Laser-Doped Silicon Solar Cells by Laser Chemical Processing (LCP) exceeding 20% Efficiency

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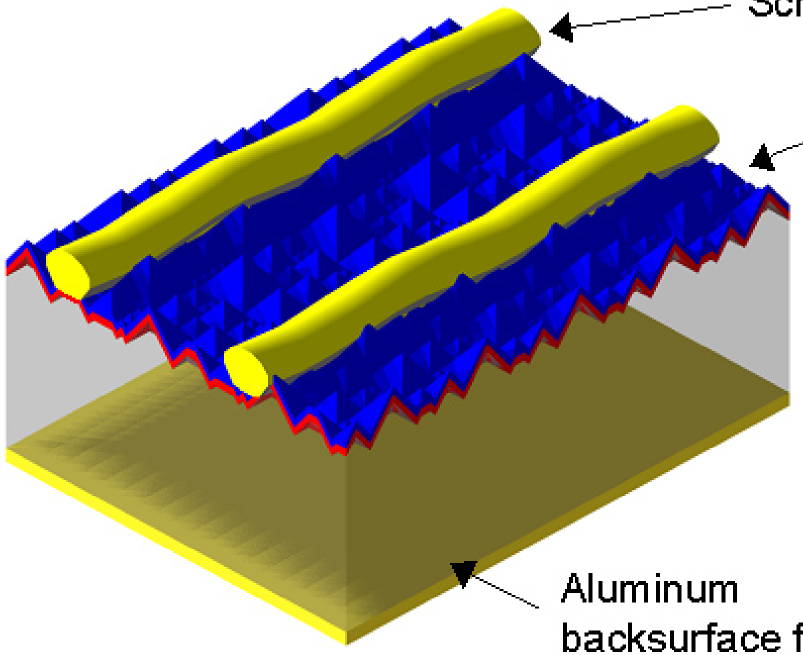
Prospects for higher efficiencies

Starting at conventional screen-printed solar cell, significant efficiency increase by

• dielectrically passivated rear side with local contacts

• **improved front side** with blue-sensitive emitters and narrow contacts



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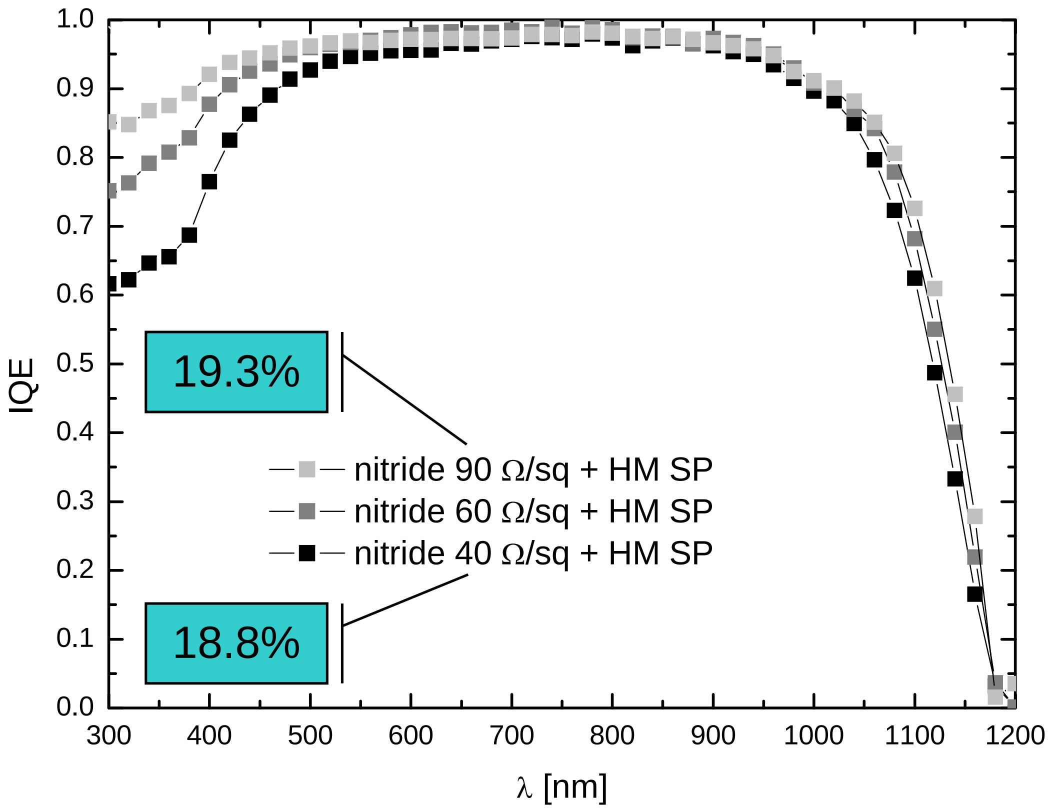

PhD A. Mette, hotmelt SP front contacts + Ag LIP

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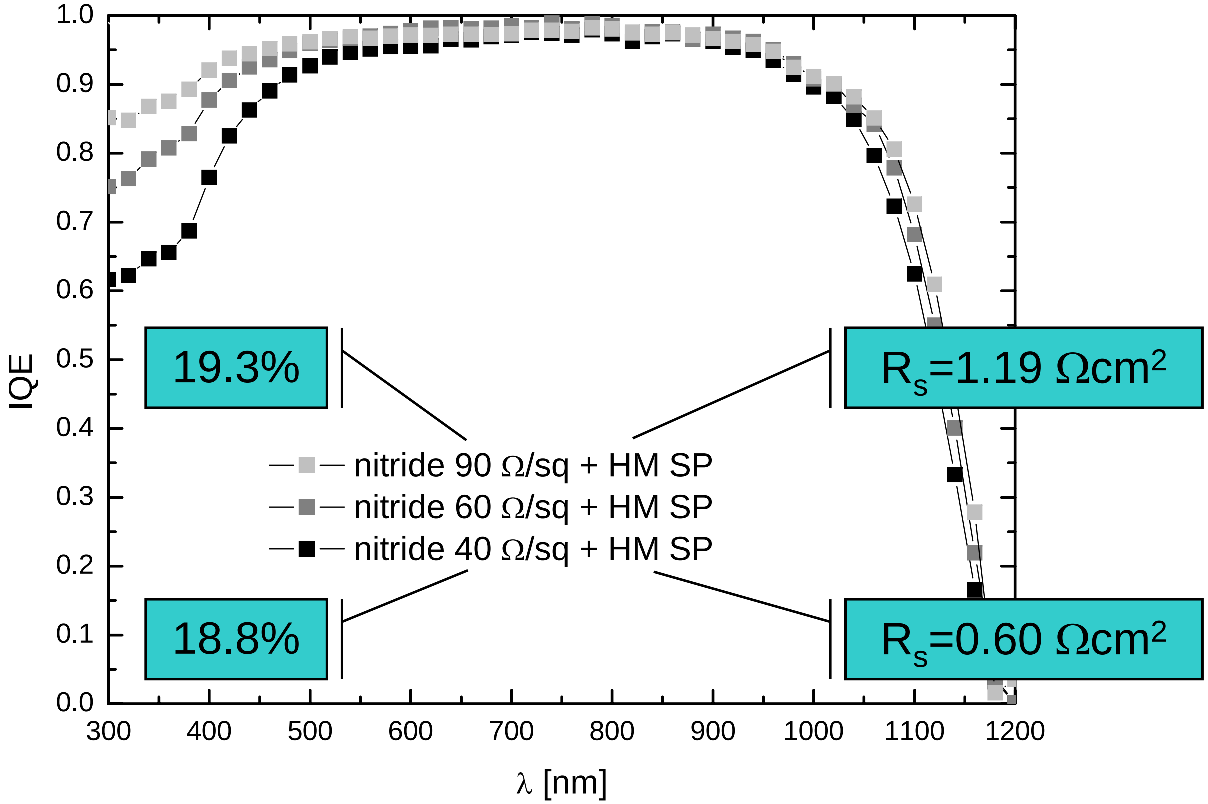
Introducing higher sheet resistance front emitters

Higher sheet resistance emitters mostly show lower surface dopant concentration

➔ Increase in contact resistance

➔ Limitation for SP contacts



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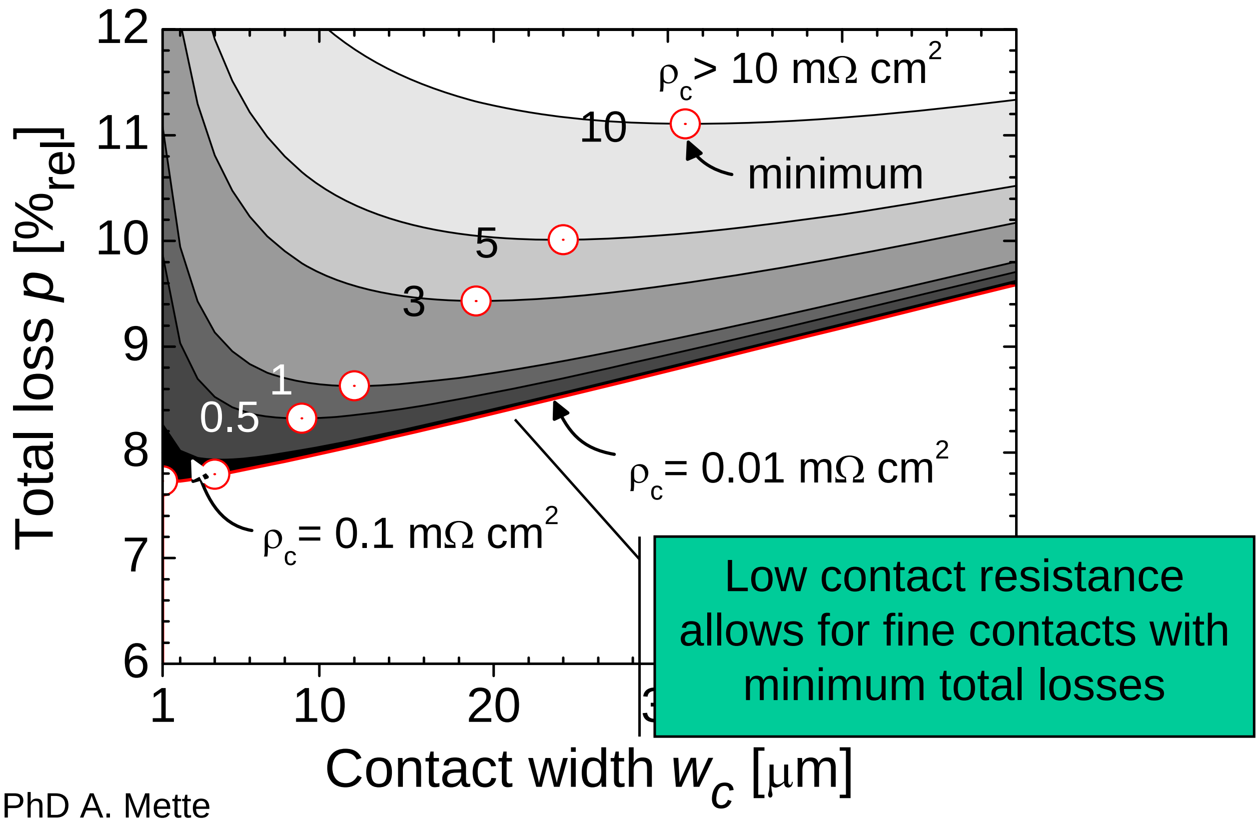
➔ Increase in contact resistance

➔ Limitation for SP contacts

➔Highly-doped local **selective emitters** can reduce contact resistance for high-efficiency emitters

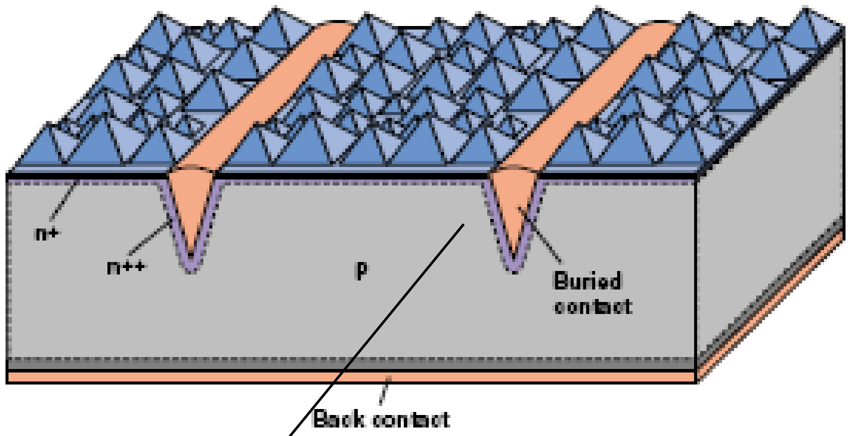


PhD A. Mette

Fabrication of selective emitters

LGBC cells: Use of laser to open AR coating, then wet etch and second diffusion

Lab cells: Use of oxide masking, PL and second diffusion



Laser-cut groove with phosphorous diffusion and plated contact

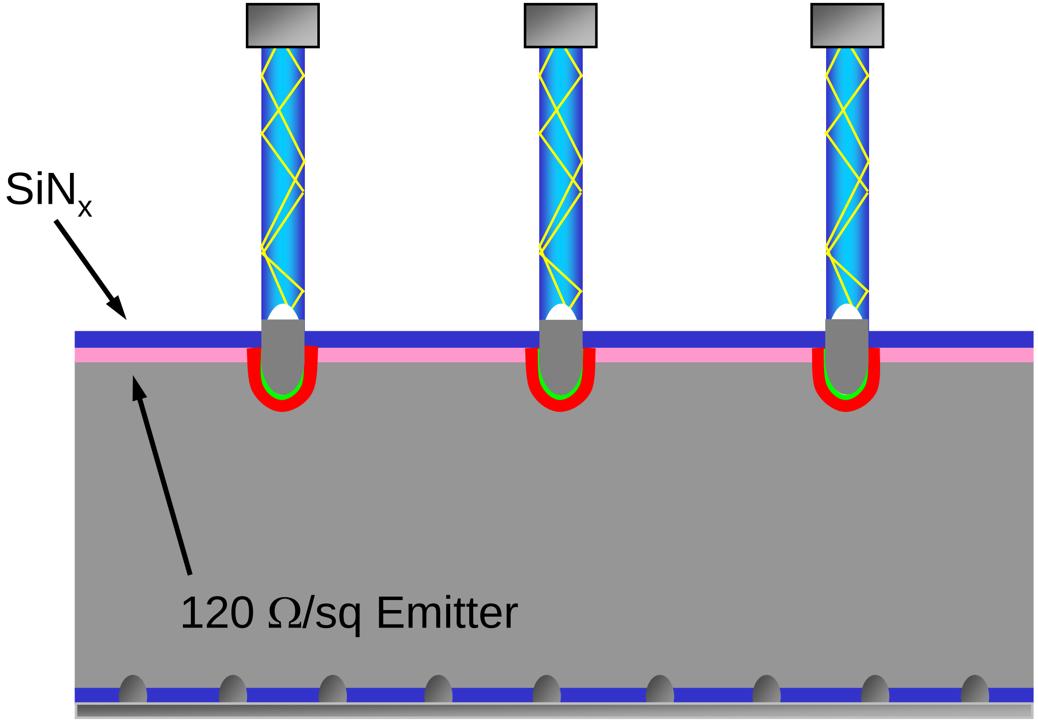
Taken from Bruton et al., Osaka 2003

Fabrication of selective emitters via LCP

LGBC cells: Use of laser to open AR coating, then wet etch and second diffusion

Lab cells: Use of oxide masking, PL and second diffusion

LCP: Use of laser within jets of phosphorous containing carrier liquids to generate local doping profiles without the need of a second diffusion



First solar cells with LCP selective emitter

Simple device structure:

- planar
- spray-on 50 Ω/sq emitter
- PECVD SiN_x front
- base material 8 Ωcm FZ(B)
- Al-BSF

LCP variation after SiN_x deposition

2 contact variants:

- PL + TiPdAg evaporation
- Ni plating

Subsequent Ag-LIP

$Nd:YVO_4$, 532nm, τ_p=10 ns, 30 kHz, EdgeWave

Energy density: 2 – 10 J/cm^2

1 or multiple passes

Nd:YAG, 1064nm , τ_p=1000 ns, 13 kHz / cw

Energy density: 40-100 J/cm^2

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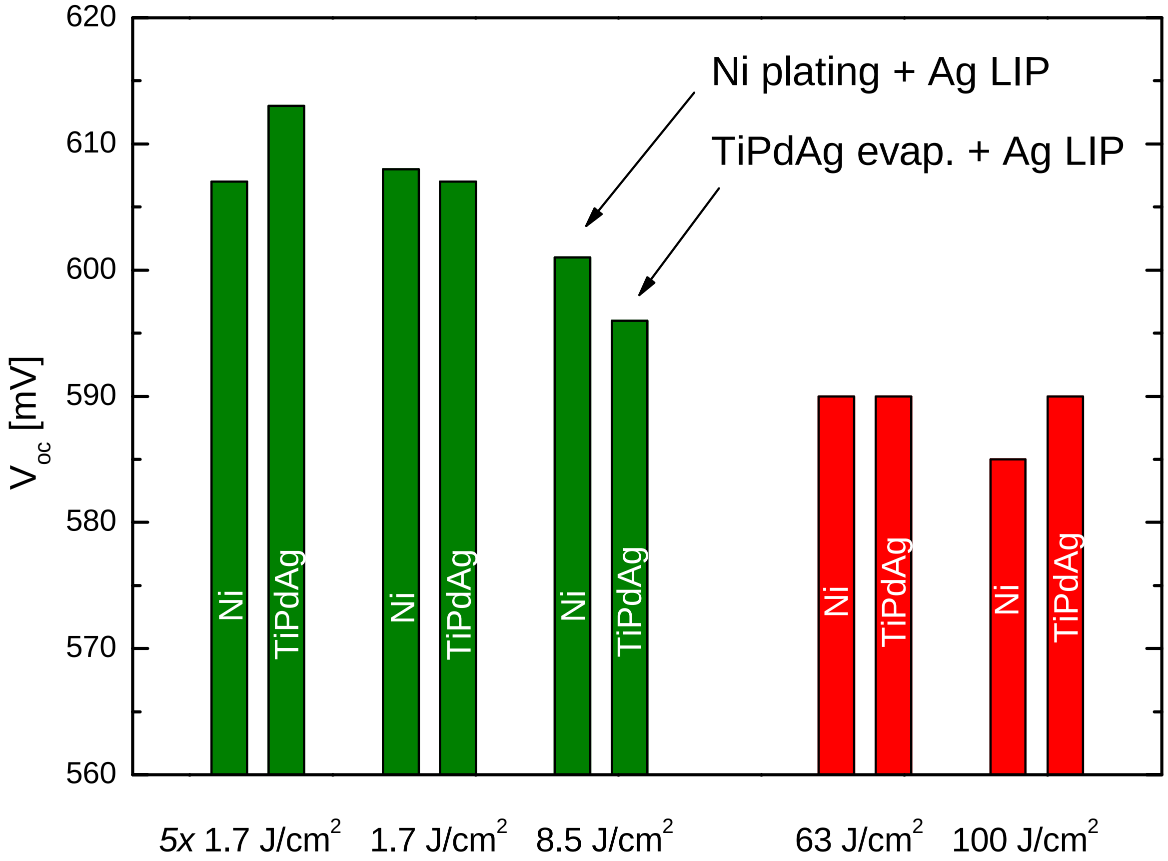


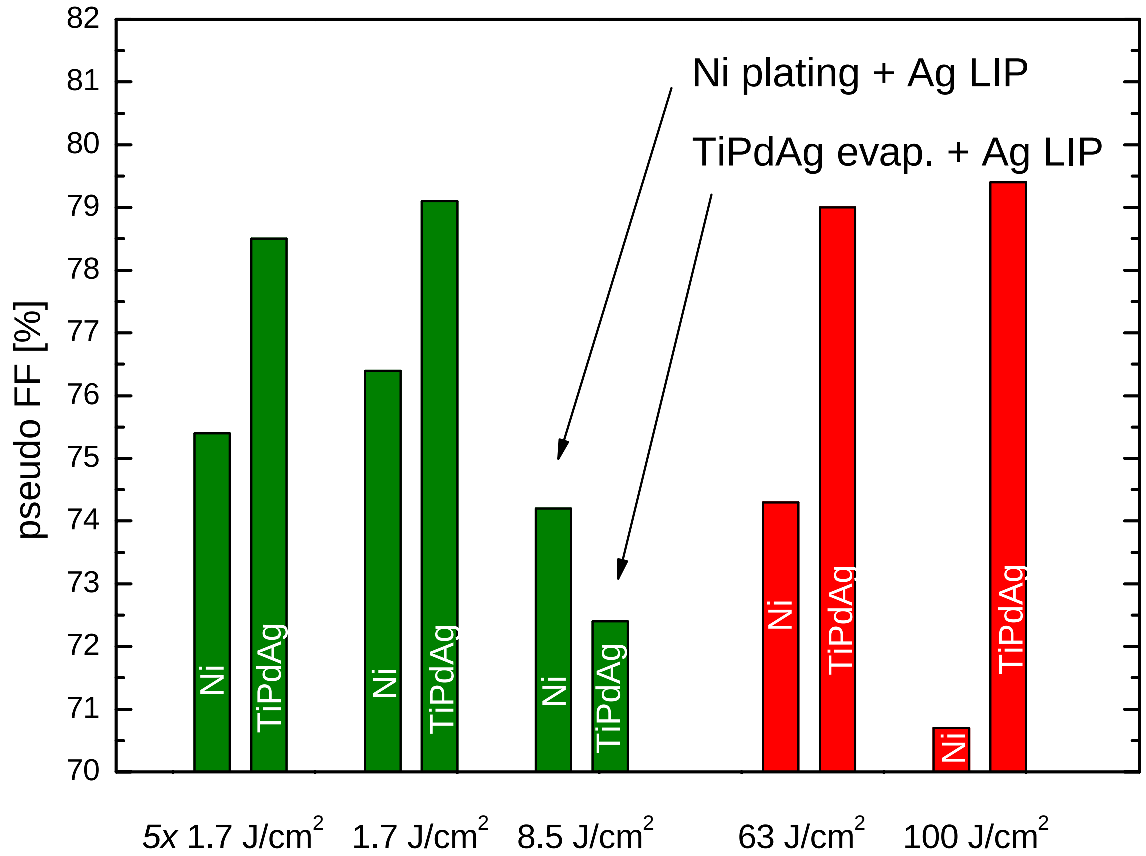
First solar cells with LCP selective emitter

Strong degradation due to Ni plating for IR laser samples

Slight degradation due to Ni plating for green laser samples

Low energy densities beneficial

PFF and Voc level acceptable



First solar cells with LCP selective emitter

Low series resistance values

Ni degradation due to **recombination** at low voltages, NOT due to series resistance increase

Green laser shows most promising results

Multiple passes seem to further reduce contact res.

		Ni			TiPdAg		
		FF [%]	□c [m□cm2]	Rs [□cm2]	FF [%]	□c [m□cm2]	Rs [□cm2]
green laser	5x 1.7 J/cm2	70.5	0.13	0.5	76.2	0.57	0.6
green laser	1x 1.7 J/cm2	72.8	0.91	0.4	76.4	1.00	0.5
green laser	8.5 J/cm2	71.5		0.7	70.3		0.5
IR laser	63 J/cm2	71.1	"0.94"	0.9	*38*	*24.3*	*15*

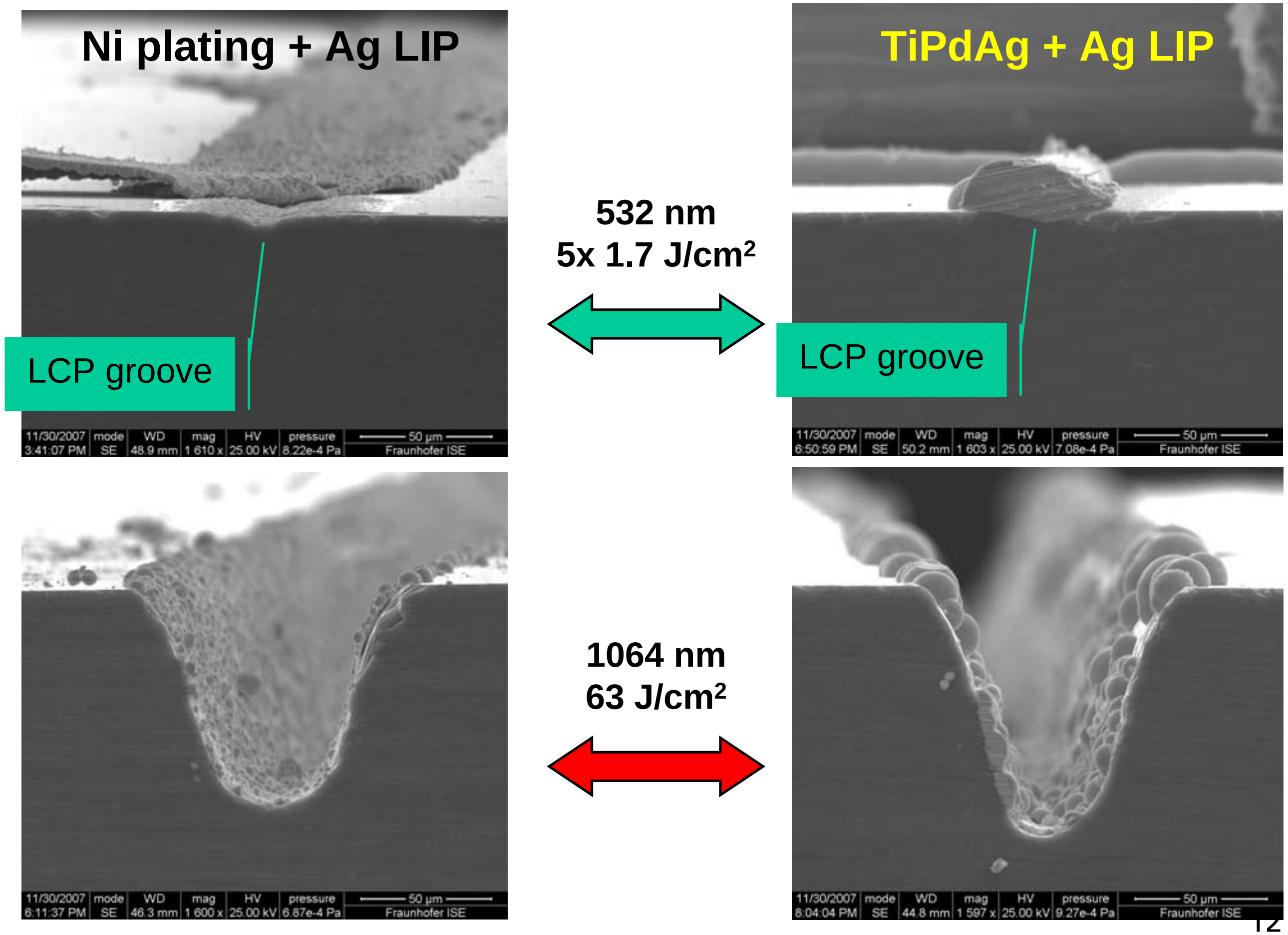
Adhesion problems during metal lift-off

First solar cells with LCP selective emitter

Cross sections prepared by dicing saw

Ni plating readily works on entire groove surface

PL-masked **evaporation** not possible in narrow and deep grooves



High-efficiency LCP solar cells

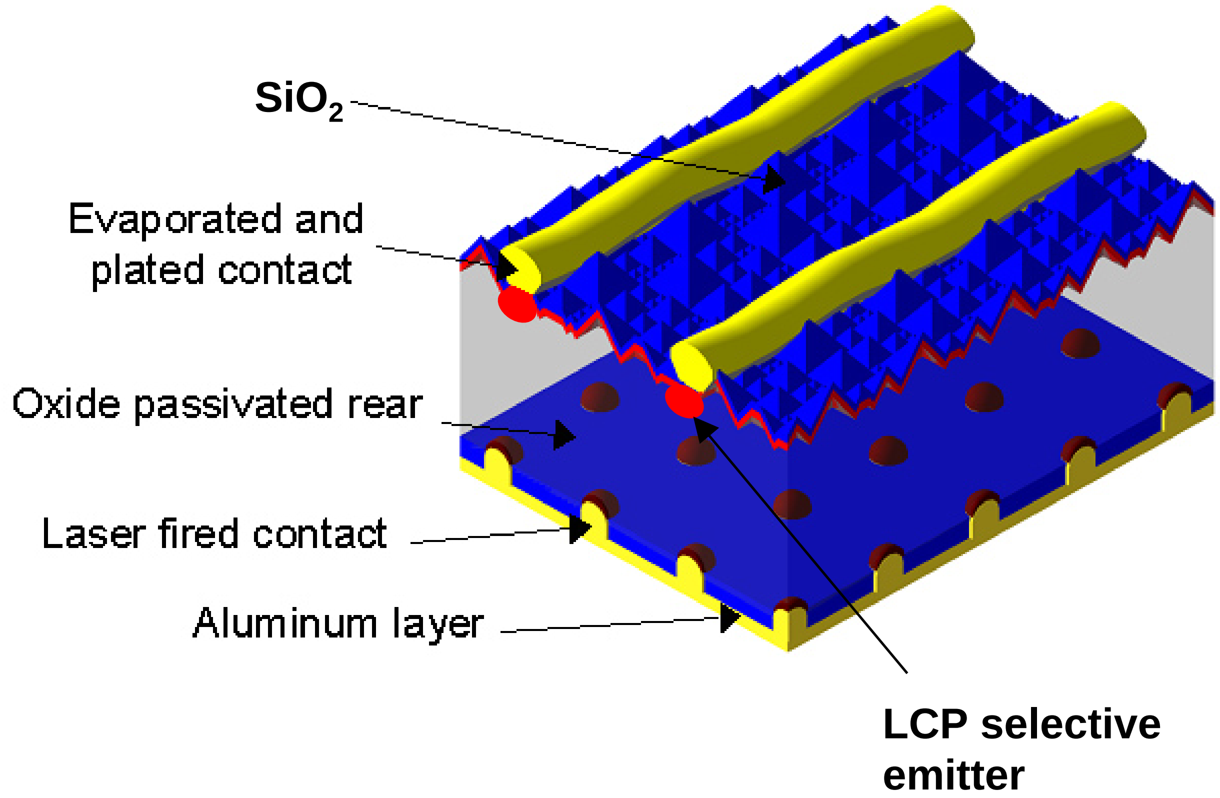
High-efficiency LFC cell structure with oxide passivation

FZ(B) 0.5 / 1 Ωcm material

LCP variation after 120 Ω/sq diffusion

105 nm AR oxidation and subsequent opening via PL

Evaporated TiPdAg and electroplated contacts



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High-efficiency LCP solar cells

Efficiencies well above 20% demonstrated

Limitations due to non optimum LFC process and texturization

TLM meas. of ρ_c [mΩcm^2]:
Reference (no LCP): 4.0
LCP: 0.9

Base resistivity	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF	η [%]
1 Ω cm	652.3	38.4	0.780	19.5
0.5 Ω cm	664.9	38.7	0.792	**20.4**

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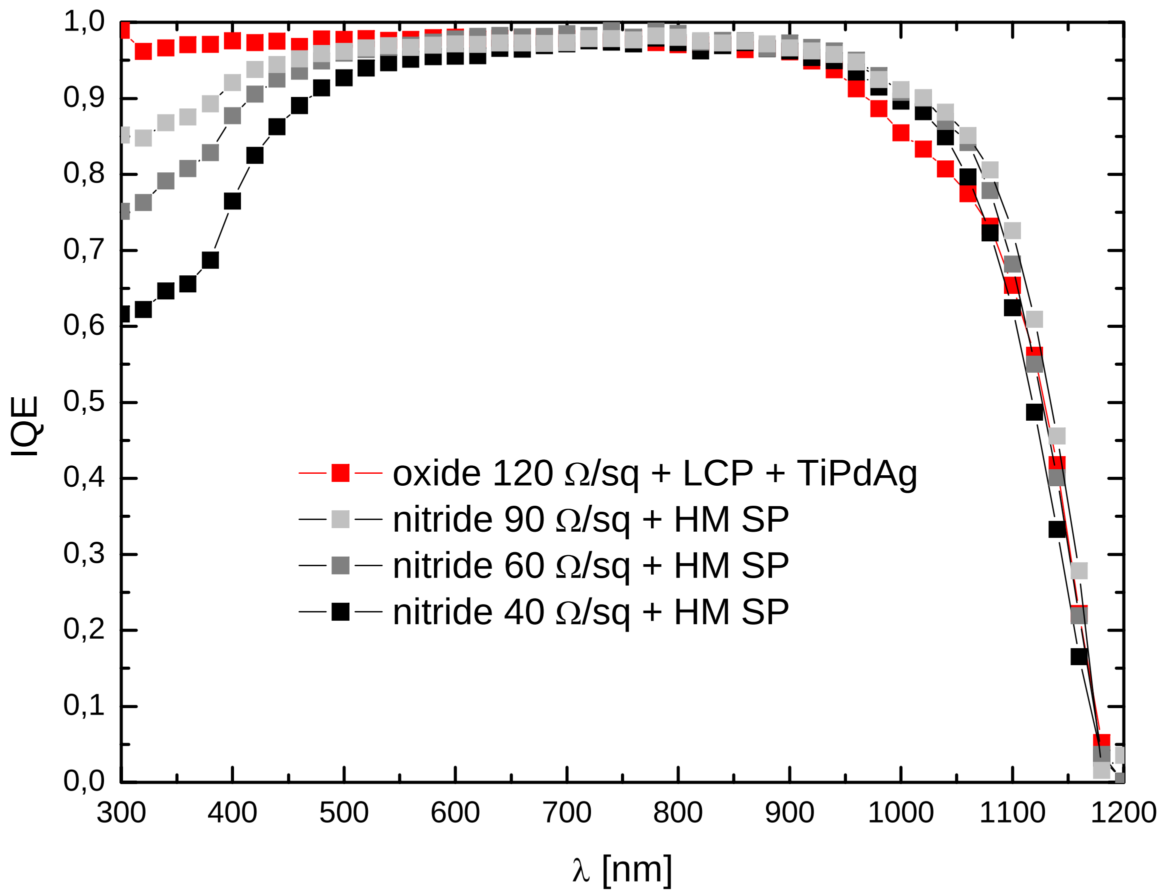
High-efficiency LCP solar cells

IQE of 120 Ω/sq emitter with oxide passivation near 100% for 300-900 nm
➔ Strong improvement of blue response

Dip around 1000 nm due to non-optimum LFC process



High-efficiency LCP solar cells - outlook

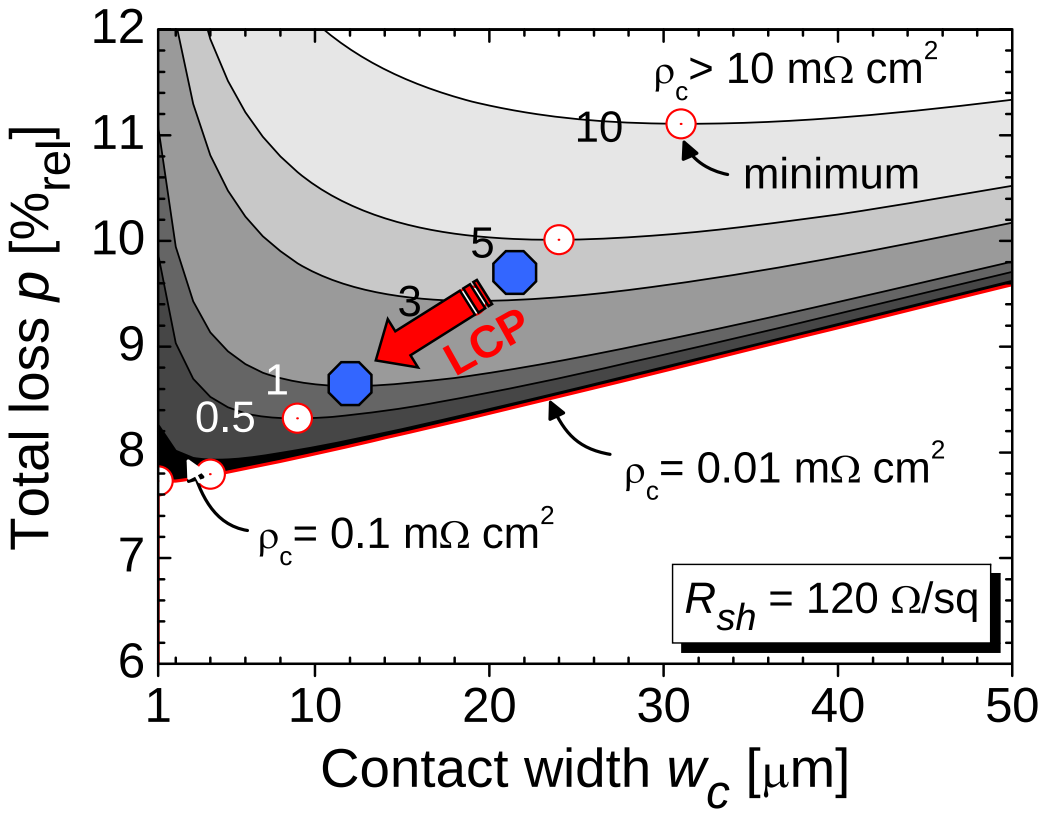
Optimum contact width from r_c measurements:

No LCP: ~ 22 µm

LCP: ~ 12 µm

Can such fine lines be grooved?

➔ 30 µm nozzles available



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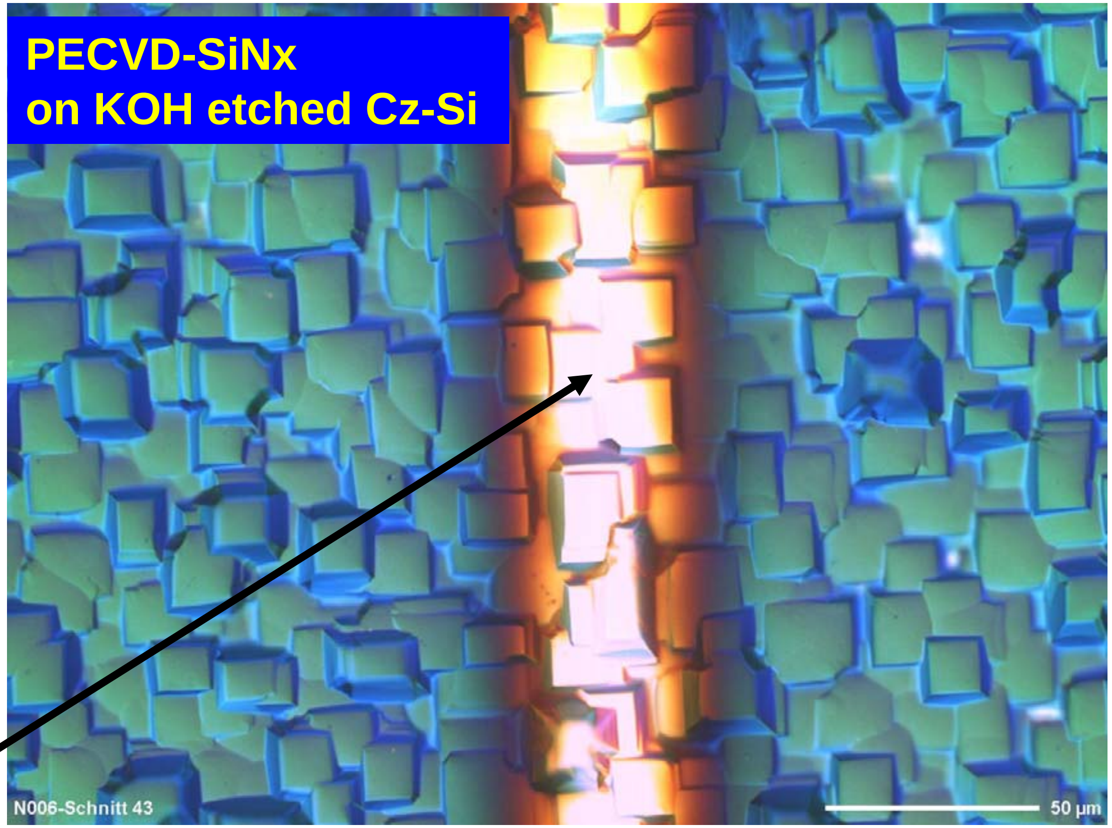
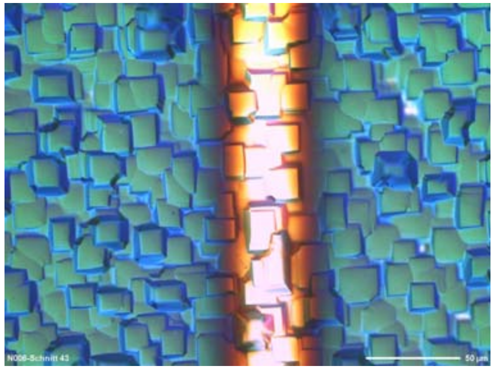
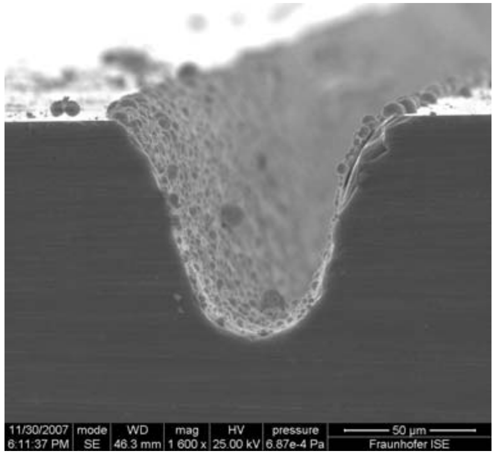


~25 µm wide opening with 150 µm nozzle

Summary





- LCP is capable of fabricating excellent selective phosphorous emitters
- LCP compatible with shallow and deep emitters
- Ni plating of LCP grooves still needs optimization
- First laser-doped silicon solar cells exceeding 20% efficiency demonstrated
- Very narrow grooves can be realized via LCP
- An elegant industrial realization of selective emitters is within reach