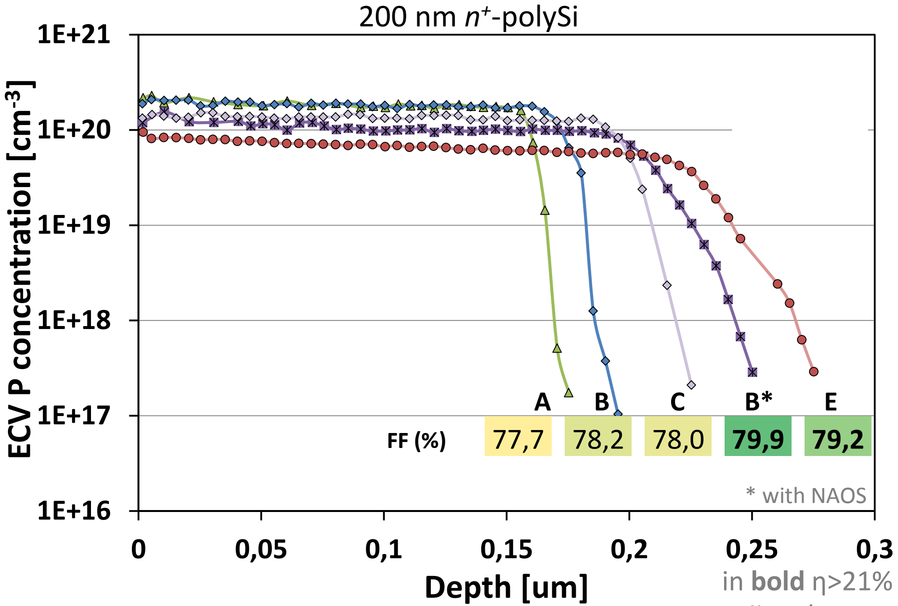




in **bold** η>21%
cells w/ BSF tail

- $J_{sc}$: increases for thinner and lower doped poly-Si layers due to reduced FCA of IR light

# Influence of $n^{+}$-polySi on PERPoly cells

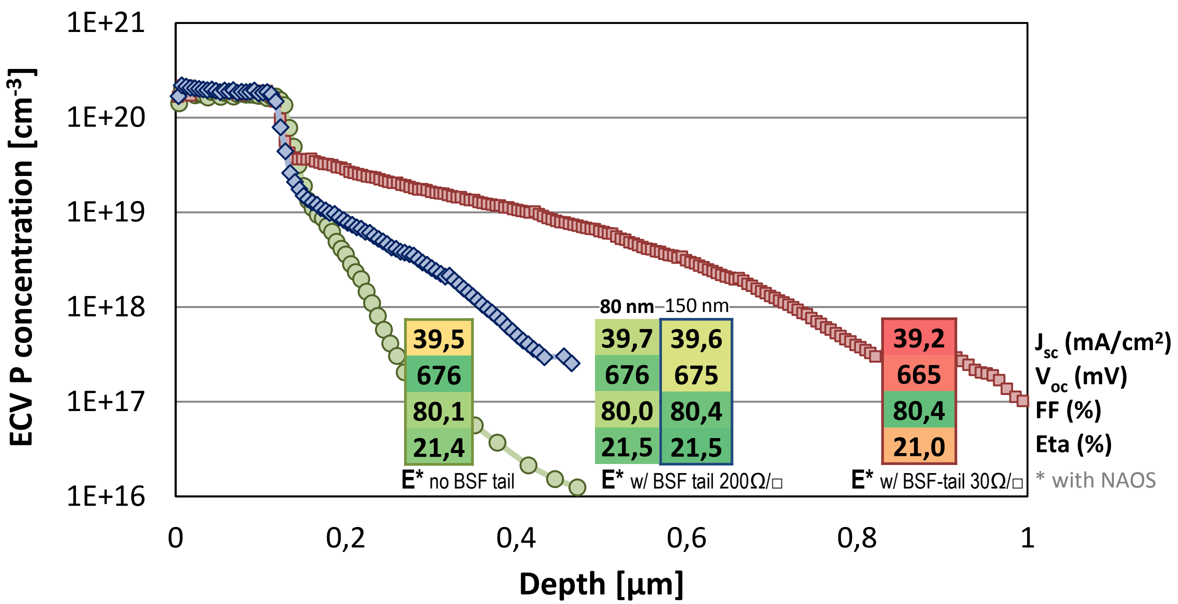



in **bold** η>21%
cells w/ BSF tail

- *FF*: strongly improved when doping profile penetrates across the thin oxide

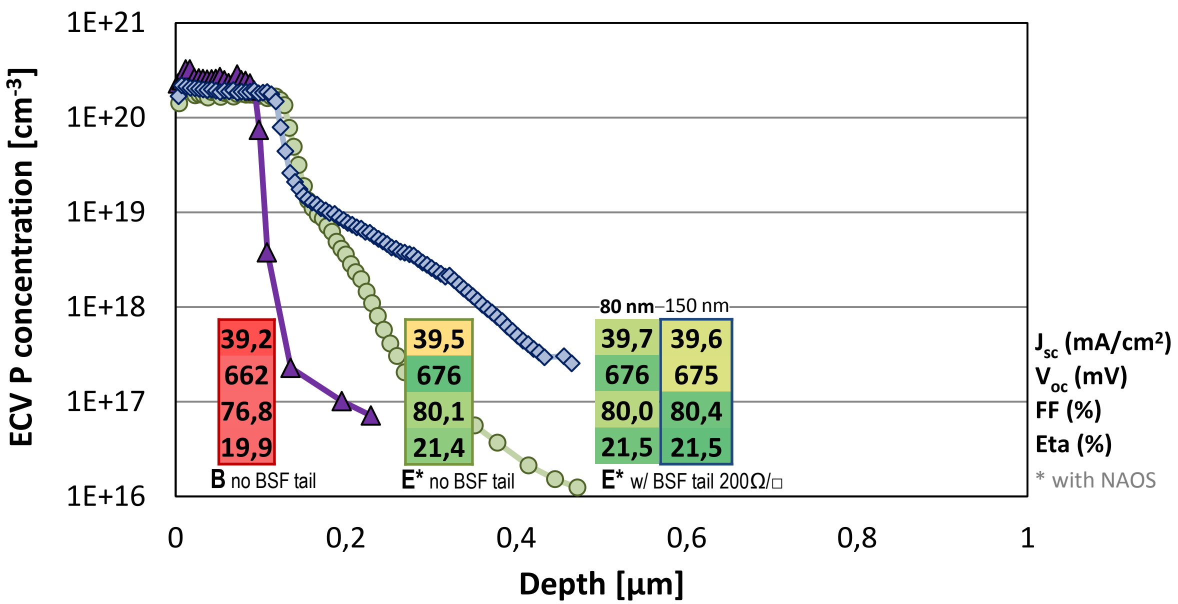
# Influence of $SiO_x$ and P-tail on PERPoly cells




- Doping level at Ox./c-Si is not critical for high FF
  but the effective charge carrier mobility of the thin oxide

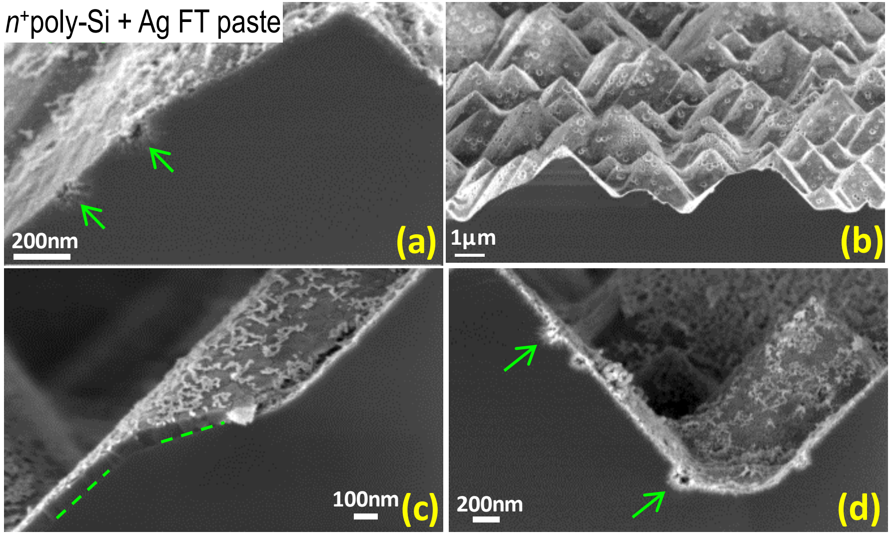
see 2AO.4.6

# Influence of $SiO_x$ and P-tail on PERPoly cells

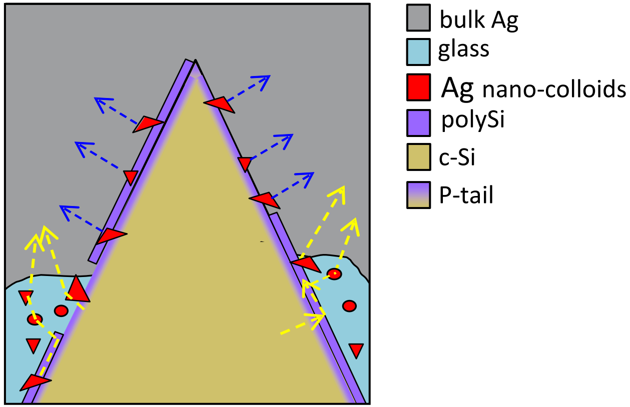


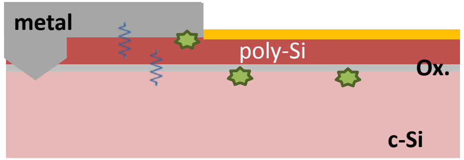

- Presence of a moderate P-tail is critical for low $J_{o,contact}$ when industrial FT metallization is used

# $n^+$poly-Si with Fire-Through metallization




(metal has been removed by etching)




see 2AO.4.6

Under FT paste:

- areas where poly-Si layer is removed
- areas where Ag nanoparticles intruded into c-Si

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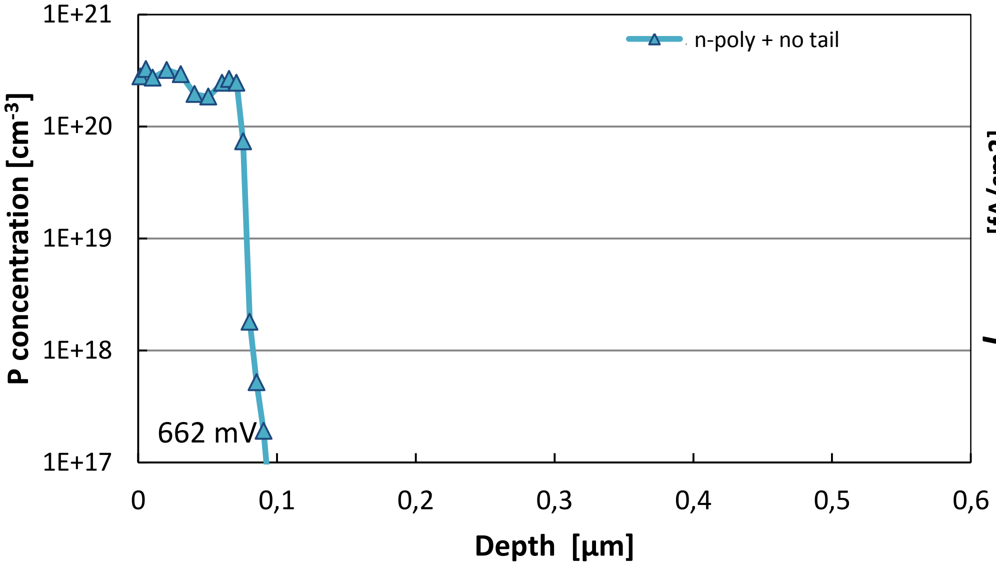
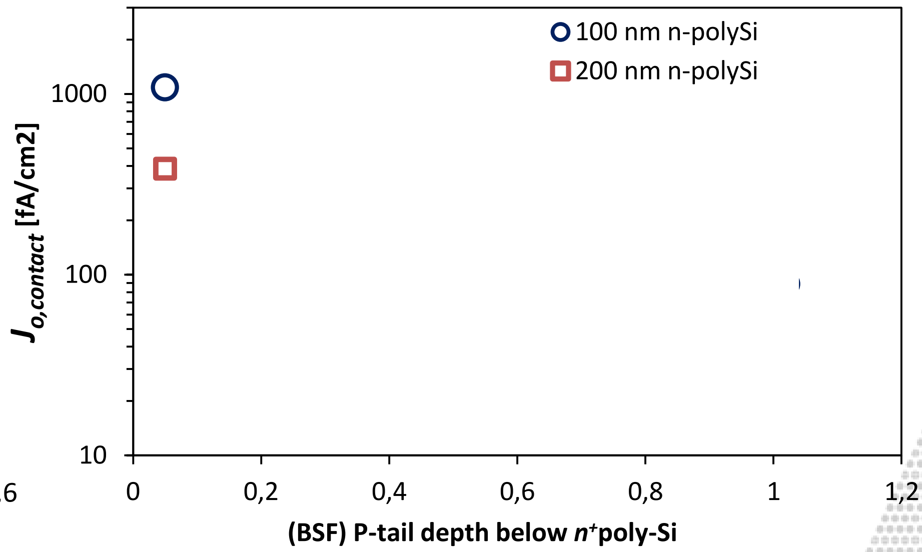
H.E.Çiftpınar, M.K. Stodolny, et al., Energy Procedia 124 (2017) 635–642

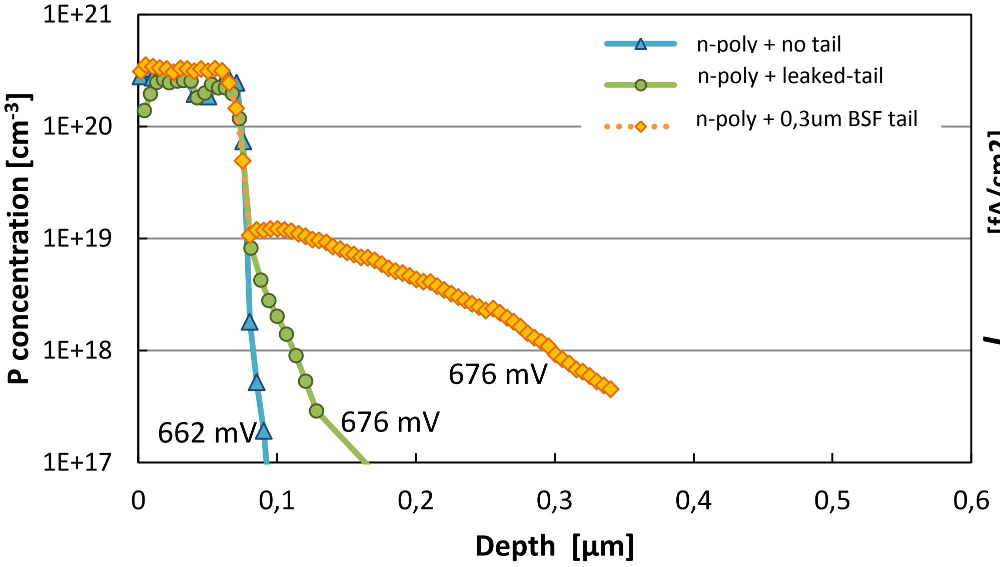
# P-tail effect on $J_{o,contact}$ of $n^+$poly-Si with FT

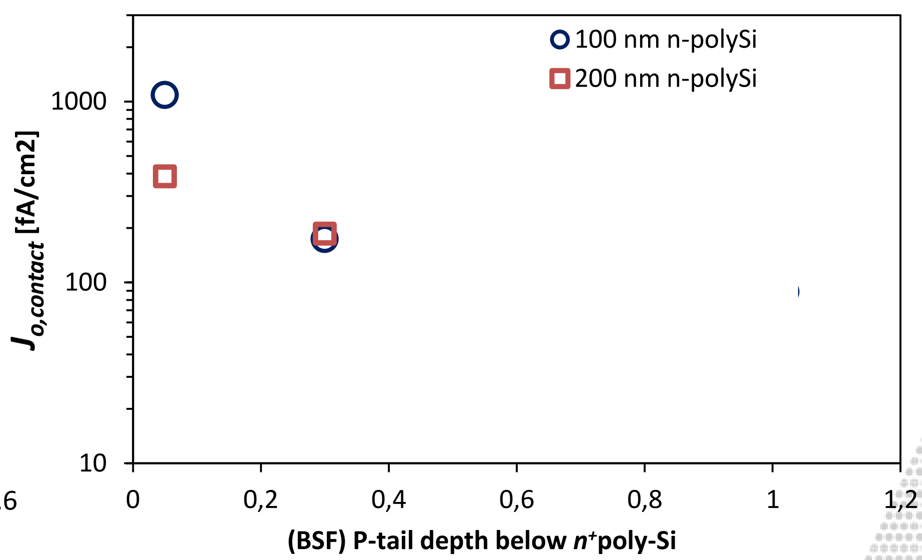



- $n^+$poly-Si without any tail shows high $J_{o,contact}$ (~400-1000 fA/cm$^2$) → ***f*** *(poly thickness)*

# P-tail effect on $J_{o,contact}$ of $n^+$poly-Si with FT

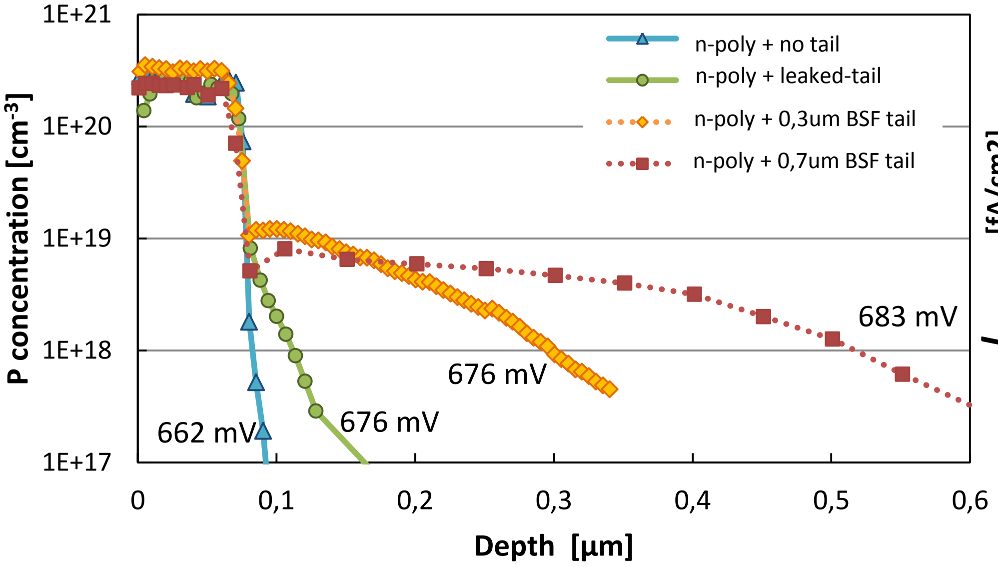


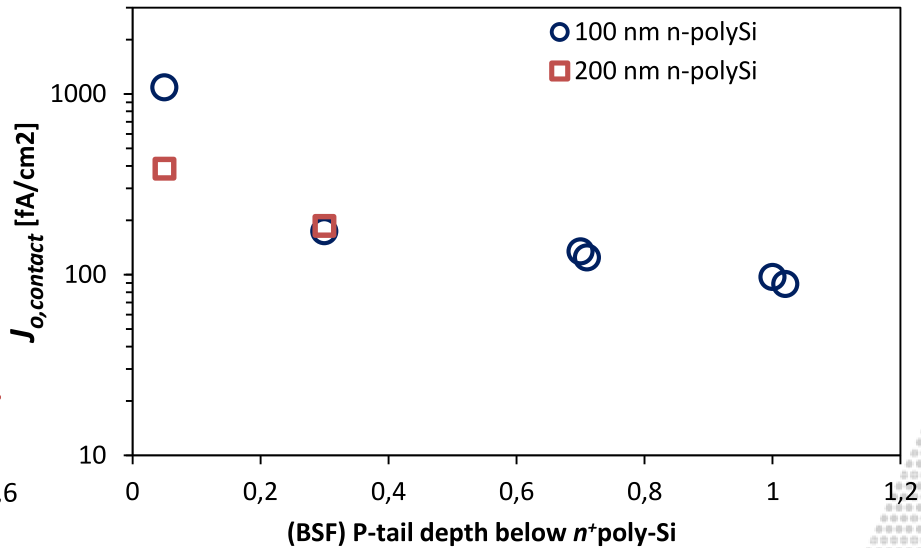




- 'Standard' PERPoly BSF 0,3µm tail reduces $J_{o,contact}$ to ~200 fA/cm$^2$

  ➔ P-tail can be obtained also with a leaky oxide

# P-tail effect on $J_{o,contact}$ of $n^{+}$poly-Si with FT

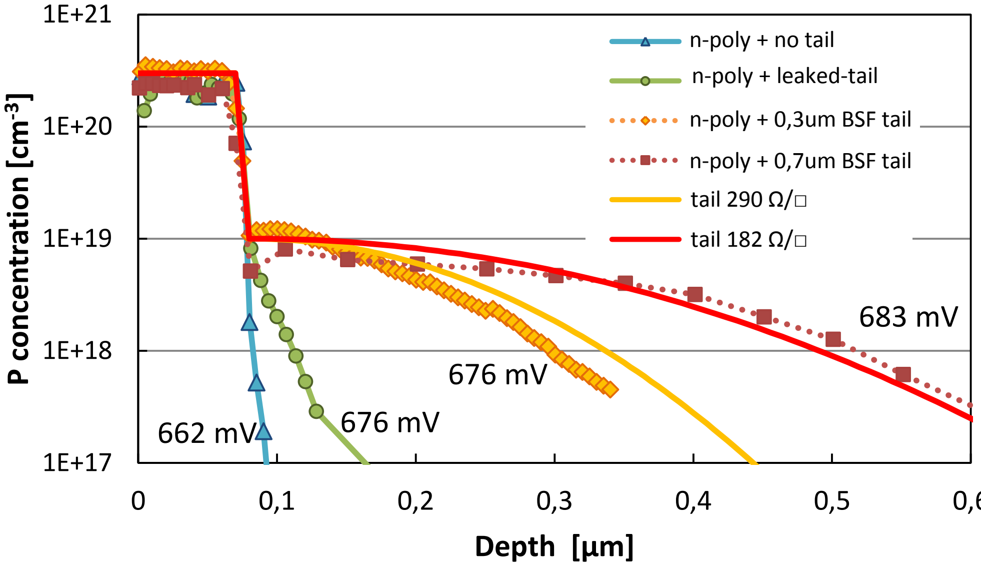


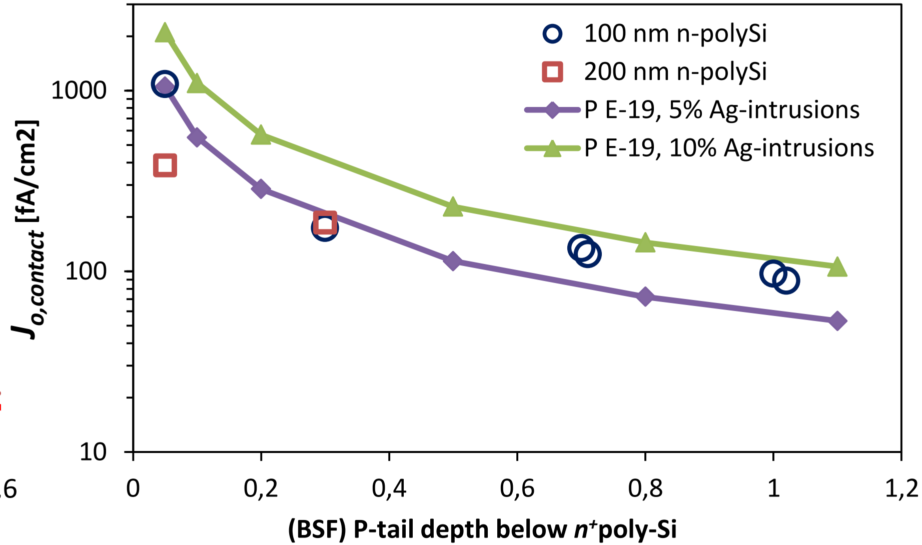




- 'Standard' PERPoly BSF 0,3µm tail reduces $J_{o,contact}$ to ~200 fA/cm$^2$
  - ➔ P-tail can be obtained also with a leaky oxide
- Deeper (but shallow) BSF tail reduces $J_{o,contact}$ further down to ~100 fA/cm$^2$

*Patent pending*

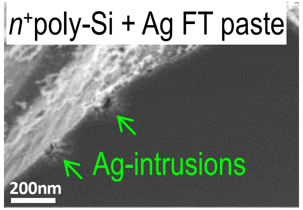
# P-tail effect on $J_{o,contact}$ of $n^{+}$poly-Si with FT

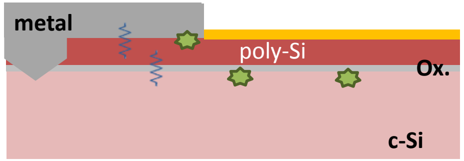



- P-tail shields the Ag-intrusions that reached c-Si
- ~5-10% area below the FT finger where Ag contacts c-Si

➔ 'industrial passivating contact' with FT metallization




see 2AO.4.6

# Conclusion

- Technical and scientific know-how on 'industrial $n^+$poly-Si passivating contact':
  - Excellent passivation on planar (~1 fA/cm²) and textured surfaces (~3 fA/cm²)
  - Oxide permeability critical for high FF while still low $J_0$ possible
  - P-profile across the poly-Si/$SiO_x$/c-Si critical for low $J_{0,contact}$ (100 fA/cm²) with FT

- 21.5% PERPoly cells in ECN pilot line on industrial tools:
  - +0.5% abs. efficiency gain demonstrated over n-PERT
    with $V_{oc}$ of 675+mV (gain of +15 mV) and Fire-Through contacts

# Thank you for your attention!

1 ECN

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