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Amorphous multi-cation and multi-anion oxide semiconductors: material design, carrier transport and device applications

Leipzig, 06.11.2020

Antonia Welk

Online Physikerinnentagung, Hamburg

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- Dr. Holger von Wenckstern
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- Oliver Lahr
- Michael Bar
- Jörg Lenzner

DFG Deutsche Forschungsgemeinschaft
AGENCE NATIONALE DE LA RECHERCHE ANR
BuildMoNa

Smart windows

[IndiaTVnews.com]

APPLICATIONS OF AMORPHOUS OXIDE SEMICONDUCTORS

Wearable electronics

[wearable-technologies.com]

[eenewseurope.com]

Smart windows

[IndiaTVnews.com]

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APPLICATIONS OF AMORPHOUS OXIDE SEMICONDUCTORS

Display technology

[media4growth.com]

[Grzegorz Petrykowski/Shutterstock]

[www.teltarif.de]

THIN FILM TRANSISTOR MATERIALS

flexible

[hothardware.com]

- amorphous
- magnetron sputtering
- room temperature deposition

[1] J. Wager, Inf. Display 30, 26 (2014)

THIN FILM TRANSISTOR MATERIALS

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transparent

[Samsung-electronics2016]

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- wide bandgap material

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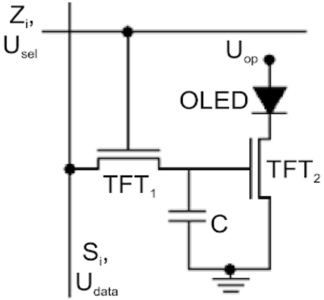
[Samsung-electronics2016]

AMOLEDs

$$\vec{j} = en\boldsymbol{\mu}\vec{E}$$



- amorphous
- magnetron sputtering
- room temperature deposition

- wide bandgap material

- high field effect mobilities μ **> 20 cm²/Vs** [1]

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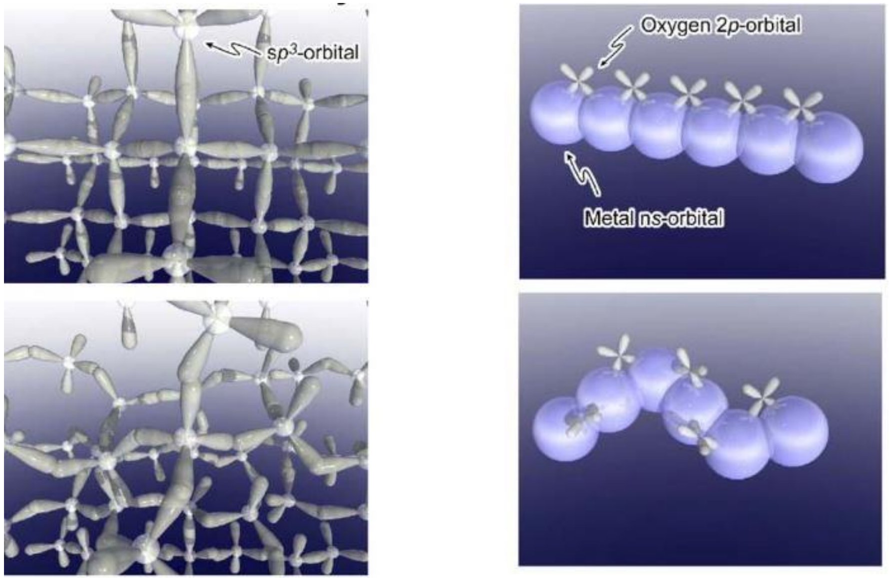
IONIC OXIDE SEMICONDUCTORS

covalent

ionic
metal: $(n\text{-}1)d^{10}ns^{0}$ $(n \geq 5)$

crystalline

amorphous



H. Hosono *et al.,* Non-Cryst. Solids, 352, 851 (2006)

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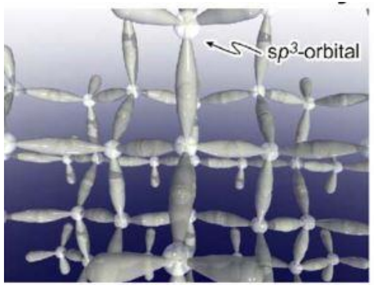

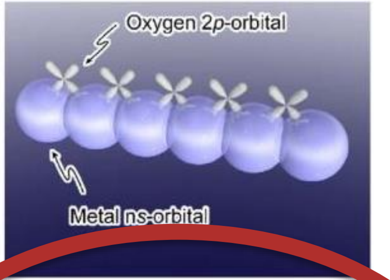

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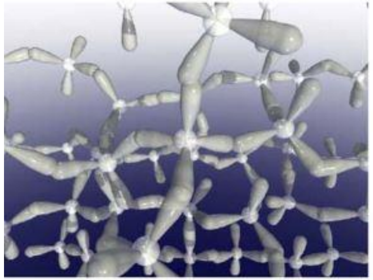

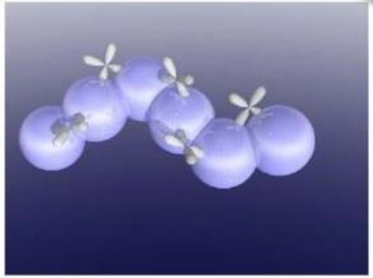

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POSSIBLE TRANSITION METALS

9	10	III	IV	V
29 Cu 63,54	30 Zn 63,54	31 Ga 63,54	32 Ge 63,54	33 As 63,54
47 Ag 63,54	48 Cd 63,54	49 In 63,54	50 Sn 63,54	51 Sb 63,54
79 Au 63,54	80 Hg 63,54	81 Tl 63,54	82 Pb 63,54	83 Bi 63,54

[Schlupp2018]

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[Schlupp2018]

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critical raw materials

European Comission, *The 2020 EU Critical Raw Materials List*, 3rd Sep. 2020

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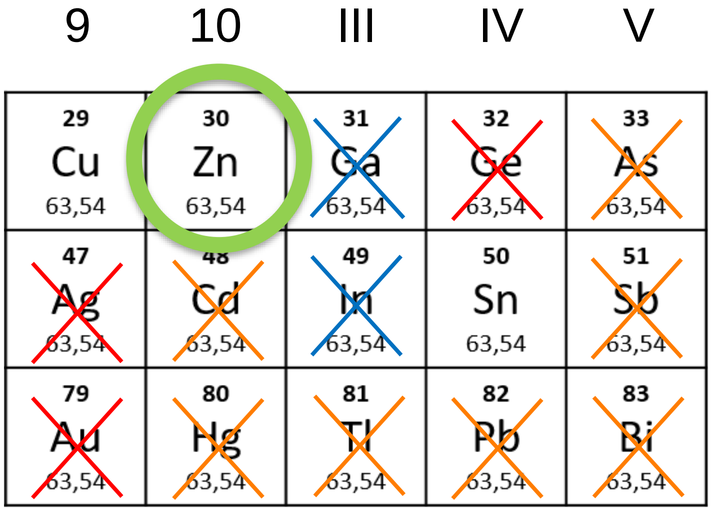

[Schlupp2018]

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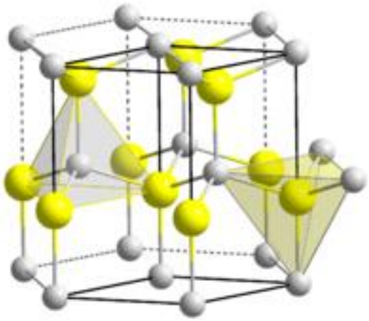
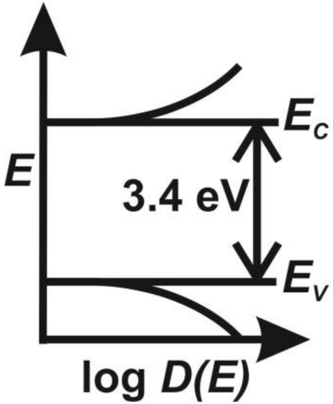
European Comission, *The 2020 EU Critical Raw Materials List*, 3rd Sep. 2020

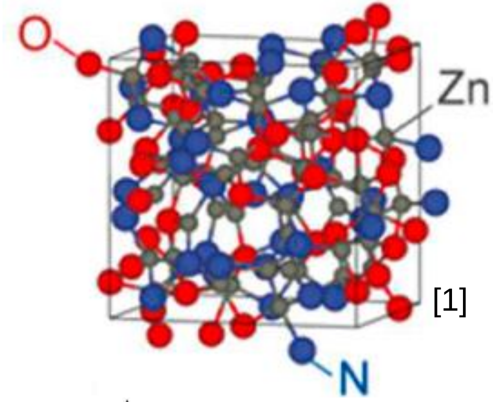
ZINC OXIDE

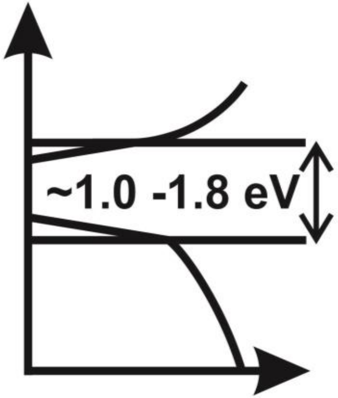


[wikipedia.org]



ZINC OXYNITRIDE





[1] H. Kim *et al.,* Sci. Rep. 3, 1459 (2013)

AMORPHOUS OXIDE SEMICONDUCTORS

anionic disorder

- a-ZnON μ = 100 cm^2/Vs

cationic disorder

- a-InGaZnO μ = 20 cm^2/Vs
- a-ZnSnO μ = 13 cm^2/Vs

[Lahr2020]

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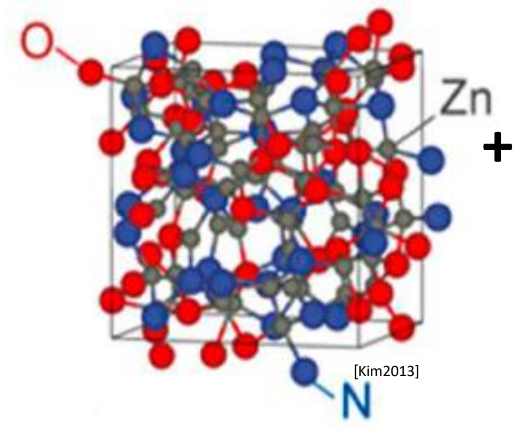
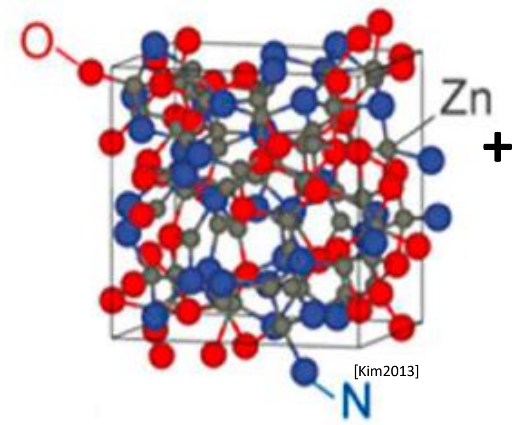
[Lahr2020]

Combining cationic and anionic disorder ?



[Kim2013]

+ Mg^{2+} = ???



+ Mg^{2+} = ???

Goal: deposition of ZnMgON thin films

FROM MATERIAL DEPOSITION TO DEVICE FABRICATION

Material design of ZnMgON thin films

FROM MATERIAL DEPOSITION TO DEVICE FABRICATION

Material design of ZnMgON thin films

ZnMgON based **pn-heterodiodes**

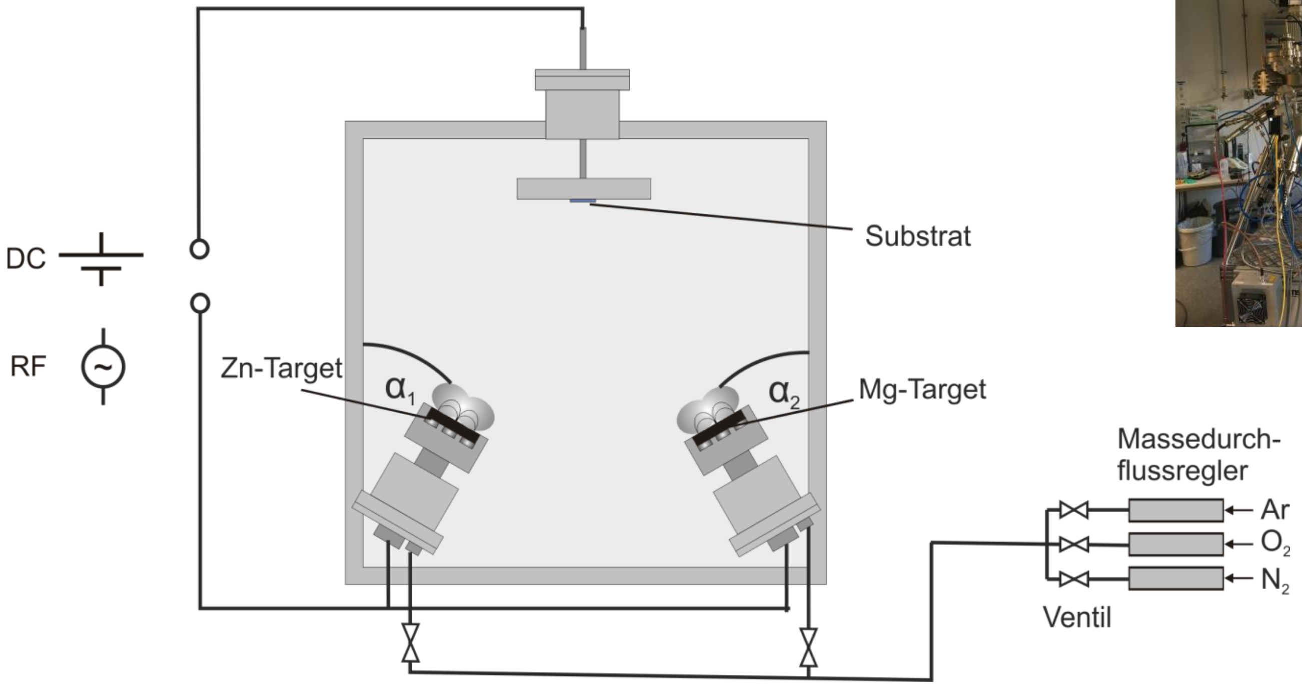
FROM MATERIAL DEPOSITION TO DEVICE FABRICATION

Material design of ZnMgON thin films

Percolation description of **charge transport** in a-ZnON and a-ZTO

ZnMgON based **pn-heterodiodes**

MAGNETRON CO-SPUTTERING



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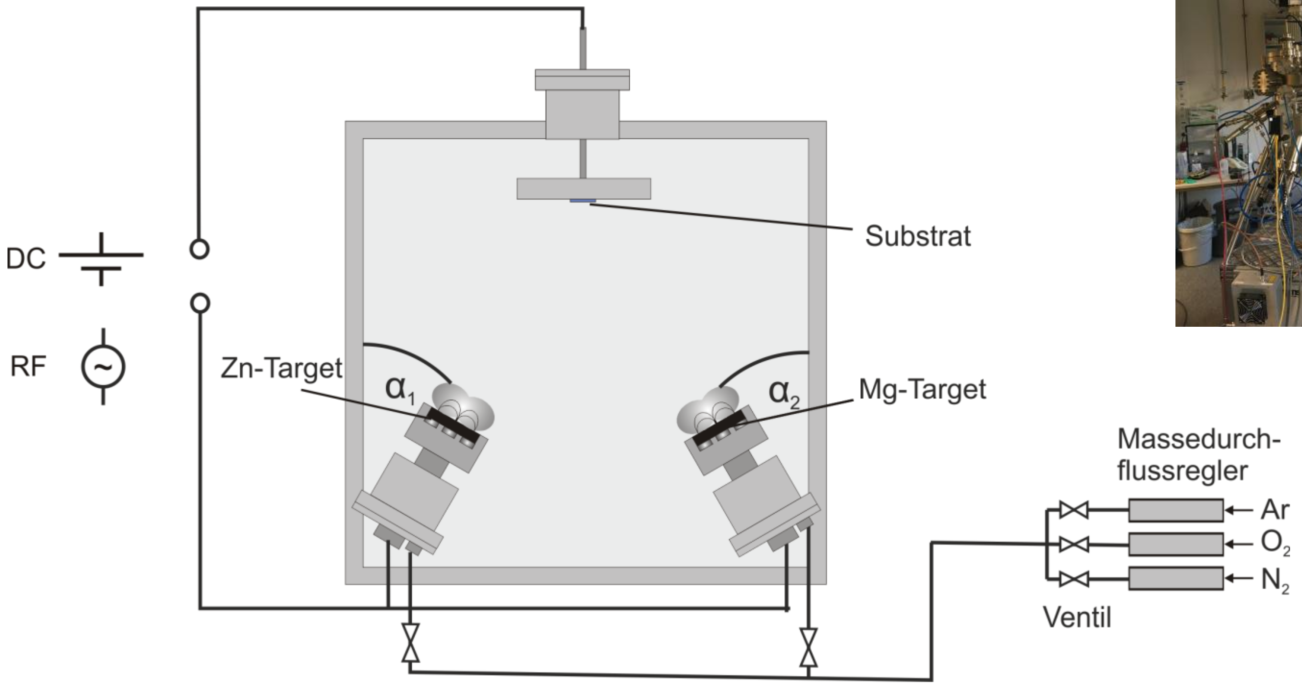
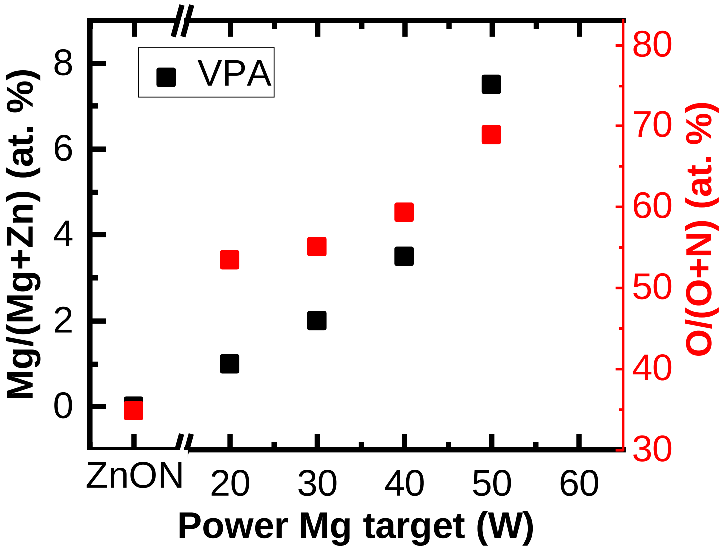


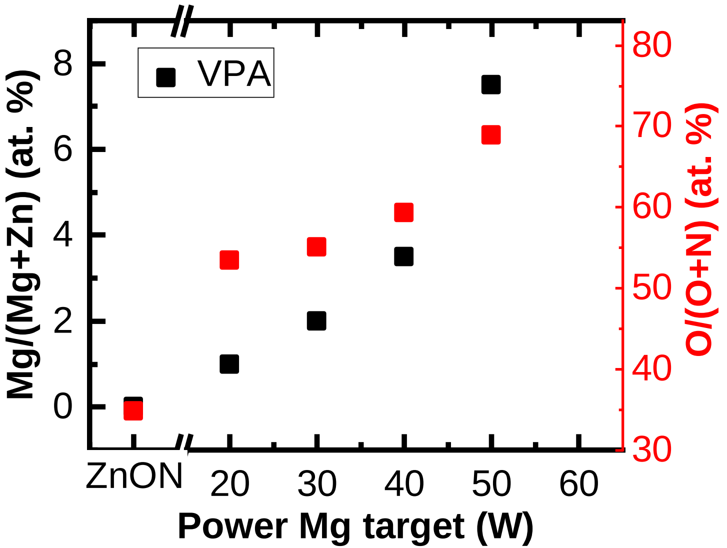
How to vary the chemical composition of the thin films?

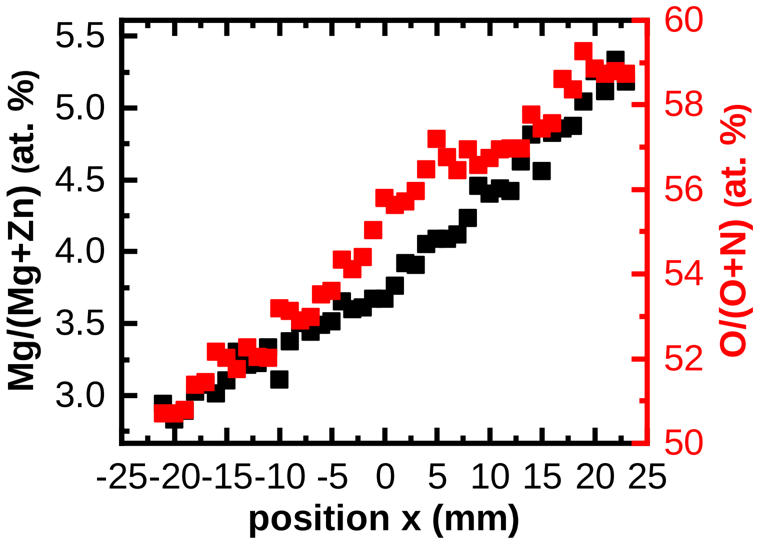
CHEMICAL COMPOSITION



Variable power approach

CHEMICAL COMPOSITION

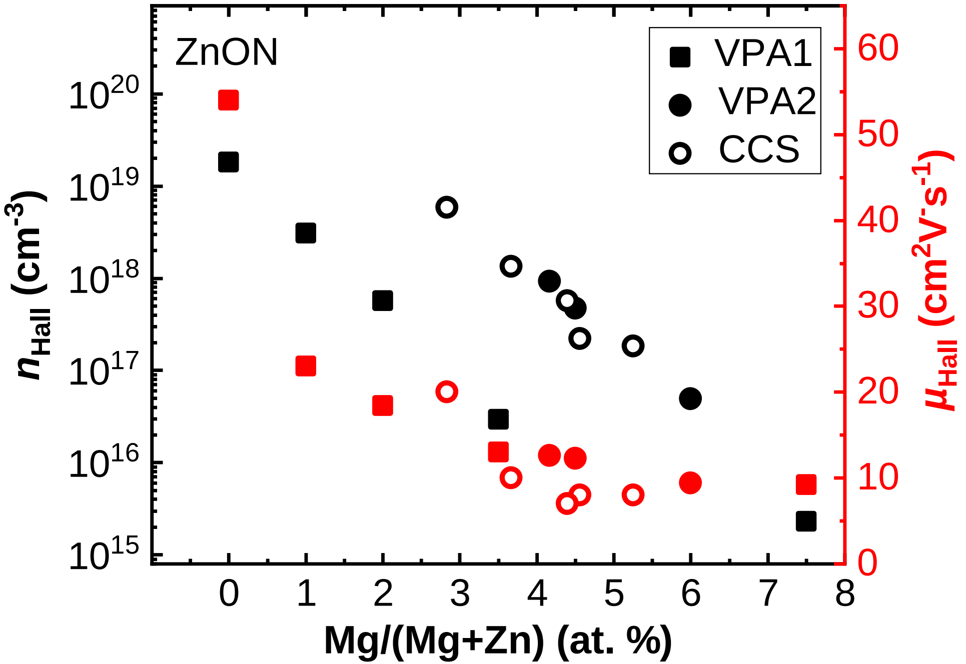




Variable power approach

Continuous composition spread

ELECTRICAL PROPERTIES



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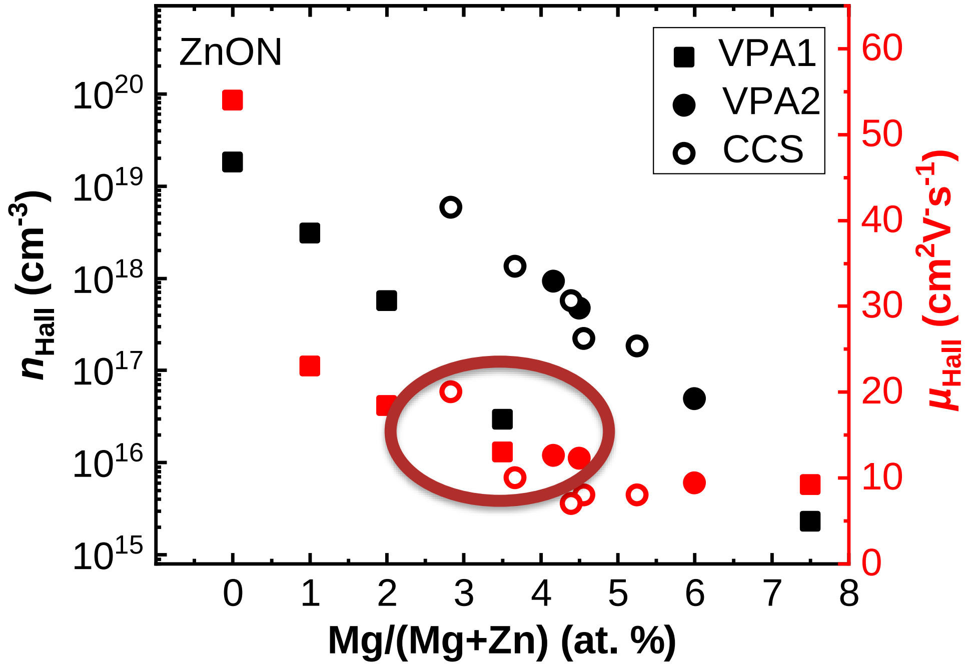
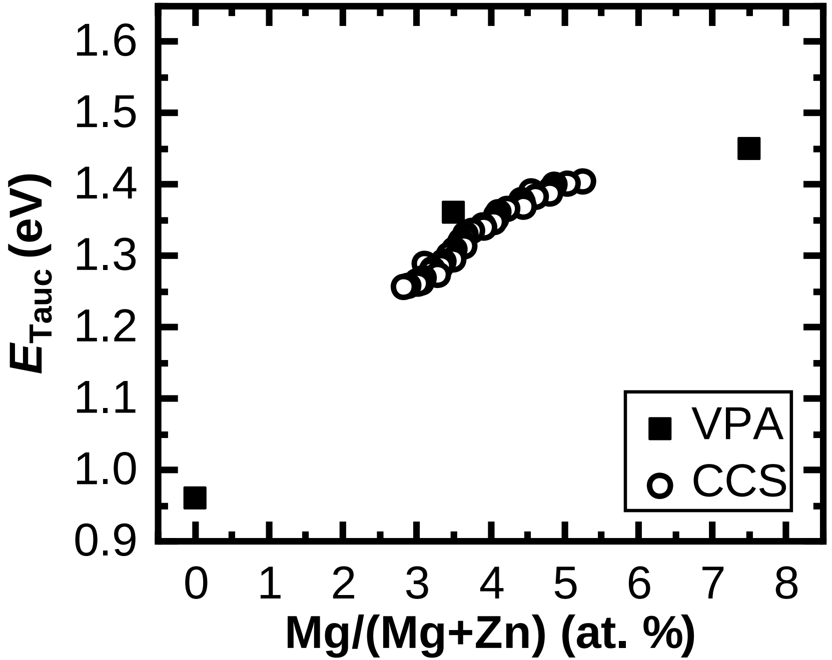


new electrical properties regime
$n \sim 10^{17} cm^{-3}$ and $\mu < 20 cm^2V^{-1}s^{-1}$

OPTICAL PROPERTIES

OPTICAL PROPERTIES



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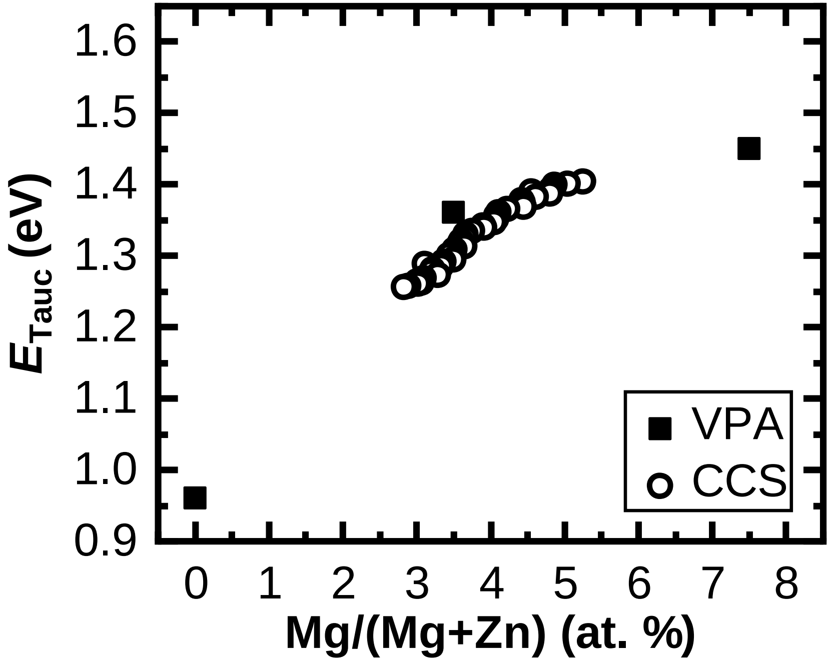
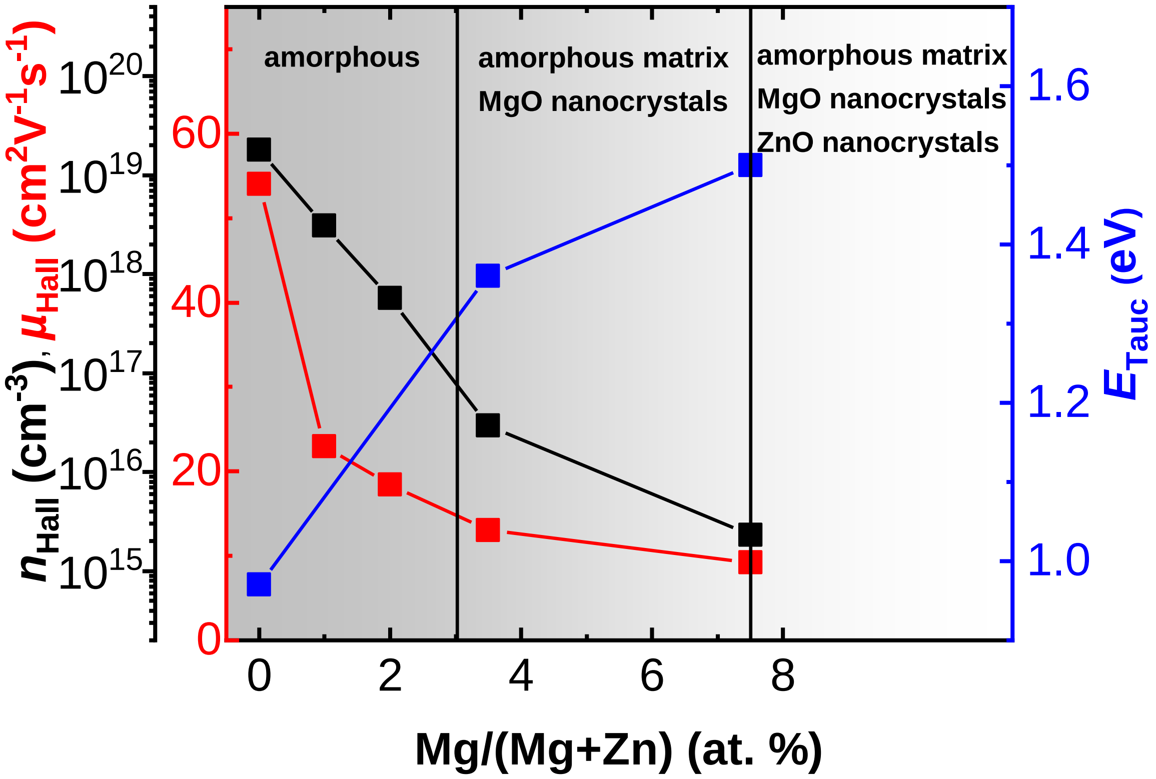


ZnMgON slightly more transparent than a-ZnON

FIGURE OF MERIT



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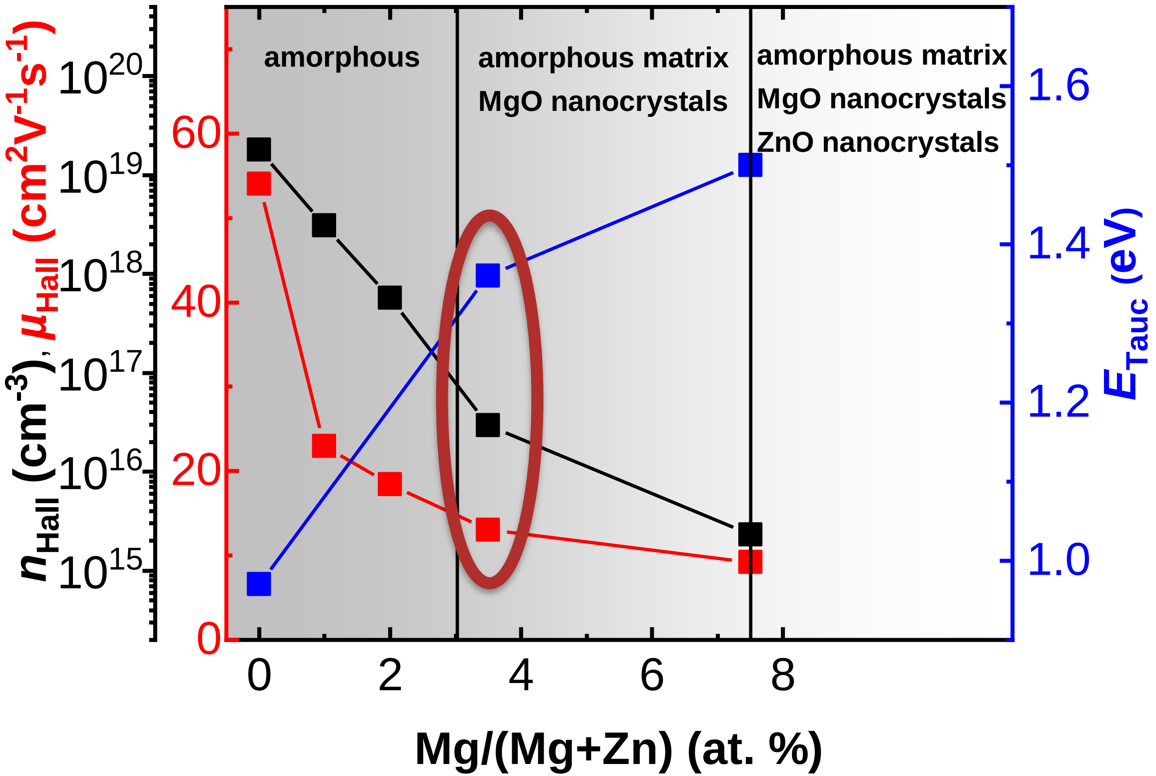

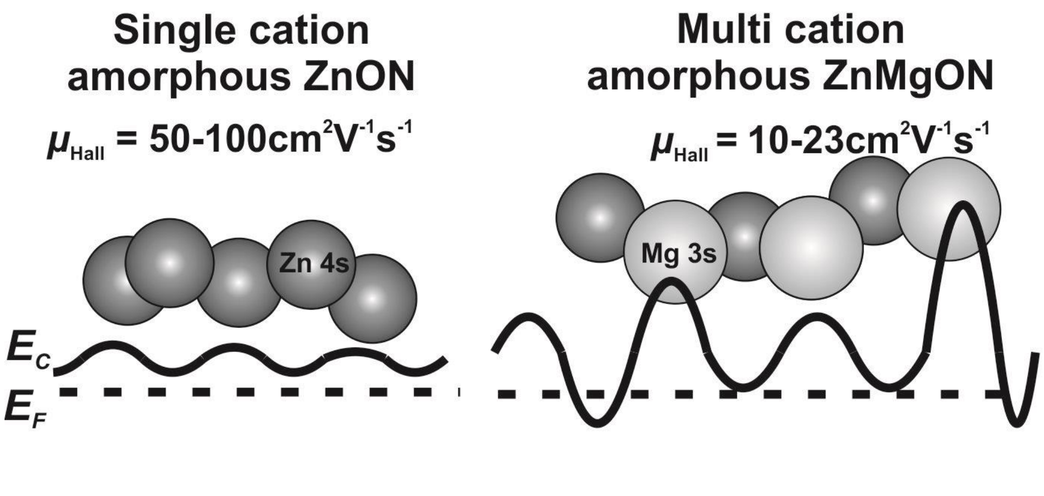

What is the effect of cationic substitution?

DESCRIPTION OF CHARGE TRANSPORT - COMBINATION OF THEORY AND EXPERIMENT

1) **Deposition** of thin films with varying doping
2) **Measuring** temperature dependent electrical properties
3) **Applying** a suitable **theoretical model**
4) **Extracting** parameters giving new material insights

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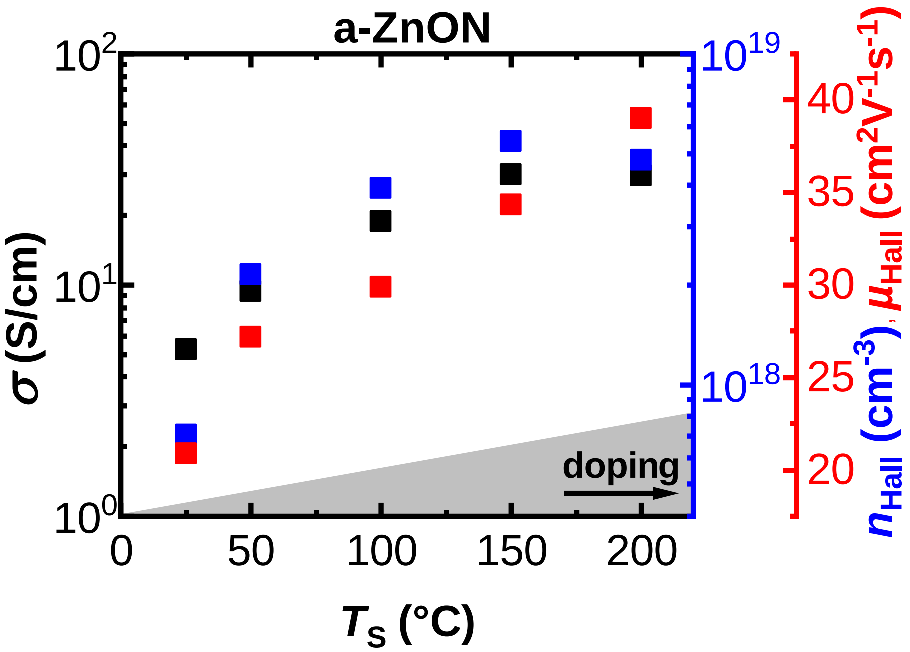

A. Reinhardt et al., Phys Status Solidi(A) 213(7), 1767-1773 (2016)

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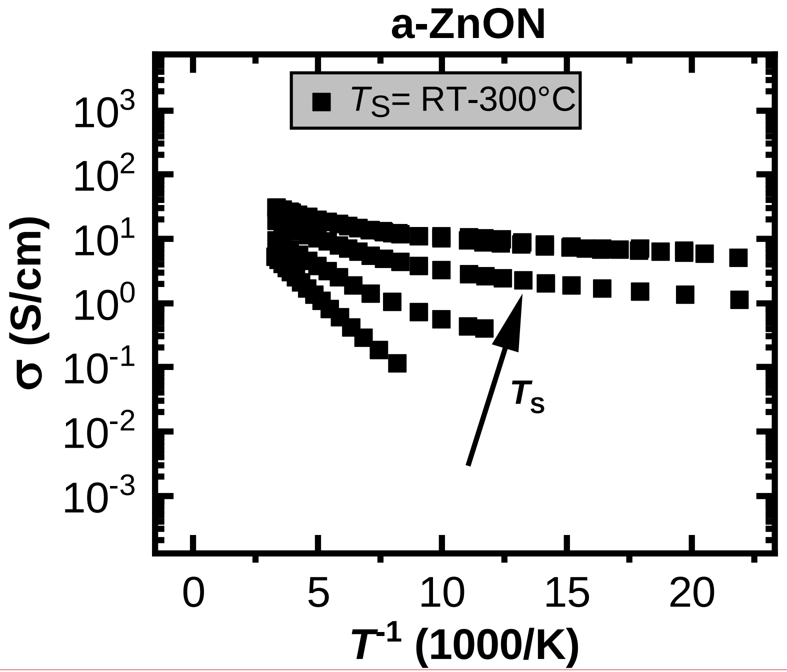

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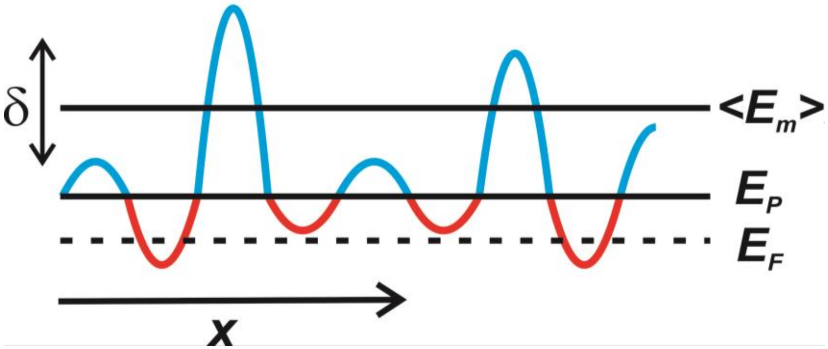

A.V. Nenashev et al., Phys. Rev. B 100, 125202 (2019)

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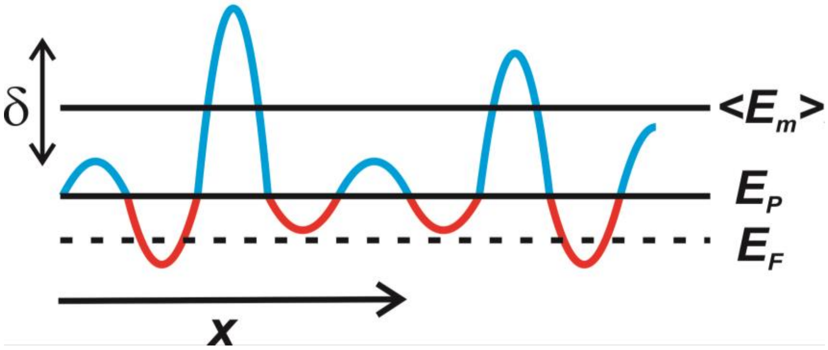

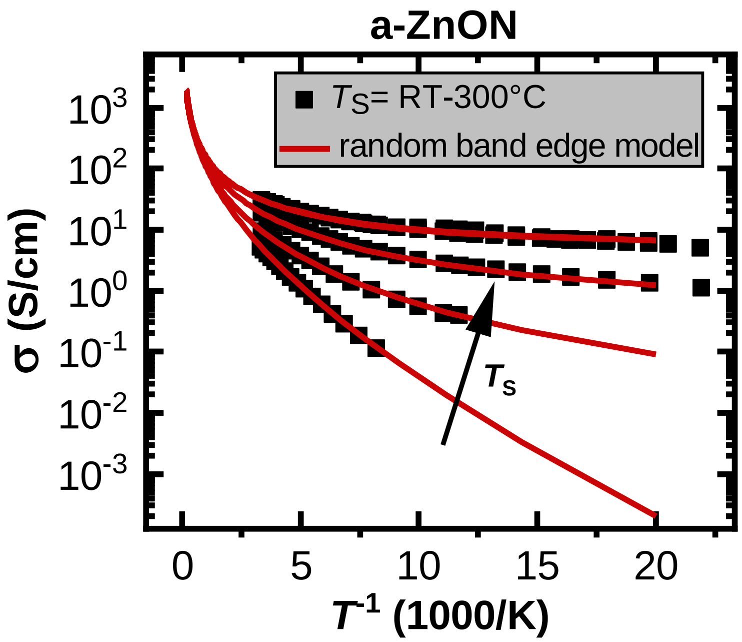

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DESCRIPTION OF CHARGE CARRIER TRANSPORT - COMBINATION OF THEORY AND EXPERIMENT

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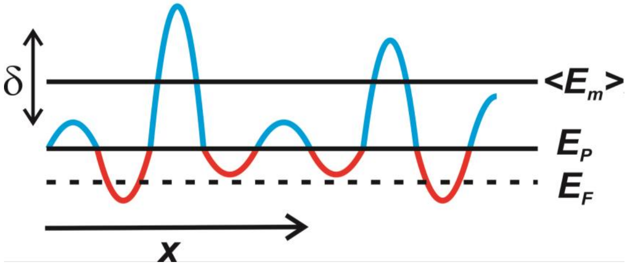

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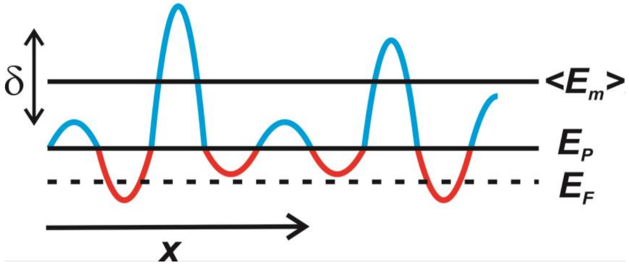

a-ZnON	a-IGZO	a-ZTO
δ ~ 20 meV	$\bar{\delta}$ = 38.5meV	$\bar{\delta}$ = 60meV

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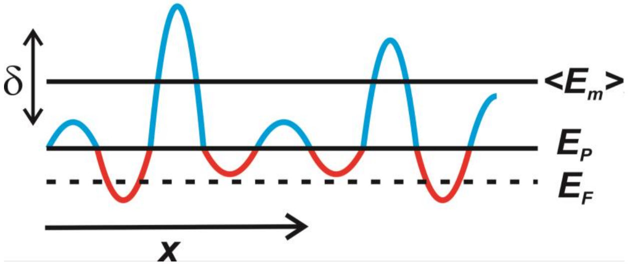
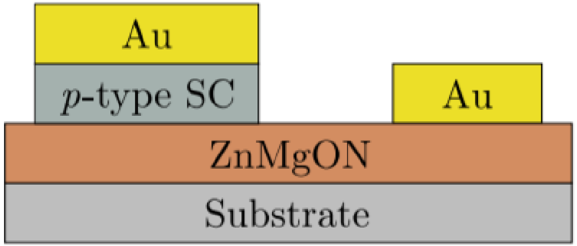


a-ZnON	a-IGZO	a-ZTO
$\delta \sim 20$ meV	$\bar{\delta} = 38.5$meV	$\bar{\delta} = 60$meV

Multi-anion compound show less potential fluctuations than multi-cation compounds

AMORPHOUS PN HETERODIODE



A. Jörns, master thesis (2020)

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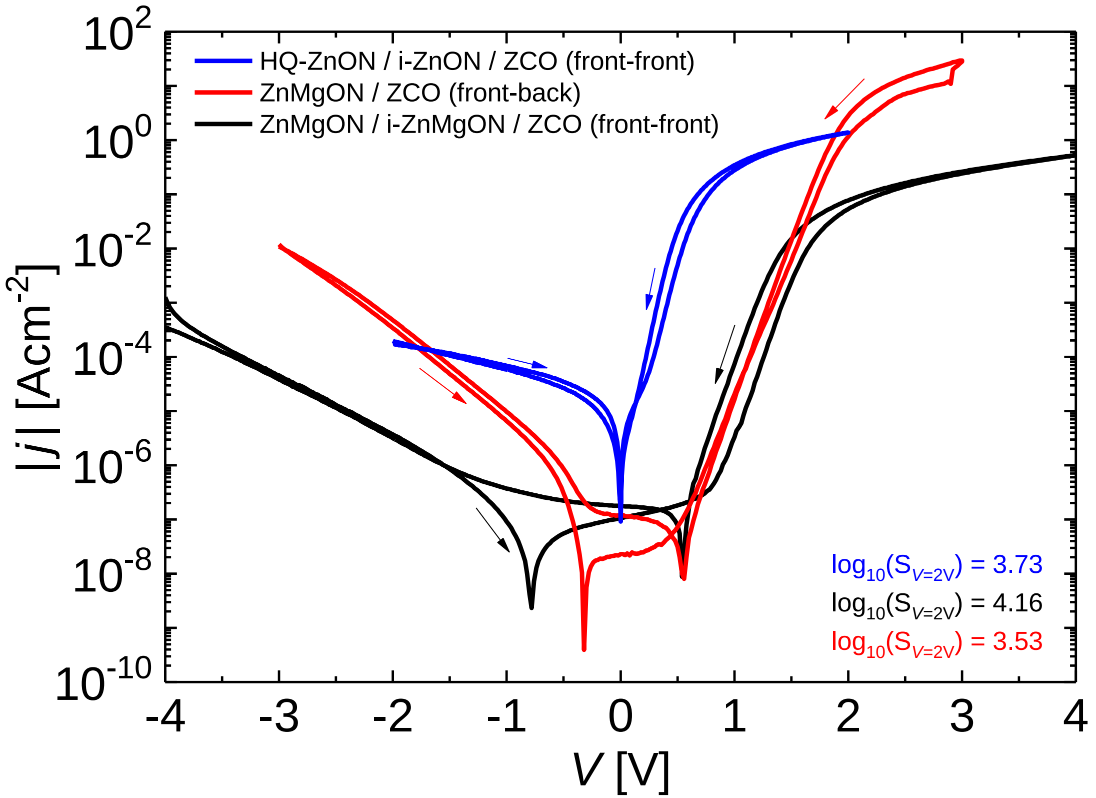
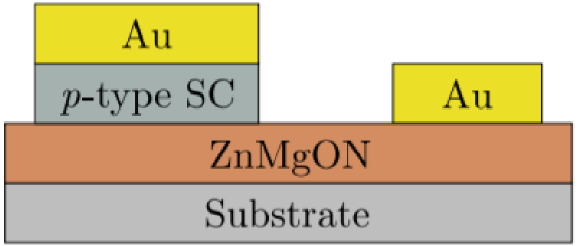


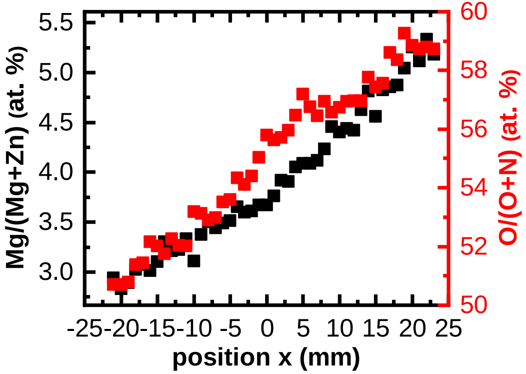


- n-type ZnMgON and p-type Zinc cobalt oxide (ZCO)
- high tunneling currents in backwards direction
- enhancement of rectification ratio

A. Jörns, master thesis (2020)

SUMMARY

- Deposition of a continuous composition spread
- Electrical properties of a-ZnON are tunable by magnesium cation substitution between n=10^{19}cm^{-3} and n=10^{15}cm^{-3}



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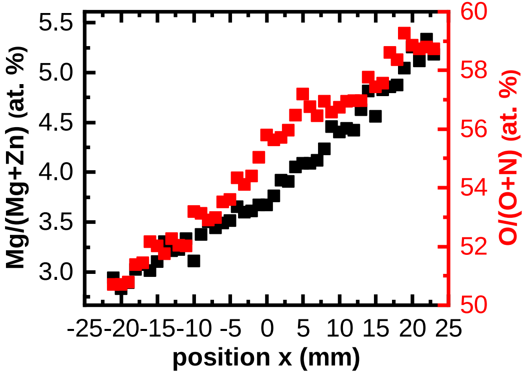

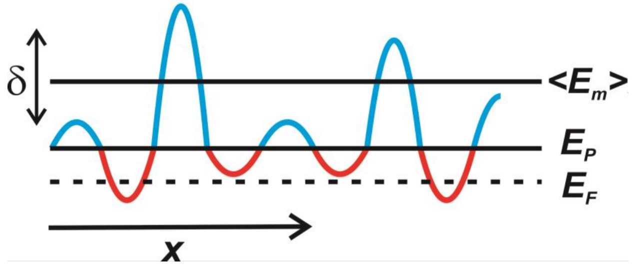

- Percolation theory can be applied to determine the distribution of the conduction band edge

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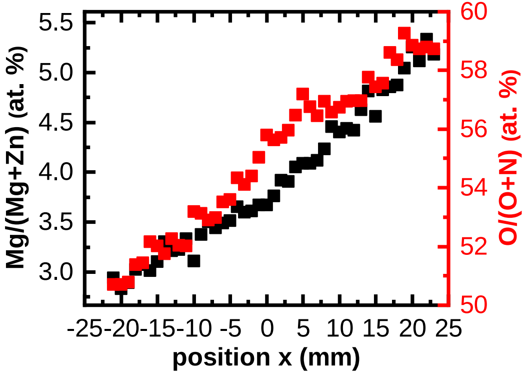

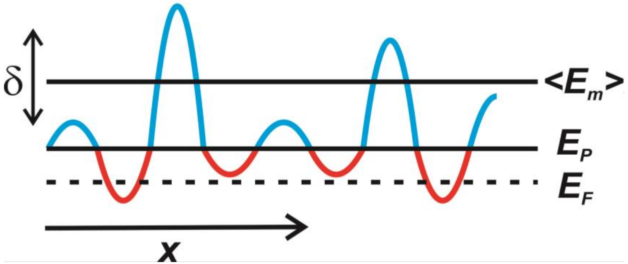

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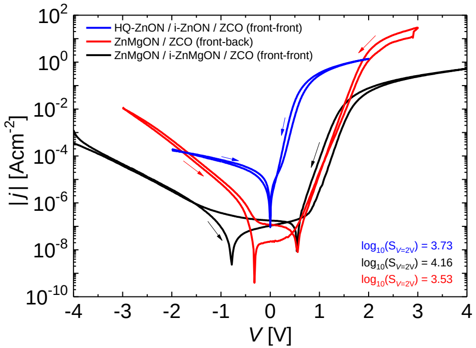
- Amorphous pn heterodiode n-ZnMgON/p-ZCO



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THANK YOU FOR YOUR ATTENTION!

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Tel +49 341 97-32615

antonia.welk@physik.uni-leipzig.de
www.uni-leipzig.de

BACKUP

THIN FILM TRANSISTOR MATERIALS

	a-Si:H	pc-Si	amorphous oxides
electron mobility	1 cm^2/Vs	30-100 cm^2/Vs	1-100 cm^2/Vs
process temperature	150-350°C	250-550°C	RT – 600°C
substrate	glass	glass	glass and plastic
uniformity	yes	no	yes
cost	low	high	low

K.-S. Park, *Proc. AM-FPD*, IEEE, Piscataway, NJ (2015)

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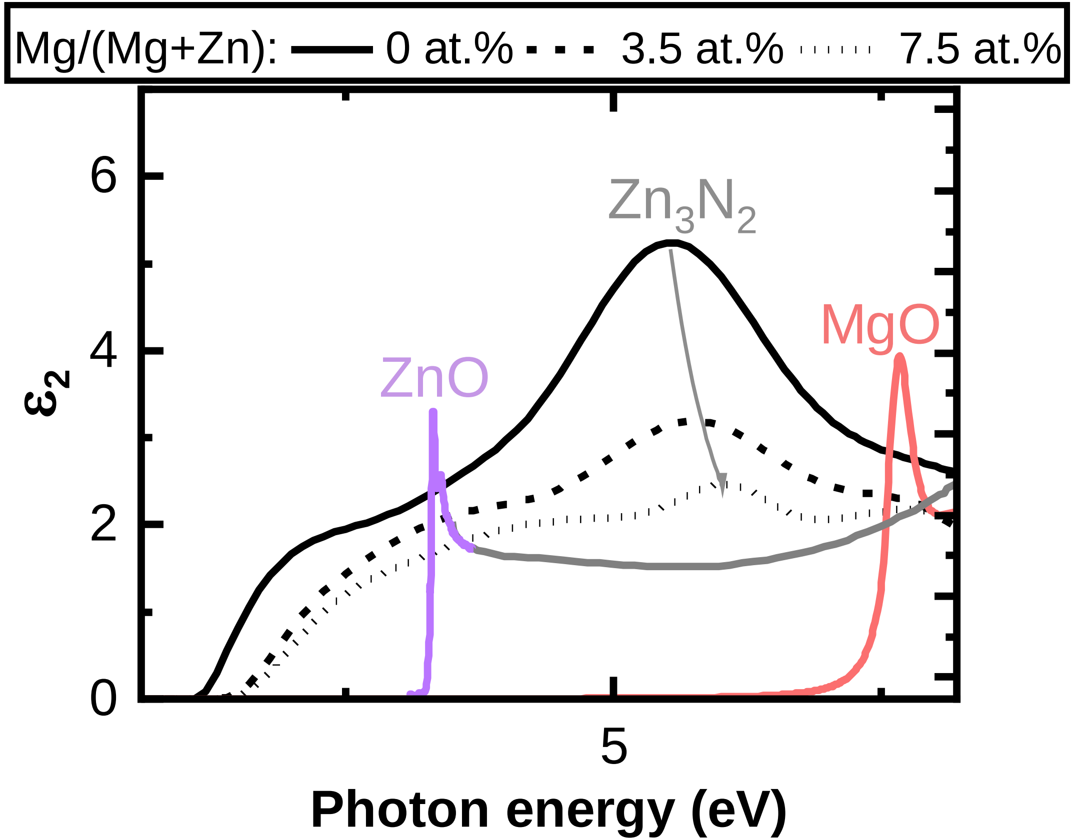
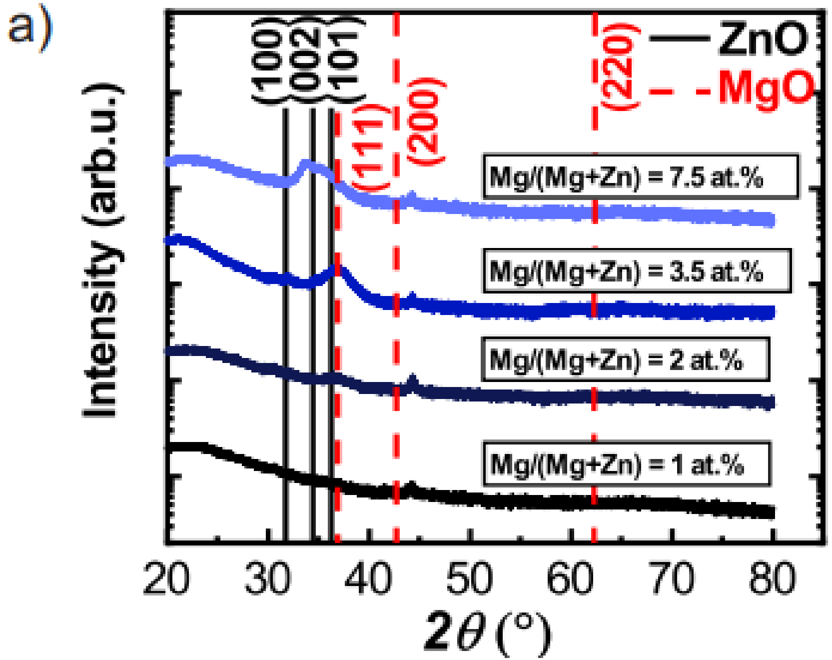
OPTICAL PROPERTIES



STRUCTURAL PROPERTIES



MAGNETRON CO-SPUTTERING

- reactive in nitrogen and oxygen atmosphere 20sccm:1sccm