Towards lean fabrication of TOPCon c-Si solar cells by co-annealing of PECVD-deposited boron source and poly-Si(n) rear contact

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Introduction

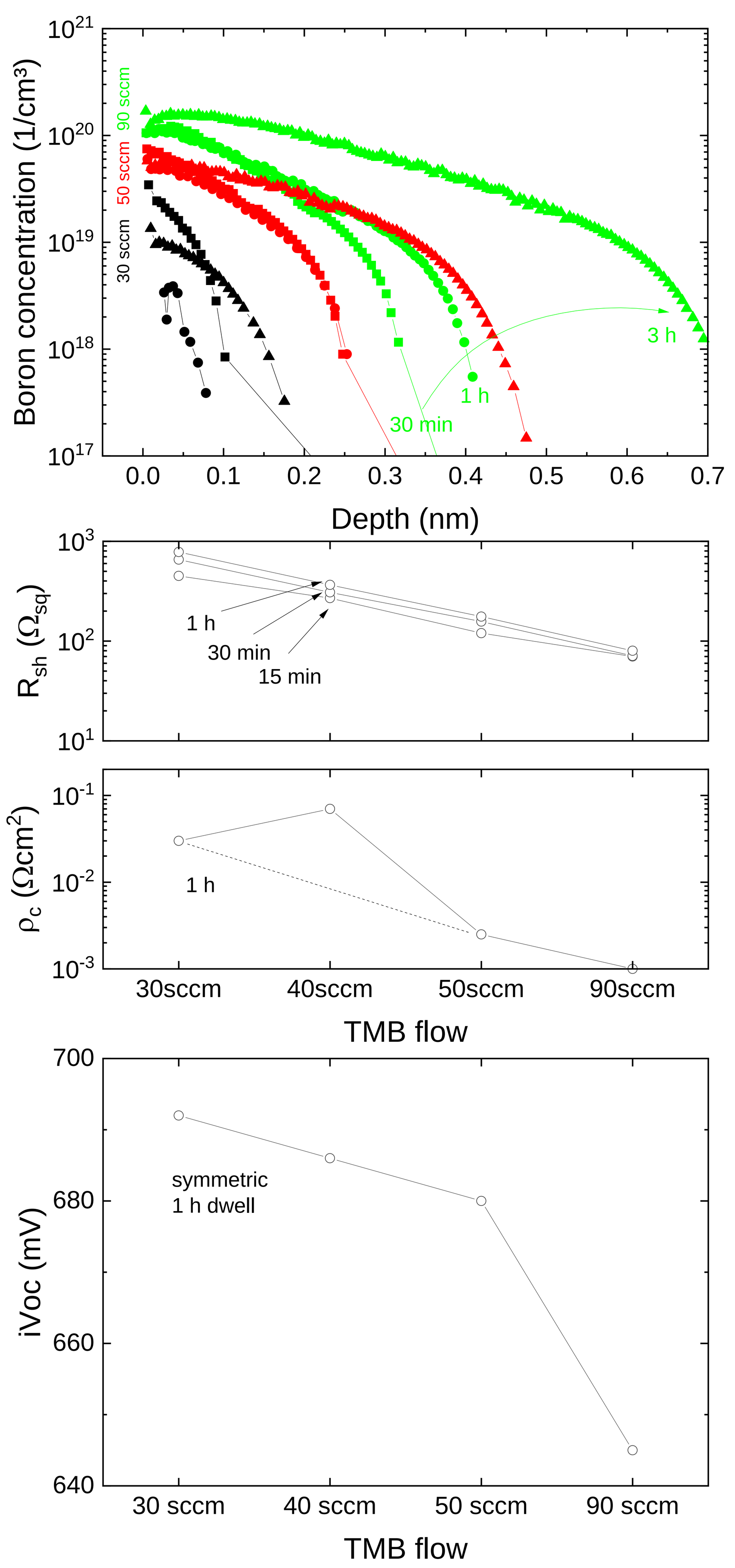
The market of c-Si solar cells changes swiftly from p-type PERC solar cells towards n-type cells with tunnel-oxide passivating contacts (TOPCon). Efficiencies close to 27% were demonstrated in pilot lines [1], but manufacturing employs multiple steps at high temperature. We propose to use a single co-annealing step for the diffusion of the p-type emitter and the formation of the n-type rear contact.

[1] JinkoSolar claims 26.89% efficiency rating for new N-type solar cell, PV Magazine (2023)

Sample design

standard process	simplified process
wafer cleaning, saw damage removal, texturing	
BBr diffusion (+ oxidation)	PECVD SiOx(p)
etching (BSG rear)	
poly-Si deposition (rear)	PECVD Si(n)
etching (BSG front, edge)	etching (SiOx)
annealing	co-annealing
dielectric: AlOx/SiNx (front), SiNx (rear)	
screen print: Ag-Al (front), Ag (rear)	
contact firing (hydrogenation)	

Variation I: boron emitter



Annealing at 900°C

Surface concentration controlled by TMB flux of SiOx(p) layer

Depth controlled by temperature and dwell time

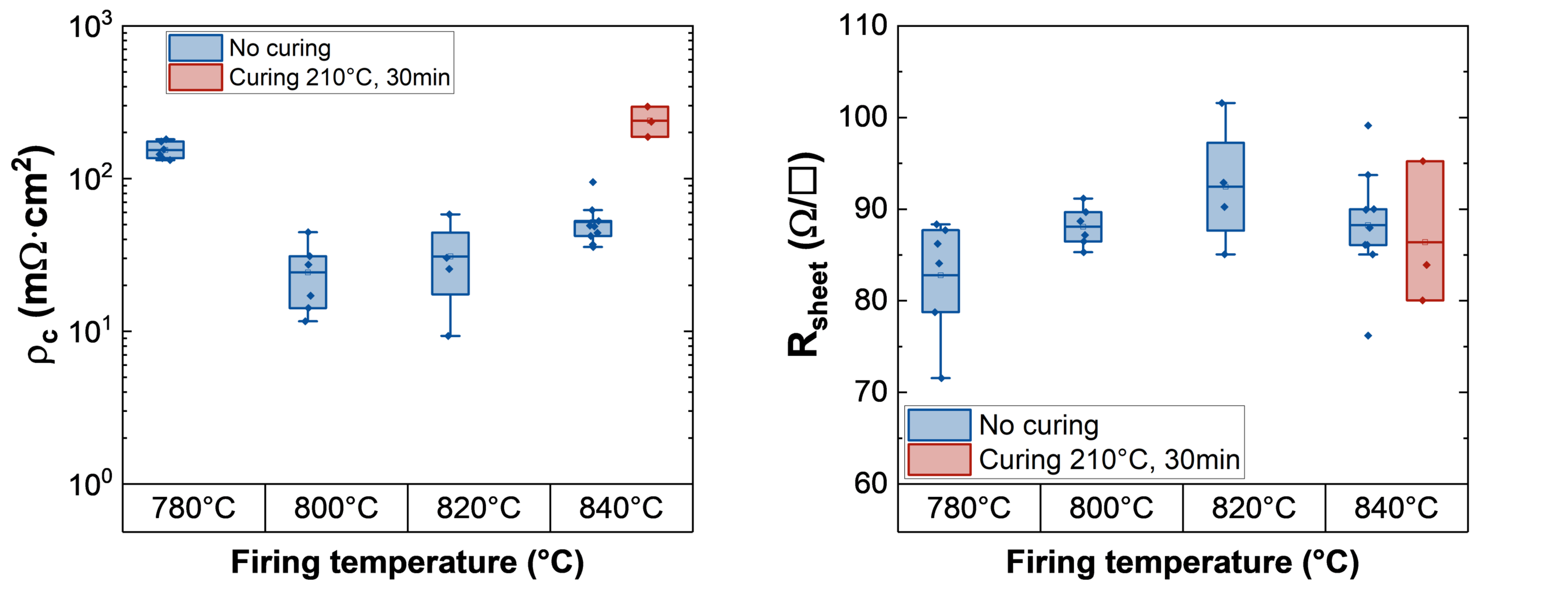
R_{sh} related to depth and boron concentration of diffusion profile => for lateral transport: < 200 Ω_{sq}

ρ_c related to surface concentration => for local finger contacts: 1…5 mΩcm²

Implied Voc of boron emitter impacted by

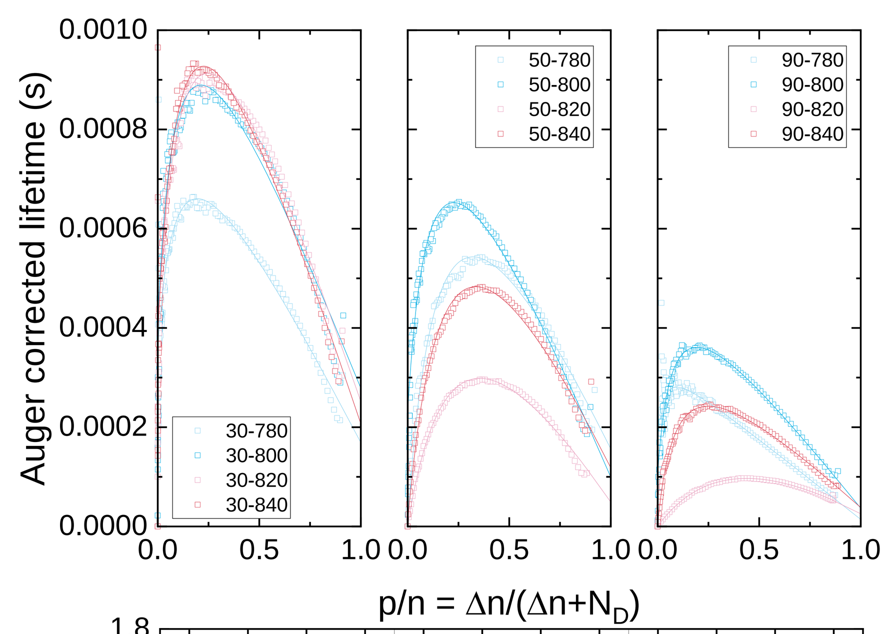
- surface concentration (surface recombination velocity with Al_2O_3 passivation)
- Auger recombination in emitter (dopant concentration and depth of diffusion profile)

Variation II: contact firing temp.



Ag/ ITO on poly-Si(n) after firing: ρ_c rather high (native oxide after fire?)
=> use full-area contact for demo cells

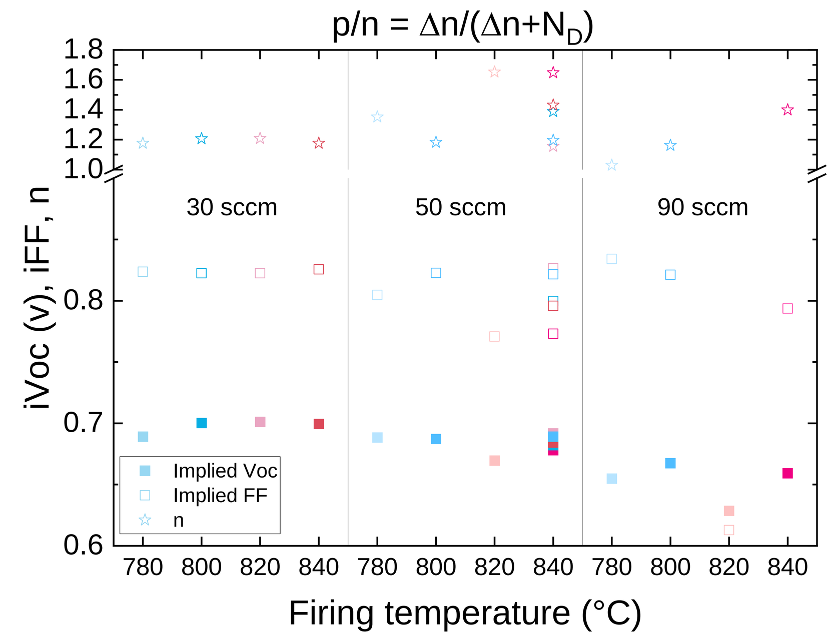
Cell precursors (w/o contacts)



Low doping yields high lifetime (defect injection by boron excess?)

High doping likely surface limited

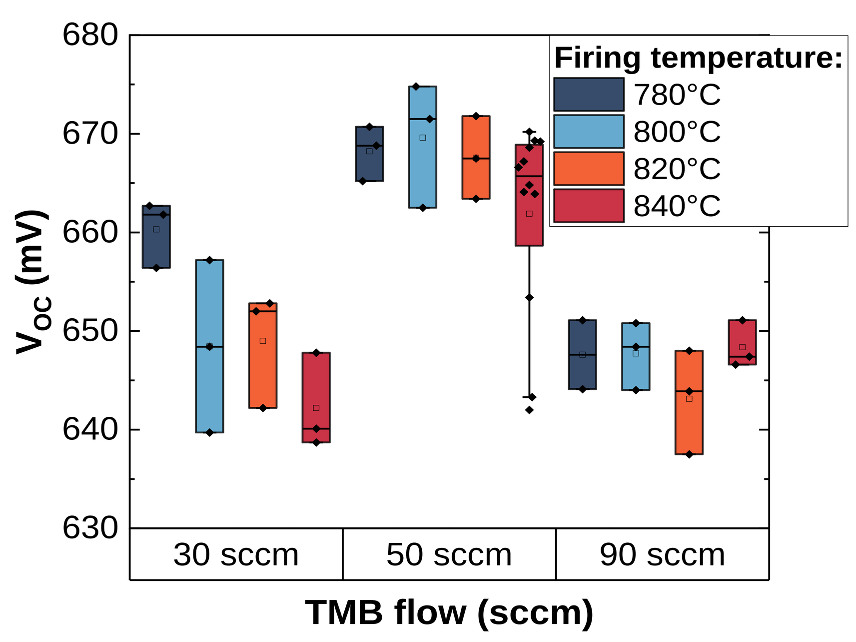
Best contact firing at 800°C (ideal hydrogen supply)



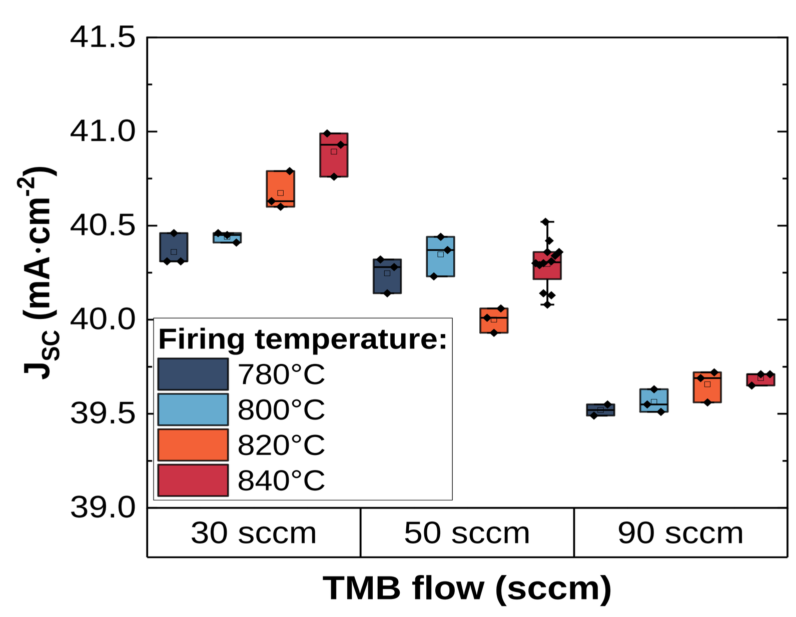
iVoc decreasing for higher emitter doping (reflecting lifetime)

iFF limitation by high diode quality factor (1.1…1.3), indicating recombination at defects in space charge region (SCR)

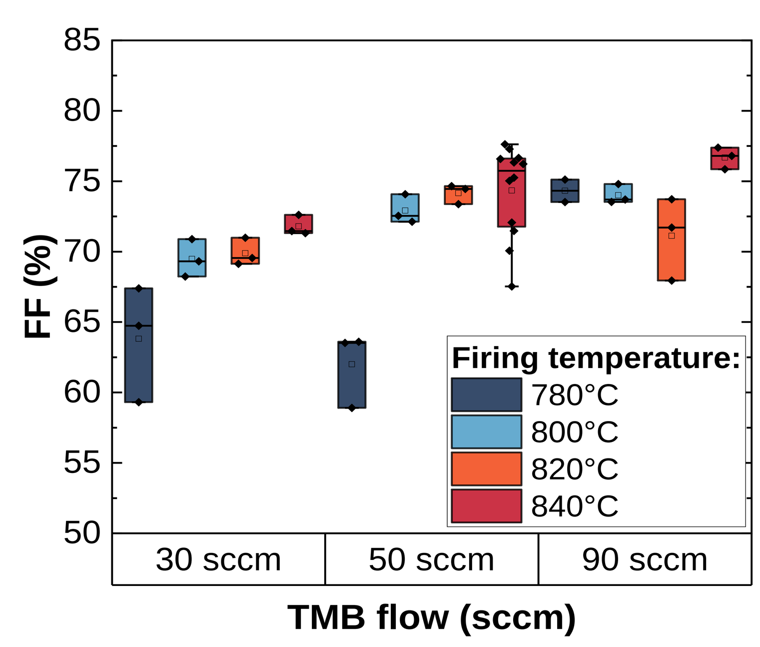
Cell results



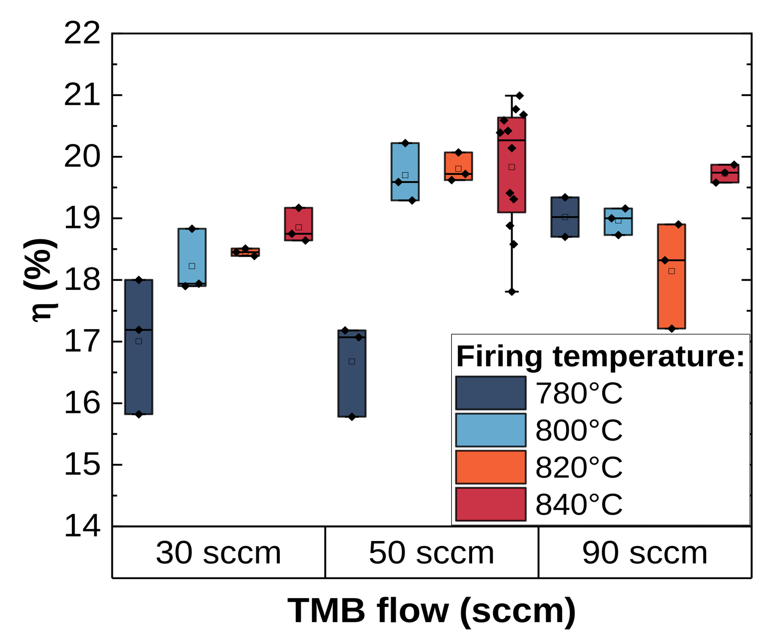
Voc for 30 sccm reduced by metal punching through shallow emitter



jsc reduced for higher emitter doping collection (blue) & parasitic abs. (IR)



FF also limited by series resistance of R_{sh} and ρ_c (esp. for 30 sccm)



Overall efficiency best for medium emitter doping and firing >800°C

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Conclusions

Simplified cell process with efficiencies up to 21%. Future work: decrease SCR recombination, reduce contact resistance, develop rear metallization