ACHIEVEMENTS AND CHALLENGES TOWARDS HIGH EFFICIENCY, LARGE AREA IBC SOLAR CELLS

BARRY O'SULLIVAN, SUKHVINDER SINGH, MAARTEN DEBUCQUOY, JOZEF SZLUFCIK

imec, Kapeldreef 75, B-3001 Leuven, Belgium

Barry.OSullivan@imec.be

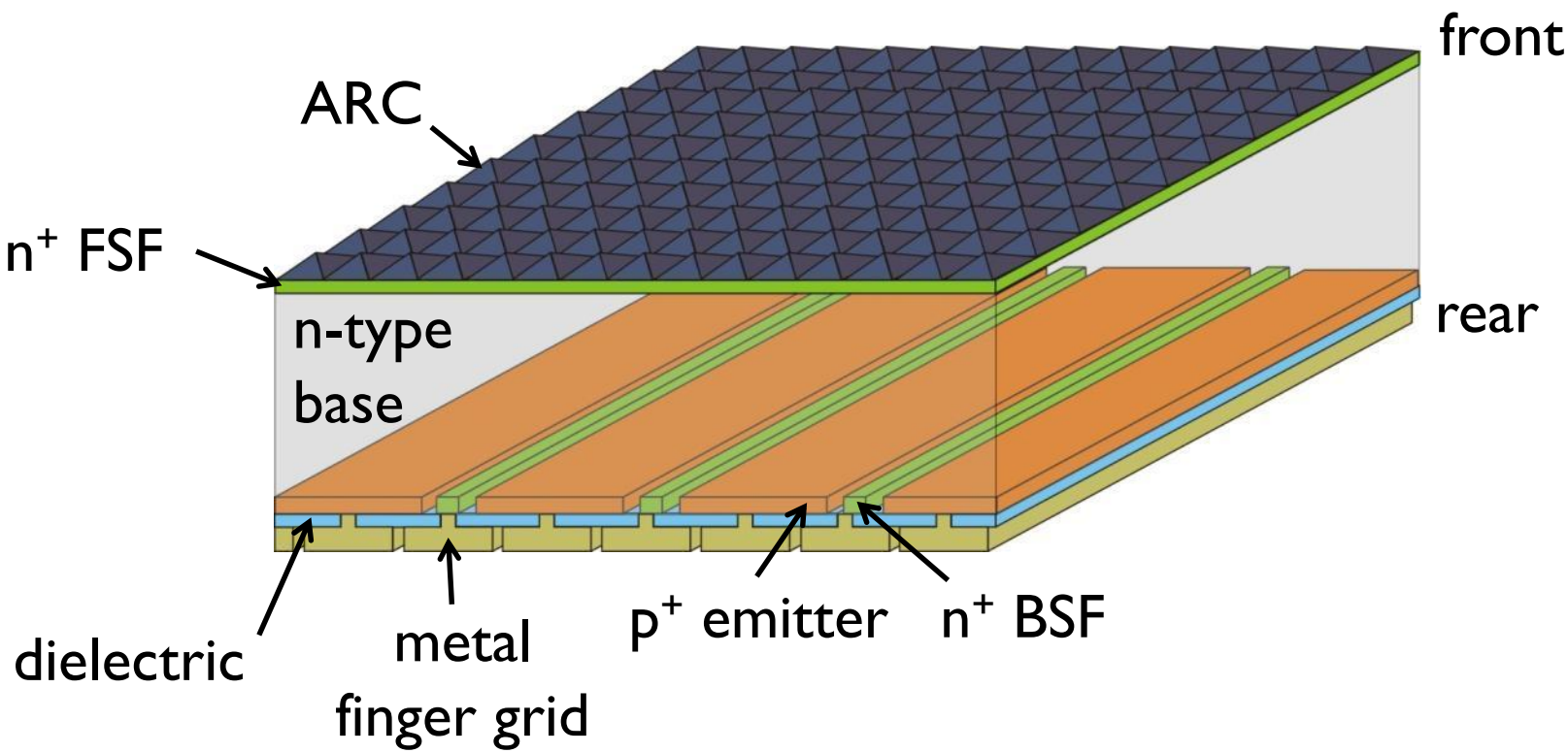
OUTLINE

- Introduction
- IBC cell process flow
- Upscaling to full size devices
- Summary: Achievements & Challenges

OUTLINE

- Introduction
- IBC cell process flow
- Upscaling to full size devices
- Summary: Achievements & Challenges

INTERDIGITATED BACK CONTACT SILICON SOLAR CELLS



IBC: STATE-OF-THE-ART

Industrial and semi-industrial homo-junction IBC cells

Reference	Year	Substrate	Area (cm^2)	Eff. (%)
[1] D. Smith, SunPower	2014	CZ, n-type	155	24.5
[1] D. Smith, SunPower	2014	CZ, n-type	121	25.0
[2] C.B. Mo, Samsung SDI/Varian	2012	CZ, n-type	155	22.4
[3] A. Halm / J. Libal, ISC Konstanz / Silfab	2012	CZ, n-type	243	21.3
[4] Bosch / ISFH	2013	CZ, n-type	~240	22.1
[5] E. Franklin, ANU/Trina Solar	2014	CZ, n-type	~240	22.9

[1] D. Smith et al., 40th IEEE PVSC, Denver, USA (2014)

[2] C.B. Mo et al., 27nd EUPVSEC, Frankfurt, Germany (2012)

[3] A. Halm et al., 27nd EUPVSEC, Frankfurt, Germany (2012)

[4] Bosch SE, press release (2013)

[5] E. Franklin et al., SNEC, Shanghai, China (2014)

IBC CELLS AT IMEC

2007:
IBC research started at imec on p- and n-type

2011:
Start of **IBC platform** development: 2x2 cm^2 cells on 4 inch n-type FZ substrates

2012:
Transfer of 2x2 cm^2 cells baseline from 4 inch FZ to **15.6 cm CZ** substrates

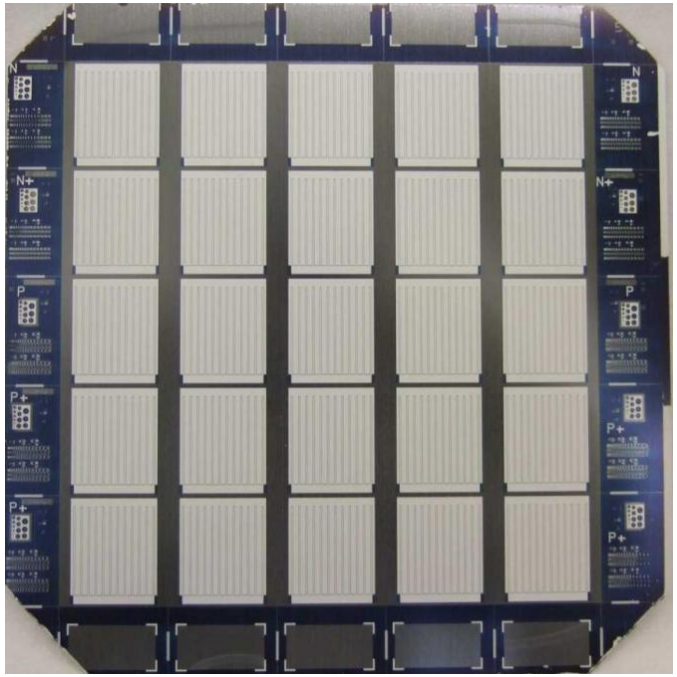
2013:
Stable baseline, applied for new developments

- Innovation
- Process simplification
- Up scaling cell area
- Incorporation into module

BASELINE AT IMEC

Wafers:

- 15.6x15.6 cm^2 semi-square
- N-type Cz



Processing:

- Diffusion
- Photolithography

Cells:

- 25 cells with an active area of 2x2 cm^2
- Surrounded by test structures

IBC STATE-OF-THE-ART

Industrial and semi-industrial homo-junction IBC cells

Reference	Year	Substrate	Area (cm^2)	Eff. (%)
[1] D. Smith, SunPower	2014	CZ, n-type	155	24.5
[1] D. Smith, SunPower	2014	CZ, n-type	121	25.0
[2] C.B. Mo, Samsung SDI/Varian	2012	CZ, n-type	155	22.4
[3] A. Halm / J. Libal, ISC Konstanz / Silfab	2012	CZ, n-type	243	21.3
[4] Bosch / ISFH	2013	CZ, n-type	~240	22.1
[5] E. Franklin, ANU/Trina Solar	2014	CZ, n-type	~240	22.9

Imec's small area IBC platform efficiencies

Reference	Year	Substrate	Area (cm^2)	Eff. (%)
[6] M. Aleman, on 4 inch FZ	2012	FZ, n-type	4	23.3*
[7] O'Sullivan, on 156 mm CZ	2013	CZ, n-type	4	23.1*

** Externally confirmed*

[6] M. Aleman, et al., 2nd SiliconPV, Leuven, Belgium (2012);

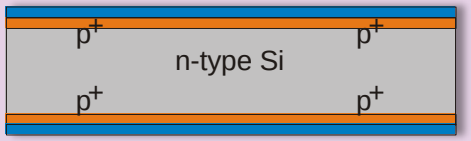
[7] B.J. O'Sullivan, et al., 28th EUPVSEC, Paris, France (2013)

OUTLINE

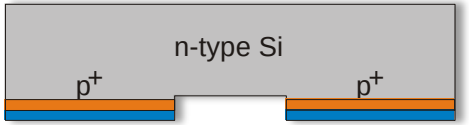
- Introduction
- IBC cell process flow
- Upscaling to full size devices
- Summary: Achievements & Challenges

BASELINE PROCESS CZ SILICON

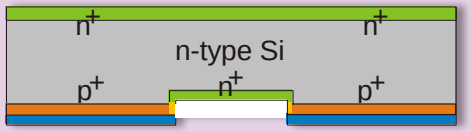
- Polishing and Emitter formation



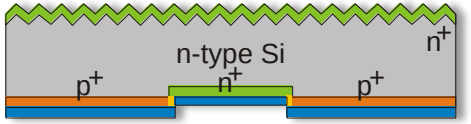
- Rear emitter patterning



- BSF formation

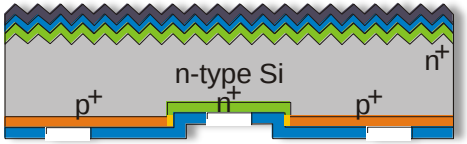


- Texturing and FSF formation



- Surface passivation, ARC

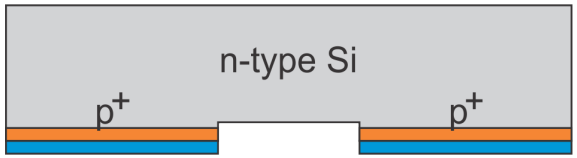
- Rear dielectric patterning



- Contact formation

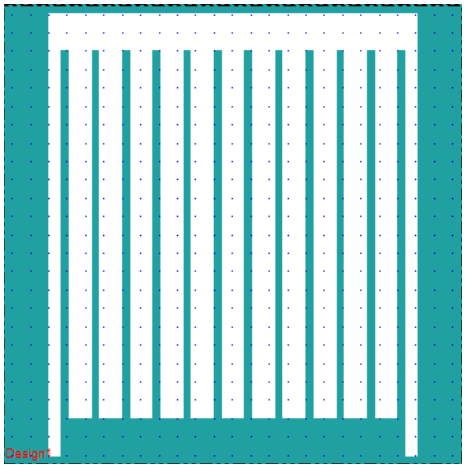
B O'Sullivan et. al., *Proc. EUPVSEC*, (2013)

LASER ABLATION FOR BSF DEFINITION



Basic laser parameters

- Power
- Speed



Continuous lines required

- Overlap between adjacent lines

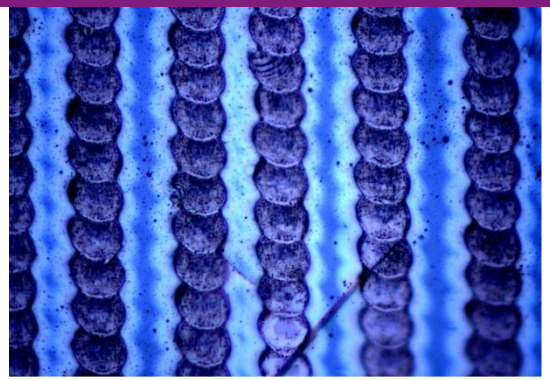
Additional optimization performed

- Emitter etch time after laser ablation

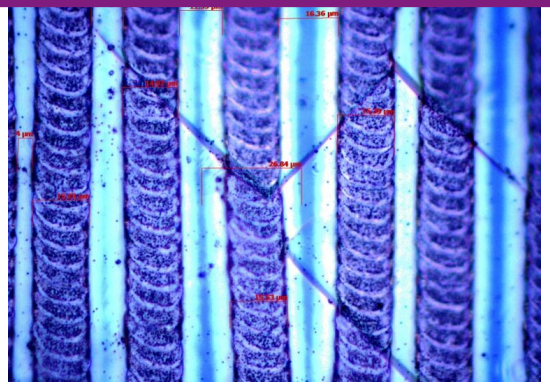
S Singh et. al., *Proc. EUPVSEC*, (2014)

LASER ABLATION: PROCESS DEVELOPMENT

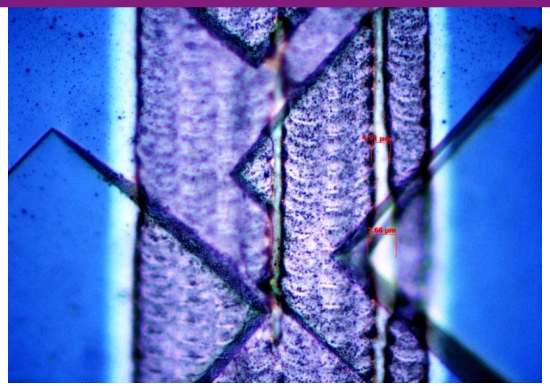
Excessive laser speed/ insufficient line overlap



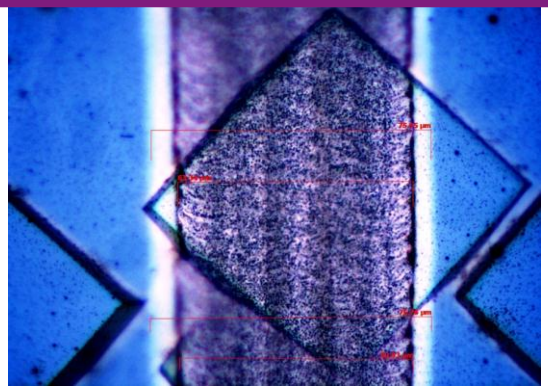
Excessive overlap within one line



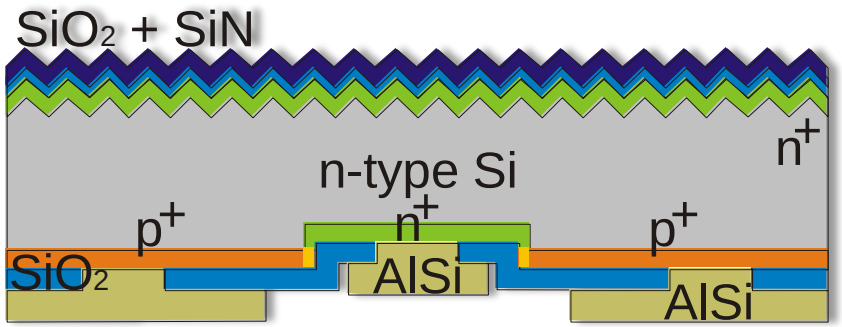
Insufficient laser power/line overlap



Optimum power and line overlap



CONTACT HOLE DEFINITION



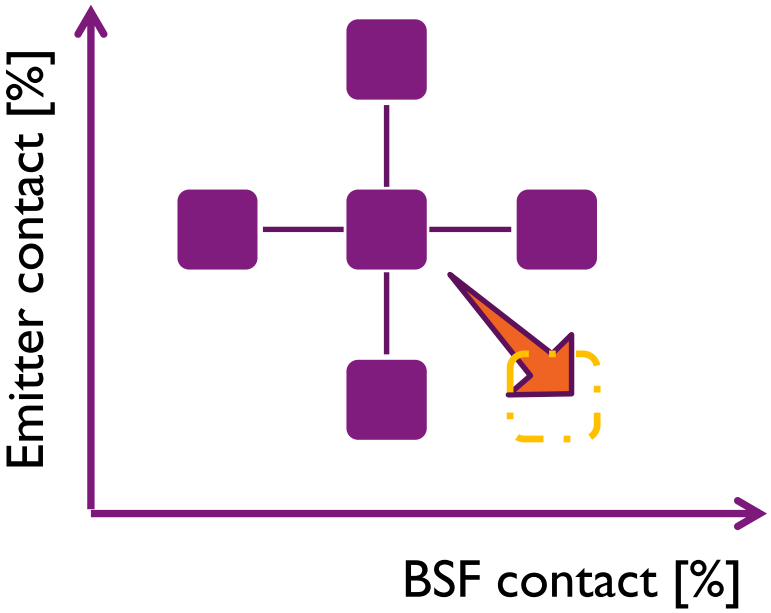
p^+ Si emitter

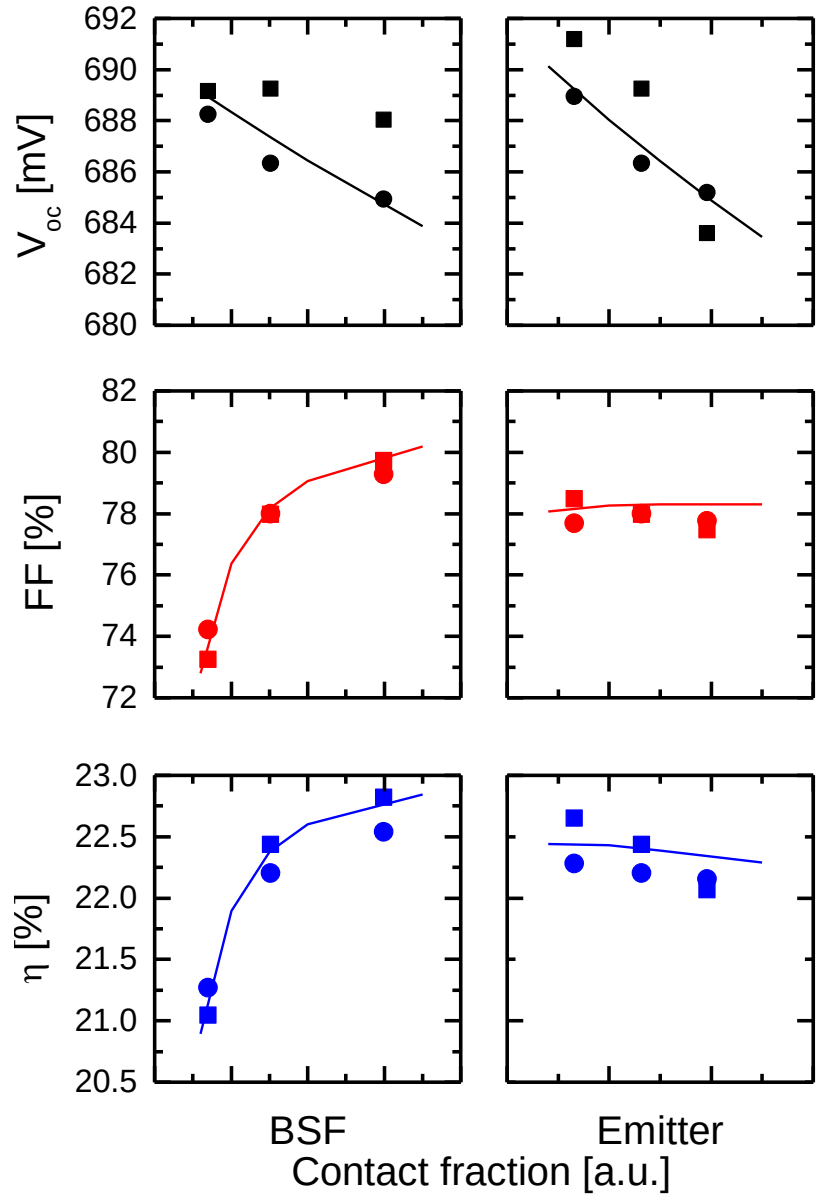
- Thermal SiO_2
- On 10^{19} cm^{-3} Boron doped region

n^+ Si BSF region

- Thermal SiO_2
- On 10^{19} cm^{-3} Phosphorus doped region

LASER ABLATED CONTACT HOLES





Increased BSF contact

Reduced emitter contact

B O'Sullivan et. al., *Proc. EUPVSEC*, (2013)

SCREEN PRINTING FOR METAL PATTERNING

AlSi PVD sputter

↓

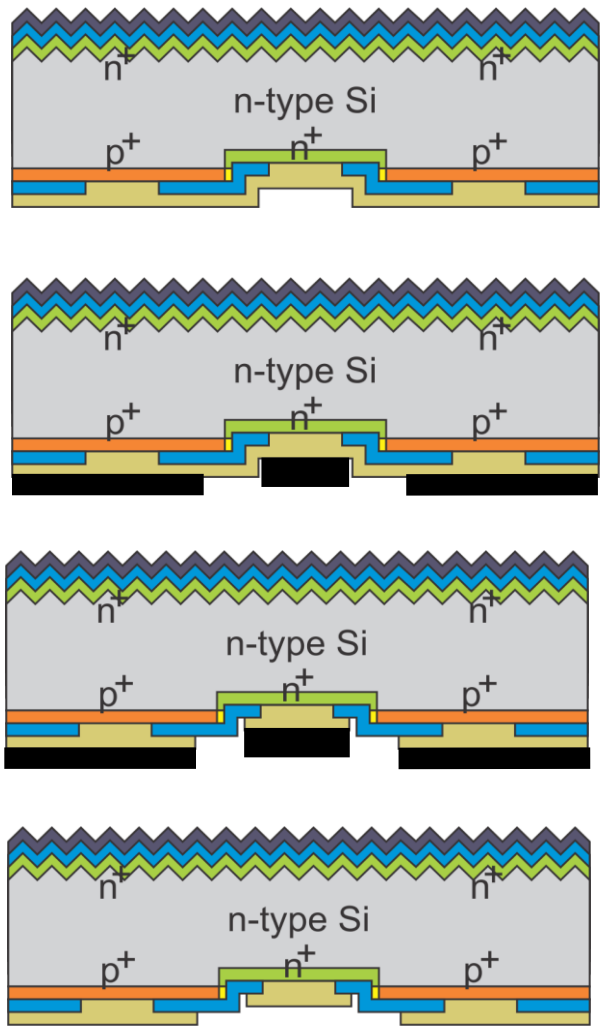
Polymer ink screen printing

↓

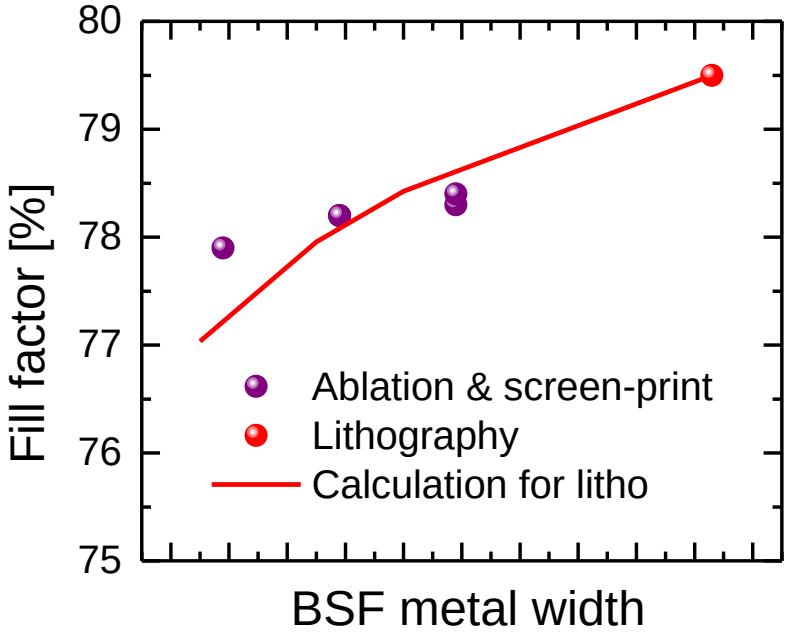
Etch metal

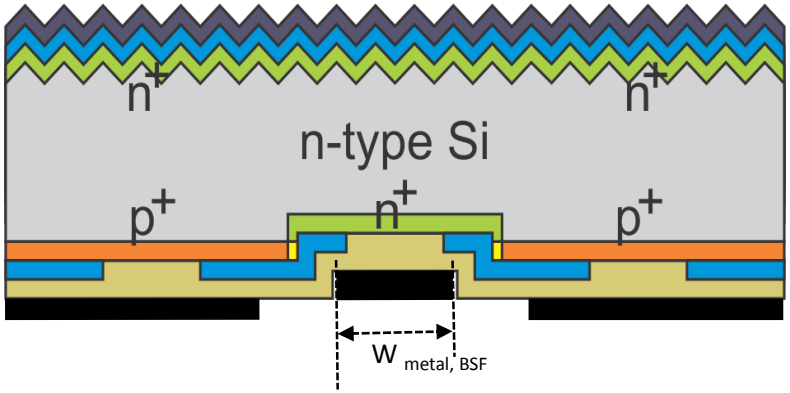
↓

Strip paste



EFFECT OF BSF METAL WIDTH





Paste control results in thinner BSF metal width

- Fill factor penalty results
- Fitting well with calculated trend line for photolitho case

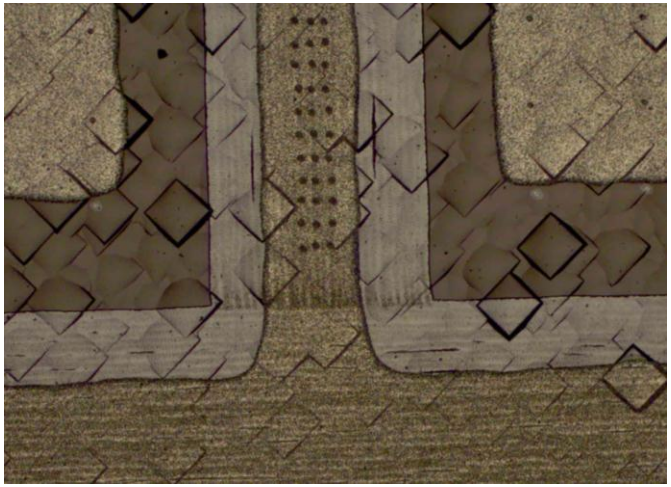
DEVICE LEVEL

Laser ablation

- BSF region definition
- Contact hole definition

Screen printing

- Metal patterning



Patterning method	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	Eta [%]
Photolithography	41.2	690	79.5	22.6
Ablation & Screen printing	41.3	687	78.5	22.2*

** Externally confirmed*

S Singh et. al., *Proc. EUPVSEC*, (2014)

17

SUMMARY: SMALL AREA CELLS

Rear side patterning

- Emitter definition: laser ablation of oxide
- Contact opening: laser ablation of oxide
- Metal patterning: screen printing polymer paste

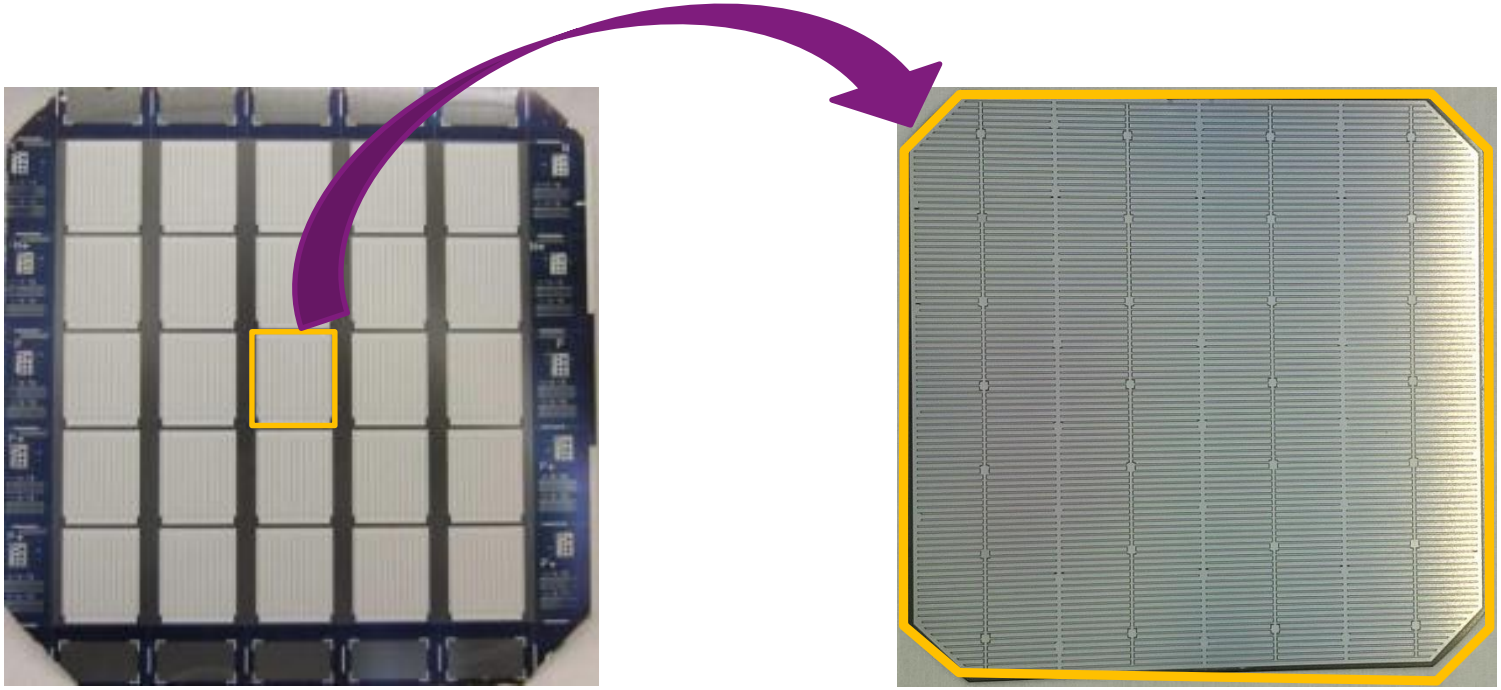
Photolitho-free best cell efficiency 22.2 %

- Design rule defined: alignment accuracy vs losses

OUTLINE

- Introduction
- IBC cell process flow
- Upscaling to full size devices
  - Impact of cell area on characteristics
- Summary: Achievements & Challenges

NEXT STEPS



Upscale cell design

Extend laser ablation and screen printing to full area

SUMMARY IV RESULTS

	Area [cm^2]	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	Eta [%]	# cells
Average	239	40.2	685	76.5	21.0	9
Best cell	239	40.1	686	77.4	21.3	

Promising J_{sc} and V_{oc} values

FF limiting performance

IMPACT OF CELL AREA

Best cell

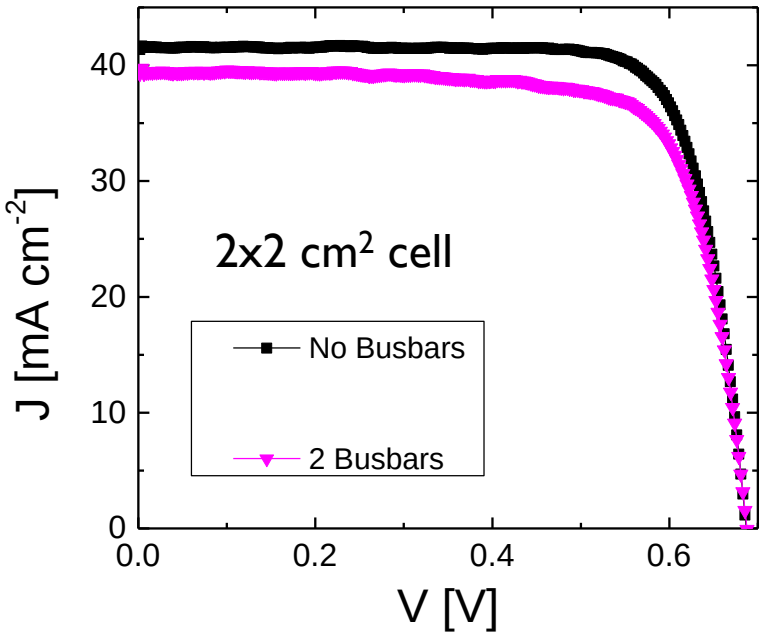
Size [cm^2]	Metal	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	η [%]
239	3 μm AlSi	40.1	686	77.4	21.3
4	2 μm AlSi	41.3	687	78.5	22.2*

V_{oc} independent of cell size

J_{sc} and FF reduce with cell size

INFLUENCE OF DESIGNATED ILLUMINATION APERTURE

(AND WHAT IT SHADES ☺)



Lower J_{sc} and FF when busbar's included

FILL FACTOR LOSS ANALYSIS

Series resistance

$$\Delta FF_{R_s} = \frac{{J_{mpp}}^2 R_s}{J_{sc} V_{oc}}$$

Shunt resistance

$$\Delta FF_{R_{sh}} = \frac{\left(V_{mpp} + J_{mpp} R_s\right)^2}{R_{sh} J_{sc} V_{oc}}$$

J_{02} loss

$$\Delta FF_{J_{02}} = FF_{J_{01}} - FF_0$$

Additional busbar-induced loss

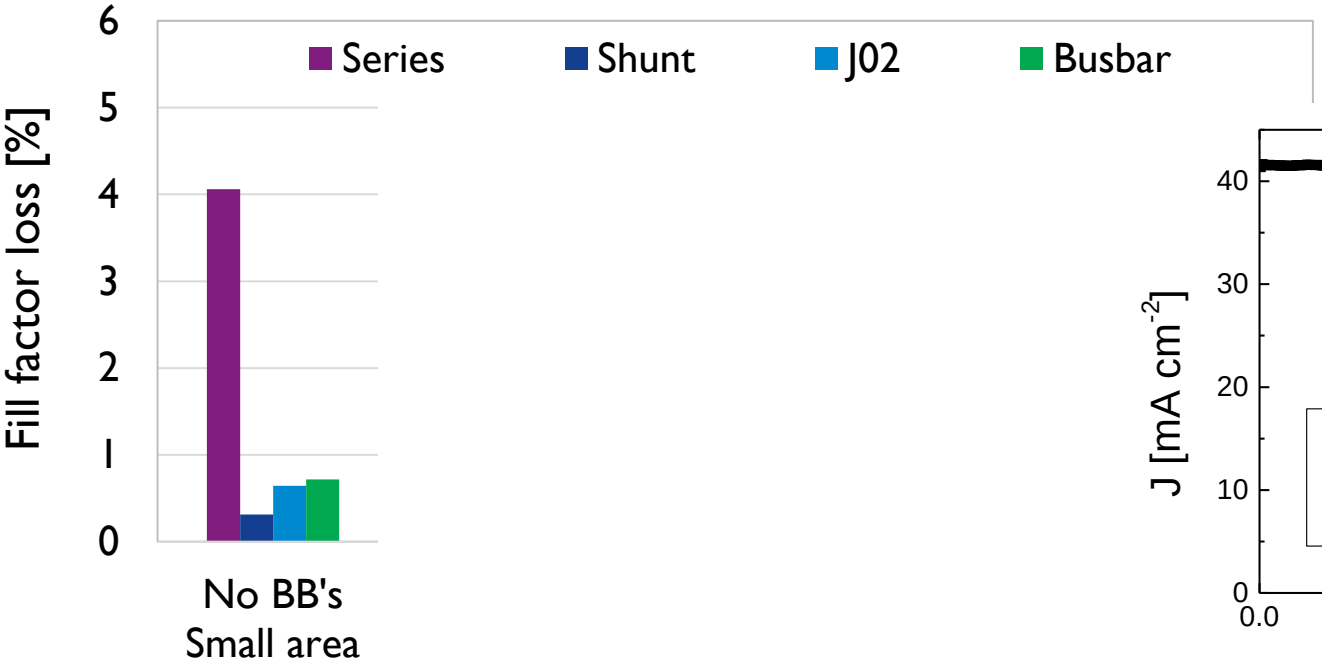
$$\Delta FF_{BB} = pFF - FF - \Delta FF_{R_s}$$

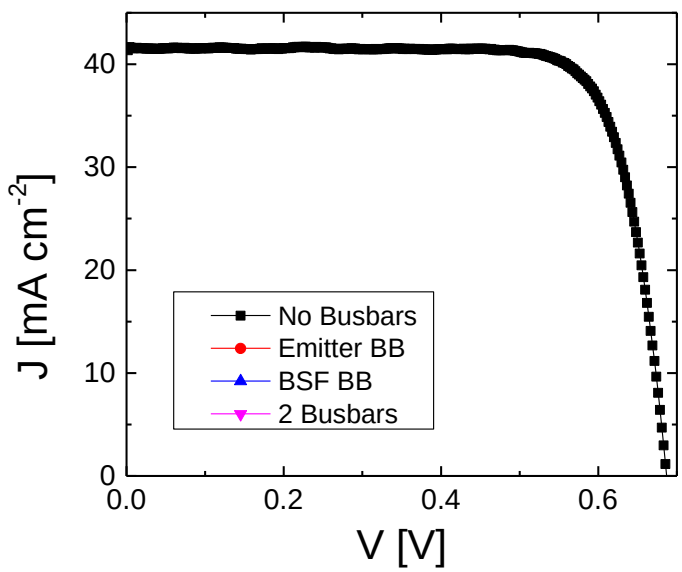
Allows decoupling of resistive loss mechanisms

A Khanna, *IEEE J. Photovoltaics*, (2013)

B O'Sullivan, *WC-PEC*, (2014)

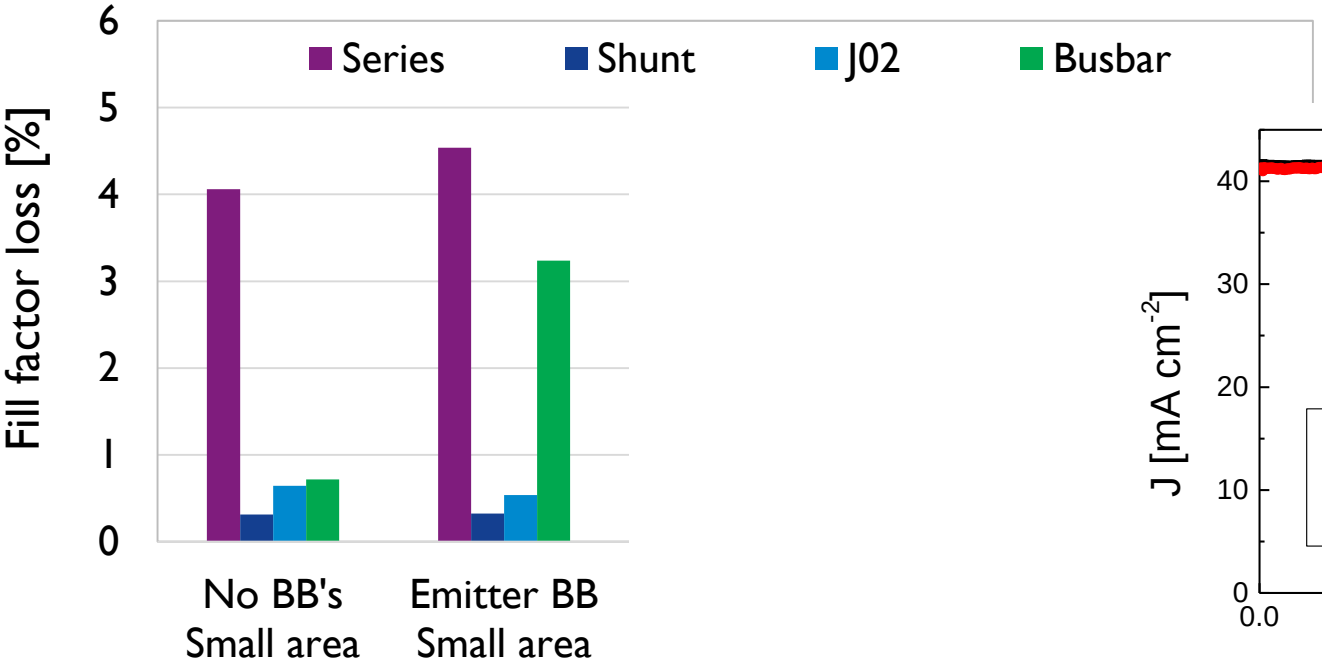
FF LOSS MECHANISMS

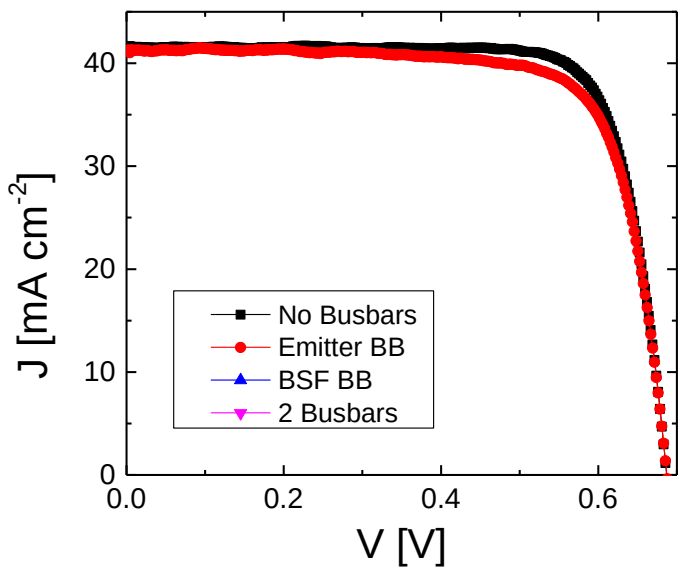




Series resistance loss is dominant

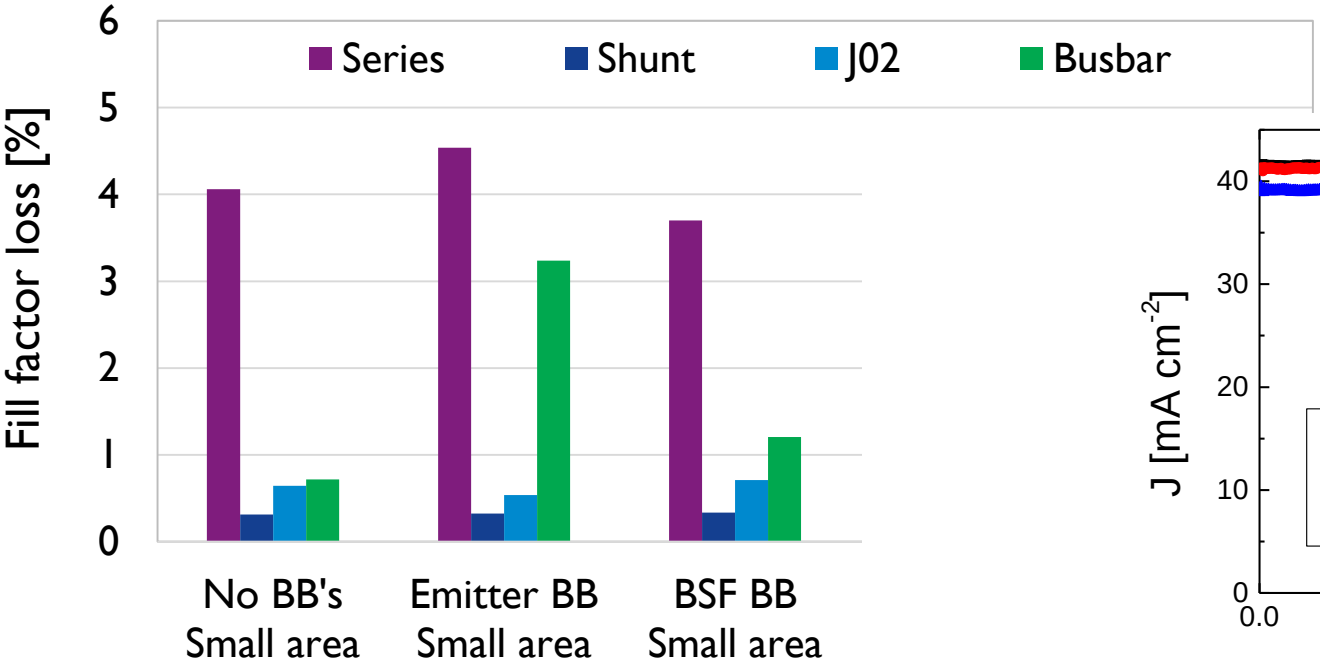
FF LOSS MECHANISMS

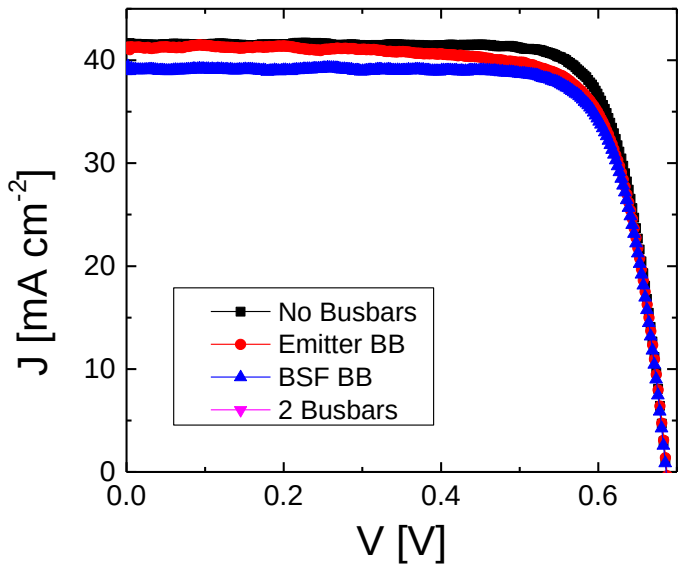




Resistive penalty for emitter BB inclusion

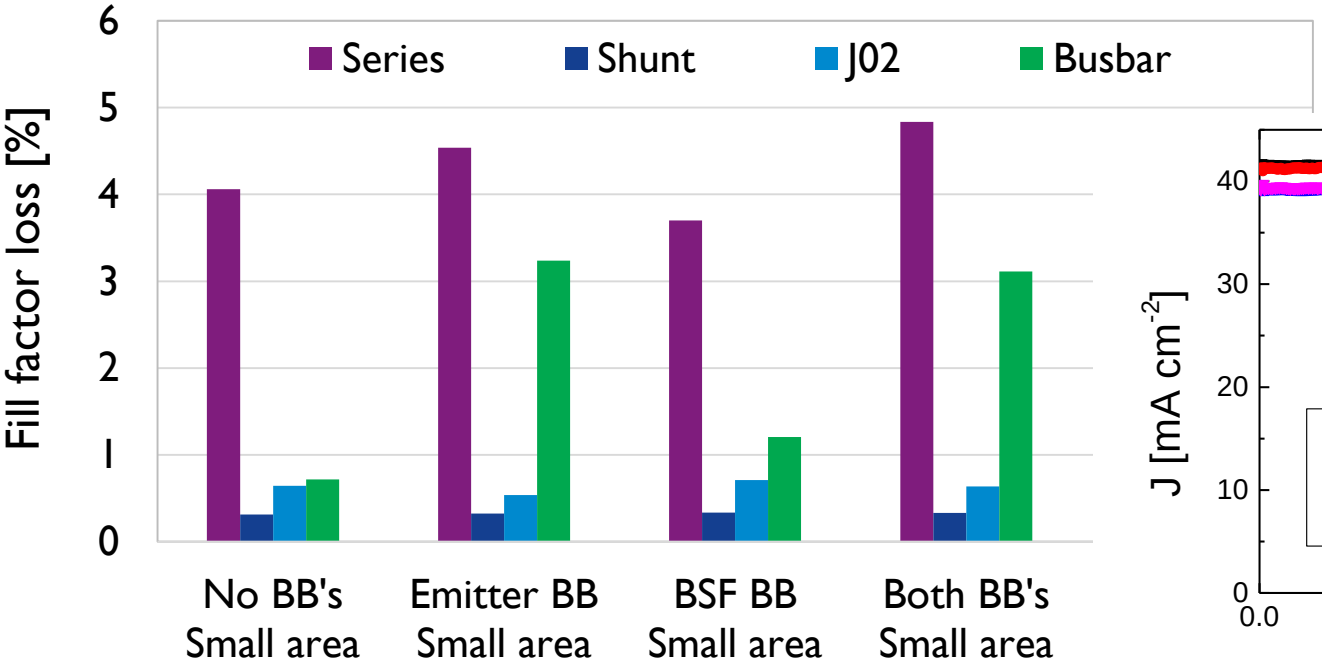
FF LOSS MECHANISMS

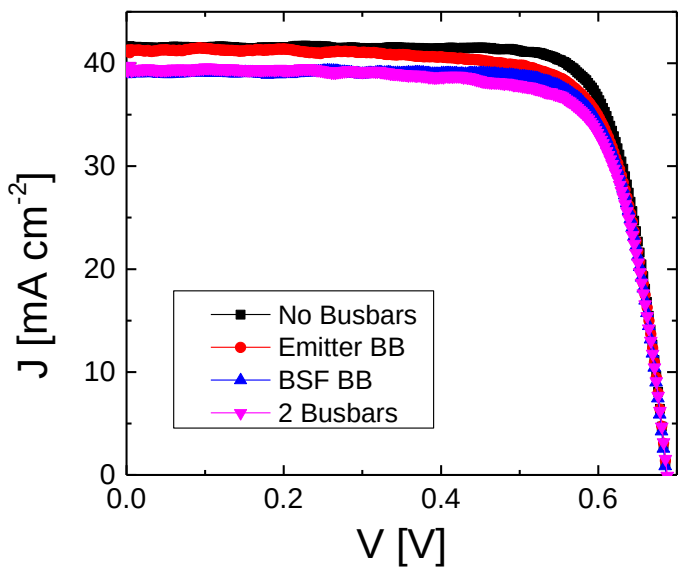




No significant impact on FF of BSF busbar

FF LOSS MECHANISMS

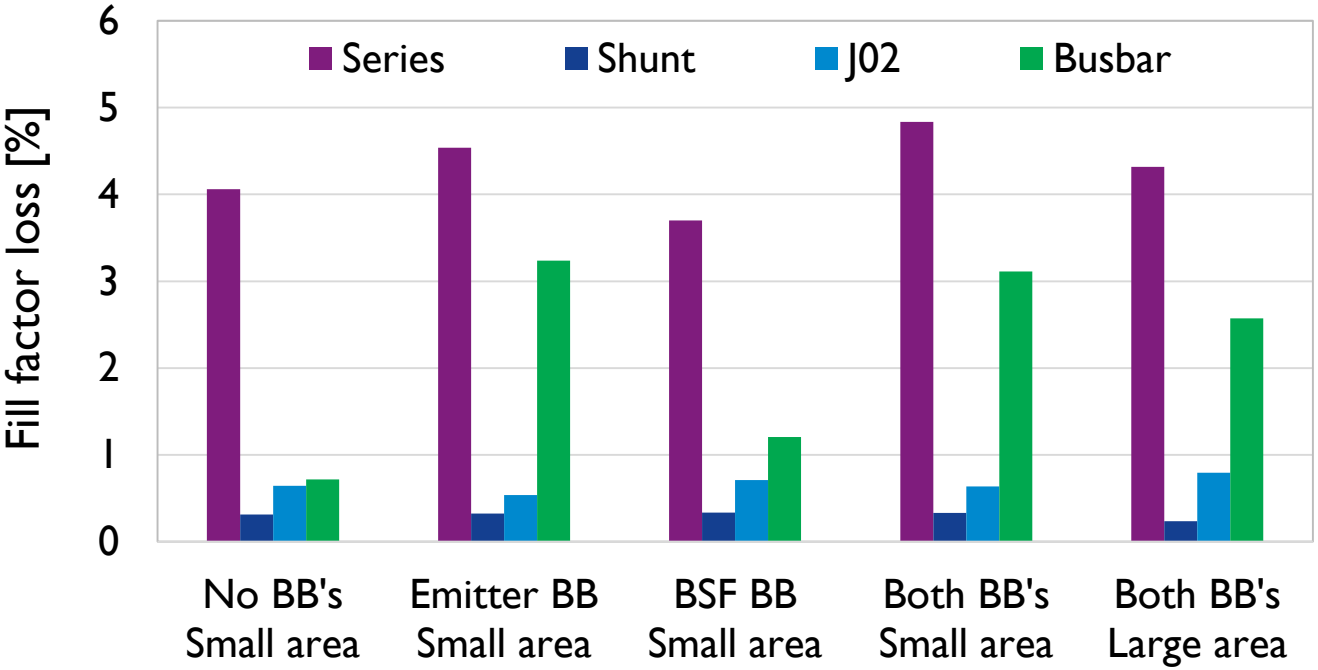




Significant series resistance losses present

Additional emitter busbar-induced loss

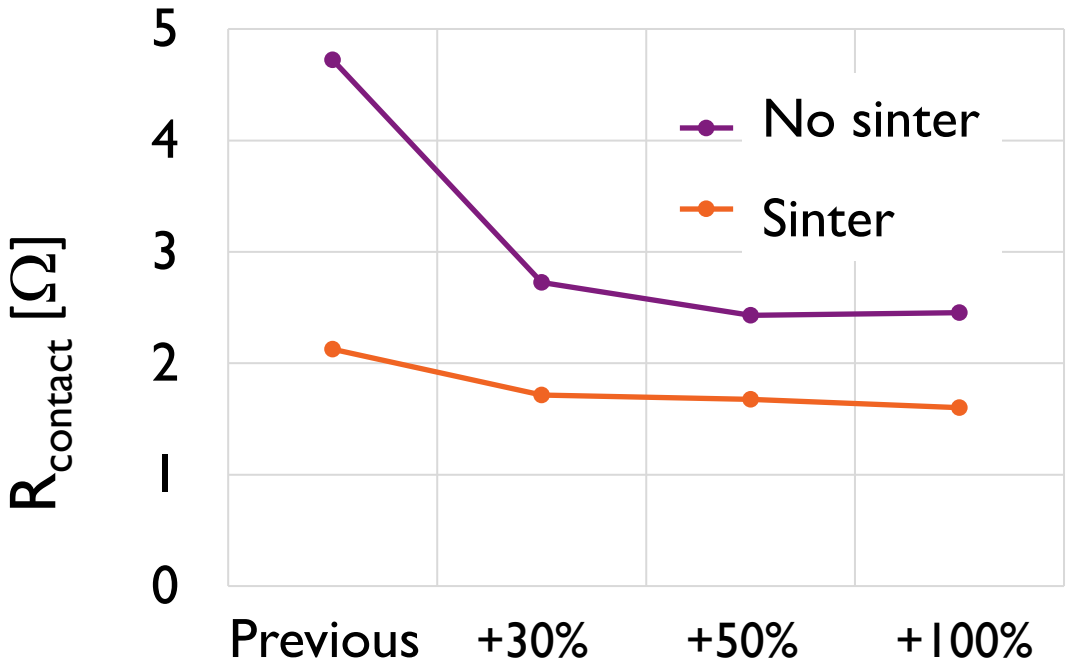
FF LOSS MECHANISMS



Similar FF losses for small and large area cells

- Series and Busbar resistances dominate

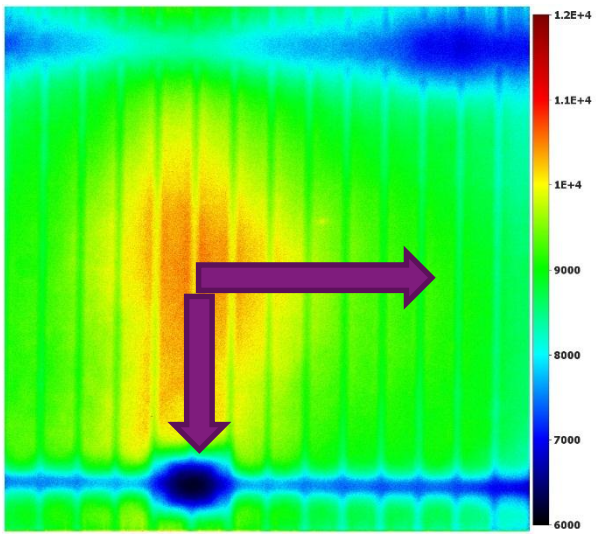
IMPACT OF BSF CONTACT DENSITY

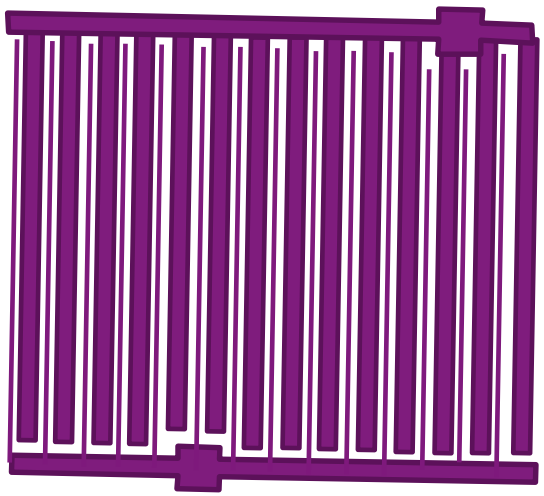


BSF contact resistance on indicates potential for FF improvement

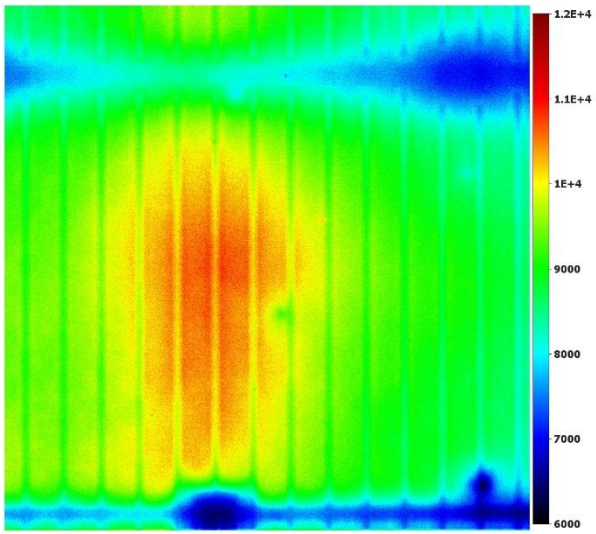
- 30% higher density implemented

SERIES RESISTANCE





Higher grid density



Lateral non-uniformity in electroluminescence

- Highest signal close to BSF contact point

Slight impact of increased grid density

Resistance dominated by BSF metal design

OUTLINE

- Introduction
- IBC cell process flow
- Upscaling to full size devices
- Summary: Achievements & Challenges

ACHIEVEMENTS

Laser ablation & polymer print processes developed

Large area IBC cells designed and fabricated

- Highest efficiency: 21.3 %
- Promising V_{oc} and J_{sc} values

Detailed analysis of fill factor losses

- Framework for performance improvement

CHALLENGES

Fill factor loss ...

- BSF metal width / paste control trade-off
- Dependence on distance from contact point

Move towards module compatible metallisation

- Cu plating development ongoing

Thank you
for your attention !

IMEC ENERGY

Financial support

- imec's industrial affiliation program in PV
- European Union's 7th Framework Programme