PFEIFFER VACUUM

MBE-TECHNOLOGY AND IN-SITU GROWTH CONTROL

7th MaNEP Winter School, Saas Fee

Andreas Kraft, Pfeiffer Vacuum GmbH

PFEIFFER VACUUM

MBE = Molecular Beam Epitaxy

Generation of thin epitaxial layers via PVD

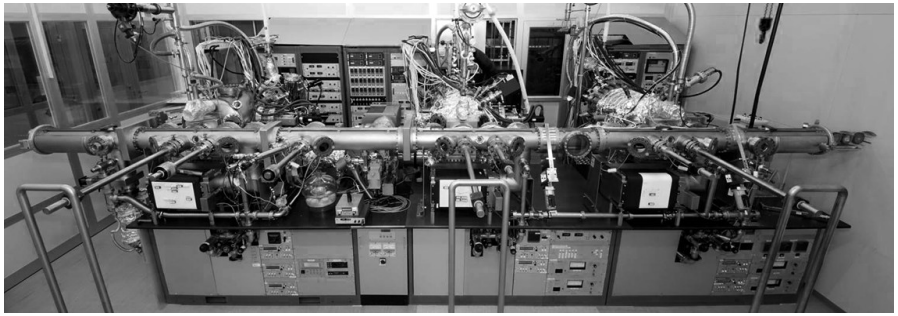
Magnetron sputtering

Thermal evaporation

e-beam evaporation

PFEIFFER VACUUM

MBE = Molecular Beam Epitaxy

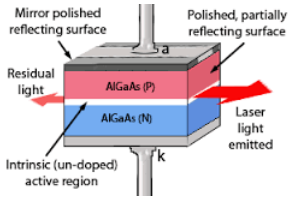


MBE facility at Walter-Schottky Insitute in Munich

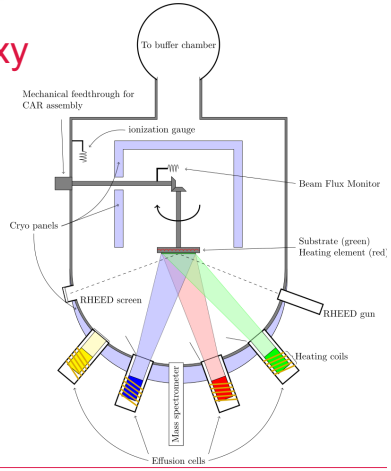
PFEIFFER VACUUM

MBE = Molecular Beam Epitaxy

- Heating of effusions cells generate molecular vapor (e.g. GaAs, InP).
- Deposition of thin epitaxial layers



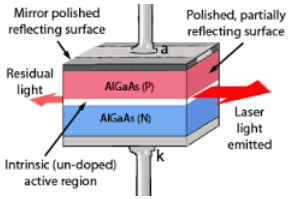
2 layer laser diode



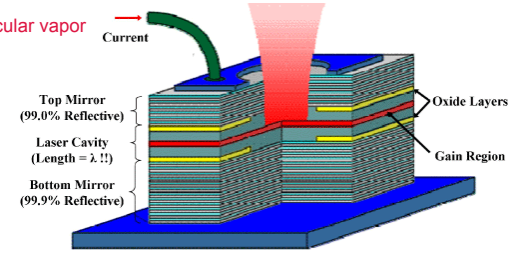
PFEIFFER VACUUM

MBE = Molecular Beam Epitaxy

- Heating of effusions cells generate molecular vapor (e.g. GaAs, InP).
- Deposition of thin epitaxial layers

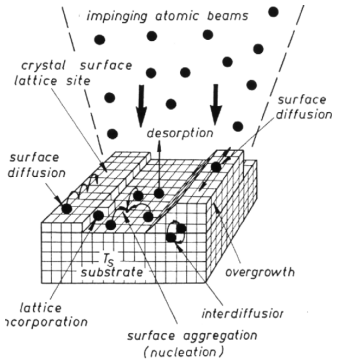


2 layer laser-diode



multi layer laser-diode, e.g. 1550 nm VCSELs at Walter-Schottky Institute, Munich

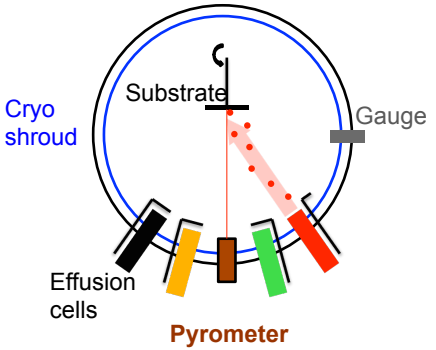
Define the problem



- How can you monitor the complex process of growth?
- How can you tell anything about the quality of your samples?

→ If something went wrong maybe you can stop the growth and save time and recourses

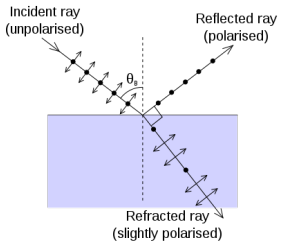
Pyrometry



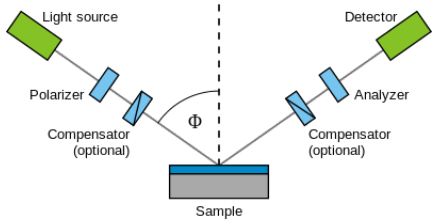
- Advantages:
  - Reliable, cheap
  - Records substrate temperature
  - Long term observation of growth
- Disadvantages:
  - Intensity depends on viewport

Ellipsometry

Remember Brewster/s-angle:



Ellipsometry



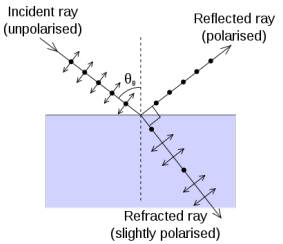
$\rho = r_p / r_s = \tan\psi \, e^{i\Delta}$: reflected normalized p-component

r_s : reflected normalized s-component

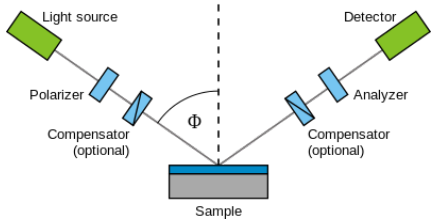
ψ: Amplitude ratio upon reflection

Δ: phase shift

Remember Brewster/s-angle:



Ellipsometry



- Advantages:
  - Film thickness measured
  - Refractive index is analyzed
  - Long term observation of growth
  - No disturbance from ambient light
- Disadvantages:
  - Model analysis necessary
  - Stable manipulator needed

$\rho = r_p / r_s = \tan\psi \, e^{i\Delta}$

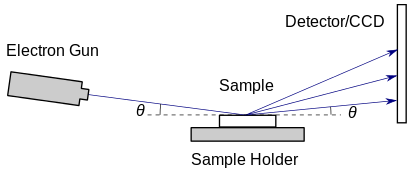
r_p : reflected normalized p-component

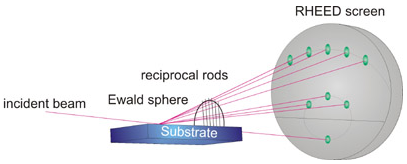
r_s : reflected normalized s-component

ψ: Amplitude ratio upon reflection

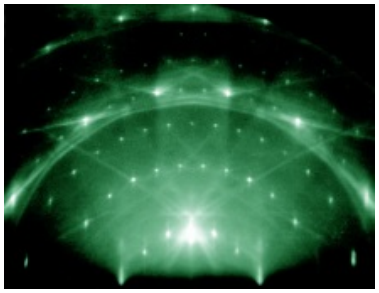
Δ: phase shift

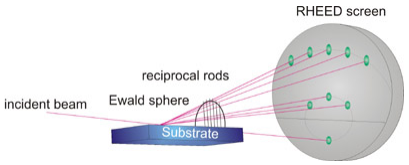
RHEED = Reflection High Energy Electron Diffraction



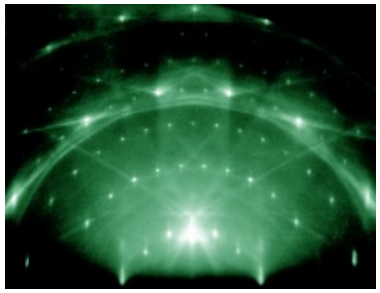


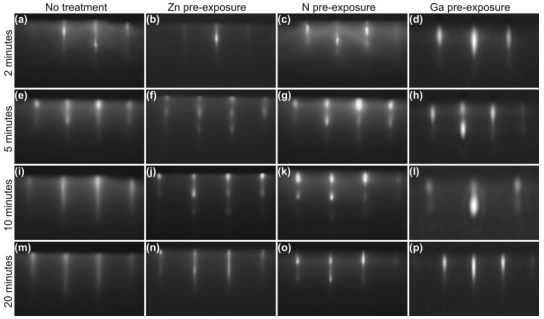
RHEED = Reflection High Energy Electron Diffraction



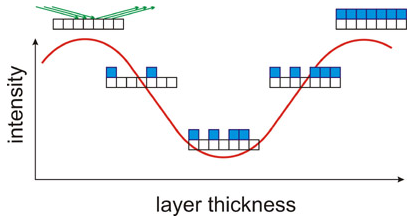


RHEED = Reflection High Energy Electron Diffraction



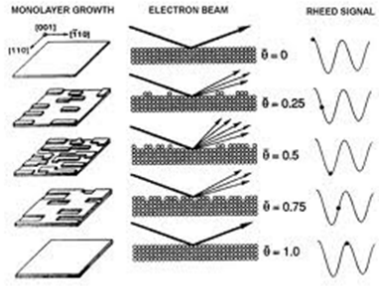


RHEED = Reflection High Energy Electron Diffraction



There is a dependence between layer thickness/integrity and intensity

RHEED = Reflection High Energy Electron Diffraction



There is a dependence between layer thickness/integrity and intensity

Figure 1: RHEED oscillation diagram taken from Neave et al 1983 [1]

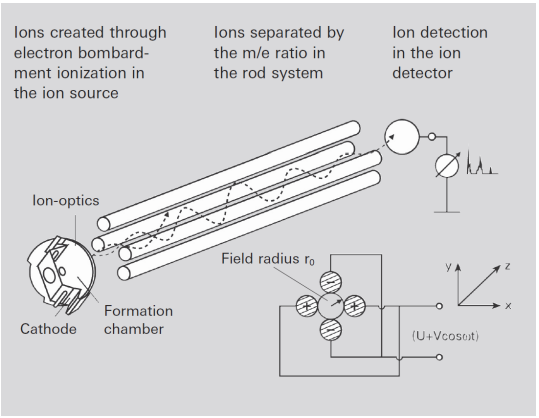
RHEED = Reflection High Energy Electron Diffraction

- Advantages:
  - Good experimental access
  - Monitor atomic layer by layer growth
  - Accurate determination of growth rates
- Disadvantages:
  - Great experimental effort (electron gun, alignment,…)

IN-SITU GROWTH CONTROL WITH MASS SPEC

How to use a quadrupole mass spectrometer for determination of growth rates?

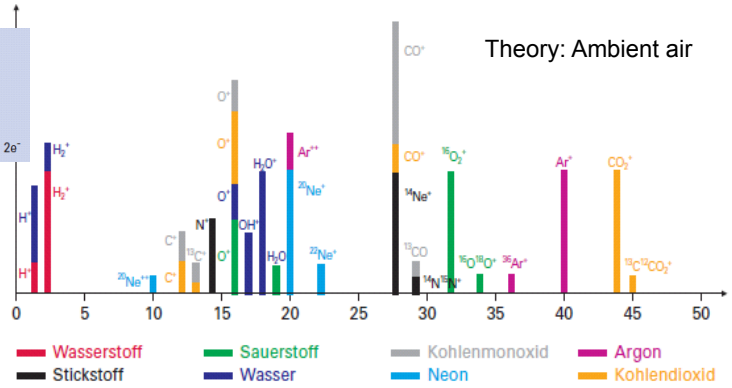
Working principle of a mass spectrometer:



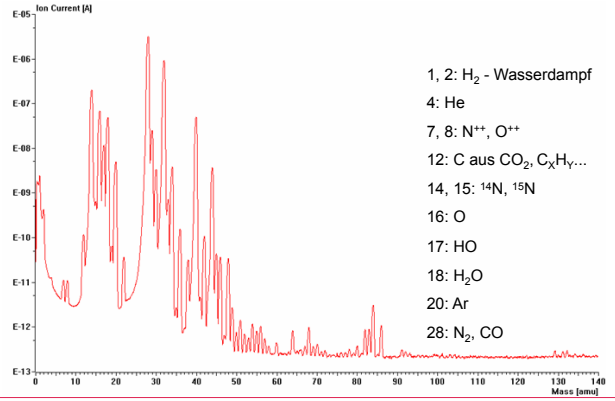
How does a mass-spec look like?

$ABC + e^- \rightarrow ABC^+ + 2e^-$
$ABC^{++} + 3e^-$
$AB^+ + C + 2e^-$
$BC^+ + A + 2e^-$
$A^+ + BC + 2e^-$
$C^+ + AB + 2e^-$
$B^+ + A + C + 2e^-$

Theory: Ambient air



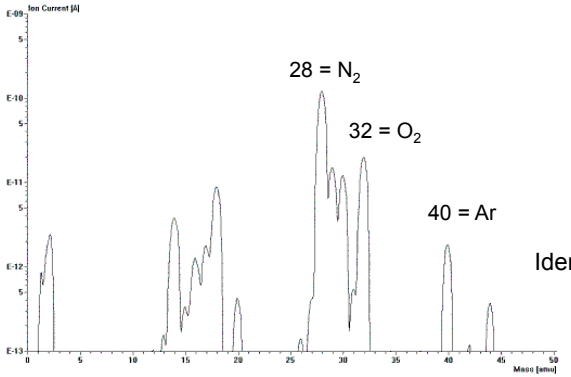
How does a mass-spec look like?



Reality: Ambient air

1, 2: H_2 - Wasserdampf
4: He
7, 8: N^{++}, O^{++}
12: C aus CO_2, C_xH_y...
14, 15: ^{14}N, ^{15}N
16: O
17: HO
18: H_2O
20: Ar
28: N_2, CO
29: $^{14}N^{15}N$
30: NO
32: O_2
34: $^{16}O^{18}O$
36, 38: ^{36}Ar, ^{38}Ar
40: Ar
44: CO_2
82, 83, 84, 86: Kr
129, 131, 132: Xe

How does a mass-spec look like?



Leak in vacuum system

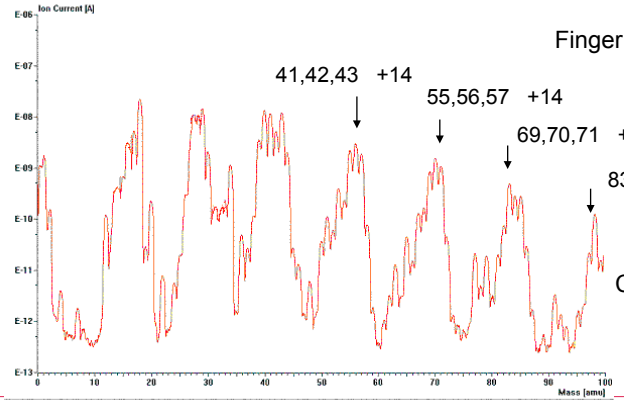
28 = N_2

32 = O_2

40 = Ar

Identification via N_2 / O_2 - ratio

How does a mass-spec look like?



Finger prints in vacuum system

41,42,43 +14

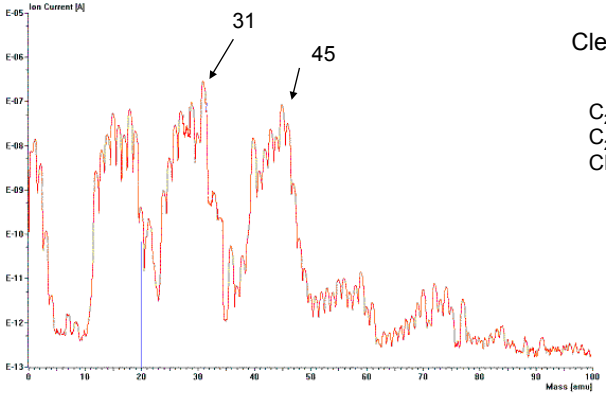
55,56,57 +14

69,70,71 +14

83,84,85....

CH_2 = 14 amu charateristic

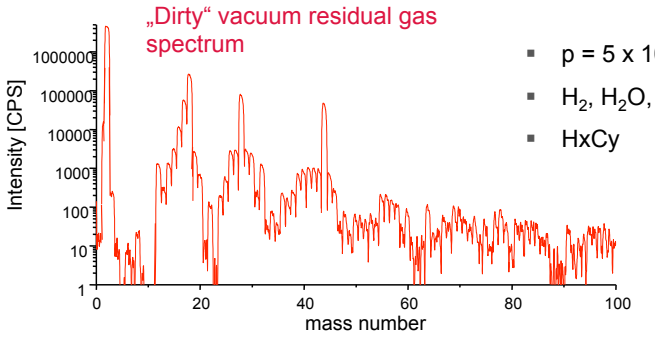
How does a mass-spec look like?



Cleaning ethanol

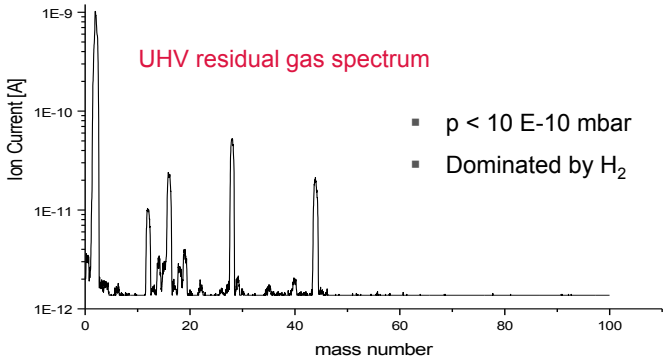
C_2H_5OH = 46
C_2H_5O = 45
CH_2OH = 31

Step 1: Create a good vacuum



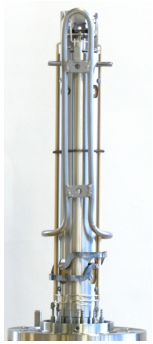
- p = 5 x 10E-8 mbar
- H_2, H_2O, CO, CO_2,
- HxCy

Step 1: Create a good vacuum



- p < 10 E-10 mbar
- Dominated by H_2

Step 2: Monitoring of material deposition

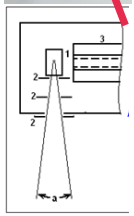


- Special application of a Mass spectrometer
- The mass spectrometer is used to measure the residual gas in the vacuum chamber
- In principal, it is possible to detect the property of the deposited material or the evaporating flux (geometry is important)

Why use a quadrupole mass spectrometer ?

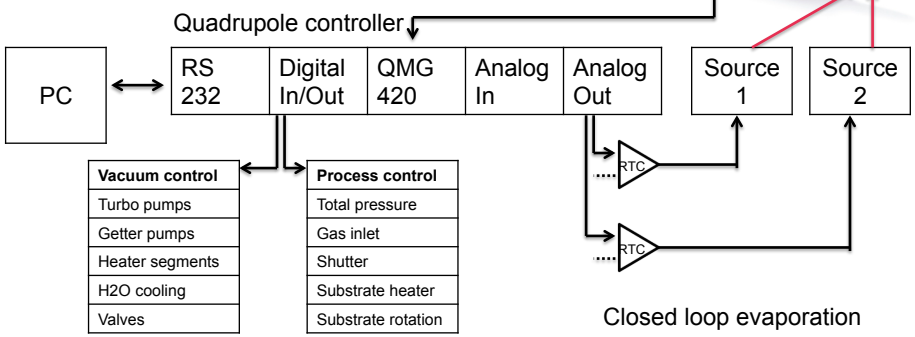
1. Mass selective detector that identifies the actual evaporating components and fragments
2. High sensitivity and large linear response for fluxes ranging from 0.001 Å/s to 100 Å/s
3. High monitoring frequencies facilitating the control of several different sources
4. Low maintenance and extended ion source lifetime due to sustainable shielding and operation under UHV

Plug and play?



- Geometry is important and has a strong impact on the measured signal
- A crossbeam ion source (1) should be used
- With the crossbeam ion source the ionization energy can be adjusted
- Aperture (2) and aperture settings have to be adapted
- Lots of engineering necessary to optimize the growth control

How could such a system work?



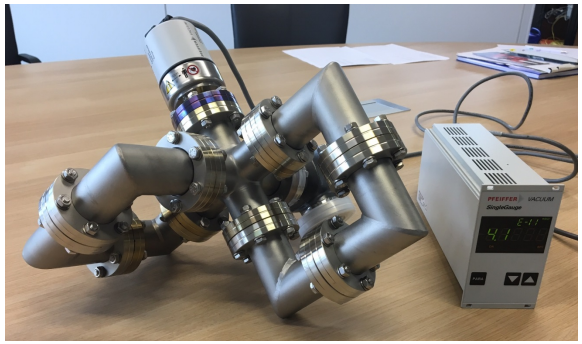
Closed loop evaporation

PFEIFFER VACUUM

CUT

PFEIFFER VACUUM

NEG*Line*



- Non evaborable getter – coating
- p < 5x10E-11 mbar
- > 30 reactivations

PFEIFFER VACUUM

NEG*Line*

- Tubes, chambers, plattes
- Tubes: 20 to 200 mm diameter and up to 4 m length
- Standard parts like angles, cross, etc.

PFEIFFER VACUUM

THANK YOU FOR YOU ATTENTION