Efficiency optimized laser processing for thin-film silicon solar modules

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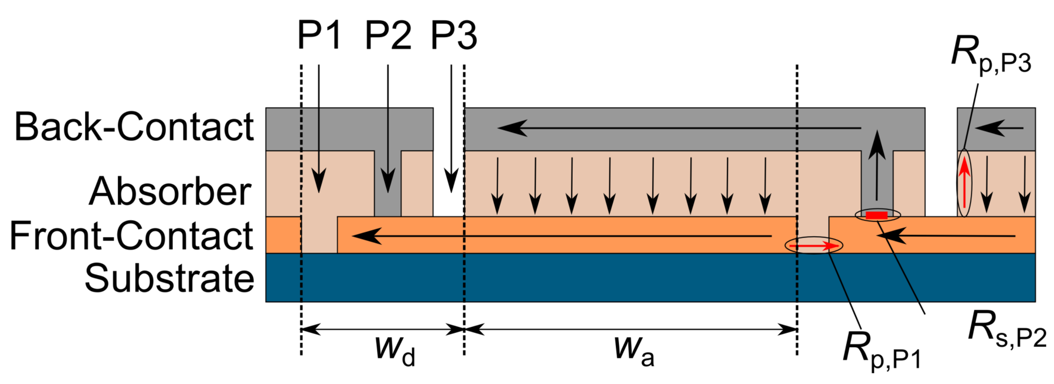
Motivation

Minimization of interconnection losses of thin-film silicon solar modules



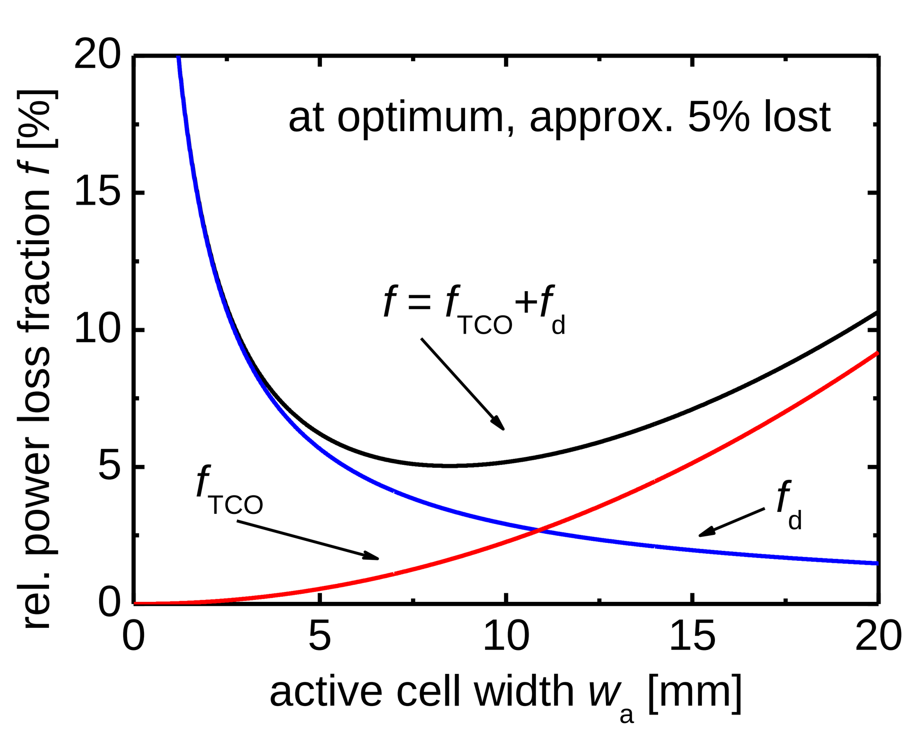
Module cell stripe in p-i-n superstrate topology

Origins of module losses

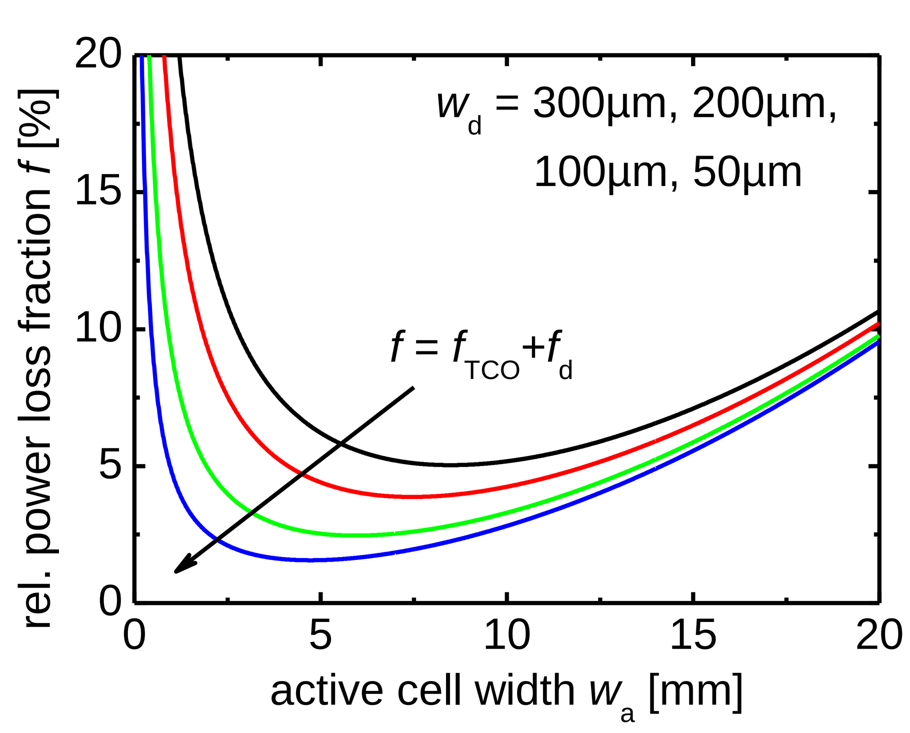
- Inherent interconnection losses

$$f = \underbrace{\boxed{\frac{w_d}{w_a+w_d}}}_{f_d} + \underbrace{\boxed{\frac{J_{MPP}}{U_{MPP}}\cdot\frac{R_\square}{3}\cdot\frac{w_d\cdot w_a^2+w_a^3}{w_a+w_d}}}_{f_{TCO}}$$

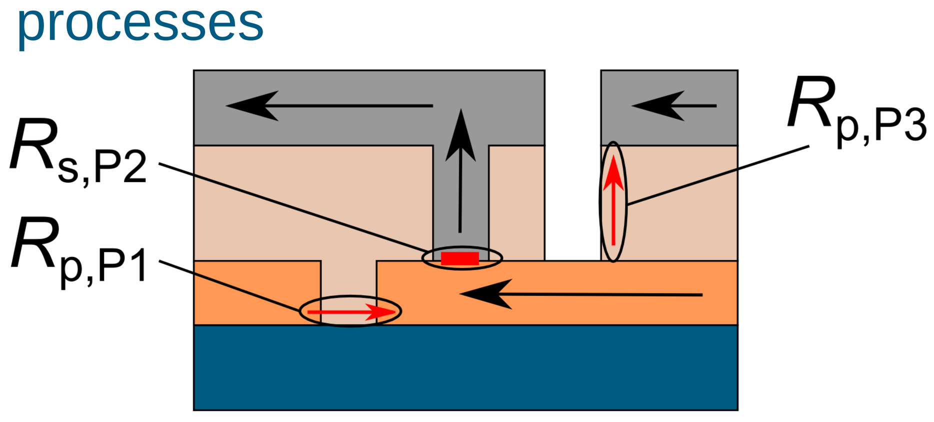
- Area loss fraction f_d
- Loss fraction due to current collection in the TCO front-contact f_{TCO}



- Influence of interconnection width reduction



- Damages due to interconnection processes



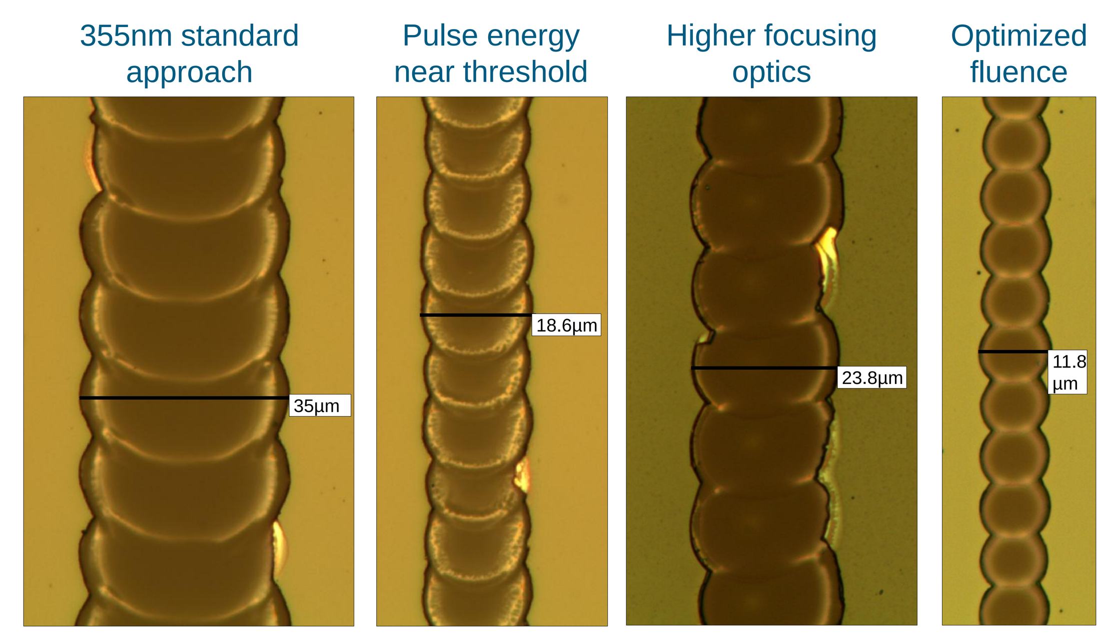
- P1: losses after absorber deposition parallel to cell $R_{p,P1} \sim w_{P1}$
- P2: formation of series resistance between two cells $R_{s,P2} \sim 1/w_{P2}$
- P3: shunt between front- and back-contact $R_{p,P3}$ due to alloying and phase changes

Conclusion

- An interconnection width reduction was achieved for the front-contact separation process P1 of ZnO:Al TCO material
- A test-structure was used to determine the residual conductivity within the scribe to determine the optimal width w_{P1} → conductivity negligible for studied system
- It was found out, that current flow changes near the edge are due to surface effects rather than bulk material changes

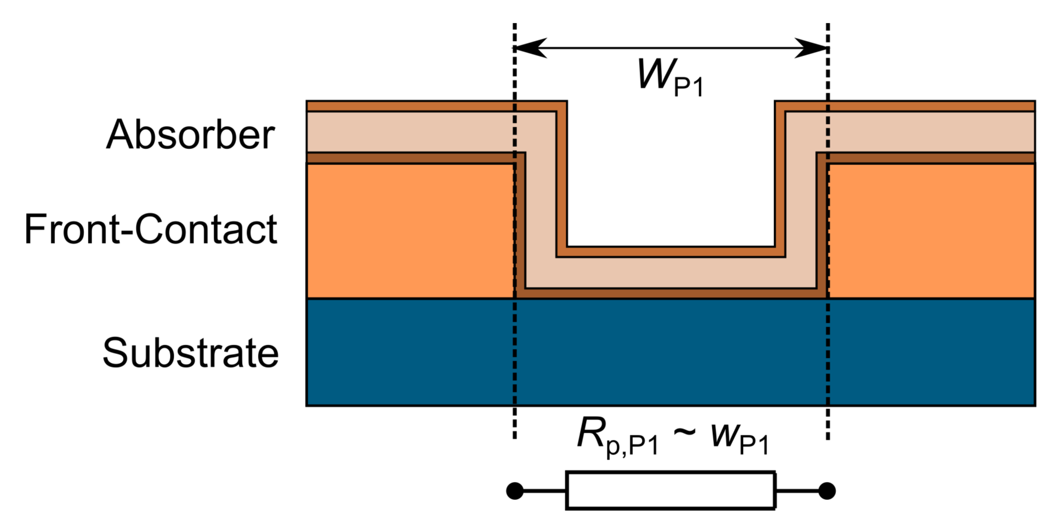
Results

P1 interconnection width reduction

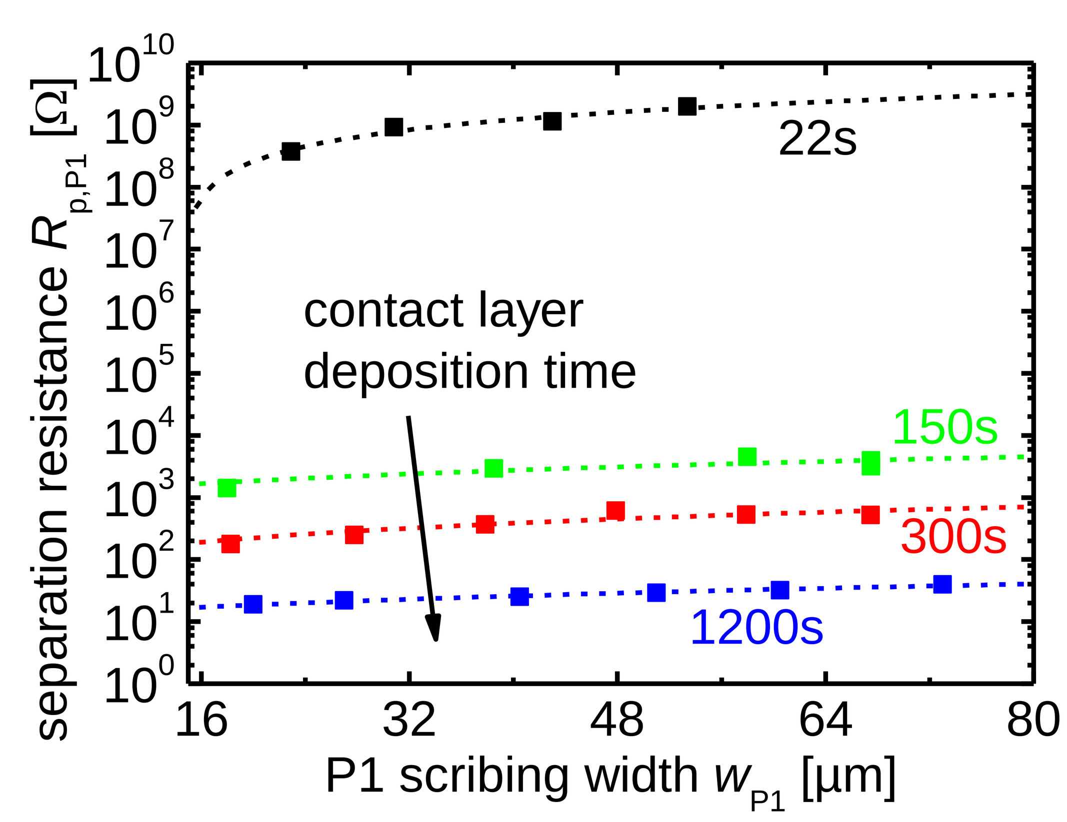


- Evolution of width reduction studies on in-house ZnO:Al TCO material before etch

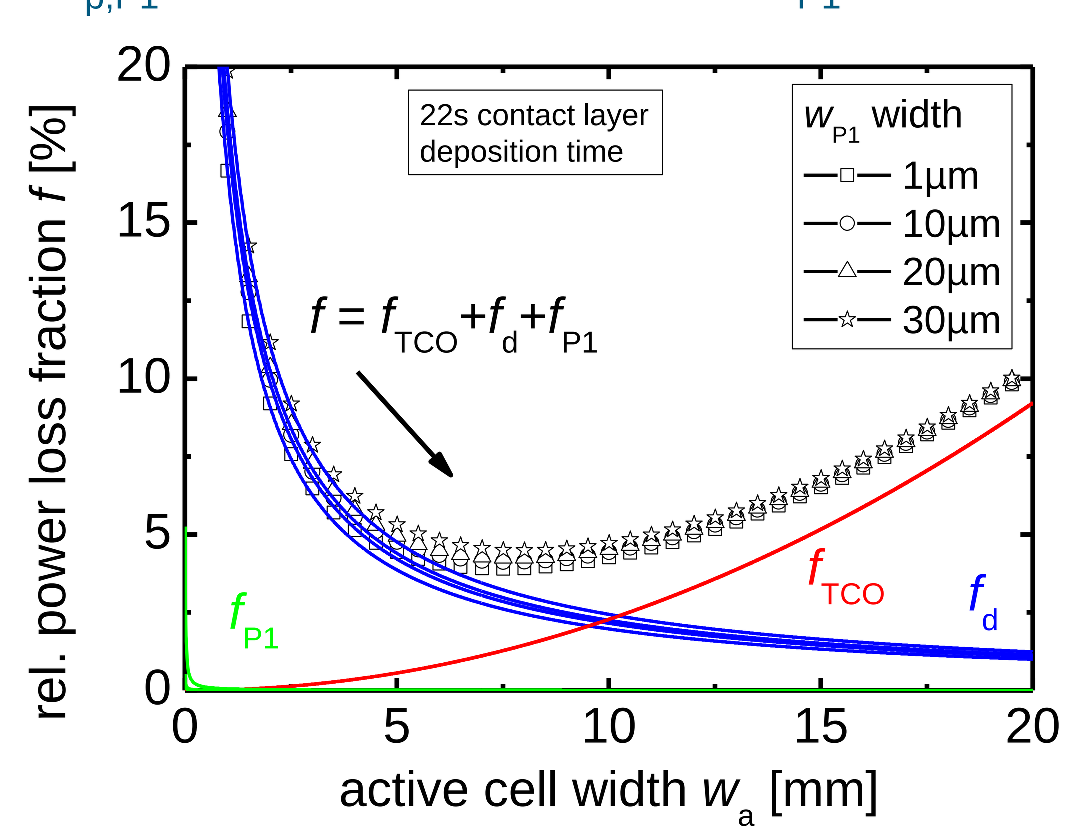
Impact of parasitic conductivity



- Investigation of highly conductive µc-Si:H(p) contact layer for a-Si:H / ZnO:Al



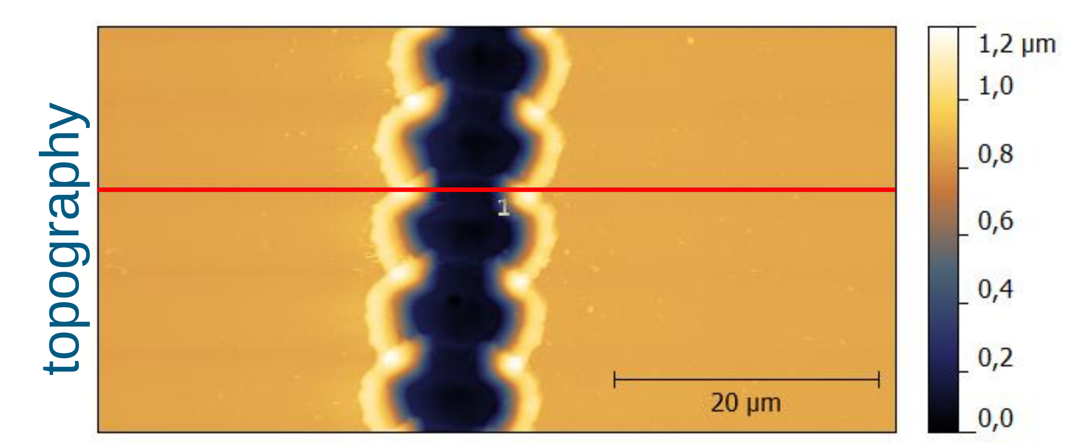
- Extend model calculations to account for $R_{p,P1}$ induced electrical losses f_{P1}

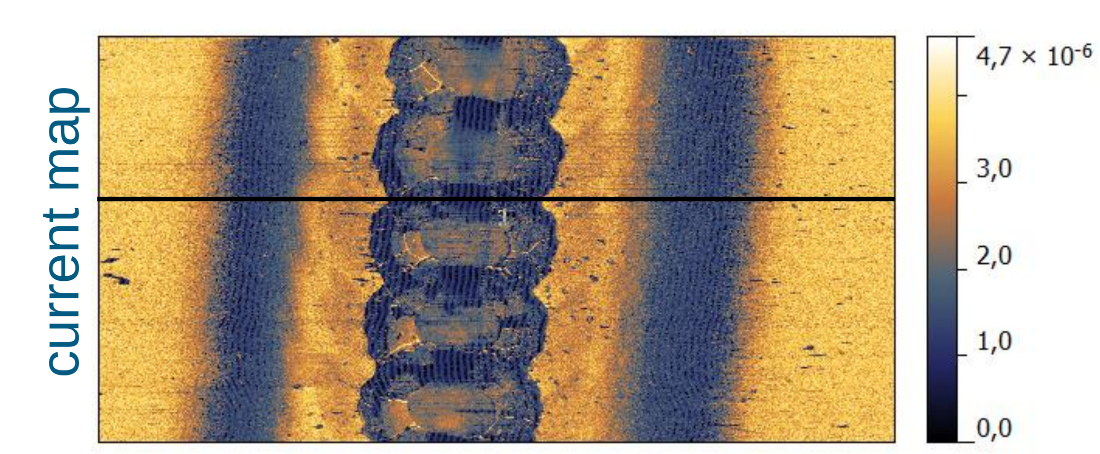


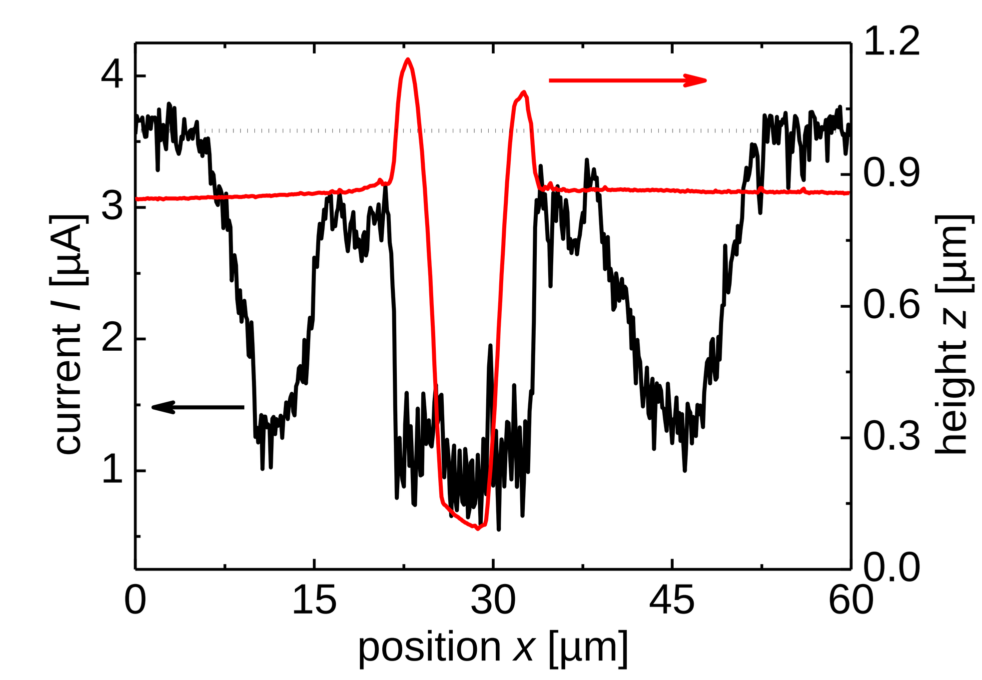
- Impact negligible → increase of efficiency!

Secondary effects – ZnO material modifications

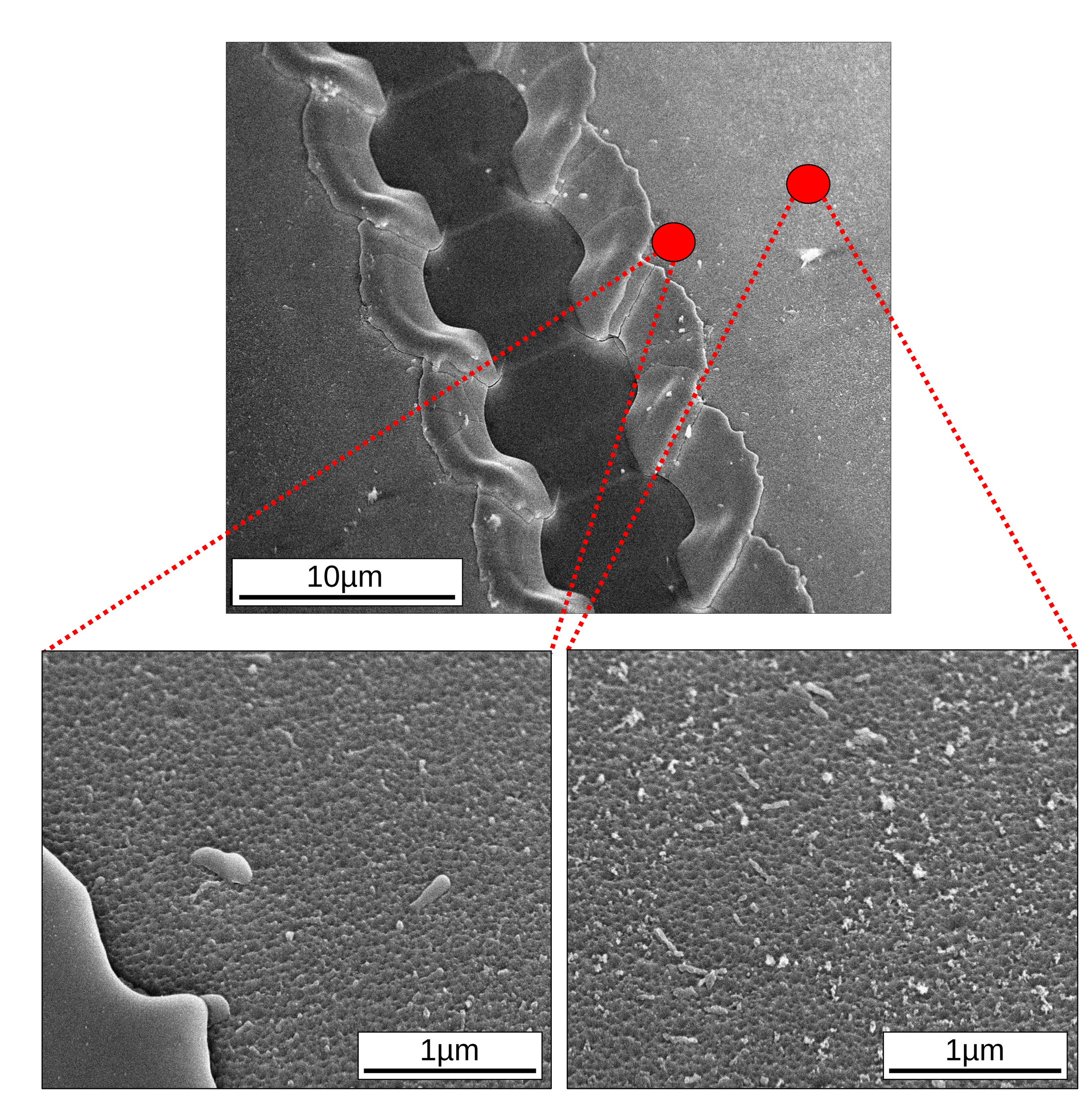
- Investigation of electrical properties with conductive AFM measurements







- Lowered current near scribe on flat TCO
- However, no current flow reduction after wet-etch! → Surface effect, no resistivity change within whole layer



- SEM morphology suggests a correlation between amount of surface debris and current flow changes in c-AFM scans

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