
HIGH MOBILITY TCOS FOR SILICON HETEROJUNCTION SOLAR CELLS

The sputter deposition of broadband transparent and highly conductive cerium and hydrogen co-doped indium oxide and its transfer to SHJ solar cells



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Martin Bivour^a, Martin Hermle^a, Takashi Koida^b

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Freiburg, Germany

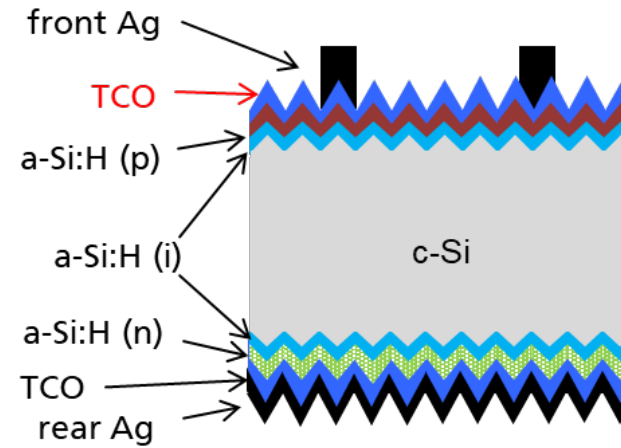
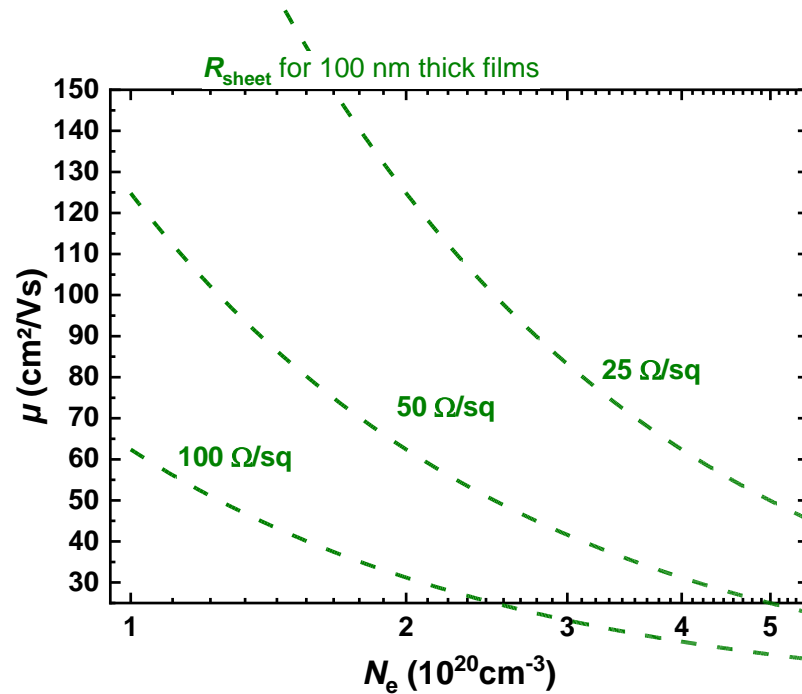
^bNational Institute of Advanced Industrial Science and
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EUPVSEC 2020

September 8th, 2020

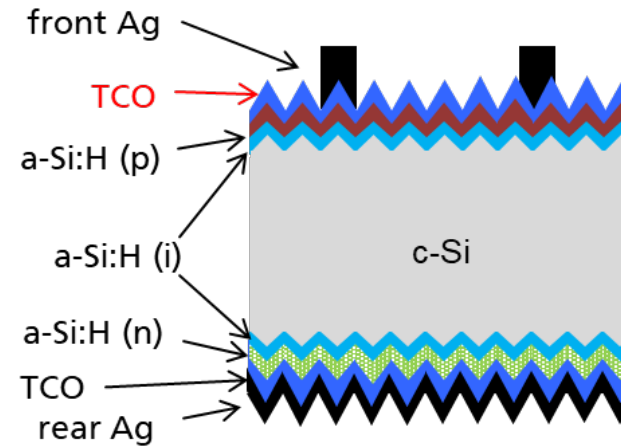
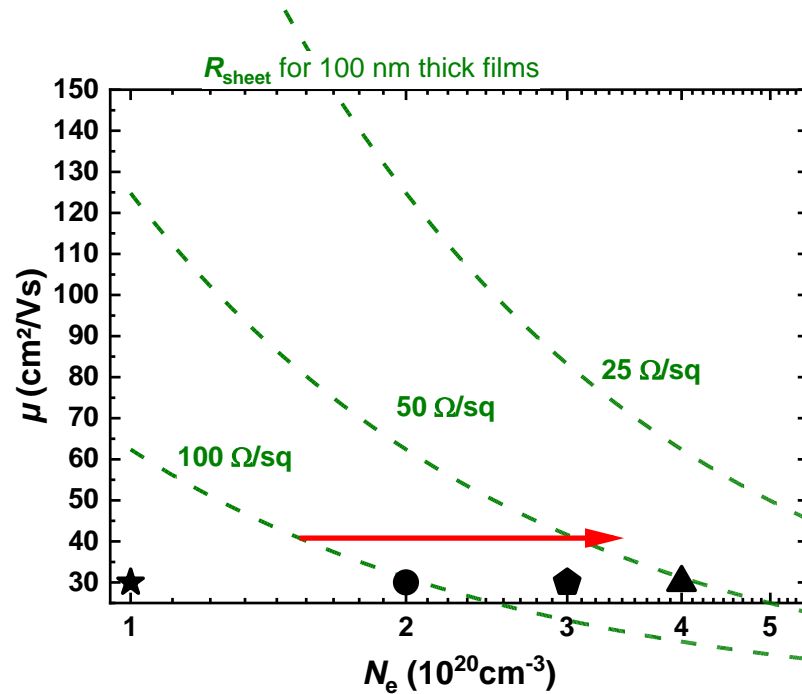
Motivation

Why is high electron mobility favorable in TCO films?



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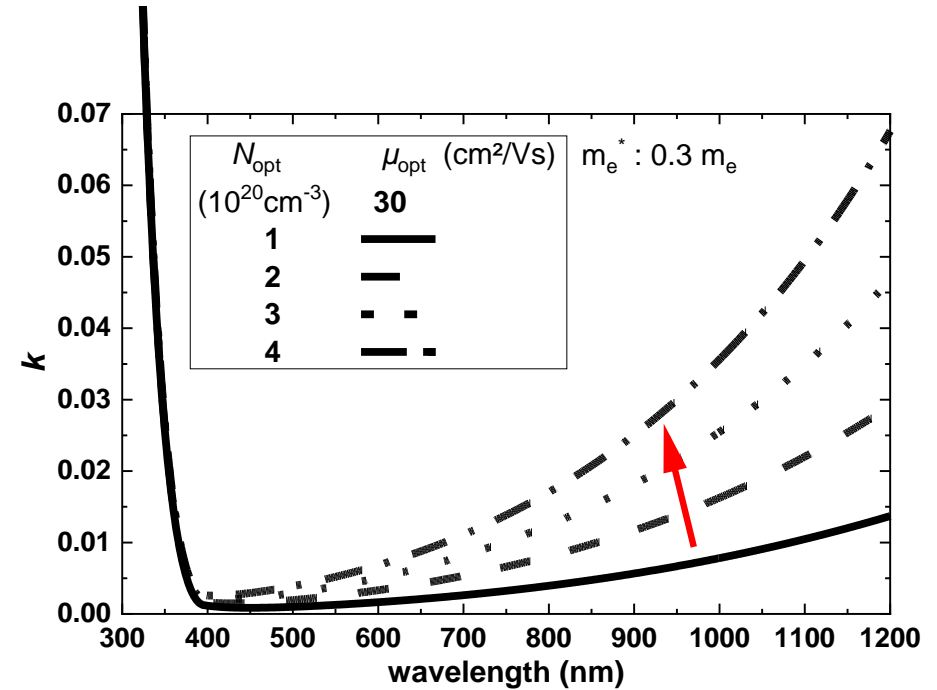
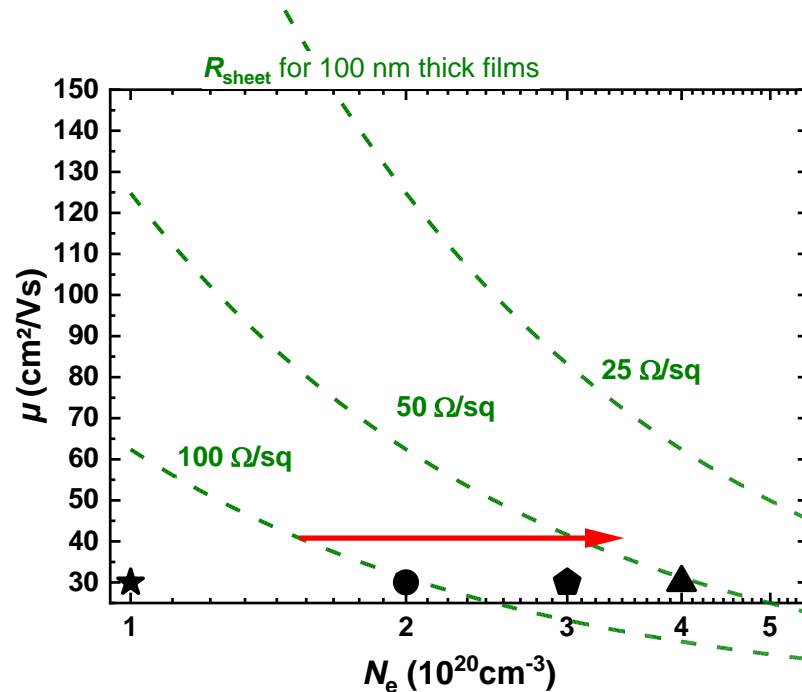
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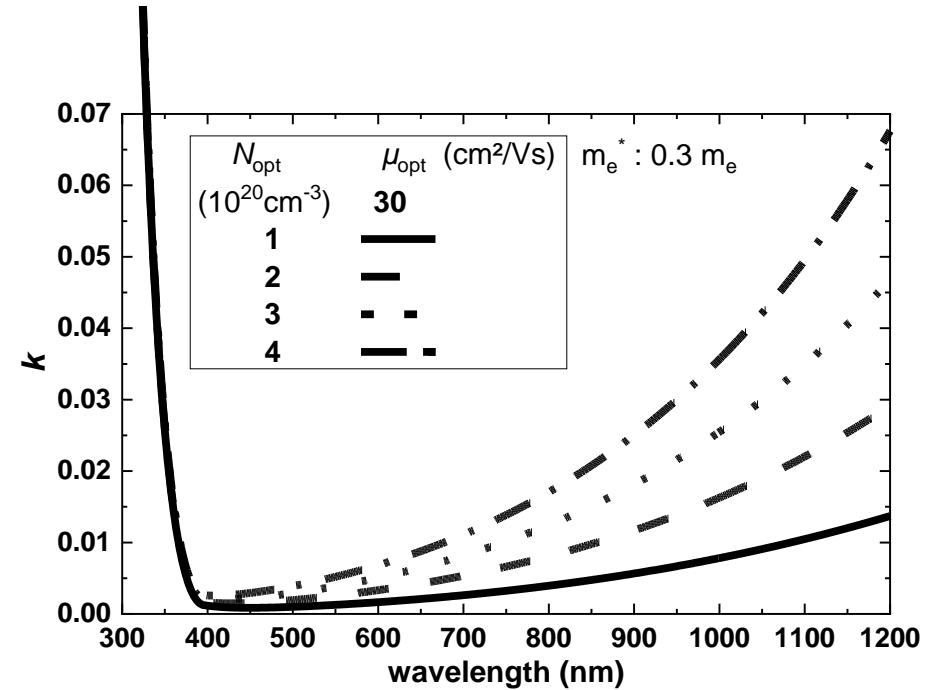
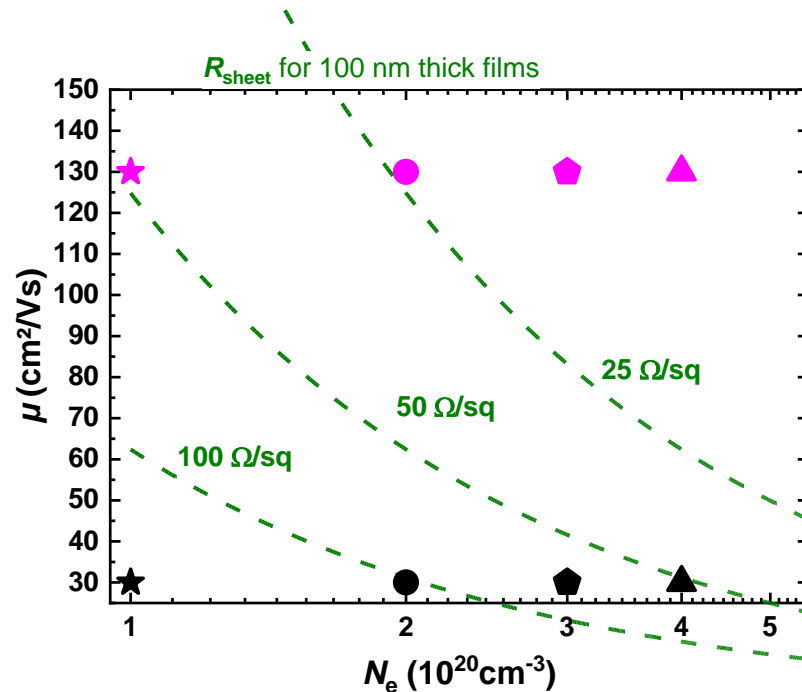
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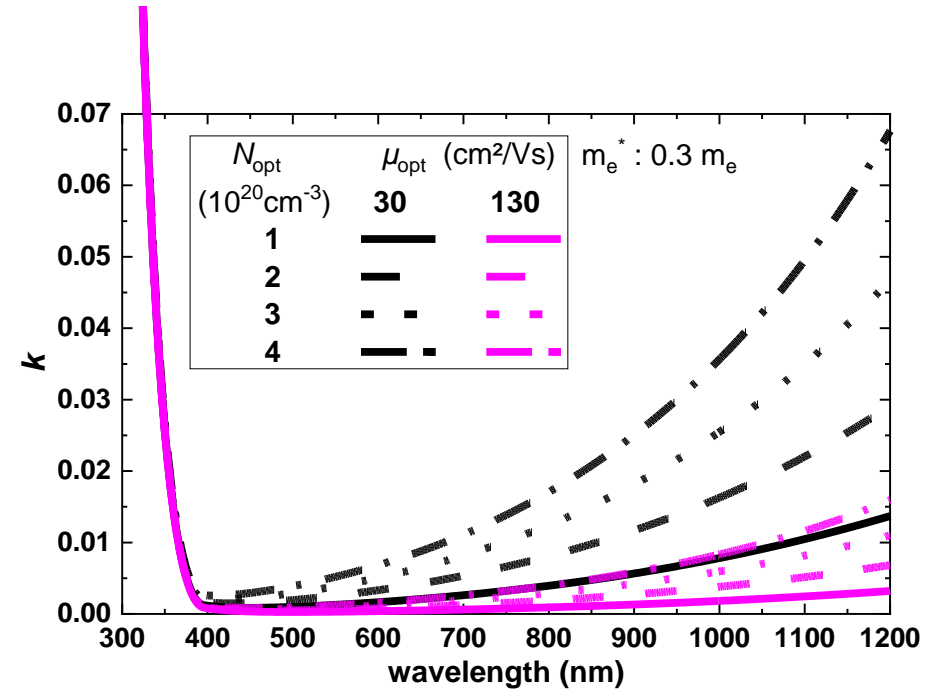
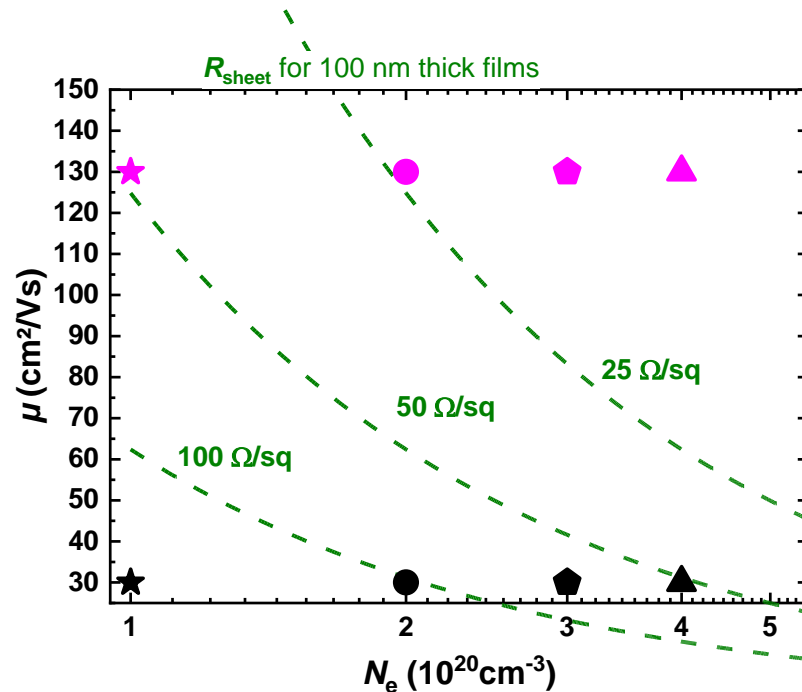
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Cerium and hydrogen co-doped indium oxide ($\text{In}_2\text{O}_3:\text{Ce,H}$)

- High quality films ($\mu > 100 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$) fabricated via reactive plasma deposition (RPD)^[2-4]

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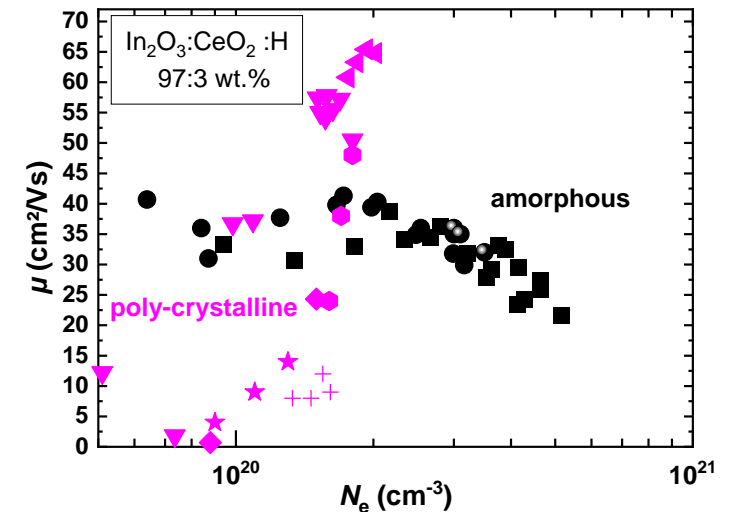
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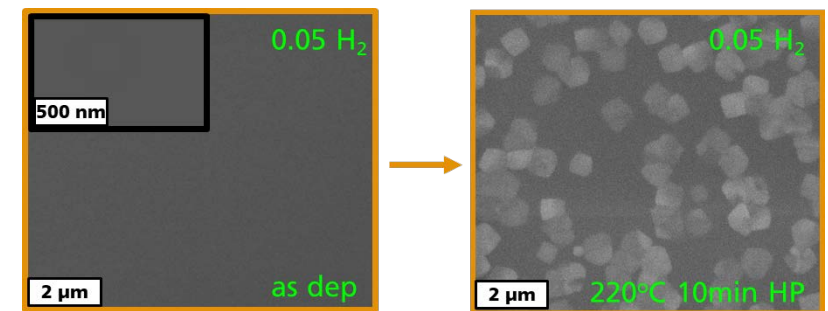
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 - crystallization temperature too high for SHJ



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Cerium and hydrogen co-doped indium oxide ($\text{In}_2\text{O}_3:\text{Ce,H}$)



Detailed analysis of Ce content, $p(\text{H}_2\text{O})$ and $p(\text{O}_2)$ via RF co-sputtering

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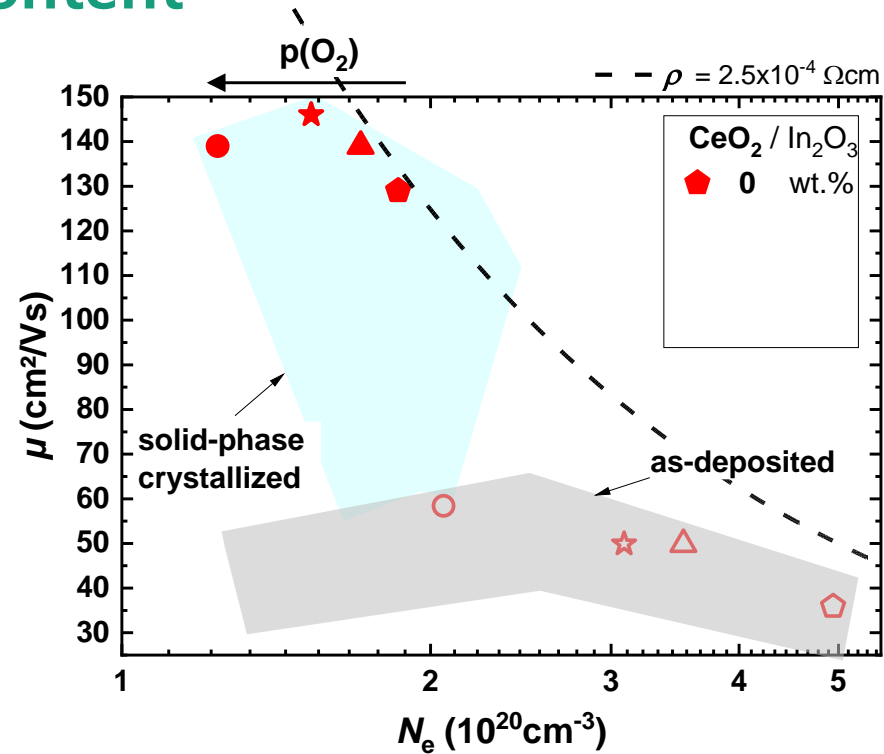
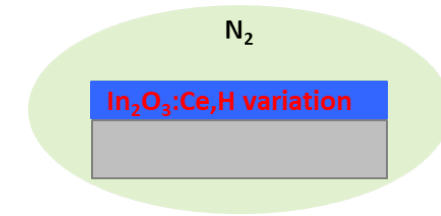
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Transfer from planar test structures to SHJ substrates

Film properties and crystallization dynamics

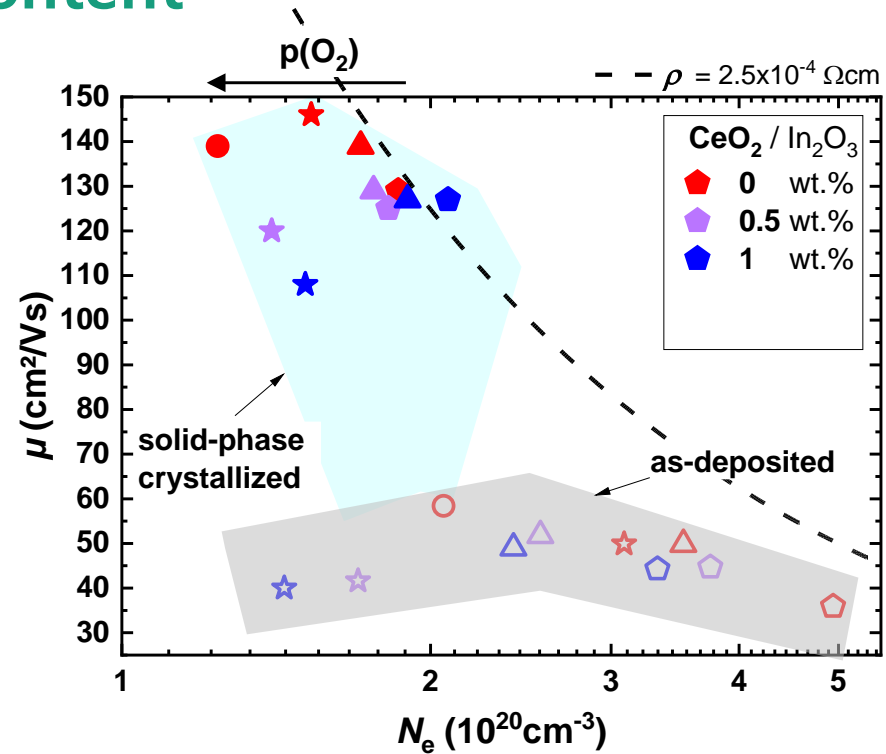
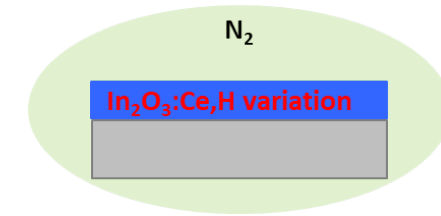
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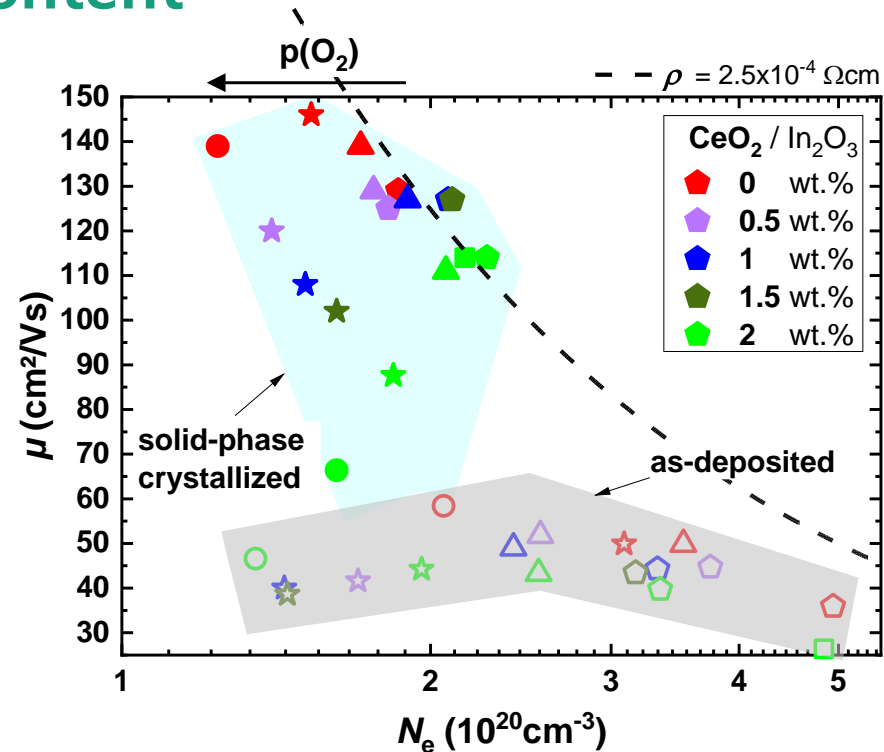
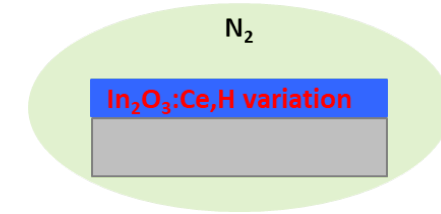
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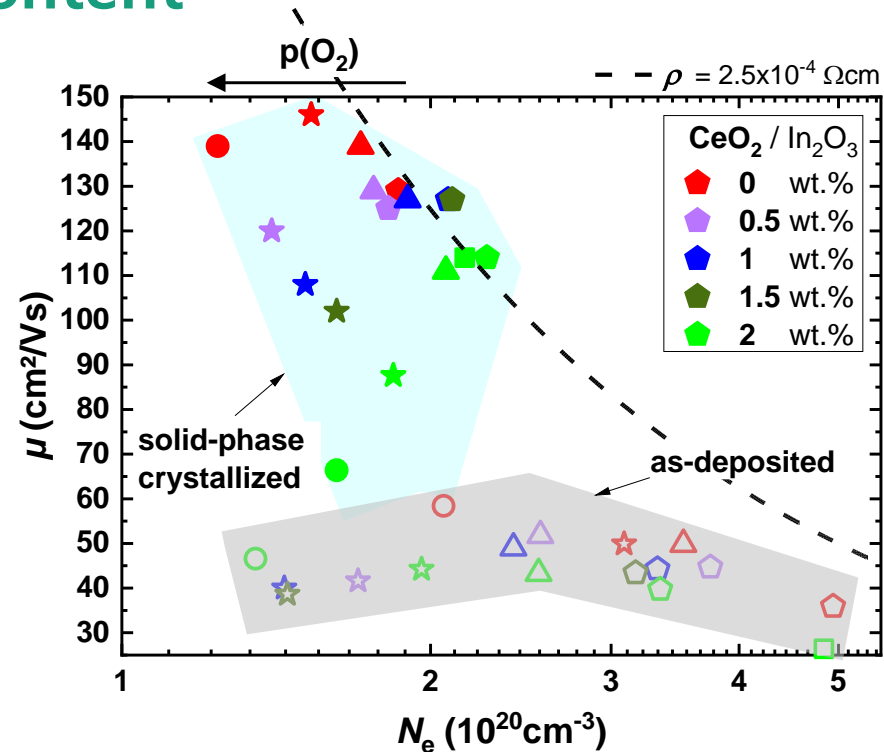
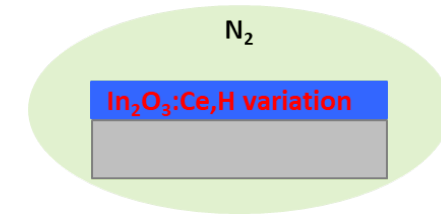
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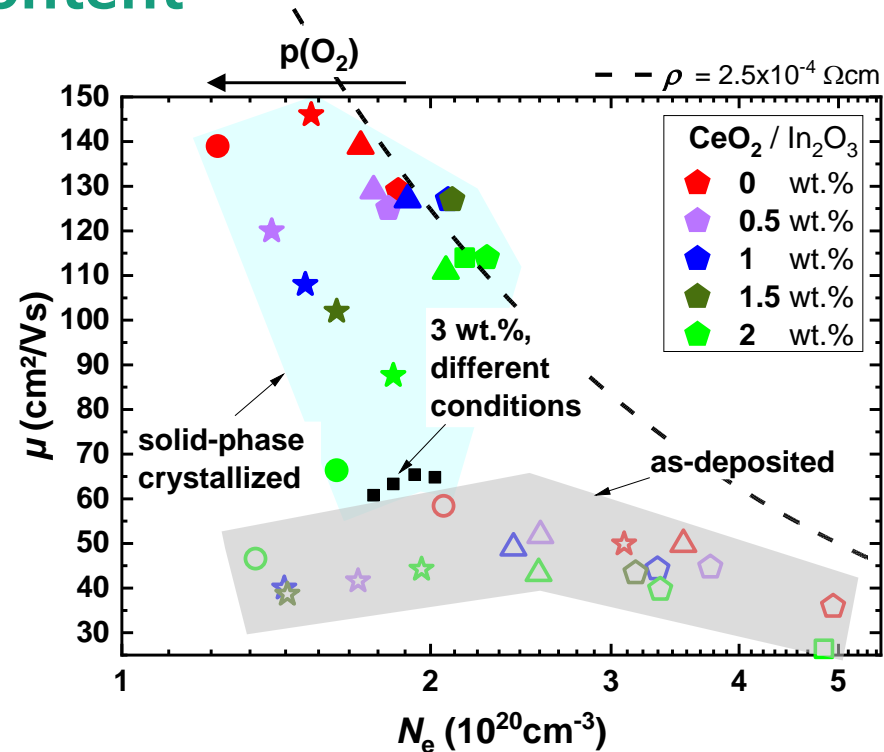
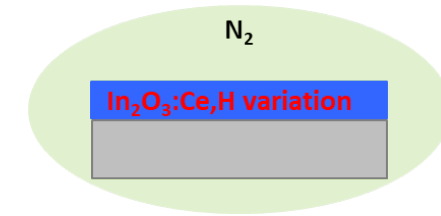
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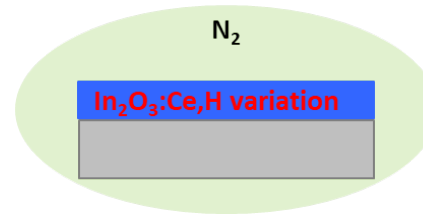
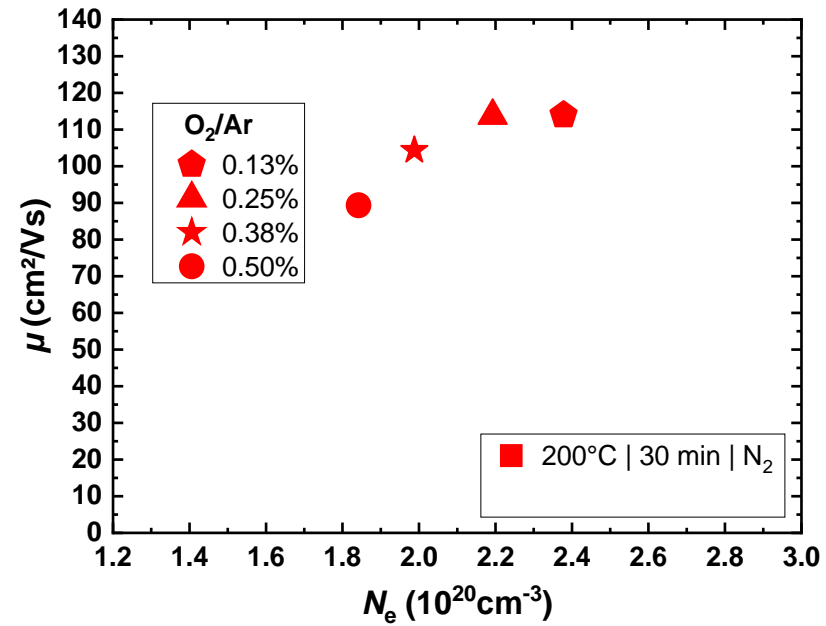
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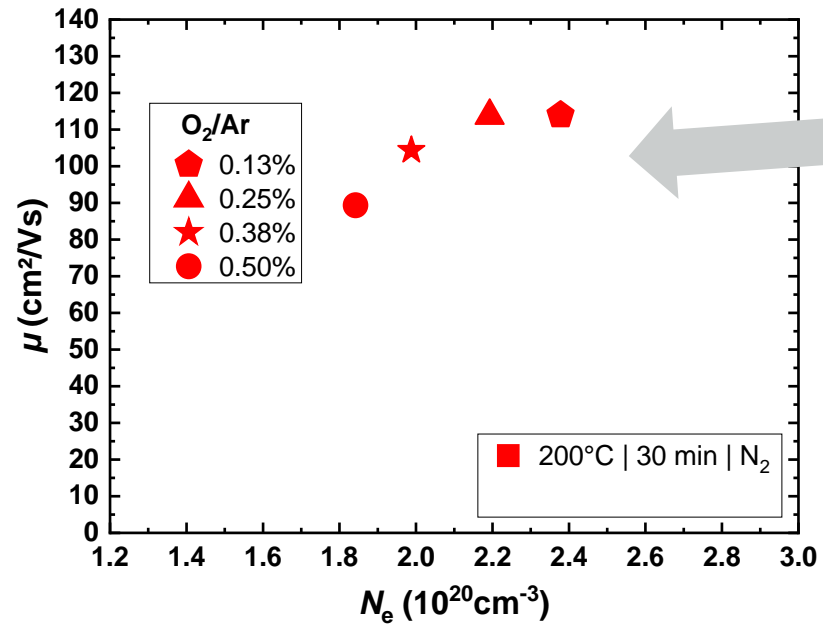
Impact of the annealing atmosphere on layer properties

Air annealing & planar substrate



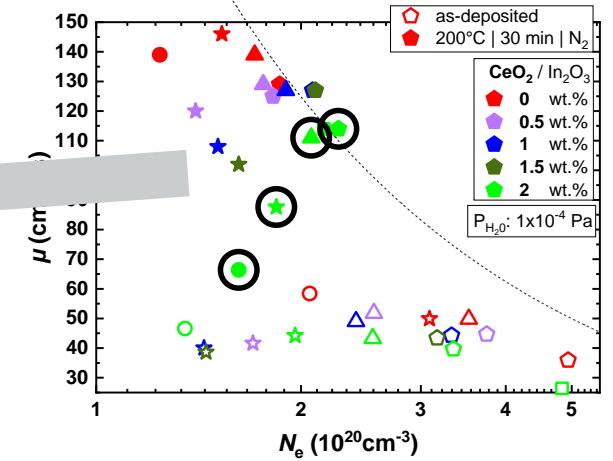
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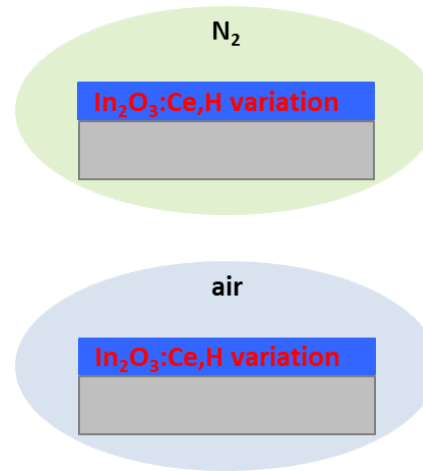
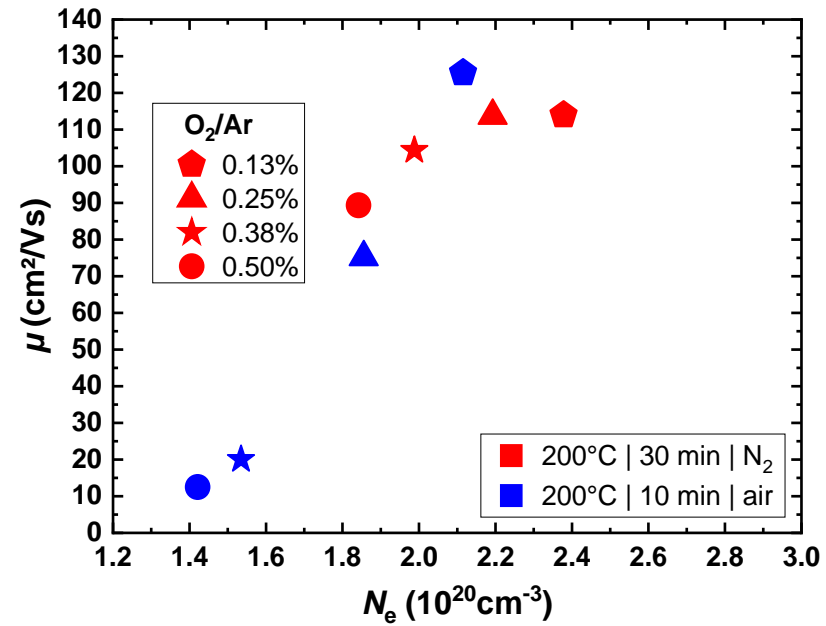
N₂

In₂O₃:Ce,H variation



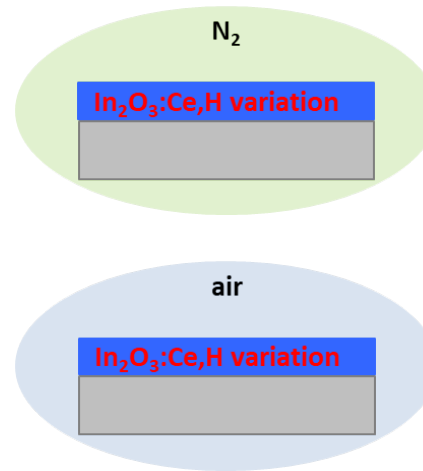
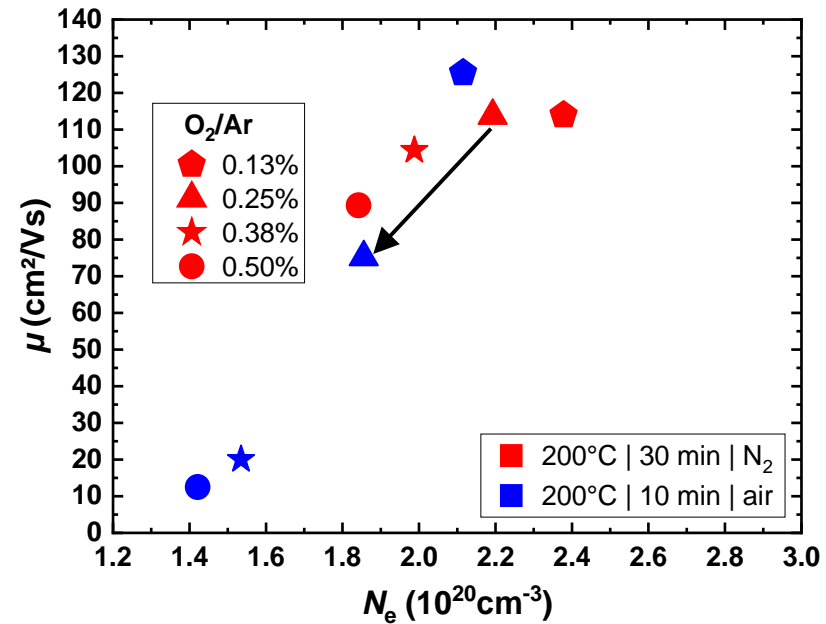
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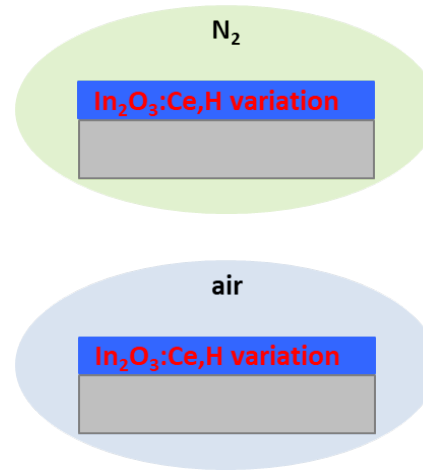
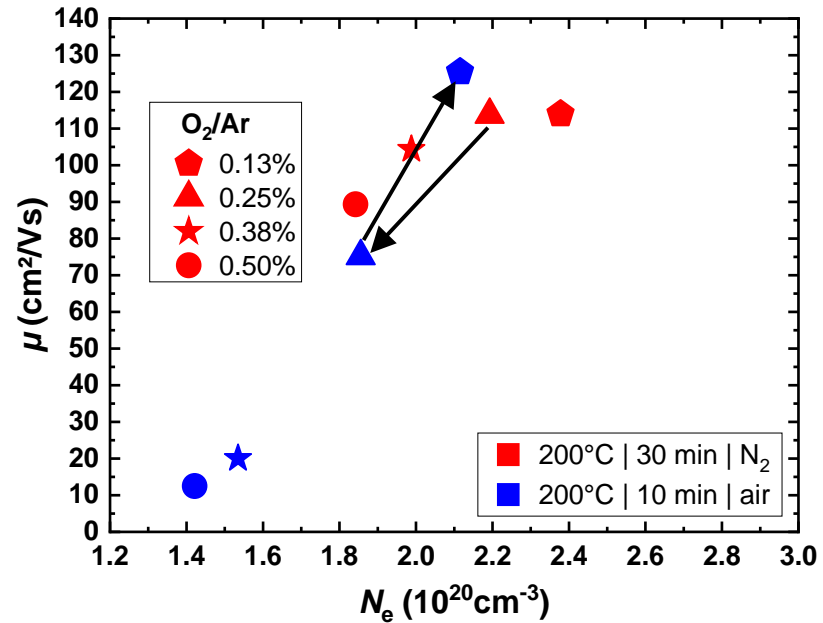
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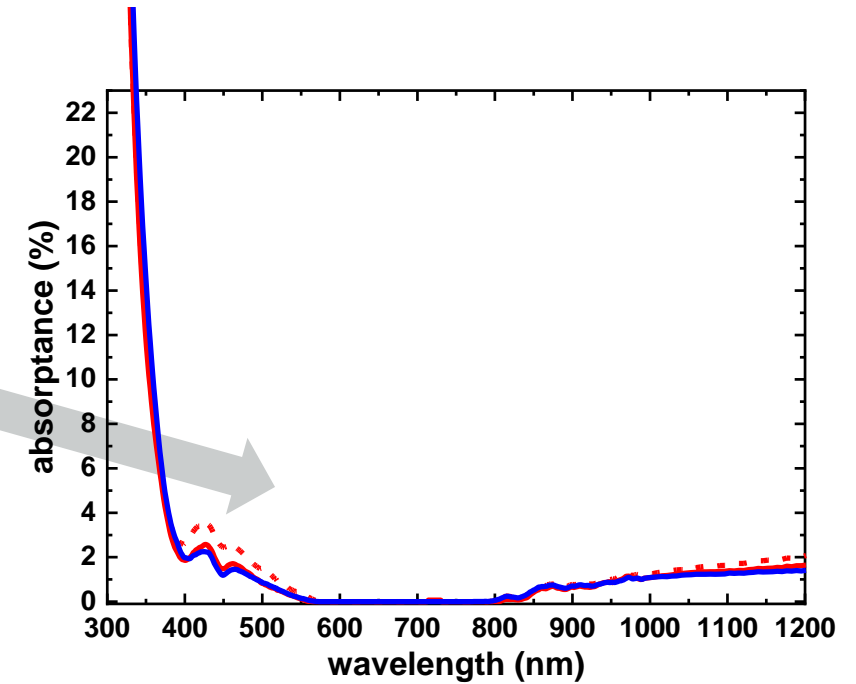
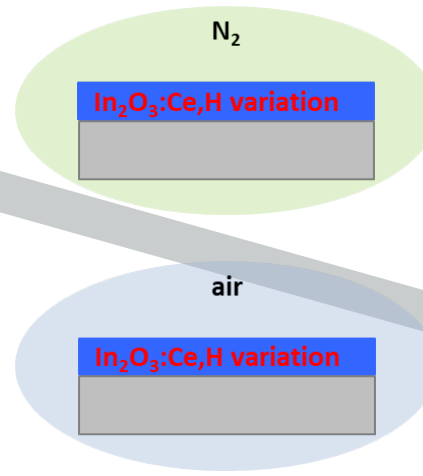
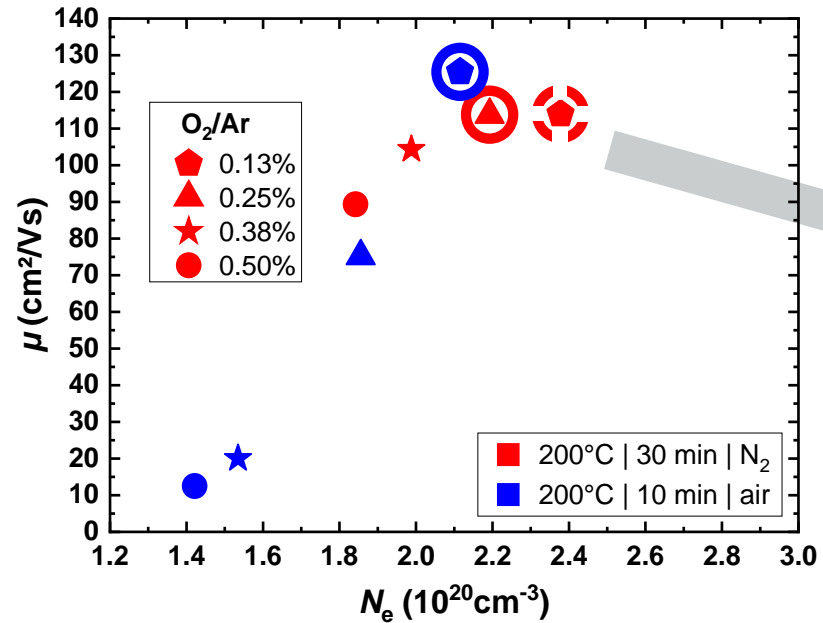
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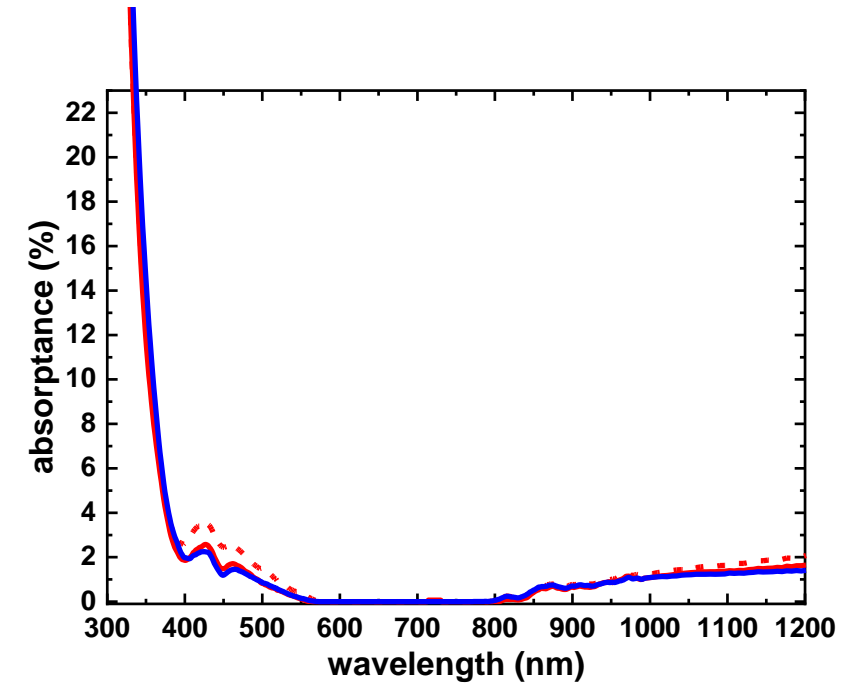
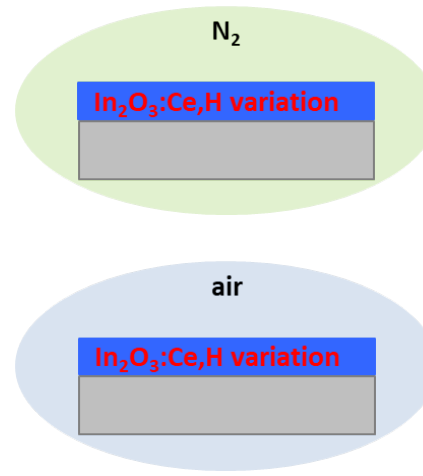
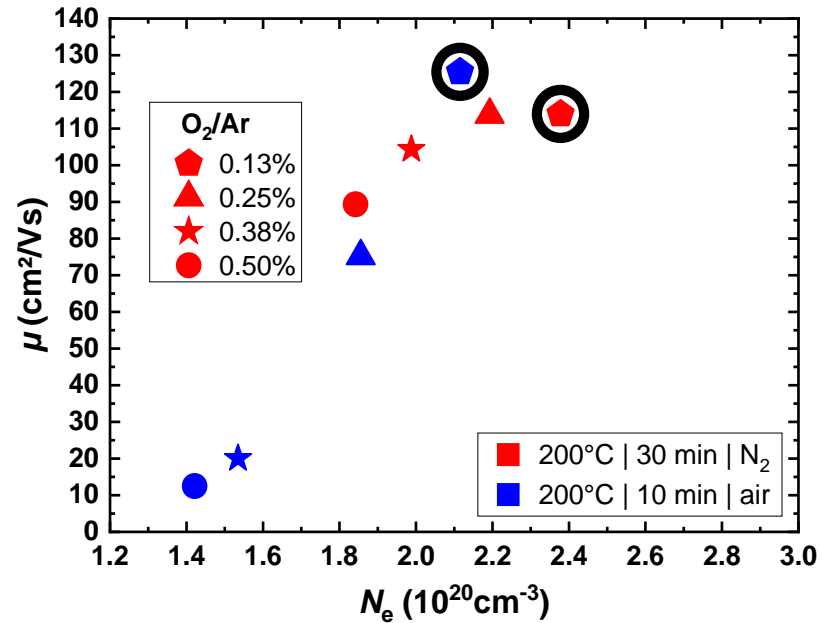
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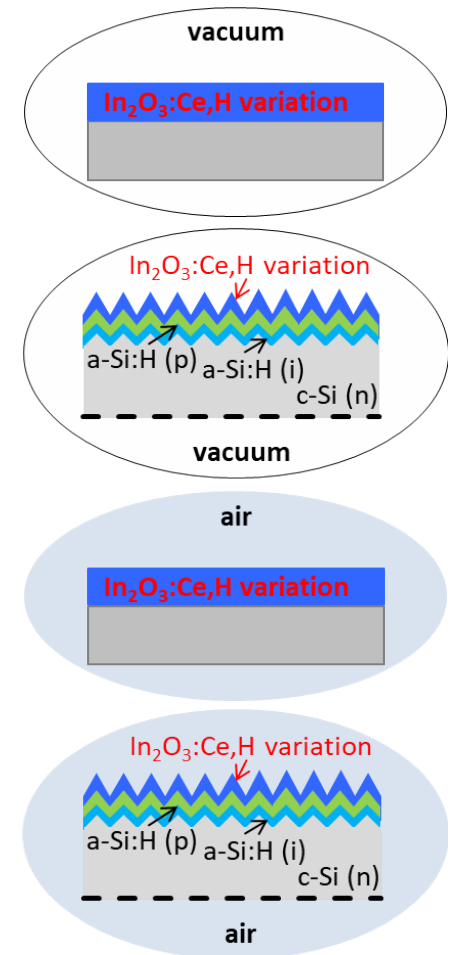
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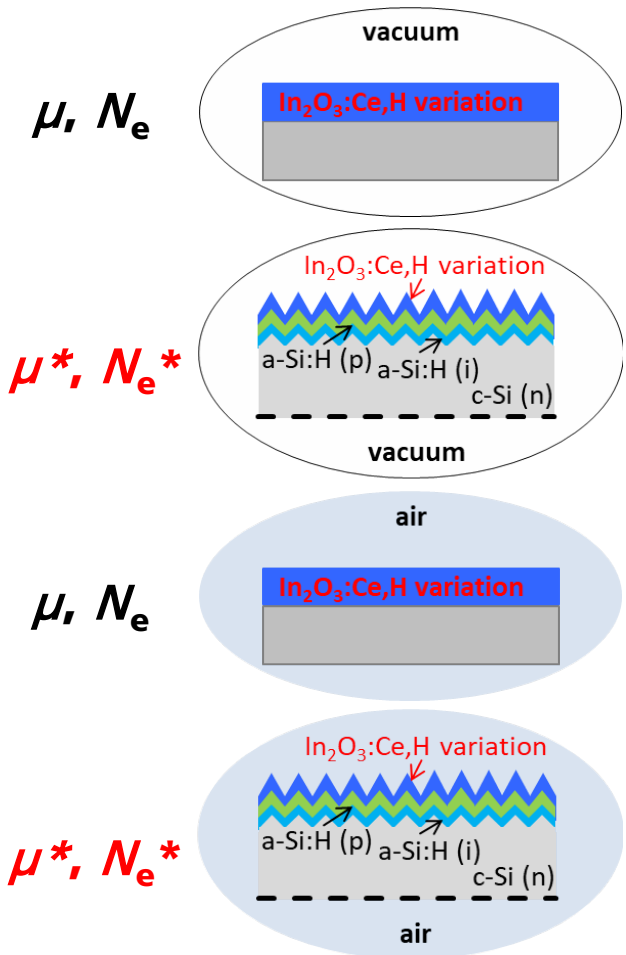
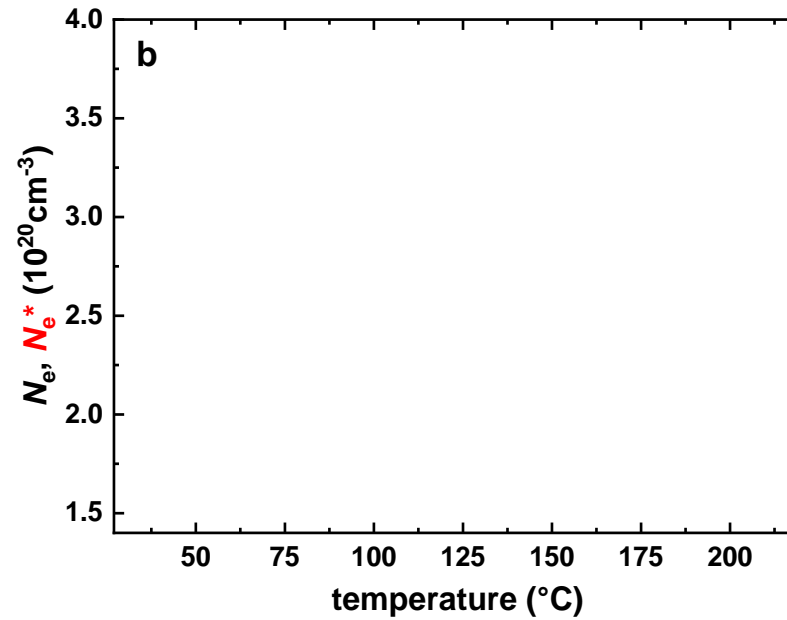
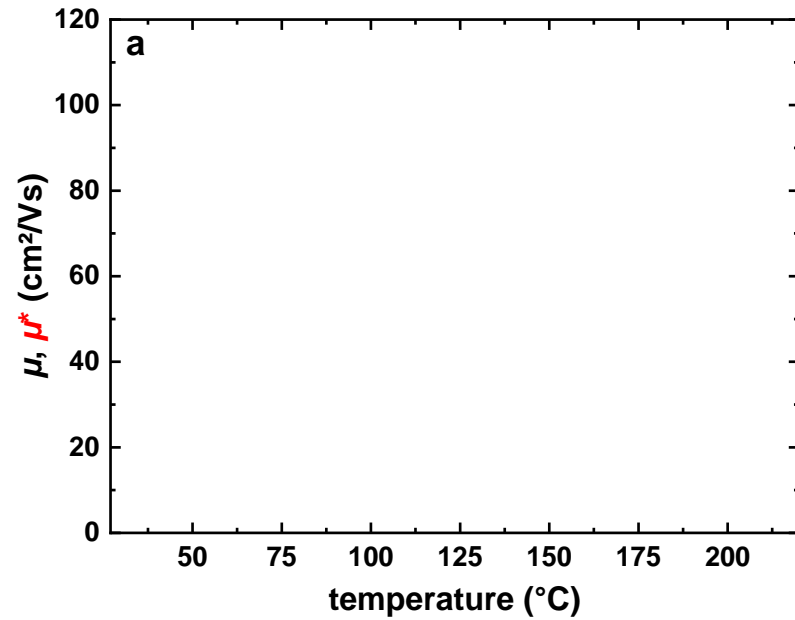
Transfer of $\text{In}_2\text{O}_3:\text{Ce,H}$ layers to SHJ substrates

Substrate-dependent film properties



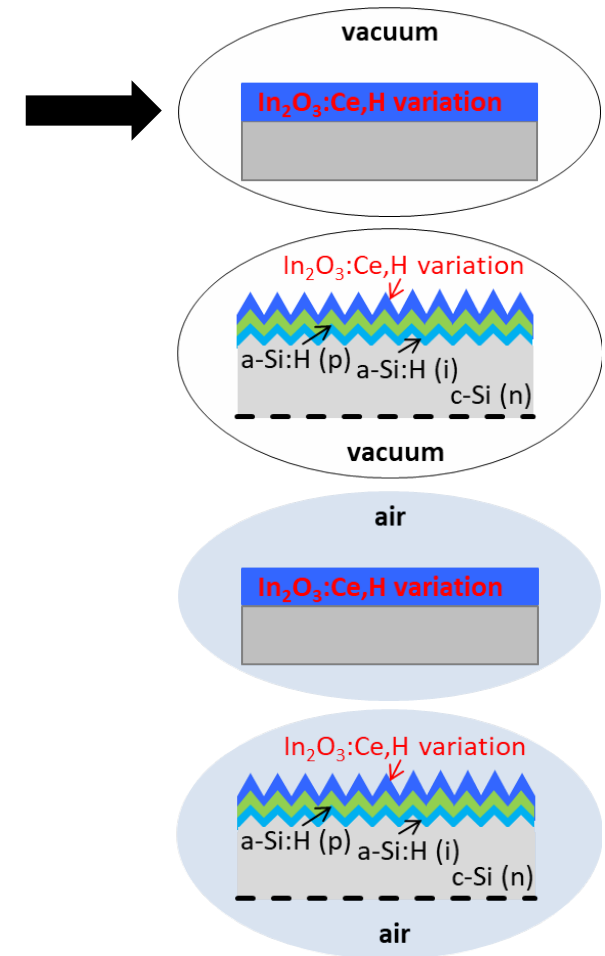
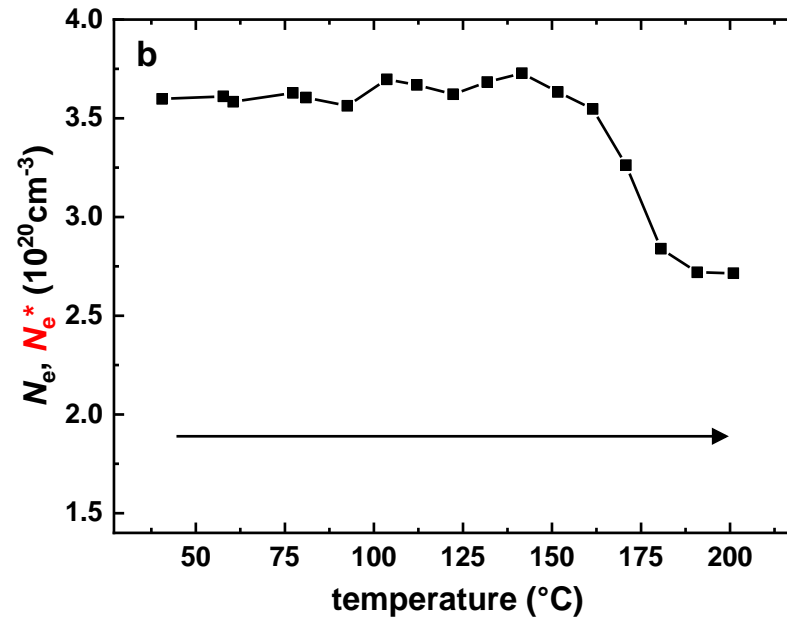
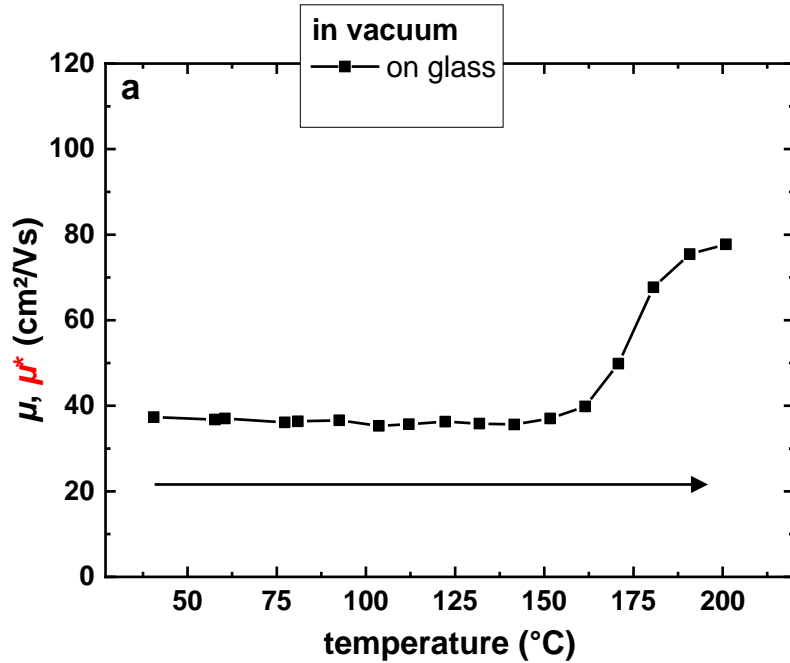
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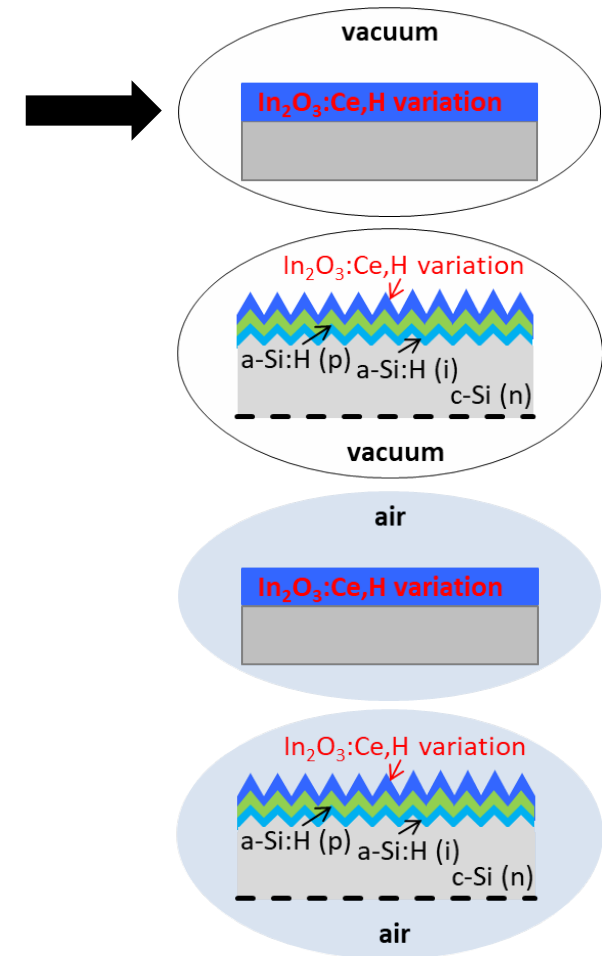
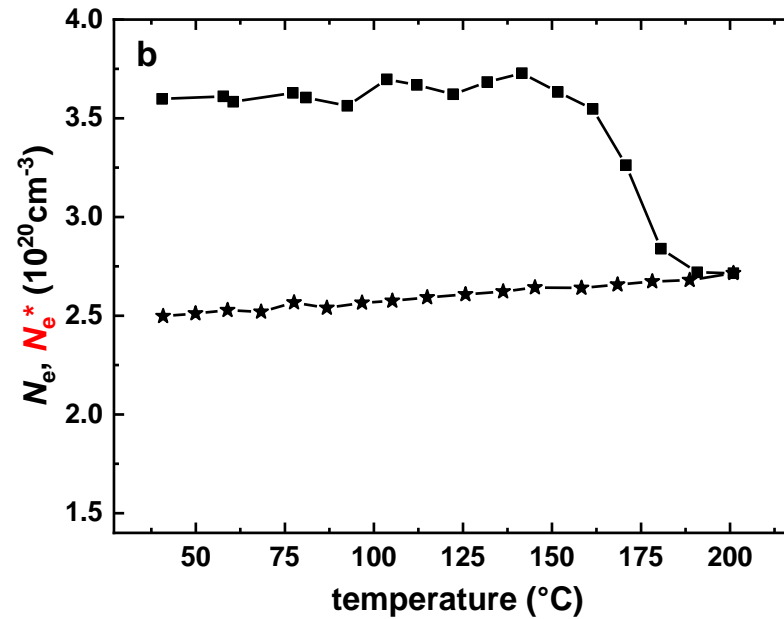
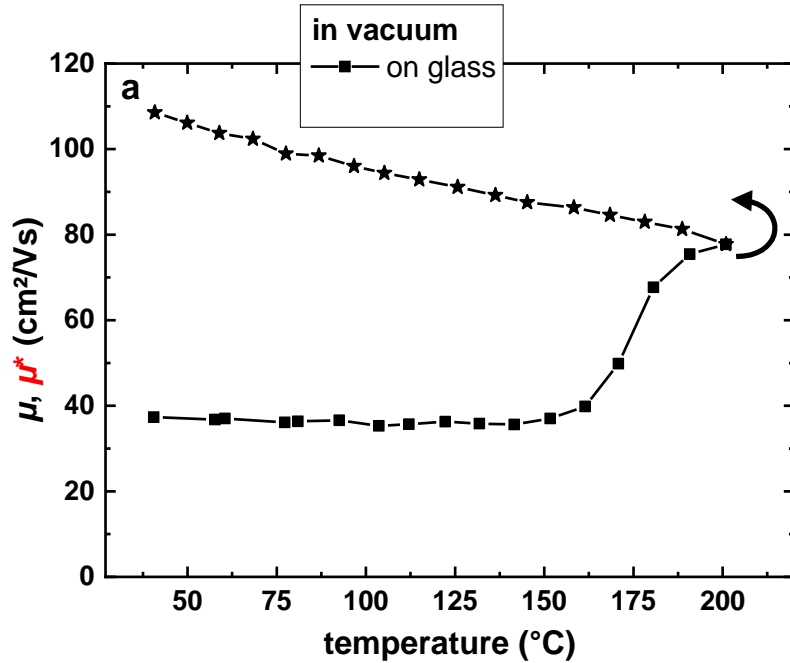
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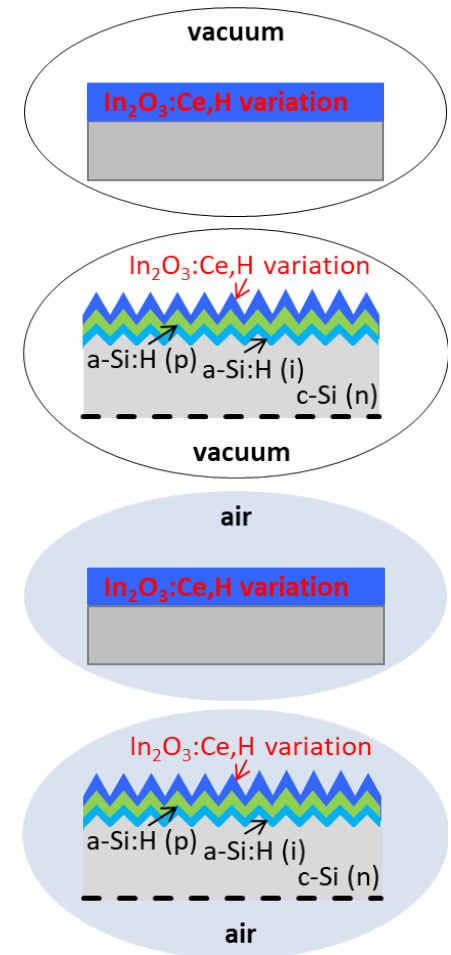
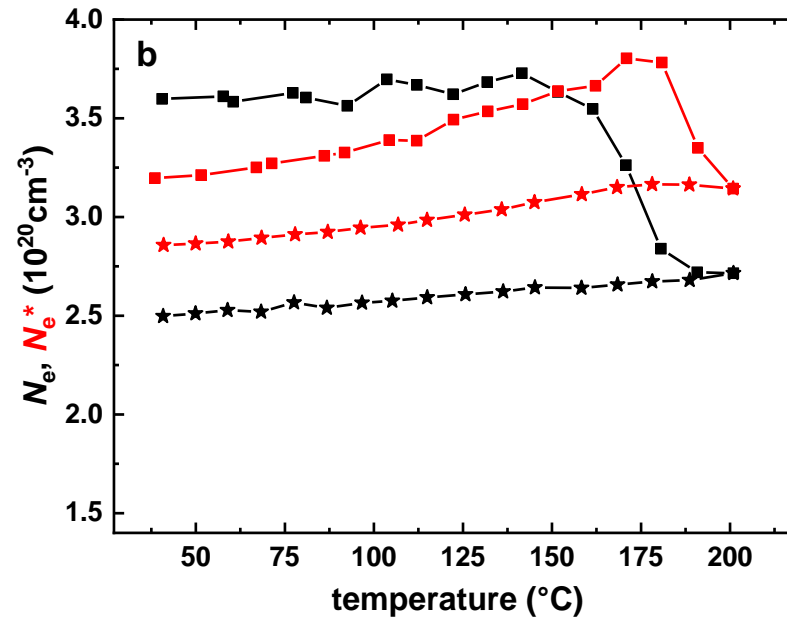
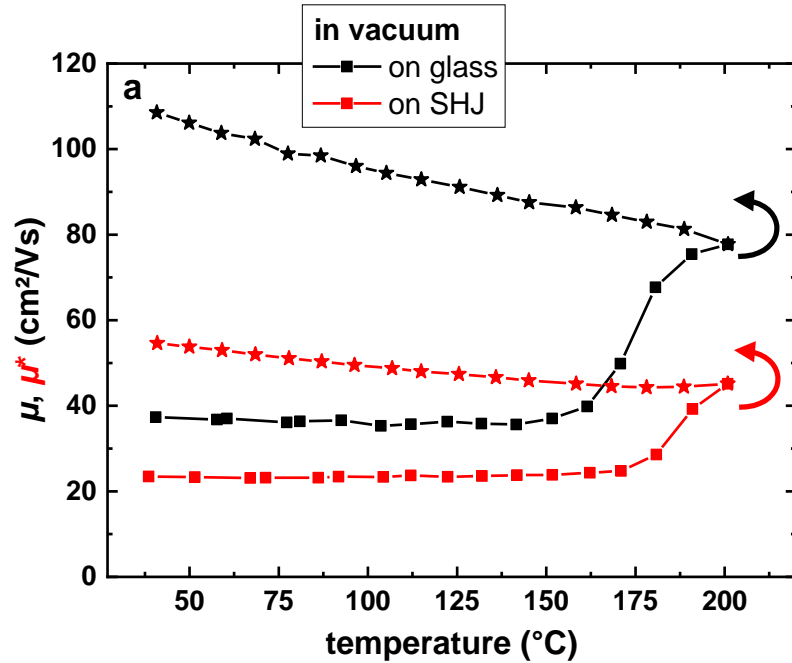
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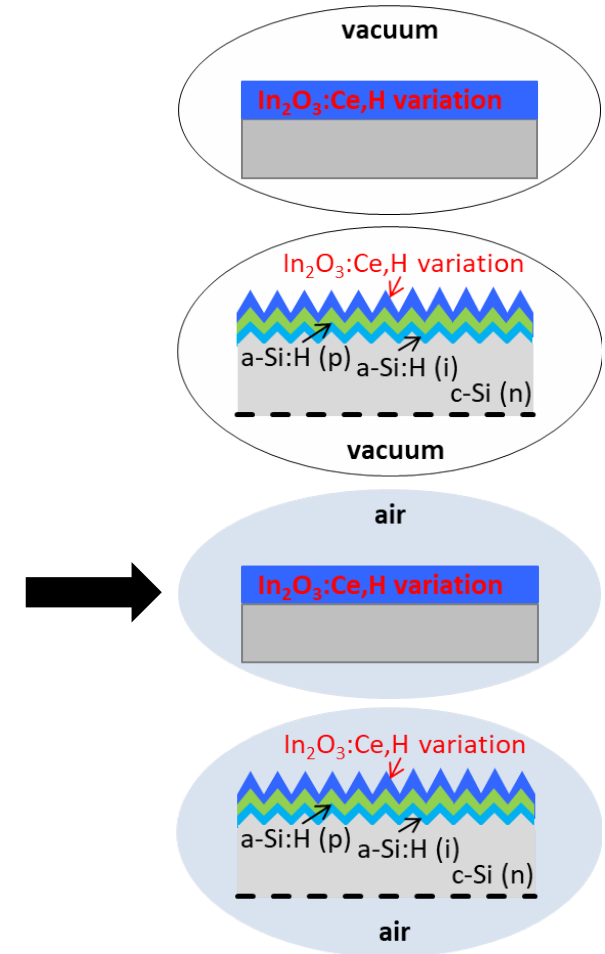
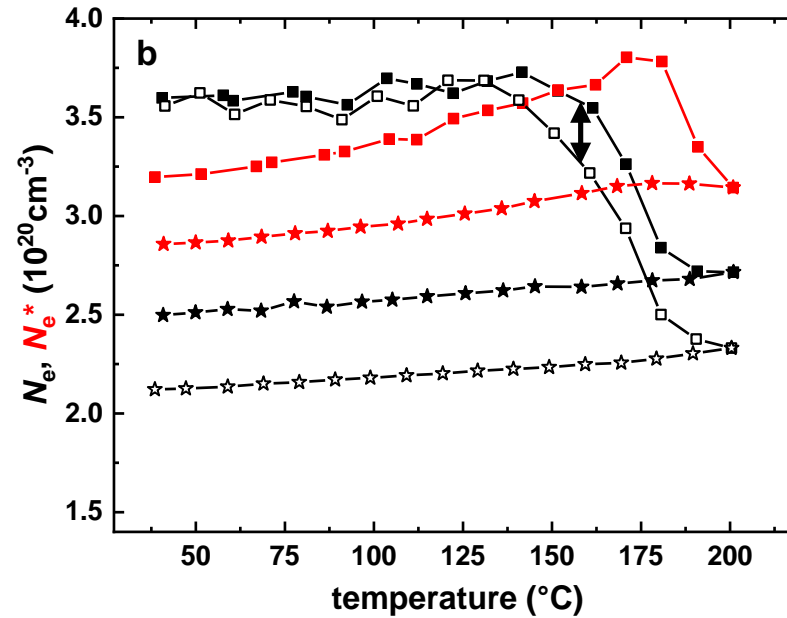
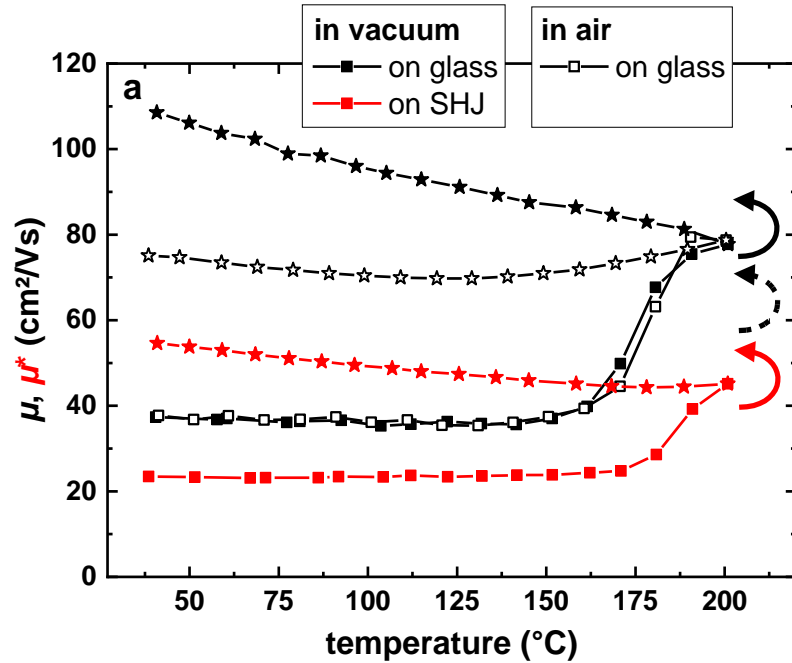
Substrate-dependent film properties



- Vacuum annealing: Similar trend for glass and SHJ

Transfer of $\text{In}_2\text{O}_3:\text{Ce,H}$ layers to SHJ substrates

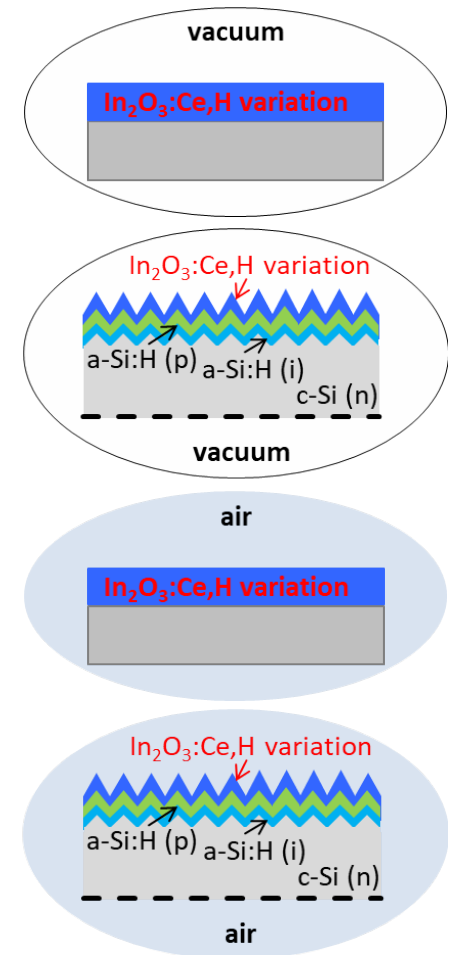
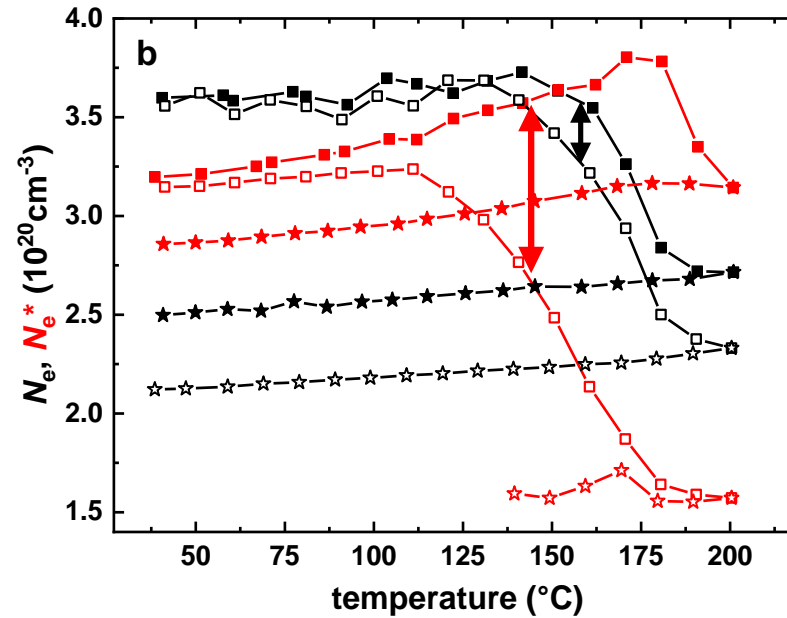
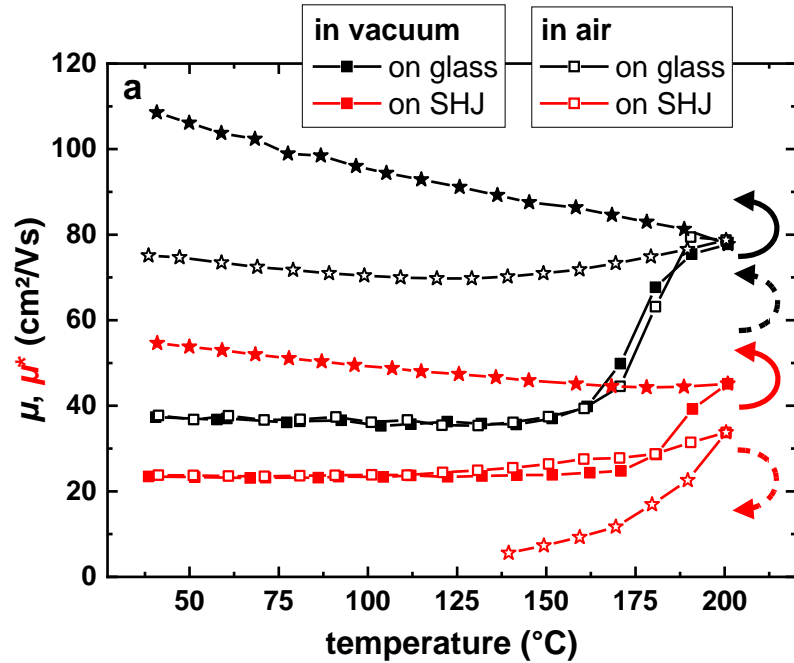
Substrate-dependent film properties



- Vacuum annealing: Similar trend for glass and SHJ
- Air annealing:
 - glass: slight \downarrow of N_e & μ

Transfer of $\text{In}_2\text{O}_3:\text{Ce,H}$ layers to SHJ substrates

Substrate-dependent film properties



- Vacuum annealing: Similar trend for glass and SHJ
- Air annealing:
 - glass: slight \downarrow of N_e & μ
 - SHJ: \downarrow of N_e & μ much more pronounced

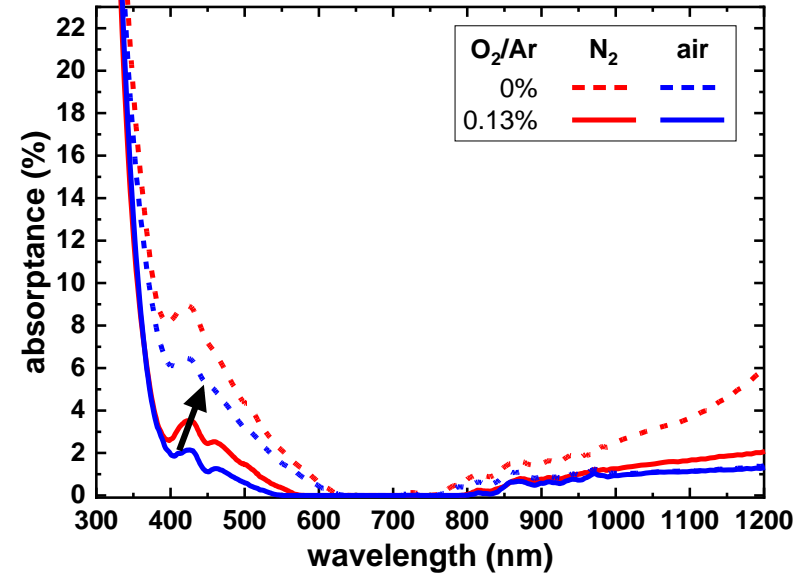
Transfer of $\text{In}_2\text{O}_3:\text{Ce,H}$ layers to SHJ substrates

Substrate-dependent film properties

- SHJ & air annealing: Low R_{sheet} only obtained for very oxygen-poor ($\sim 0\% \text{O}_2$) deposition

Transfer of $\text{In}_2\text{O}_3:\text{Ce,H}$ layers to SHJ substrates

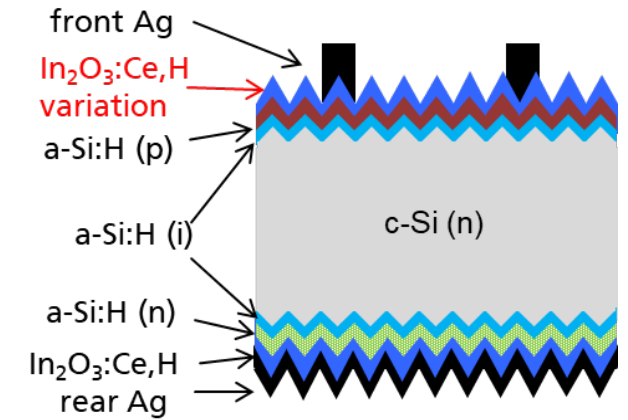
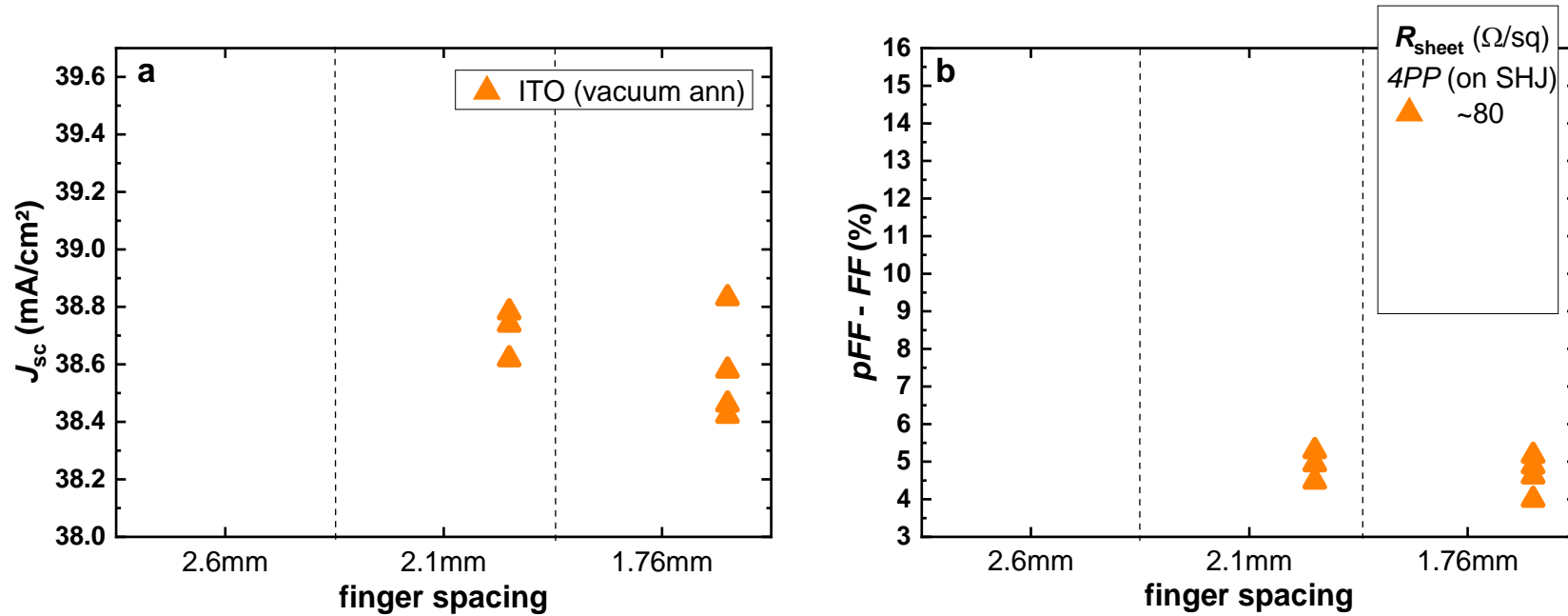
Substrate-dependent film properties



- SHJ & air annealing: Low R_{sheet} only obtained for very oxygen-poor ($\sim 0\%$ O₂) deposition
- But: Significant absorption remaining for short wavelengths (here measured on planar substrates)

In₂O₃:Ce,H layers in SHJ cells

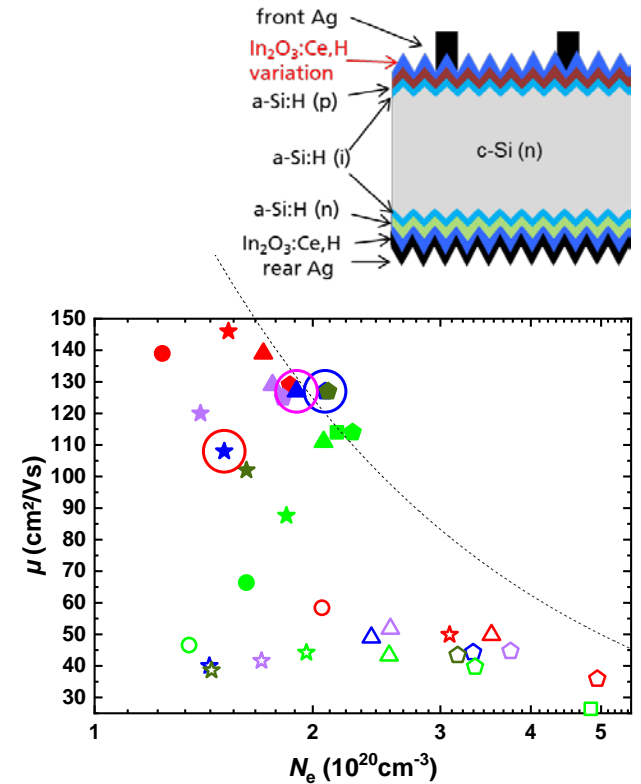
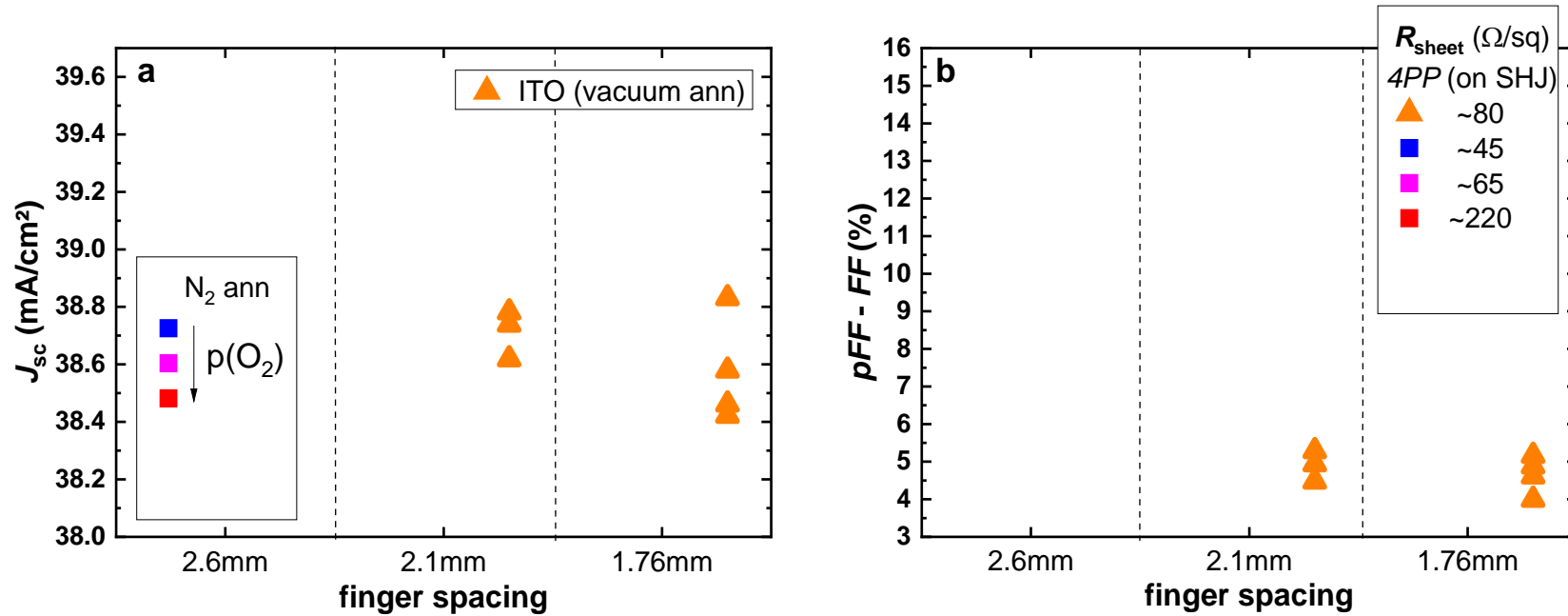
Optical performance and resistive losses



- SHJ solar cells with lab-type metallization, non optimized (V_{oc} : 710 ± 5 mV, pFF = 83 ± 1 %)

In₂O₃:Ce,H layers in SHJ cells

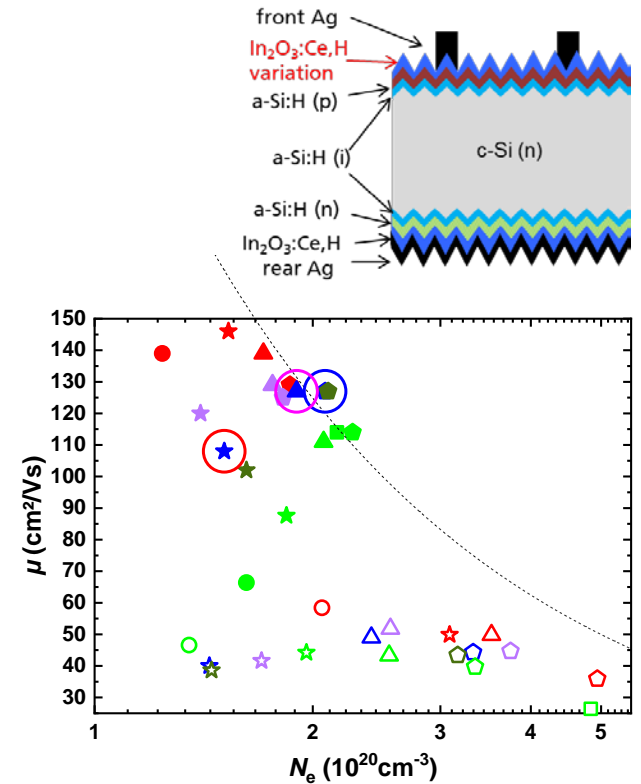
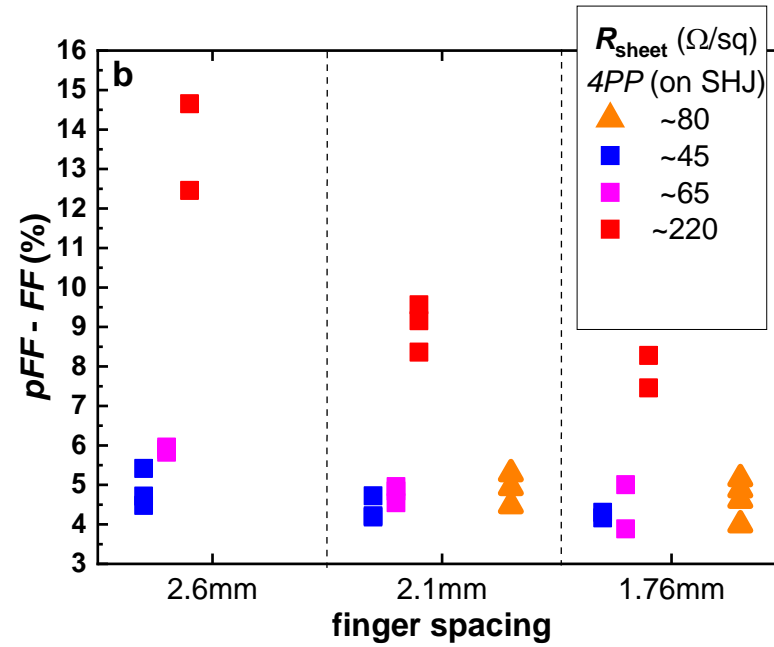
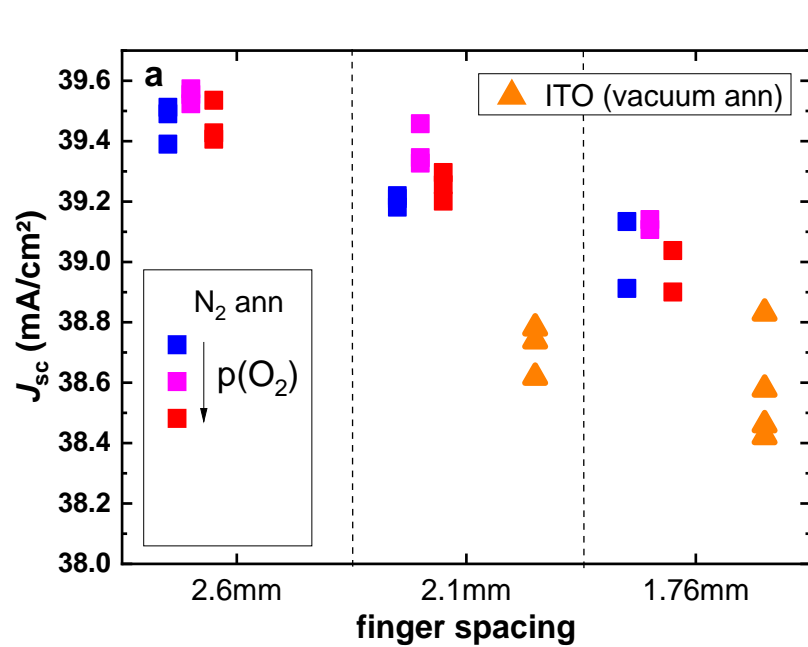
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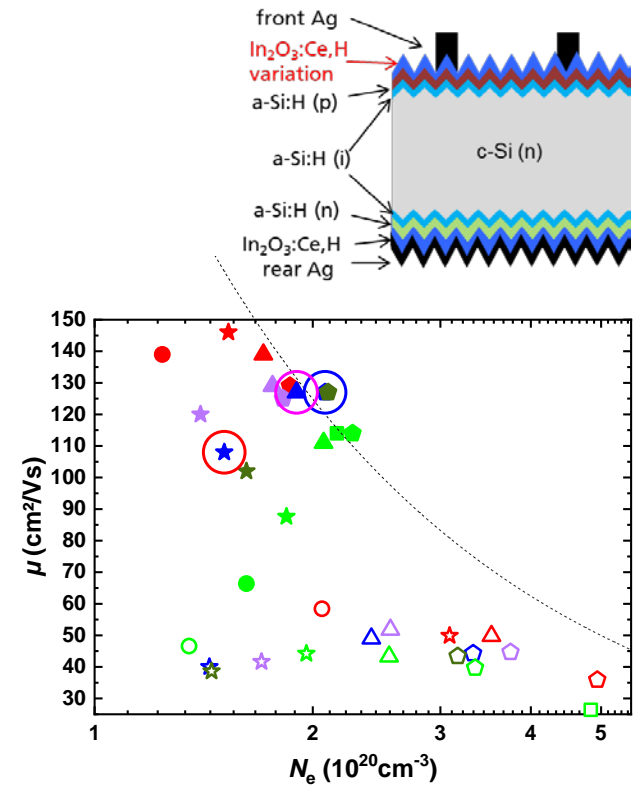
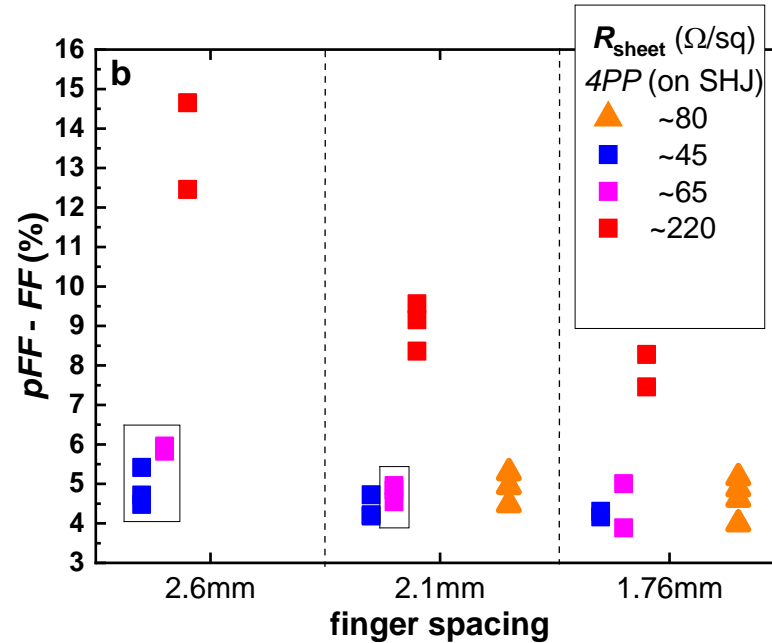
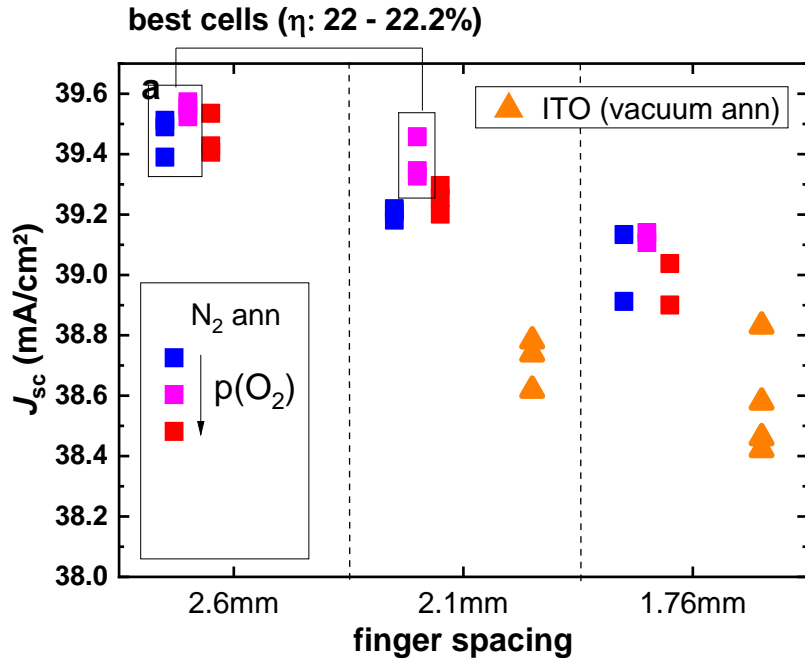
Optical performance and resistive losses



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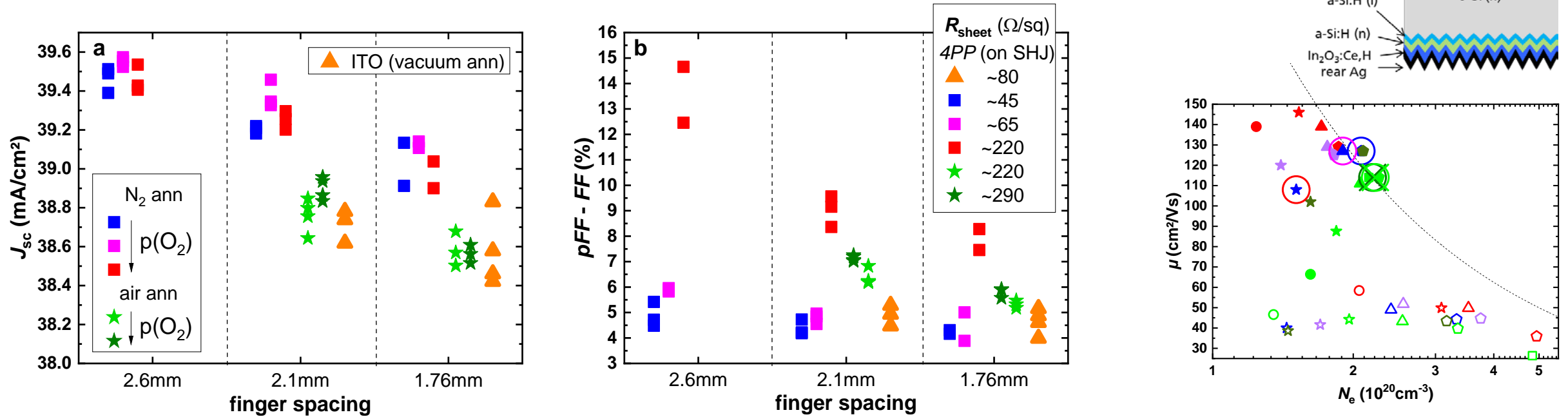
Optical performance and resistive losses



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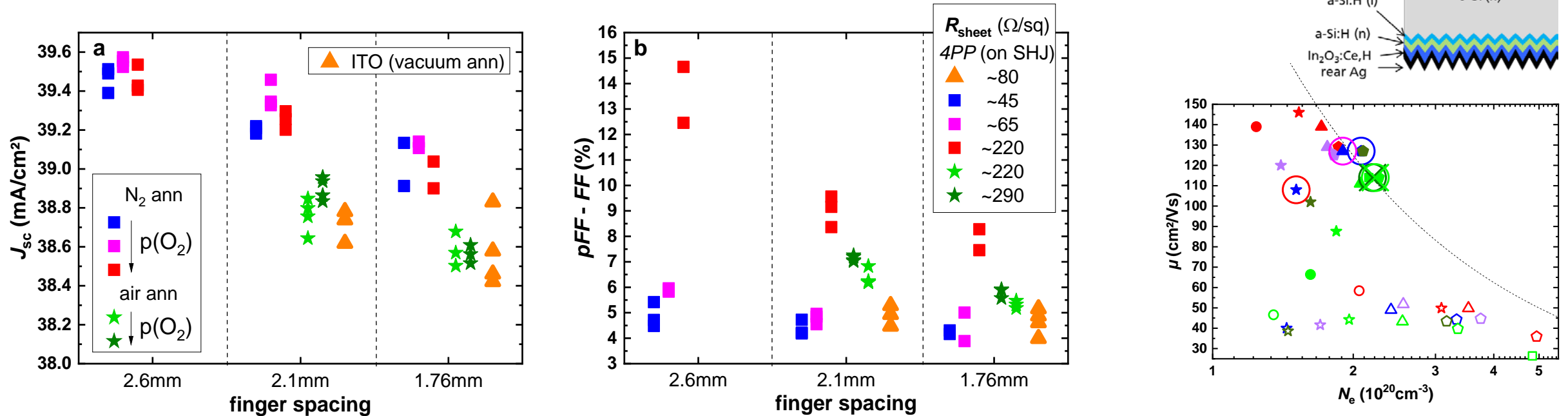
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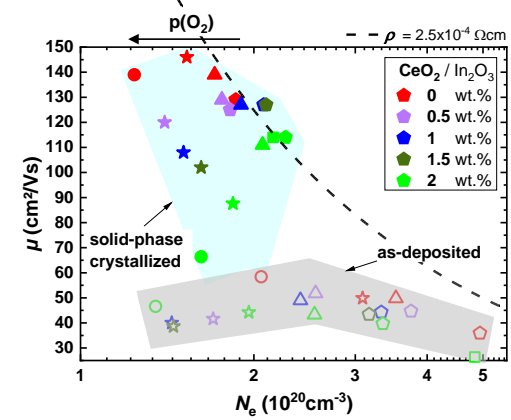
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- In₂O₃:Ce,H & N₂ annealing: $J_{sc} \uparrow$ (+ 0.6 mA/cm² vs ITO), large pitch applicable due to low R_{sheet}
- Air annealing: Poorer electrical & optical performance

Summary and outlook

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Summary

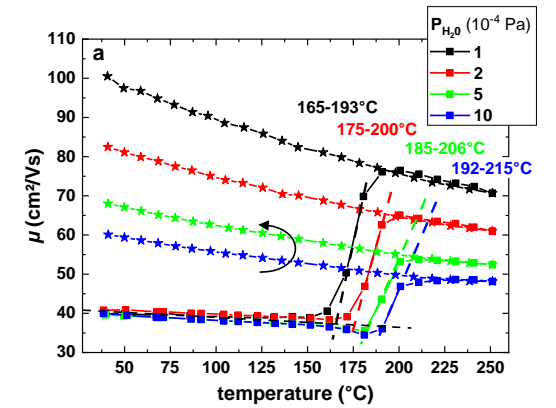
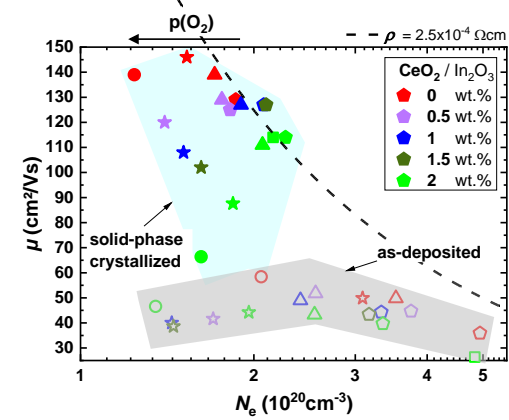
- Cerium efficient dopant



Summary and outlook

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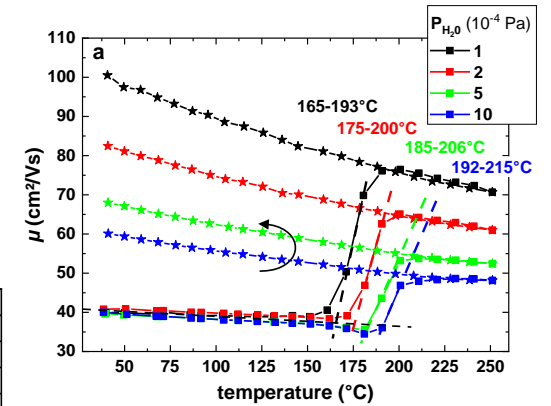
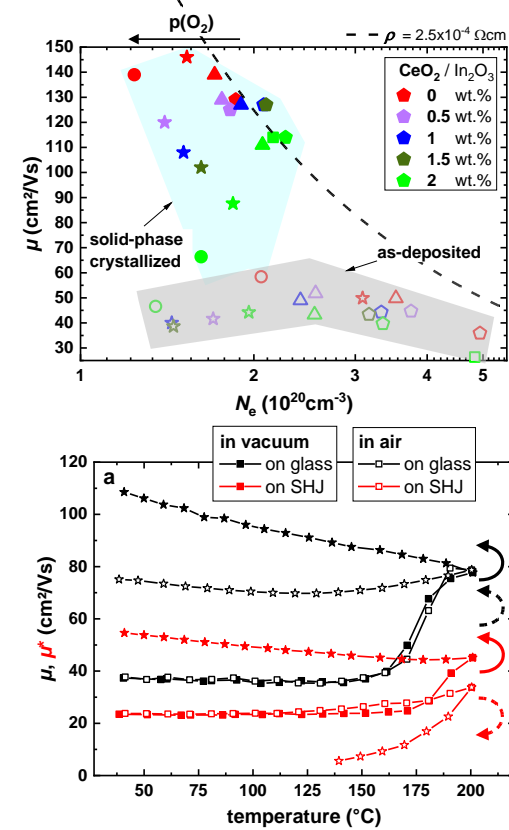
- Cerium efficient dopant
- Water partial pressure critical



Summary and outlook

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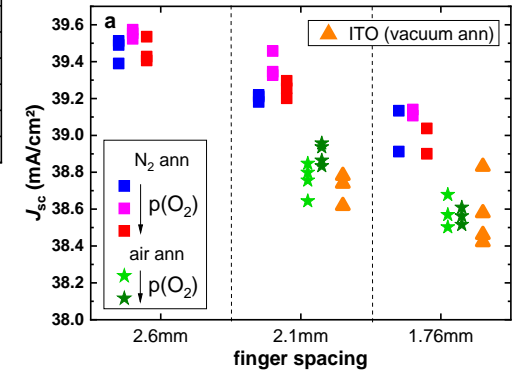
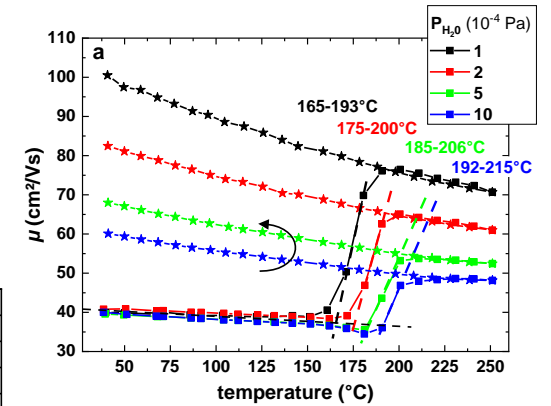
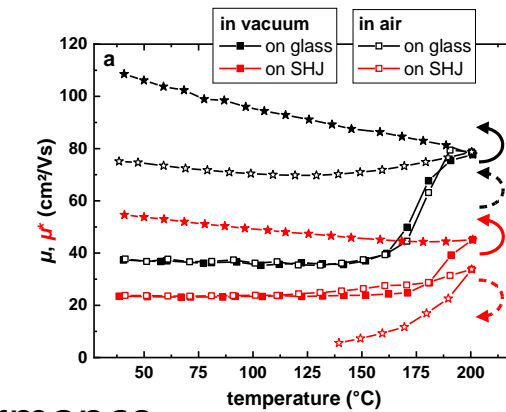
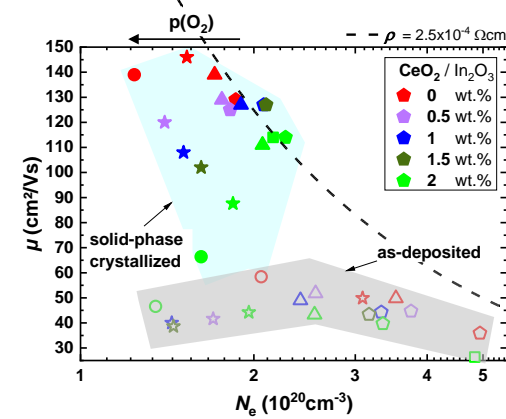
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Summary and outlook

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- Cerium efficient dopant
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- High potential of $\text{In}_2\text{O}_3:\text{Ce,H}$ reflected in solar cell performance



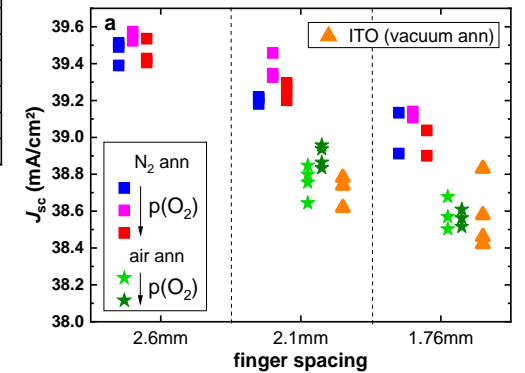
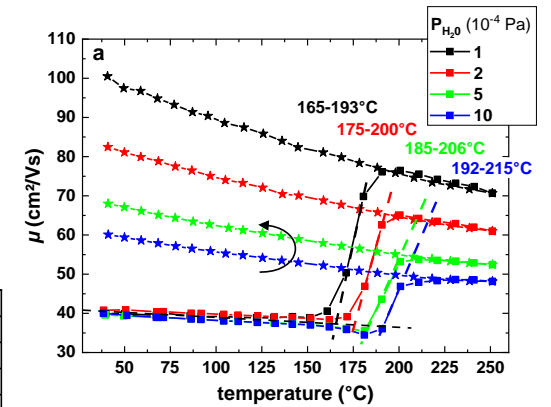
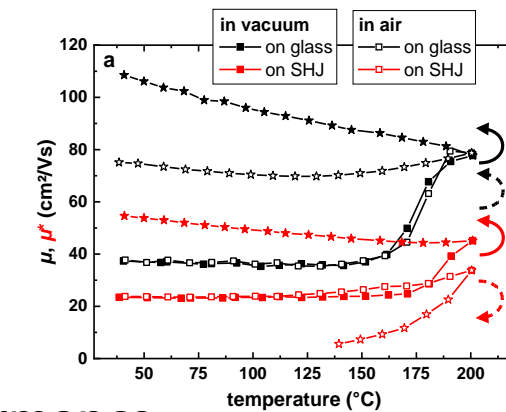
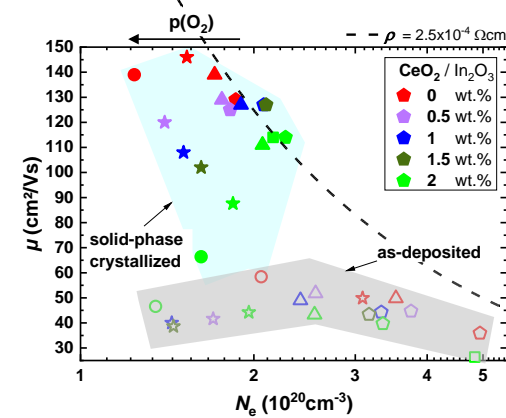
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Ongoing investigations and outlook

- Transfer to industrial-like DC sputter coater



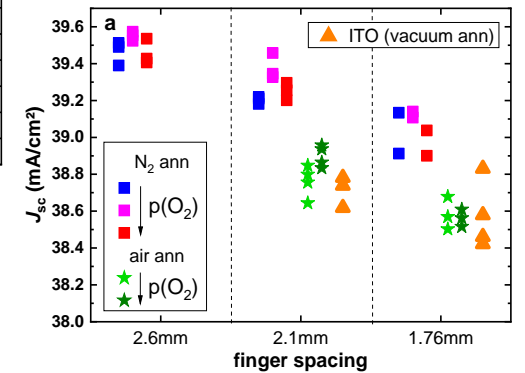
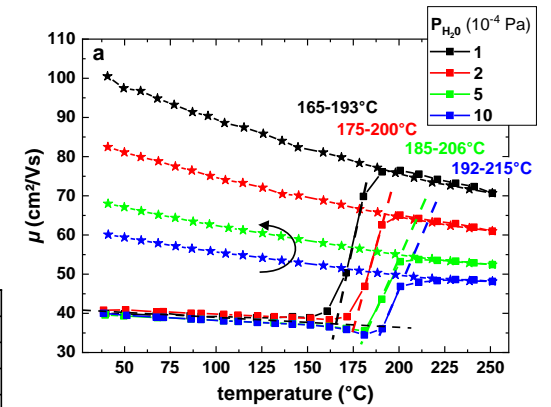
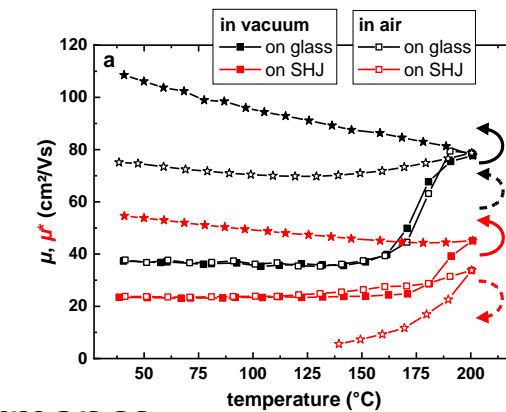
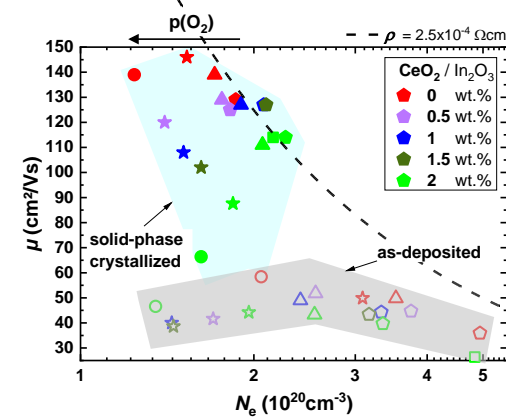
Summary and outlook

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Ongoing investigations and outlook

- Transfer to industrial-like DC sputter coater
- Reduce TCO thickness and combine with capping layer, e.g. with spray coated TiO_x ⁷



Thanks to the co-workers at AIST and F-ISE!

Thank you for your Attention!

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Gefördert durch:



aufgrund eines Beschlusses
des Deutschen Bundestages

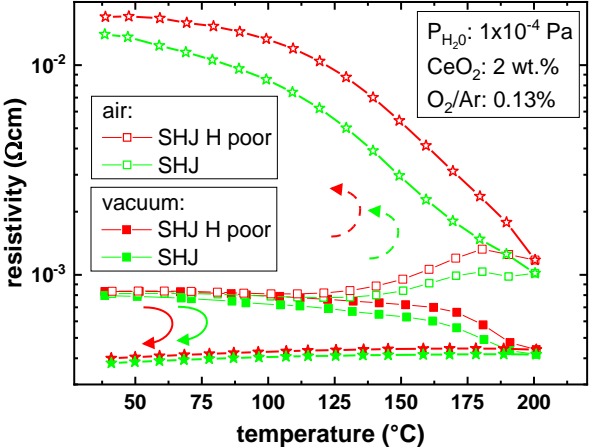
Leo Tutsch

leonard.tutsch@ise.fraunhofer.de

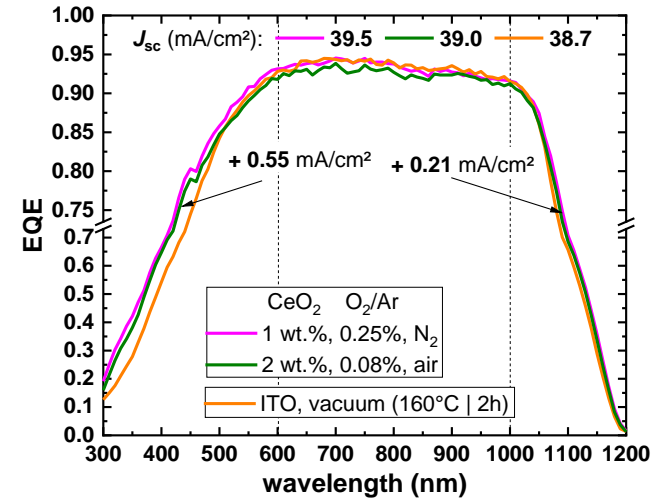
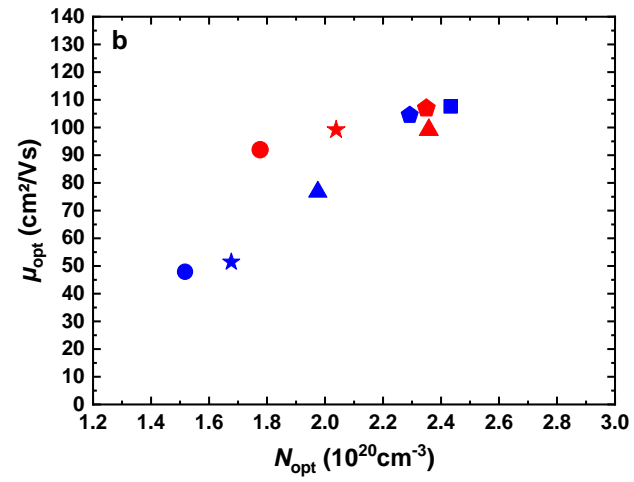
Publications of Fraunhofer ISE at EU PVSEC 2020 available on:

<http://www.ise.fraunhofer.de/eupvsec2020>

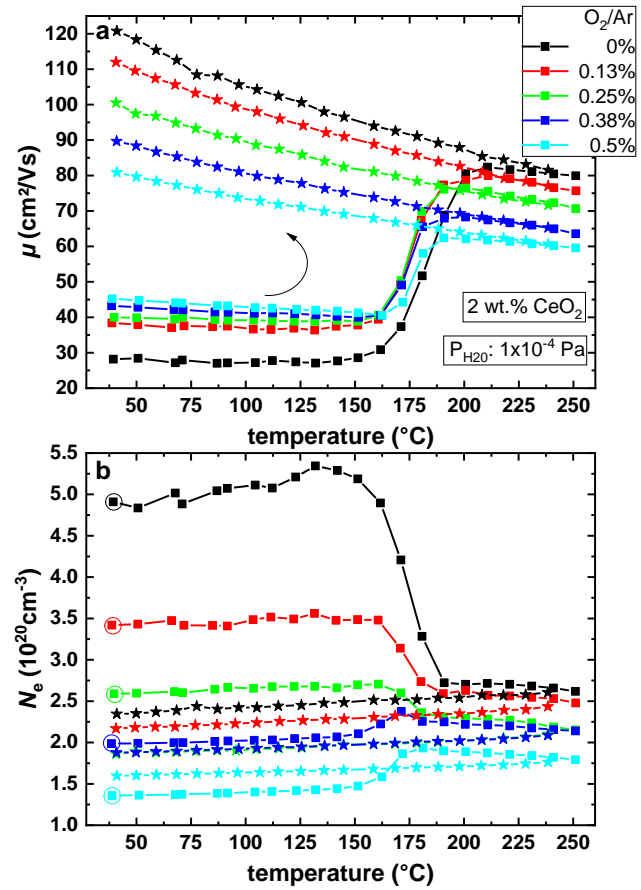
Appendix



Appendix



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