Updates on APCVD Processing for TOPCon Structures and Laser Doping

nPV-Workshop March 31st

Schmid Today
Innovations

The facts

- Founded 1864: More than **155** years family-owned company
- **800+** Staff
- **250** Patents and trademarks
- **150+** Scientists, developers and engineers
- **3000** sqm Research labs and prototype manufacturing
- **3** Production sites in Germany, USA and China.
- **3** Joint ventures in South Korea, Turkey and Saudi-Arabia

Innovation as Basis of our Success

Electronics

Photovoltaics

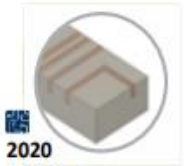
Energy Systems

1968
First printed circuit board automation systems in the industry

2003
Inline atmospheric pressure chemical vapour deposition (APCVD)

2011
Selective emitter

2017
Electric charging station with VRFB



2020
ET-Board

1986
First horizontal desmear and E-less Cu

2005
Single Side Etching processes for silicon wafers without additives

2011
Vertical transport with clamping

2019
Nanosilicon for Lithium batteries

1995
Intermittent Etching

2010
Fully automated PV factory solutions with intralogistics

2017
Alkaline polish

2020
C+ vertical

2020
P+ Single Plater

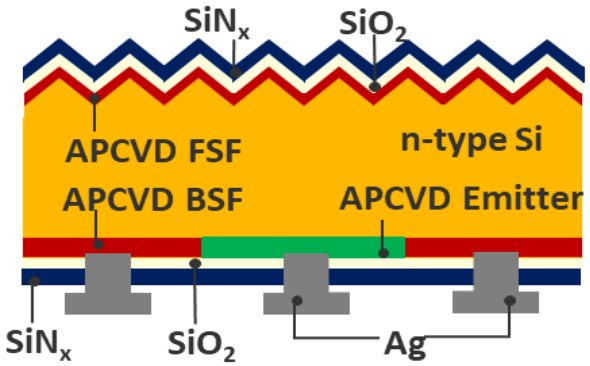
- APCVD (Atmospheric Pressure Chemical Vapor Deposition)

- Alkaline horizontal texturing
- Alkaline (NO_x free) single side etching

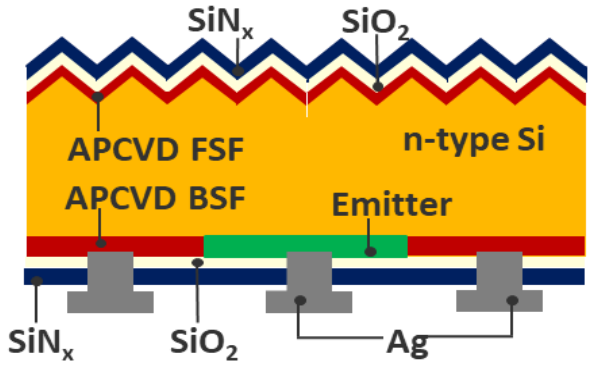
APCVD Doping Glasses

APCVD-PSG and BSG as doping source for IBC process

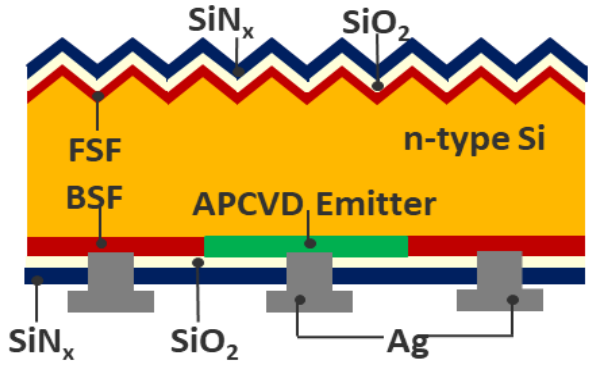
- Currently 3 different IBC solar cells are being investigated using doped APCVD glass layers as diffusion source



- **Complete APCVD IBC** with APCVD BSG emitter and APCVD PSG FSF & BSF



- **Hybrid APCVD IBC with BBr_3** tube diffused emitter and APCVD PSG for FSF & BSF

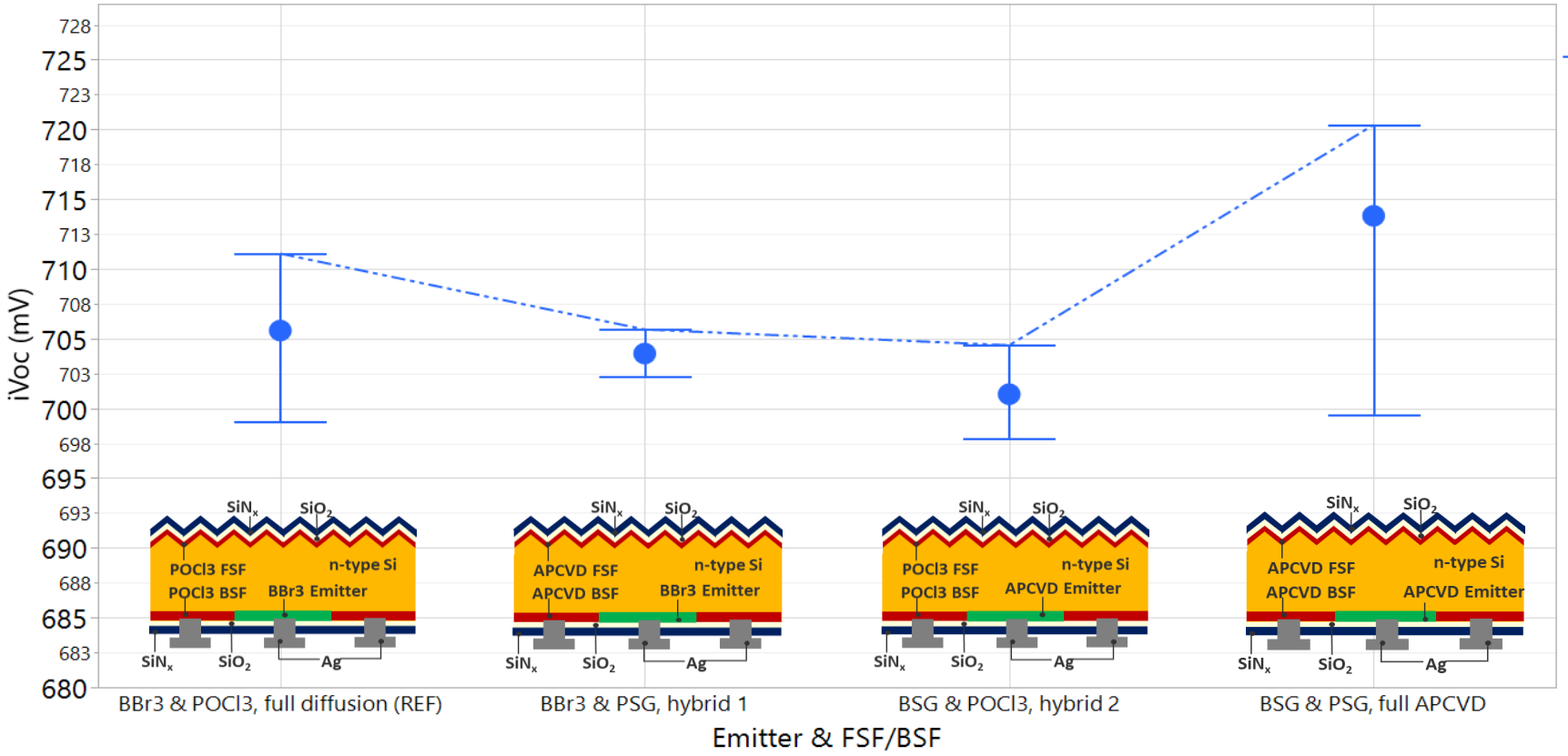


- **Hybrid APCVD IBC with $POCl_3$** tube diffused FSF & BSF and APCVD BSG emitter

APCVD Doping Glasses

APCVD-PSG and BSG as doping source for IBC process

- Implied V_{oc} up to 720 mV for full APCVD IBC structure developed and processed at ISC Konstanz
- APCVD doping glass development and depositions on Schmid R&D Tool @ University of Konstanz

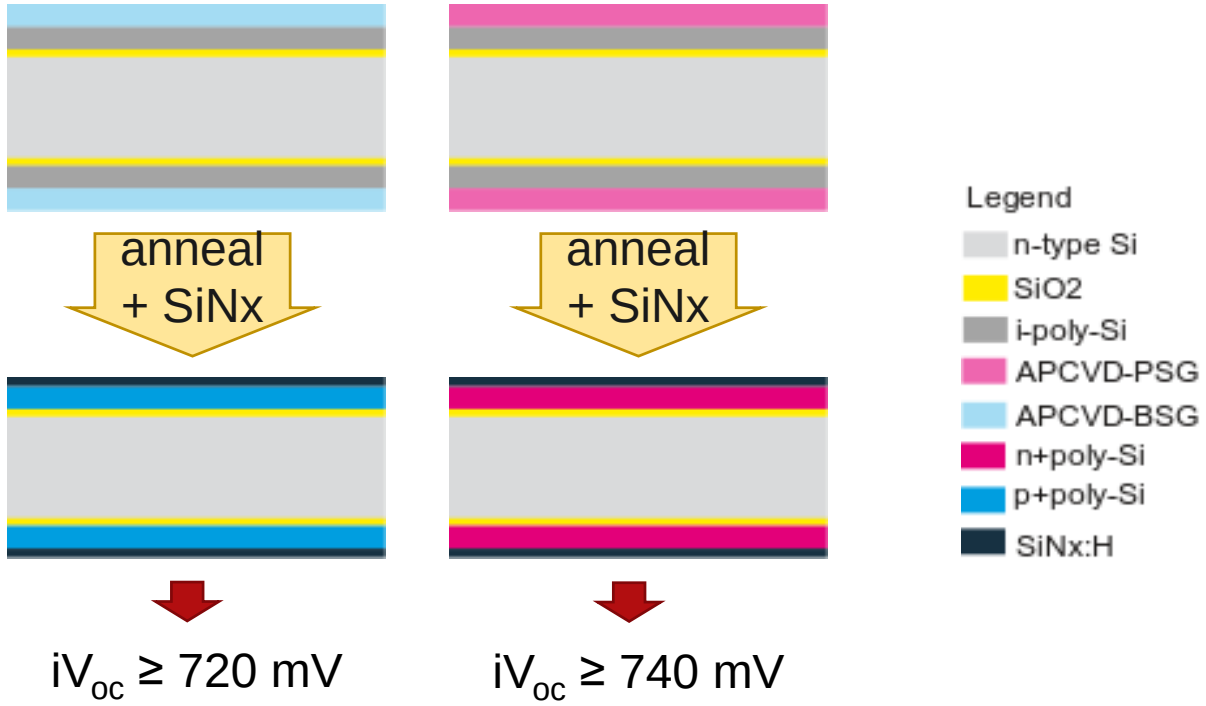


Part of this work was financially supported by the German Federal Ministry for Economic Affairs and Climate Action (FKZ 03EE1018A).

APCVD Doping Glasses

APCVD-PSG and BSG as ex-situ doping source for i-polySi

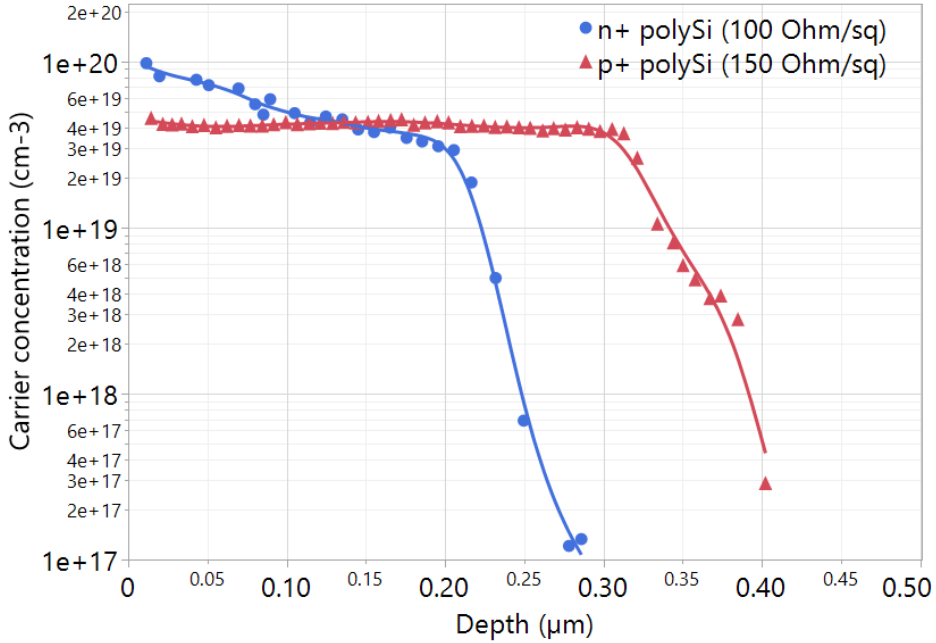
- Implied V_{oc} and ECV profiles of n+ and p+ ex-situ APCVD doped polySi
- APCVD doping glass development and depositions on Schmid R&D Tool @ Schmid TCS, polySi deposited @ISC (LPCVD)



$iV_{oc} \geq 720$ mV

$iV_{oc} \geq 740$ mV

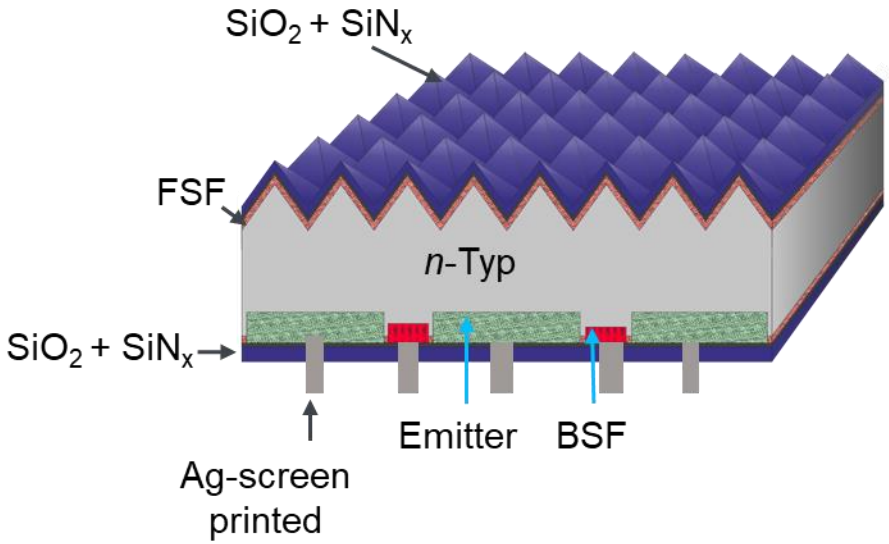
ECV of ex-situ doped i-polySi



APCVD Doping Glasses

APCVD BSG Laser Doping

- IBC solar cell with Laser doped APCVD BSG emitter with $V_{oc,max}$ = 691 mV and η_{max} = 23% *
- cell development by *ipv* Stuttgart (Laser doping, front end) and ISC Konstanz (processing, back end)
- APCVD doping glass development and depositions on Schmid R&D Tool @ Schmid TCS



ISC research for a sunny future

* Renate Zapf-Gottwick, Sven Seren, Susana Fernandez-Robledo, Evariste-Pasky Wete, Matteo Schiliro, Mohamed Hassan, Valentin Mihailetchi, Thomas Buck, Radovan Kopecek, Jürgen Köhler, Jürgen-Heinz Werner, Solar Cell Laser Boron Doping with Layers from Atmospheric Pressure Chemical Vapor Deposition, to be published by MDPI Solar Journal, 2022

APCVD TOPCon Solar Cells

- M2 format TOPCon solar cells with APCVD BSG emitter and APCVD in-situ doped n-polySi
- Cell development and processing at FhG ISE
- APCVD doping glass / poly-Si development and depositions on Schmid R&D Tool @ Schmid TCS

	Group	*IV* Parameter			
		V_{oc} / mV	j_{sc} / mA/cm²	*FF* / %	*η* / %
Best CalLab*	A) BBr3 Emitter + LPCVD Reference	705	40,9	81,6	**23,6**
	C) APCVD Emitter + LPCVD Reference	702	40,8	81,4	**23,3**
	G) APCVD Emitter + wet chem. Oxide + APCVD poly-Si	693	40,2	81,2	**22,7**

*Calibrated measurements at Fraunhofer ISE CalLab PVCells using Pasan GridTouch unit with 30 wires on a golden, reflective chuck with full area rear side contact

APCVD TOPCon Solar Cells: easy upgrade to TOPCoRE cell design

- TOPCoRE Cell Design *
- p-type Si TOPCoRE cell with Al_2O_3 passivation of the bare c-Si front surface without a full-area front surface field, but with highly doped p++ regions

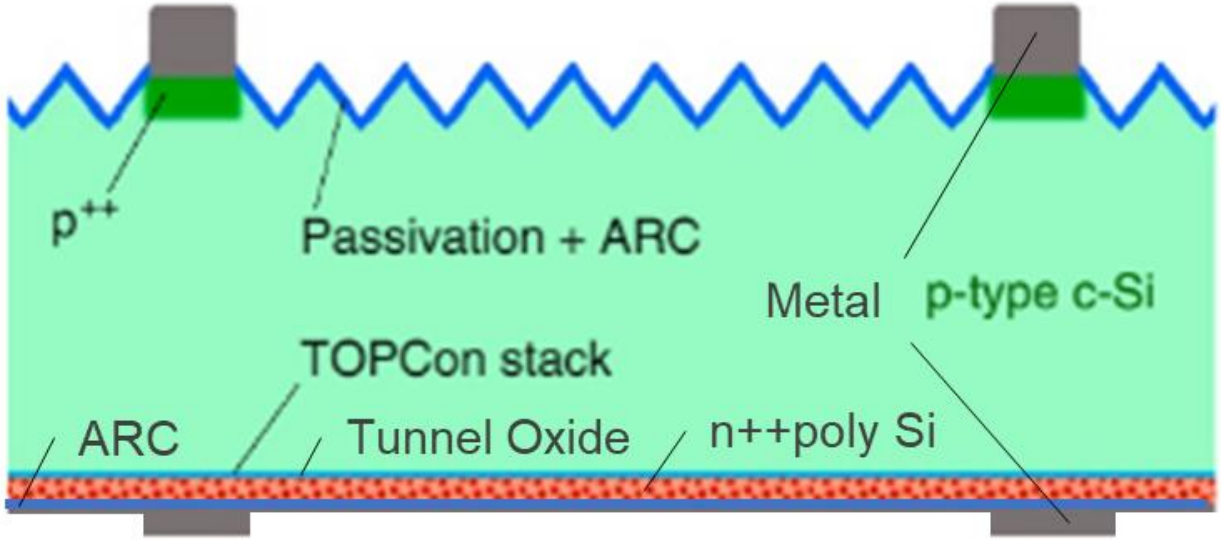


Table 1 | *I–V* parameters of the best cells

ρ_b (Ω cm)	*P* (µm)	V_{OC} (mV)	J_{SC} (mA/cm²)	*FF* (%)	η (%)
FJ TOPCon cells made of n-type c-Si (n-FJ)					
1	1,000	724.1	42.87	83.1	25.8
TOPCon BJ cells made of p-type c-Si (p-BJ)					
1	833	731.7	41.74	84.5	25.8
1	1,000	732.3	42.05	84.3	26.0
10	1,000	729.6	42.40	82.5	25.5

The measurements of the best cells per variation shown in Fig. 3 were independently confirmed by Fraunhofer ISE CalLab. All the cells were of area 2 × 2 cm² (designated illumination area) and were measured under standard testing conditions.

* A. Richter et al., Design rules for high-efficiency both-sides-contacted silicon solar cells with balanced charge carrier transport and recombination losses, April 2021 Nature Energy 6(4):1-10

APCVD TOPCon Solar Cells: easy upgrade to TOPCoRE cell design

APCVD TOPCon
Process Sequence

- APCVD processes
  → scalable to large wafer formats (M10, G12)
- APCVD processes (quasi) single sided
- tunnel oxide ~ 2 nm (O_3 based or thermal)
- annealing step could possibly be omitted
  as APCVD polySi layers are already up to 80% crystalline depending on deposition temperature [*]
- process can easily be adapted for
  both materials (n- or p-type Si) by
  changing the APCVD processes:
  BSG ⇔ PSG and n^+poly ⇔ p^+polySi
- APCVD TOPCon process easily
  adaptable / expandable to APCVD TOPCoRE cell design

APCVD TOPCon → APCVD TOPCoRE

n-type Cz MX wafer	*p-type Cz MX wafer*
Texture	Texture
APCVD BSG front + clean	APCVD BSG front + clean
Diffusion BSG (drive in)	Laser doping
Single side etch	Single side etch
APCVD n-polySi (rear)	APCVD n-polySi (rear)
Single side etch	Single side etch
Annealing	Annealing polySi + thin oxide
Al_2O_3/SiN_x passivation (front)	Al_2O_3/SiN_x passivation (front)
SiN_x passivation (rear)	SiN_x passivation (rear)
Ag/Al grid (front) & Ag grid (rear)	Ag grid (front) & Ag grid (rear)
FFO	FFO
IV Testing	IV Testing

* A. Merkle, S. Seren, H. Knauss, B. Min, B. Terheiden, J. Steffens, R. Peibst, R. Brendel, *Atmospheric Pressure Chemical Vapor Deposition of in-situ doped amorphous silicon layers deposited for passivating contacts,* Proc. 35th EU PVSEC, Brussels, 2018

Alkaline Etching

Design

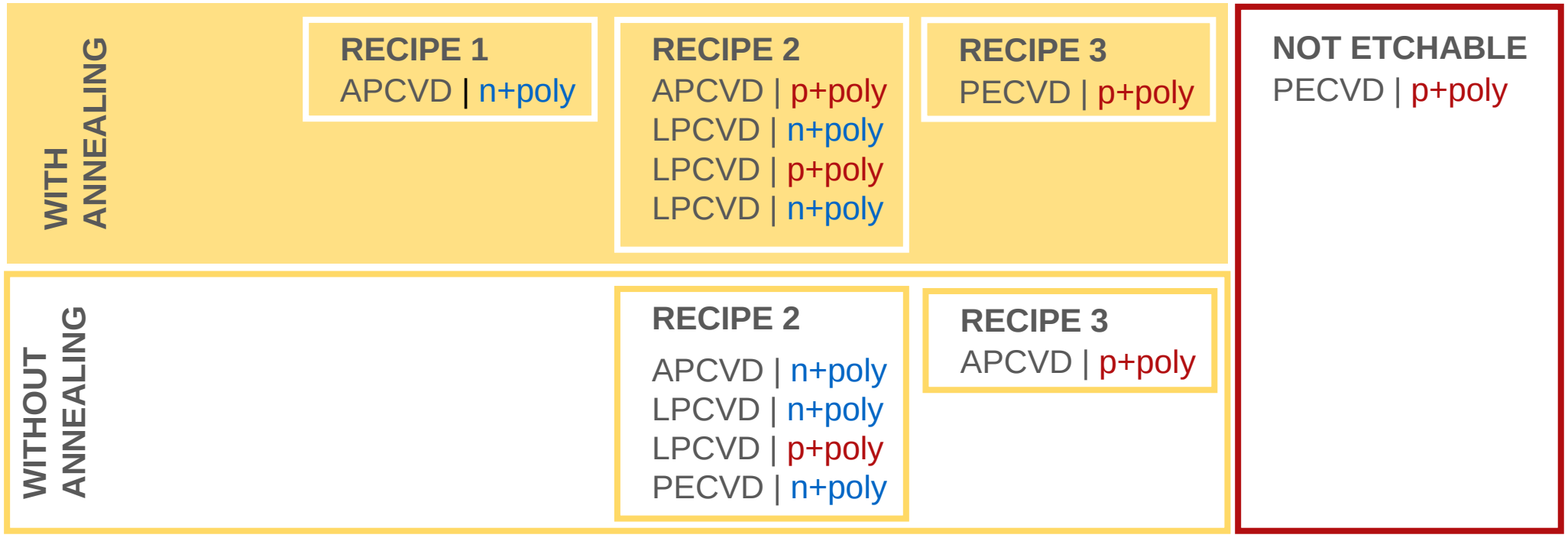
- High throughput HNO_3 free alkaline wet processing tool
- Up to 10.000 wph M12 throughput
- Different tool configuration available for:
  - Polishing
  - Oxide removal
  - Wrap around removal for poly-Si, BSG, PSG
  - PSG etch
  - Wet tunnel oxide generation

Alkaline Single Side Etching 10-lane

Alkaline Etching

Poly-Si Etch

- Alkaline Poly-Si wrap around capabilities
- Unique process know how for n and p doped poly-Si



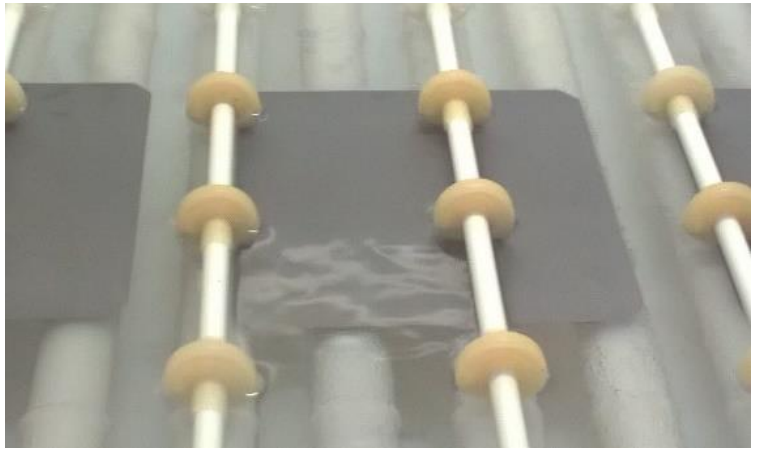
Poly-Si etching requires different RECIPES depending on the Poly-Si layer properties

Tunnel Oxide

Horizontal wet inline processing

Wet Chemical Tunnel Oxide for TOPCon Structures

- inline, ozone based wet tunnel oxide generation



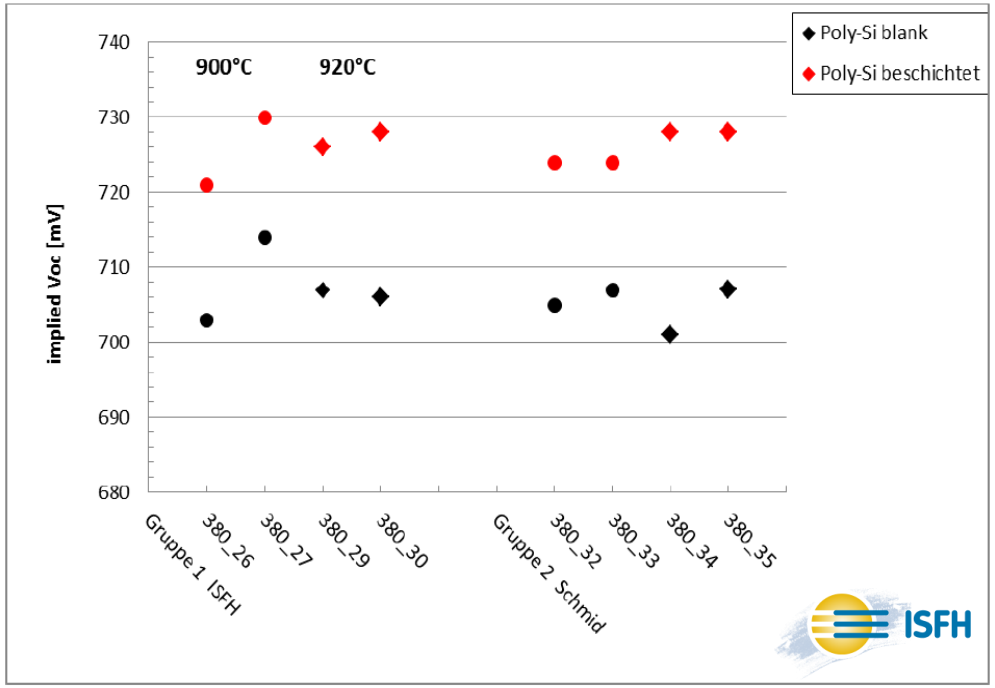
Tunnel Oxide

Horizontal wet inline processing

Wet Chemical Tunnel Oxide for TOPCon Structures

Inline wet chemical tunnel oxide growth:

- cleaning sequence 1 (organic impurities)
- cleaning sequence 2 (metallic impurities)
- growing tunnel oxide: DIW + ~ 20 ppm O_3
- wafer hydrophilic, oxide thickness (ellipsometry on CMP wafer) ~2 nm
- iV_{oc} on symmetric lifetime samples (APCVD p-polySi, AlO_x/SiN, annealed) comparable to ISFH wet chemical oxide



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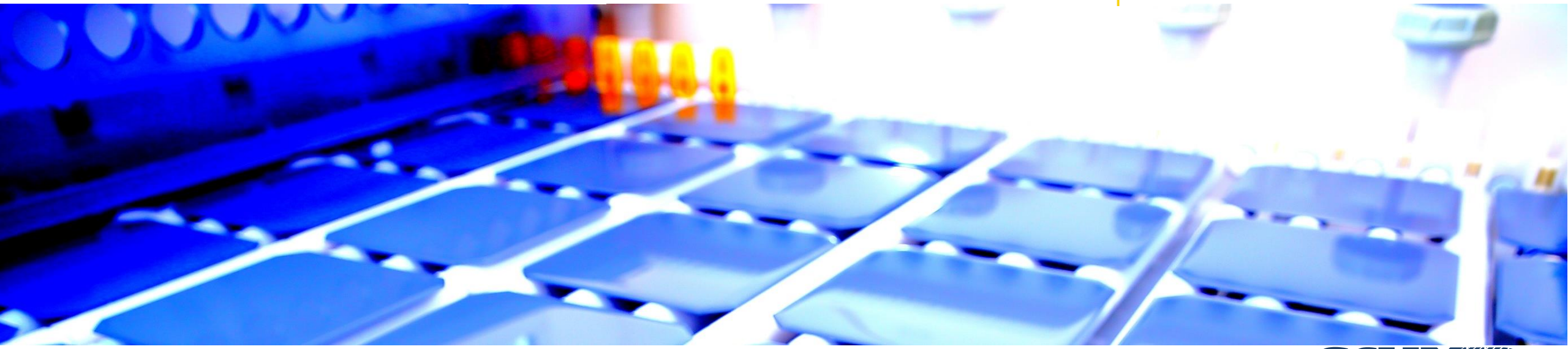
Summary

- Demonstrated different lean processes for IBC cells with $\eta \geq 23\%$ using the APCVD doped glasses
- APCVD-PSG and BSG is suited as ex-situ doping source for i-polySi
- In situ doped APCVD n/p-Poly in combination with APCVD doped glasses enables TOPCon/TOPCoRE
- Alkaline wet tool for different wet chemical processing task supporting high ETA cell architectures
- Wet chemical tunnel oxide generation for passivated contacts using O_3
- Many thanks to: Sven Seren,



THANK YOU FOR YOUR ATTENTION

Please feel free to contact us if you have any questions

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