FRAUNHOFER-INSTITUT FÜR SOLARE ENERGIESYSTEME ISE

Atmospheric Pressure Dry Textured Solar Cells

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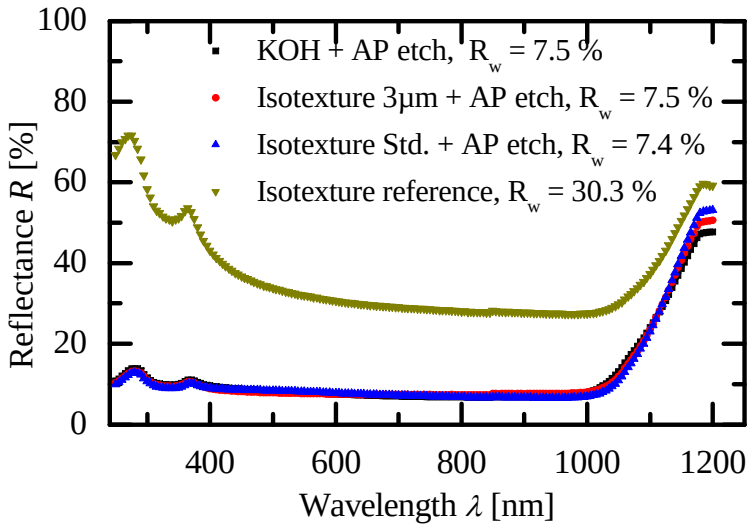
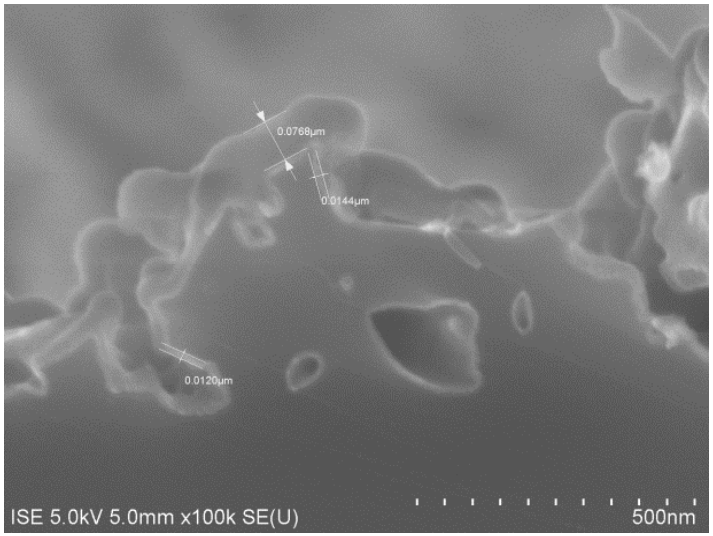
Mask-less atmospheric pressure dry etching technology

- Thermally induced environmentally friendly dry etching using F_2 gas
- Spontaneous etching of *c*-Si without need of plasma
- Results show better optical properties of the dry texture than wet-chemical texture
- Electrical properties not optimal due to porosity of the structures



Comparison of the optical properties of different dry etched and wet chemical surface



SEM image surface showing passivation layers (10 nm Al_2O_3 and 70 nm SiN_x and inherent porosity of texture surface

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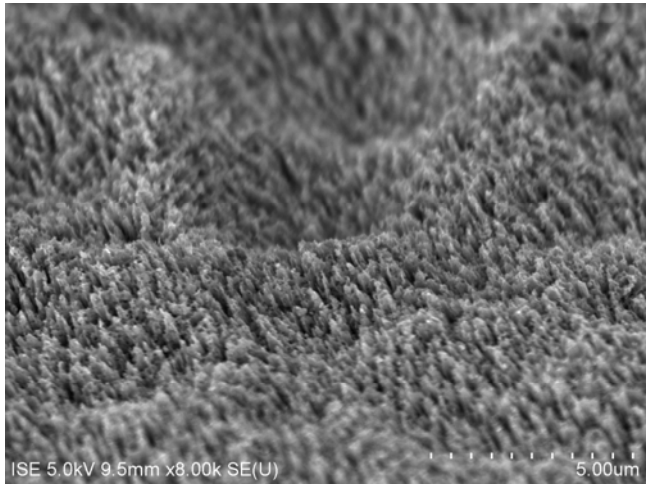
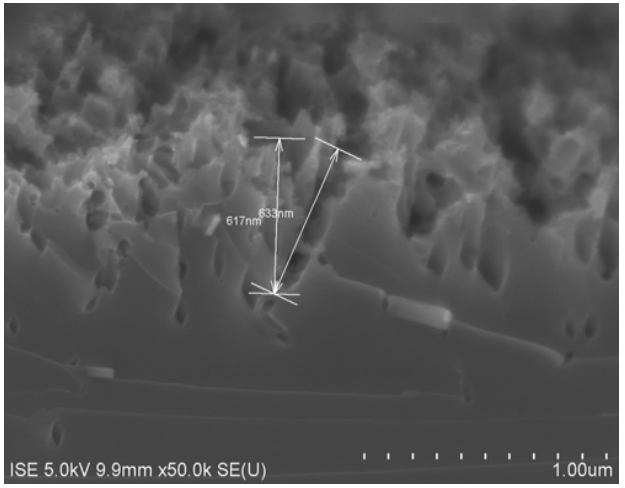
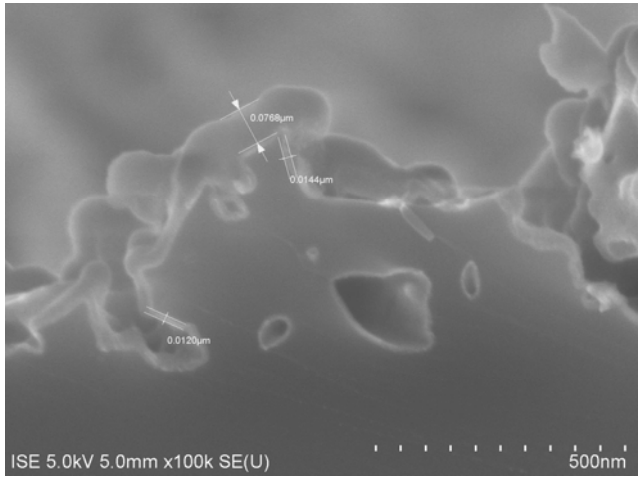
An Overview of Texture



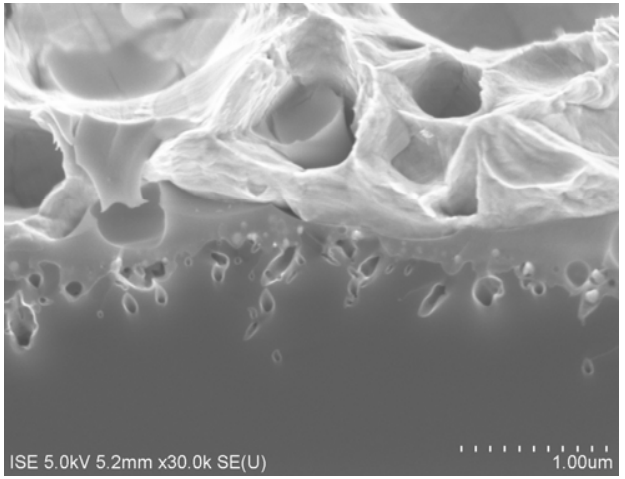
Overview of dry texture



Cross-sectional overview of dry texture



SEM image surface showing passivation layers (10 nm Al_2O_3 and 70 nm SiN_x and inherent porosity of texture surface



Cross-sectional SEM image of a busbar

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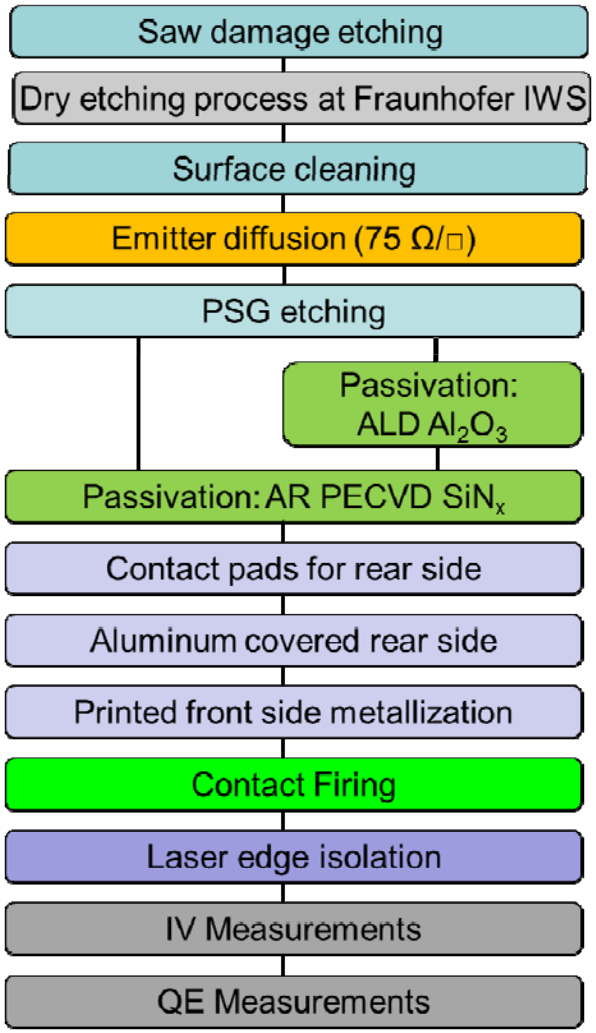
First Al Back Surface Field (Al-BSF) solar cell batch



Process flow for Al-BSF cells

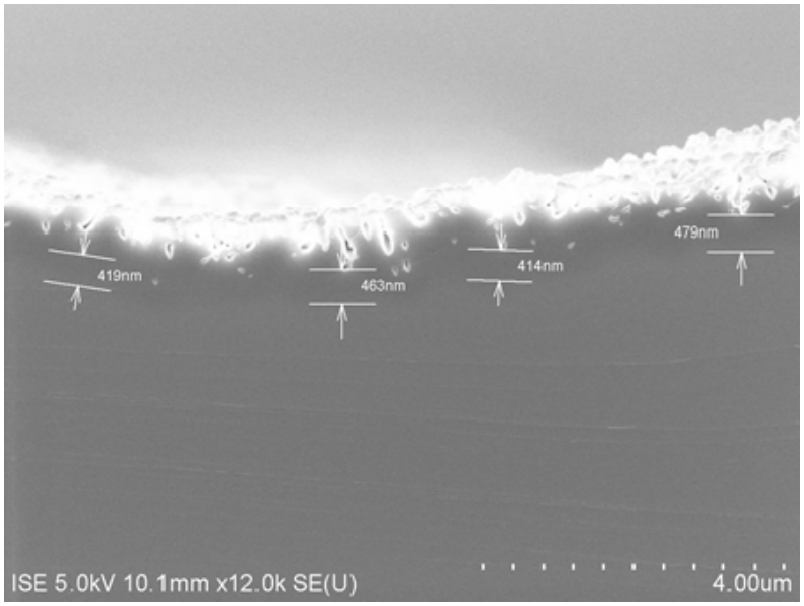
First Al-BSF solar cell batch

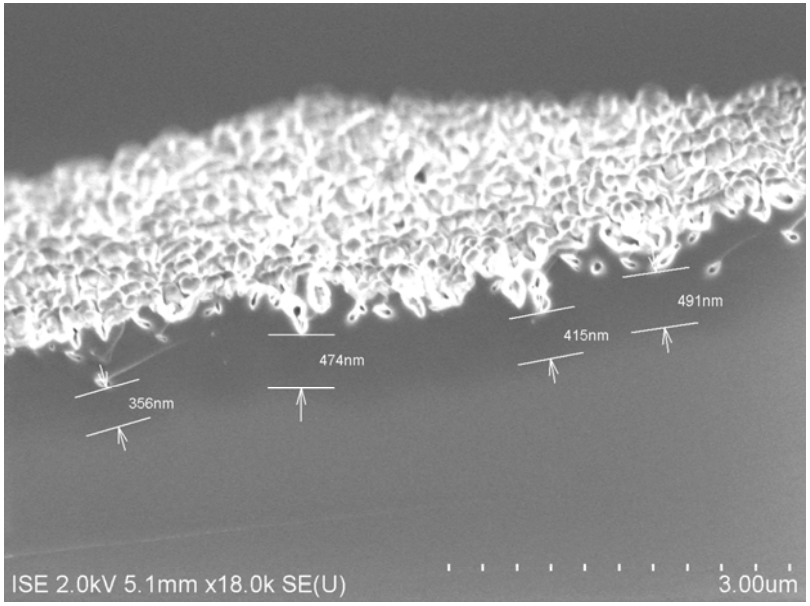
- *p*-type mc wafers
  - Reference cells (Isotexture)
  - Test cells (SDR + dry-texture)
    - Front passivation – PECVD SiN_x (P1)
    - Front passivation – ALD AlO_x + PECVD SiN_x (P2)

- $POCl_3$ Diffusion – 70 Ω/sq
  - Average R_{sh} for reference cell: 68.10 Ω/sq
  - Average R_{sh} for dry textured cell: 49.11 Ω/sq

- Screen printed front and rear contacts
  - Average R_c for reference cell: 5.68 mΩ/cm^2
  - Average R_c for dry textured cell: 20.53 mΩ/cm^2

SEM overview





Cross-sectional overview of dry textured surfaces after diffusion and passivation

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Cell results

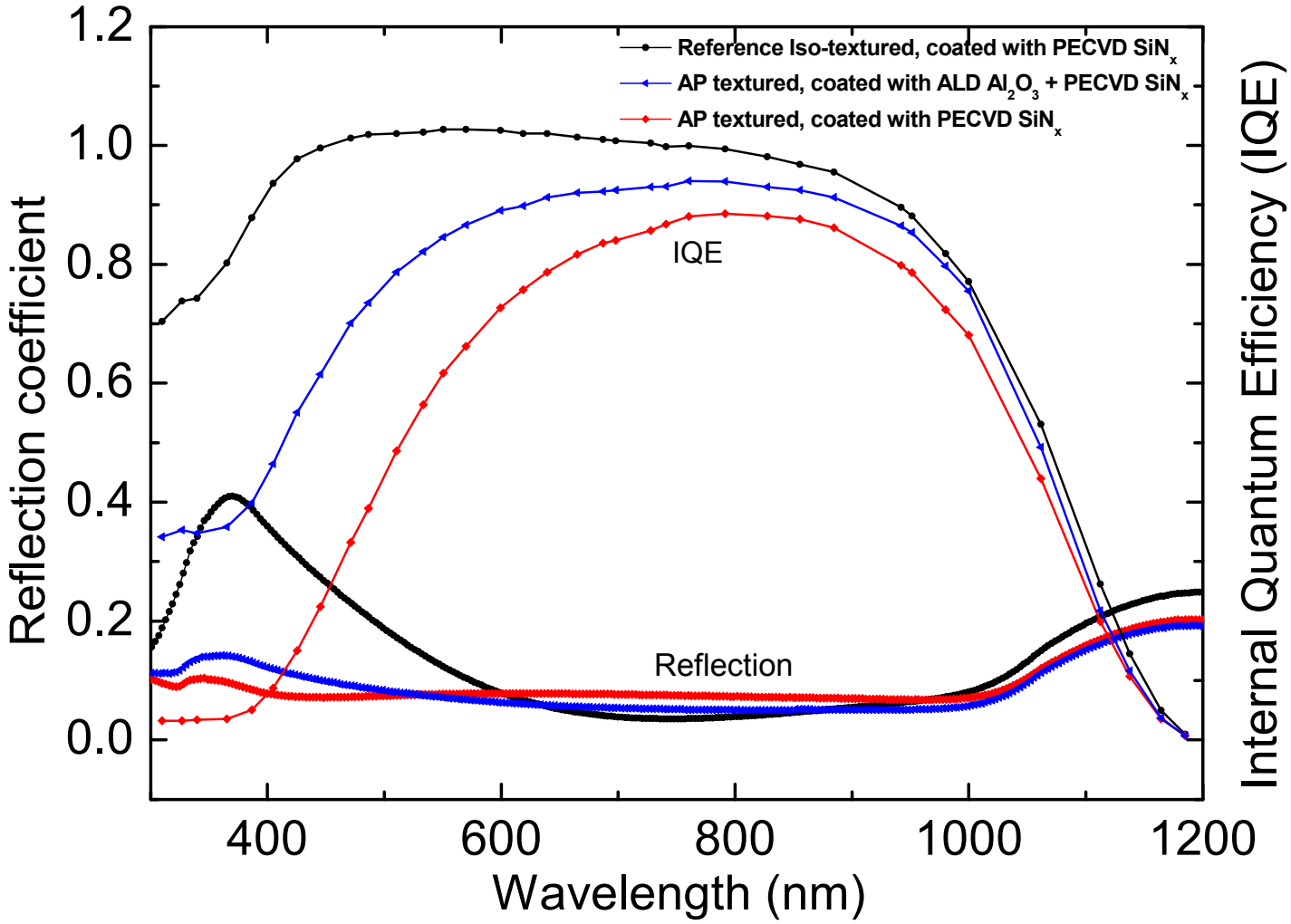
PECVD SiN_x (P1)

Best cell results	V_{oc} (mV)	J_{sc} (mA)	η (%)	FF (%)	Loss due to R_s (%)	J_{01} (pA/cm²)	J_{02} (nA/cm²)	S_{ser} (Ωcm²)	S_{sh} (Ωcm²)
Reference cells	615.4	34.08	16.53	78.78	2.88	1.19	20	0.77	14528
Test cells (SDR)	580.7	26.85	11.64	74.68	4.46	3.97	52	1.07	1843

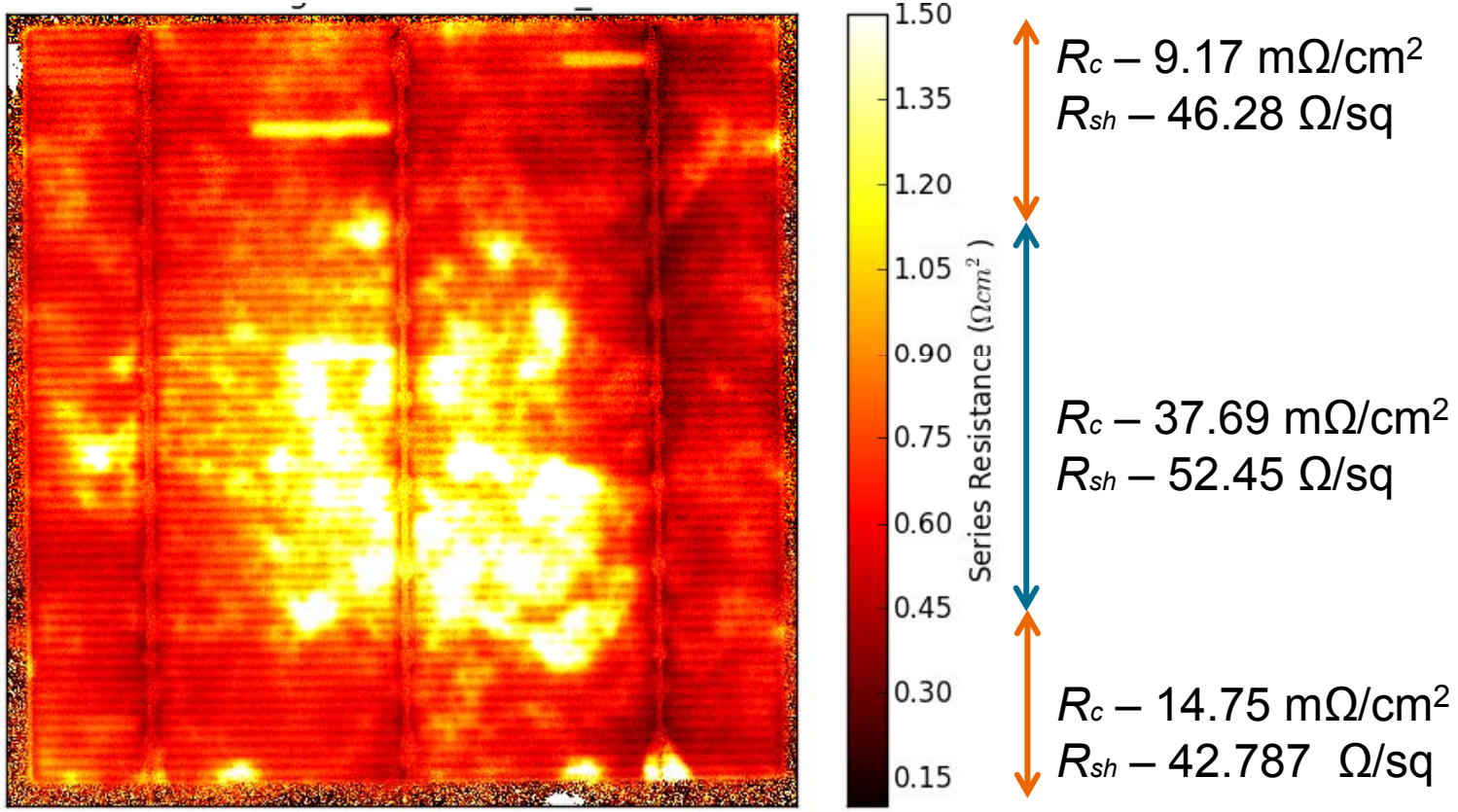
ALD AlO_x + PECVD SiN_x (P2)

Best cell results	V_{oc} (mV)	J_{sc} (mA)	η (%)	FF (%)	Loss due to R_s (%)	J_{01} (pA/cm²)	J_{02} (nA/cm²)	S_{ser} (Ωcm²)	S_{sh} (Ωcm²)
Reference cells	614.9	34.48	16.38	77.26	3.05	1.06	38	0.66	4640
Test cells (SDR)	602.6	31.34	14.22	75.32	3.61	2.07	21	0.79	792
Test cells (Isotexture)	602.2	32.23	15.05	77.55	1.95	1.31	56	0.47	1326

Quantum Efficiency



Power loss due to contacts



Series resistance map extracted from CDCR measurements of dry etched wafer

Rc and *Rsh* measured by using TLM

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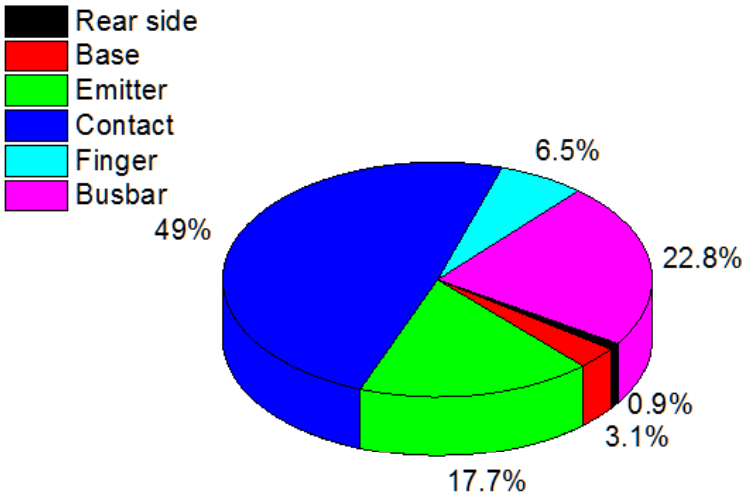
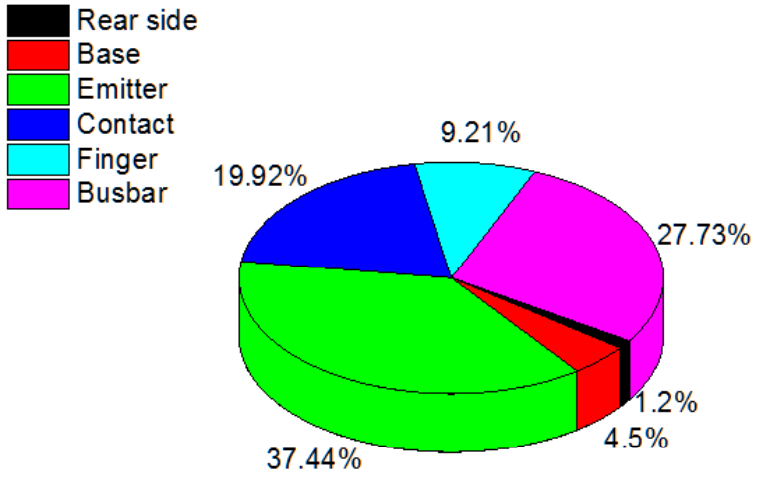
Loss analysis

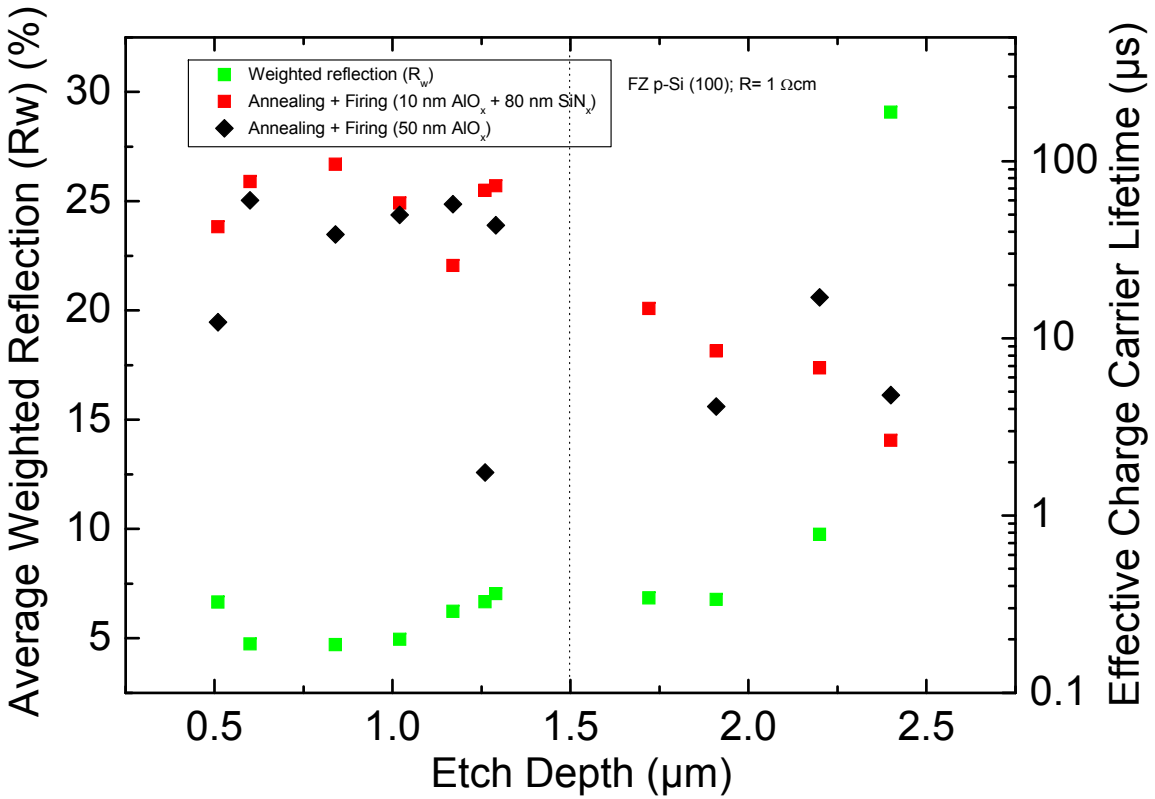


Ohmic power loss distribution of the dry textured cell



Ohmic power loss distribution of an isotextured cell

Lifetime results



Comparison of the electrical performances of dry etched surfaces after passivating them using thin and thick ALD AlOx

- Thicker ALD Al_2O_3 layer promising after annealing (τ_{eff} up to 280 µs), but not stable after high temperature process

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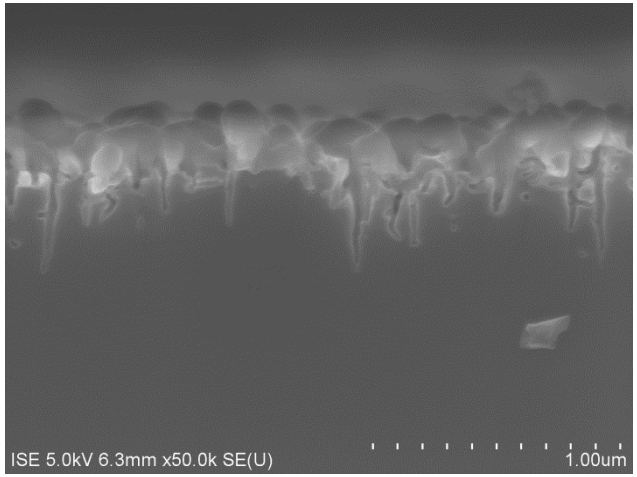
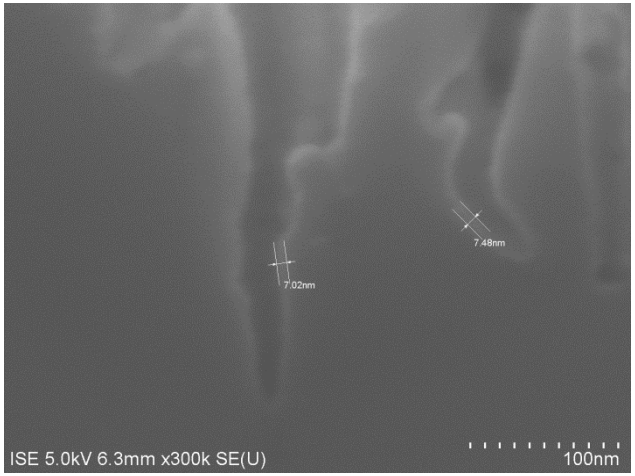
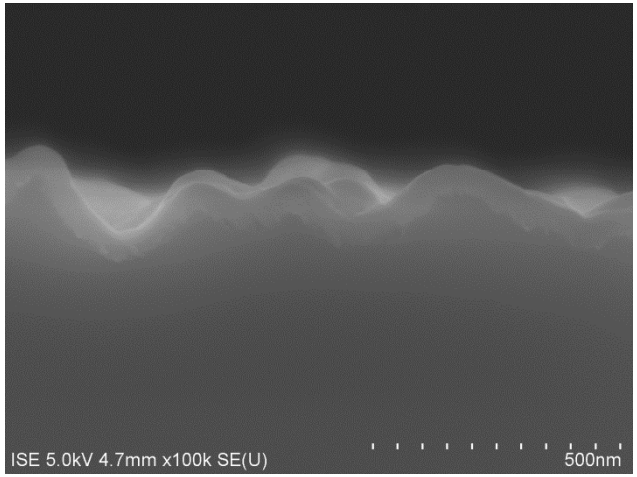
Latest results



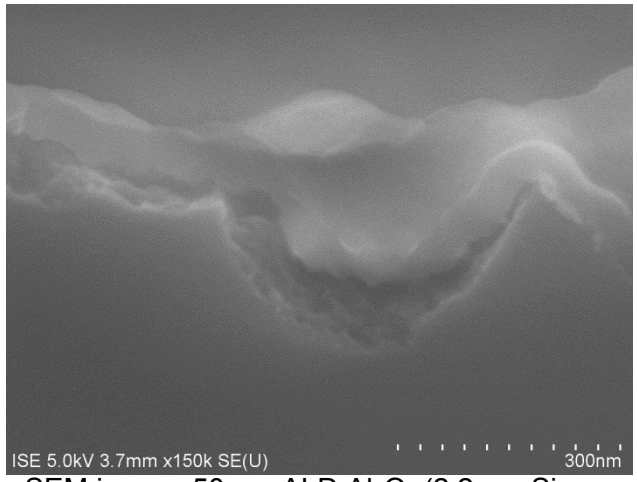
SEM image: ALD Al_2O_3 + SiN_x (0.84 µm Si removal)



SEM image: 10 nm ALD Al_2O_3 (0.84 µm Si removal)



SEM image: 50 nm ALD Al_2O_3 (2.2 µm Si removal)



SEM image: 50 nm ALD Al_2O_3 (2.2 µm Si removal)

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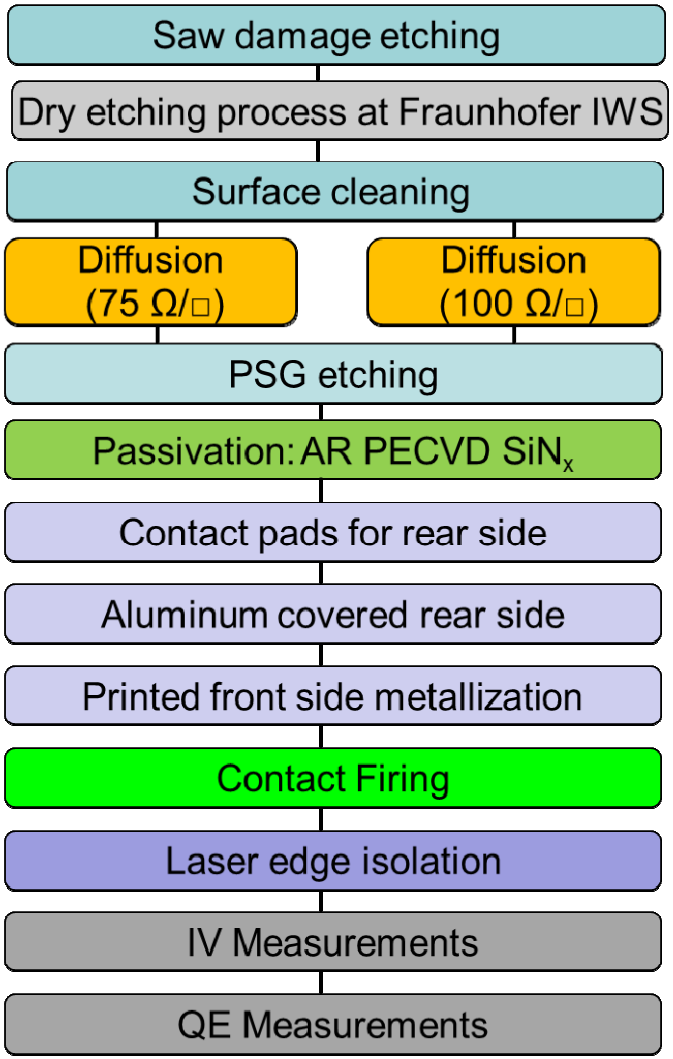
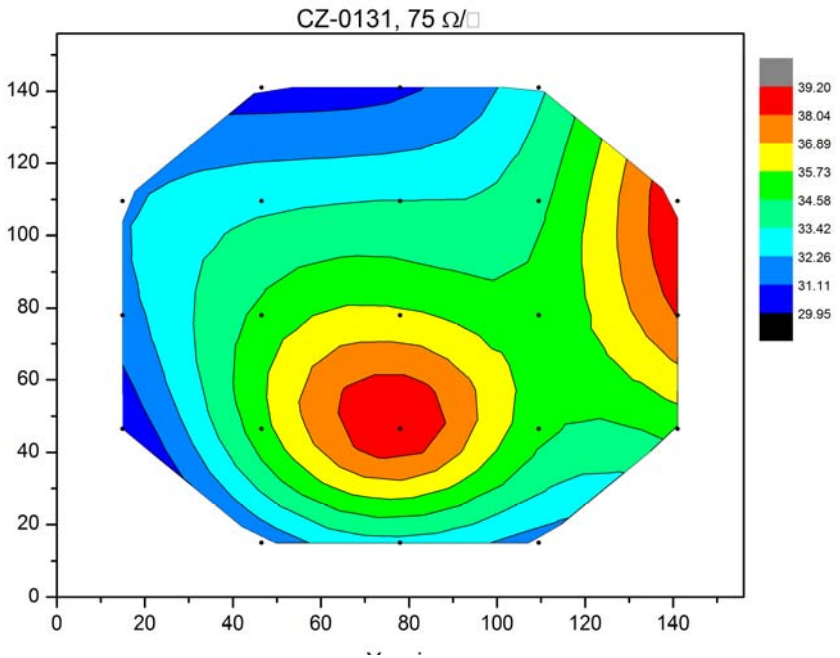
Al-BSF solar cell batch

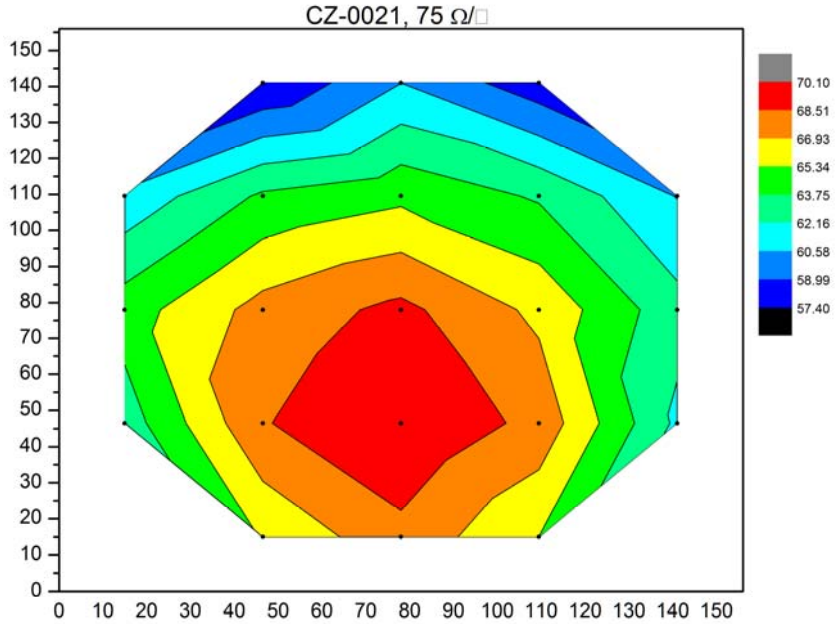


Process flow for Al-BSF cells

Diffusion process in nano-structured surface



Dry textured cell with 75 Ω/□ emitter



Wet textured cell with 75 Ω/□ emitter

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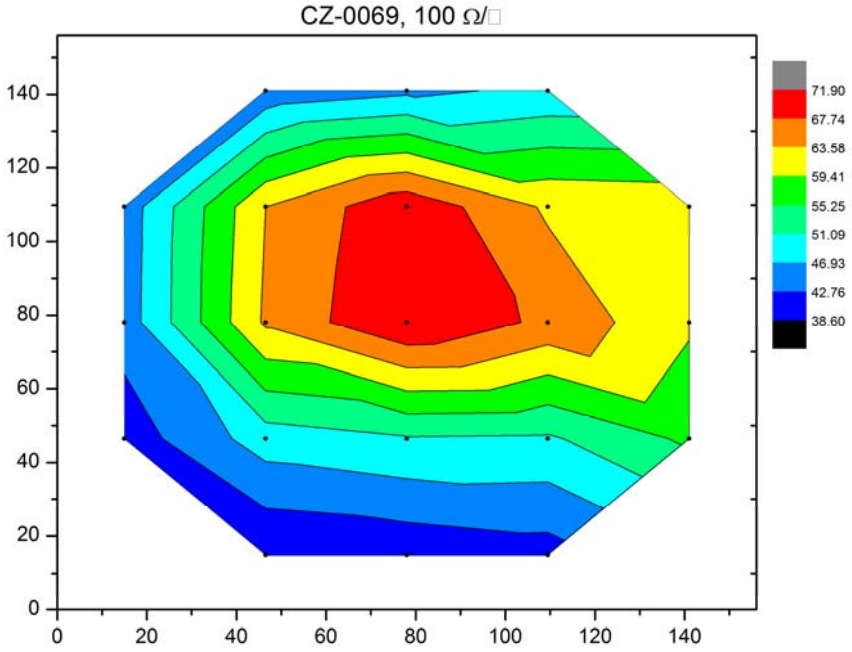
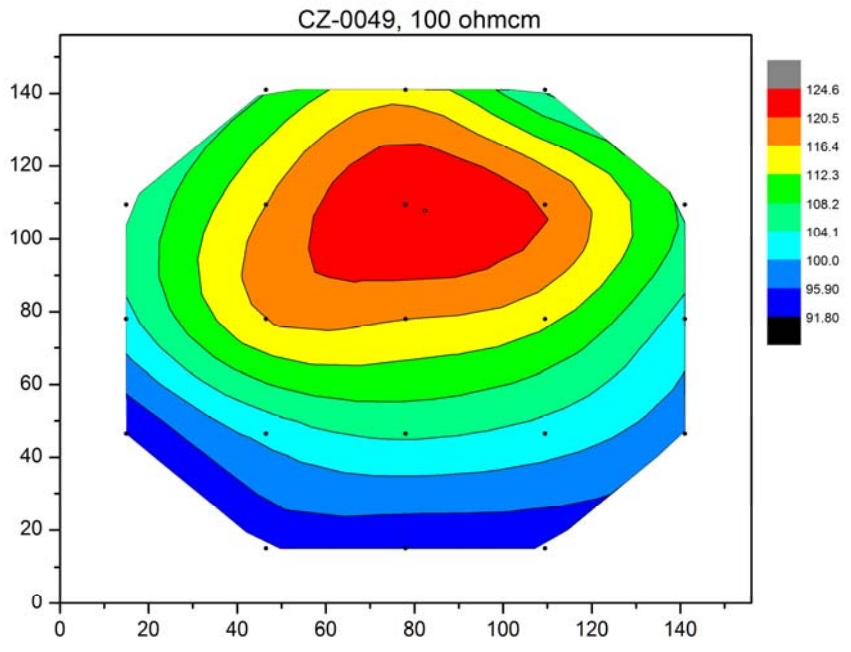
Diffusion process in nano-structured surface



Dry textured cell with 100 Ω/□ emitter



Wet textured cell with 100 Ω/□ emitter

Diffusion process in nano-structured surface

- Inhomgenous dopant distribution in the Wafer area
- Problems:
  - Hygroscopic nature of the textured surface
  - Texture homogeneity along the wafer area

- High sheet resistance
  - Better blue response of the cell
  - Risk of having too low surface [P] for screen printing

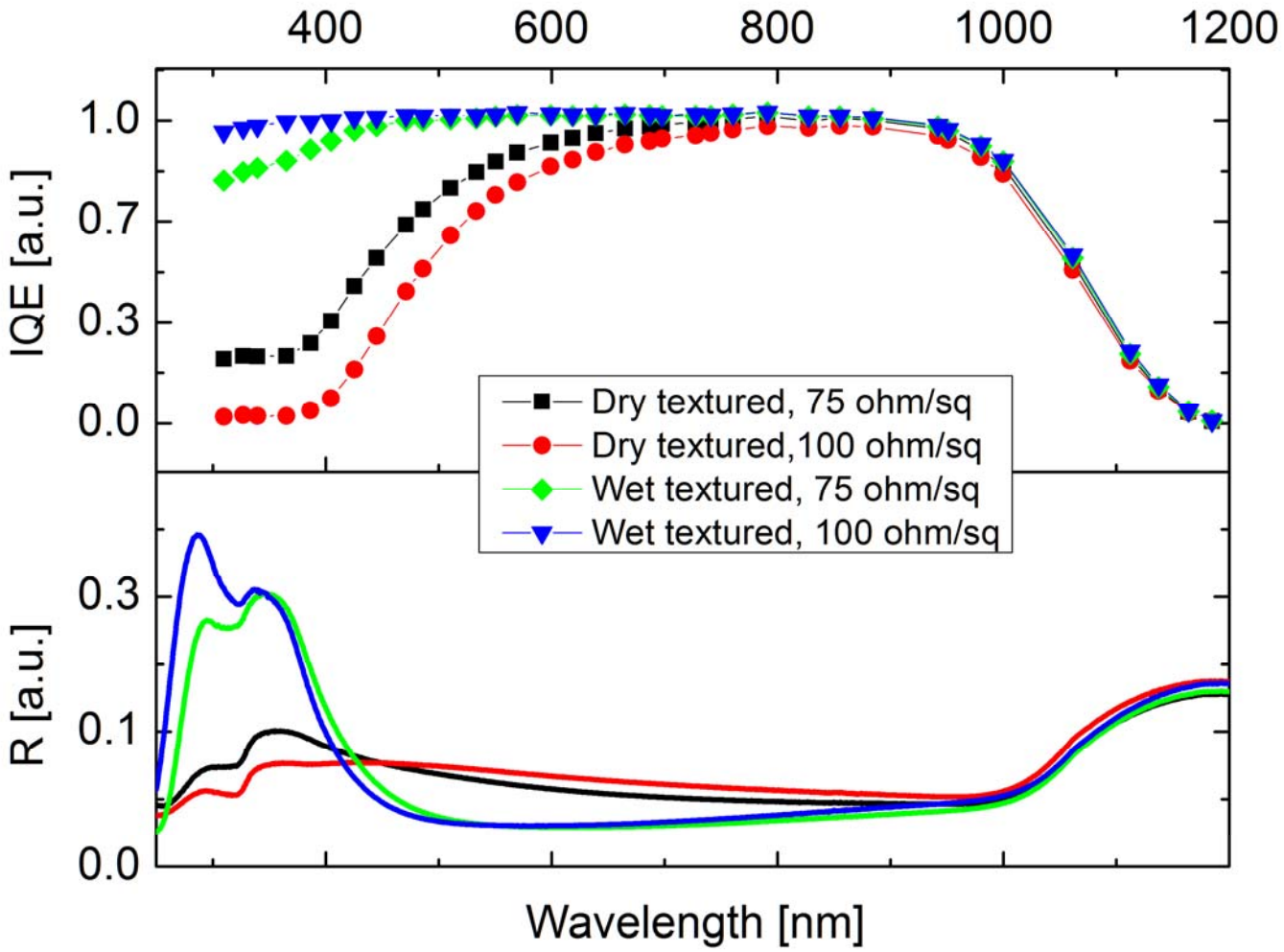
- Low sheet resistance
  - High doping leading bad blue response of the cell
  - Higher Auger recombination

Al-BSF solar cell batch (CZ mono)

Best cell results **(75 Ω/□)**	V_{oc} (mV)	J_{sc} (mA)	η (%)	FF (%)	Loss due to R_s (%)	J_{01} (pA/cm^2)	J_{02} (nA/cm^2)	S_{ser} (Ωcm^2)	S_{sh} (Ωcm^2)
Reference cells	628.6	36.37	18.03	79.21	3.10	0.54	25	0.56	18916
Test cells	612.4	31.54	13.66	70.73	12.23	1.05	12	2.35	41100

Best cell results **(100 Ω/□)**	V_{oc} (mV)	J_{sc} (mA)	η (%)	FF (%)	Loss due to R_s (%)	J_{01} (pA/cm^2)	J_{02} (nA/cm^2)	S_{ser} (Ωcm^2)	S_{sh} (Ωcm^2)
Reference cells	625.4	35.39	10.88	49.15	32.98	0.11	44	5.93	14443
Test cells	593.0	25.40	7.40	49.11	33.39	0.83	27	7.78	15078

Quantum Efficiency



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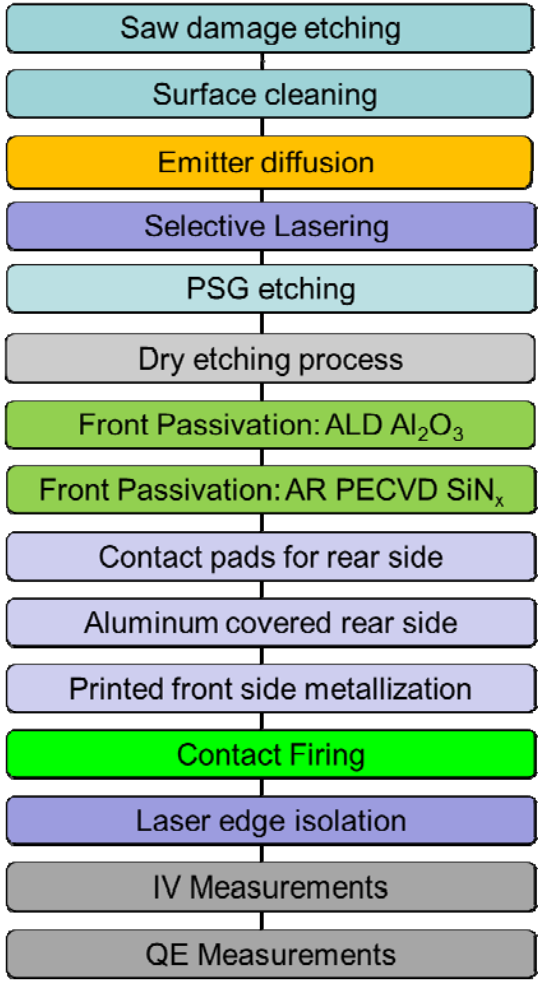
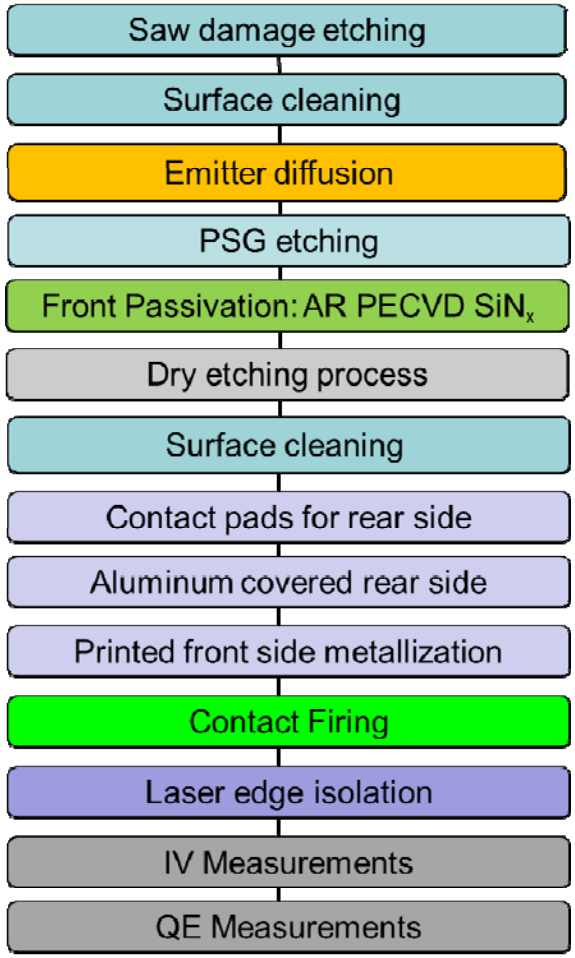
Conclusion

- Cell process needs to be optimized for AP textured wafers
- Optimization of the emitter necessary for AP etched wafers
  - Drying of wafes before diffusion process
  - Modifications in the tube diffusion process
- Surface passivation still a major issue for AP etched wafers
  - Slower depositon of ALD Al_2O_3 layer
  - Other passivation layers: Thermal SiO_x
  - Adaptation of texture for better passivation
- Possibility of alternative cell process flow designs need to be investigated.

Alternative solar cell design for AP textured cells



Cell process design 1



Cell process design 2

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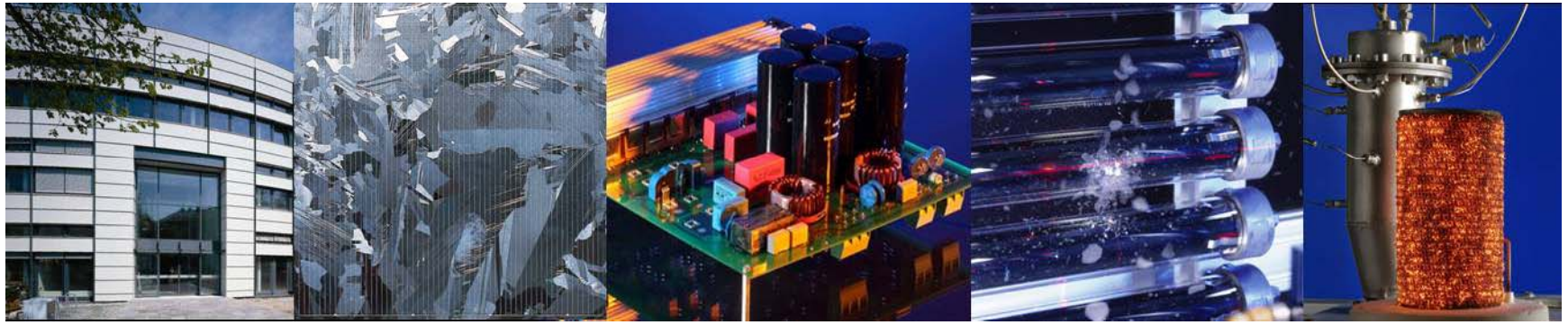
Vielen Dank für Ihre Aufmerksamkeit!



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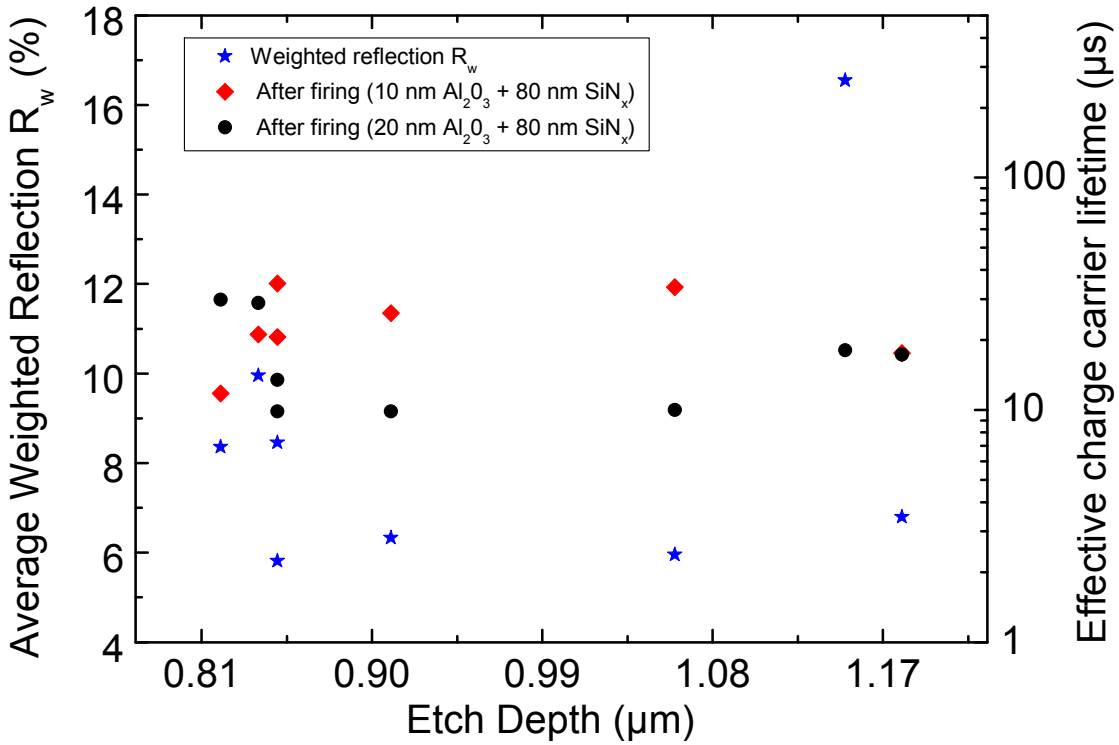
Latest lifetime results-1 (first set of FZ wafers, 120422)

- Improved surface passivation achieved with ALD Al_2O_3
- Very less amount of Si removal required : Best results with 0.6 – 0.8 µm removal
- Improvement of optical properties : R_w ~ 4.5% (mono), 8% (multi)
- Improvement in electrical properties : τ_{eff} ~ 95 µs after Firing

Latest results – 2 (2nd set of FZ wafers, 120422)



Comparison of the electrical performances of dry etched surfaces after passivating them using thin and thick ALD Al_2O_3

- Alternative passivation:
  - Thermal SiO_x layer optimization for the textured surfaces
  - Sputtered layers !

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