Revised Parametrization of the Recombination Velocity at SiO_2/SiN_X-Passivated Phosphorus-Diffused Surfaces

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A. Wolf[1], J. Egle[1], S. Mack[1] H. Höffler[1],
D. Herrmann[1], S. Lohmüller[1], J. Horzel[1], A. Fell[1,2]

[1] Fraunhofer ISE
[2] AF simulations

11th SiliconPV conference

April 21st 2021

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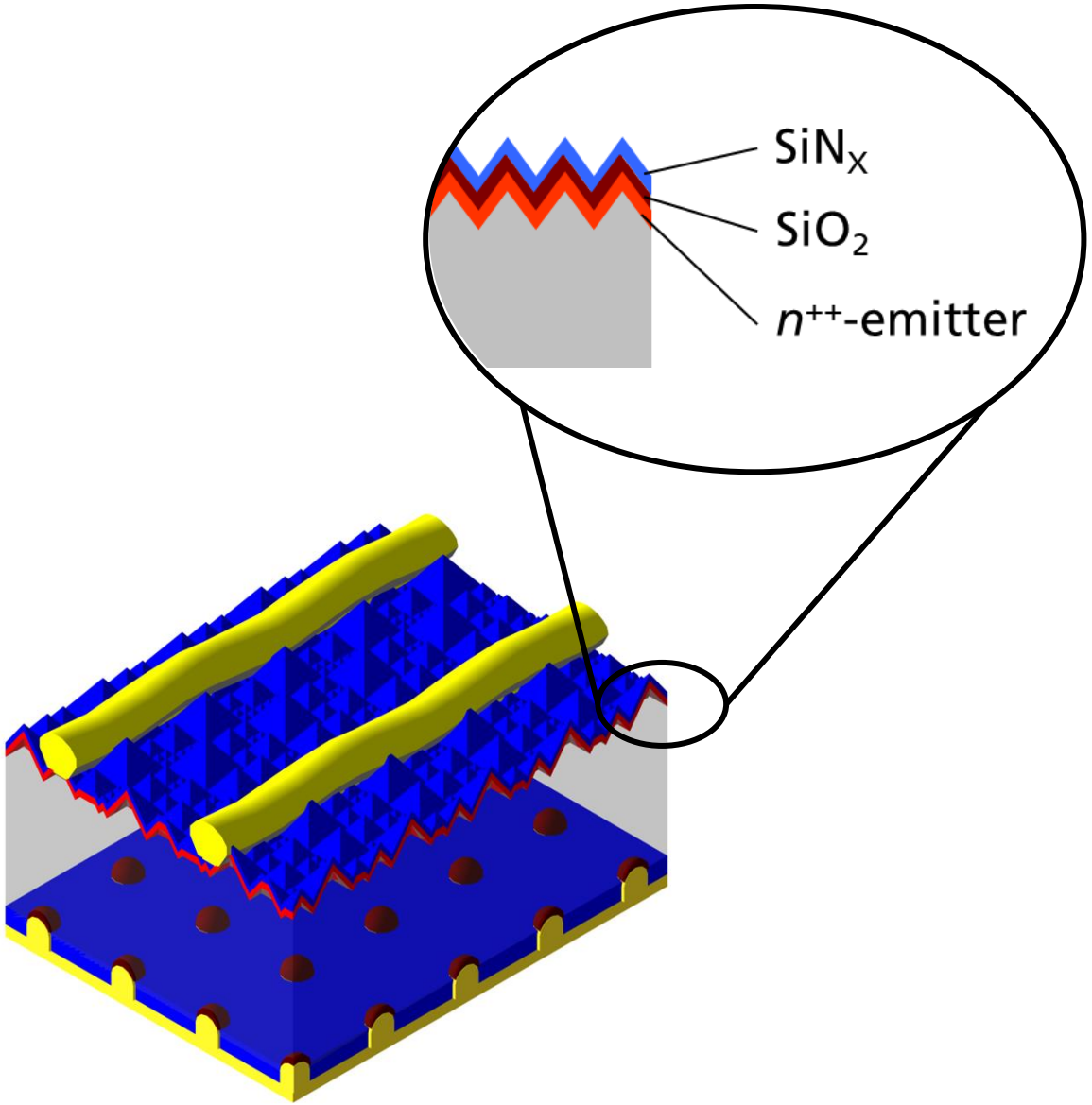
Motivation

- Emitter passivation by thermal SiO_2 + PECVD SiN_X frequently used in industrial production of PERC
- Dependence of SRV on surface doping concentration intensively studied in the literature[1-4], mostly by QSSPC
- Black et al. showed systematic calibration deviation for QSSPC[5]
- Limited accuracy of literature data?
- Impact of oxidation temperature?

➔ **Reassessment of SRV-parametrization necessary**



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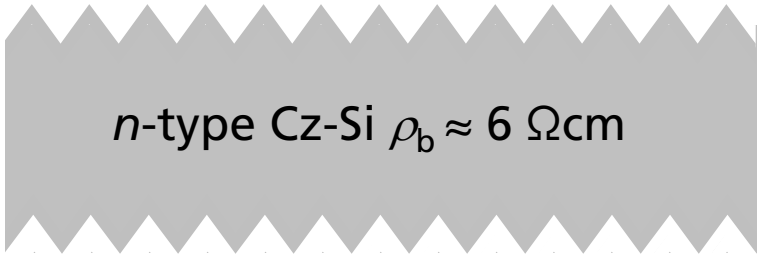
[1] R. R. King et al., IEEE TED vol. 37, 1990
[2] A. Cuevas et al., JAP vol. 80, 1996
[3] M. J. Kerr et al., JAP vol. 89, 2001
[4] A. Kimmerle et al., JAP vol. 119, 2016
[5] Black et al., IEEE JPV vol. 9, 2019

PECVD: Plasma enhanced chemical vapor deposition
PERC: Passivated emitter and rear cell
SRV: Surface recombination velocity
QSSPC: Quasi steady state photoconductance decay

Experimental Approach
Symmetric $n^+/n/n^+$-structure

- Alkaline textured surface



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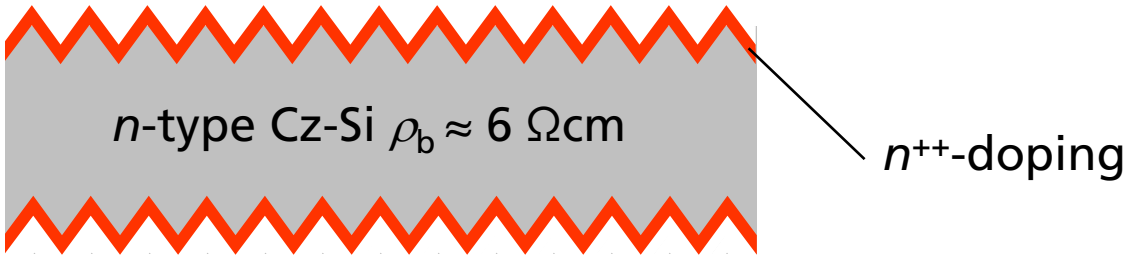
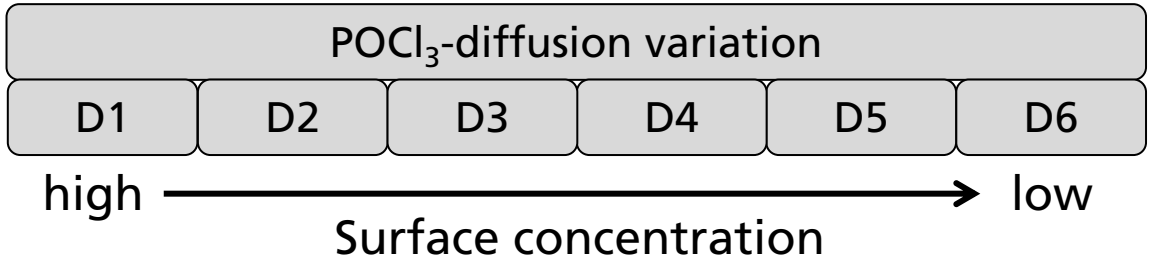
Experimental Approach
Symmetric $n^+/n/n^+$-structure

- Alkaline textured surface
- 6 different $POCl_3$ processes D1 to D6
  - Variation in in-situ oxidation





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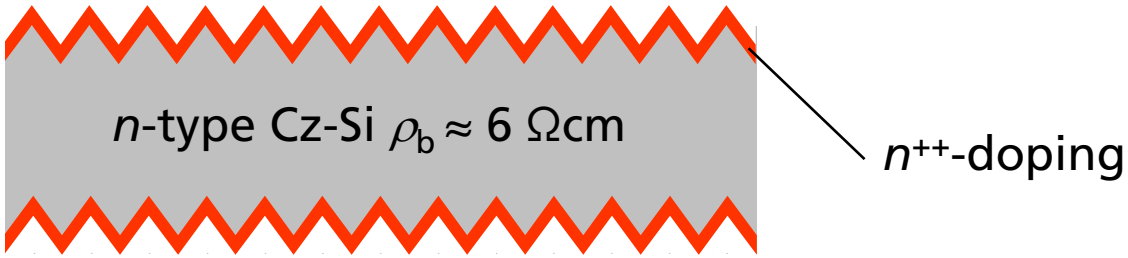

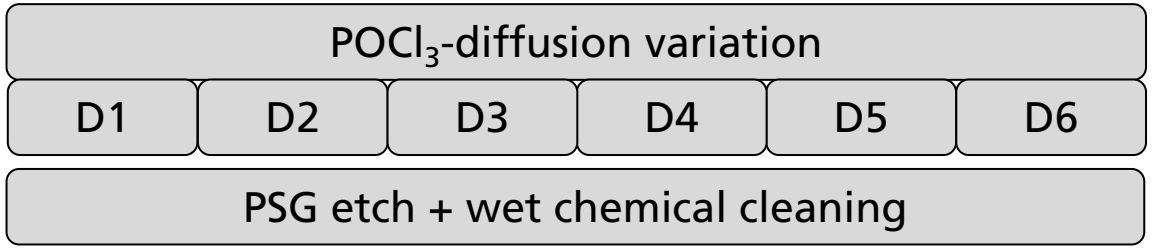

PSG: Phosphosilicate glass

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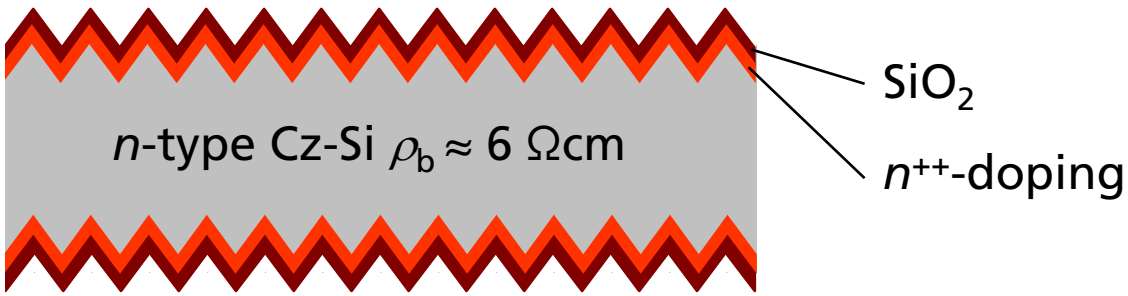
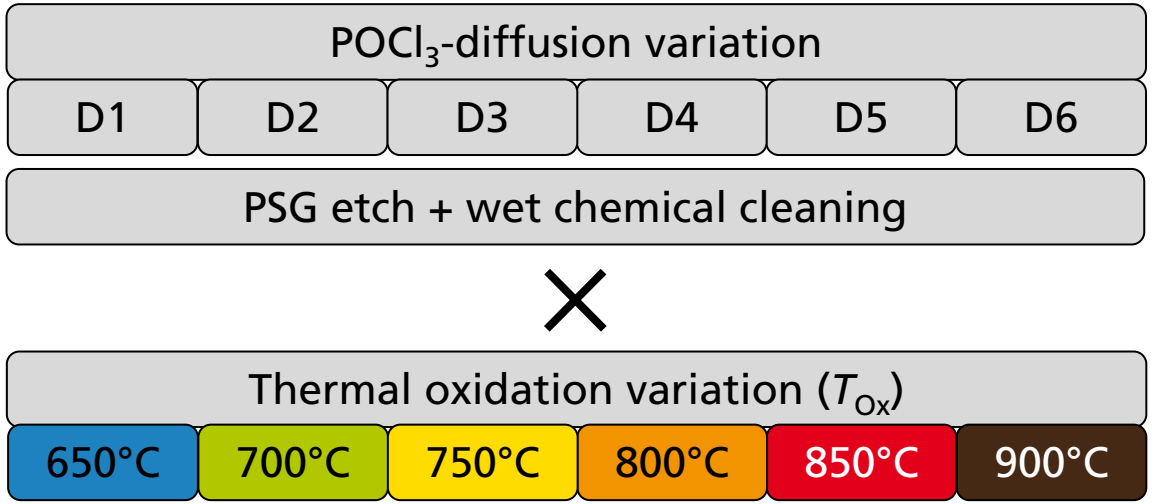
Experimental Approach
Symmetric $n^+/n/n^+$-structure

- Alkaline textured surface
- 6 different $POCl_3$ processes D1 to D6
  - Variation in in-situ oxidation
- 6 thermal oxidations at different T_{OX}
  - Adjusted time yields 3nm $\lesssim d_{OX} \lesssim$ 6 nm





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PSG: Phosphosilicate glass
T_{OX}: Oxidation plateau temperature
d_{OX}: Oxide layer thickness

Experimental Approach
Symmetric $n^+/n/n^+$-structure

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- 6 different $POCl_3$ processes D1 to D6
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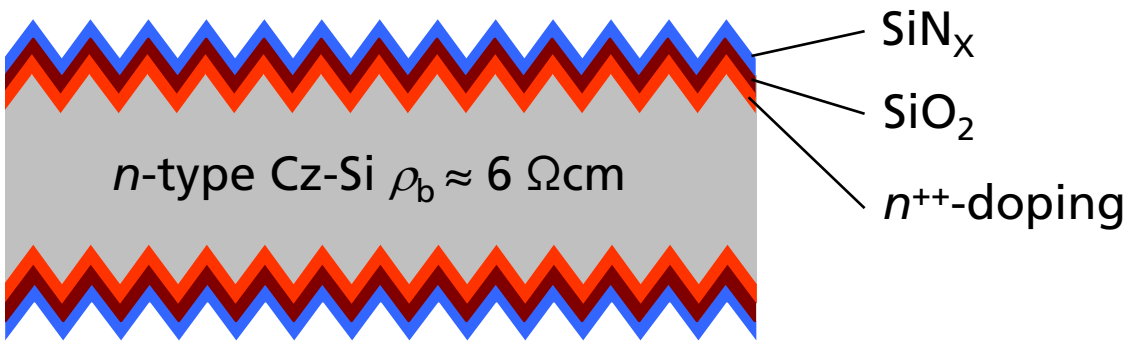
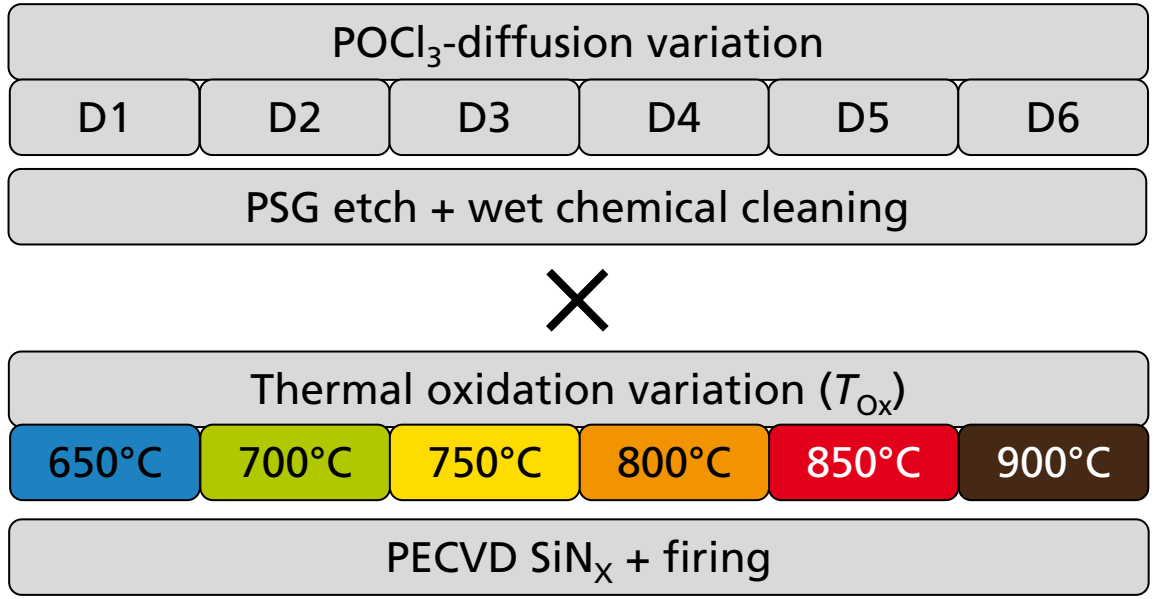
- 6 thermal oxidations at different T_{OX}
  - Adjusted time yields 3nm $\lesssim d_{OX} \lesssim$ 6 nm

➔ 25 diffusion / oxidation combinations with 3 samples each





PSG: Phosphosilicate glass
T_{OX}: Oxidation plateau temperature
d_{OX}: Oxide layer thickness

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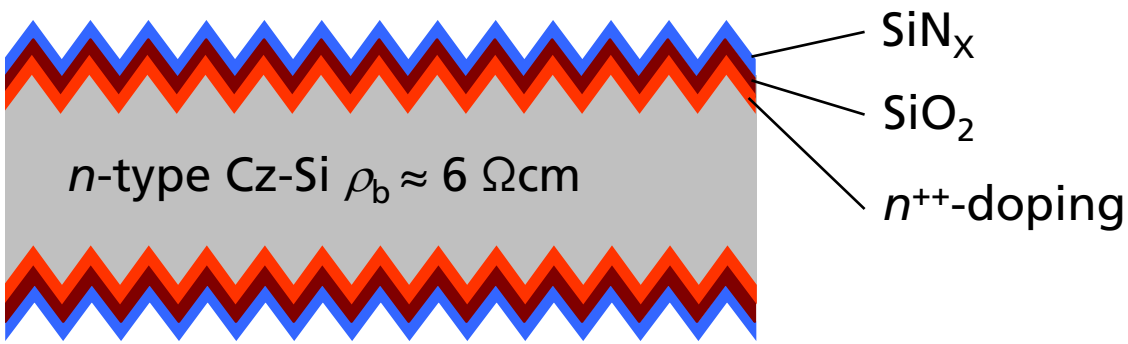
Experimental Approach
Sample Characterization

- Carrier lifetime and recombination parameter j_{0e}
  - QSSPC in wafer centre in generalized mode
  - Wafer specific data for ρ_b and W
  - Thickness dependent coil sensitivity[1]
  - Injection dependent BGN and carrier diffusion considered[2]



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[1] Black et al., IEEE JPV vol. 9, 2019
[2] A. Kimmerle et al., Sol Mat vol. 142, 2015

j_{0e}: Dark saturation current density
ρ_b: Base resistivity
W: Wafer thickness
BGN: Band gap narrowing

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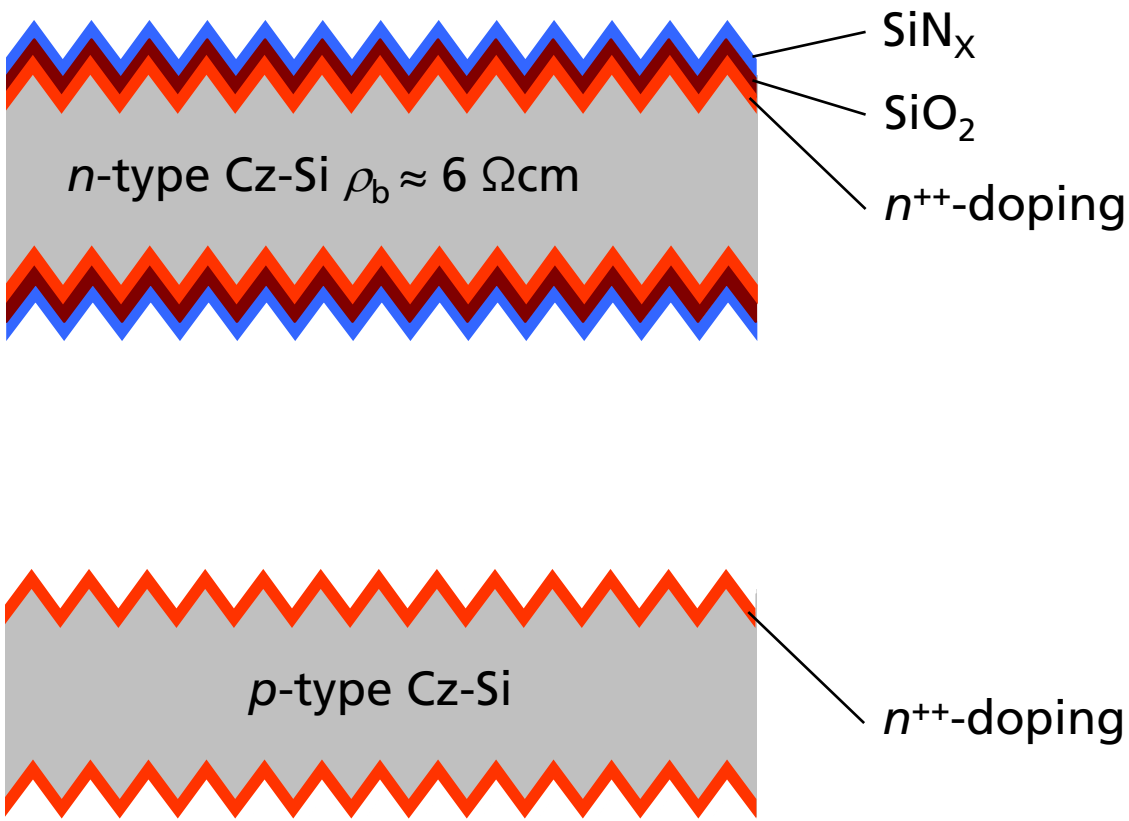
Experimental Approach
Sample Characterization

- Carrier lifetime and recombination parameter j_{0e}
  - QSSPC in wafer centre in generalized mode
  - Wafer specific data for ρ_b and W
  - Thickness dependent coil sensitivity[1]
  - Injection dependent BGN and carrier diffusion considered[2]
- Sheet resistance R_{sh} and doping profile
  - 4pp measurements
  - ECV profiling
  - Scaling of doping profile by $f_{ECV} \approx 1.45$ to match measured R_{sh}[3]



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[1] Black et al., IEEE JPV vol. 9, 2019
[2] A. Kimmerle et al., Sol Mat vol. 142, 2015
[3] Werner et al., Energy Proced. Vol 124, 2017

j_{0e}: Dark saturation current density
ρ_b: Base resistivity
W: Wafer thickness
BGN: Band gap narrowing

R_{sh}: Sheet resistance
4pp: Four point probe
ECV: Electrochemical capacitance voltage
f_{ECV}: Surface enlargement factor

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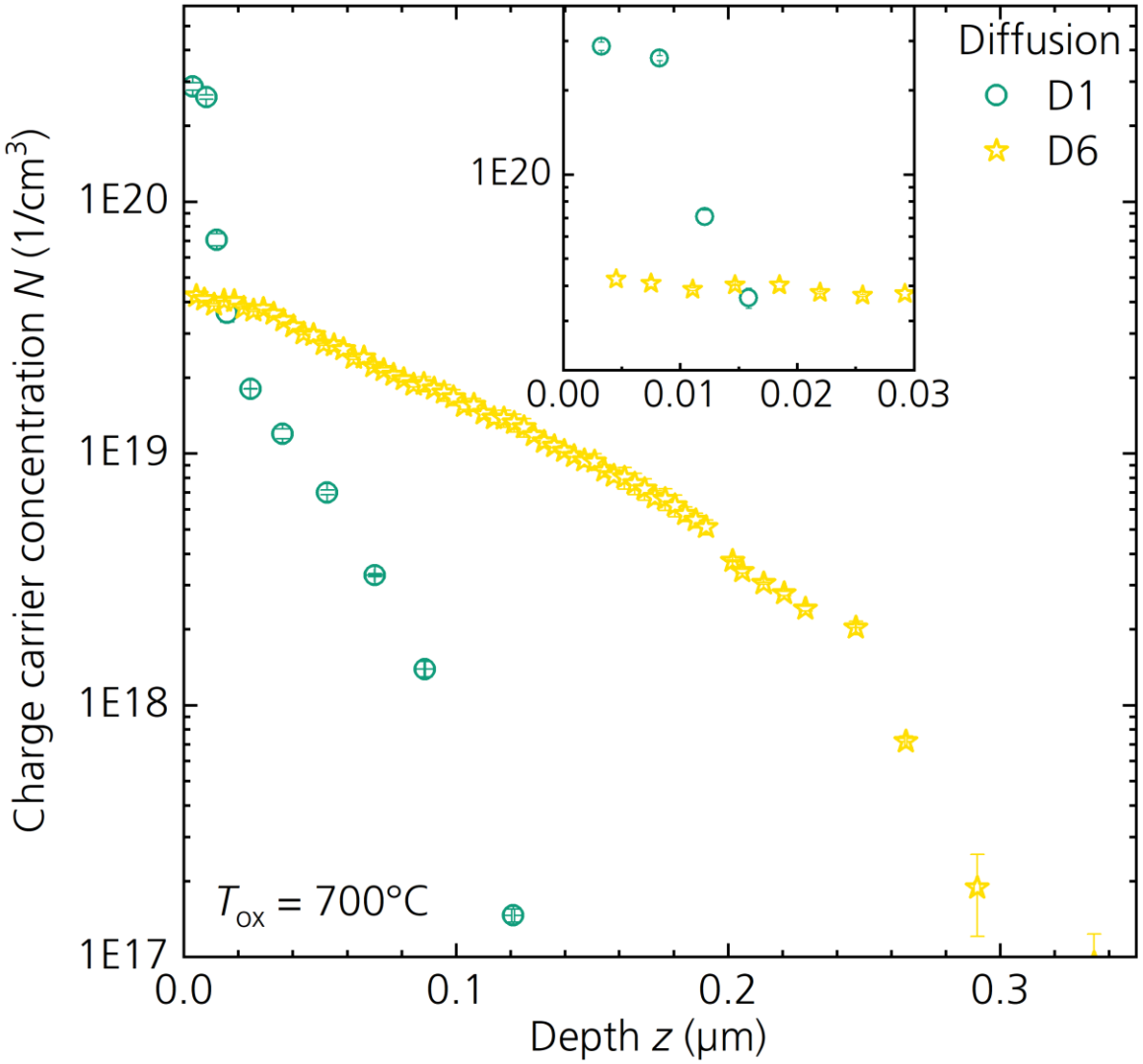
Doping Profiles
Diffusion Process Variations

- D1: Only PSG deposition
- D6: Strong in-situ oxidation



PSG: Phosphosilicate glass

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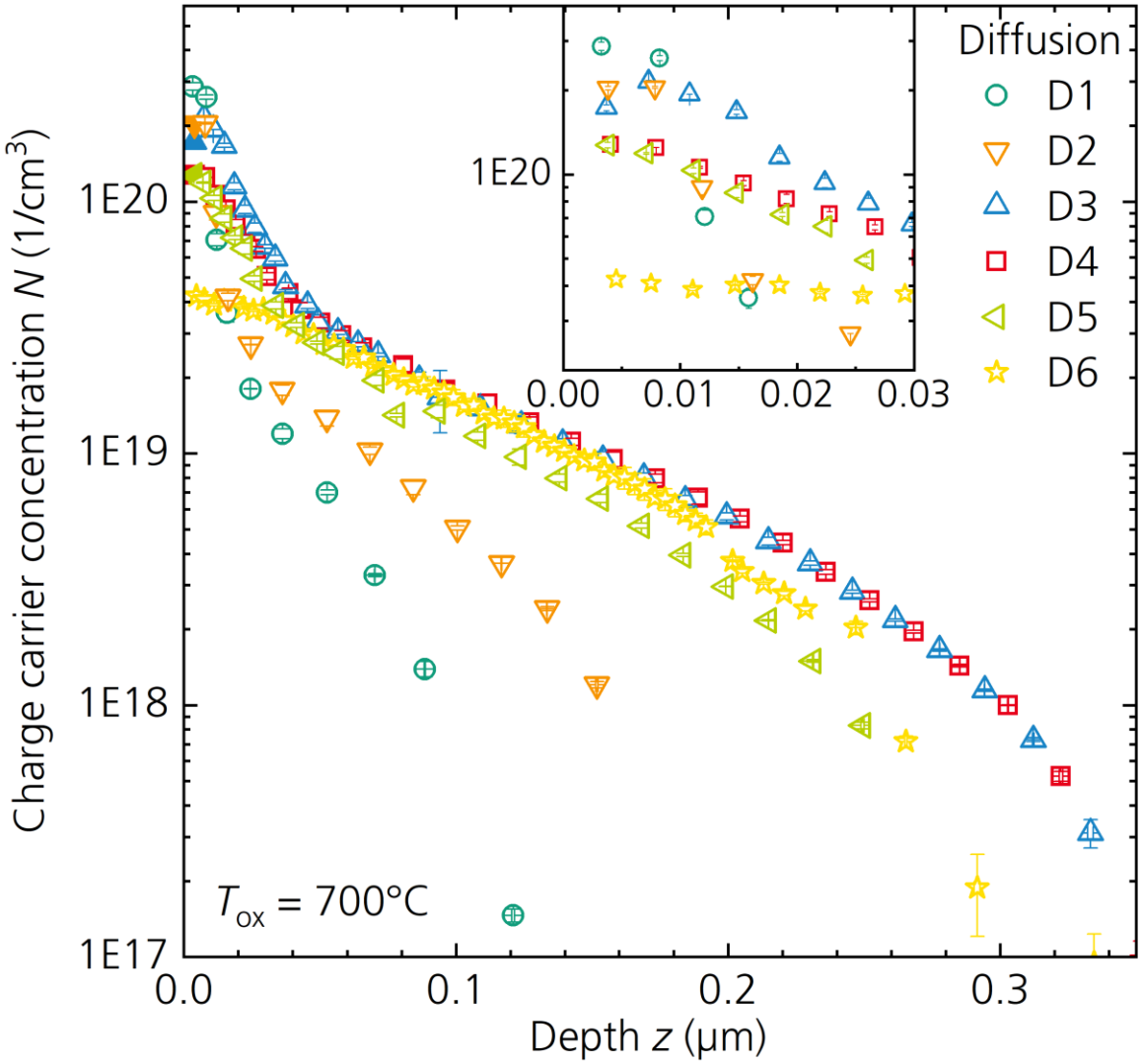
Doping Profiles
Diffusion Process Variations

- D1: Only PSG deposition
- D6: Strong in-situ oxidation
- Sheet resistance 90 Ω/sq ≲ R_{sh} ≲ 220 Ω/sq
- Initial surface concentration
  $4 \times 10^{19} \lesssim N_S \lesssim 3 \times 10^{20}$ cm^{-3}



PSG: Phosphosilicate glass
N_S: Surface doping concentration

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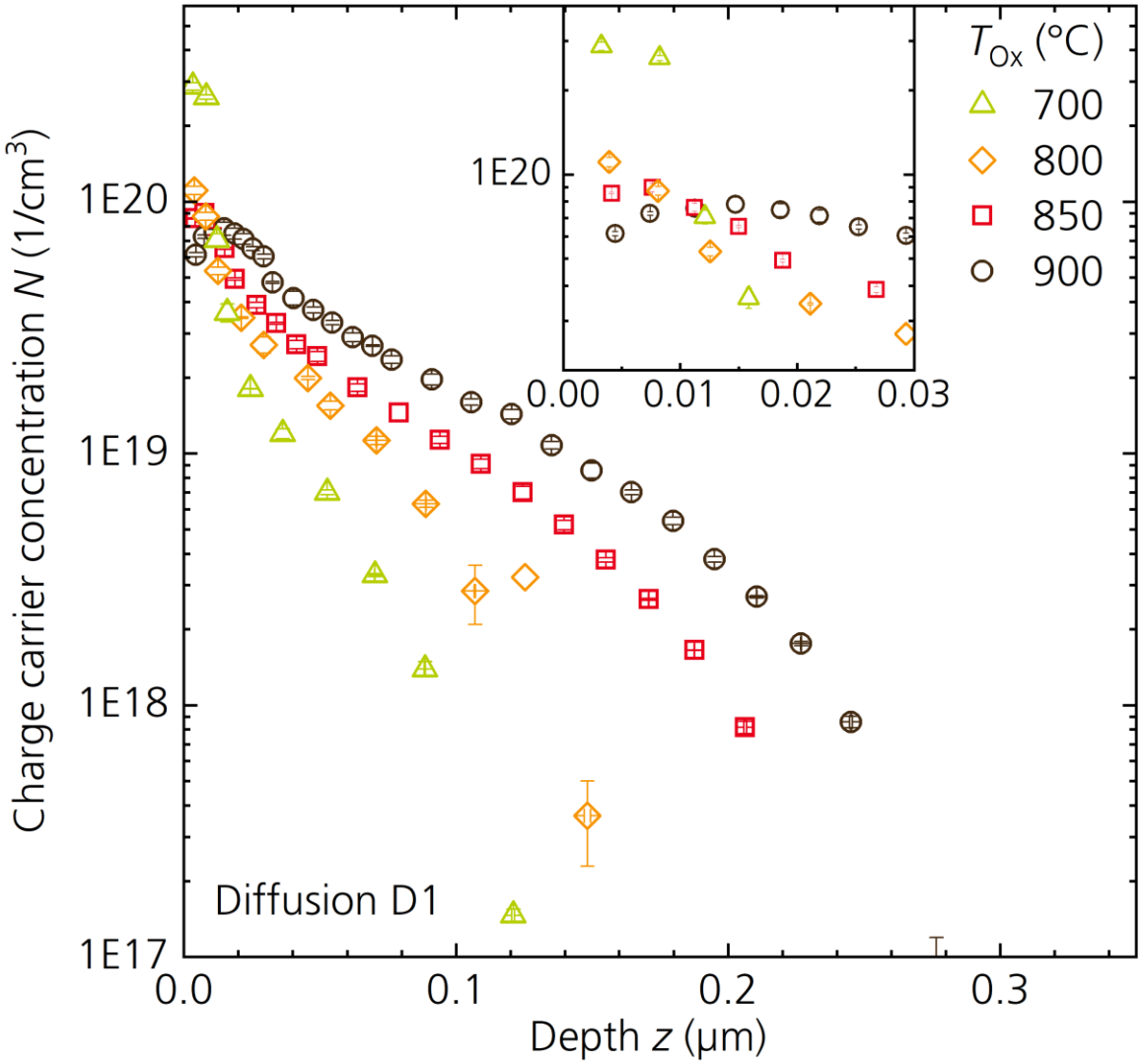
Doping Profiles
Impact of T_{OX}

- Reduction in N_S and increase in depth for higher T_{OX}



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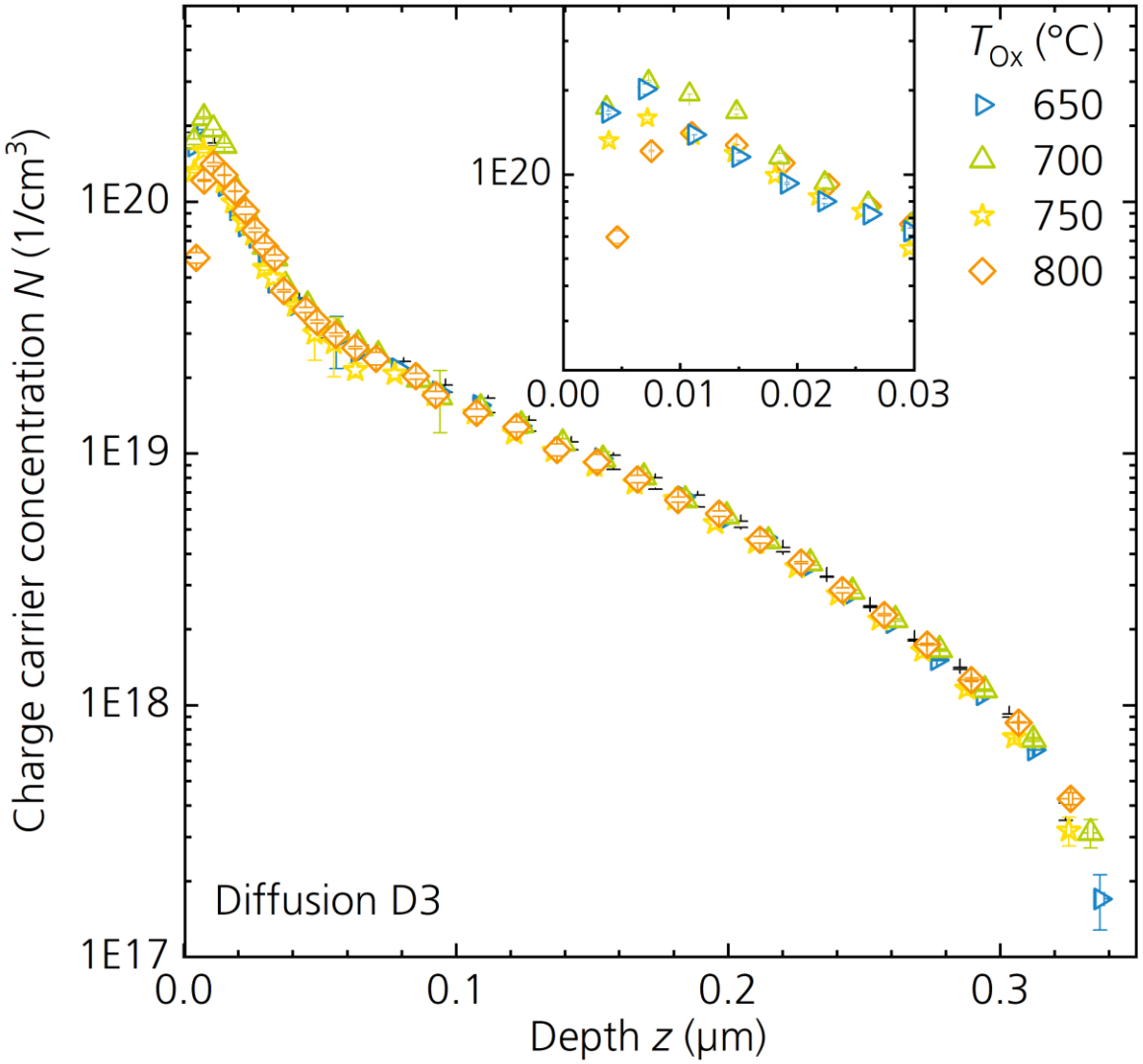
Doping Profiles
Impact of T_{OX}

- Reduction in N_S and increase in depth for higher T_{OX}
- Depletion of surface doping concentration observed[1]



[1] J. Horzel et al., this conference, poster sesssion Thu 2, poster J07

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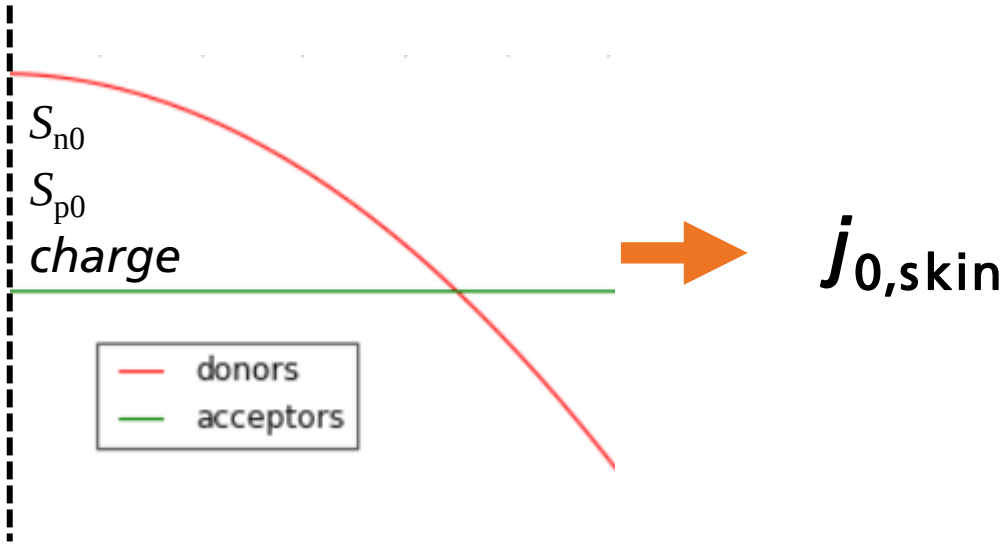
Numerical Simulation
Procedure

- QUOKKA3 Skin Solver 1D simulation[1]
- Input parameters
  - ECV carrier concentration profile scaled to R_{sh}
  - Average value for j_{0e} from 3 samples individually scaled to $j_{0e,1D} = j_{0e} / f_{ECV}$
- Surface charge is not considered
  - ➔ Effective or lumped SRV value S_{eff}



[1] A. Fell et al., Sol Mat vol. 173, 2017

S_{eff}: Effective surface recombination velocity

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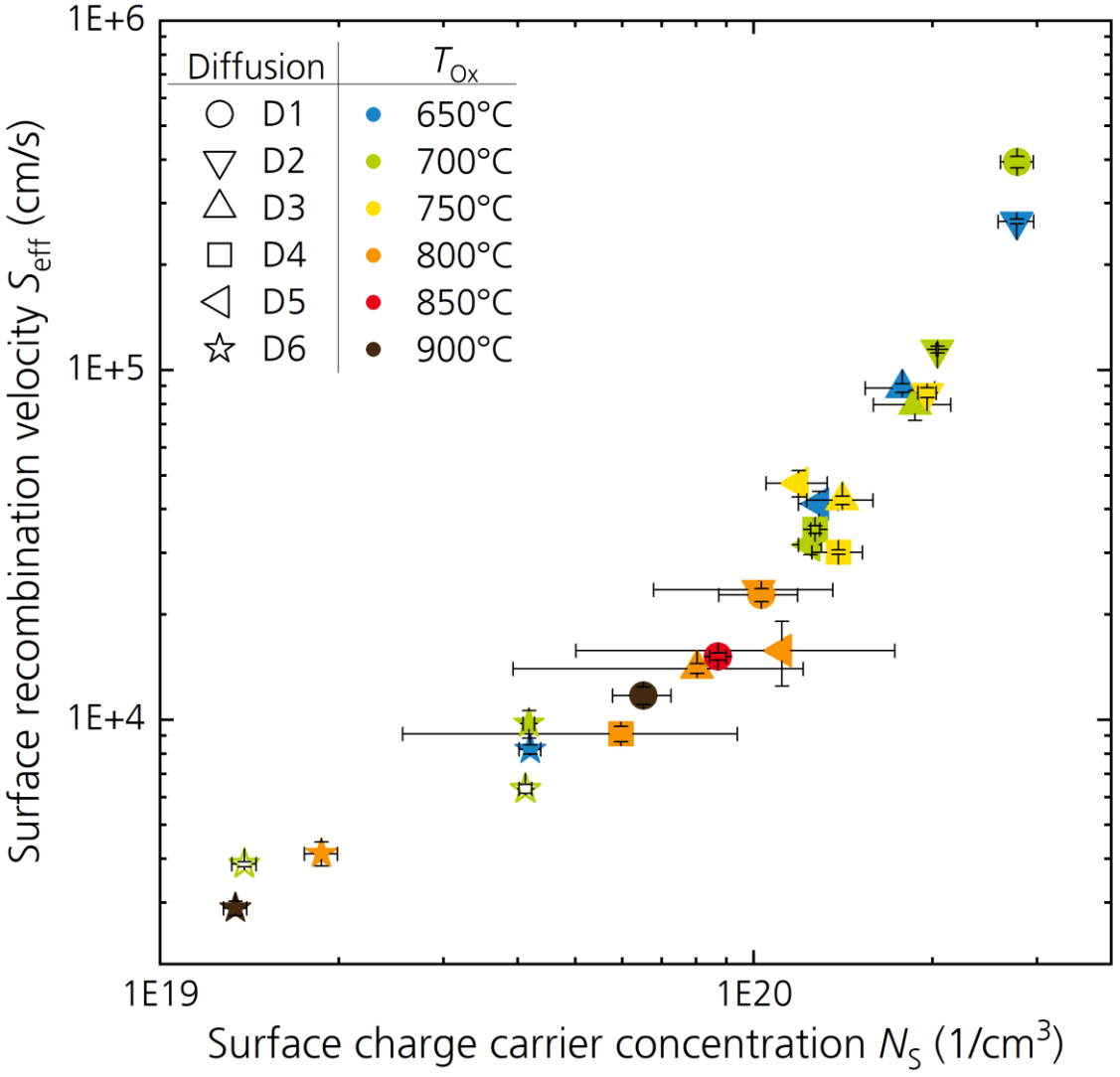
Surface Recombination Velocity
Results

- Strong dependence on N_S evident
- No clear trend for T_{OX} visible at similar N_S



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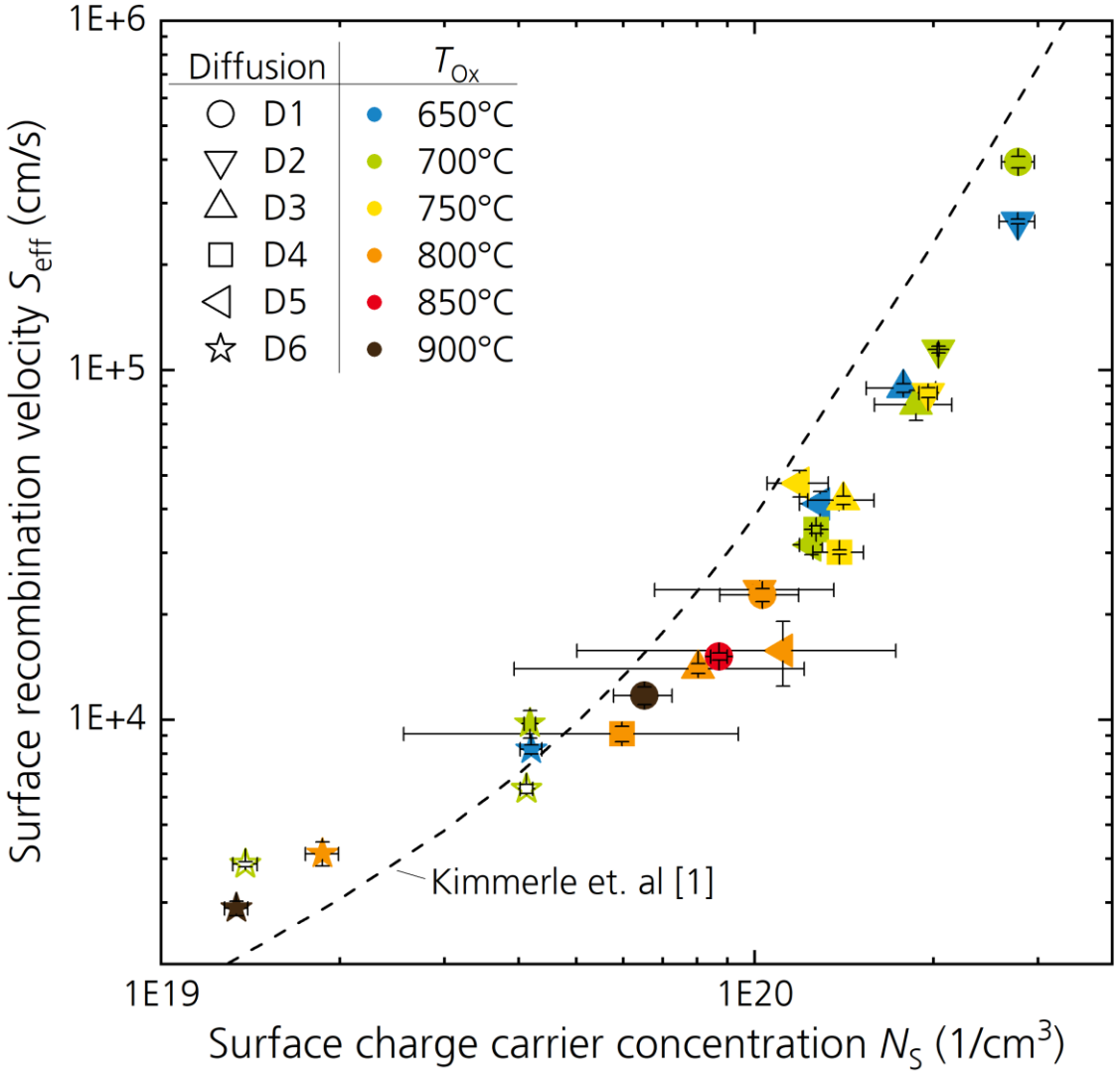
Surface Recombination Velocity
Results

- Parameterization from literature[1]

$$S_{\mathrm{eff}} = S_{\mathrm{eff}\,1}\left(\frac{N_S}{10^{19}\mathrm{cm}^{-3}}\right)^{\gamma_1} + S_{\mathrm{eff}\,2}\left(\frac{N_S}{10^{19}\mathrm{cm}^{-3}}\right)^{\gamma_2}$$

Source	S_{eff1} (cm/s)	γ_1	S_{eff2} (cm/s)	γ_2
Ref. [1]	1531	0.9	26	3



[1] A. Kimmerle et al., JAP vol. 119, 2016

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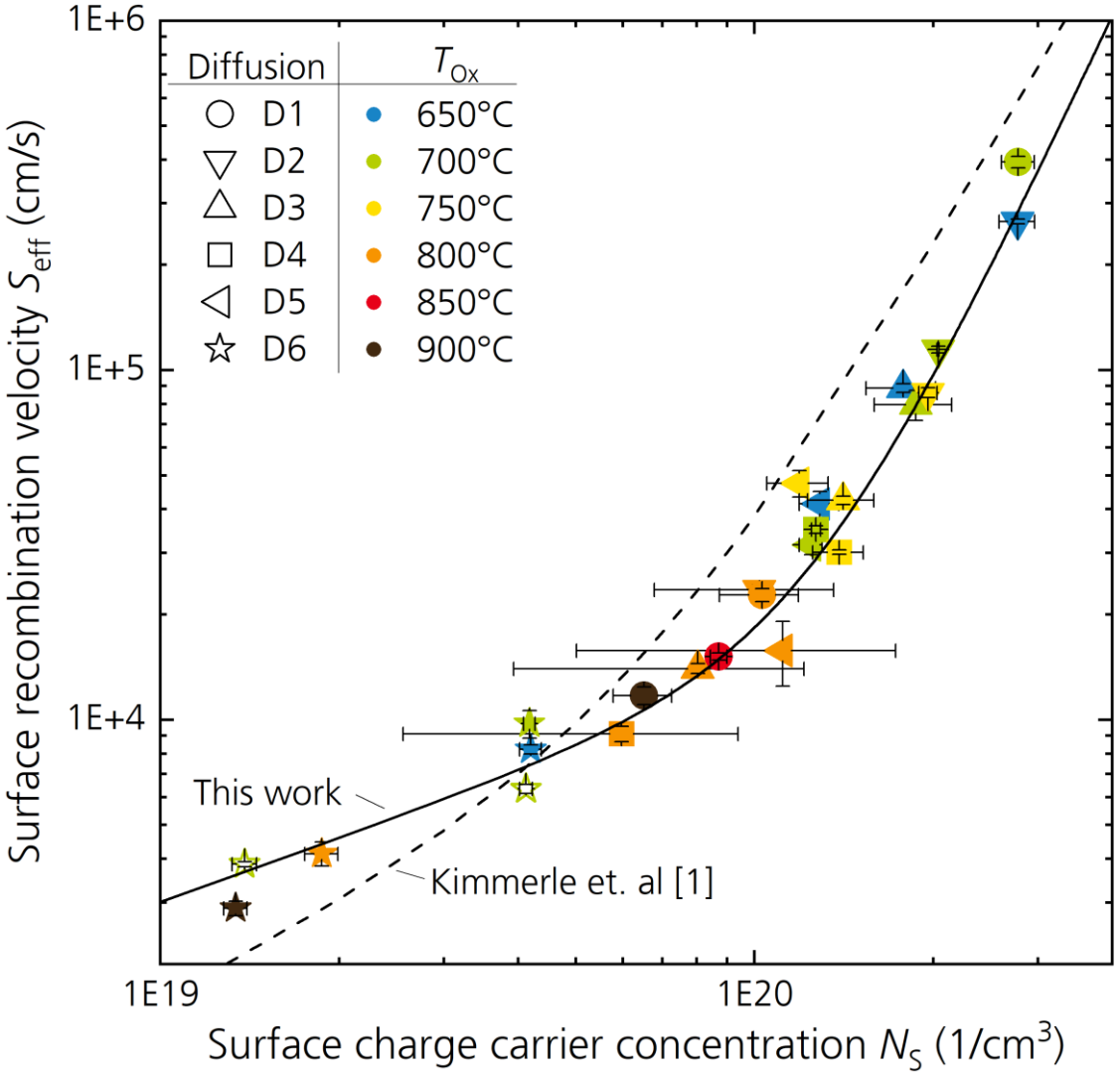
This work	3004	0.61	1.30	3.67



[1] A. Kimmerle et al., JAP vol. 119, 2016

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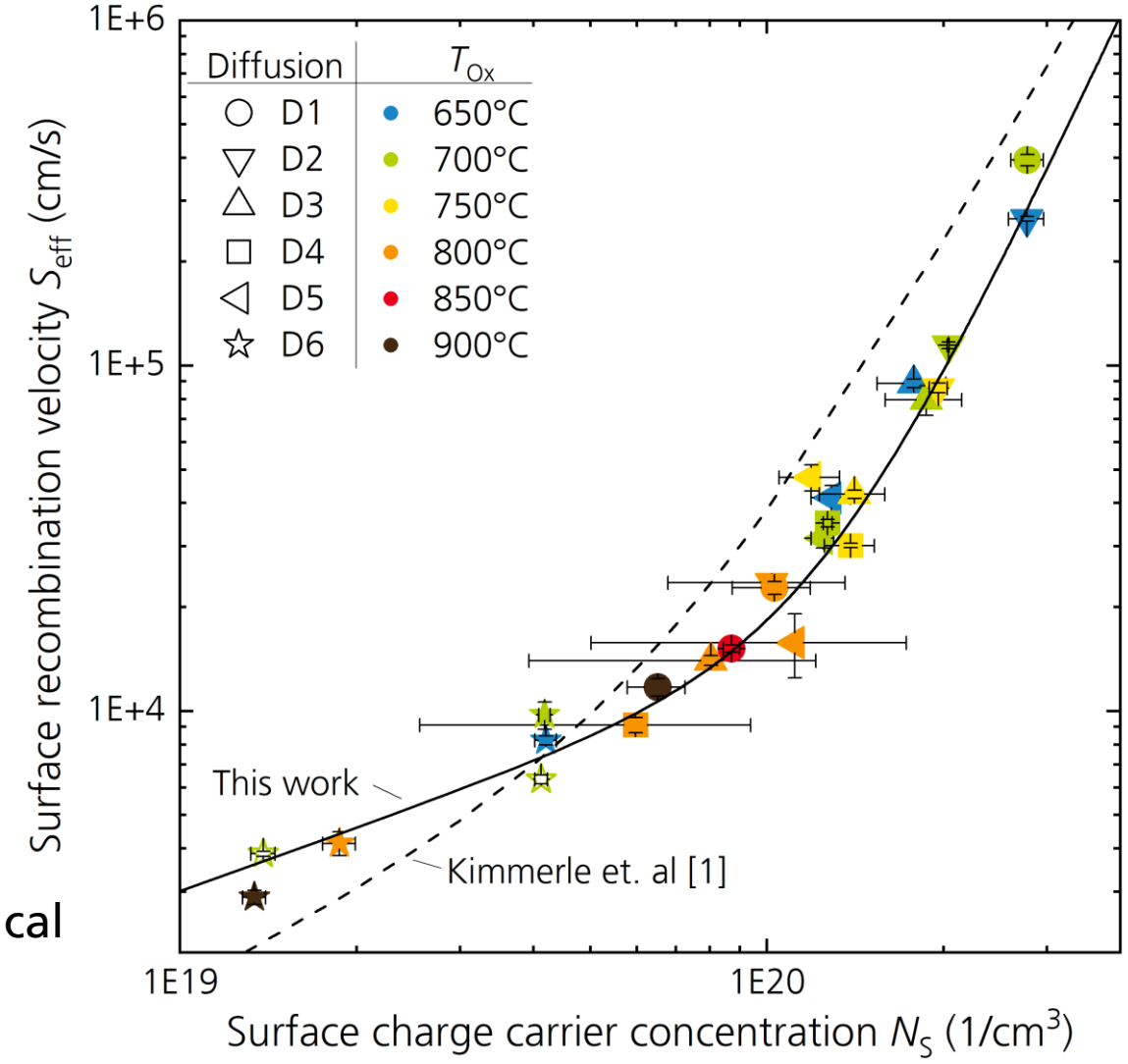
- Deviation possibly due to
  - New calibration, definition of N_S, technological improvement, sample preparation, …



[1] A. Kimmerle et al., JAP vol. 119, 2016

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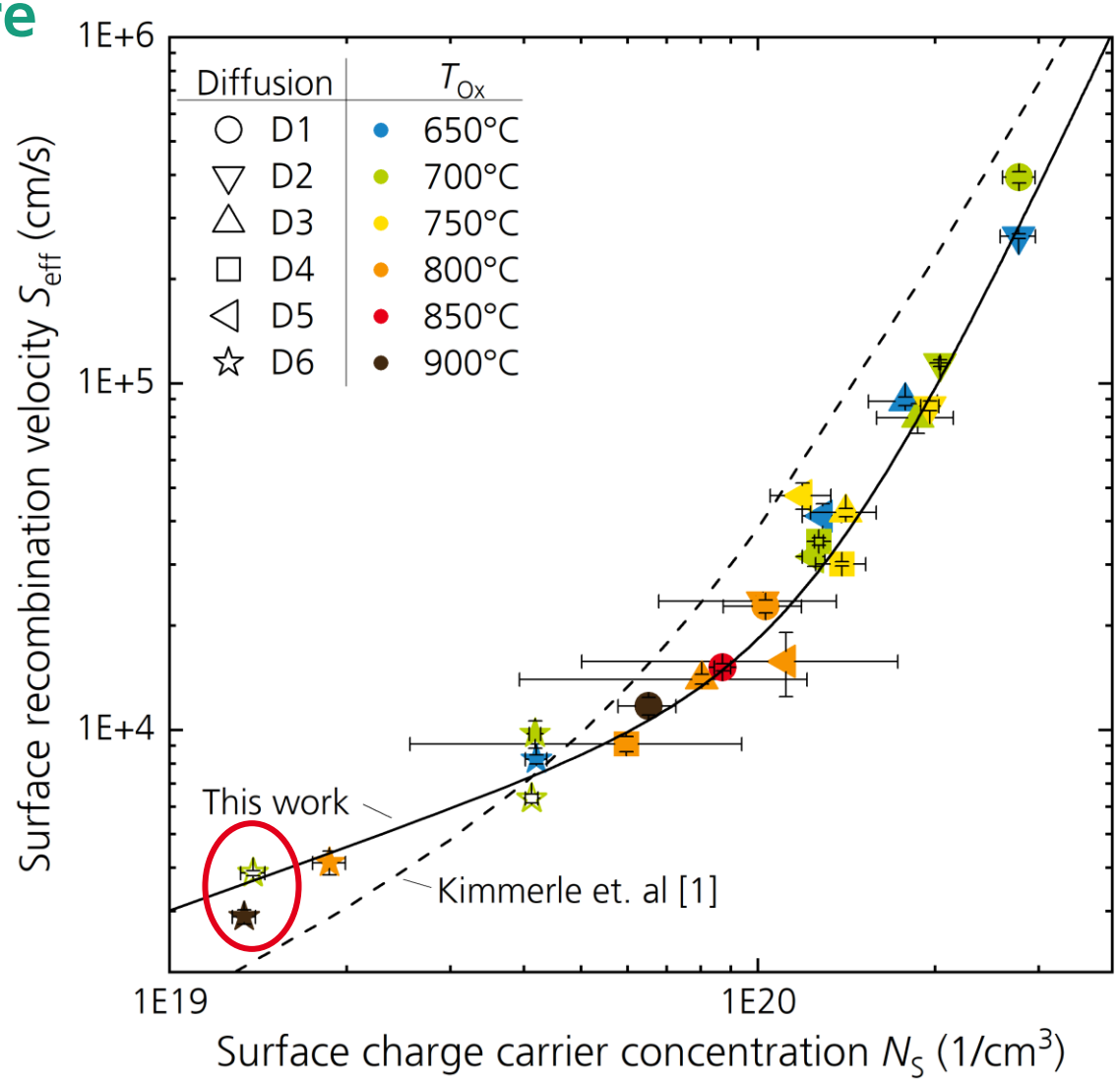
Surface Recombination Velocity
Dependence on Oxidation Temperature

- Parameterization based on data for all T_{OX}
- Separate experiment to investigate possible impact of T_{OX}



[1] A. Kimmerle et al., JAP vol. 119, 2016

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Surface Recombination Velocity
Dependence on Oxidation Temperature

$POCl_3$-diffusion D6 with $N_S = 4x10^{19}$ cm^{-3}

PSG etch + wet chemical cleaning

Therm. oxidation **900°C** $N_S = 1x10^{19}$ cm^{-3}	Therm. oxidation **700°C** $N_S = 4x10^{19}$ cm^{-3}

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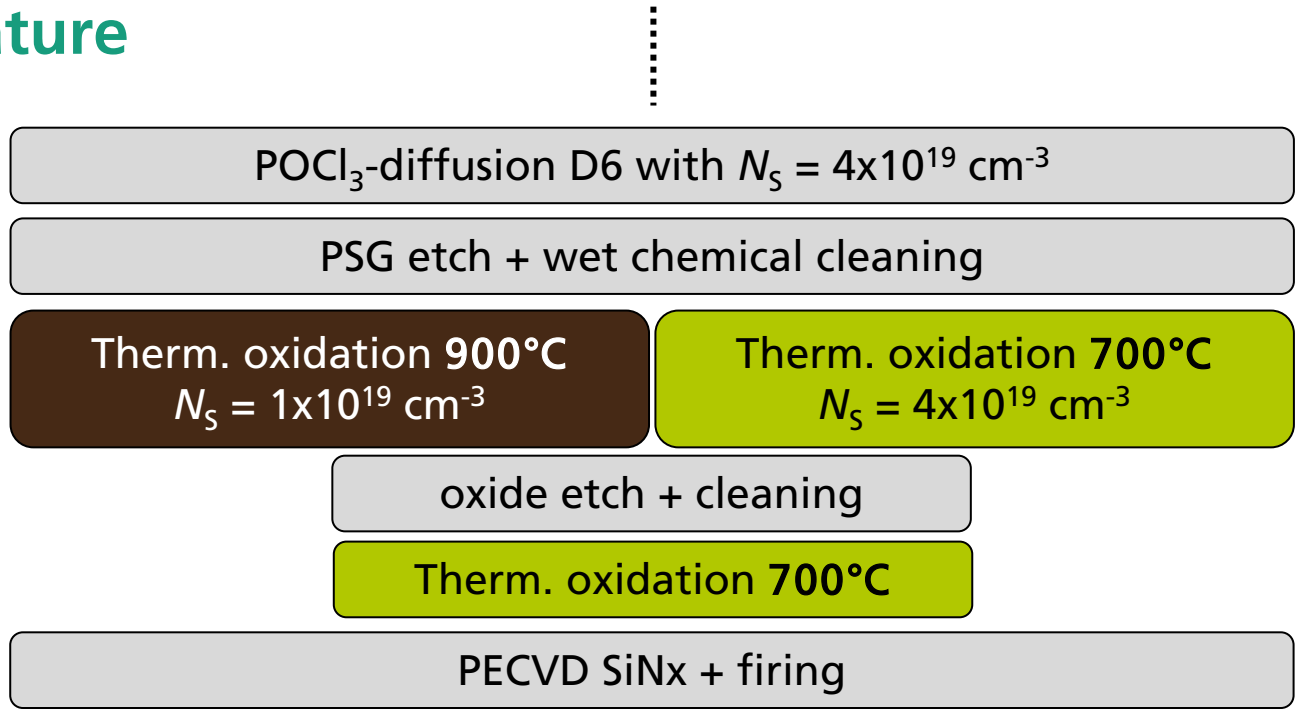
Surface Recombination Velocity
Dependence on Oxidation Temperature



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Surface Recombination Velocity
Dependence on Oxidation Temperature

- Replacing **900°C** oxide by 700°C oxide increases j_{0e} and S_{eff}

POCl$_3$-diffusion D6 with N_S = 4x10^{19} cm^{-3}

PSG etch + wet chemical cleaning

Therm. oxidation **900°C** N_S = 1x10^{19} cm^{-3}

Therm. oxidation **700°C** N_S = 4x10^{19} cm^{-3}

oxide etch + cleaning

Therm. oxidation **700°C**

PECVD SiNx + firing

j_{0e} (fA/cm²)	38 ± 1	46 ± 1
S_{eff} (cm/s)	2900 ± 100	3850 ± 50

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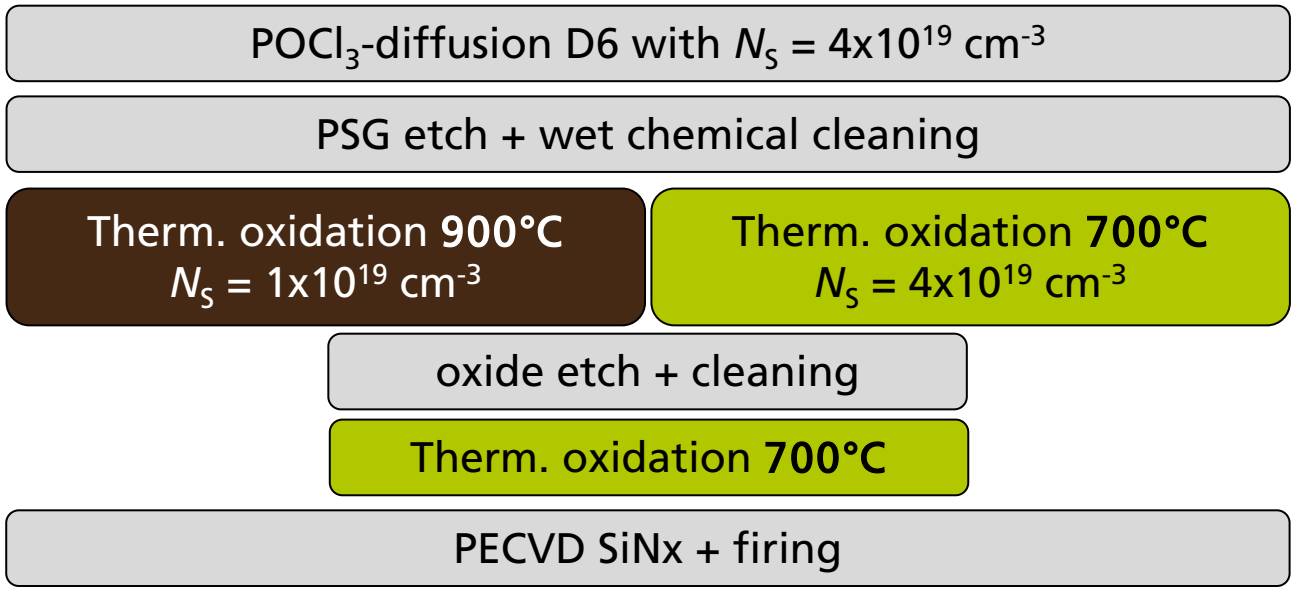
Surface Recombination Velocity
Dependence on Oxidation Temperature

- Replacing **900°C** oxide by 700°C oxide increases j_{0e} and S_{eff}
- Replacing **700°C** oxide by 700°C oxide reduces j_{0e} and S_{eff}

➔ Indication for superior passivation quality for higher oxidation temperature[1]



j_{0e} (fA/cm²)	38 ± 1	46 ± 1	45 ± 1	56 ± 4
S_{eff} (cm/s)	2900 ± 100	3850 ± 50	6300 ± 150	9700 ± 700

[1] E. H. Nicollian and J. R. Brews, MOS physics and technology (Wiley-Interscience, 2002)

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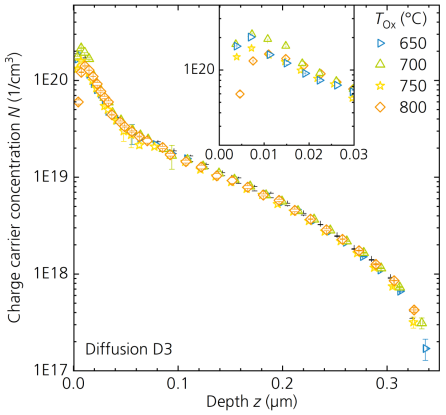
Revised Parameterization of the SRV at SiO_2/SiN_X-Passivated Surfaces

Summary & Conclusion



- Investigation of j_{0e} and S_{eff} using symmetric $n^+/n/n^+$-structures and numerical 1D modelling
  - Variation of doping profile and oxidation temperature[1]
  - Implementation of recent QSSPC calibration

[1] J. Horzel et al., this conference, poster sesssion Thu 2, poster J07

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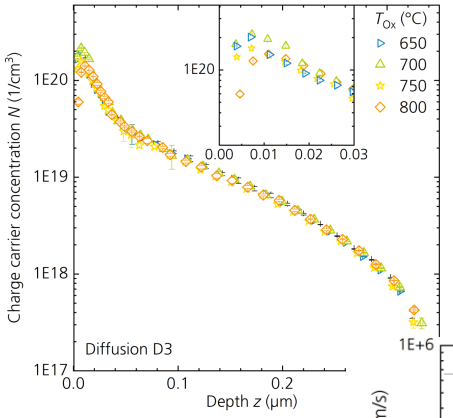
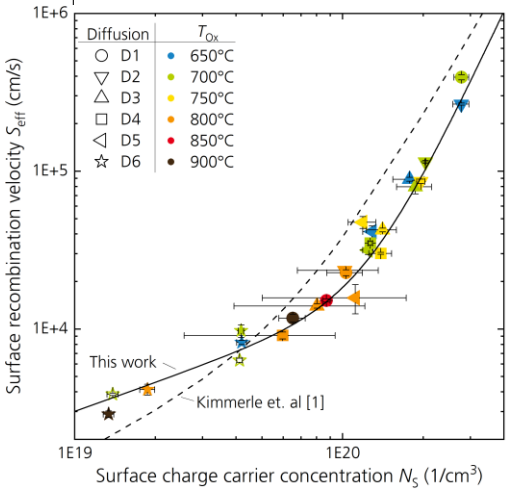
- Revised S_{eff} -parameterization





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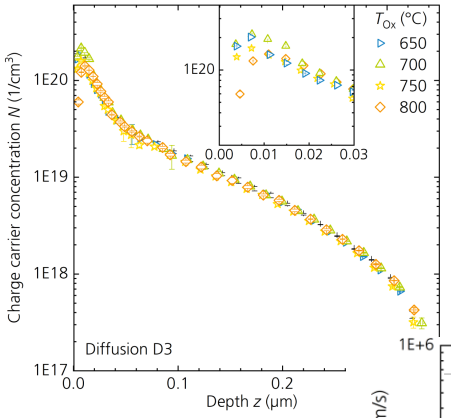
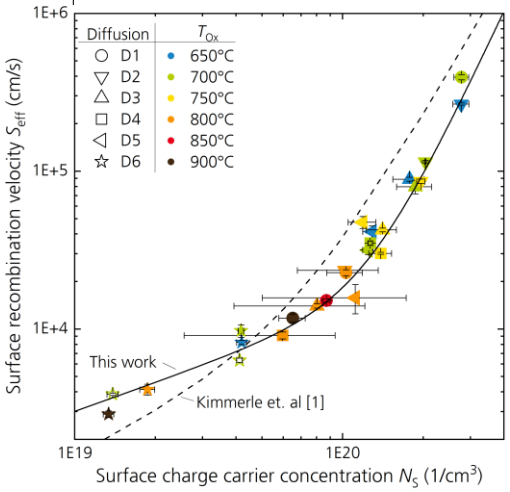
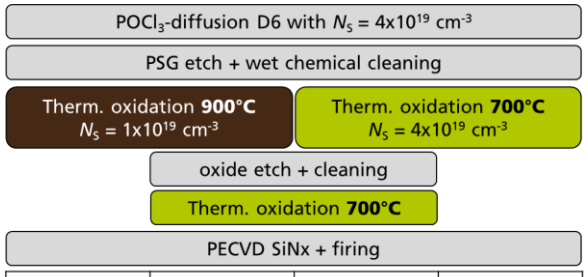




- Revised S_{eff} -parameterization

- Indication for superior passivation quality for higher oxidation temperature



j_{0e} (fA/cm²)	38 ± 1	46 ± 1	45 ± 1	56 ± 4
S_{eff} (cm/s)	2900 ± 100	3850 ± 50	6300 ± 150	9700 ± 700

[1] J. Horzel et al., this conference, poster sesssion Thu 2, poster J07

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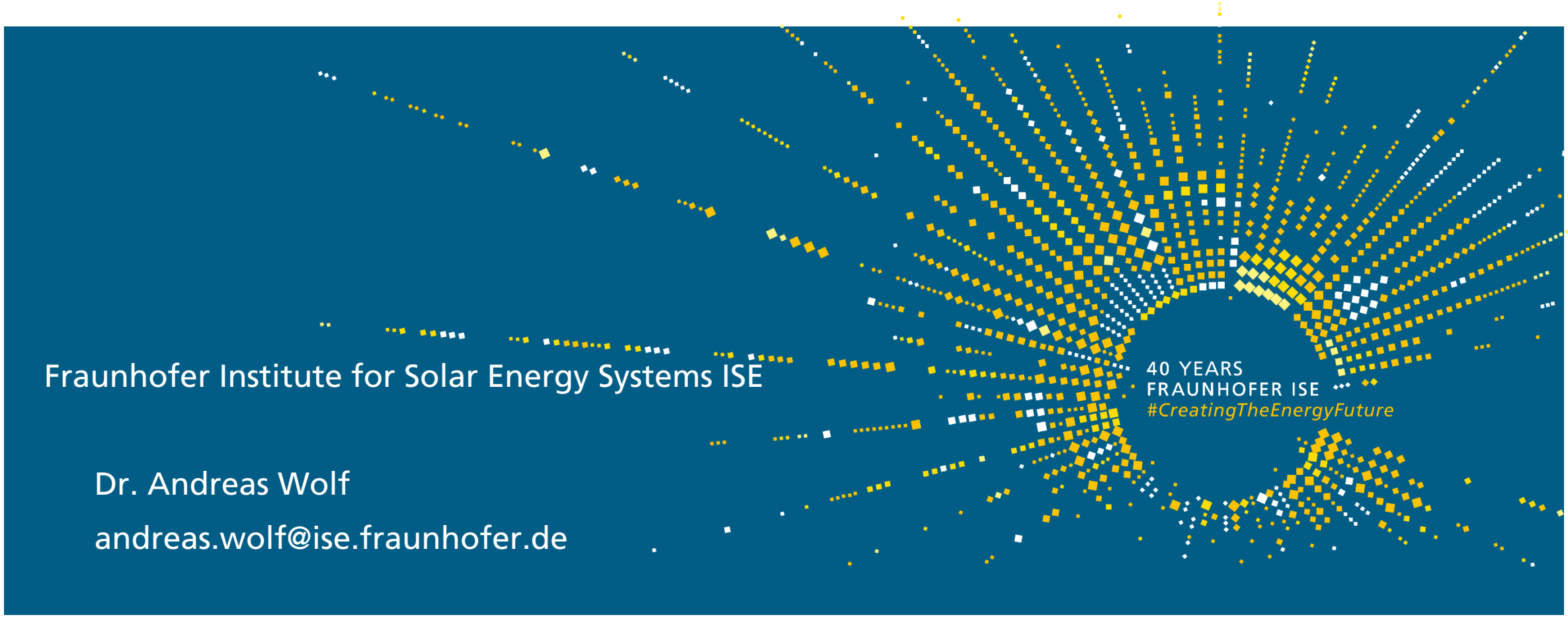

Fraunhofer Institute for Solar Energy Systems ISE

Dr. Andreas Wolf

andreas.wolf@ise.fraunhofer.de

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