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PASSIVATING CONTACTS ACTIVITIES AT PVLAB AND CSEM IN NEUCHÂTEL

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[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT) Photovoltaics and Thin-Film Electronics Laboratory (PV-Lab), Rue de la Maladière 71b, 2002 Neuchâtel, Switzerland.
[2] CSEM, PV-Center, Jaquet-Droz 1, 2002 Neuchâtel, Switzerland.
*Now at ANU
**Now at NREL

17e Congrès photovoltaïque national (2019)

R&D in photovoltaics and energy systems in Neuchâtel

EPFL PV-lab IMT NEUCHATEL

EPFL
IMT/PV-Lab (1984)
- Fundamental research
- Advanced devices

csem PV-Center

CSEM, RTO
PV-Center (since 2013)
- Focus on techn. transfer
- Dev. for industry, innovation

Production and commercialization

Industrial partners
Spin-off, Start-ups

In contracts with over 40 companies

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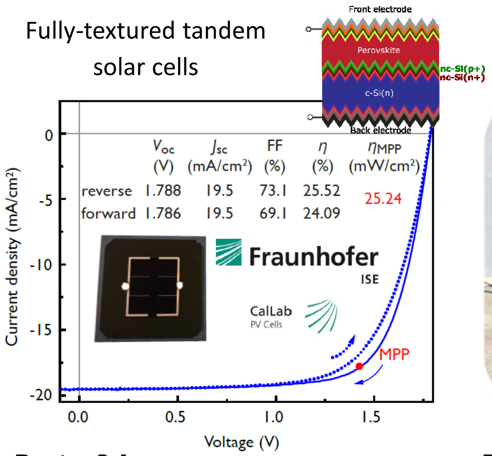
Contributions at PVT-19

Fully-textured tandem solar cells



Poster 3 A
High-performance tandem solar cells with improved stability and cost competitive manufacturing

A glass-free lightweight aesthetic PV module with maximal durability

Lightweight
(6 Kg/m²)

Poster 8 B.
Composite-based lightweight PV modules for building integrated and portable applications

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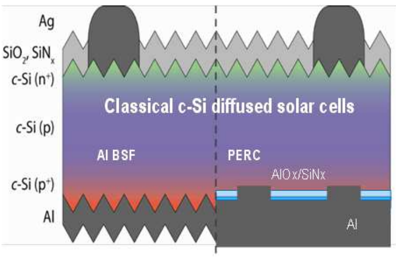
Motivation

Direct contact between c-Si and metal
Recombinative contact
→ Lower operating voltage & V_{oc}



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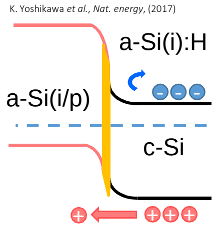
Motivation

Passivating contacts → *Ultimate solution for high efficiency*

→ Blocking of non collected carriers
→ Extraction of collected carriers

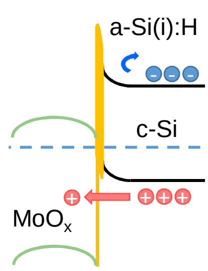
- Silicon Heterojunction (HJT)
- Transition metal oxides (TMOs)
- Poly-Si based passivating contacts [2,3]

K. Yoshikawa *et al.*, *Nat. energy*, (2017)

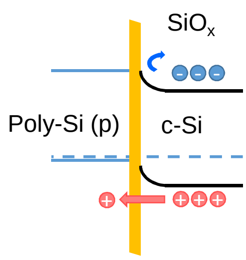


LOW T° (<250)

J. Geissbühler *et al.*, Appl. Phys. Lett., (2015)



LOW T° (<250)



HIGH T° (>700)

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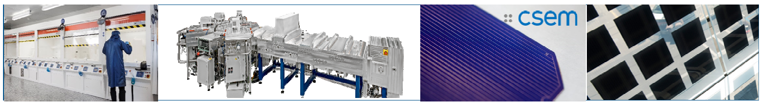
[2] A. Richter *et al.*, Sol. Energy Mater Sol., (2017)
[3] F. Haase et al., Sol. Energy Mater Sol., (2018)

EPFL

Heterojunction : lean process flow, thin film coating key

MATURE INDUSTRIAL COST EFFECTIVE PROCESS FLOW: SIMPLE, LOW T°
FULL AREA HOLE and ELECTRON SELECTIVE PASSIVATING CONTACTS

Pulling & slicing	Wet-process	PECVD	PVD	METALLIZATION	MODULE
Silicon wafer material	c-Si surface preparation	a-Si:H doped & intrinsic	TCO	Screen-printing curing 200°C	Interco / lamination



CSEM SILICON HETEROJUNCTION R&D PLATFORM

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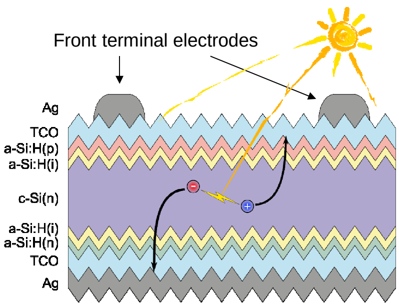
HJT cell structure

Transport losses mitigation in the shell if SHJ solar cells – n-type thin silicon multilayers



Schematic description of a standard monofacial SHJ solar cell.

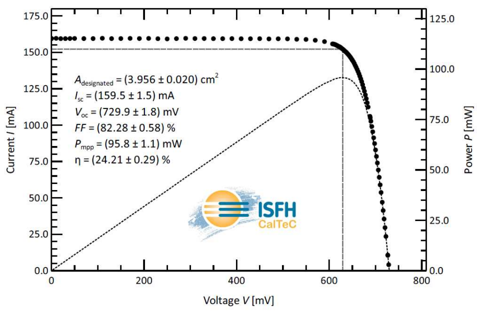


Fig. 2: Plot of the measured current-voltage characteristics under standard test conditions.

- High FF of 82.28% and J_{SC} of 40.32 mA/cm²
- V_{OC} of 729.9 mV and efficiency of 24.21%

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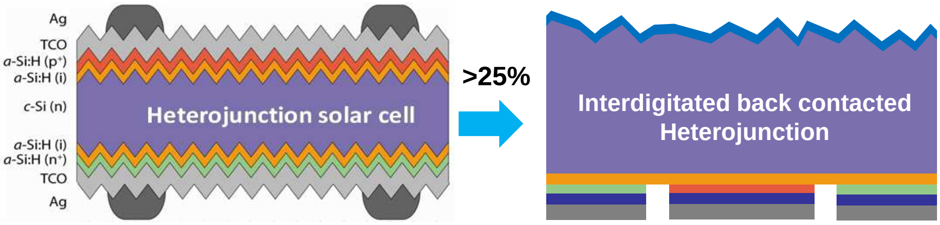
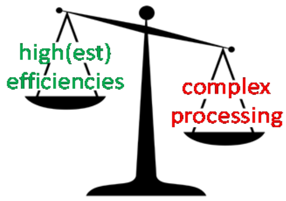
HJT: Upgrade scenario to IBC-HJT



World record Panasonic 25.1 %
[D. Adachi, Appl. Phys. Lett. 107, 233506 (2015)]

World record Kaneka 26.7 %
[K. Yoshikawa, Nature Energy 2, 17032 (2017)]

Challenge for **cost-effective** manufacturing keeping **high-efficiency**



To solve the dilemma:
Tunnel IBC-HJT

High **E**fficiency **I**nter-**DI**gitated cell concept SwissMade

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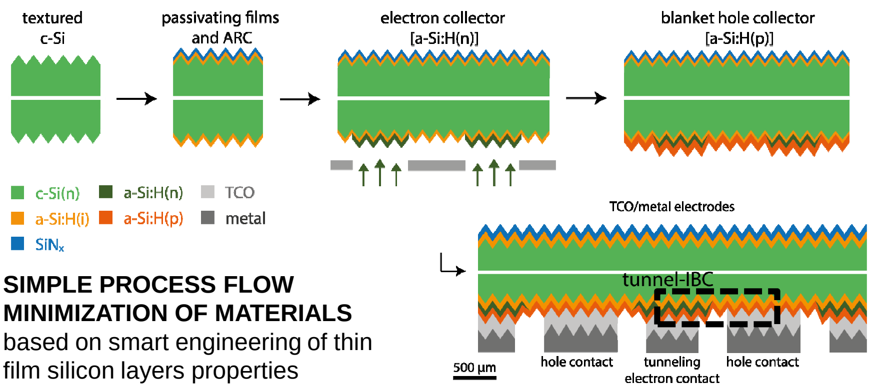
HJT: Upgrade scenario to IBC-HJT



SIMPLE PROCESS FLOW
MINIMIZATION OF MATERIALS
based on smart engineering of thin film silicon layers properties

[A Tomasi, et al., Nature Energy]

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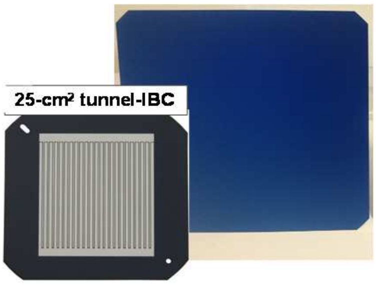
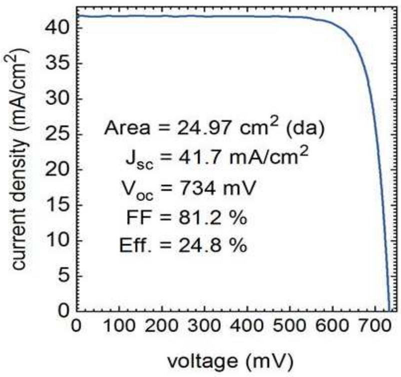
HJT: Upgrade scenario to IBC-HJT

NEXTBASE

TUNNEL IBC-HJT process of CSEM: SIMPLE PROCESS FLOW, MINIMIZE MATERIALS (Indium-free).

Certified EFFICIENCY
See C. Ballif, session 6





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Motivation

Passivating contacts → *Ultimate solution for high efficiency*

→ Blocking of non collected carriers
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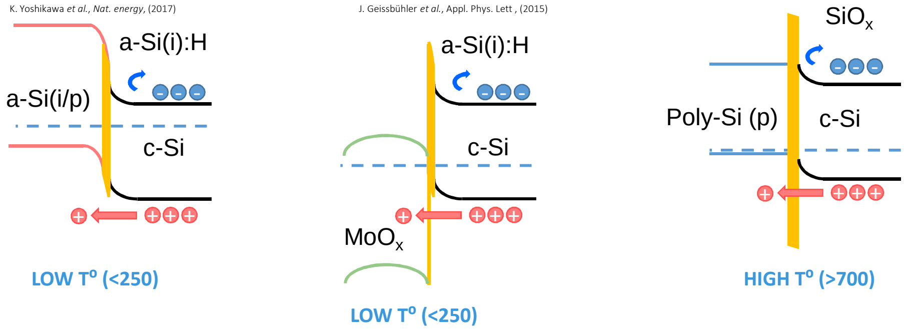
- Silicon Heterojunction (HJT)
- Transition metal oxides (TMOs)
- Poly-Si based passivating contacts

K. Yoshikawa *et al., Nat. energy*, (2017)
J. Geissbühler *et al.*, Appl. Phys. Lett., (2015)



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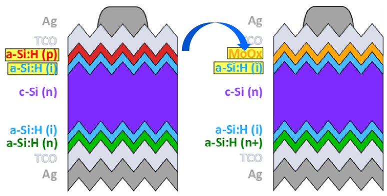
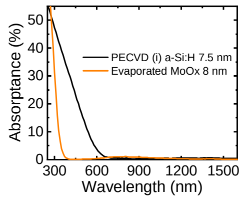
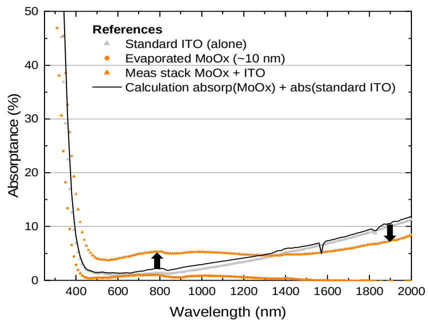
Replacing doped a-Si with more transparent TMO

Parasitic absorption under 600 nm:

- (p) a-Si:H in HIT structure responsible for J_{SC} losses
- MoO_x more transparent
- But MoO_x + ITO absorbs visible light!







- Mitigating this loss allows high Jsc
- Best MoO_x cell performance similar to SHJ reference

V_{oc} [mV]	FF [%]	J_{sc} [mA/cm²]	η [%]
725	77.6	39.77	22.37

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Motivation

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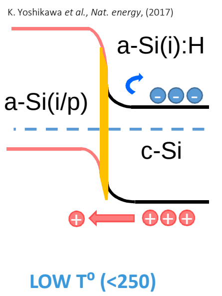
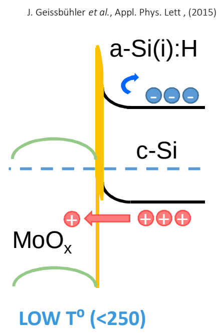
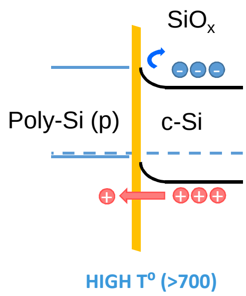
- Poly-Si based passivating contacts







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High-temperature passivating contacts: PV-LAB roadmap

Focus on p-type wafers:

- Still preferred by the PV industry.
- The high T process improves the bulk properties

"Smart" thin-films by PECVD:

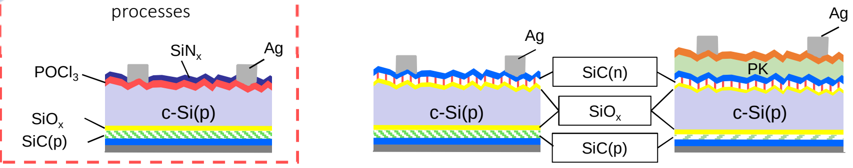
- High throughput
- Large flexibility for cell integration
- Additive single-side process

Poster 4 A:
Silicon doped alloys deposited by PECVD on tunneling oxide for high-efficiency c-Si solar cells

p-PERC upgrade with passivating contacts implementable in today's manufacturing processes

Next generation of two sides contacted solar cells with passivating contacts with efficiency >25%

Monolithic textured tandem solar cells with two sides passivating contacts with efficiency >28%



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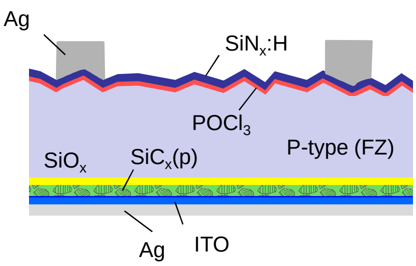
FPC integration with co-firing of Ag-paste contacting a front P-diffused emitter in *p-type* solar cells

- Wafer Texturing
- $POCl_3$ diffusion
- Rear side etching (alkaline)
- Cleaning and SiO_x-growth
- PECVD a-SiC_x(p):H (rear)
- SiN_x:H (front and rear)
- Screen priting Ag-paste (front)
- Firing (CAMINI) (800°C, 3s)
- Single side etching SiN_x:H
- Metallization (sputtered ITO/Ag)

Non-standard processes

Same processing steps as for a PERC cell



1. Electrical contact between emitter and Ag-paste
2. Hydrogenation of front and rear

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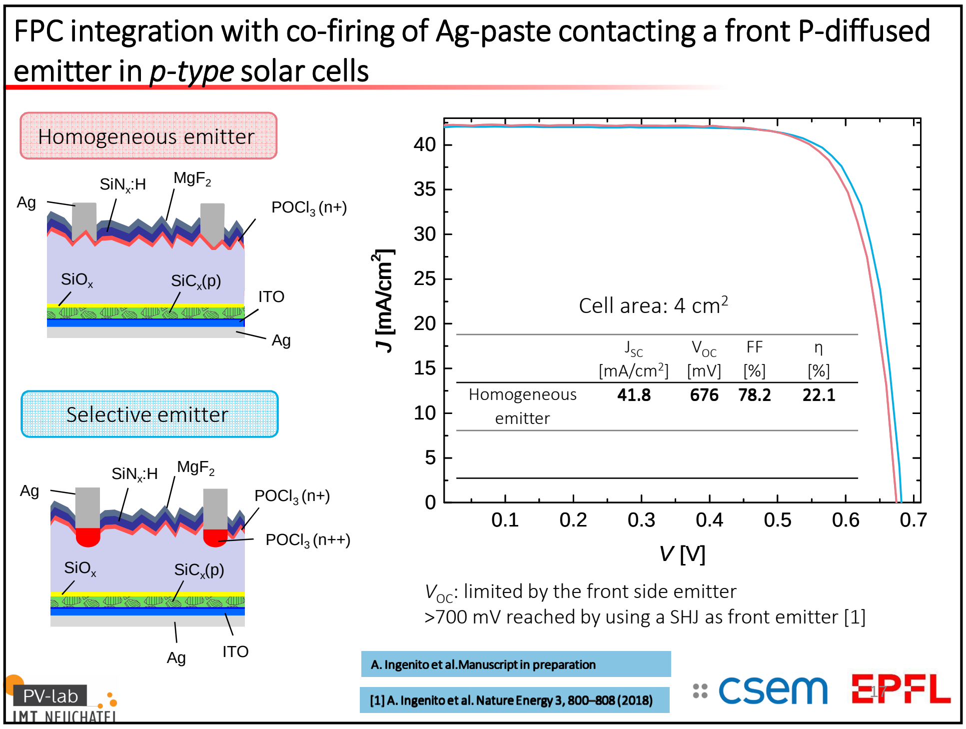
FPC integration with co-firing of Ag-paste contacting a front P-diffused emitter in p-type solar cells
Homogeneous emitter
Ag
SiNx:H
MgF2
POCl3 (n+)
SiOx
SiCx(p)
ITO
Ag
Selective emitter
Ag
SiNx:H
MgF2
POCl3 (n+)
POCl3 (n++)
SiOx
SiCx(p)
Ag
ITO
J [mA/cm2]
V [V]
Cell area: 4 cm2
Jsc [mA/cm2] | Voc [mV] | FF [%] | η [%]
Homogeneous emitter | 41.8 | 676 | 78.2 | 22.1
Voc: limited by the front side emitter
>700 mV reached by using a SHJ as front emitter [1]
A. Ingenito et al. Manuscript in preparation
[1] A. Ingenito et al. Nature Energy 3, 800–808 (2018)
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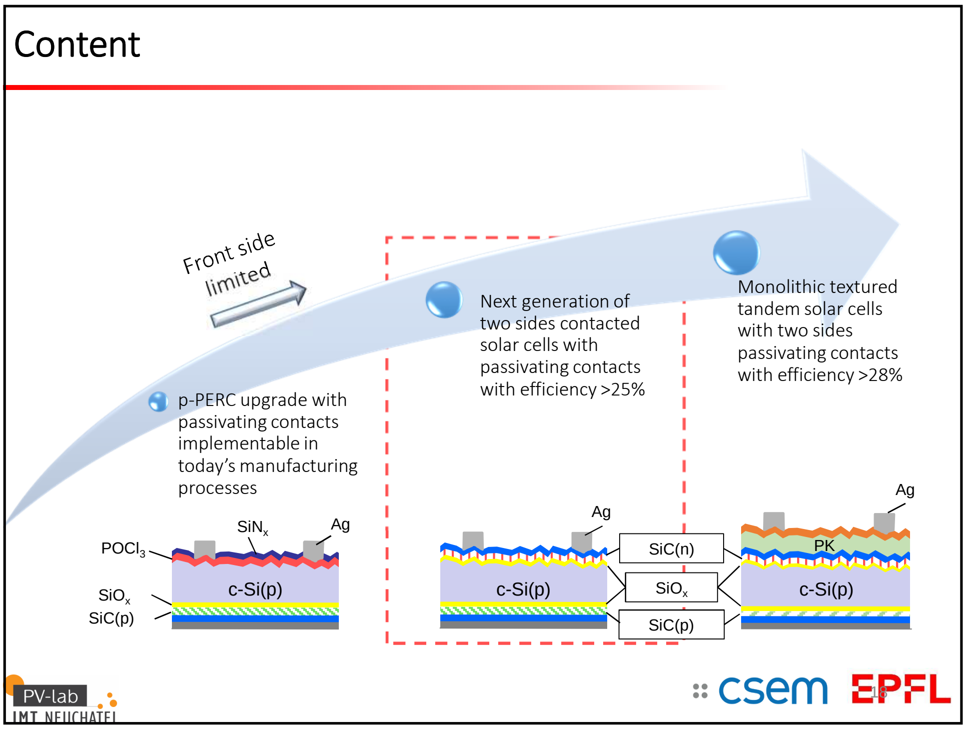
Content
Front side limited
p-PERC upgrade with passivating contacts implementable in today's manufacturing processes
Next generation of two sides contacted solar cells with passivating contacts with efficiency >25%
Monolithic textured tandem solar cells with two sides passivating contacts with efficiency >28%
POCl3
SiNx
Ag
c-Si(p)
SiOx
SiC(p)
Ag
c-Si(p)
SiC(n)
SiOx
SiC(p)
Ag
PK
c-Si(p)
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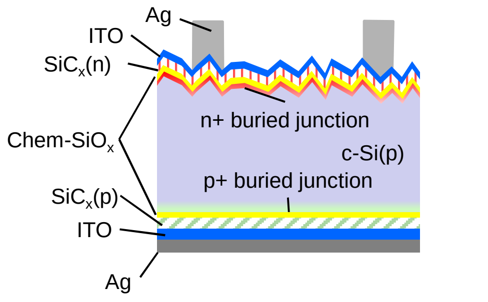
Process flow of co-annealed front and rear contacted SiC_x-based c-Si solar cells

- Single side texturing
- «Chem-SiO_x» grown in HNO_3
- PECVD SiC_x(n) front
- PECVD SiC_x(p) rear
- Co-Annealing (850˚C)
- Hydrogenation (SiN_x:H)
- Stripping SiN_x:H
- Metallization*

*Sputtered ITO/Ag rear side
*Sputtered ITO/ screen printed Ag paste front side



-Potential demonstrated with ion implanted passivated contacts on n-type FZ [1] and CZ [2] wafers

[1] F. Feldmann et al., IEEE, Portland, 10.1109/PVSC.2017.8366558 (2016)
[2] R. Peibst et al. J-PV DOI: 10.1109/JPHOTOV.2018.2813427 (2018)

A. Ingenito et al. JPV, (2018), 9, (2018)
G. Nogay et al., JPV , JPV, 99, 1-8 (2018)

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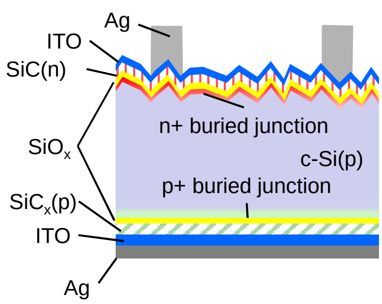
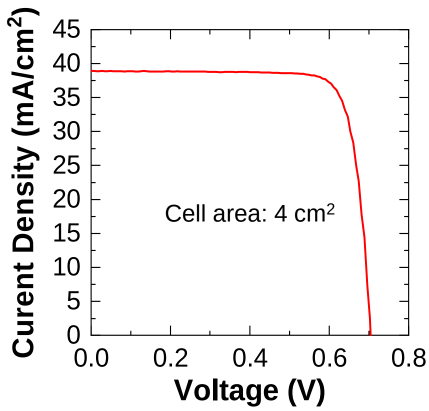
Front side textured, rear side planar cells



V_{oc} [mV]	FF [%]	J_{sc} [mA/cm²]	η [%]
705	81.7	39.2	22.6



G. Nogay et al., JPV 99, 1-8 (2018)

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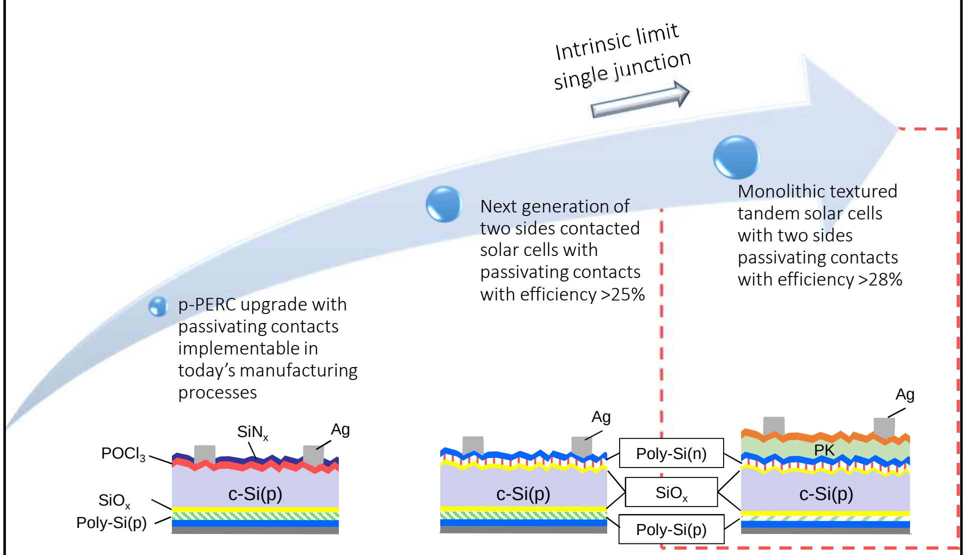
Content



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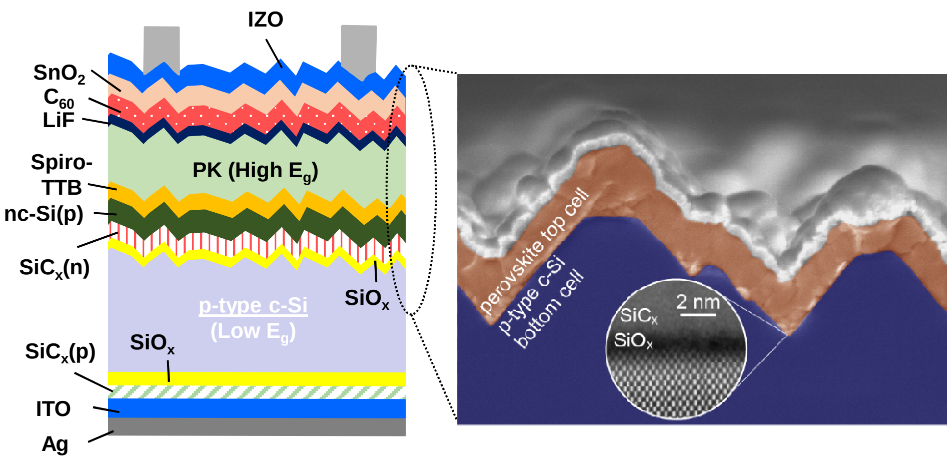
Front side textured monolithic PK/c-Si tandem solar cells



F. Sahli *et al.* Adv. Energy mat. (2017)
F. Sahli & J. Wener et al., Nature Materials, (2018)

G. Nogay, F. Sahli et al., Accepted for publication on ACS letter (2019)

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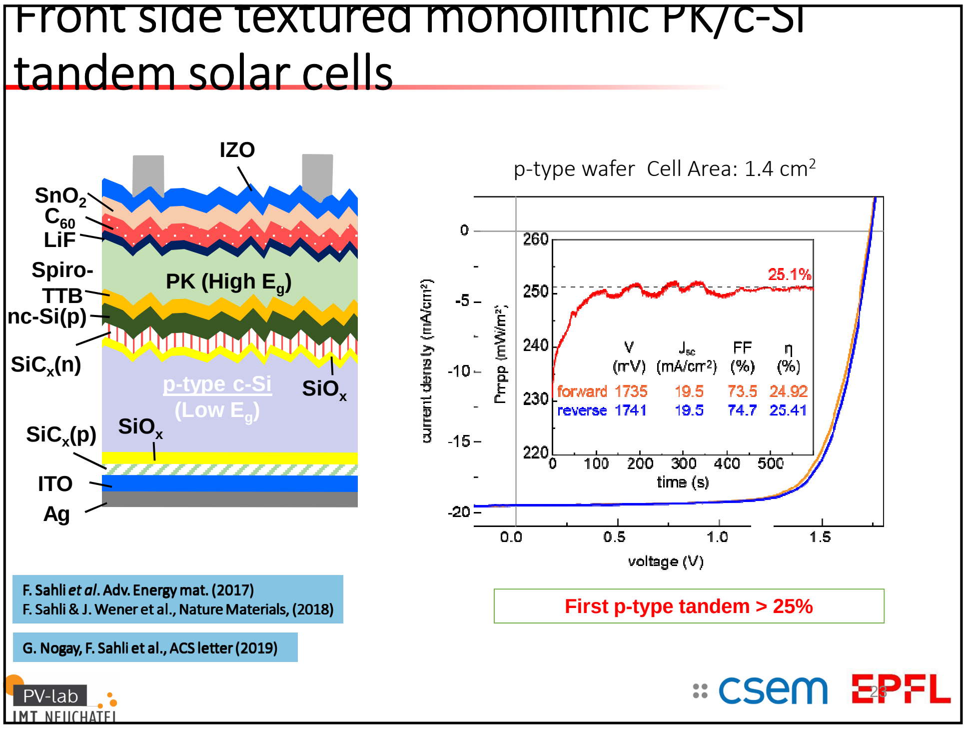
Front side textured monolithic PK/c-Si tandem solar cells
IZO
SnO2
C60
LiF
Spiro-TTB
nc-Si(p)
SiCx(n)
PK (High Eg)
p-type c-Si (Low Eg)
SiOx
SiCx(p)
SiOx
ITO
Ag
p-type wafer Cell Area: 1.4 cm2
current density (mA/cm2)
voltage (V)
Pmpp (mW/m2)
time (s)
25.1%
V (mV) Jsc (mA/cm2) FF (%) η (%)
forward 1735 19.5 73.5 24.92
reverse 1741 19.5 74.7 25.41
F. Sahli et al. Adv. Energy mat. (2017)
F. Sahli & J. Wener et al., Nature Materials, (2018)
G. Nogay, F. Sahli et al., ACS letter (2019)
First p-type tandem > 25%
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THANK YOU FOR YOUR ATTENTION!
2 nm
SiCx
SiOx
Frank Mayer,
Arnaud Savoy,
Philippe Wyss,
Christophe Allebé,
Gizem Nogay,
Florent Sahli,
Jérémie Werner,
Juan J. Diaz Leon,
Frank Mayer,
Mario Lehmann,
Esteban Rucavado,
Josua Stückelberger,
Santhana E. Moorthy,
Tom Wirtz,
Sylvain Nicolay,
Quentin Jeangros,
Matthieu Despeisse,
Franz-J. Haug
Christophe Ballif
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Confederaziun svizra
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