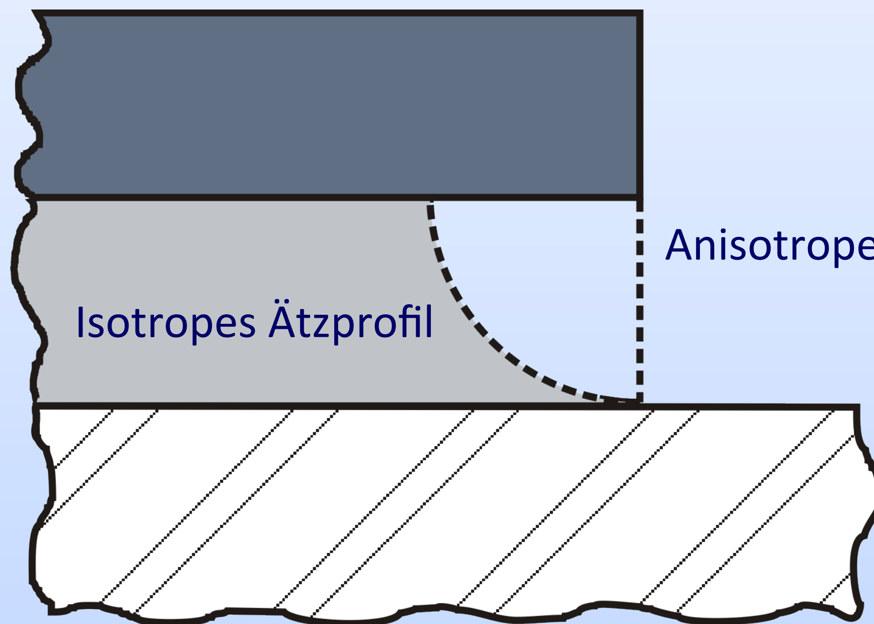
Ätzen

Das Ätzen

Kategorisierung:

- physikalische Verfahren
- chemische Verfahren
- Kombination aus Chemie und Physik



Anisotropes Ätzprofil

Selektivität
$$S = \frac{R^{\text{Material 1}}}{R^{\text{Material 2}}}$$

Anisotropiefaktor
$$A = 1 - \frac{R^{\text{Lateral}}}{R^{\text{Vertikal}}}$$

PD Dr. Andriy Romanyuk

Selektivität vs. Anisotropie

Nasschemisches Ätzen | Barrel Ätzen (BE) | Plasma Ätzen (PE) | Reaktives Ionenätzen(RIE) | Reaktives Ionenstrahlätzen (RIBE) | Sputterätzen (IE) | Ionenstrahlätzen (IBE)

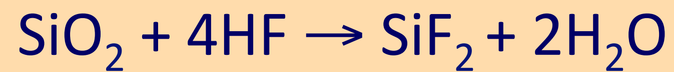
chemische Verfahren

Kombination aus Chemie und Physik

physikalische Verfahren

PD Dr. Andriy Romanyuk

Nasschemisches Ätzen



Ätzprozess:

1. Diffusion des Reagens an die Oberfläche
2. Chemische Reaktion an der Oberfläche
3. Diffusion der Reaktionsprodukte in die Umgebung

<u>Siliziumoxid</u>

- DHF (5:1 – 250:1)
- BHF (NH_4F:HF 5:1 – 500:1)

<u>Siliziumnitrid</u>

- HF 49%
- H_3PO_4 80%

<u>Polysilizium</u>

- HF/HNO_3 (1:1 – 1:10)
- KOH/Benz. Alkohol

Trockenätzen

Anwendungen:

- Strukturierung von Dielektrika
- Strukturierung der Polysilizium
- Tiefenätzen von Silizium (DRIE)
- Strukturierung von Metallen

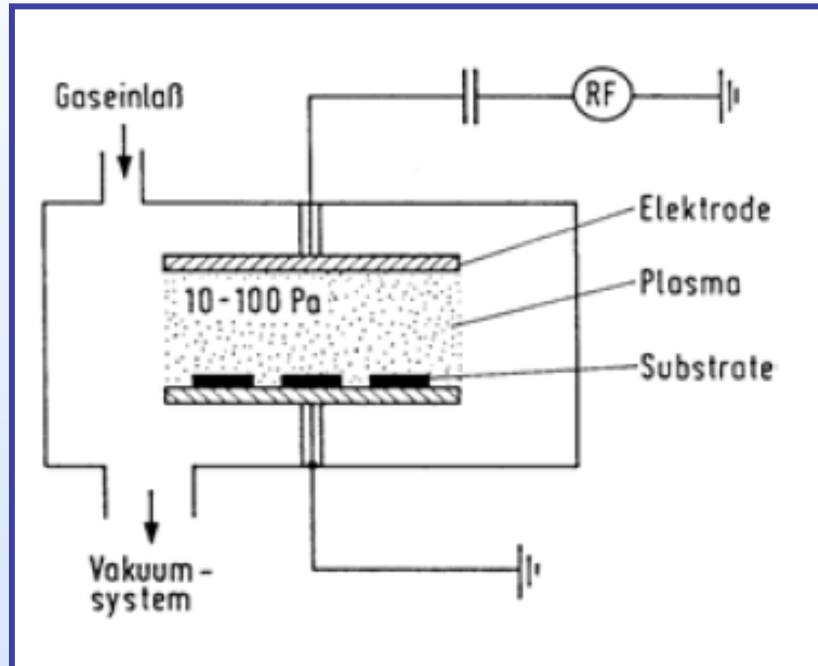
Teilschritte:

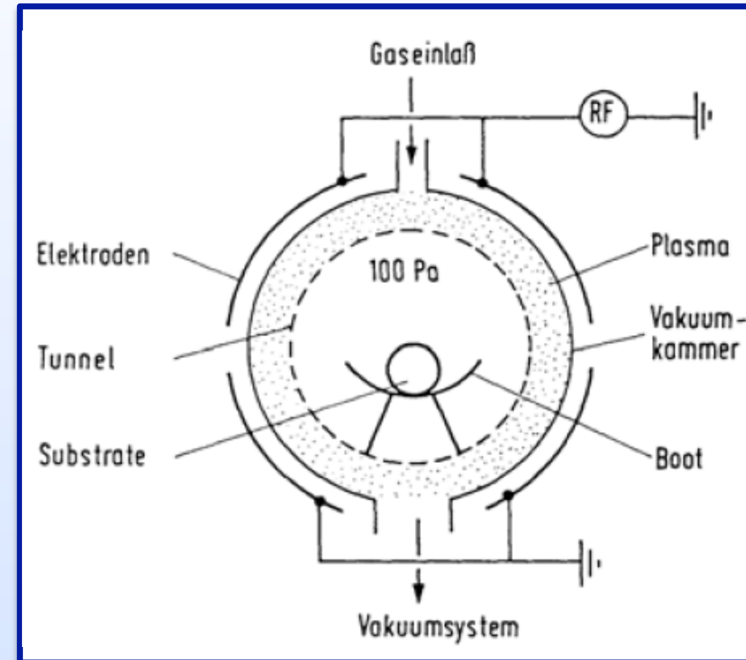
- Erzeugung reaktiver Teilchen
- Transport der Teilchen zur Substrat
- Ätzung der Oberfläche
- Abtransport der Reaktionsprodukte

Reaktionspartner:

- inerte Ionen (Ar^+) $\Rightarrow$ mechanische Wirkung
- reaktive Ionen (CF_3^+) $\Rightarrow$ chemische Wirkung
- reaktive Radikalen (F^*, O^*, CF_3^*)

Plasmaätzen



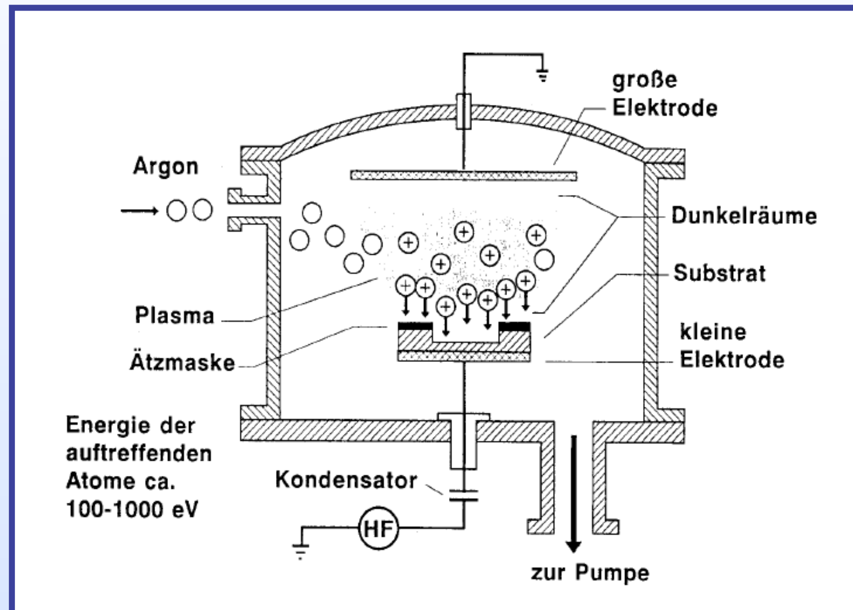


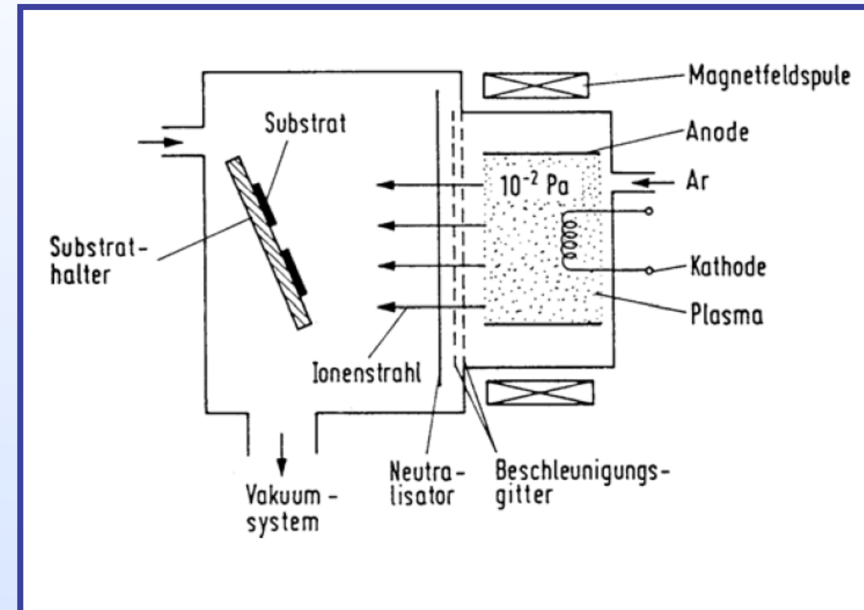
- Angriff durch chemischer Radikale
- schwache physikalischer Angriff durch Ionen

Folglich:

- geringe Anisotropie
- hohe Selektivität

Sputterätzen (ion milling) und Ionenstrahlätzen (ion beam milling)





Sputterätzen

- Plasma und Ätzkammer nicht getrennt
- hohe Anisotropie bei niedrigen Drucken
- geringer Selektivität

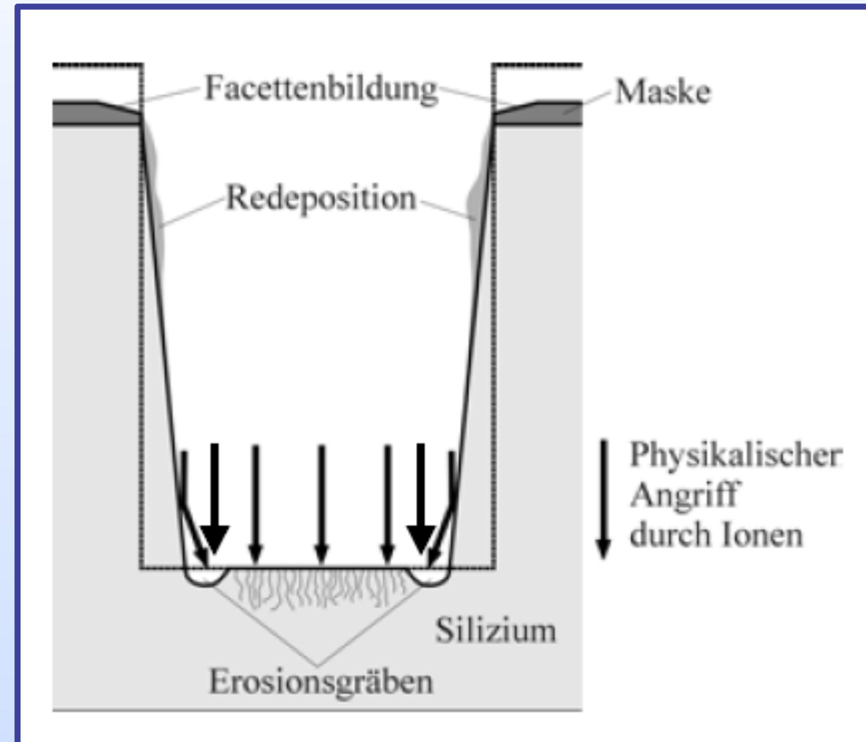
Ionenstrahlätzen

- Plasma und Ätzkammer sind getrennt
- sehr hohe Anisotropie ist möglich
- geringer Selektivität

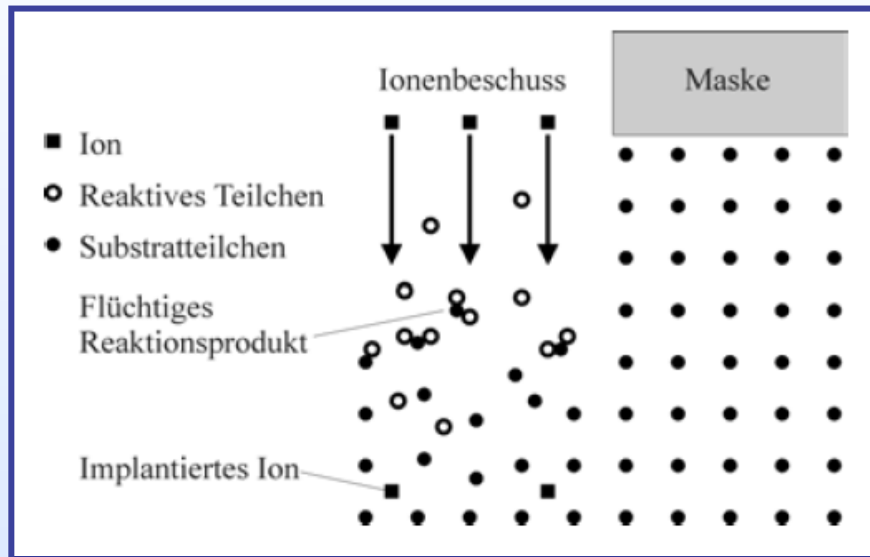
Sputterätzen

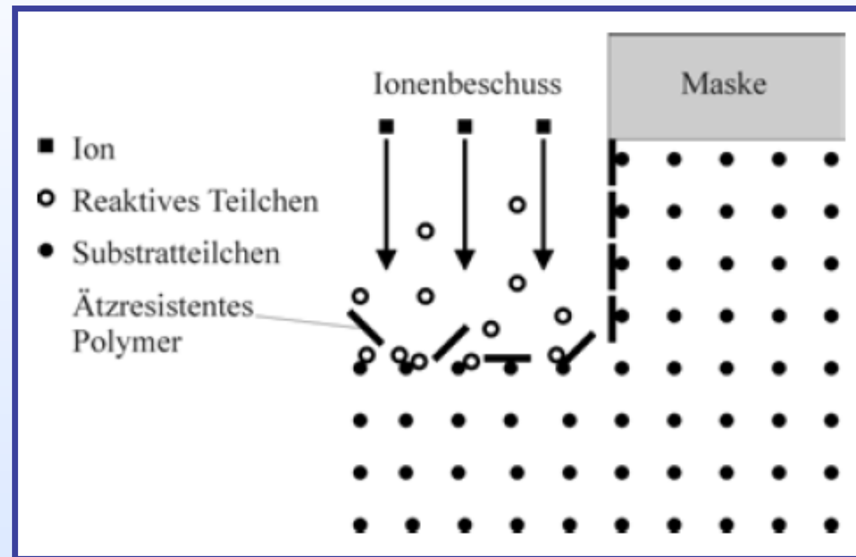
Probleme

- Redeposition
- Erosionsgraben (trenching)
  - Reflexion an der Seiten
  - Lokale Erhörung der Ionendichte
  - höhere Ätzrate
  - Erosionsgraben
- Absputtern der Maske
- Fecettenbildung
- Implantation der Ionen



Reaktives Ionenätzen (Reactive Ion Etching)

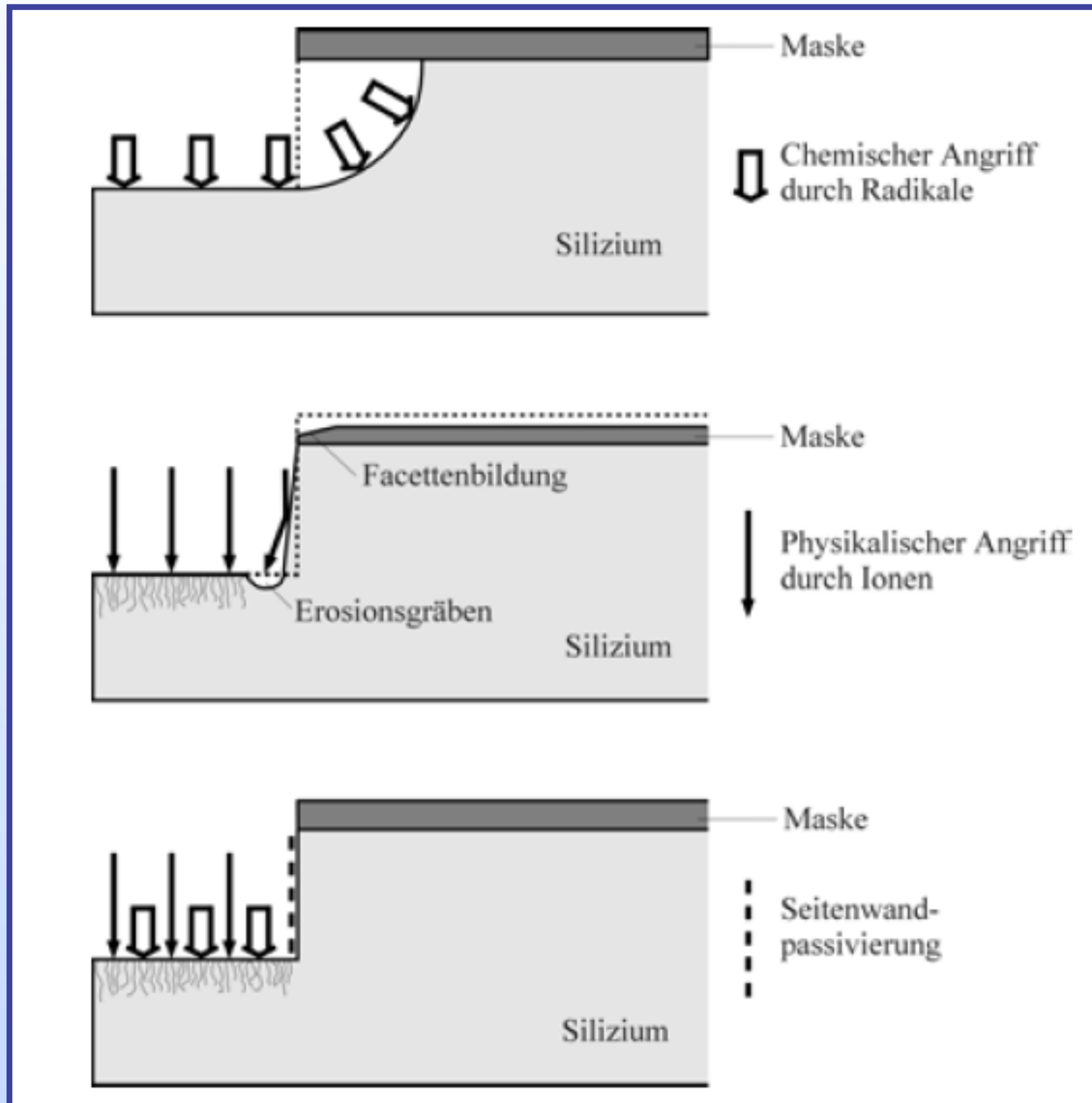




- Gemisch aus reaktiven und inerten Gasen
  ⇒ Kombinierter chemischer und physikalischer Ätzangriff

- Vorteile:
  - hohe Selektivität
  - hohe Anisotropie
  - senkrechte Wände
  - hohe Ätzrate
  - Seitenwandpassivierung

Vergleich der Ätzprofile

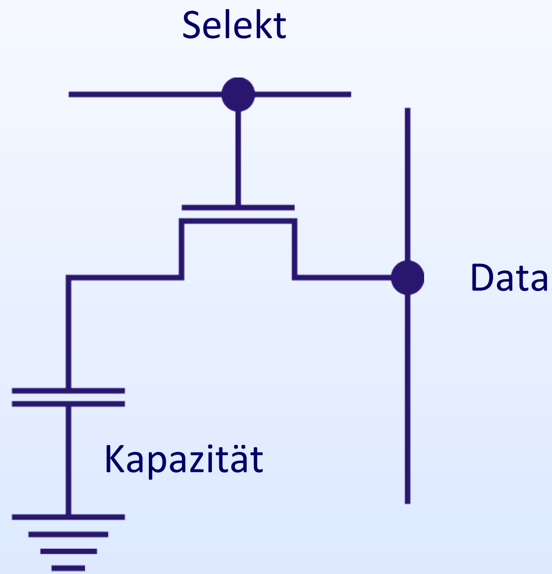


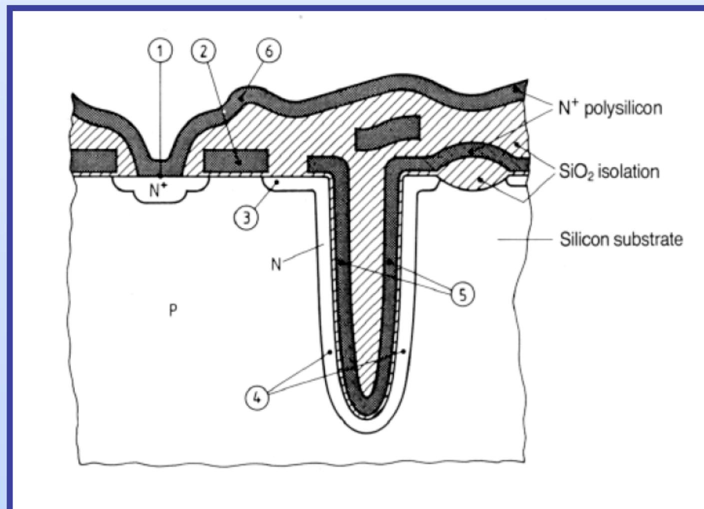
Plasmaätzen

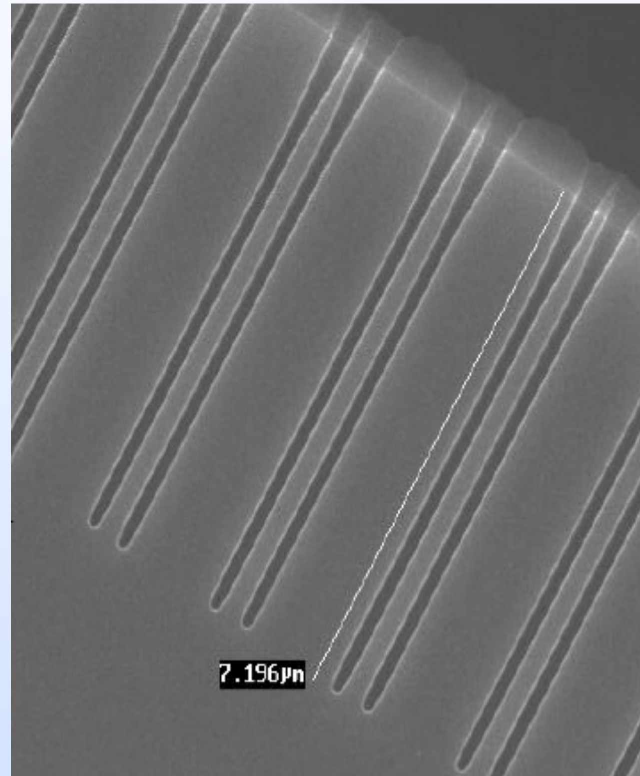
Sputterätzen

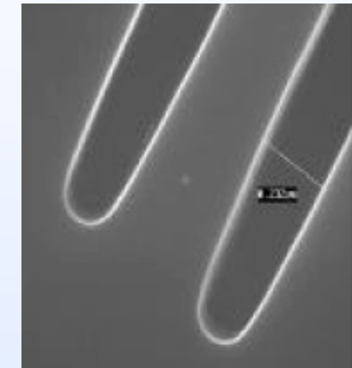
Reaktives Ionenätzen

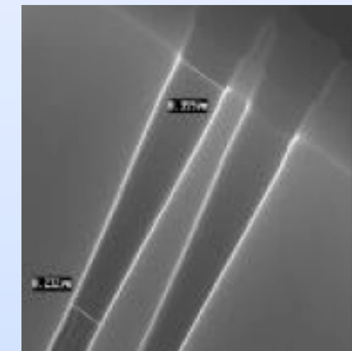
Deep Trench Capacitor











Herausforderungen:

- hohe Aspekt Ratio
- hohe Selektivität
- Uniformität

Prozesskontrolle

IEP (Interferometric Endpoint Control)

- Detektion von der Ätztiefe für Endpointkontrolle

OES (Optical Emission Spectroscopy)

- Plasmamonitoring für Endpointkontrolle

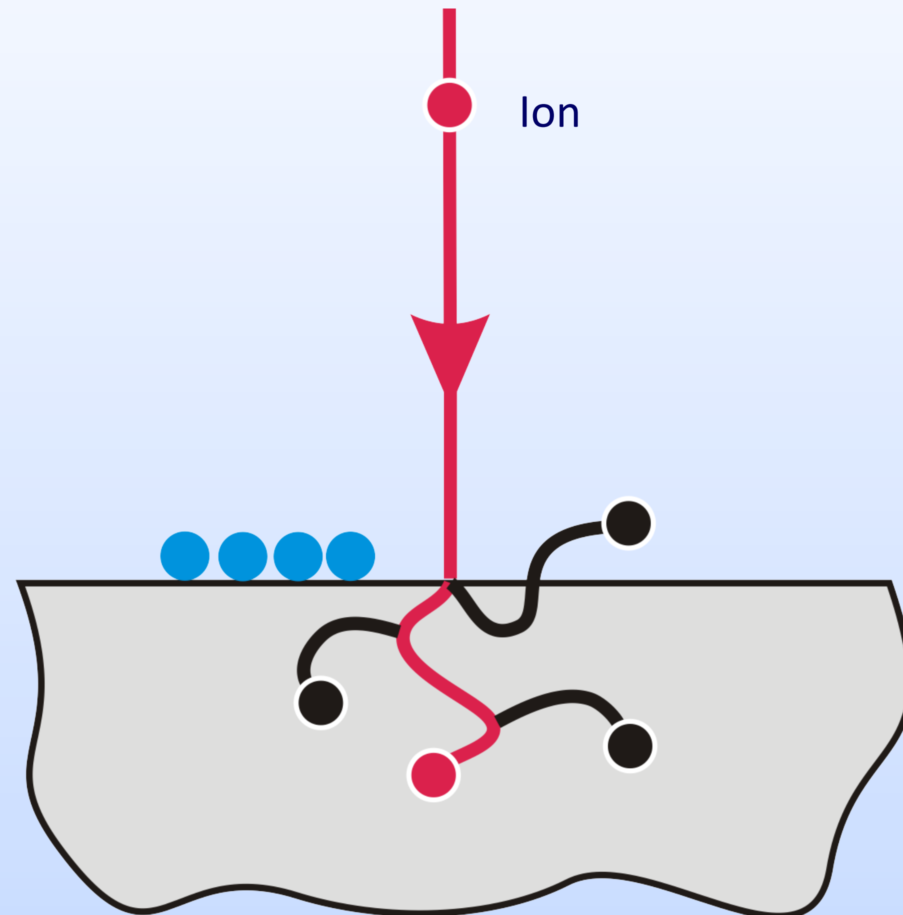
HERCULES

- Monitoring von Plasma elektrischen Parameter

Focused Ion Beam (FIB)

Ion Solid Interaction

- Sputtering
- Damage
- Implantation
- Secondary electron/ion emission
- Surface chemical reactions
  - Deposition
  - Enhanced etching



Vergleich FIB/SEM

		FIB	SEM	Ratio
Particle	type	Ga+ ion	electron	
	elementary charge	+1	-1	
	particle size	0.2 nm	0.00001 nm	20.000
	mass	$1.2\ .10^{-25}$ kg	$9.1.10^{-31}$ kg	130.000
	velocity at 30 kV	$2.8.10^{5}$ m/s	$1.0\ 10^{8}$ m/s	0.0028
	velocity at 2 kV	$7.3.10^{4}$ m/s	$2.6.10^{7}$ m/s	0.0028
	momentum at 30 kV	$3.4.10^{-20}$ kgm/s	$9.1.10^{-23}$ kgm/s	370
	momentum at 2 kV	$8.8.10^{-21}$ kgm/s	$2.4.10^{-23}$ kgm/s	370
Beam	size	nm range	nm range	
	energy	up to 30 kV	up to 30 kV	
	current	pA to nA range	pA to uA range	
Penetration depth	In polymer at 30 kV	60 nm	12000 nm	
	In polymer at 2 kV	12 nm	100 nm	
	In iron at 30 kV	20 nm	1800 nm	
	In iron at 2 kV	4 nm	25 nm	
Average electrons	secondary electrons	100 - 200	50 - 75	
signal per 100				
particles at 20 kV	back scattered electron	0	30 - 50	
	substrate atom	500	0	
	secondary ion	30	0	
	x-ray	0	0.7	

Quelle: FEI Company

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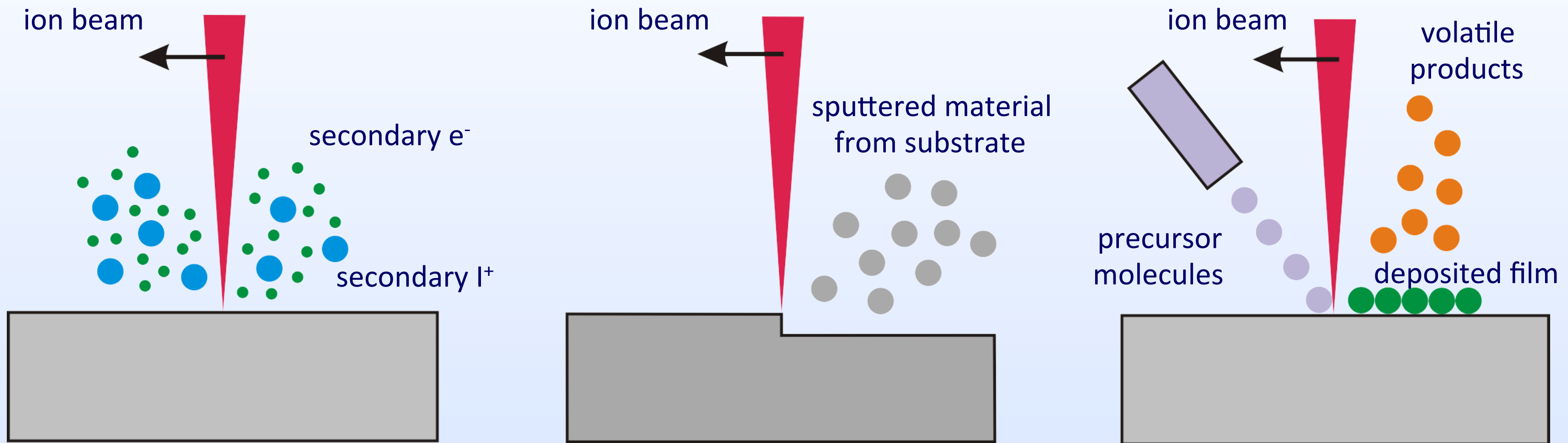
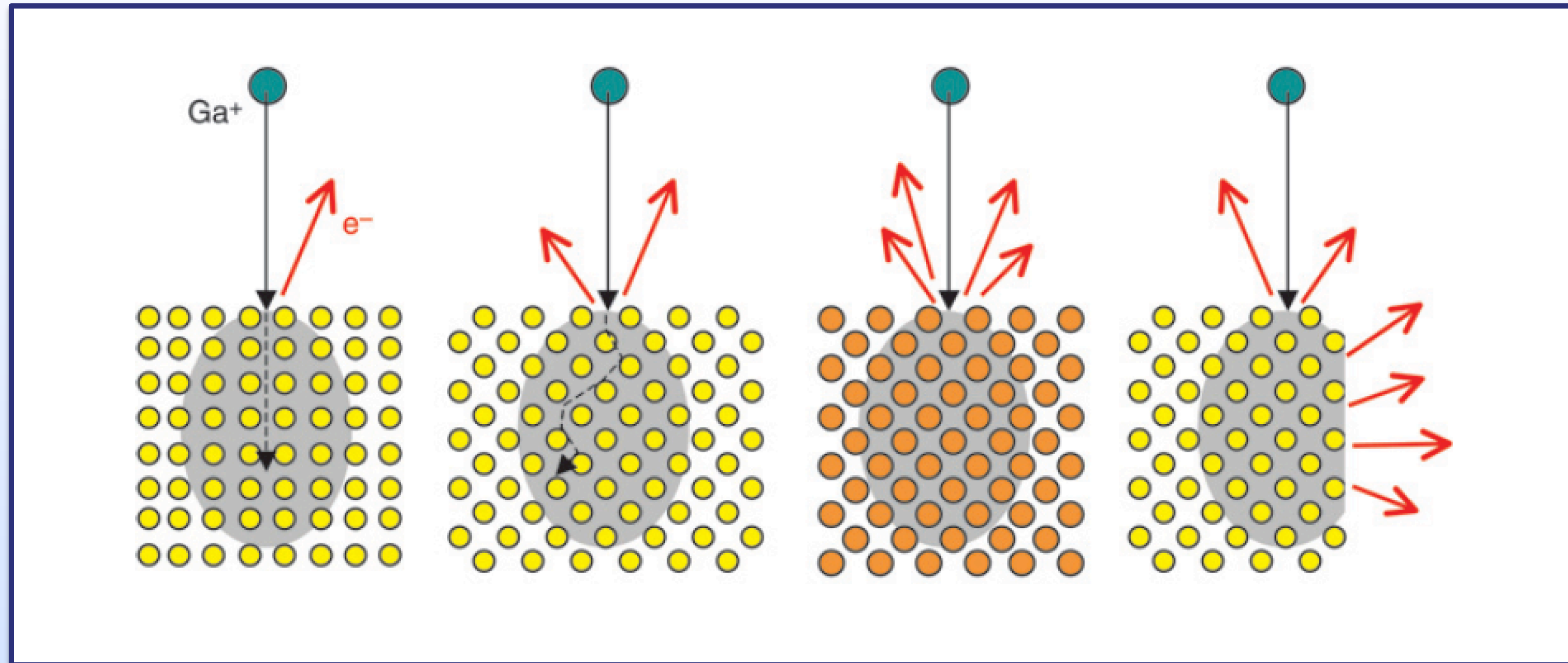
Basic Operation Modes



- Emission of secondary ions and electrons
  - ➢ **FIB Imaging**
- Sputtering of substrate atoms
  - ➢ **FIB milling**
- Chemical interactions
  - ➢ **FIB deposition**
  - ➢ **Enhanced (preferential) etching**

FIB Imaging

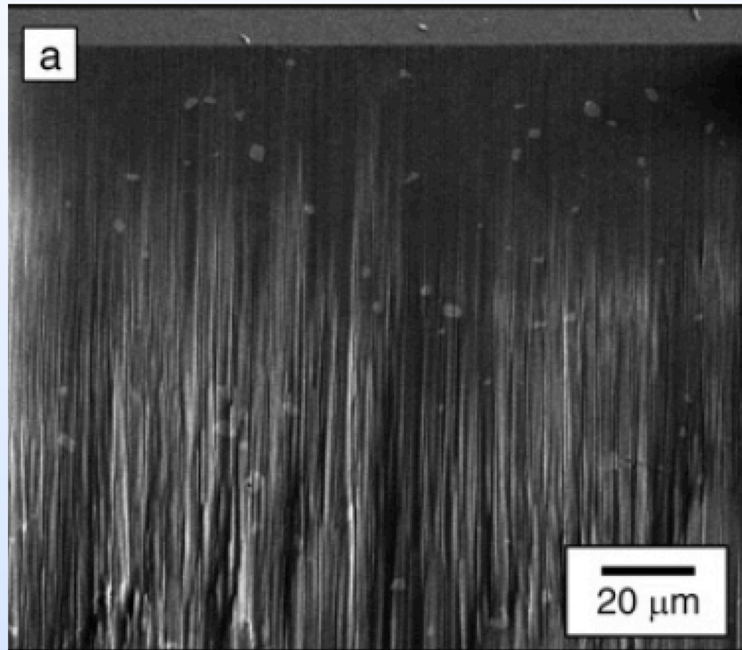


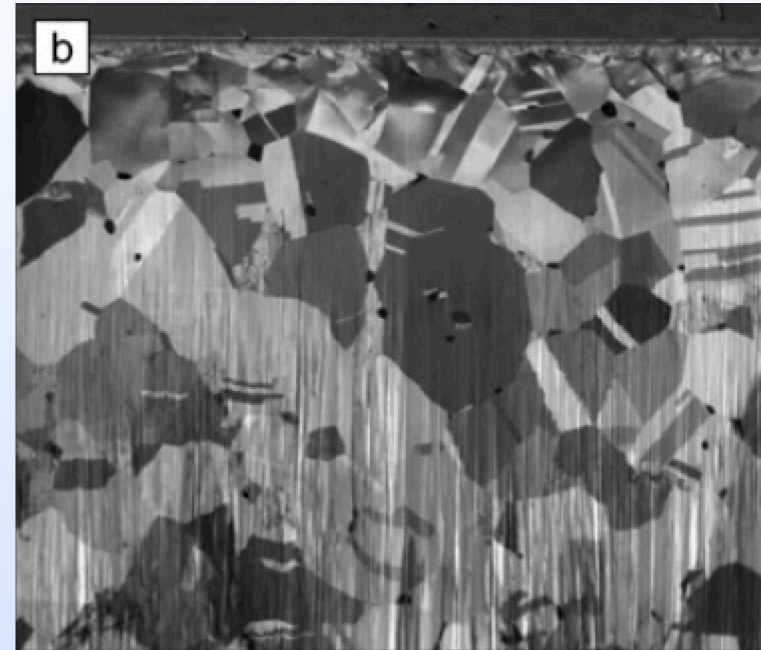
C.A.Volkert and A.M. Minor, MRS Bulletin, V32, May 2007, p. 389.

Effect of:

- crystal orientation
- atomic mass
- surface geometry

FIB Imaging





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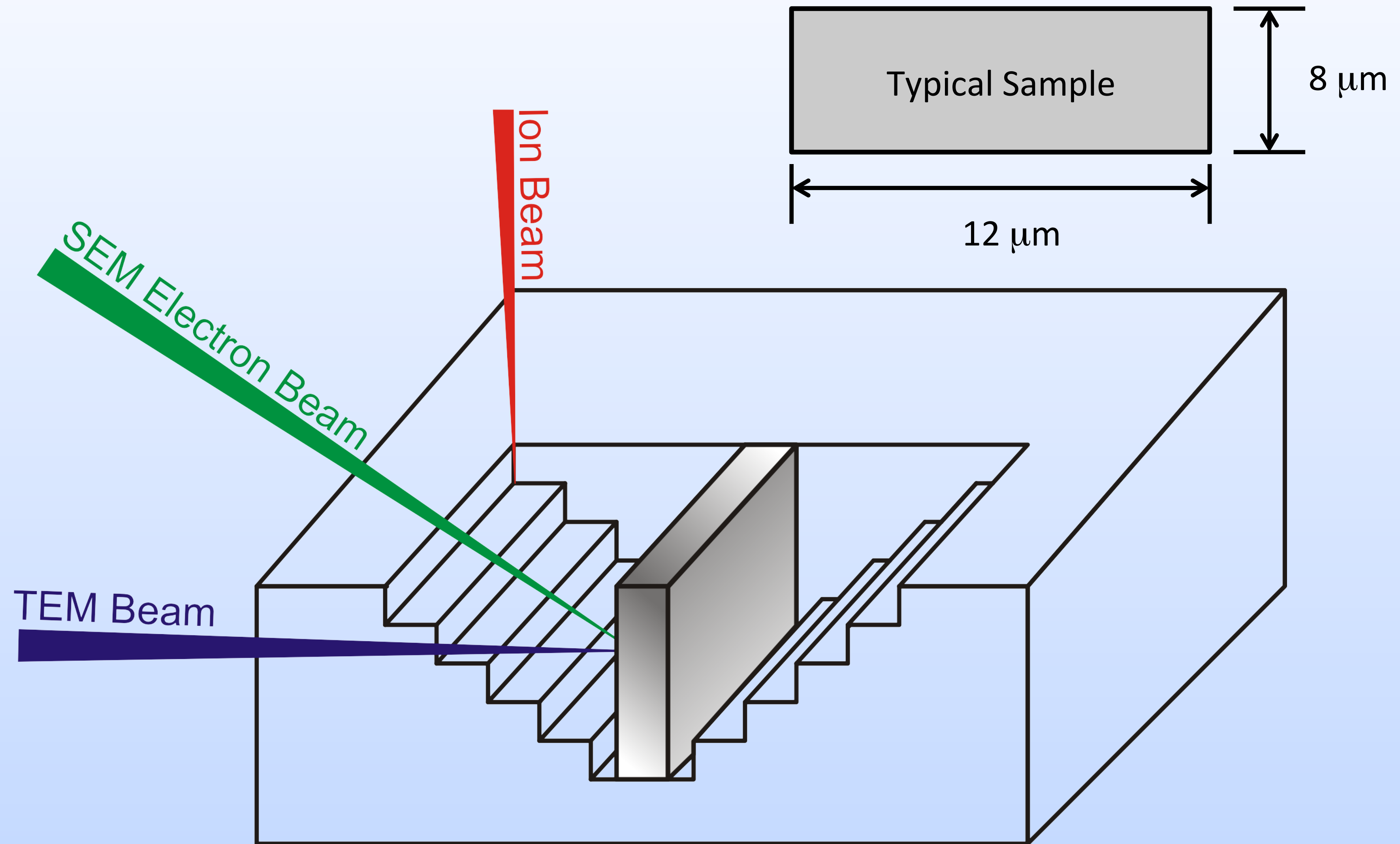
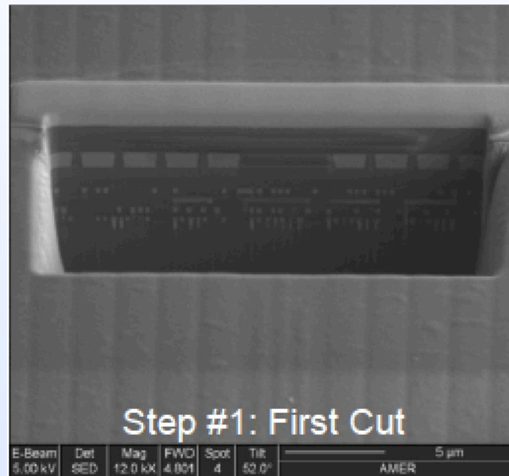
Brass: SE Image

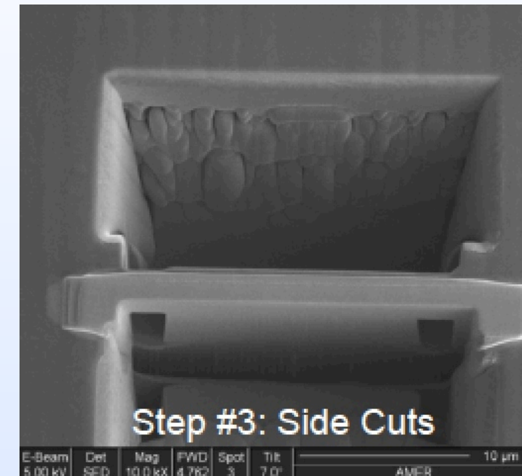
Brass: ISE Image

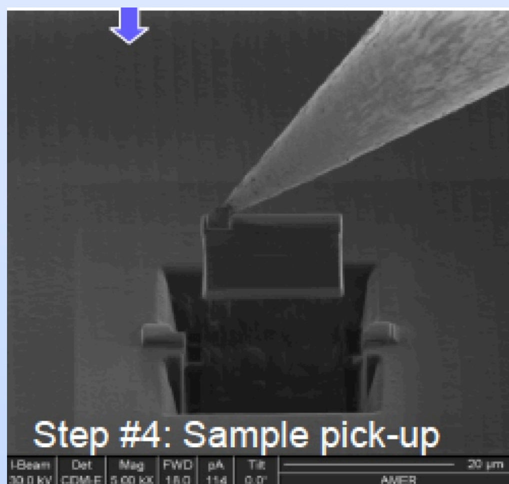
S/TEM Sample Preparation: Lift-Out

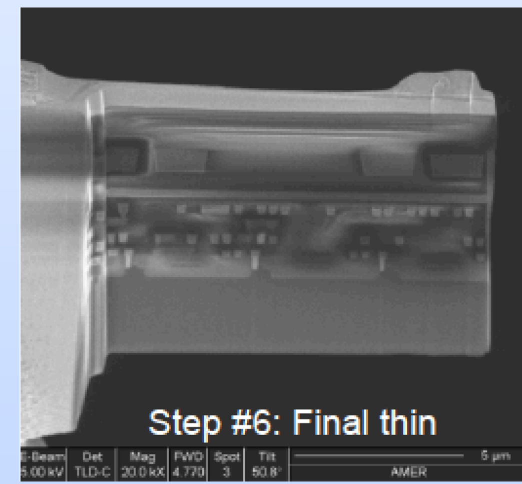


S/TEM Sample Preparation

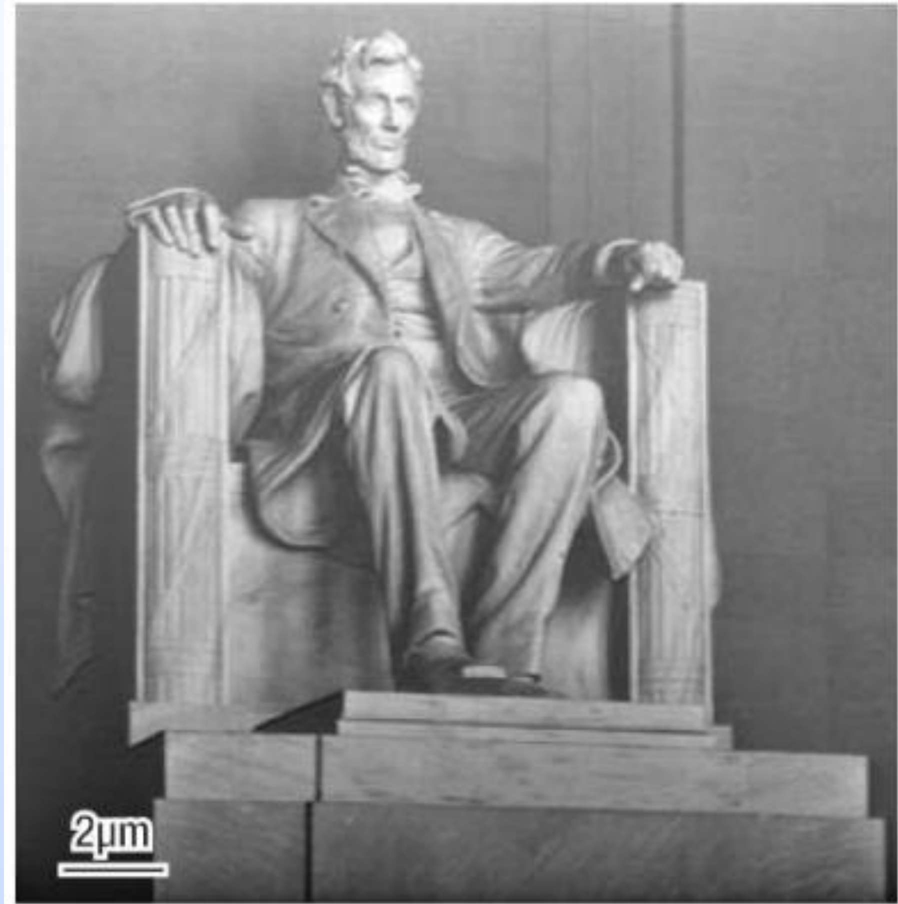








FIB milling

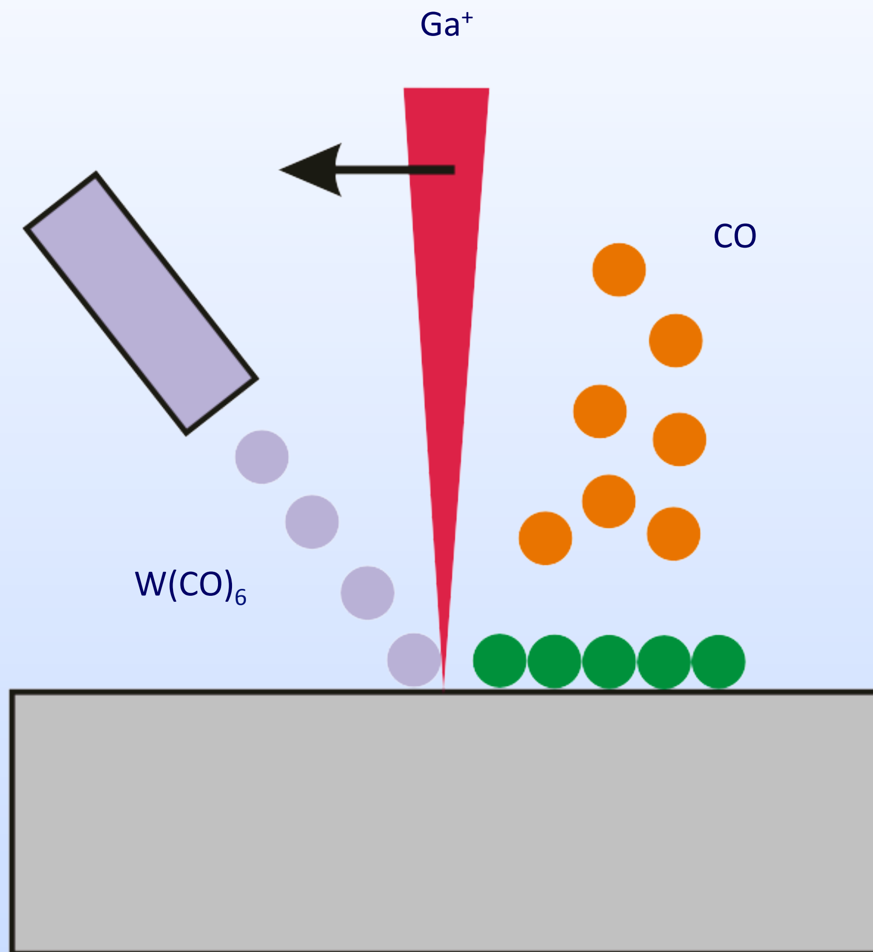


Barack Obama patterned into silicon

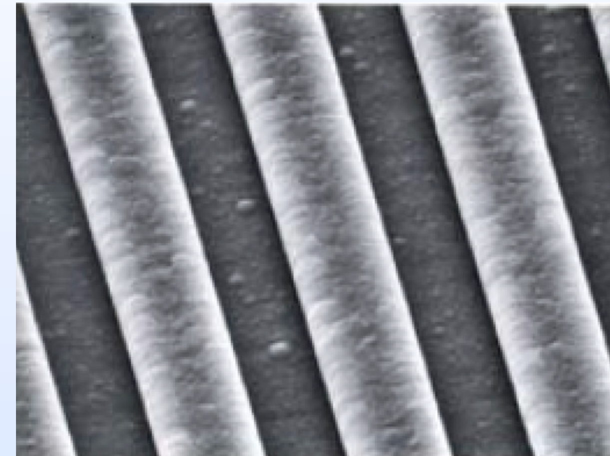
Lincoln Memorial patterned into silicon

Quelle: ZEISS

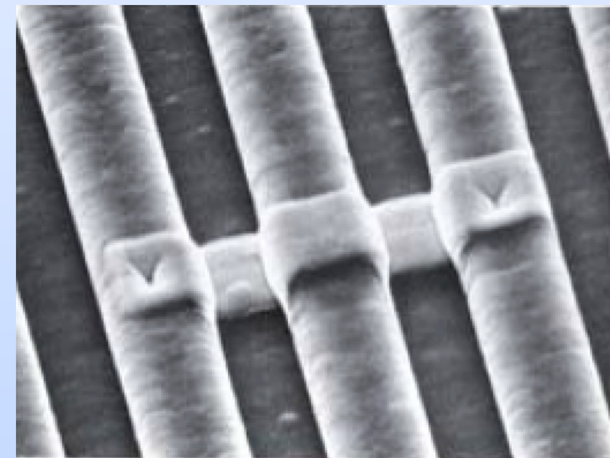
FIB: Circuit Modification



before modification



after modification



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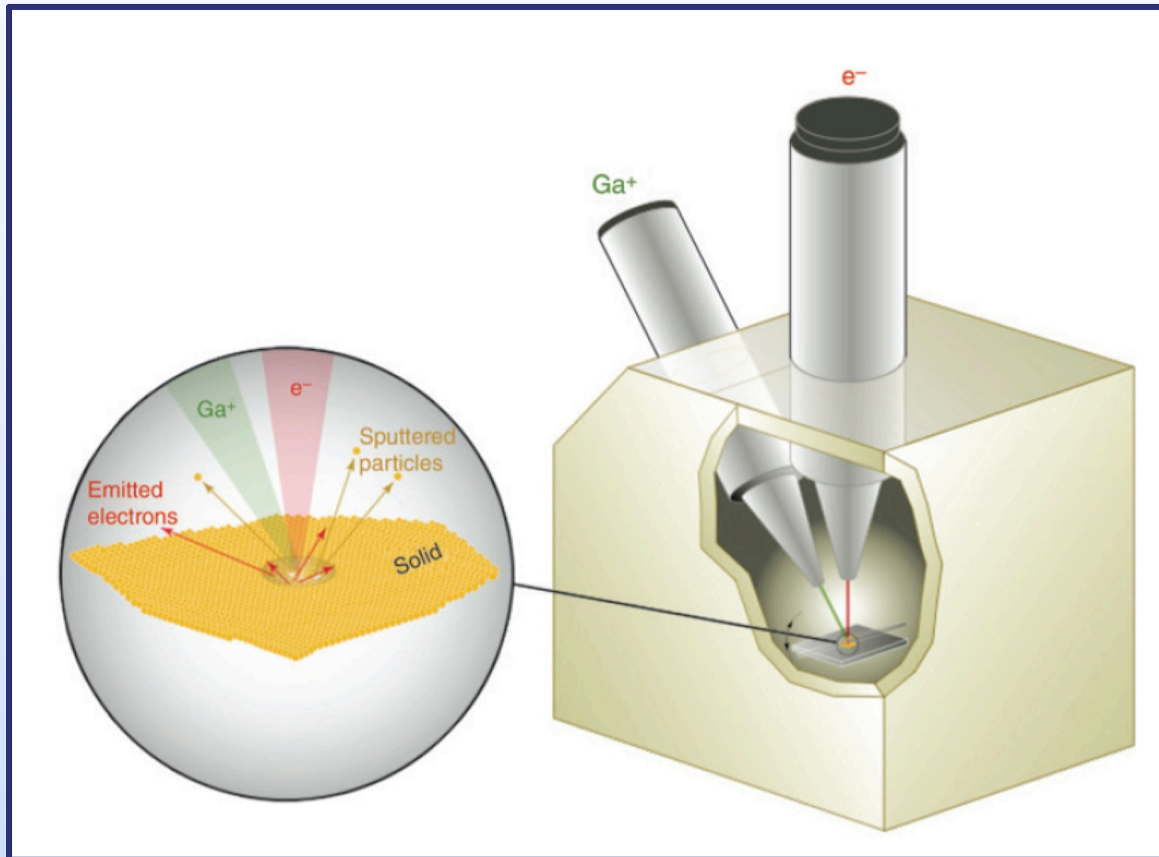
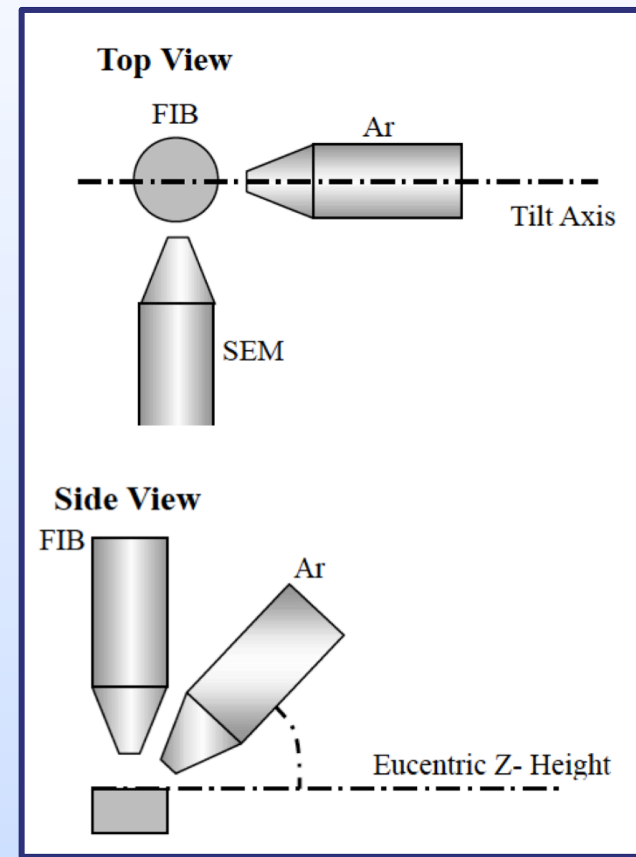
FIB Limitations

- Not useful for large sections
- Heating (destructive to soft materials)
- Re-deposition of sputtered materials
- Surface damage (damaged layer lower limit 10 nm, upper limit 100 nm)
  - ➢ Minimization by:
    - Gas-assisted etching
    - Gently finishing the specimen surface
    - Reducing the incidence angle and/or beam intensity
    - *Ex-situ* wet chemical etching

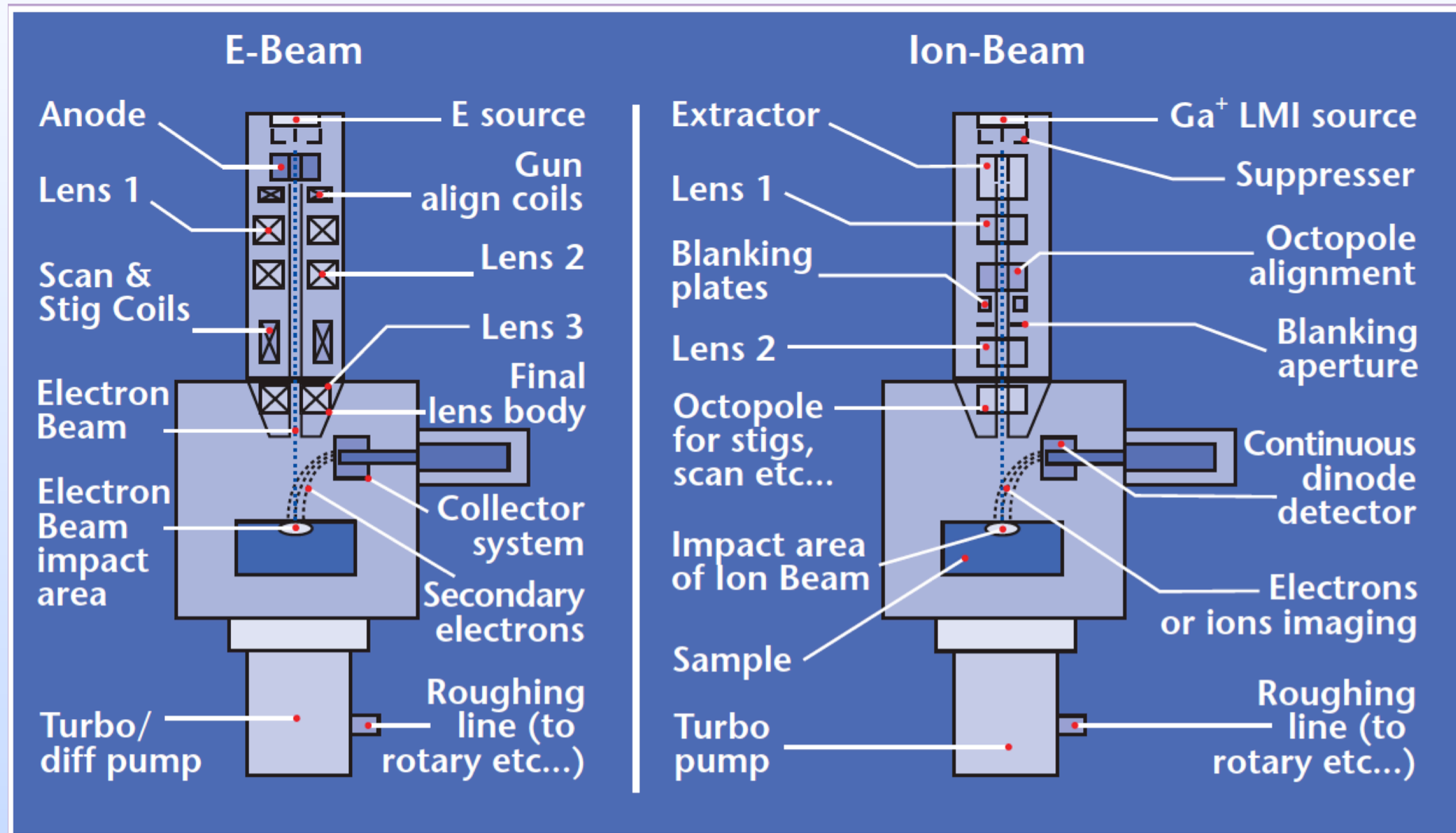
FIB Hardware





C.A.Volkert and A.M. Minor, MRS Bulletin, V32, May 2007, p. 389.
S. Sadayama et al., Microscopy and Microanalysis, V12, 2006, p. 1298.

FIB Hardware



Quelle: FEI Company

Literatur

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