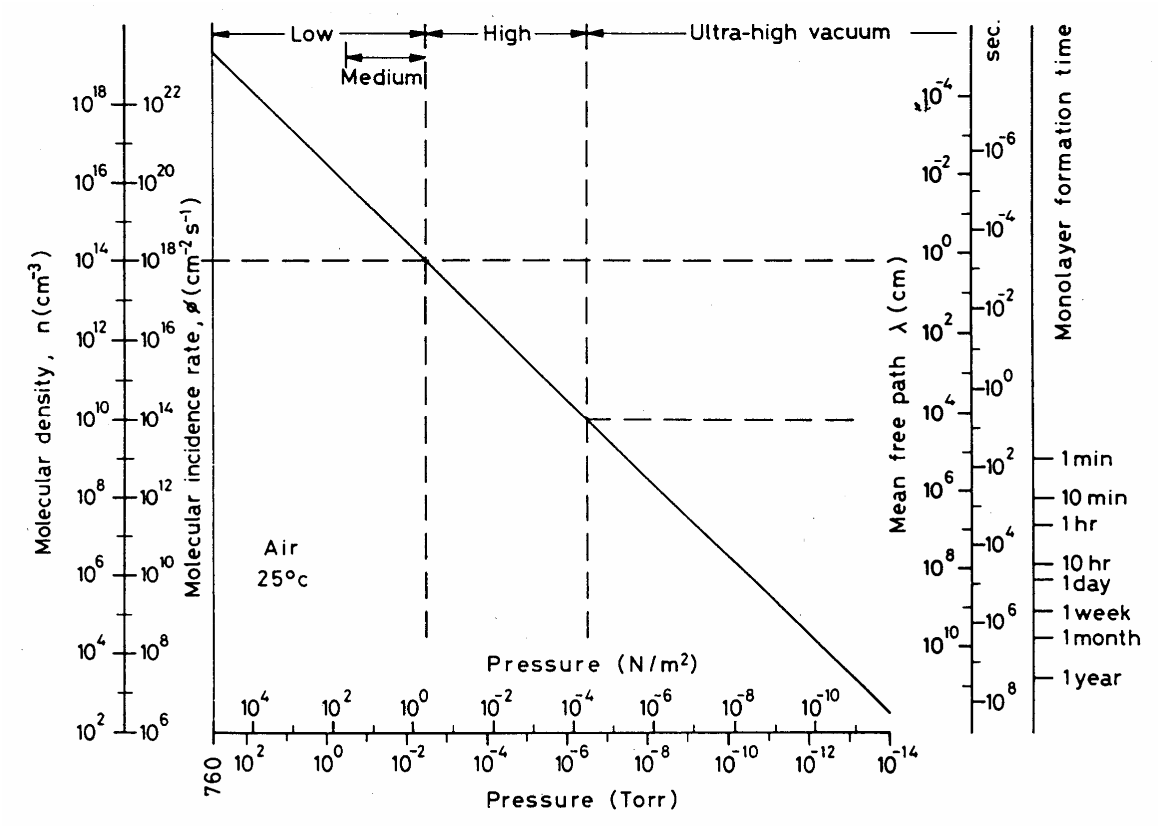
Appendix

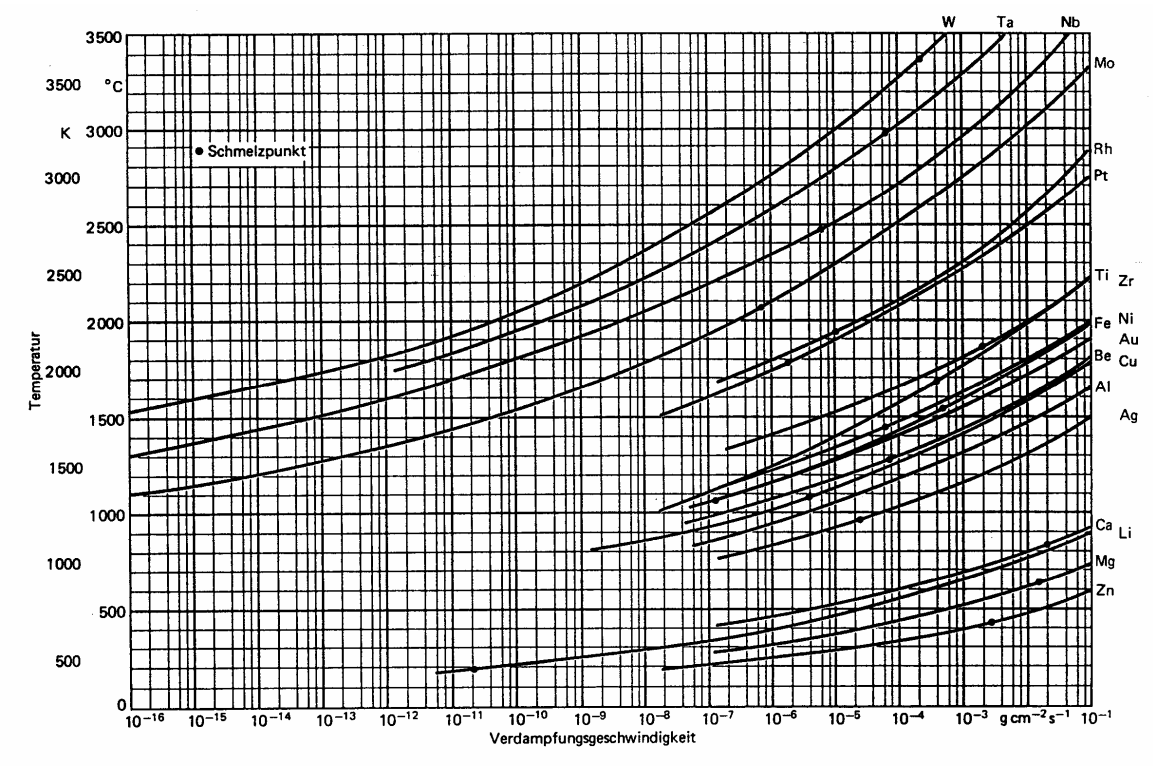
Vacuum Technique:



Time for the formation of a monolayer in dependence on the ambient pressure
Particle density ***n***, impingement rate ***Φ***, mean free path ***λ***
[13, p. 2]

Appendix

Evaporation Technique:



Evaporation velocity in high vacuum in dependence on the source temperature
[3, p. 20]

Appendix

Sputtering:

Target	Sputterausbeute Y für E_i in eV						E_{thres}	E_0
	200	600	1 000	2 000	5 000	10 000		
	Atome/Ion						eV	eV/Atom
Ag	1,6	3,4				8,8	15	2,94
Al	0,35	1,2			2,0		13	3,33
Au	1,1	2,8	3,6	5,6	7,9		20	3,92
C	0,05	0,2					-	7,39
Co	0,6	1,4					25	4,40
Cr	0,7	1,3					22	4,11
Cu	1,1	2,3	3,2	4,3	5,5	6,6	17	3,50
Fe	0,5	1,3	1,4	2,0	2,5		20	4,13
Ge	0,5	1,2	1,5	2,0	3,0	3,98	25	-
Mo	0,4	0,9	1,1		1,5	2,2	24	6,88
Nb	0,25	0,65					25	-
Ni	0,7	1,5	2,1				21	4,45
Os	0,4	0,95					-	8,19
Pd	1,0	2,4					20	3,90
Pt	0,6	1,6					25	5,95
Re	0,4	0,9					35	8,06
Rh	0,55	1,5					24	5,76
Si	0,2	0,5	0,6	0,9	1,4		-	4,68
Ta	0,3	0,6			1,05		26	8,10
Th	0,3	0,7					24	5,97
Ti	0,2	0,6		1,1	1,7	2,1	20	4,86
U	0,35	1,0					23	5,00
W	0,3	0,6			1,1		33	8,80
Zr	0,3	0,75					22	6,34
	Moleküle/Ion							
CdS (1010)	0,5	1,2						
GaAs (110)	0,4	0,9						
GaP (111)	0,4	1,0						
GaSb (111)	0,4	0,9	1,2					
InSb (110)	0,25	0,55						
PbTe (110)	0,6	1,40						
SiC (0001)		0,45						
SiO_2			0,13	0,4				
Al_2O_3			0,04	0,11				

Sputter yield ***Y*** of different materials as a function of the energy E_i of impinging Ar-Ions, threshold energy E_{thresh} and sublimation energy E_O [1, p. 98]

Appendix

Analytical Methods:

Tabelle 8–7. Analysemethoden und ihre Charakterisierungsart.

Methode	Abkürzungen	Anregung/Detektion *)	Charakterisierungsart			elektronische Eigenschaften	Referenzen
			Chemische Analyse	Molekülkristallstrukturen	Mikroskopie		
Light Microscopy	LM	hν → hν			×		[8–335]
Laser Scanning Microscopy	LSM	hν → hν			×		[8–314; 8–416]
Ramanscattering	RS	hν → hν		×			[8–395; 8–398 bis 8–402]
X-ray Photoelectron Spectrosc.	XPS	hν → c	×				[8–340; 8–341; 8–434 bis 8–437]
Ultra Violet PS	UPS	hν → e				×	[8–435; 8–436]
Laser Microprobe Mass Anal.	LAMMA	hν → i	×				[8–438]
Photo Acustic Spectroscopy	PAS	hν → ph			×		[8–403]
Scanning Electron Microscopy	SEM	e → e			×		[8–467; 8–430; 8–431; 8–432]
(Scan)Transmission Electr. Micr.	(S)TEM	e → e		×			[8–466; 8–463 bis 8–466]
Electron Beam Induced Current	EBIC	e → e			×	×	[8–467; 8–468; 8–469]
Voltage Contrast Microscopy	VCM	e → c			×	×	[8–335]
Low Energy Electron Diffraction	LEED	e → c		×			[8–357; 8–408; 8–409]
Reflective High EED	RHEED	e → e		×			[8–359; 8–418; 8–419]
Auger Electron Spectroscopy	AES	e → e	×		×		[8–340; 8–433; 8–434]
Electron Energy Loss Spectr.	EELS	e → e	×	×		×	[8–357; 8–404 bis 8–407]
Electron Micro Probe	EMP	e → hν	×				[8–439]
X-Ray Emission Spectroscopy	XES	c → hν	×		×		[8–431; 8–432; 8–458; 8–459; 8–460]
Ion Scattering Spectroscopy	ISS	i → i	×	(×)			[8–340; 8–410; 8–434]
Secondary Ion Mass Spectrosc.	SIMS	i → i	×		×		[8–340; 8–346; 8–354; 8–440; 8–441; 8–442]
Rutherford Backscattering	RBS	i → i	×	(×)			[8–454; 8–455; 8–456]
Secondary Neutral Mass Spectr.	SNMS	i → n	×				[8–355]
Particle Induced X-Ray Emission	PIXE	i → hν	⁄				[8 356]
Field Ion Microscopy	FIM	ε → i	×	×			[8–340]
Scanning Tunneling Microscopy	STM	ε → e		×	×	(×)	[8–428; 8–429]
Scanning Acoustic Microscopy	SAM	ph → ph			×		[8–416; 8–417]

*) hν Photonen, ph Phononen, e Elektronen, i Ionen, n Neutralteilchen, ε elektrisches Feld

[3, p. 342]

Appendix

Calculation of the conductivity of thin films:

The starting point of all following considerations is the current density $\vec{j}_e$,

$$\vec{j}_e = -ne\vec{v} = -e\vec{v}\int_N \frac{dn}{V} = -e\vec{v}\frac{N}{v} = -ne\vec{v}$$

Since e and $\vec{v}$ are known, the electron density n has to be calculated:

$dn = 2 \cdot f_0(E) \cdot d\Phi$ $\quad d\Phi$ ... Ohase space volume

$f_0(E) = \dfrac{1}{1+e^{(E-E_f/k_B T)}}$ ... Fermi-distribution

$d\Phi = \dfrac{d^3 x d^3 p}{h^3}$ ... dimensionless, number of states in a phase space element of the size $d^3 x d^3 p$

From quantum mechnaics the number of possible states within a phase space element with the generalized co ordinates *(q,p)*: $\dfrac{d^3 q d^3 p}{h^3}$ is known: in a phase space element of the size h^3 there can be only one state

a) Conductivity without electric field

$$\vec{j}_e = -e\int_{R,\vec{v}} \vec{v}\frac{dn}{V} = -2e\int_{R,\vec{v}} \vec{v} f_0(\vec{v})\frac{d\Phi}{V} = \left| d\Phi = \left(\frac{m}{h}\right)^3 d^3 x d^3 v \right| =$$

$$-2e\left(\frac{m}{h}\right)^3 \frac{1}{V} \cdot \underbrace{\int_{\vec{R}} d^3 x}_{V} \int_{\vec{v}} \vec{v} f_0(\vec{v}) d^3 v = -2e\left(\frac{m}{h}\right)^3 \int_{\vec{v}} \vec{v} f_0(\vec{v}) d^3 v = 0$$

b) Conductivity with electric field in an infinite medium: Ohm's law

Application of Boltzmann's transport theory:

General formulation of Boltzmann's equation:

$$\frac{df(\vec{r},\vec{v},t)}{dt} = \left(\frac{\partial f}{\partial t}\right)_{coll}$$

i. e. changes in the distribution function are only due to collisions (extremely short interactions of the components of the system).

Total differential:

$$\frac{\partial f}{\partial t} + \vec{\nabla}_r f \underbrace{\frac{d\vec{r}}{dt}}_{v} + \vec{\nabla}_v f \underbrace{\frac{d\vec{v}}{dt}}_{a=\vec{F}/m=-\frac{e\vec{E}}{m}} = \left(\frac{\partial f}{\partial t}\right)_{coll}$$

Special shape of Boltzmann's equation for the electric field:

$$\frac{\partial f}{\partial t} + \vec{v}\vec{\nabla}_r f - \frac{e\vec{E}}{m}\vec{\nabla}_v f = \left(\frac{\partial f}{\partial t}\right)_{coll}$$

Ansatz for the collision term determines the detailed solution of Boltzmann's equation:

$$f(t) - f_0 = C \cdot e^{-t/\tau}$$

$$\left(\frac{\partial f}{\partial t}\right)_{coll} = -\frac{f(t) - f_0}{\tau}$$

Boundary conditions: $\vec{E}$ -field in *x*-direction, homogenuous field strength.

Ansatz: $f = f_0 + A$, $A=A(E)$...distortion term, independent of $\vec{v}$

$$\vec{v}\vec{\nabla}_r(f_0 + A) - \frac{eE}{m}\frac{\partial(f_0 + A)}{\partial v_x} = -\frac{1}{\tau}(f_0 + A - f_0)\text{, da}(\vec{\nabla}_r f_0 = 0)$$

$$\frac{eE}{m}\frac{\partial f_0}{\partial v_x} = \frac{1}{\tau}A$$

$$A = \frac{eE}{m}\tau\frac{\partial f_0}{\partial v_x}$$

The current density is again calculated by:

$$\vec{j}_e = -ne\vec{v} = -e\int\vec{v}\frac{dn}{V} = \left|dn = 2\cdot f(\vec{v})d\Phi\right| = -2e\left(\frac{m}{h}\right)^3\frac{1}{V}\int_{\vec{R},\vec{v}}\vec{v}f(\vec{v})d^3x d^3v$$

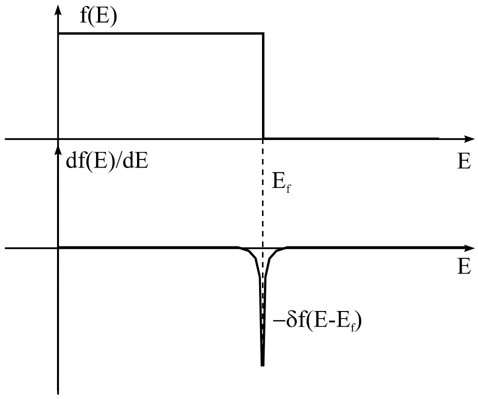
Calculation of one component of $\vec{j}$, j_x:

$$f = f_0 + A = f_0 + \frac{eE}{m}\tau\frac{\partial f_0}{\partial v_x}$$

$$j_x = -2e\left(\frac{m}{h}\right)^3\frac{1}{V}\int_{\vec{R}}d^3x\underbrace{\int_v f_0(\vec{v})v_x d^3v}_{=0} - \frac{2e^2E}{m}\left(\frac{m}{h}\right)^3\tau\frac{1}{V}\int_{\vec{R}}d^3x\int_v v_x\frac{\partial f_0}{\partial v_x}d^3v =$$

$$= \left|\frac{1}{V}\cdot\int_{\vec{R}}d^3x = 1\right| = \underbrace{-2e^2E\frac{m^2}{h^3}\tau}_{C}\int_{\vec{v}}v_x\frac{\partial f_0}{\partial v_x}d^3v$$

In the above equation only the derivation $\frac{\partial f_0}{\partial v_x}$ is unknown. It can be calculated by the known Fermi distribution and yields a Delta function (see sketch):



$$j_x = C\int_{\vec v} v_x \frac{\partial f_0}{\partial v_x} d^3v = \left| d^3v = 4\pi v^2 dv \right| = C\cdot\int_{\vec v} v_x \frac{\partial f_0}{\partial v_x} 4\pi v^2 dv = \left| \frac{\partial f_0}{\partial v_x} = \frac{\partial f_0}{\partial E}\frac{\partial E}{\partial v_x} = \frac{\partial f_0}{\partial E}\cdot m v_x \right| =$$

$$= C\cdot 4\pi m\int_{\vec v} v_x^2 \underbrace{\frac{\partial f_0}{\partial E}}_{-\delta(E-E_f)} v^2 dv$$

$$j_x = -2e^2 E\tau \frac{m^2}{h^3}\cdot 4\pi m\int_{\vec v} v_x^2\cdot[-\delta(E-E_f)]v^2 dv = 8\pi e^2 E\tau\left(\frac{m}{h}\right)^3\cdot \underbrace{\int_{\vec v} v_x^2\cdot[\delta(E-E_f)]v^2 dv}_{*}$$

* : Solution of the integral: solve analogous equations in y and z and the determines $j_x+j_y+j_z$:

$$* = \int_{\vec v}[v_x^2+v_y^2+v_z^2]\delta(E-E_f)v^2 dv = \int_{\vec v} v^4\delta(E-E_f)dv = \left| dv = \frac{dE}{mv} \right| = \int_E m^{-1}v^3\delta(E-E_f)dE =$$

$$= \int_E m^{-1}\left(\frac{2E}{m}\right)^{3/2}\delta(E-E_f)dE = m^{-1}\left(\frac{2E_f}{m}\right)^{3/2} = m^{-1}v_f^3$$

$$j_x = \frac{1}{3}(j_x+j_y+j_z) = 8\pi e^2 E\tau\frac{m^2}{h^3}\cdot v_f^3$$

Arbitrary co ordinate system:

$$j = \frac{1}{3}j_x = \frac{8\pi e^2 E\tau m^2 v_f^3}{3h^3}E = \sigma E$$

$$\sigma = \frac{8\pi e^2 E\tau m^2 v_f^3}{3h^3} = \frac{ne^2}{m}\tau \text{, weil}$$

$$n = \frac{1}{V}\int dn = \frac{1}{V}\int_{\vec R,\vec v} 2 f_0\left(\frac{m}{h}\right)^3 d^3x d^3v = \frac{8\pi}{3}\left(\frac{v_f m}{h}\right)^3$$

c) Conductivity of thin films: Fuchs-Sondheimer-equation

Ansatz: $f = f_0 + A$, *A=A(E, z)*...distortion term, independent of $\vec{v}$, but now dependent on the position within the film

Possible boundary conditions:

* Specular reflection at the film interfaces: no difference to the bulk

* Diffuse reflection at the film interfaces:

Ansatz for *f(v,E.z)*: $f = f_0 + A(E,z)$

Boundary condition for diffuse reflection: f(z=0)=f_0

$$f(z=0) = f_0 = \underbrace{\frac{eE\tau}{m}\frac{\partial f_0}{\partial v_x}(1+K)}_{A(z=0)} + f_0$$

$$\Rightarrow K = -1$$

$$j = \underbrace{-2e\left(\frac{m}{h}\right)^3 \tau \int \vec{v}\left(f_0 + \frac{eE}{m}\frac{\partial f_0}{\partial v_x}\right) d^3v}_{j_0} \underbrace{+2e\left(\frac{m}{h}\right)^3 \tau \int \vec{v}\,\frac{eE}{m}\frac{\partial f_0}{\partial v_x} \cdot e^{-\frac{z}{\tau v_z}} d^3v}_{\substack{\text{zulösen für} \\ z=0 \to z=D \\ I}}$$

For solving I the average from z = 0 to *z=D* has to be calculated, then $\Rightarrow$ script. 4.57

Appendix

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