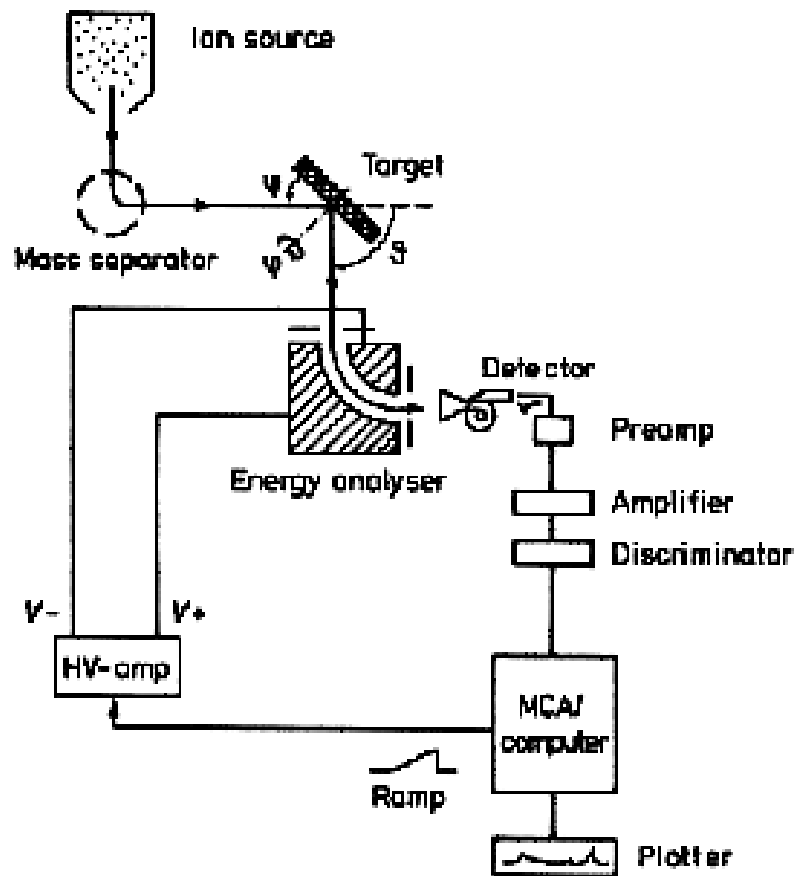


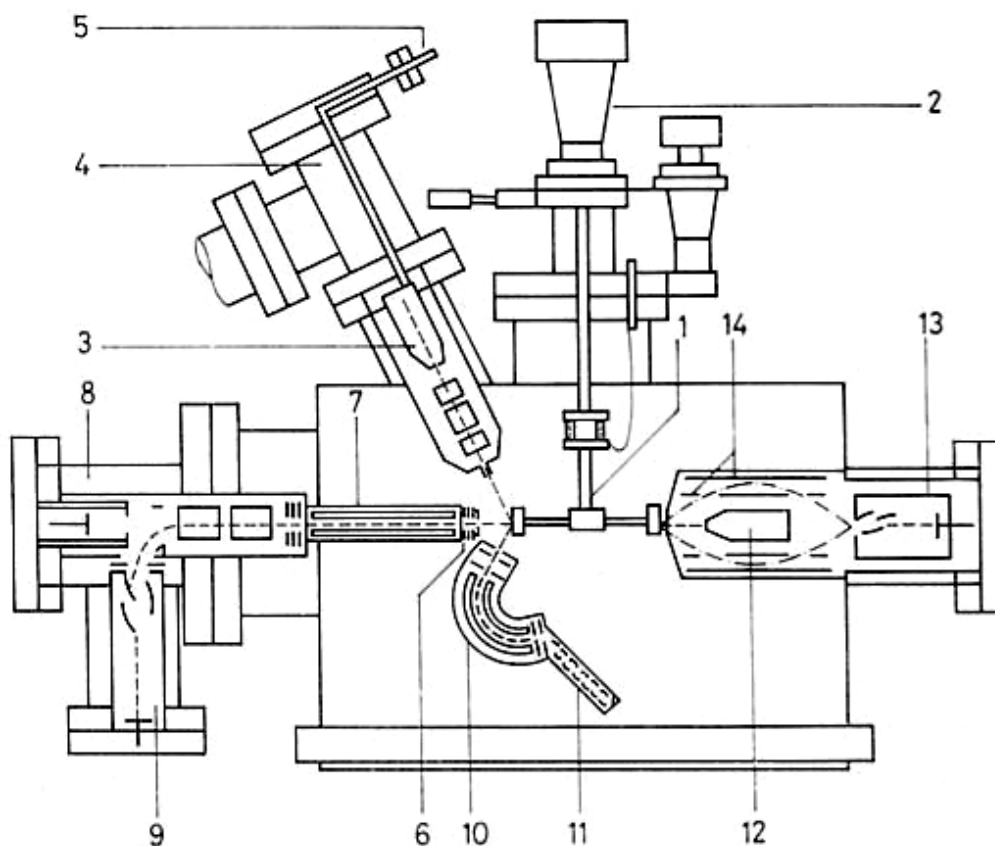
$$\frac{E_1}{E_0} = \frac{1}{(1+A)^2} \left[\cos\theta_1 \pm \sqrt{A^2 - \sin^2\theta_1} \right]^2 \quad A = \frac{M_2}{M_1} > 1.0$$

$$\frac{E_2}{E_0} = \frac{4A}{(1+A)^2} \cos^2\theta_2$$

Zu den Grundlagen der Ionenstreu-Spektroskopie



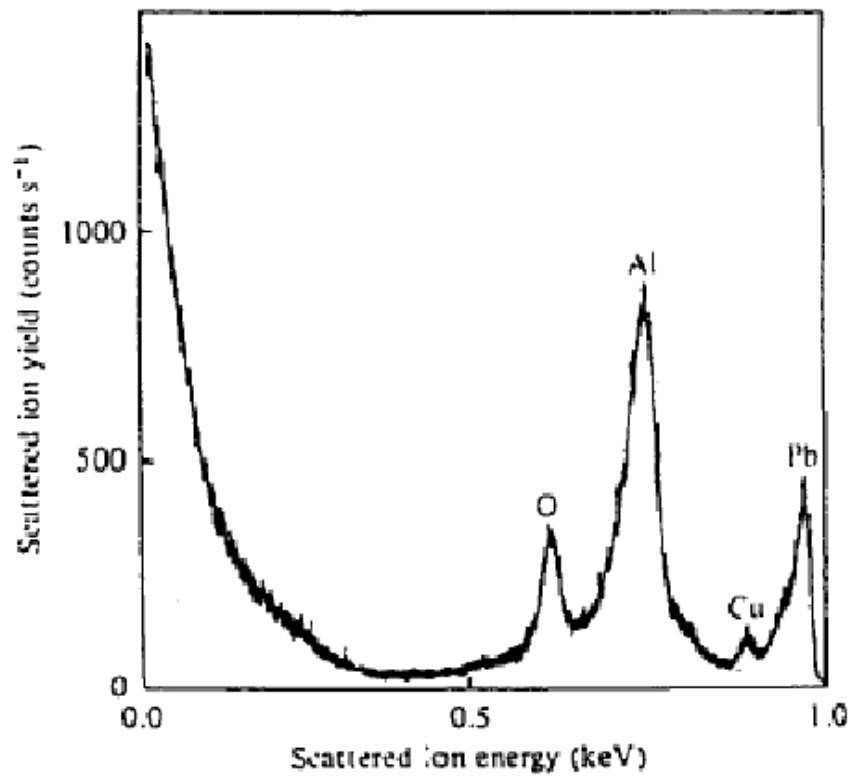
Prinzipieller Aufbau eines ISS



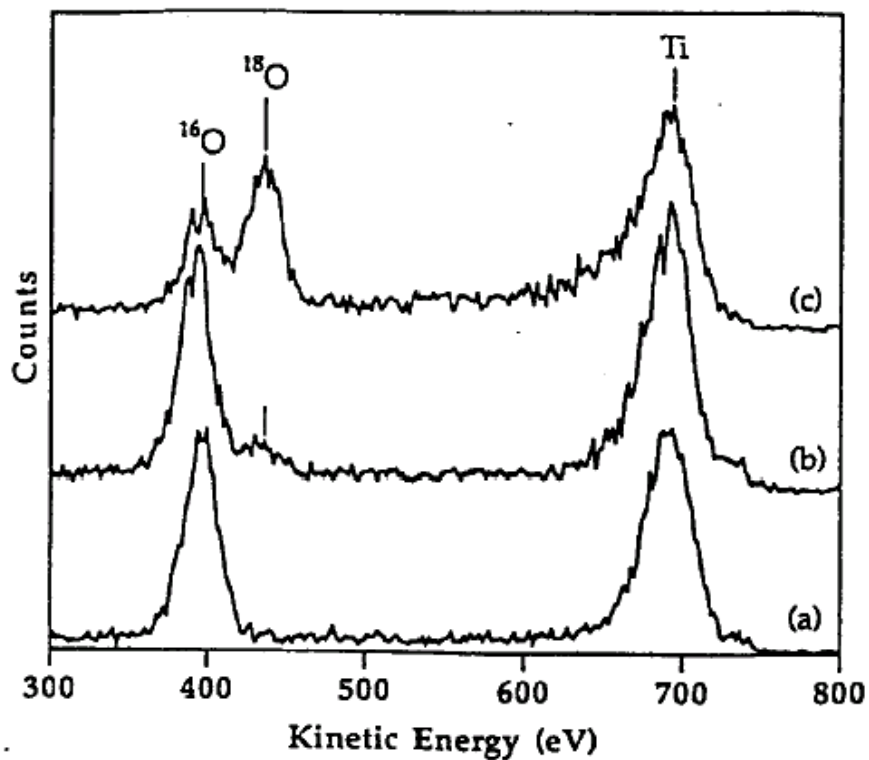
ISS in einem AES / SIMS - Gerät: **Folie**

4-Ionenkanone mit 5-Gaseinlaß; 1-Probenmanipulator,

10-Energiefilter mit 11-Sekundärelektronenvervielfacher

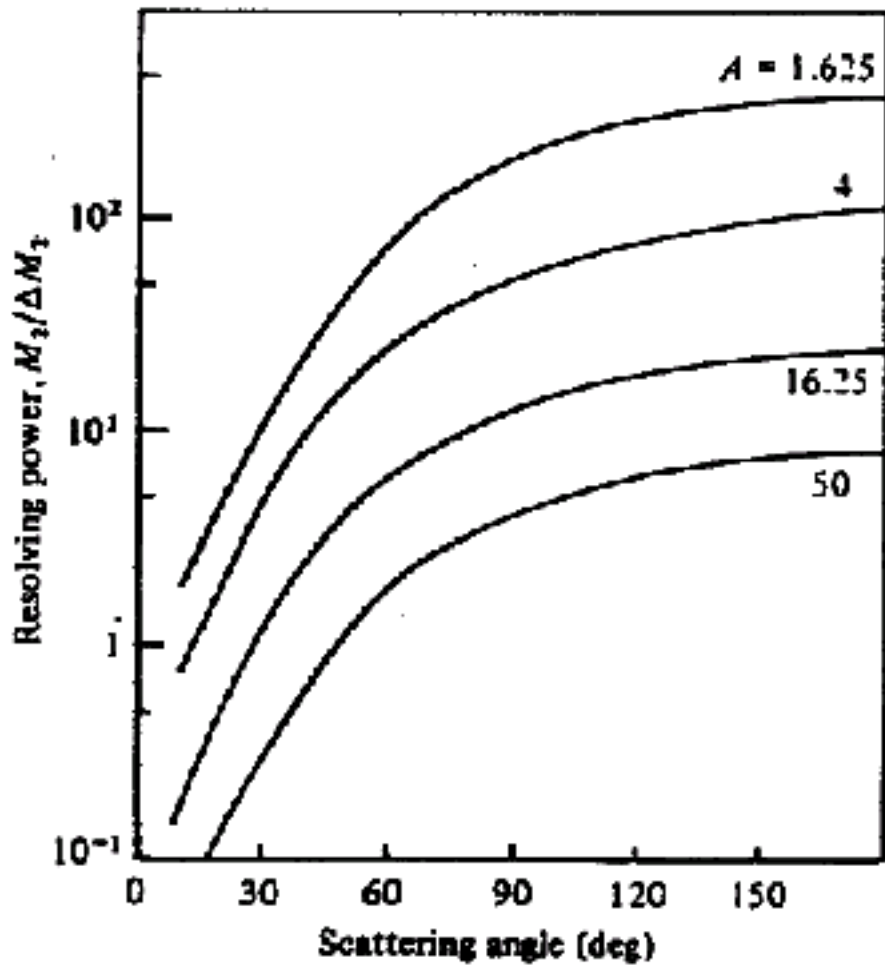


kontaminierte Legierung, Streuwinkel 90°

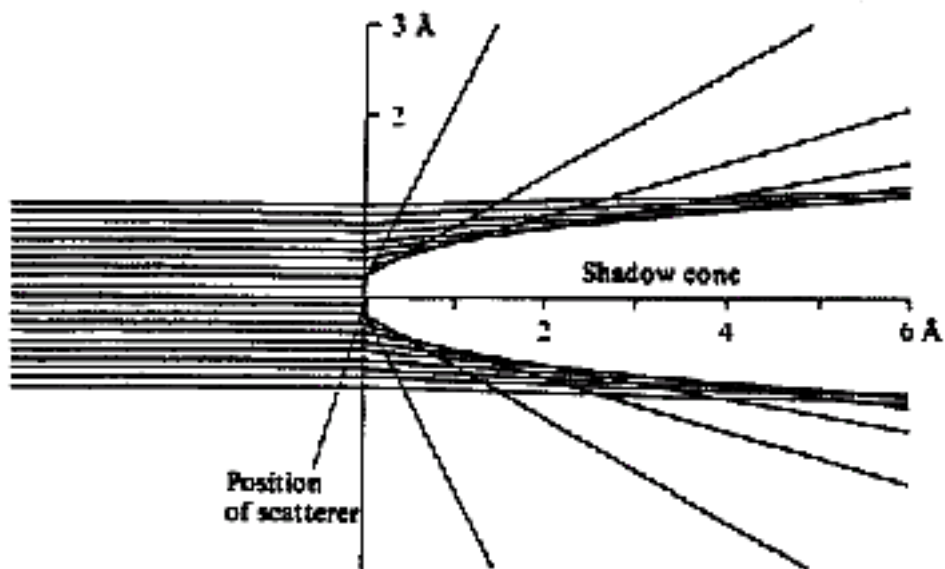


O¹⁸ Adsorption an eine TiO Oberfläche

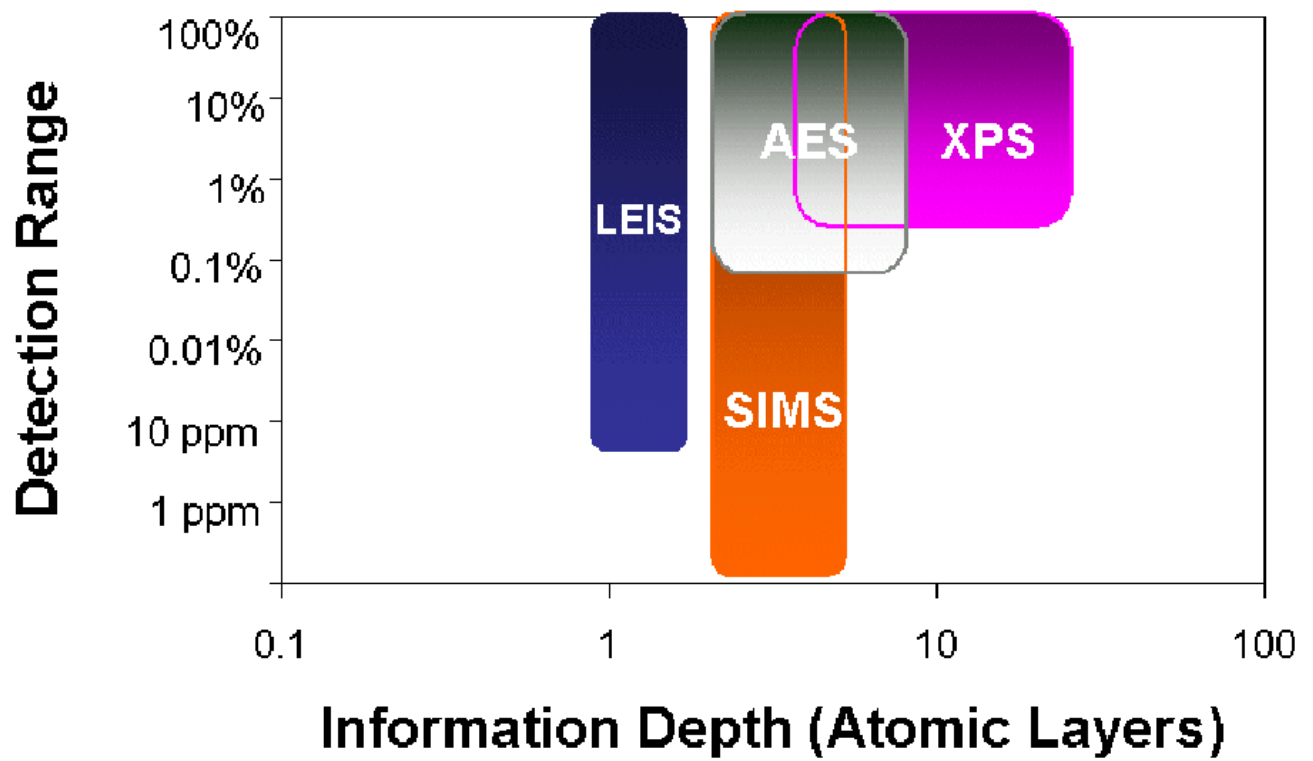
a) stöchiometrisch, b) unterstöchiometrisch, c) stark unterstöchiometrisch



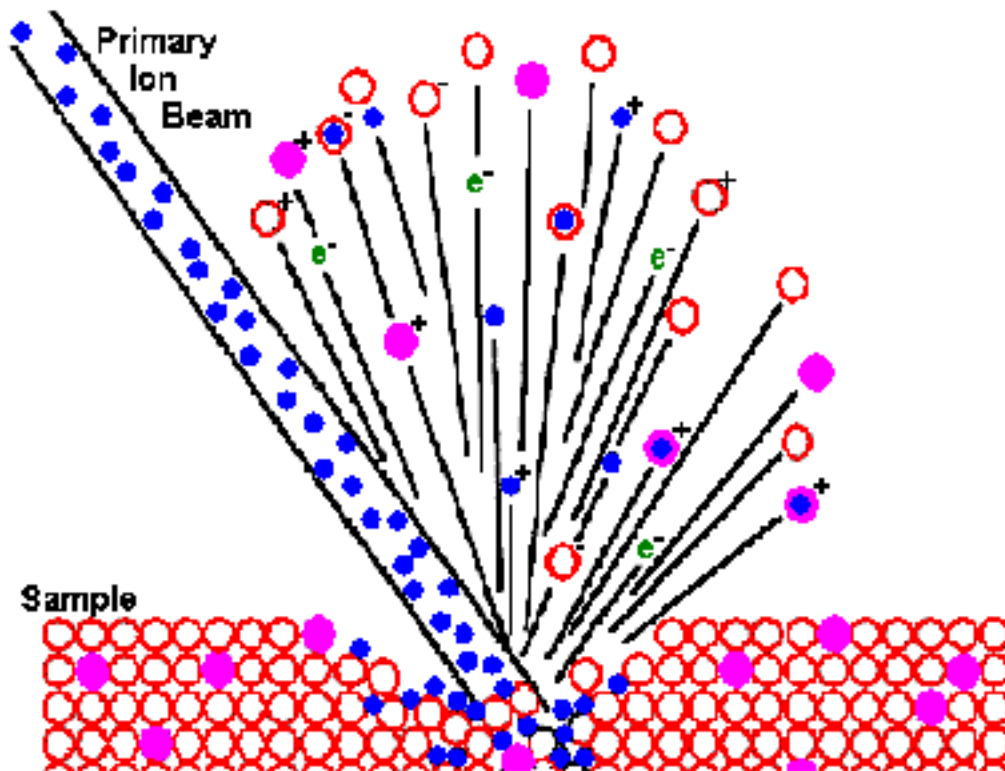
Massenauflösung als Verhältnis des Streuwinkels und des Massenverhältnisses M_1/M_2



zu Abschattungseffekten bei der ISS



Eigenschaften der ISS



SIMS-Prinzip: Ionenstrahspattern

Table 2.1 Typical operating parameters of an extractor-type ion source

Electron emission current	10 μ A–10 mA
Source pressure	10^{-7} – 5×10^{-4} mbar
Ion energy spread	10 eV
Ion energy	0.1–5 keV
Beam size range at sample	0.1–2 mm
Maximum ion current	10^{-3} A
Corresponding spot size	0.8 mm
Minimum beam diameter	0.1 mm
Corresponding beam current	800 nA
Current density at sample	4 mA cm $^{-2}$
Beam brightness	10^{-2} A cm $^{-2}$ sr $^{-1}$
Neutrals content (maximum)	2–4%

Table 2.2 Typical plasma and beam parameters of a duoplasmatron ion source

Operating pressure	10^{-2} mbar
Electron temperature	5×10^4 K
Ion density	10^{12} cm $^{-3}$
Acceleration voltage	10 keV
Extraction gap	3 mm
Mass (argon)	40
Ion temperature	1500 K
Current density of extracted beam	20 mA cm $^{-2}$
Beam brightness	100–200 A cm $^{-2}$ sr $^{-1}$
Reduced beam brightness	10–20 A cm $^{-2}$ sr $^{-1}$ V $^{-1}$

spot 100 μ m

Table 2.3 Characteristics of a caesium surface ionization source

Operating temperature	1200–1300 K
Initial energy spread	0.2 eV (2 kT)
Current density of extracted beam	100 mA cm $^{-2}$
Beam brightness	50–500 A cm $^{-2}$ sr $^{-1}$
Reduced beam brightness	5–50 mA cm $^{-2}$ sr $^{-1}$ V $^{-1}$

spot 200 nm

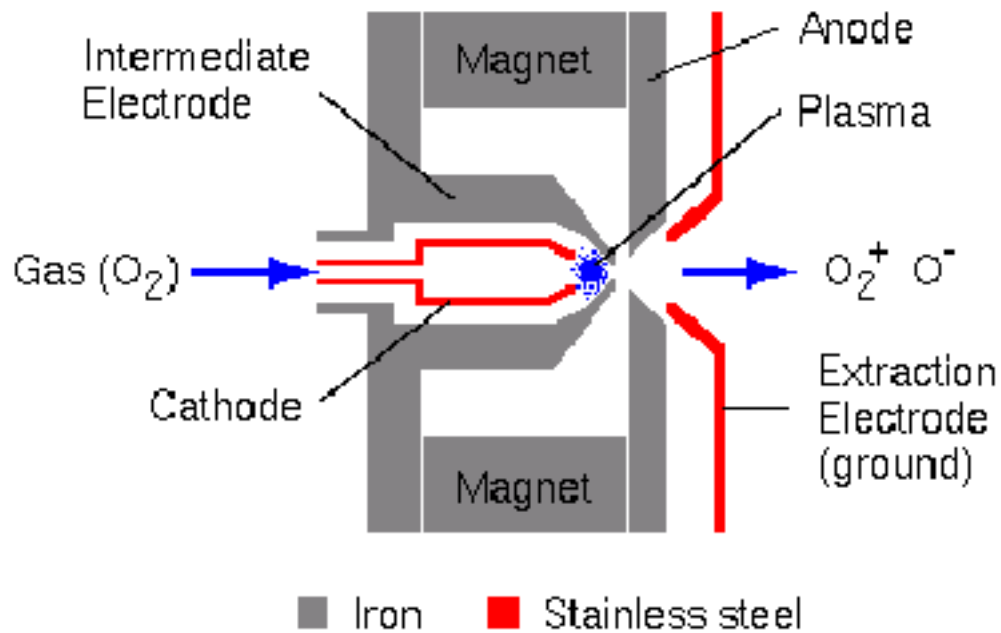
spot 2 μ m

Table 2.4 Characteristic data of liquid metal field ionization source

Total ion current	2–3 μ A
Angular current density	20 μ A sr $^{-1}$
Energy spread	5 eV
Virtual source size	50 nm
Beam brightness	10^6 A cm $^{-2}$ sr $^{-1}$
Ions	Ga, In, Au, ...

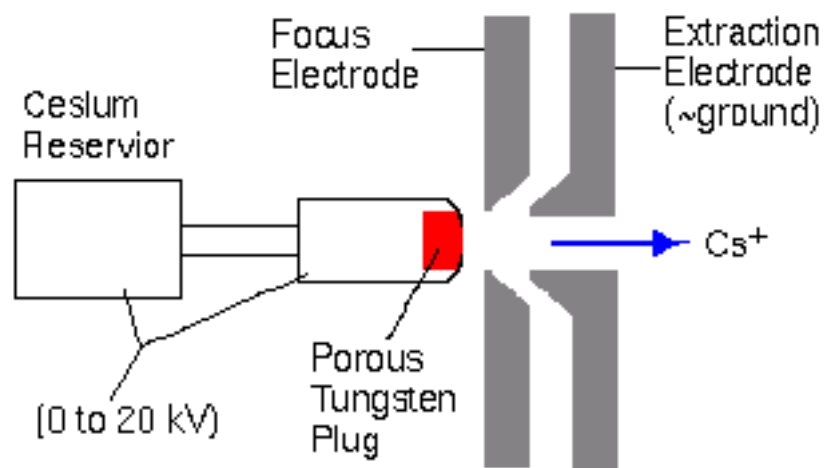
spot 20 nm

Duoplasmatron

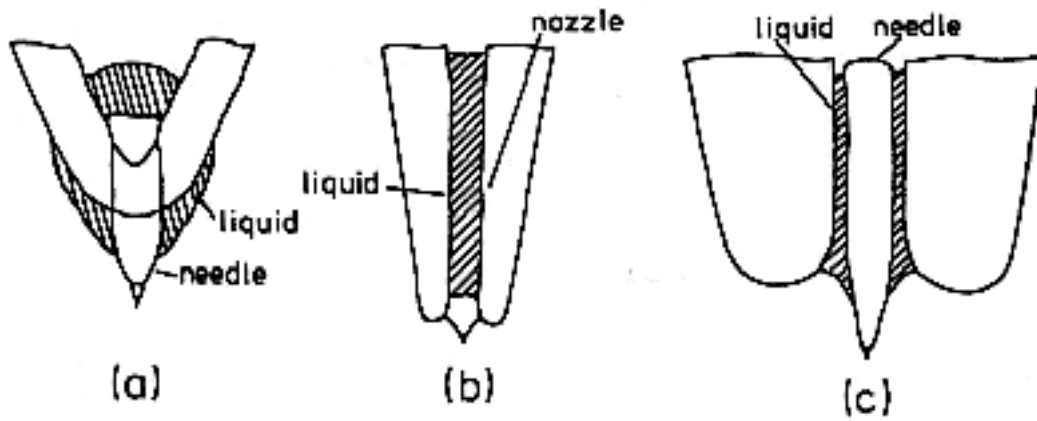


Duoplasmatron-Ionenquelle

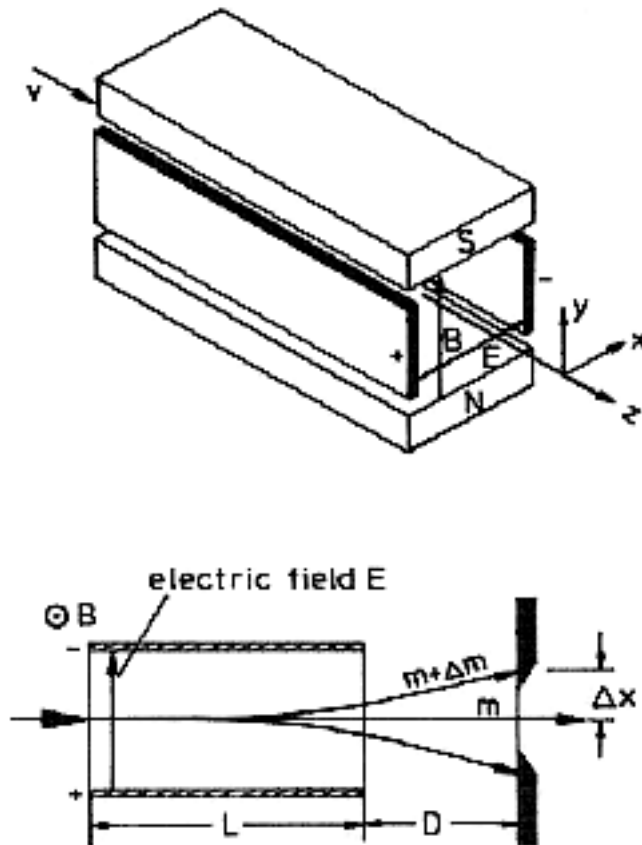
Cesium Surface Ionization Source



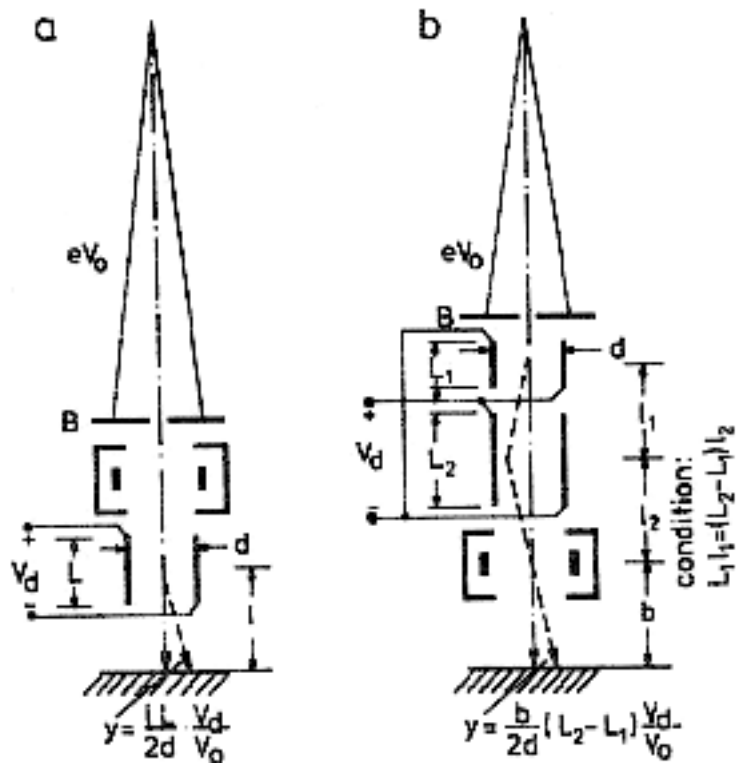
Cs-Ionenquelle



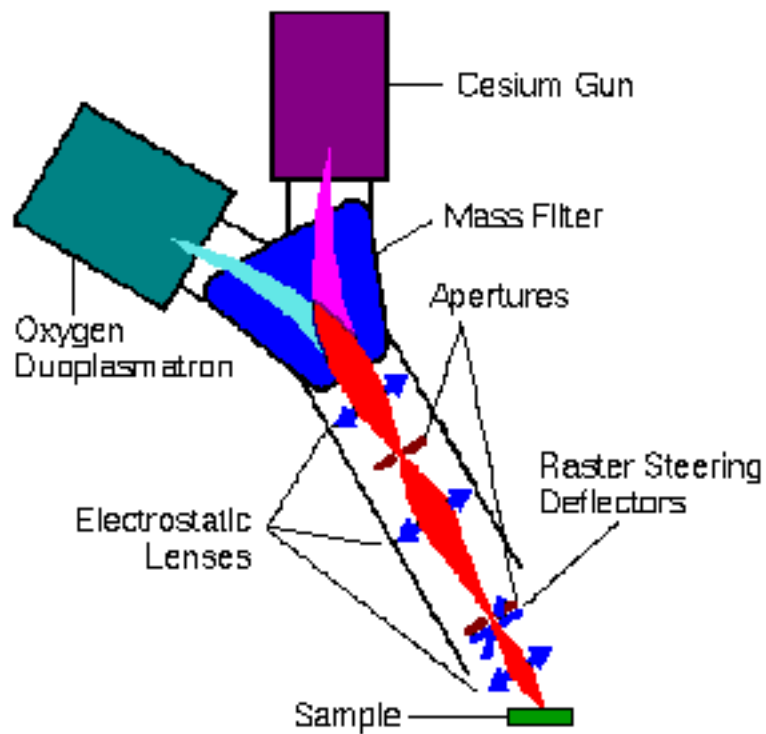
Feldemissionsspitzen einer Ga-Quelle



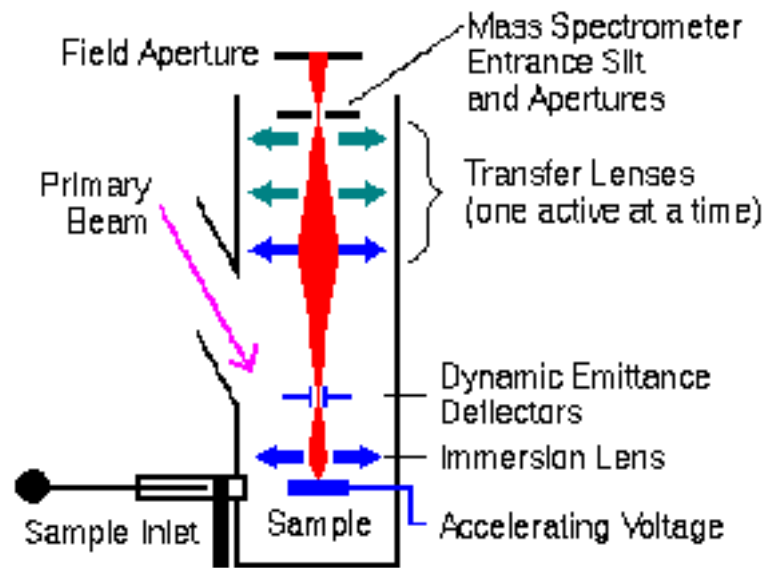
Aufbau einen Wien-Filter



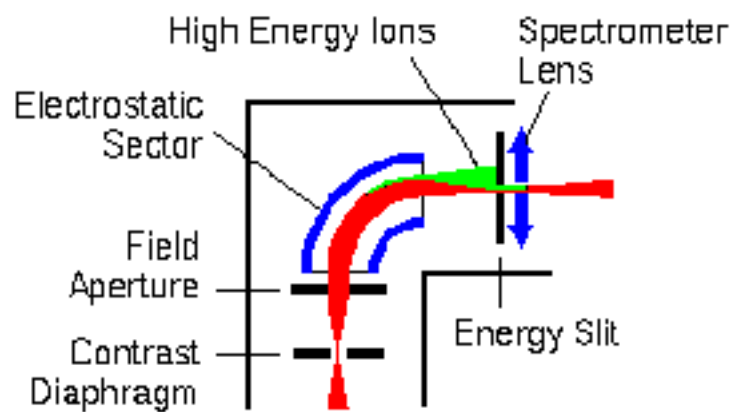
Elektrostatische Ablenkung, zwei Möglichkeiten



SIMS mit zwei Ionenquellen



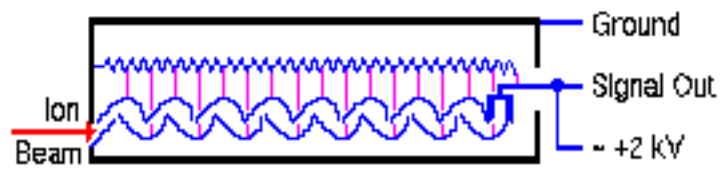
Sekundärionenextraktion



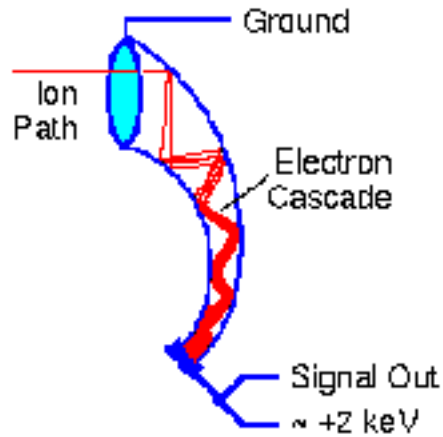
Energiefilter

Detektoren:

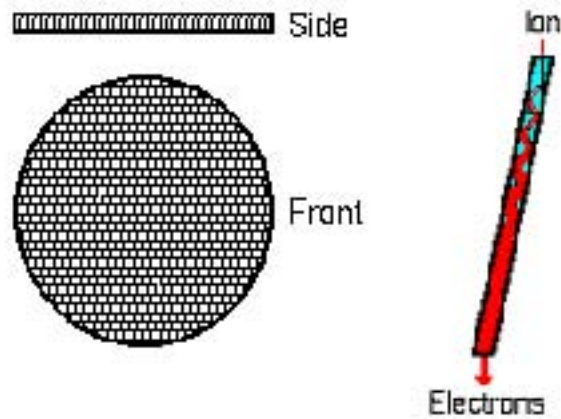
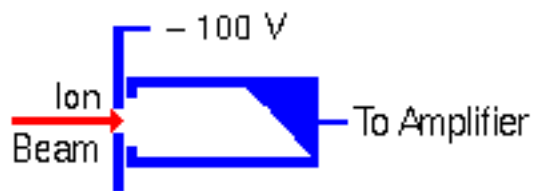
SEV



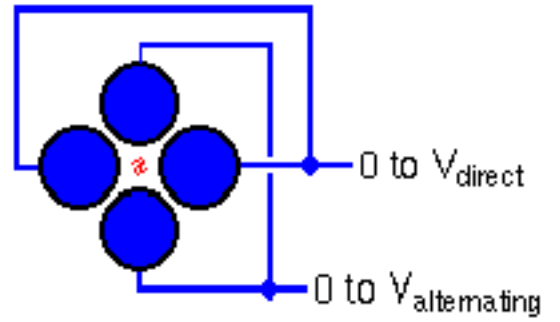
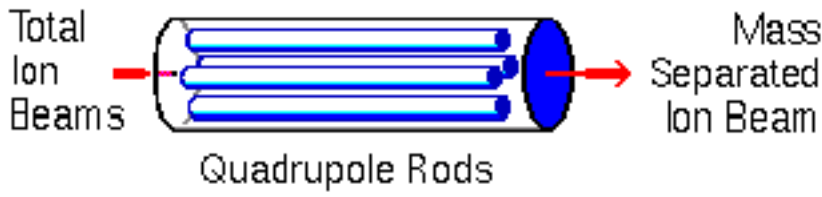
Kanal-SEV
(Channeltron)



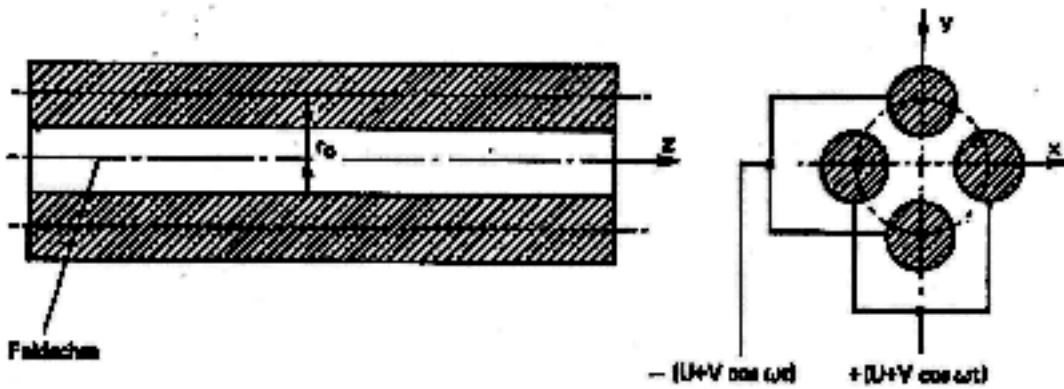
Faraday-Cup



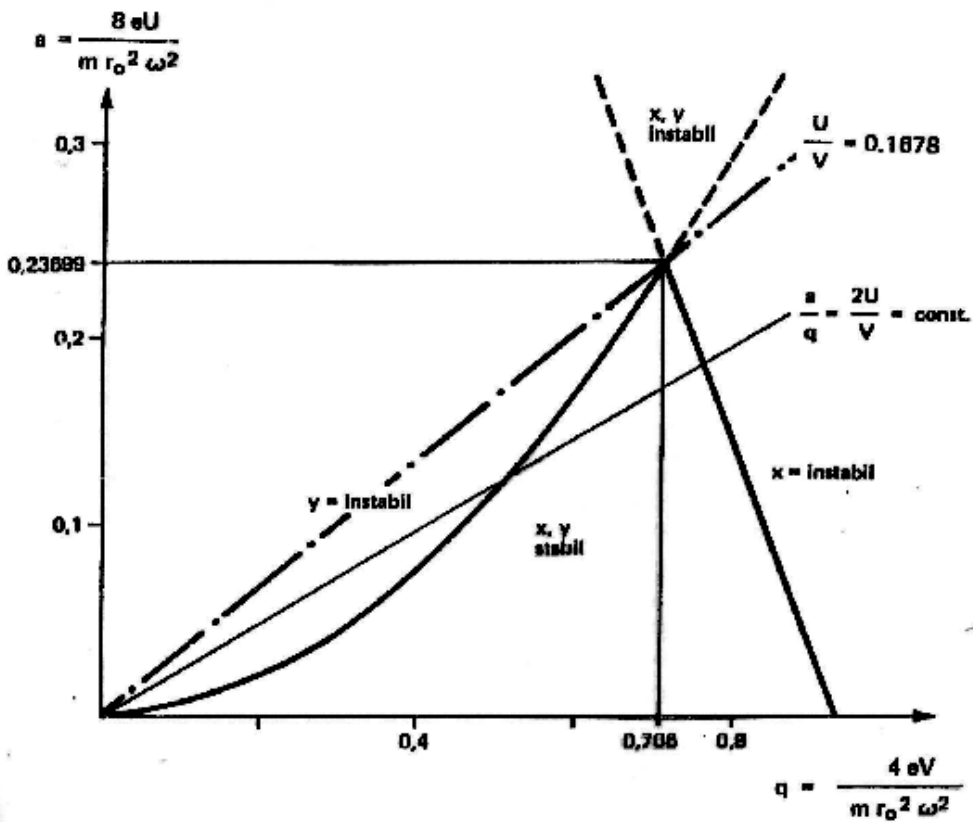
Multi Channel Plate (MCP) - Image Detector



Quadrupol-Massenfilter

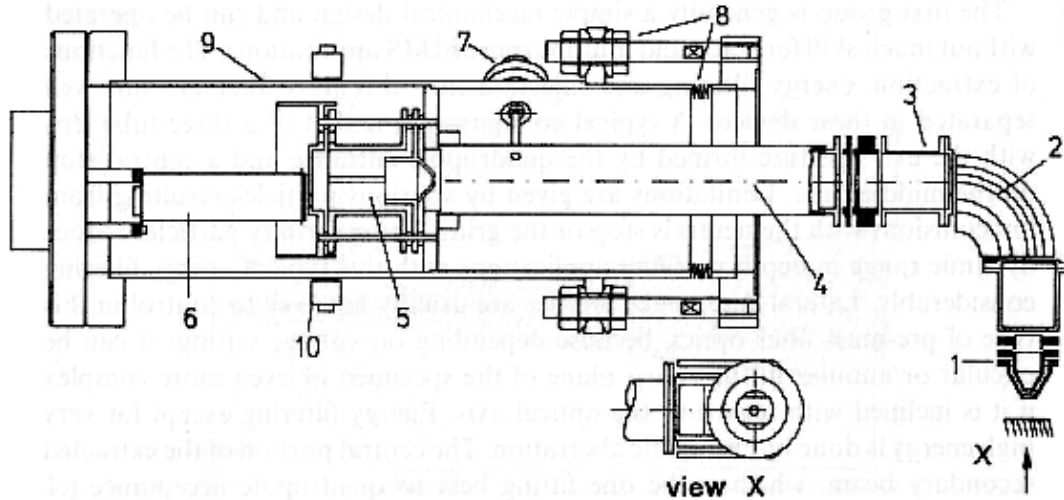


Quadrupol-Geometrie



Quadrupol-Stabilitätsdiagramm

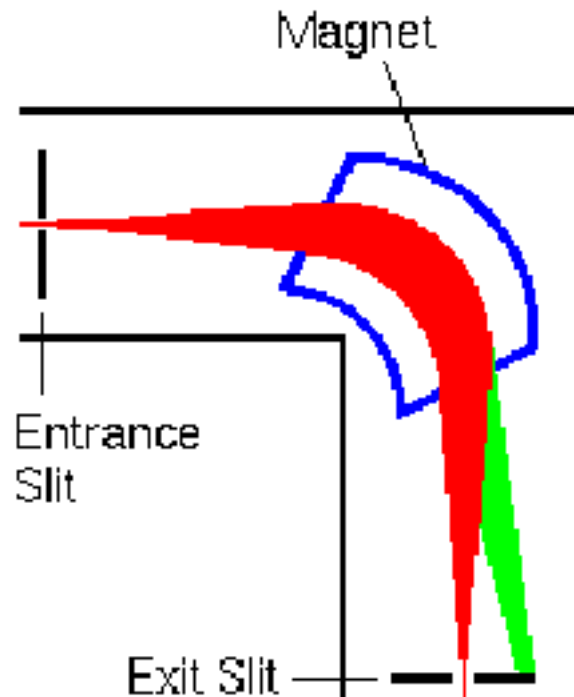
- | | |
|--|--|
| 1 extraction lens | 6 Cu-Be multiplier |
| 2 simulated spherical capacitor energy filter | 7 rf-feedthrough |
| 3 transfer lens | 8 port aligner |
| 4 quadrupole mass filter | 9 analyzer housing |
| 5 post-quadrupole extraction and deflection lens | 10 magnets for electron suppression in negative SIMS |



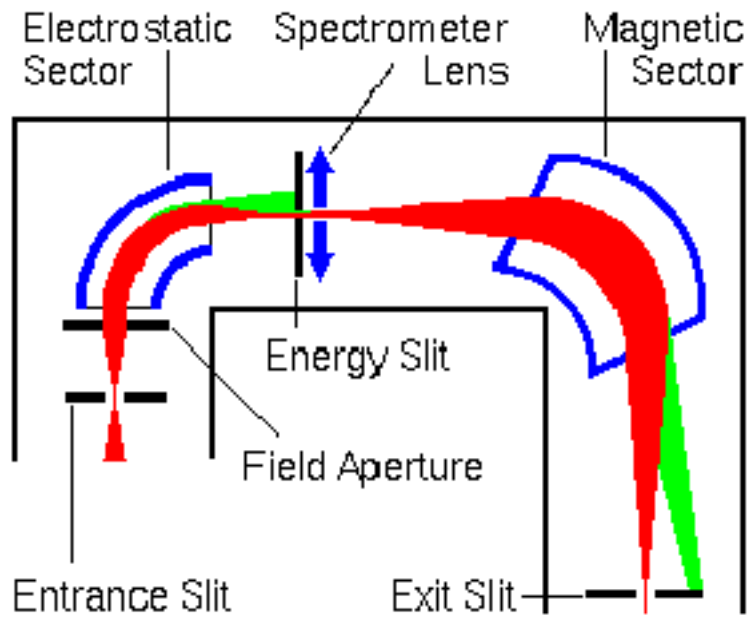
Aufbau eines SIMS-Ansalyators mit Quadrupol

mit
 m/q - Masse zu Ladung
 B - Magnetfeld
 V - Beschleunigungsspannung
 R - Bahnkrümmungsradius
 ergibt sich:

$$\frac{m}{q} = \frac{B^2}{2V} \cdot r^2$$



Aufbau eines magnetischen Sektorfeld-Ansalyators



Schema eines doppeltfokussierenden Massenspektrometers

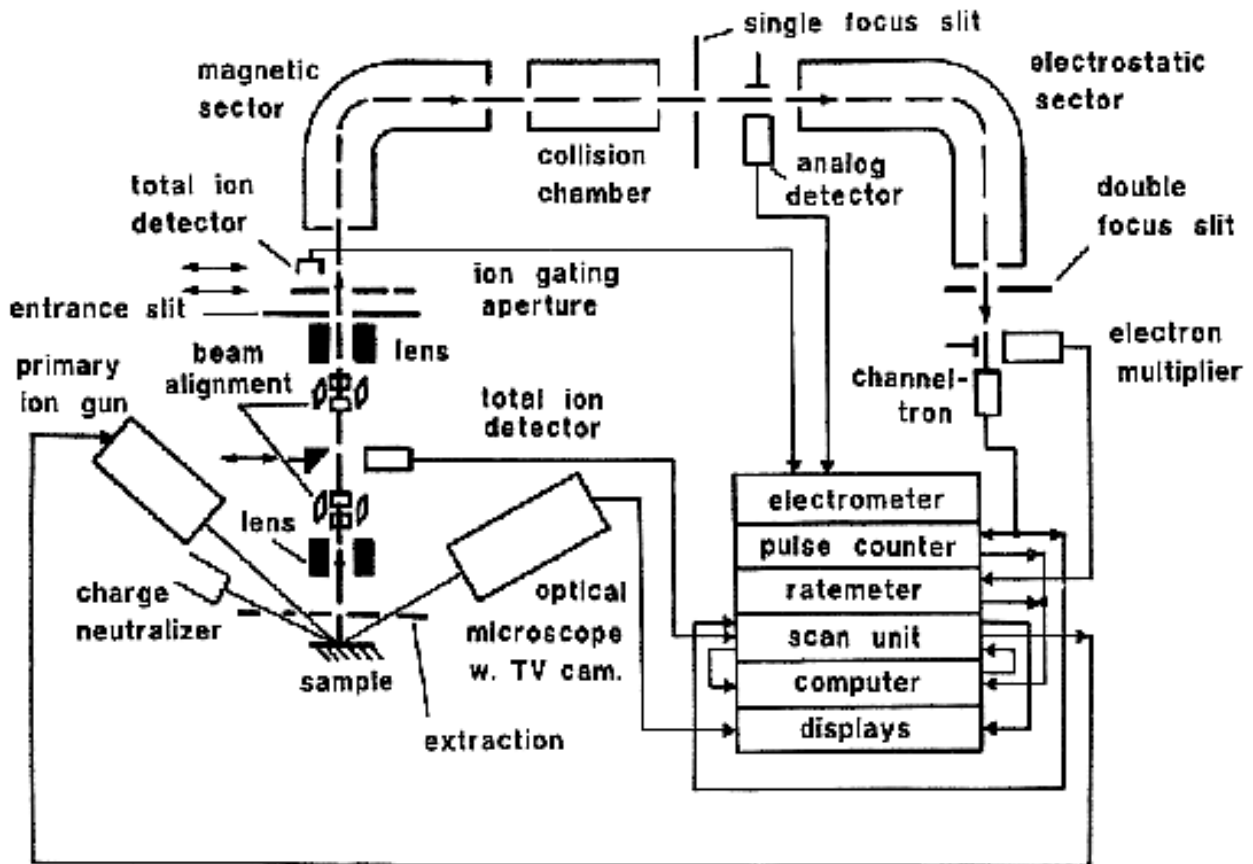
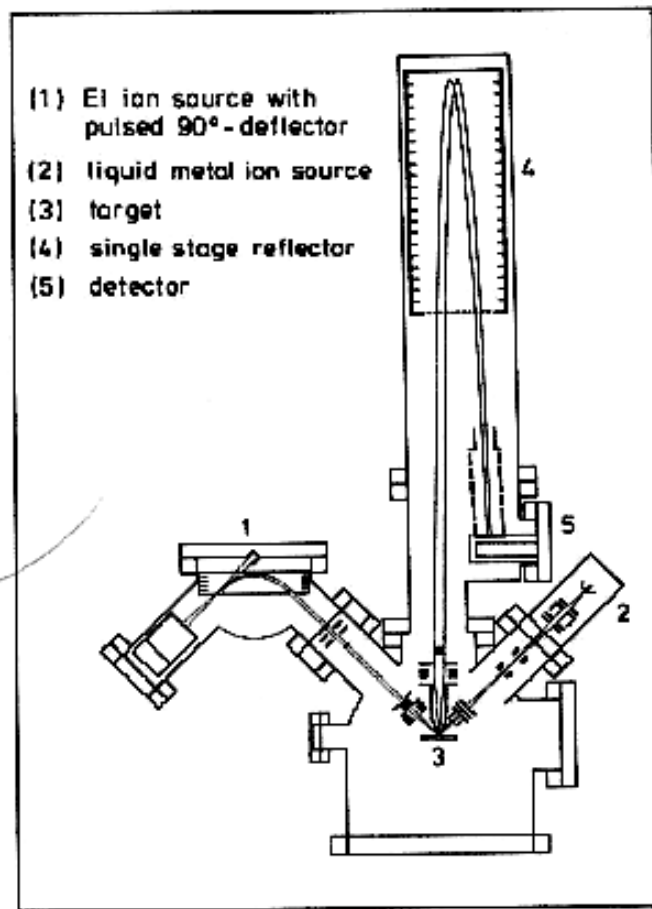
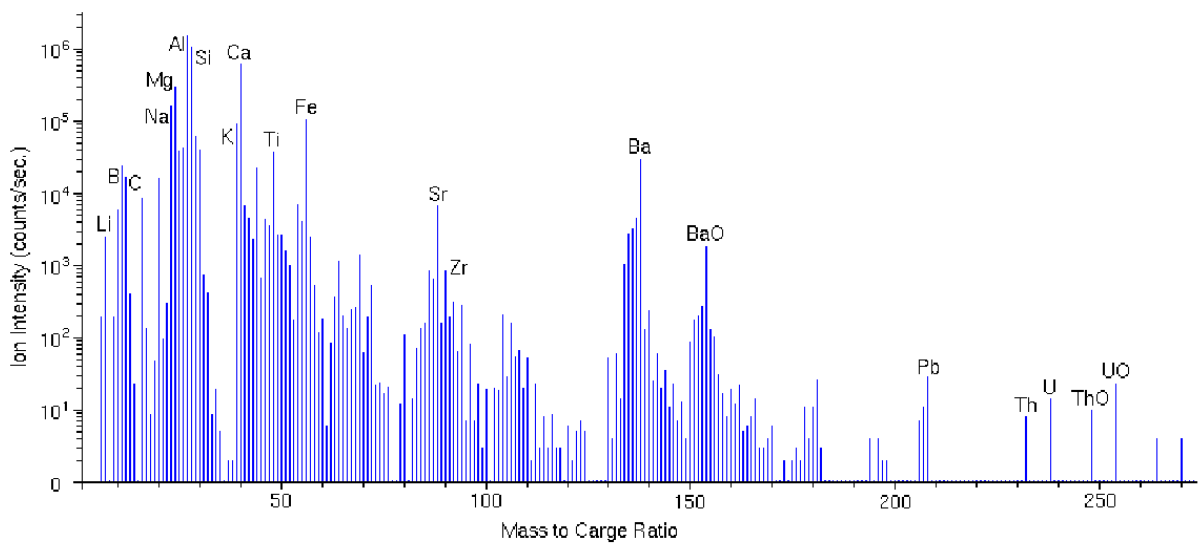


Figure 2.24 Schematic of a double-focusing magnetic sector field secondary ion microprobe⁹³

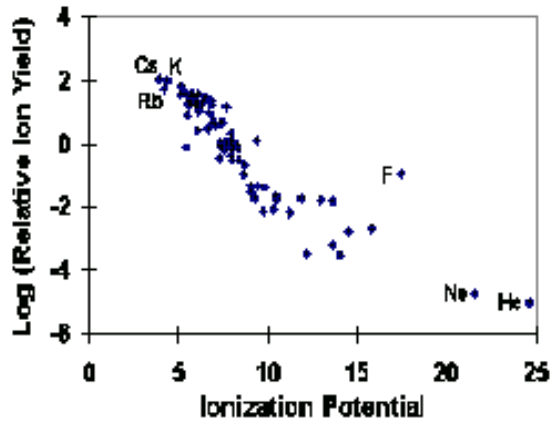
SIMS-Gerät mit magnetischem Sektorfeld-Analysator



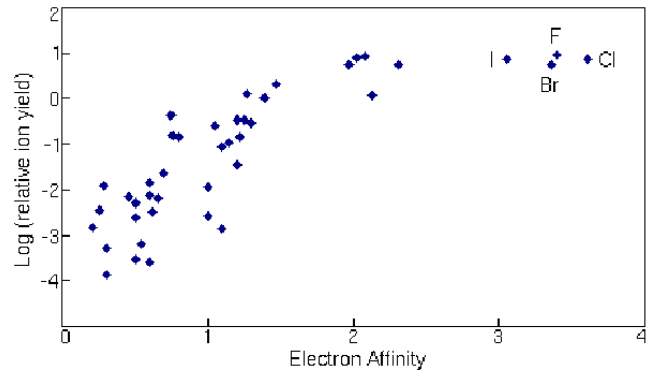
Flugzeit- (TOF-) Massenspektrometer



Beispiel für ein SIMS-Spektrum: Spektrum eines Flugasche-Partikels



O₂-Ionen
Ausbeute an negativen Ionen



Cs-Ionen
Ausbeute an positiven Ionen

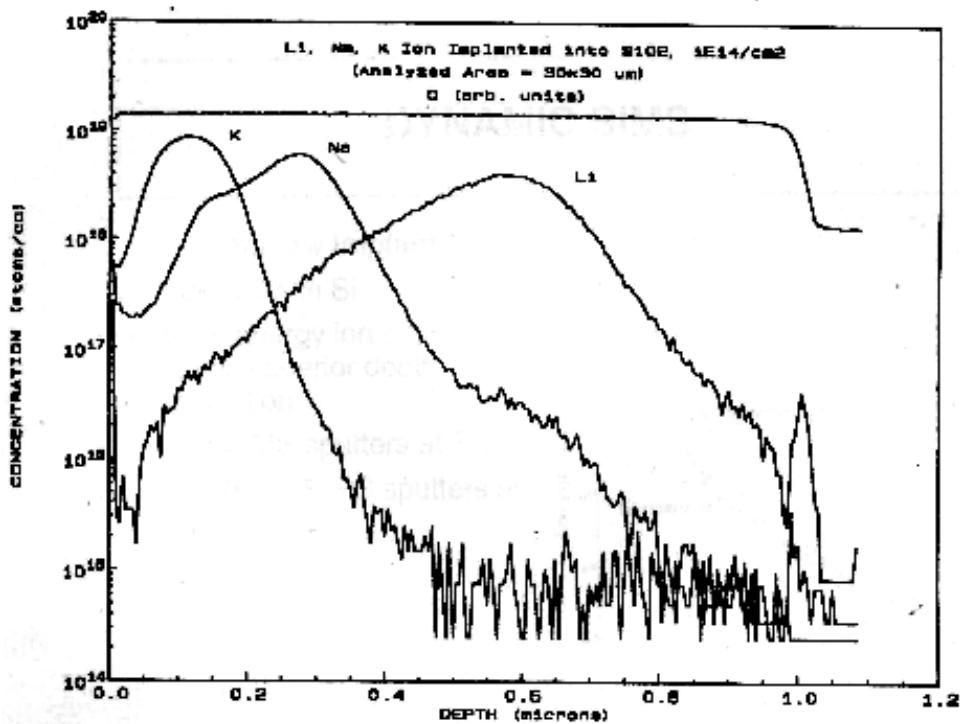
H																		He			
Li	Be															B	C	N	O	F	Ne
Na	Mg															Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr				
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe				
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn				
Fr	Ra	Ac																			
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu						
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr						

Was misst man ?

Massenspektrometer Typ	Erreichbare Massentrennung $m/\Delta m$ (FWHM) ¹⁾	Transmission ²⁾ In SIMS-Geräten	Registrierung eines Massenspektrums	Primärionenstrahl	Einsatz
Quadrupol-MS	~300	10^{-2}	sequentiell	kontinuierlich	SIMS Tiefenprofil-Analysen
Magnetisches Sektorfeld-MS	10000	30 %	sequentiell	kontinuierlich	
Flugzeit-MS	3000	~ 20 %	quasi-simultan	gepulst	Oberflächen-SIMS

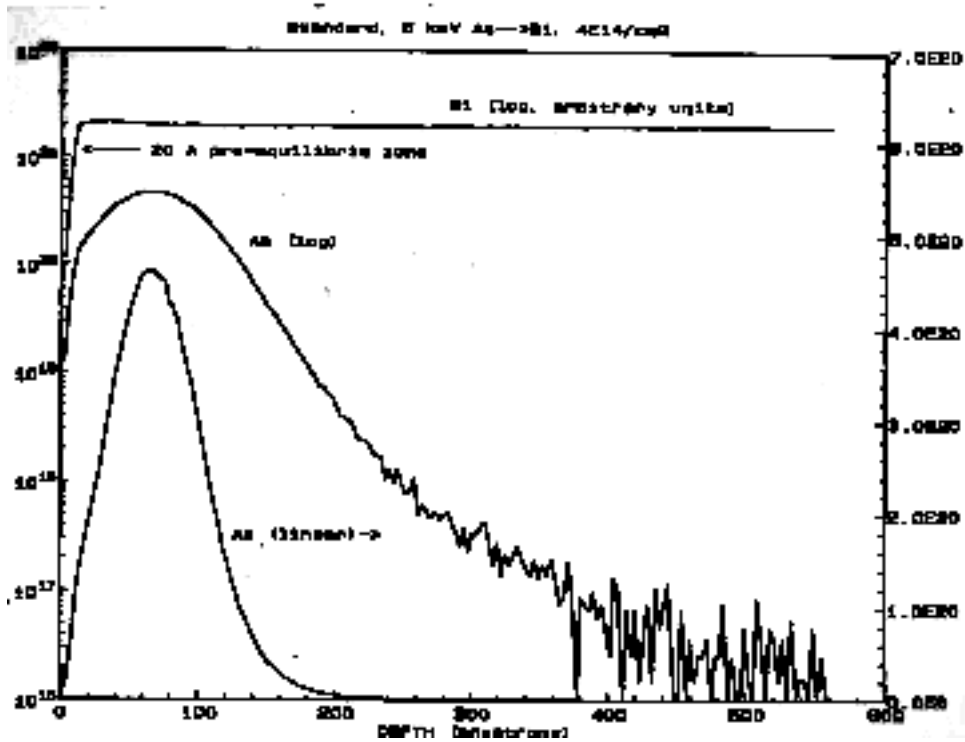
Gegenüberstellung der Massenspektrometertypen

Beispiele SIMS:

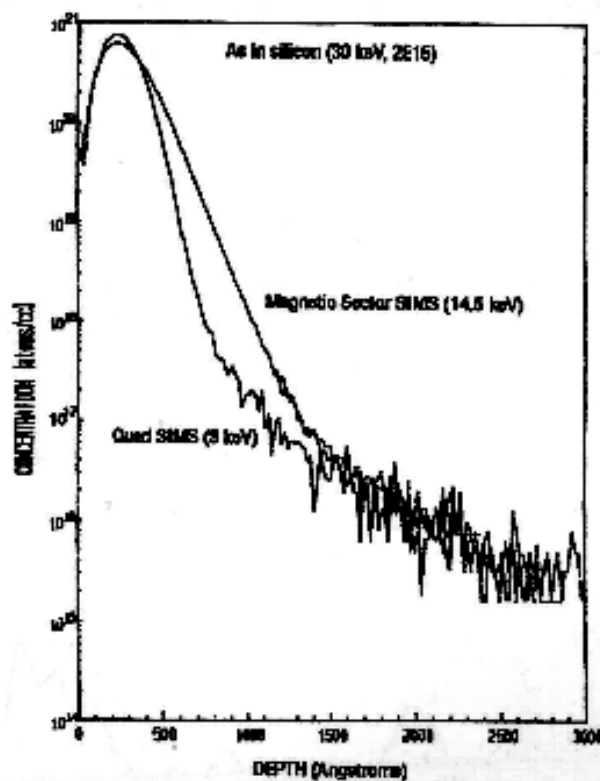


Implantationen

K-, Na- und Li- Implantationen in SiO₂

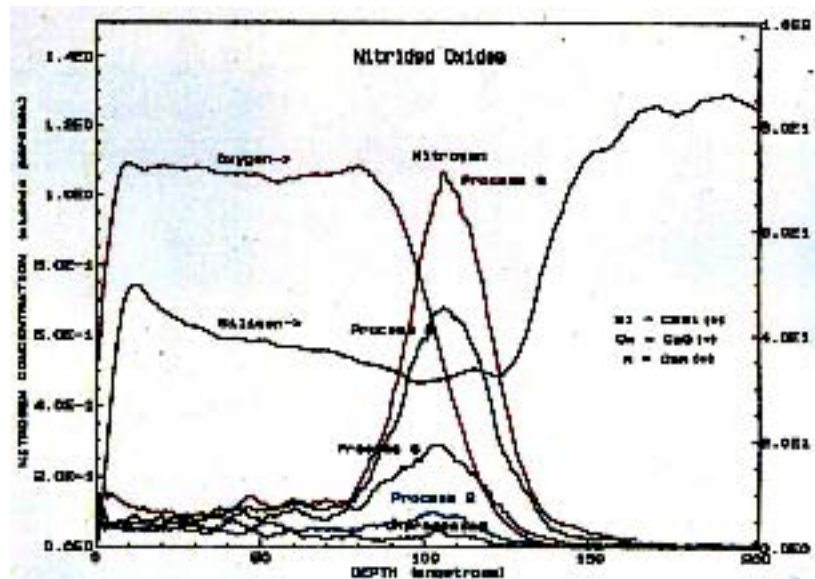


Implantationsprofil (SIMS) in linearer und logarithmischer Darstellung

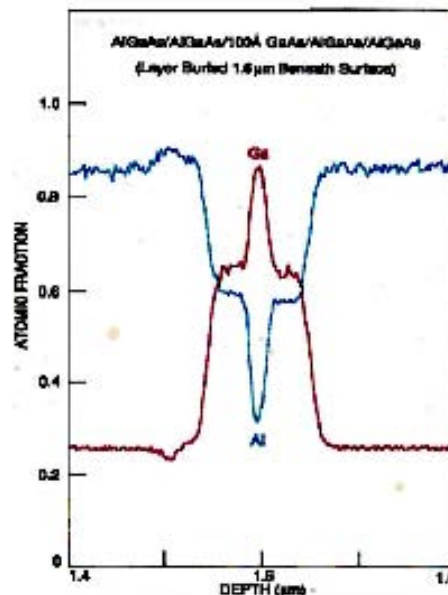


Vergleich verschiedener Analytoren bei flacher As-Implantation

Schichtfolge
SIMS-Tiefenprofil



AlGaAs-Multilayer



$$I_{S(A)} = I_p \cdot S \cdot \alpha_A \cdot c_A \cdot i_{S(A)} \cdot \eta_A$$

$I_{S(A)}$ = Sekundärionenintensität des gemessenen Isotops von Element A [cps]

I_p = Primärionenintensität [Ionen/s]

S = Sputterausbeute [Atome/Primärion]

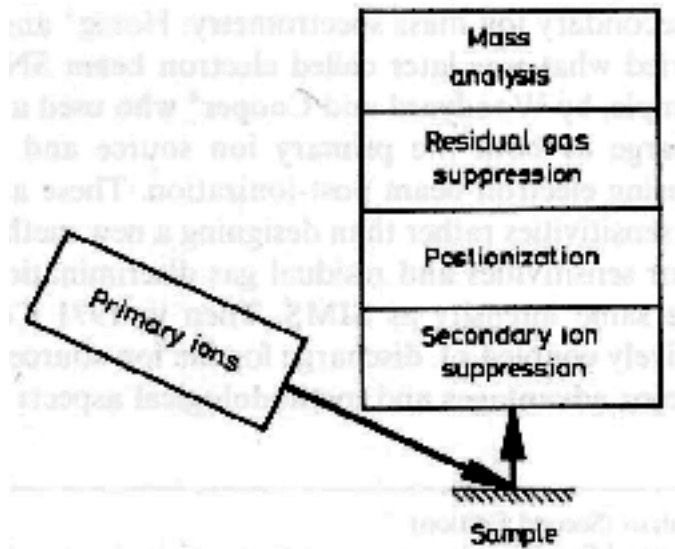
α_A = Ionisierungswahrscheinlichkeit der gesputterten Atome (α_A^+ -positive, α_A^- -negative Sekundärionen)

c_A = atomare Konzentration von Element A in der Probe

$i_{S(A)}$ = Isotopenhäufigkeit

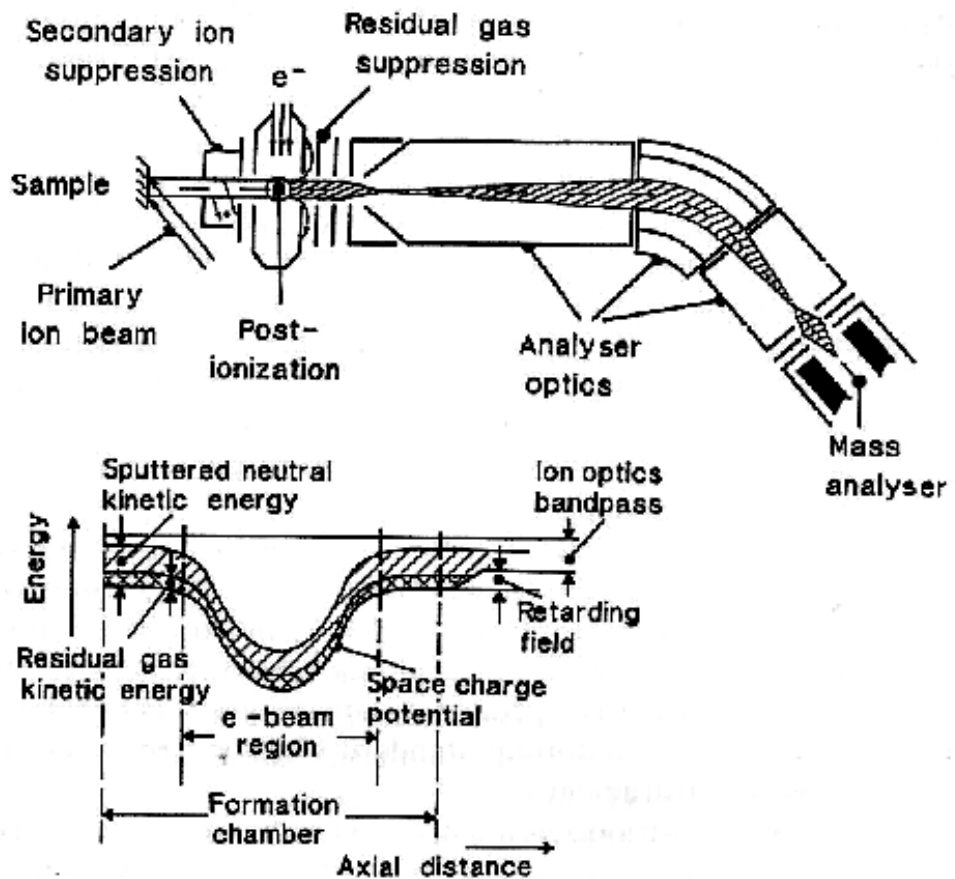
η_A = Wirkungsgrad der Sekundärionenmessung für Element A (Ausbeute der Ionenextraktion, Transmission des Massenspektrometers, Detektorwirkungsgrad)

Zur Quantifizierung bei SIMS

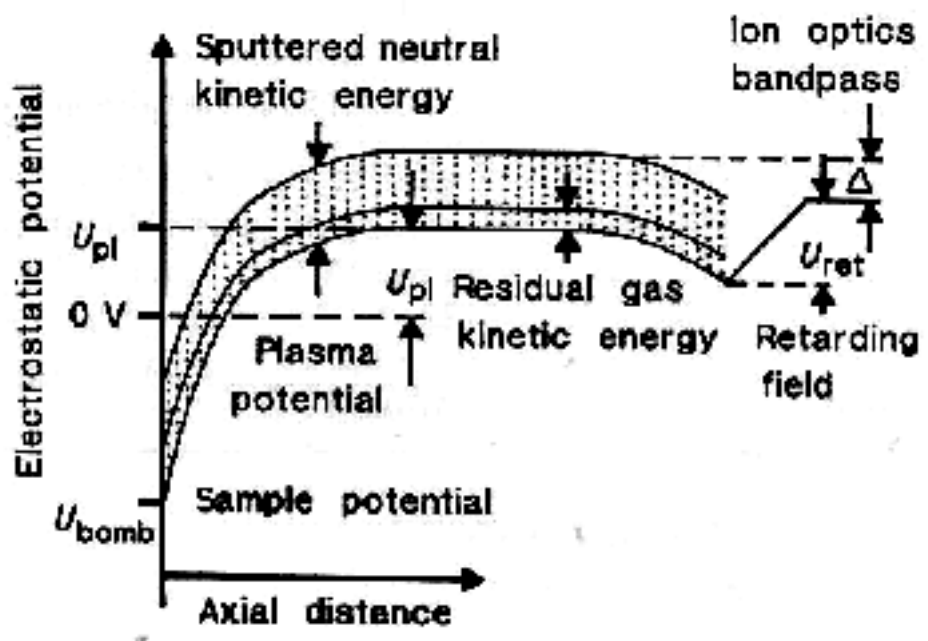
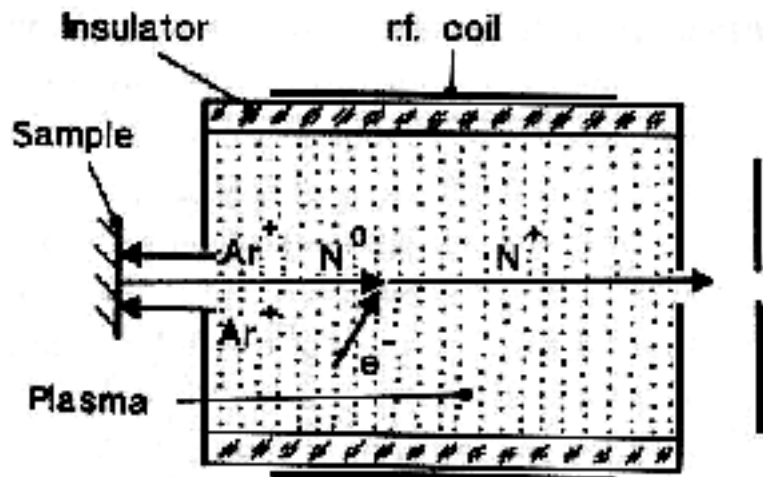


Prinzip der SNMS

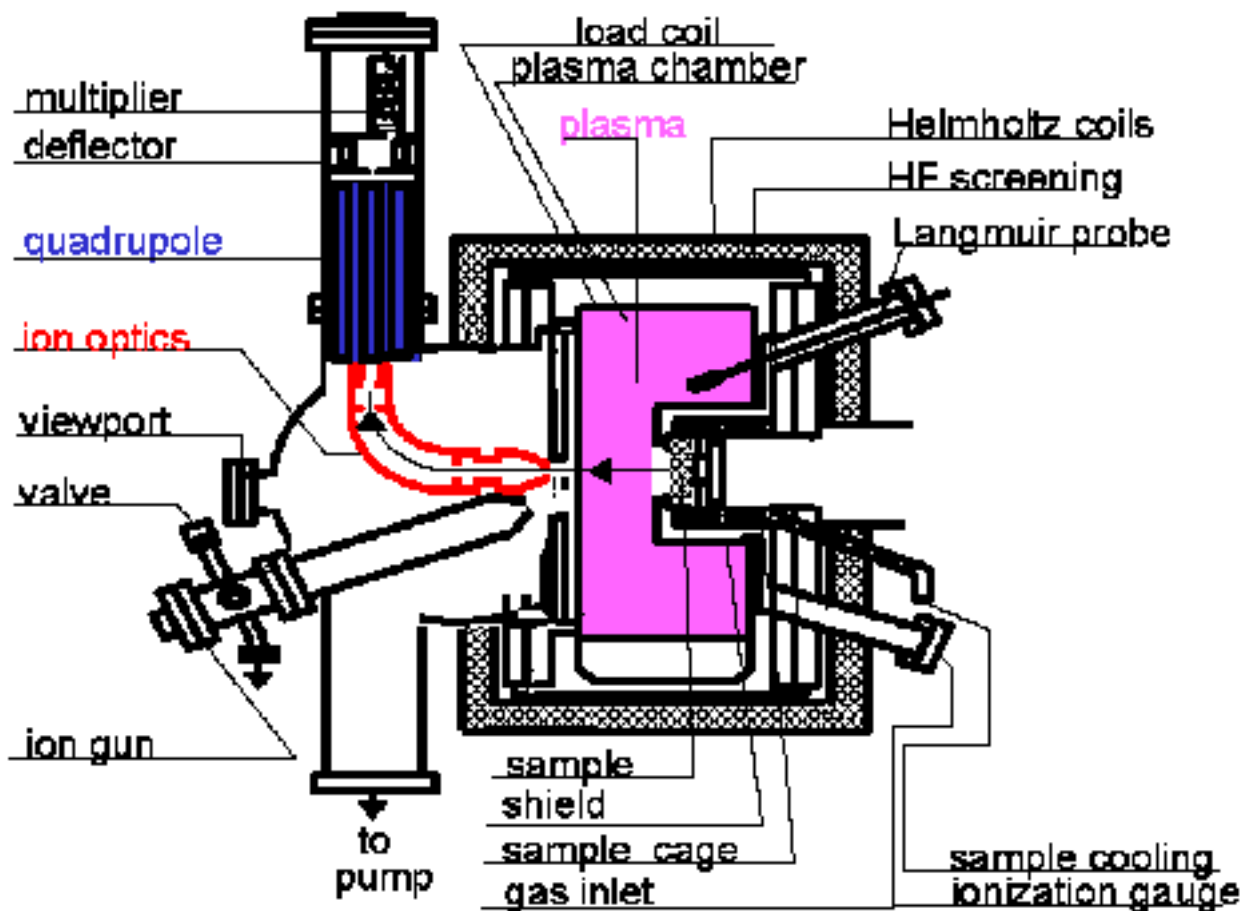
Sputtered Neutral Mass Spectrometry (SNMS)



Elektronenstrahl-SNMS, Aufbau und Energieverlauf



Plasma-SNMS, Aufbau und Energieverlauf



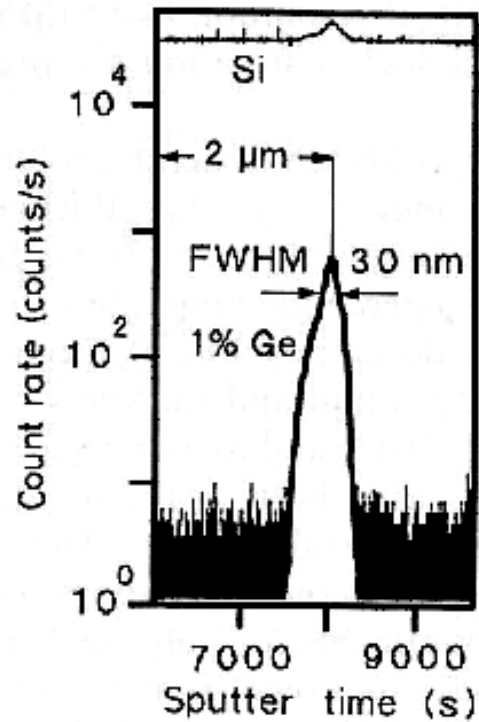
Aufbau eines Sekundär-Neutralteilchen-Massenspektrometers

Table 8.4 Relative sensitivity factors in electron gas SNMS for some elements and various bombardment voltages

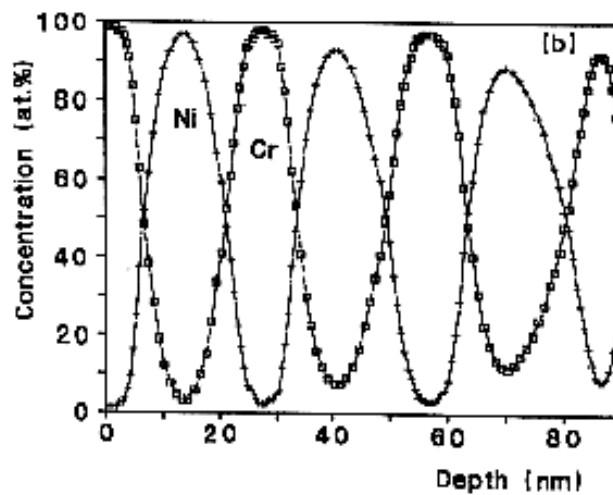
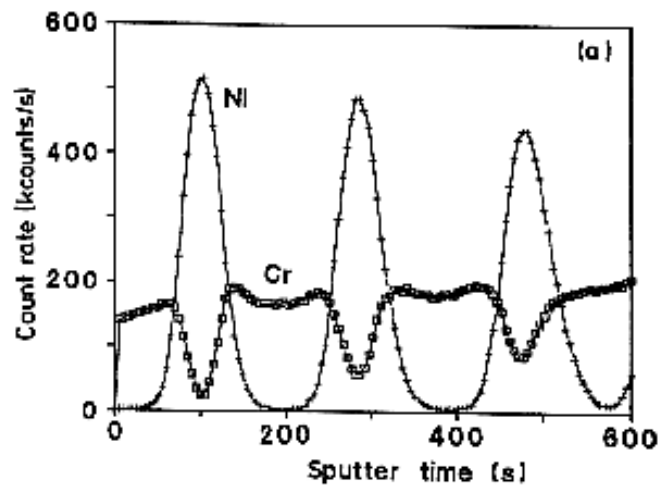
Element	Bombardment voltage			Element	Bombardment voltage		
	600 V	800 V	1000 V		600 V	800 V	1000 V
Ag	1.1	0.9	1.2	Mn	1.05	1	0.95
Al	0.4	0.3	0.35	Mo	0.6	0.48	0.56
As	1.3-1.5	1.5	1.45	N		10-15	
Au	1.2	1.0	1.1	Na	0.2	0.2	0.25
B	0.3	0.2-0.5	0.3	Nb	0.3	0.3	0.35
Ba	0.25-0.4	0.1-0.3	0.25	Ni	1.3	1.25	1.4
Be	0.3	0.3	0.35	O	5	5	6.5
Bi	0.2	0.3	0.22	P		1.2	1.3
C		4	4.2	Pb	0.2	0.25	0.2
Ca	0.85	0.5	0.8	Pd	1	1.2	1.1
Cd	0.7-1.1	0.8	0.95	Pt	0.8	1.2	0.85
Ce		0.3	0.33	Rb			0.4
Co	1	1	1.1	Rh	0.8	0.5	0.6
Cr	0.88	0.85	0.92	S	1.3	1.2	1.2
Cs	0.2	0.2	0.2	Sb	1.5	1.3	1.3
Cu	0.6-1	0.7-1	0.72	Se		0.8	1.2
F			5	Si	0.45	0.4	0.42
Fe	1	1	1	Sn	1.2	1.1	1.2
Ga	0.5	0.55	0.65	Sr	0.5	0.4	0.55
Ge	0.8	0.8	0.88	Ta	0.9-1.3	1.4	0.8-1.2
Hg			0.25	Te	1	1.4	1.2
In	0.3-0.4	0.3	0.35	Th	0.3	0.25	0.31
J			0.8	Ti	0.65	0.6-1.2	0.85
K	0.2	0.25	0.3	V			0.5
La	0.3-0.8	0.25	0.3	W	1.2	1.2	0.75
Li		0.3	0.3	Y	0.5	0.6	0.42
Mg	0.2	0.2	0.4	Zn	1.2-1.4	1.3	1.5
				Zr	0.6-1	0.7	0.8

relative
Empfindlichkeits-
faktoren der
SNMS

Beispiele:

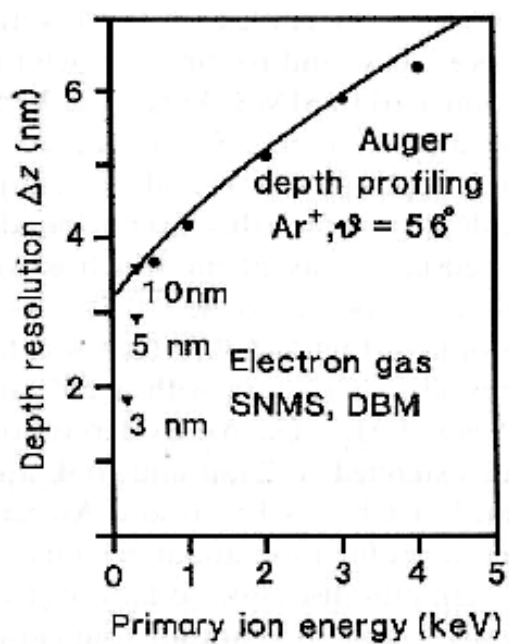
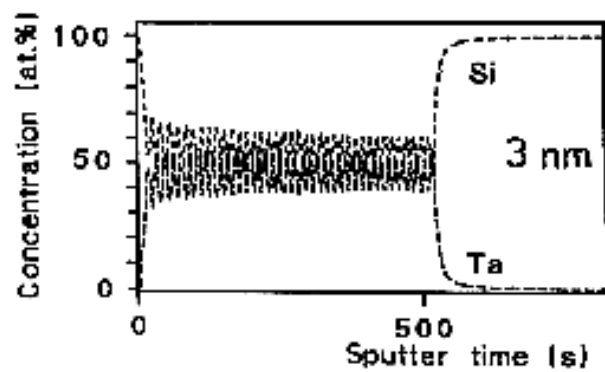
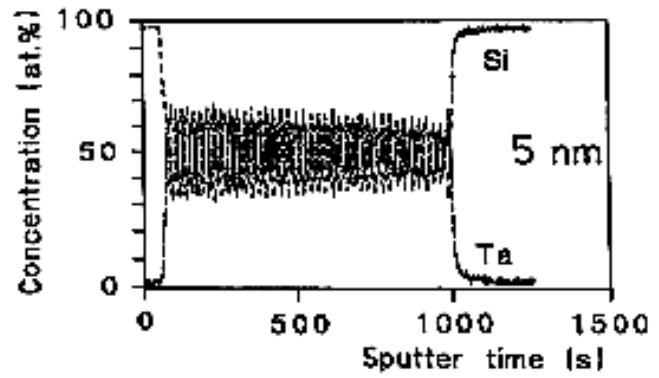
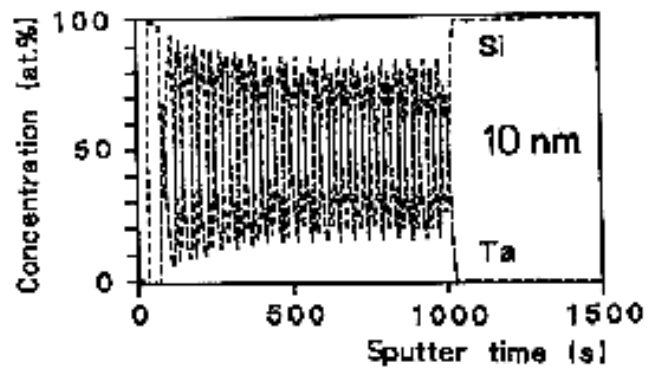


vergrabene Schicht
mit 1% Ge in Si



Ni-Cr- Multilayer
Messprofil und
quantifiziertes
Tiefenprofil
(beide Achsen)

Si/Ta-Multilayer,
variable Bilayerdicke



Vergleich der Tiefenauflösung
AES - SNMS