Laser Chemical Processing (LCP) of Silicon Solar Cells

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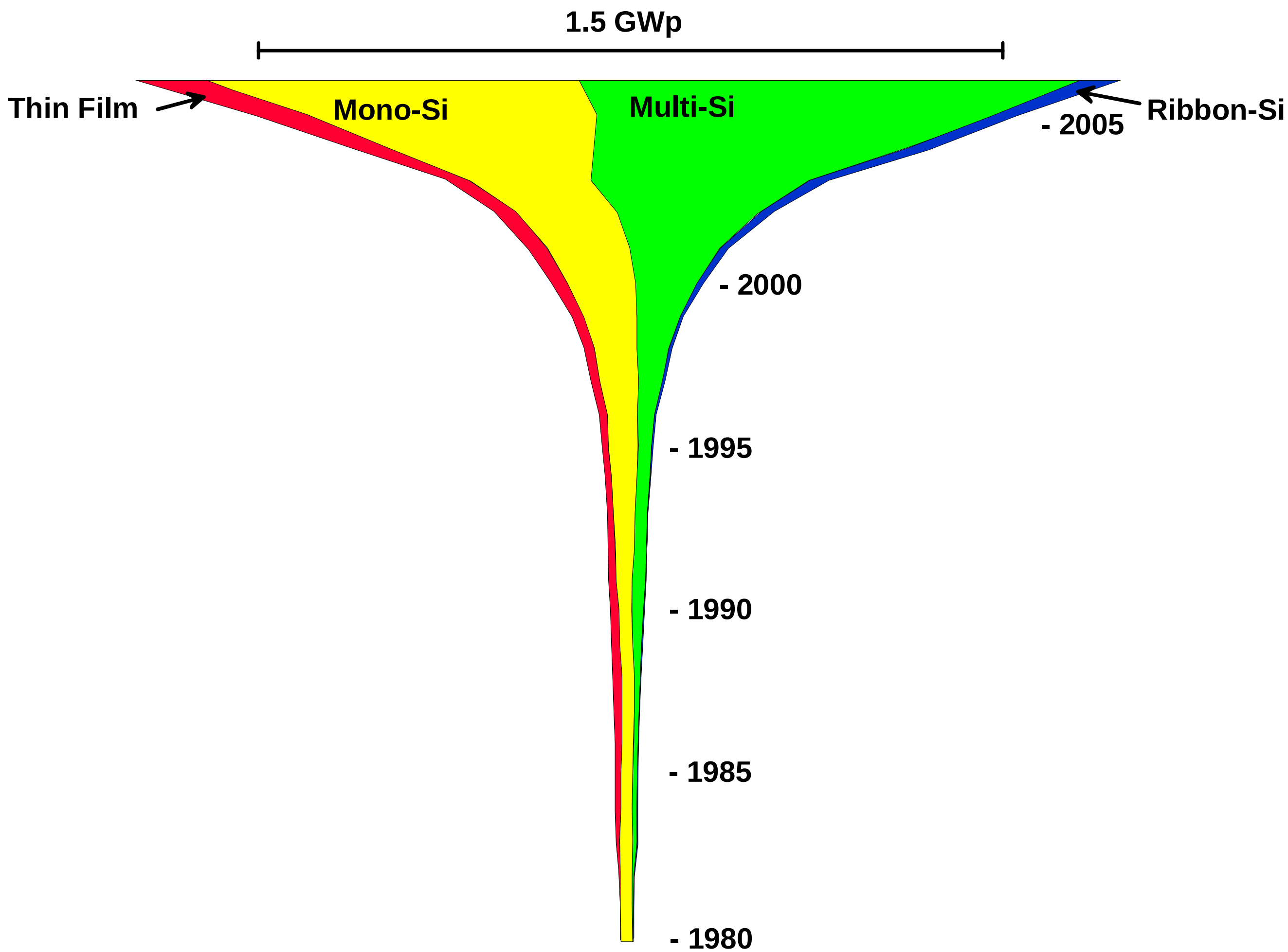
CLEO/QELS and *PhAST* 2008
San Jose, CA, USA
May 4-9, 2008

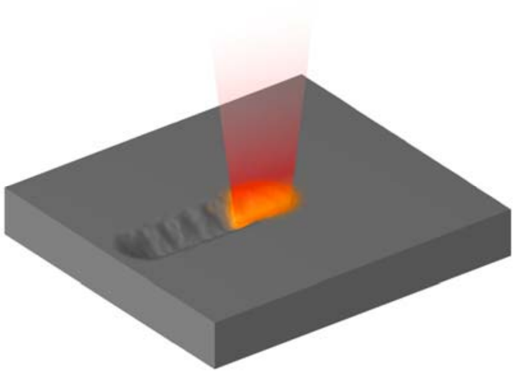
Fraunhofer Institut
Solare Energiesysteme
ISE

Motivation for crystalline Si wafer PV

- PV is a mature technology with dynamic & strong growth
- Enormous market expectation (100 % renewables)
- The relative share of crystalline silicon wafer technology is > 90 %
- Material intensive industry needs vast amount of production machines with **throughput of ~2000 pcs/h**



Premises for laser processes applied in photovoltaics



*PV needs **fast, precise and low-cost processes** (current technologies: screen printing, wet etching, tube diffusion, PECVD SiN_x, rapid thermal firing)*

Laser technology advantages:

- capability to process a wide variety of materials (e.g. silicon, metals, dielectrics)
- selective processing of variable structure with lateral structure dimensions from 10-1000 µm without harming underlying layers or structures
- variable adaptation of processing depth from shallow (few nm´s) to complete wafer thickness (up to 250 µm)
- minimal thermal and mechanical impact on wafer substrate

Standard solar cell production process

starting point

silicon wafer, cut from ingot or block

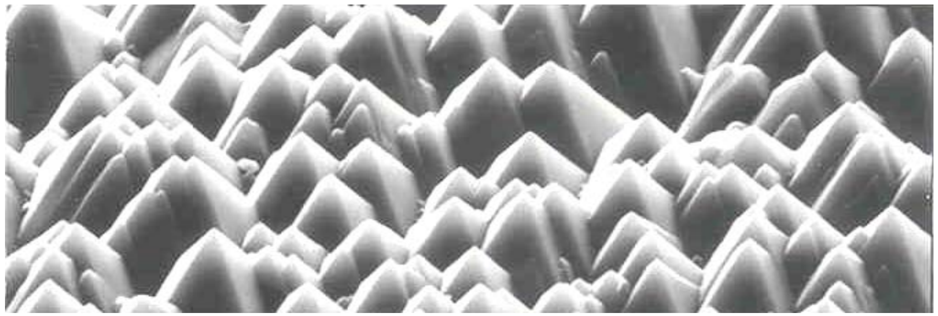
by multi-wire slurry saw

Standard solar cell production process

damage etch / texturization

inline / batch wet chemistry

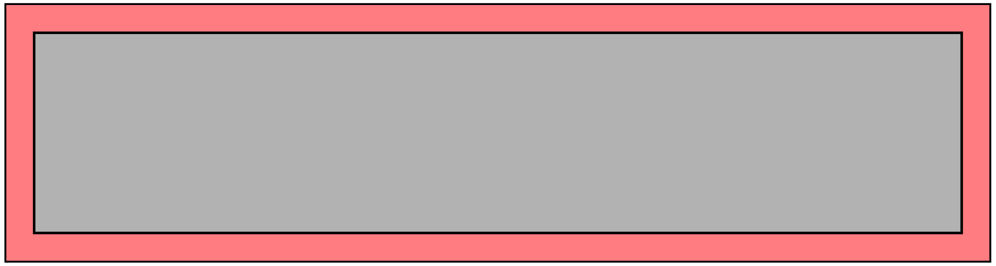
⇔ removal of saw damage



Standard solar cell production process

damage etch / texturization

diffusion



tube furnace /

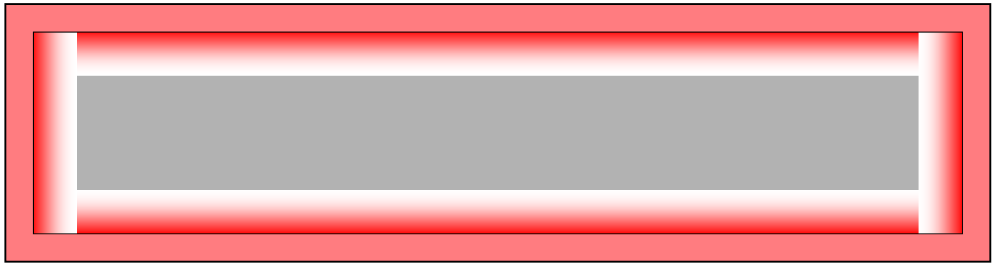
spray-on deposition + belt furnace

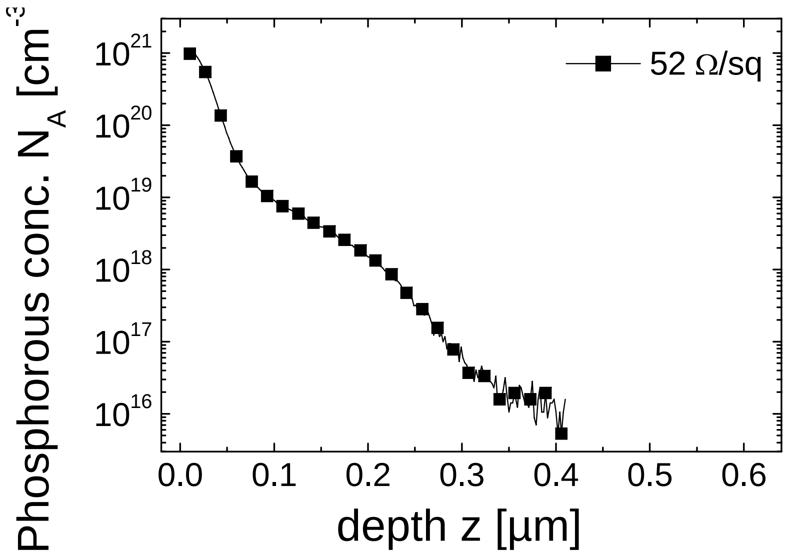
⇔ emitter formation

Standard solar cell production process

damage etch / texturization

diffusion





tube furnace /

spray-on deposition + belt furnace

⇔ emitter formation

Standard solar cell production process

damage etch / texturization

diffusion

PSG wet chemical etch

inline / batch wet chemistry

⇔ removal of phosphorous silicate glass (PSG)

Standard solar cell production process

damage etch / texturization

diffusion

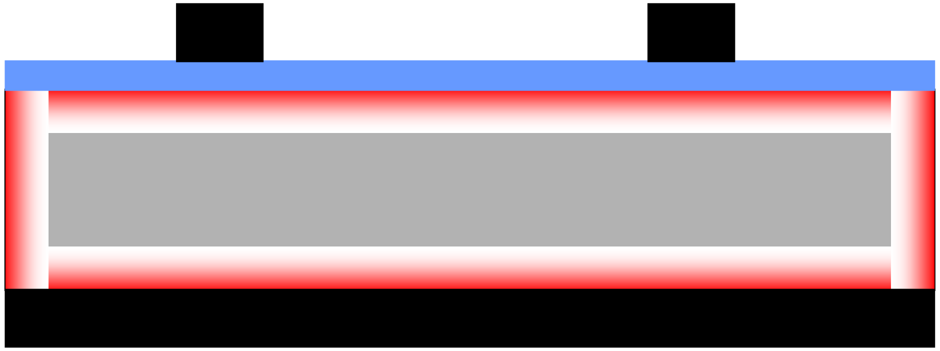
PSG wet chemical etch

antireflection coating

PECVD / sputtering deposition of SiN layer

⇔ reduction of reflection losses

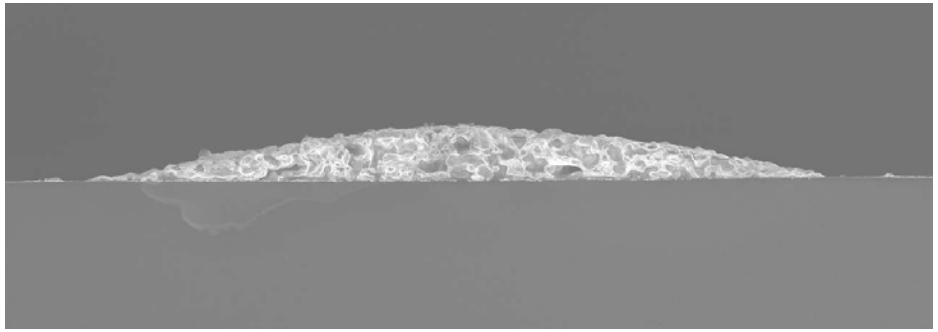
Standard solar cell production process



- damage etch / texturization
- diffusion
- PSG wet chemical etch
- antireflection coating
- contact deposition

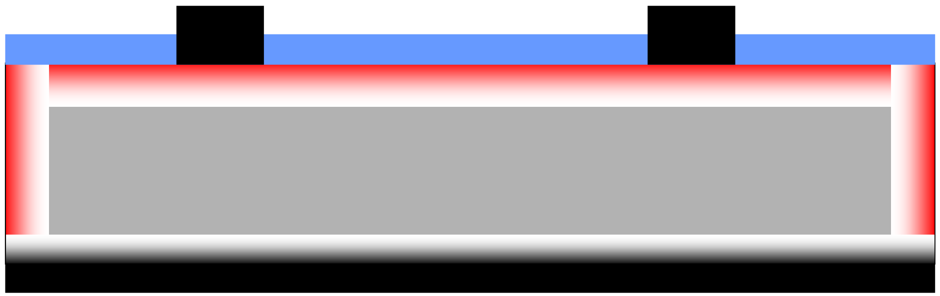
screen printing of metal pastes

⇔ Ag H-Bar on front / Al full coverage on rear



Standard solar cell production process

- damage etch / texturization
- diffusion
- PSG wet chemical etch
- antireflection coating
- contact deposition
- contact formation



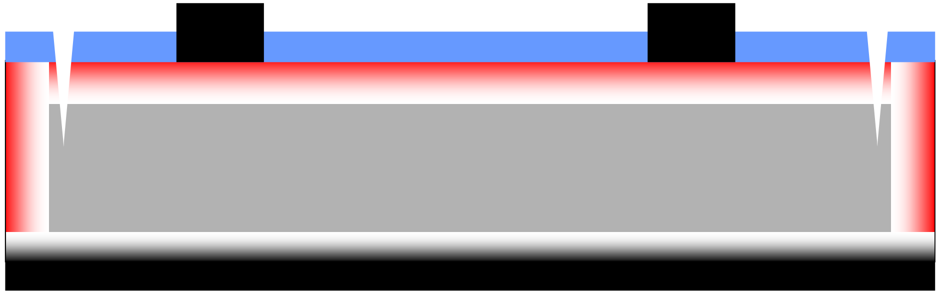
inline belt furnace

⇔ alloying of electrical contact

Standard solar cell production process

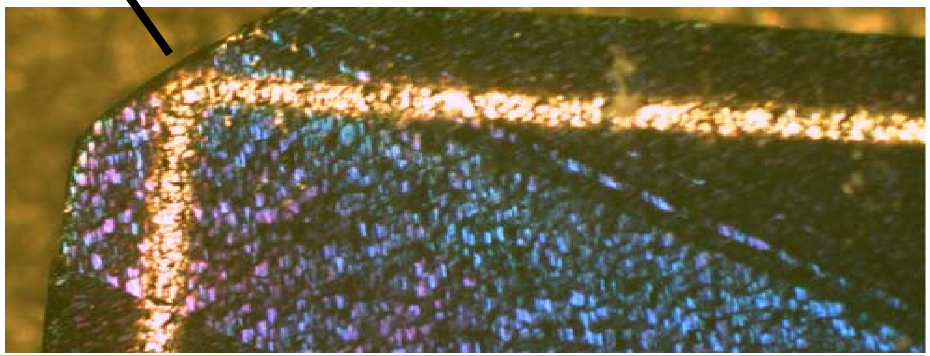
- damage etch / texturization
- diffusion
- PSG wet chemical etch
- anti
- contact deposition
- contact formation
- edge isolation

The only standard laser process in PV production today!



electrical isolation of front and rear

⇔ laser grooving on front side around edge



Novel cell concepts require additional laser processes

ablation of silicon bulk material

Groove	groove cutting (depth < 50 µm / width ~ 10-50 µm)
Drill	drilling of via holes (width ~ 10-1000 µm / depth ~ 0.1-250 µm)
Tex	surface texturization

other processes

Metal	metal ablation / alloying / soldering
Dielectric	ablation of dielectric layers (< 300 nm thick, width ~ 10-1000 µm)
Doping	diffusion of phosphorous / boron in silicon material

Technological laser solutions for PV application

conventional „dry“ lasers

xy-stage
process gas
high accuracy
medium speed

Scanner
no process gas
medium accuracy
high speed

flying optics
process gas
high accuracy
medium speed

liquid-jet-guided lasers

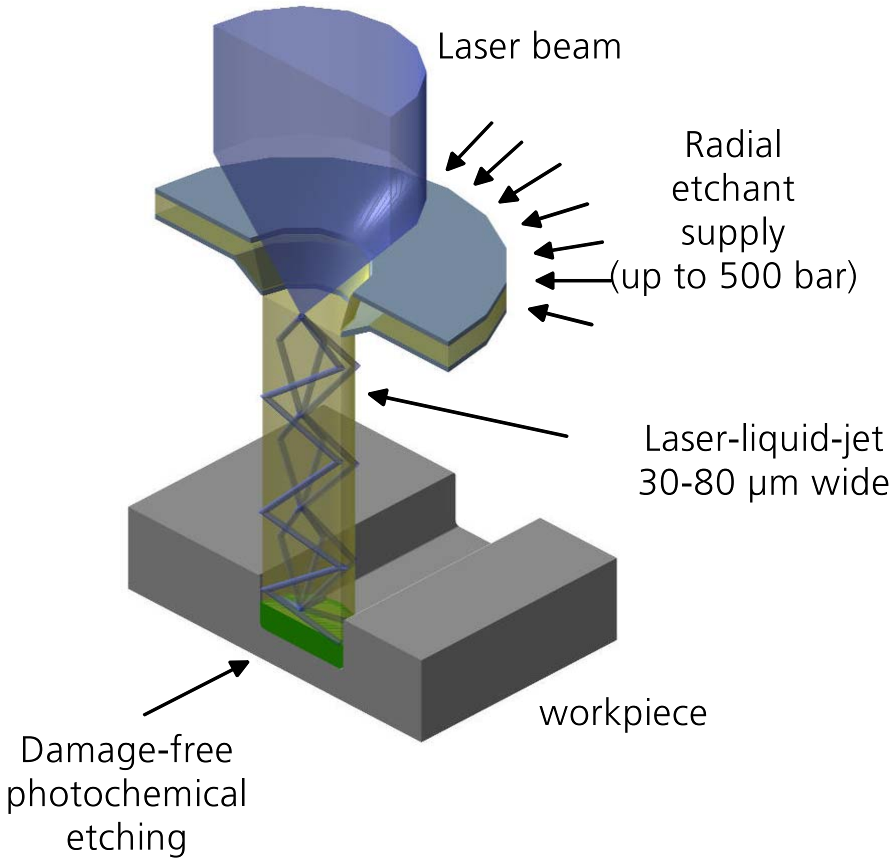
LaserMicroJet®
➔ ***water***

Laser Chemical Processing (LCP)
➔ ***chemistry***

xy-stage
cleaning by liquid jet
high accuracy
medium speed

Laser Chemical Processing (LCP) principle

- Based on the liquid-jet guided laser from Synova®
- Combination of laser and high-speed chemical jet
- Laser-catalyzing of chemical reactions (etching, doping, deposition, …)
- Gentle wet chemical interactions with low / no damage
- Flexible scanning paths
- Patent pending at Fraunhofer ISE

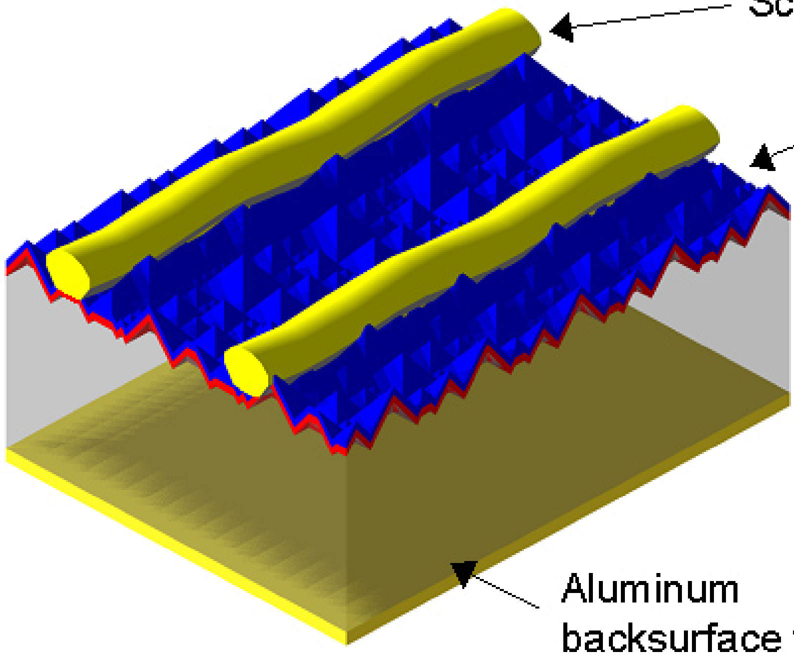


Prospects for higher efficiencies

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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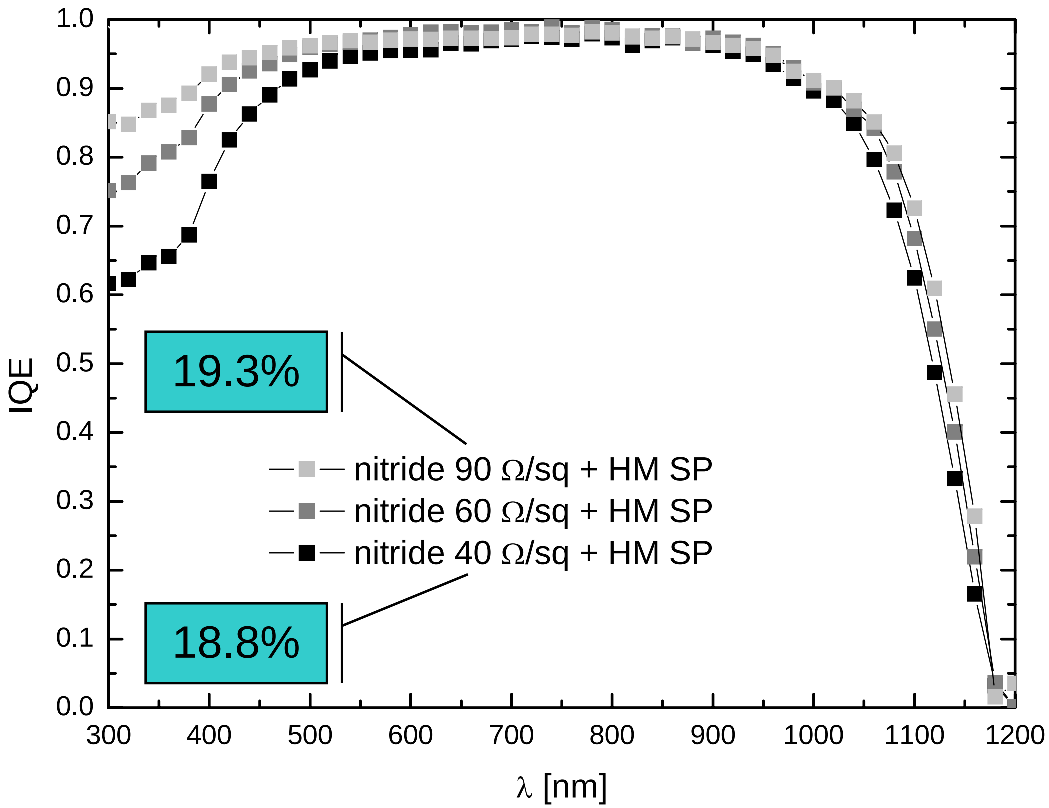


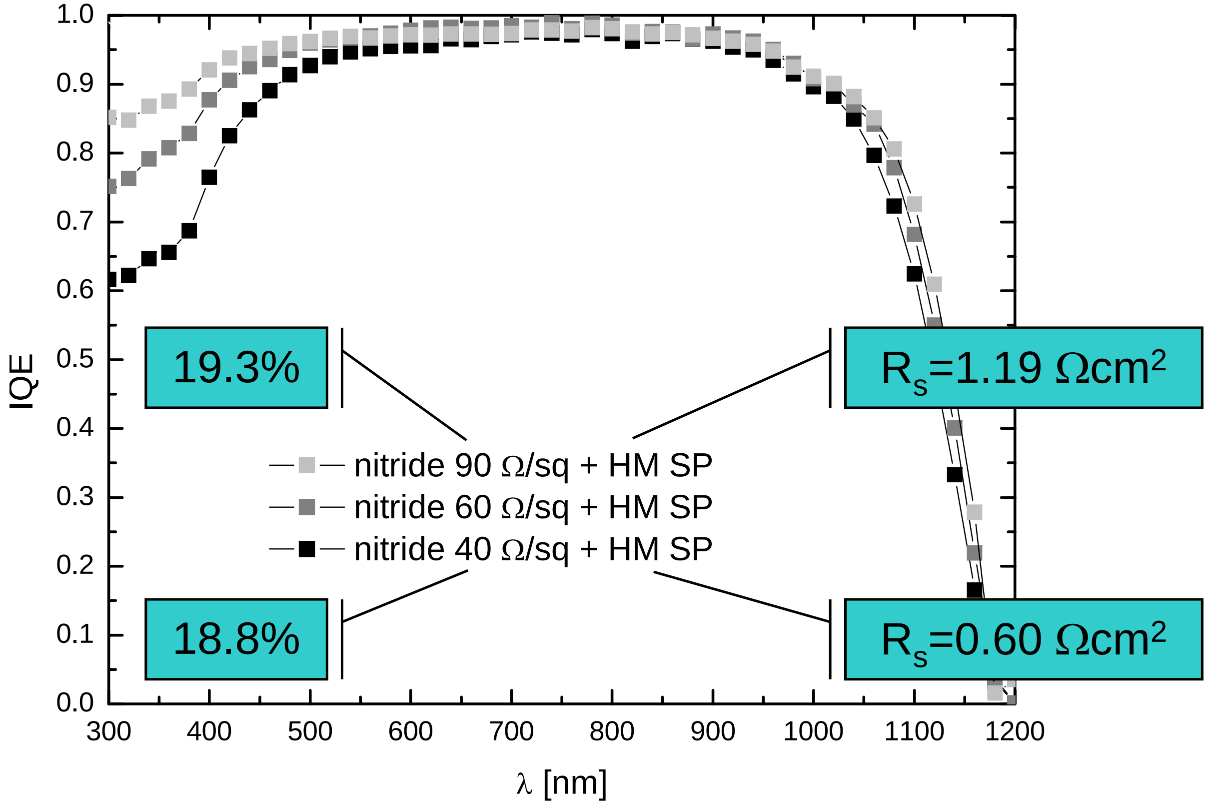
PhD A. Mette, hotmelt SP front contacts + Ag LIP

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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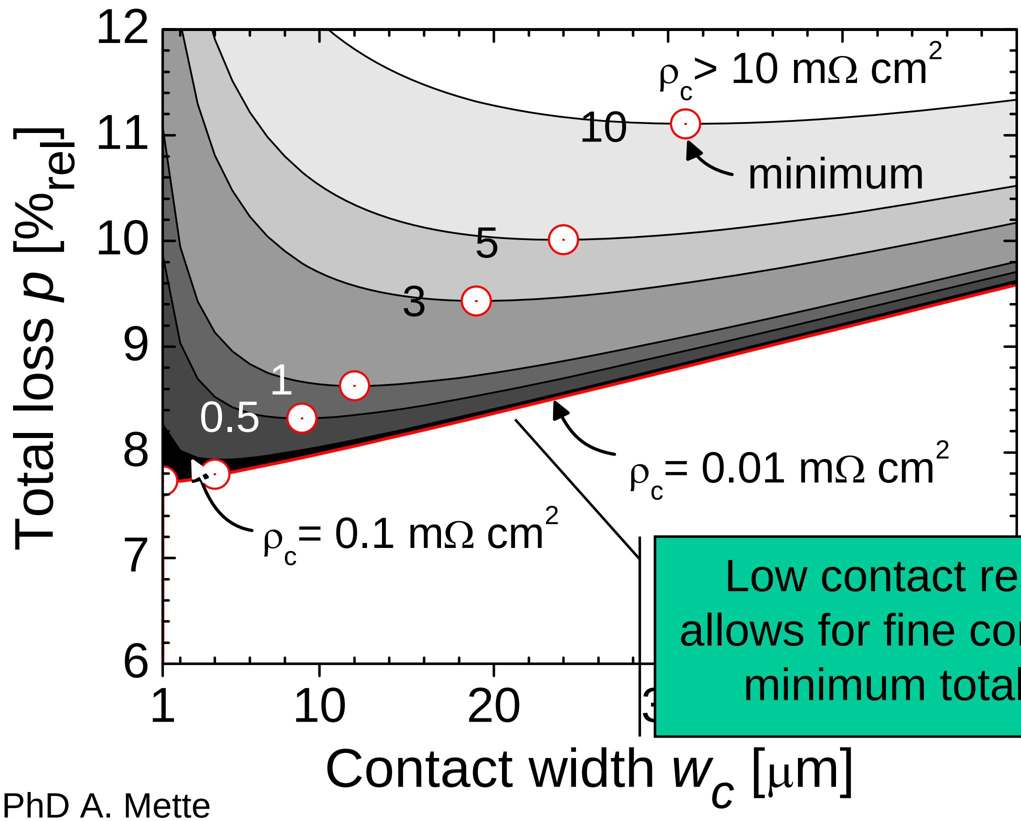
Introducing higher sheet resistance front emitters

Higher sheet resistance emitters mostly show lower surface dopant concentr.

➔ Increase in contact resistance

➔ Limitation for SP contacts

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



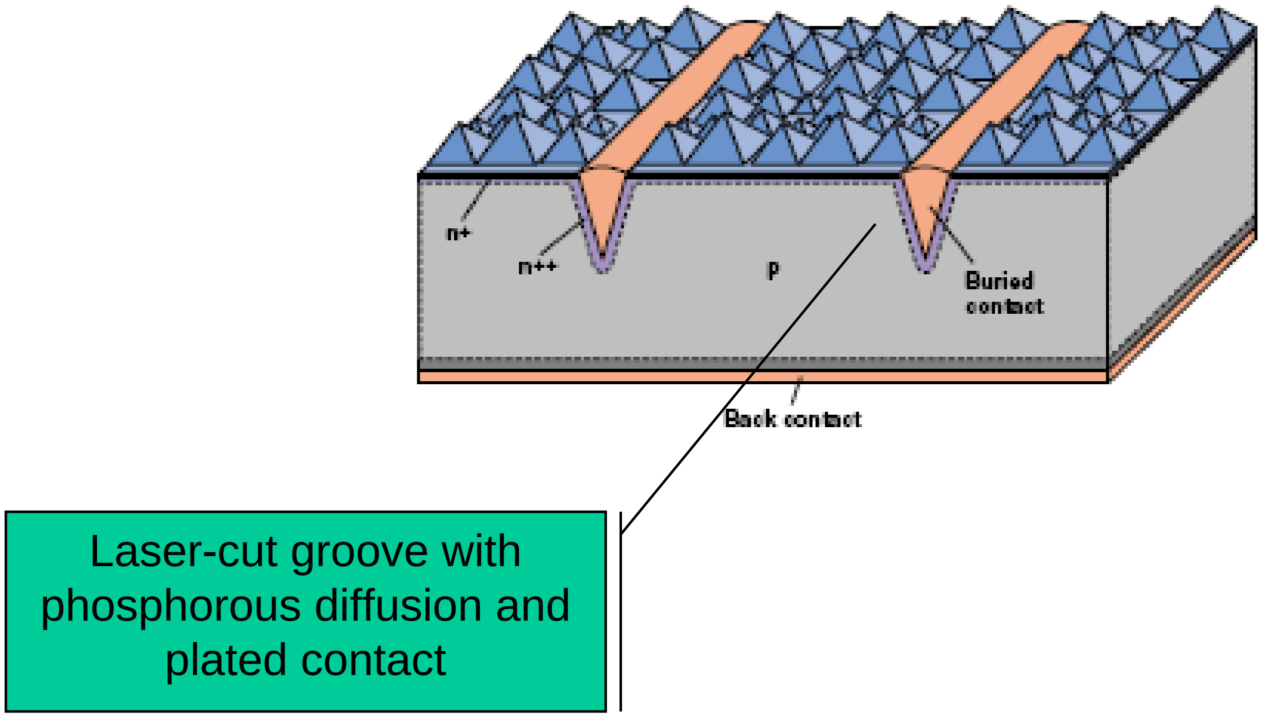
Low contact resistance allows for fine contacts with minimum total losses

PhD A. Mette

Fabrication of selective emitters

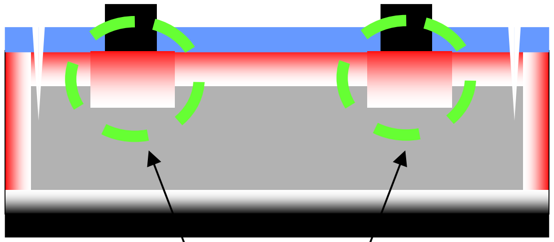
LGBC cells: Use of laser to open AR coating, then wet etch and second diffusion

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

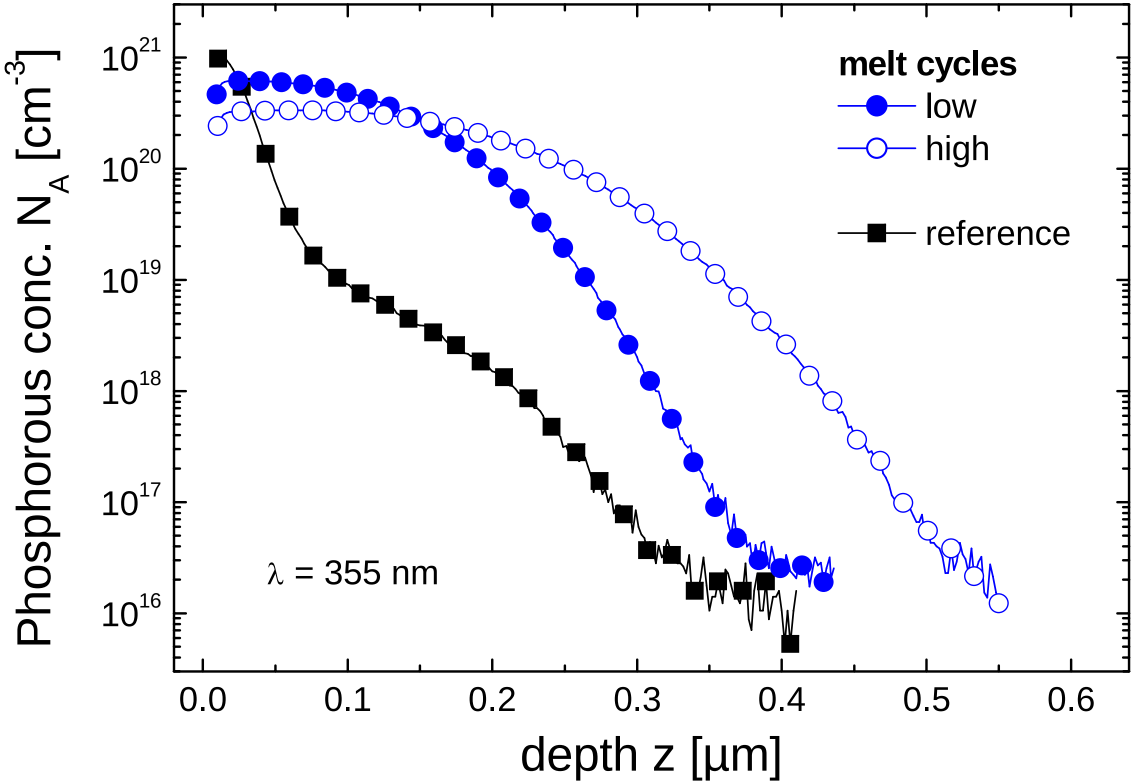


Taken from Bruton et al., Osaka 2003

‘Dry’ laser doping



Selective doping



- laser ~10 ns / VIS (IR & UV)
- wet or dry lasers
- stage / flying optics / scanner

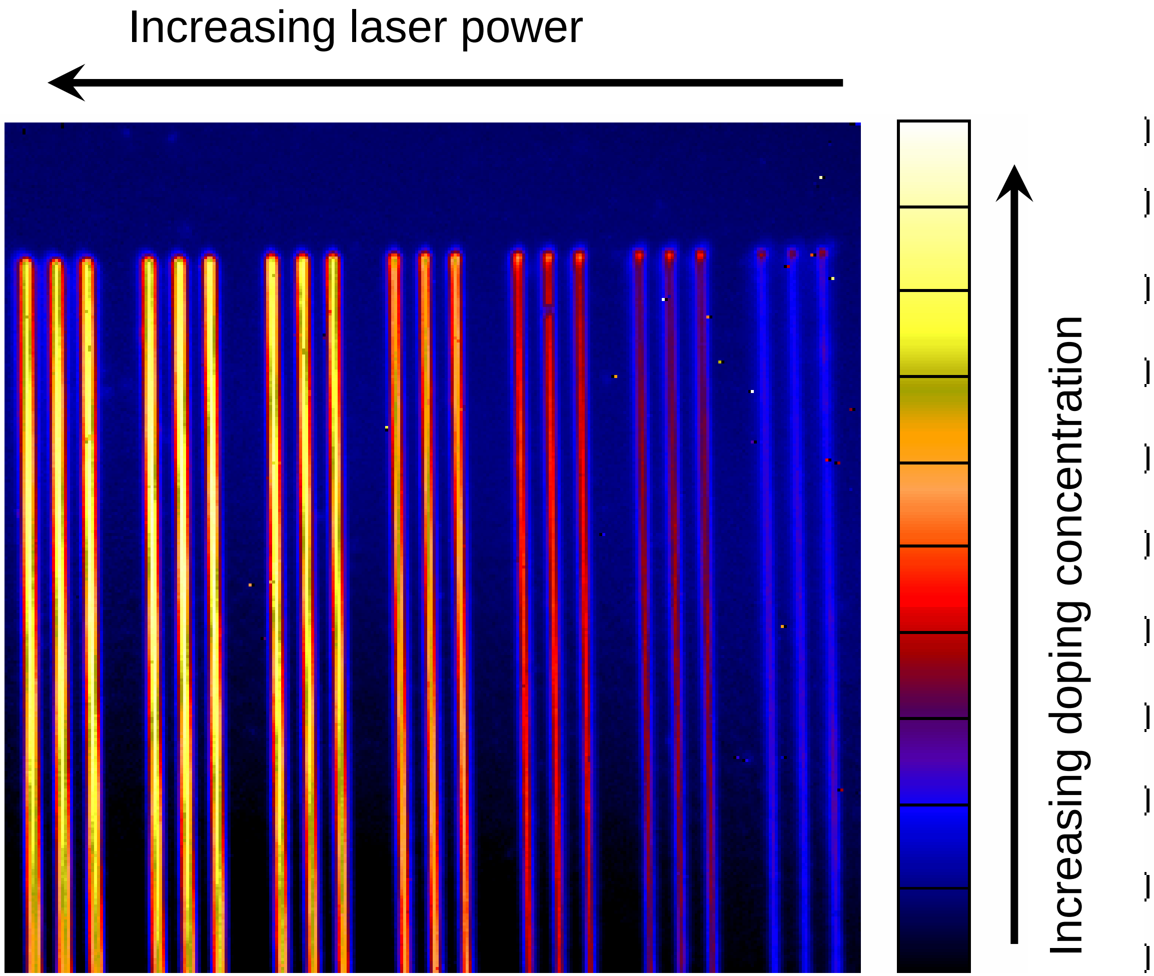
- faster doping diffusion (diffusion constant liquid ⇔ solid)
- more possibilities to influence diffusion profile / depth

Laser doping with LCP (carrier liquid: H_3PO_4)

Grooves on p-type wafer

Measuring of R_{sh}

- Groove width <100 µm
- Sheet resistance between 15 and 40 Ω/sq
- No parasitic side-doping outside the grooves

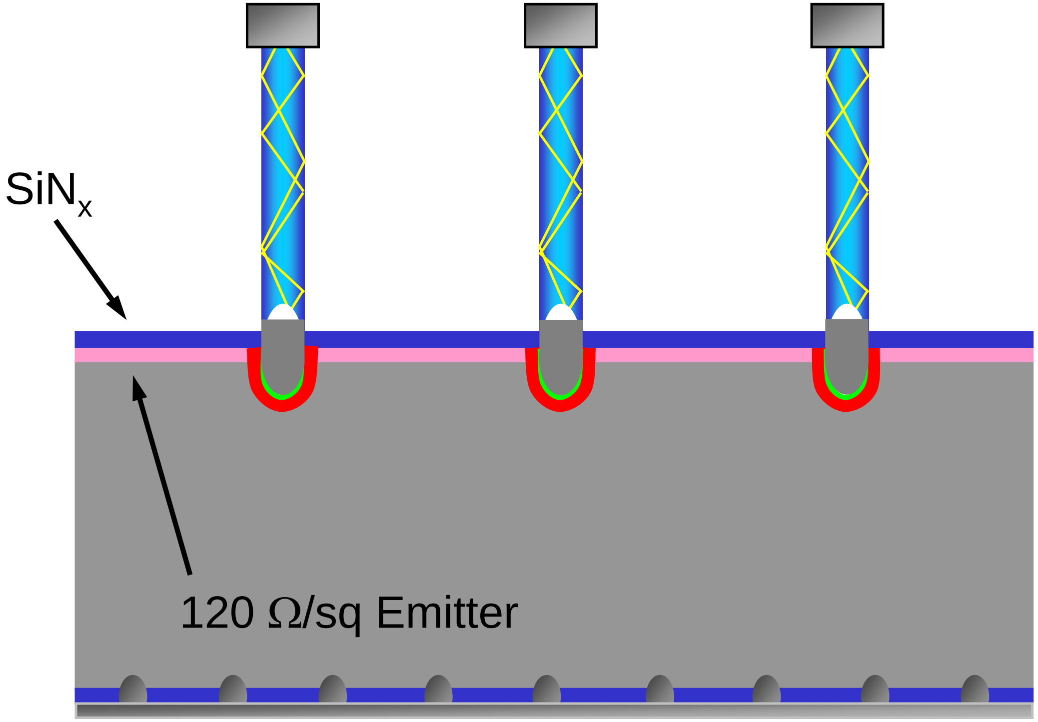


Fabrication of selective emitters via LCP

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/cm²

1 or multiple passes

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

Energy density: 40-100 J/cm²

First solar cells with LCP selective emitter

Simple device structure:

- planar
- spray-on 50 Ω/sq emitter
- PECVD SiN_x front
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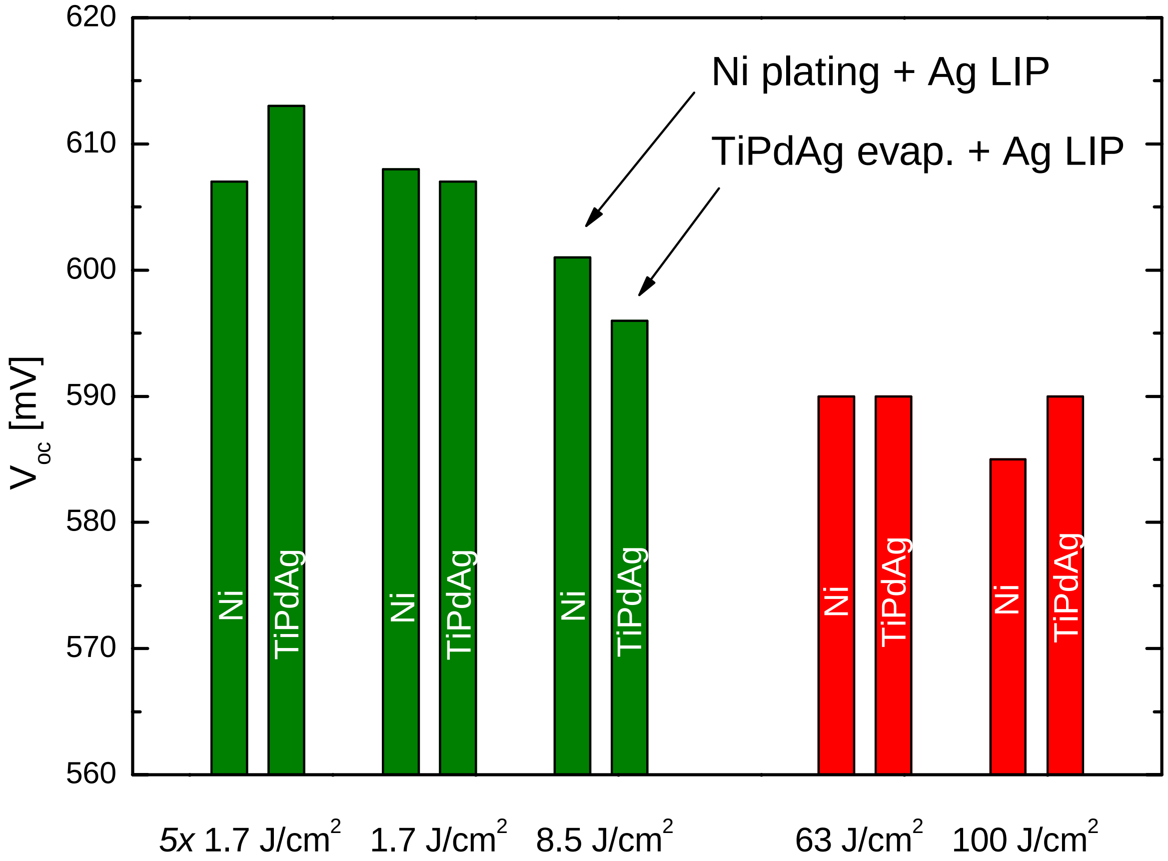


First solar cells with LCP selective emitter

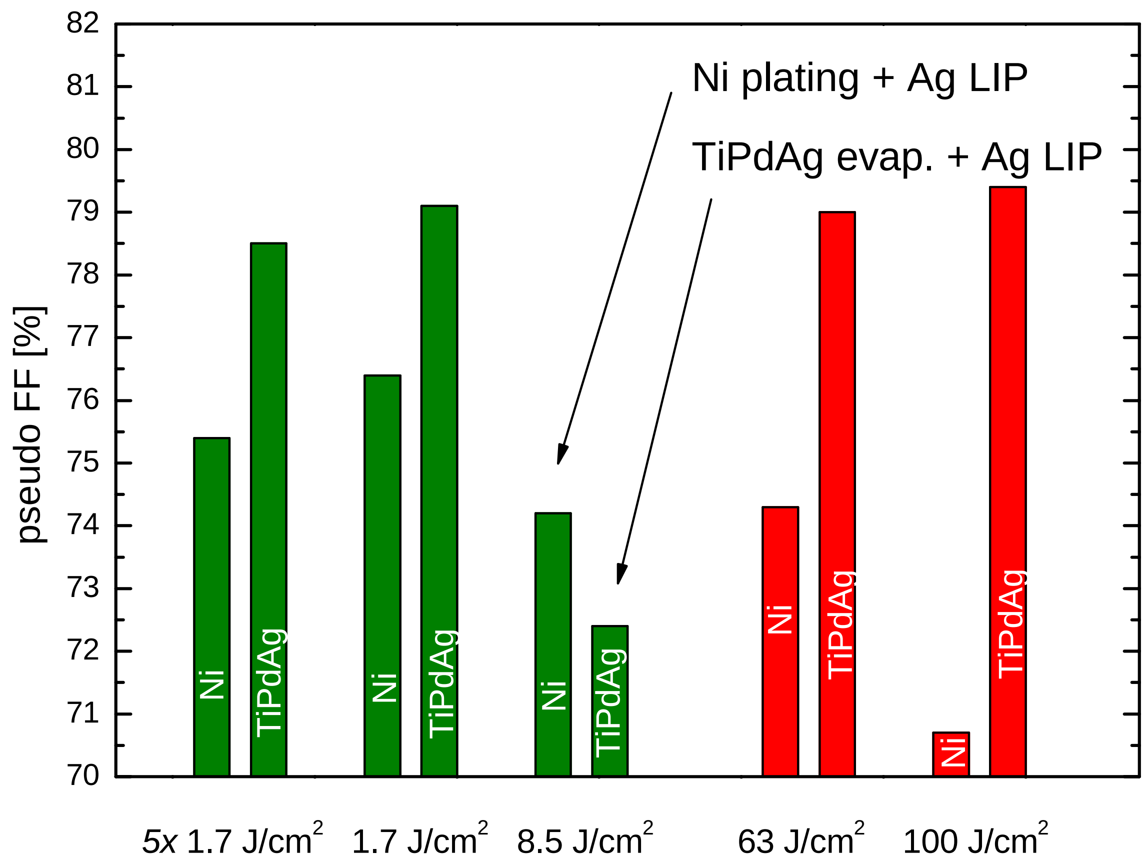
Strong degradation due to Ni plating for IR laser samples

Slight degradation due to Ni plating for green laser samples

Low energy densities beneficial

PFF and Voc level acceptable

➔ Green laser most promising

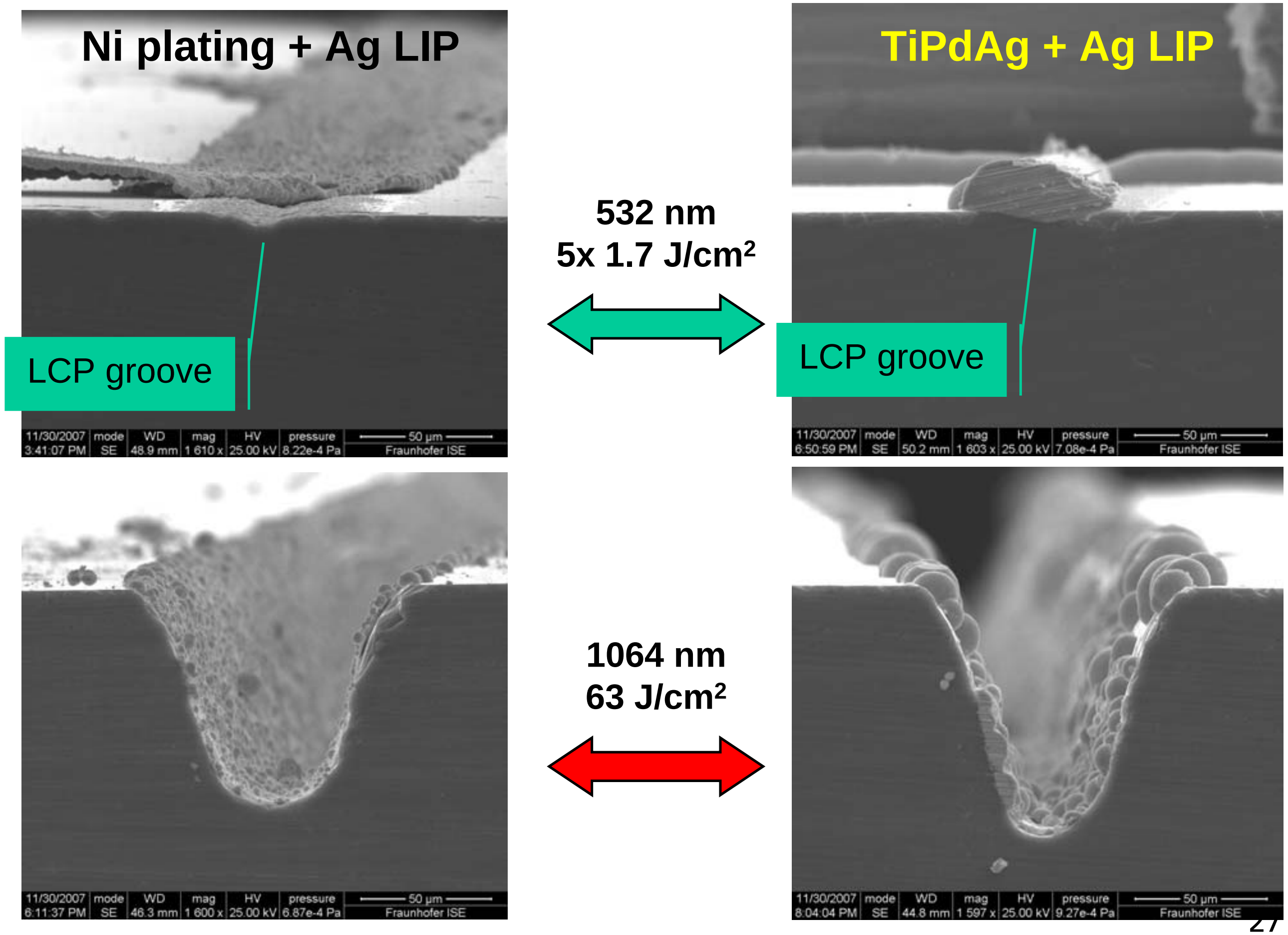


First solar cells with LCP selective emitter

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

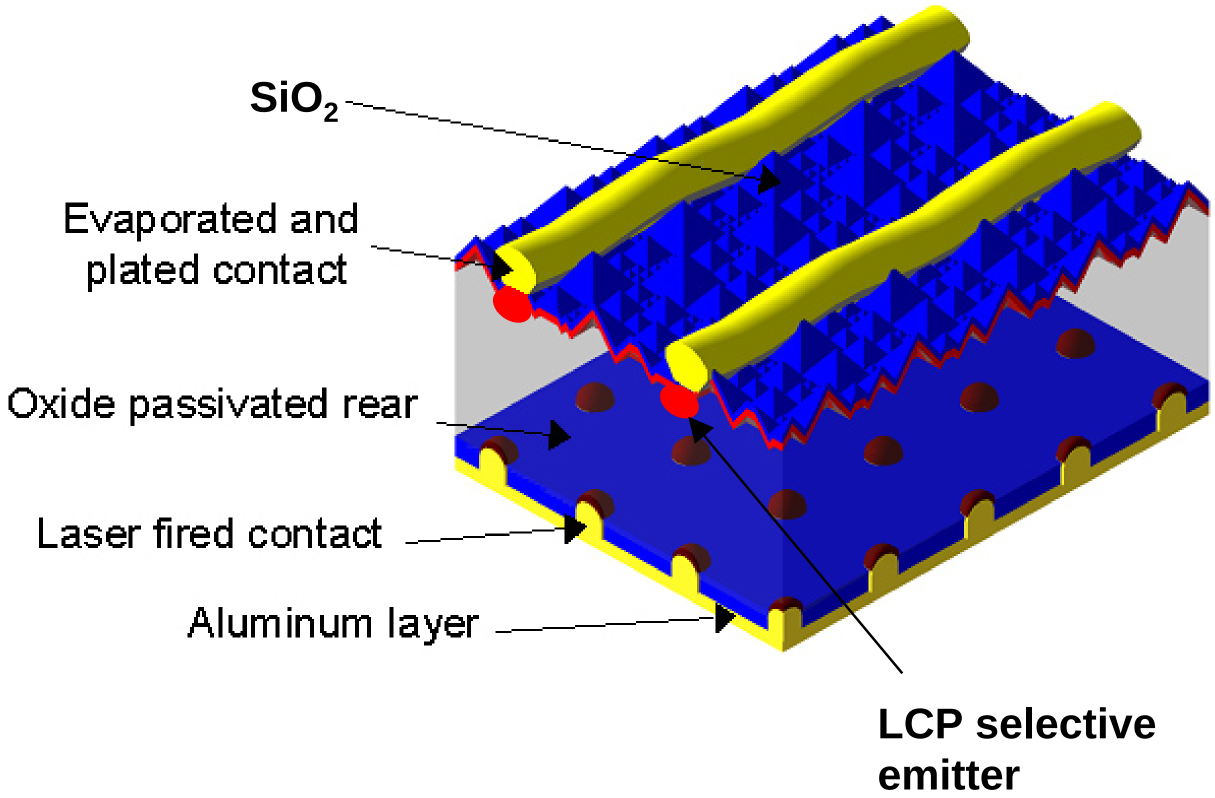
High-efficiency LFC cell structure with oxide passivation

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



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

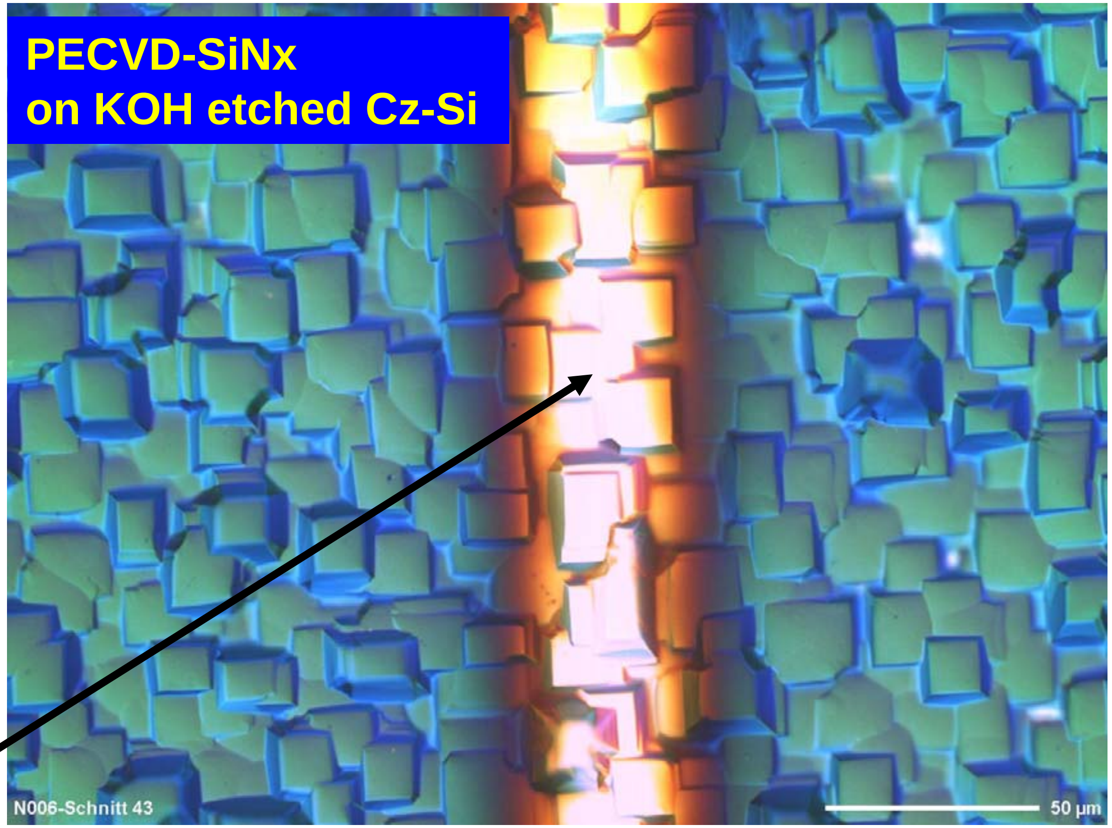
Base resistivity	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF	η [%]
1 Ω cm	652.3	38.4	0.780	19.5
0.5 Ω cm	664.9	38.7	0.792	**20.4**

High-efficiency LCP solar cells - outlook

Optimum contact width can be significantly reduced via low LCP contact resistance

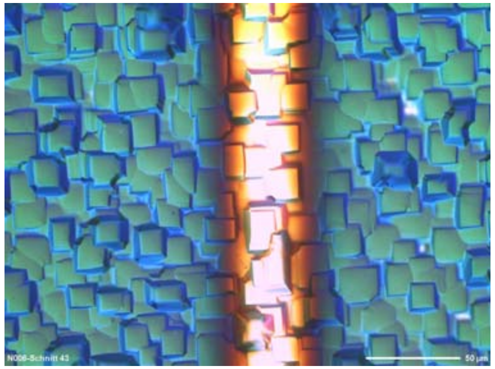
Can such fine lines be grooved?

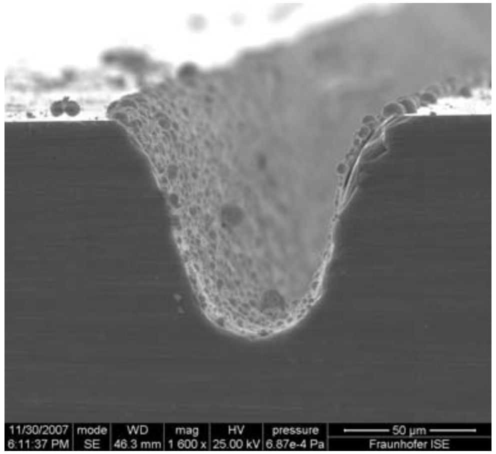
➔ 30 µm nozzles available



~25 µm wide opening with 150 µm nozzle

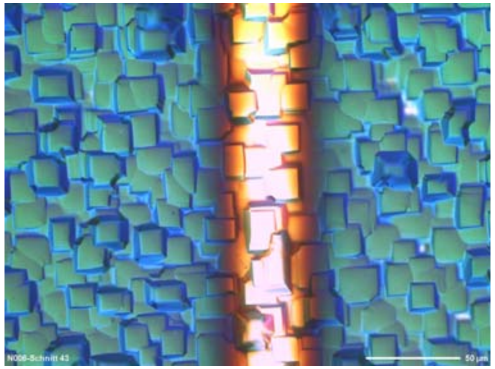
Summary

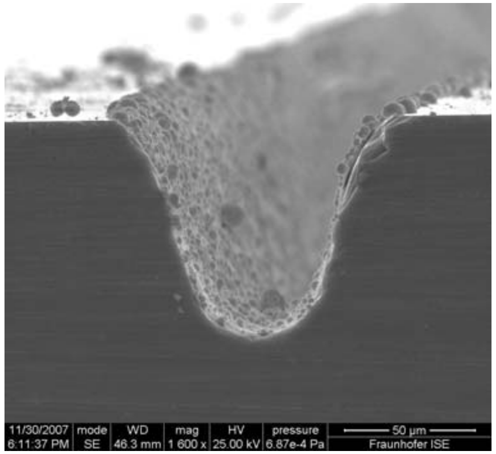




- LCP is capable of fabricating excellent selective phosphorous emitters
- LCP compatible with shallow and deep emitters
- Ni plating of LCP grooves still needs optimization
- First laser-doped silicon solar cells exceeding 20% efficiency demonstrated
- Very narrow grooves can be realized via LCP
- An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

Acknowledgements





- Staff at Fraunhofer ISE:

  M. Alemán, A. Fell, A. Grohe, S. Hopman, K. Mayer, M. Mesec, R. Müller, G. P. Willeke, S. W. Glunz

- Industry partners:

  Deutsche Cell GmbH, Manz Automation AG, REC group and Synova S.A.