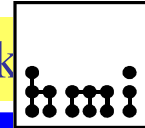


Magnetrongesputterte Oxidschichten: Wie beeinflusst die Teilchenenergie die elektrischen Eigenschaften?

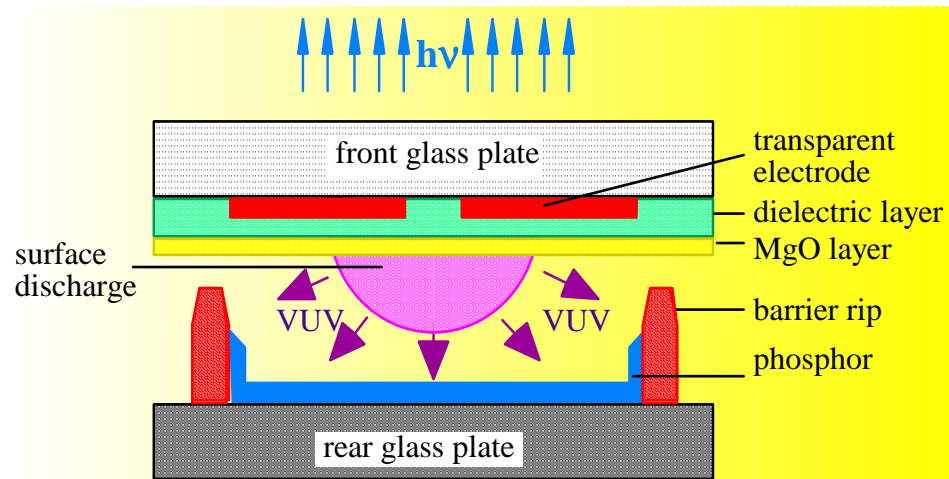
K. Ellmer, R. Mientus

- Transparente Elektroden
- Optimierungsstrategie
- Energetik des Magnetron-sputterns
- Transport in hochdotierten HL
- Beweglichkeit von ZnO u. ITO
- Einfluß der Ionenenergie?
- Zusammenfassung/Ausblick

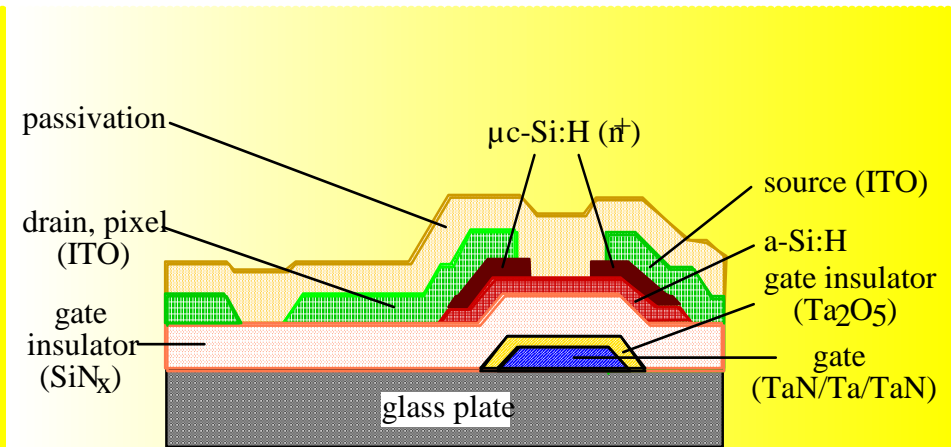




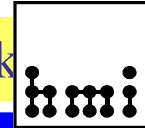
Transparente Elektroden 1: Plasma- und Flüssigkristallanzeigen (ITO)



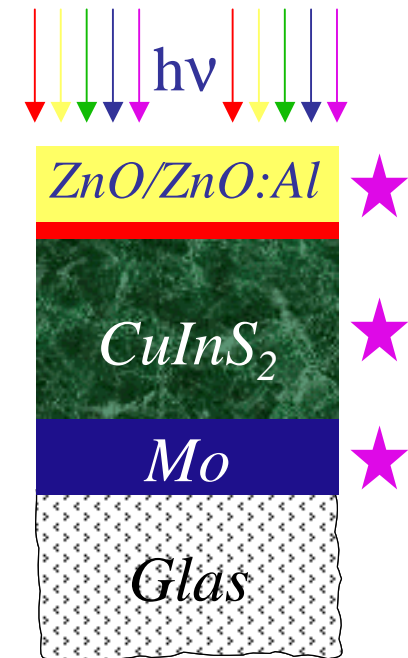
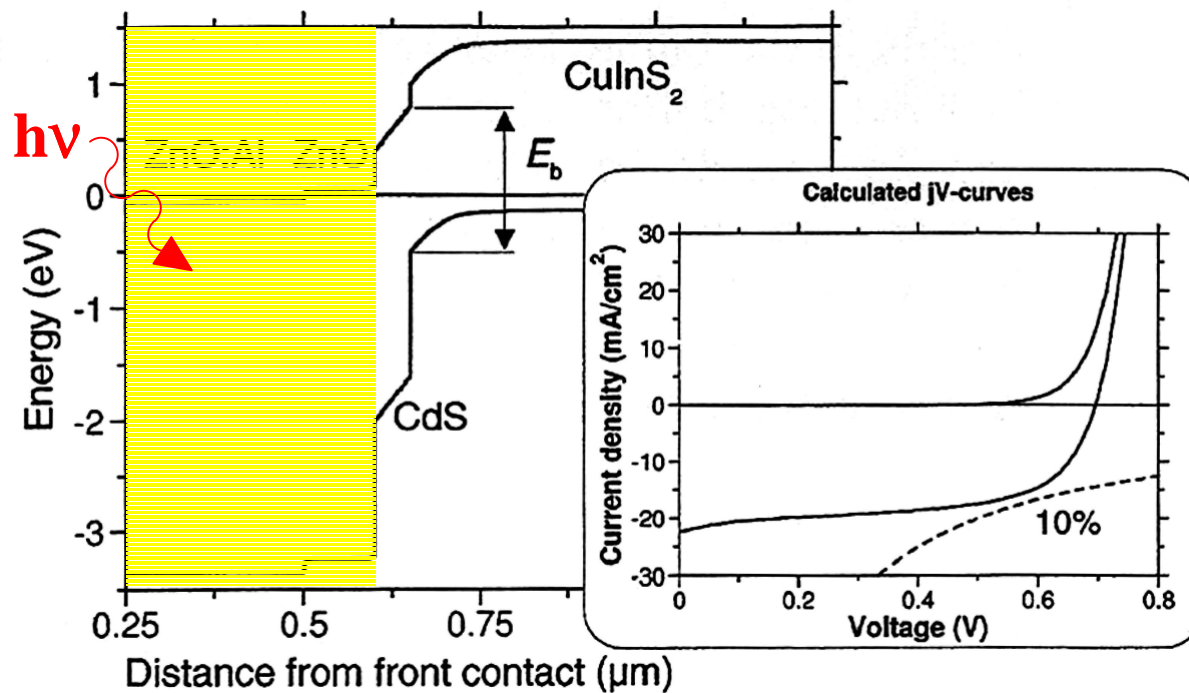
Jüstel, Philips Aachen (2000)



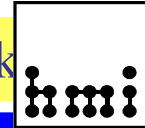
Katayama, Sharp Nara (1999)



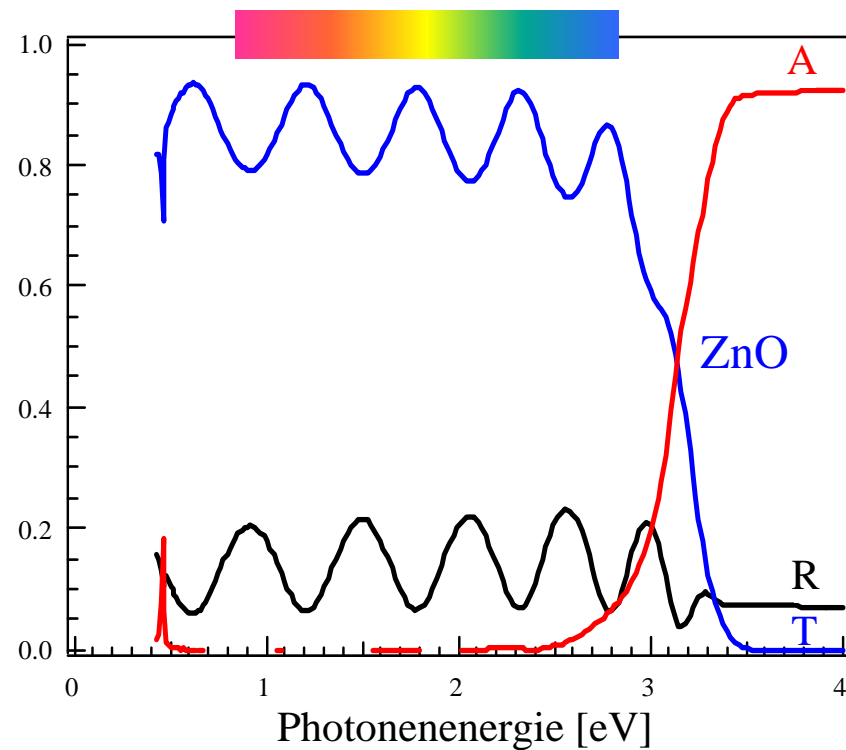
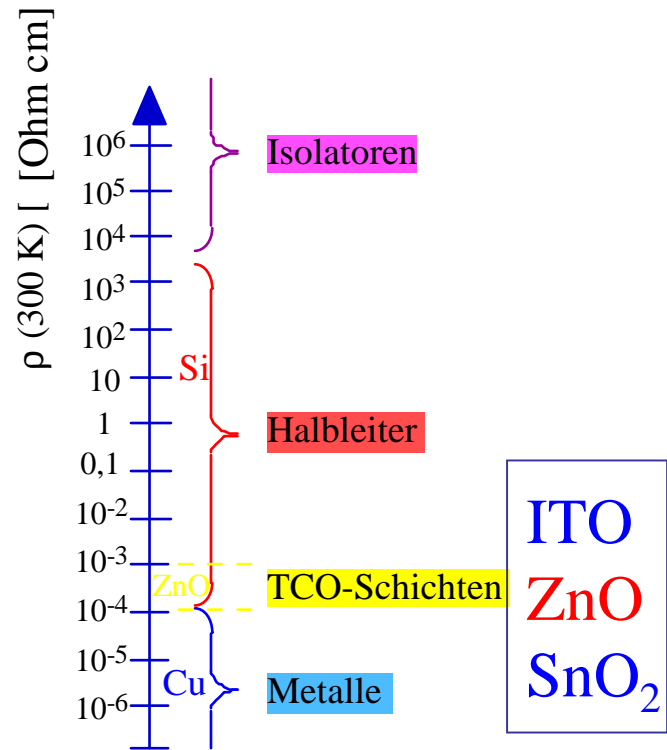
Transparente Elektroden 2: Fensterschichten in Solarzellen (ZnO)



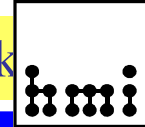
Klenk, TSF 387(2001)135



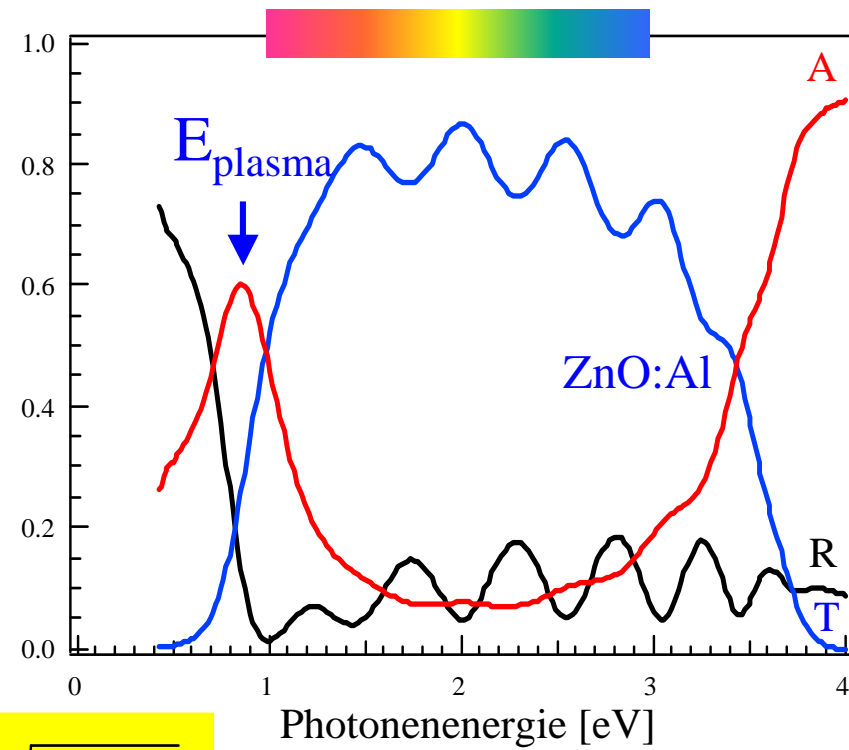
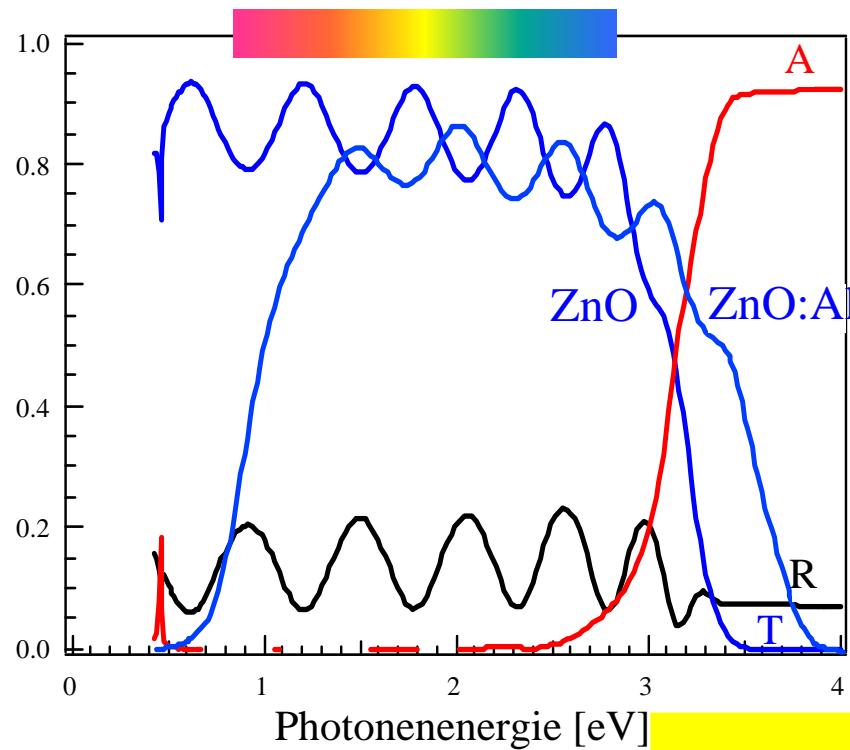
TCO-Fenster- und Kontaktschichten



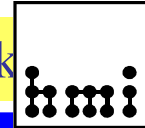
$$\rho = 1/(e\mu N)$$



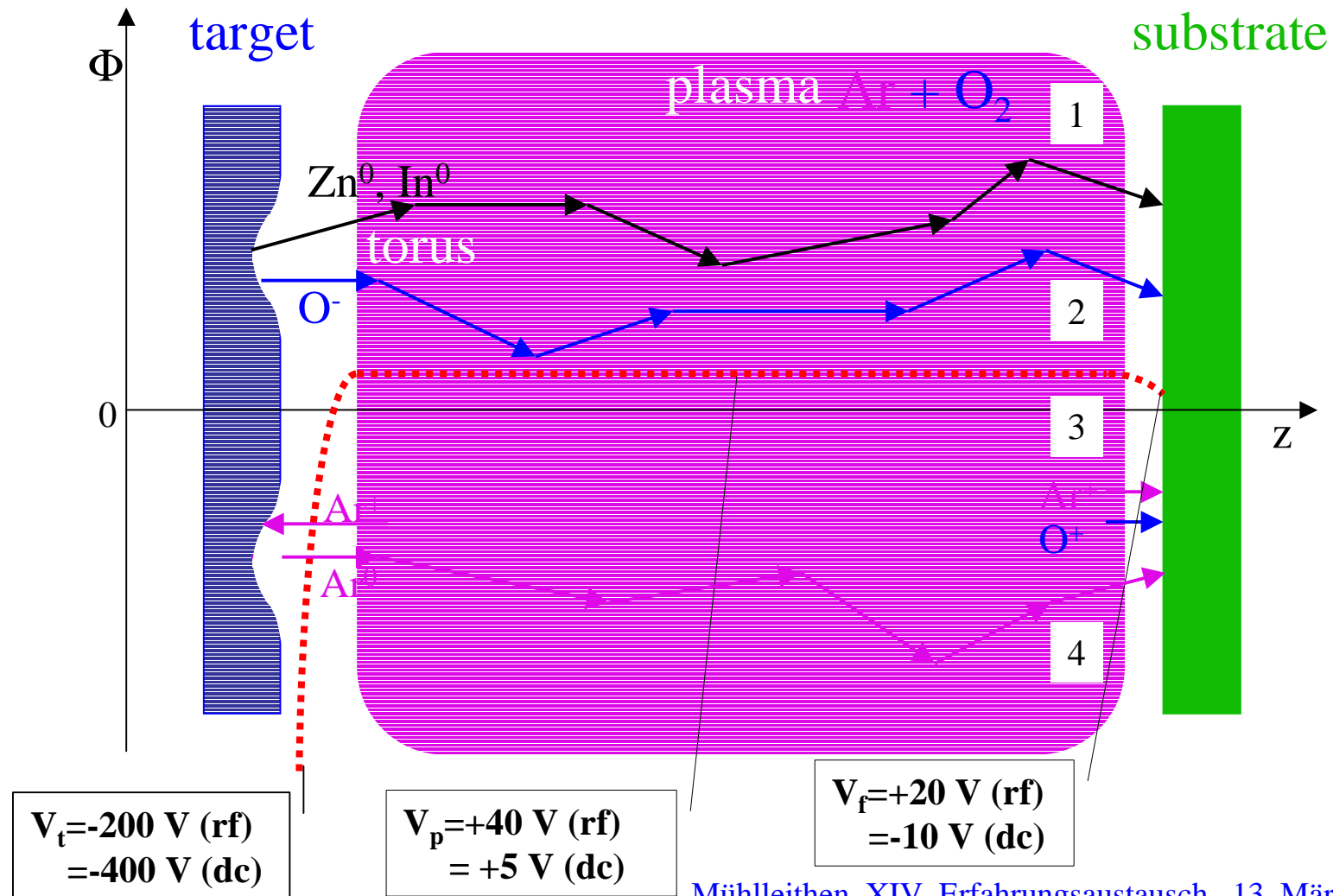
Optische Eigenschaften von ZnO-Schichten

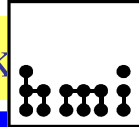


$$E_{plasma} = \frac{h}{2\pi} \sqrt{\frac{e^2 N}{m^* \epsilon_r \epsilon_0}}$$



Teilchen in einer Magnetron-Entladung





Ladungsträgerstreuung in TCO- Einkristallen

$$\mu_{Hac} = r_{Hac} \frac{\sqrt{8\pi} \hbar^4 e}{3 L_T^2 \sqrt{m^*}^5 (kT)^3}$$

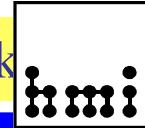
Streuung an akustischen
Phononen (intrinsisch)

$$\mu_{Hopt} = r_{Hopt} \phi \frac{e}{2\pi\omega_0 m^*} \left[\exp\left(\frac{\hbar\omega_0}{kT}\right) - 1 \right]$$

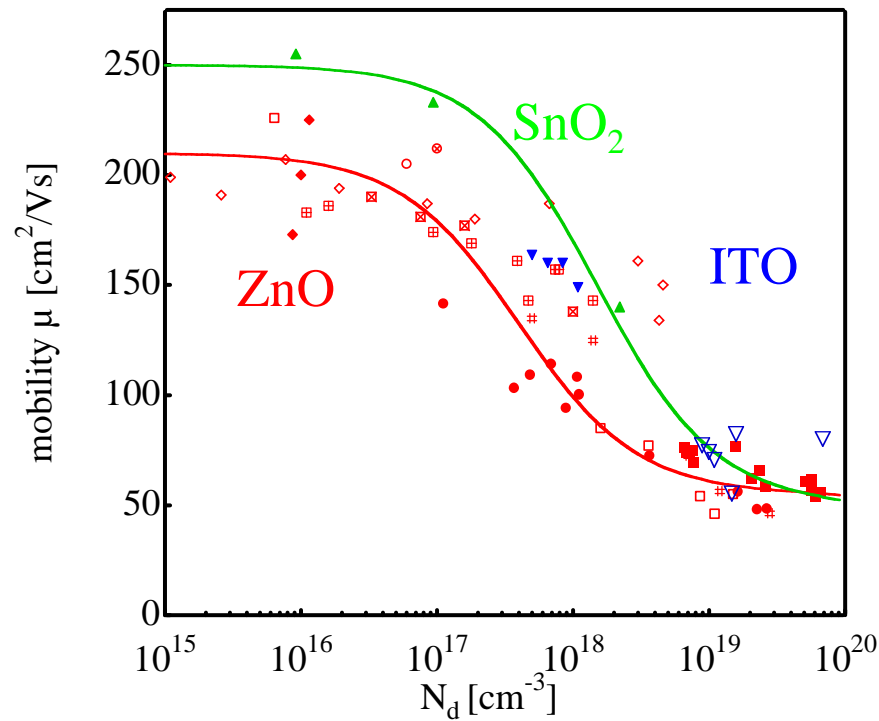
Streuung an polaroptischen
Phononen (intrinsisch)

$$\mu_{Hii} = r_{Hii} \frac{128\sqrt{2\pi} (\epsilon\epsilon_0)^2 (kT)^{3/2}}{\sqrt{m^*} N_T^2 e^3 \left[\ln\left(\frac{24m^* \epsilon\epsilon_0 (kT)^2}{ne^2 \hbar^2}\right) \right]}$$

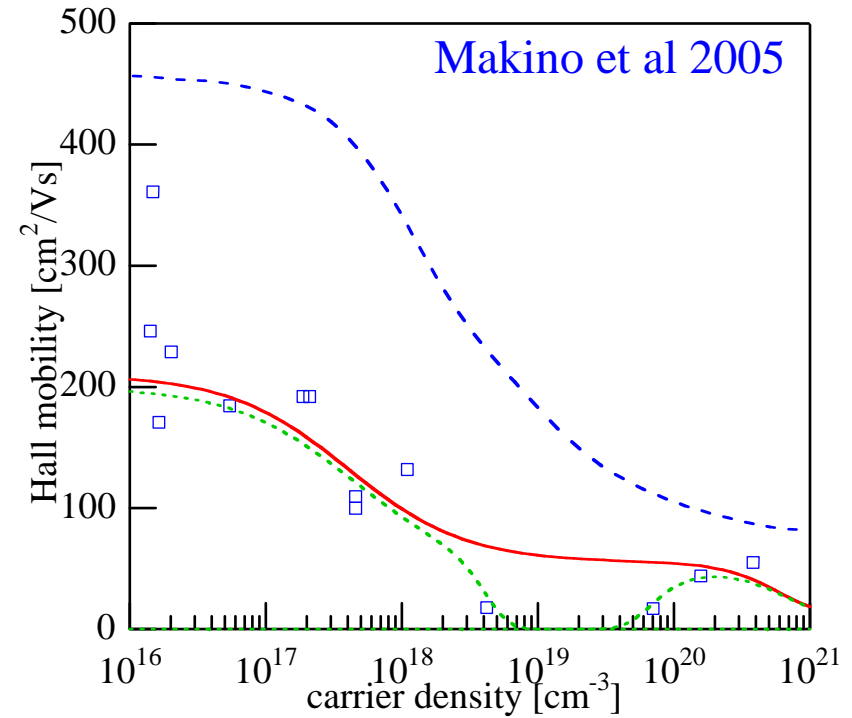
Streuung an ionisierten
Störstellen (extrinsisch)



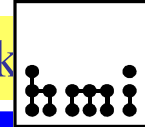
Ionisierte Störstellenstreuung in ZnO



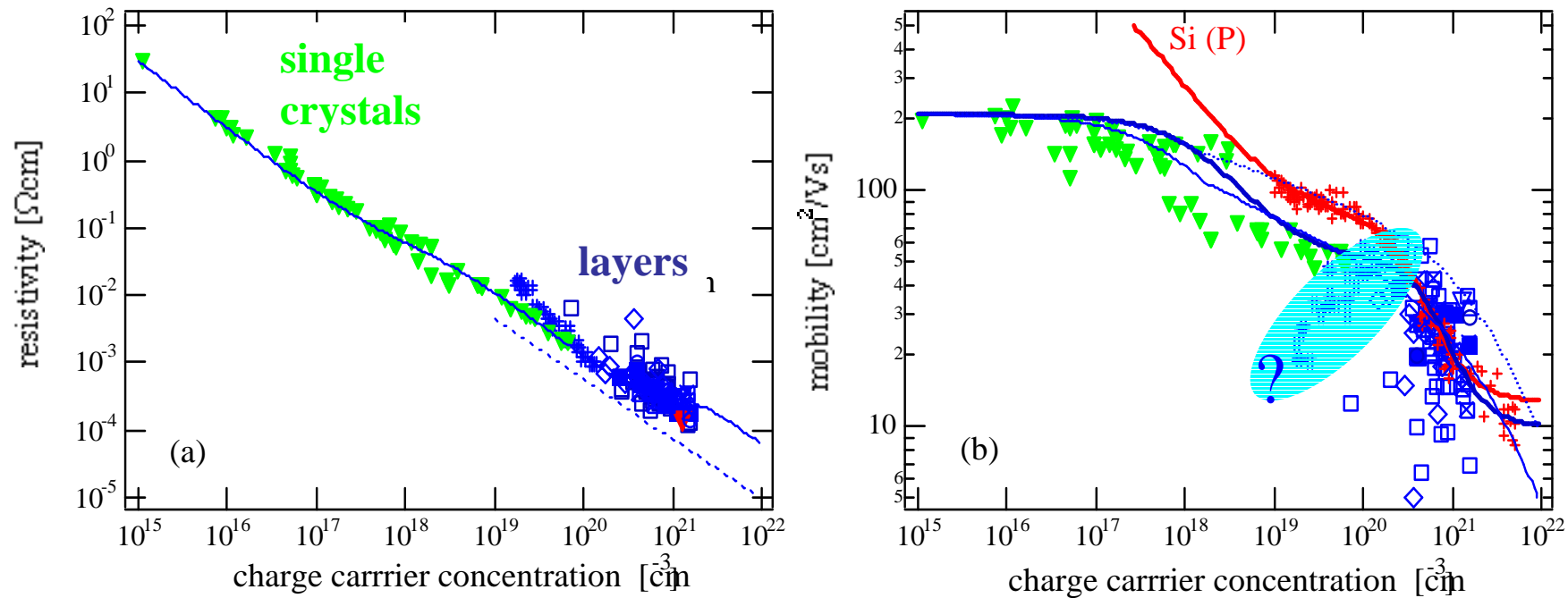
c-ZnO



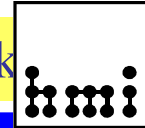
epi-ZnO
ScAlMgO₄



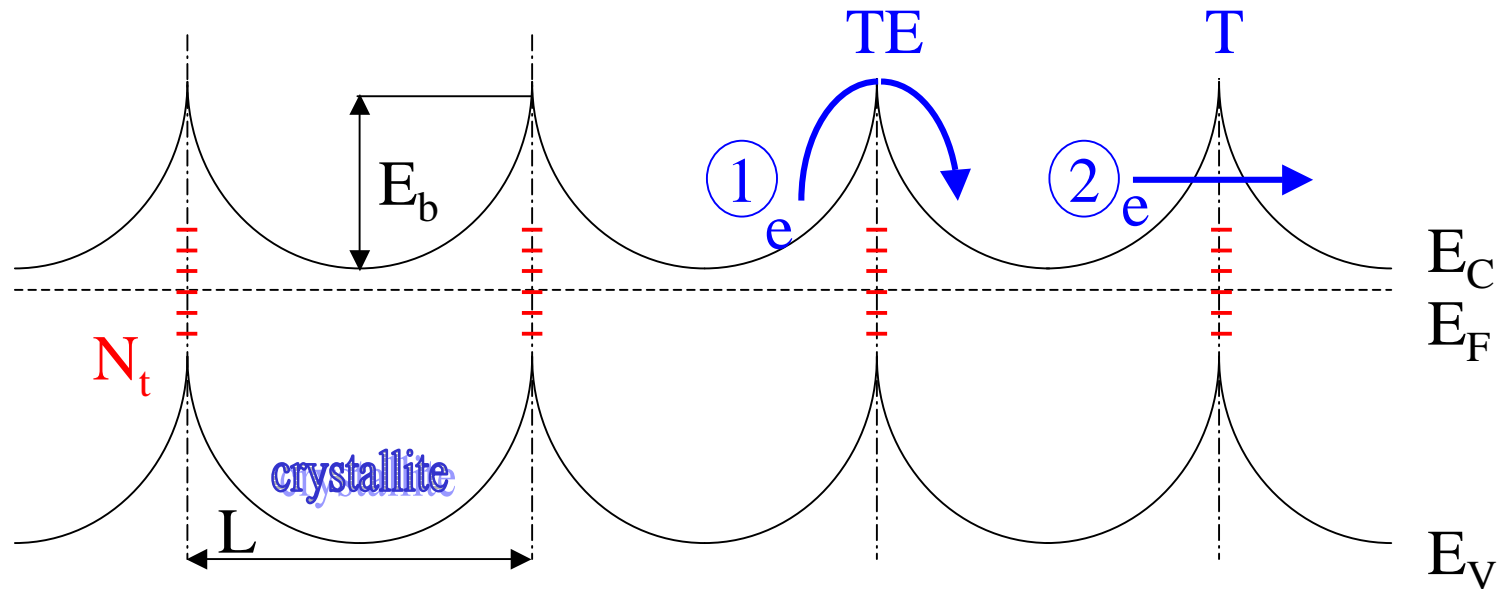
Transporteigenschaften von ZnO-Schichten



- Untere Grenze von ρ etwa $1,5 \cdot 10^{-4}$ Ohmcm
- Obere Grenze von N etwa $1,5 \cdot 10^{21}$ cm^{-3}
- Streuung an ionisierten Störstellen dominiert (phys. Grenze)



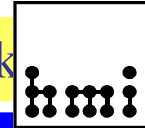
Korngrenzendominierter Transport



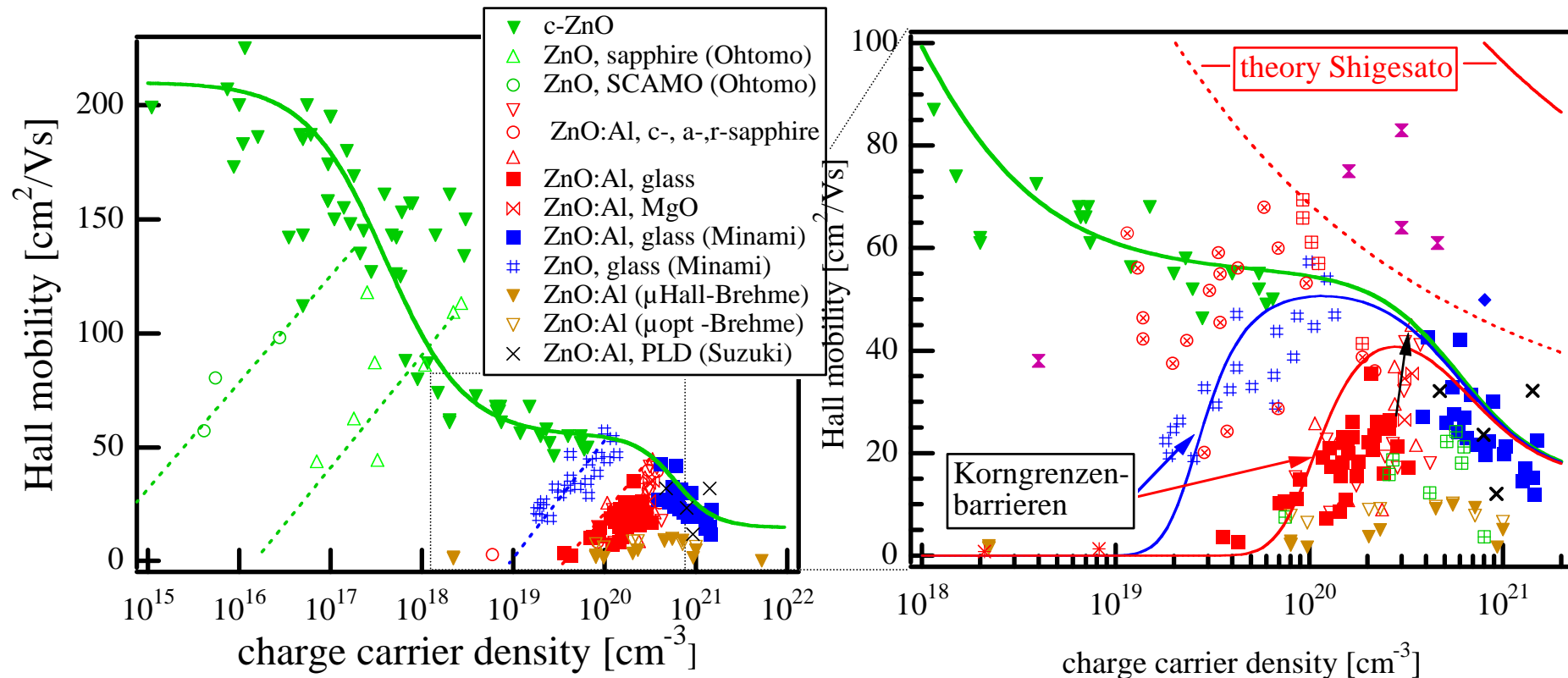
$$\mu_{\text{eff}} = \frac{q}{2\pi m^* kT} \exp\left(-\frac{(qN_t)^2}{8\epsilon N kT}\right) \quad \text{for } LN > Q_t$$

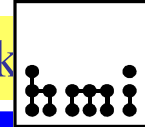
(extrinsisch)

Seto, JAP 46(1975)5247



Beweglichkeit von c-ZnO und poly-ZnO



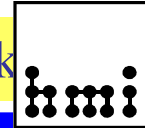


Defektdichte N_t von polykristallinen TCO-Schichten

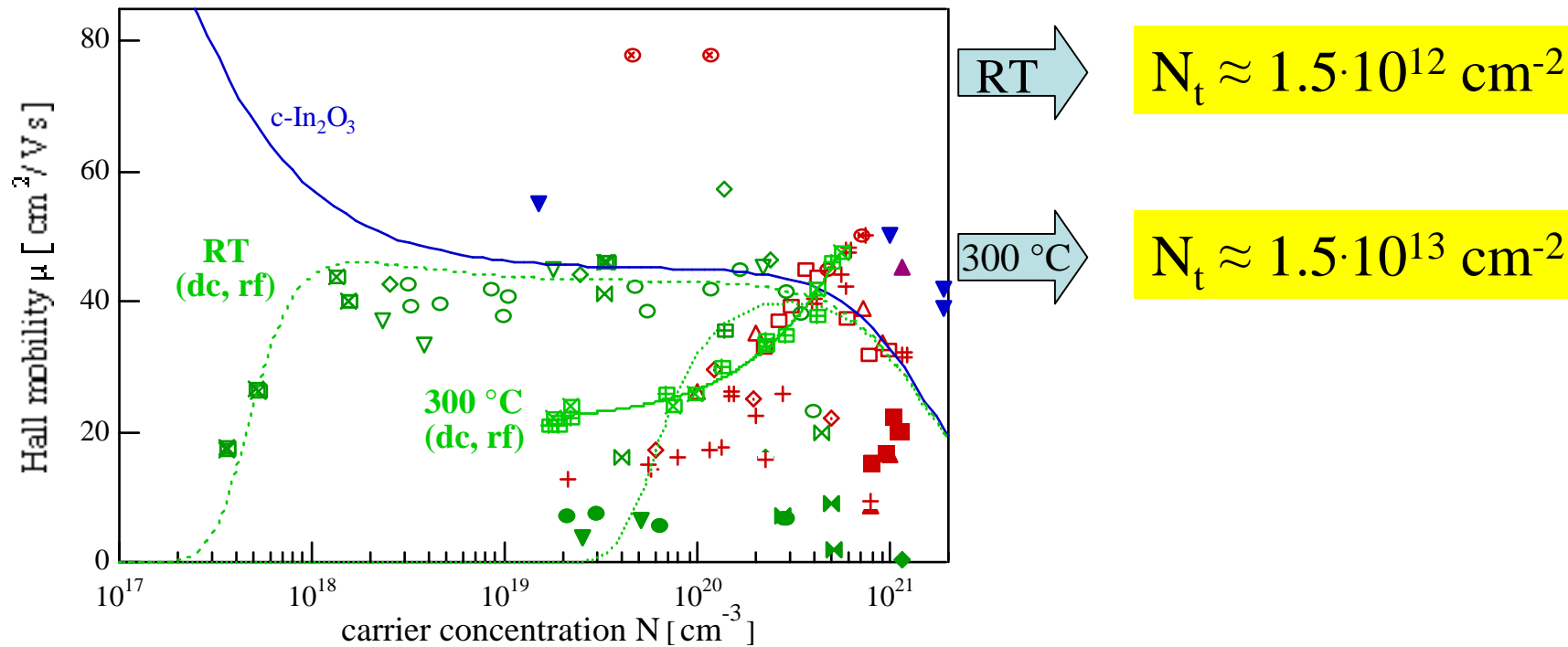
Film:dopant	Growth	Method	Excitation (U_{dis} [V])	N_t [cm^{-2}]	Source
ZnO:Al	epitaxial	MS	RF (200)	$1.3 \cdot 10^{13}$	[31]
ZnO:Al	on glass	RMS	DC (425)	$3 \cdot 10^{13}$	[33]
ZnO:Al	on glass	RMS	MF (340)	$3 \cdot 10^{13}$	[35]
ZnO	on glass	MS*	RF	$7 \cdot 10^{12}$	[2]
ZnO:Al,Ga	epitaxial	PLD	-	$5 \cdot 10^{12}$	[39]
ZnO	epitaxial	PLD	-	$1.5 \cdot 10^{13}$	[40]
In_2O_3 :Sn	on glass	RMS/MS	DC (400) RF (250)	$1.5 \cdot 10^{13}$	this work
In_2O_3 :Sn	on glass	MS	RF-diode (2000)	$2.5 \cdot 10^{13}$	[48]
SnO_2 :F,Cl	on glass	SP	-	$4 \cdot 10^{12}$	[49]
CdIn_2O_4	on glass	RMS	DC (2000)	$1.5 \cdot 10^{13}$	[6]

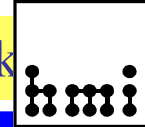
RMS, MS – reactive magnetron sputtering, PLD – pulsed laser deposition, SP – spray pyrolysis,

DC, RF, MF – direct current, radio frequency, mid frequency excitation, p-DC – pulsed DC excitation, * - substrates arranged perpendicular to the target (reduced ion bombardment)



Beweglichkeit von ITO-Schichten

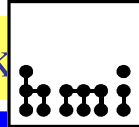




Zusammenfassung

- **Hochdotierte ZnO-Schichten sind 2-3 mal hochohmiger wie ITO, eingesetzt in flachen Anzeigen.**
- **ZnO-Schichten weisen hohe Korngrenzen-Defektdichten auf.**
- **Defekte in amorphem ITO viel weniger wirksam.**
- **Rolle der Ionenenergie beim Magnetronspütern unklar: Nicht vorhanden bei amorphem ITO!**

- **Unterschied ITO-ZnO: Piezoelektrizität des ZnO!**



Ausblick/Herausforderungen

- Defektstrukturfe (Punktdefekte, Versetzungen)
- Korngröße L ?/ Defektcluster ($\sim Z^2$)
- **Modulationsdotierung**

Dank an M. Mossner, F. Liersch, G. Vollweiler, S. Seidel, H. Tributsch