UNIVERSITÄT SIEGEN

LOT

GaN-based photocathodes for high brightness electron beams

Bundesministerium für Bildung und Forschung

Marc Schumacher

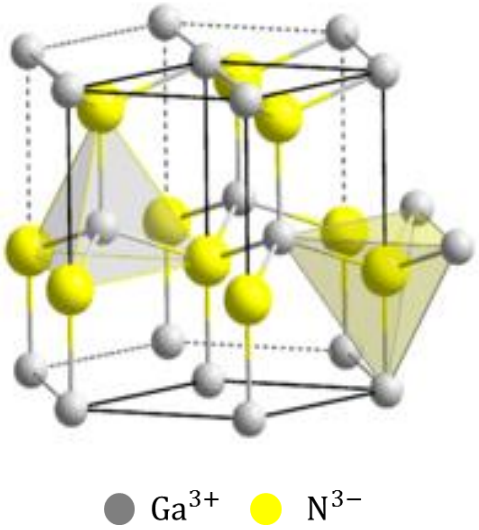
Aims

- Synthesis and modification of GaN films
- Characterisation of the synthesis parameters and topographical effects
- Focus of research:
  - → High QE
  - → Long lifetime
  - → Film-substrate adhesion

Gallium nitride - GaN

Properties

- Semiconductor
- Wide bandgap ≈ 3.4 eV (@ 300 K)
- Melting point > 2500 °C
- Crystal structure: wurtzite
  (hexagonal crystal system)

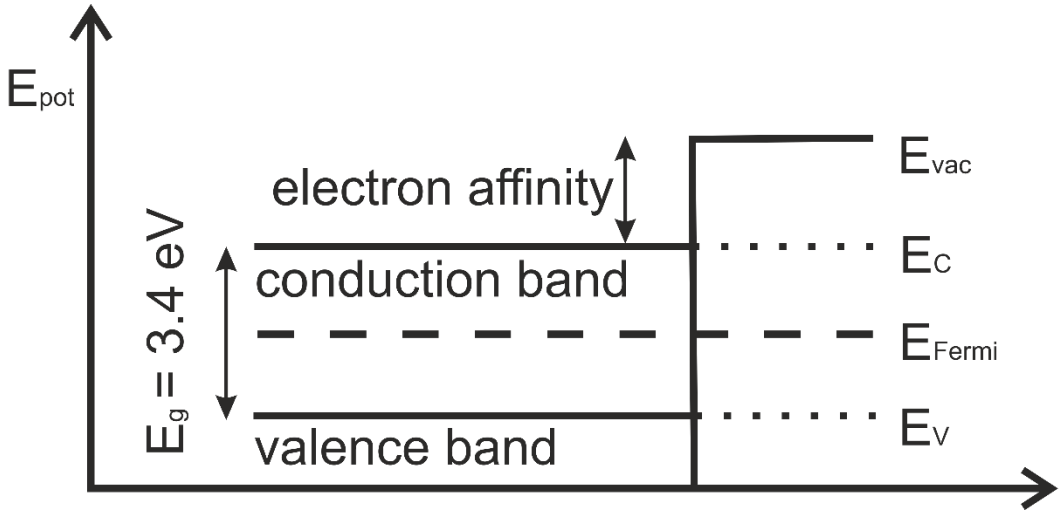


Applications

- Light-emitting diodes
- **Photocathode**
  - → Can be used in the λ-range between 150 – 400 nm
  - → High QE expected (≥ 50 %)
  - → Thermal and chemical stability

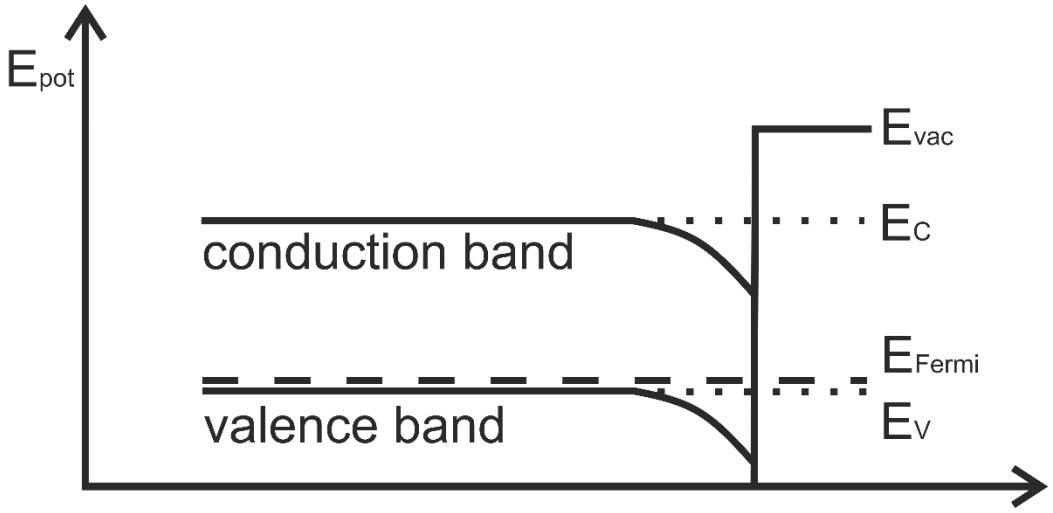
Energy band diagram GaN

→ High potential barrier for the electrons (vacuum energy, E_{vac})
→ Hence, the excited electrons can not leave the surface!



P-type doping with Mg

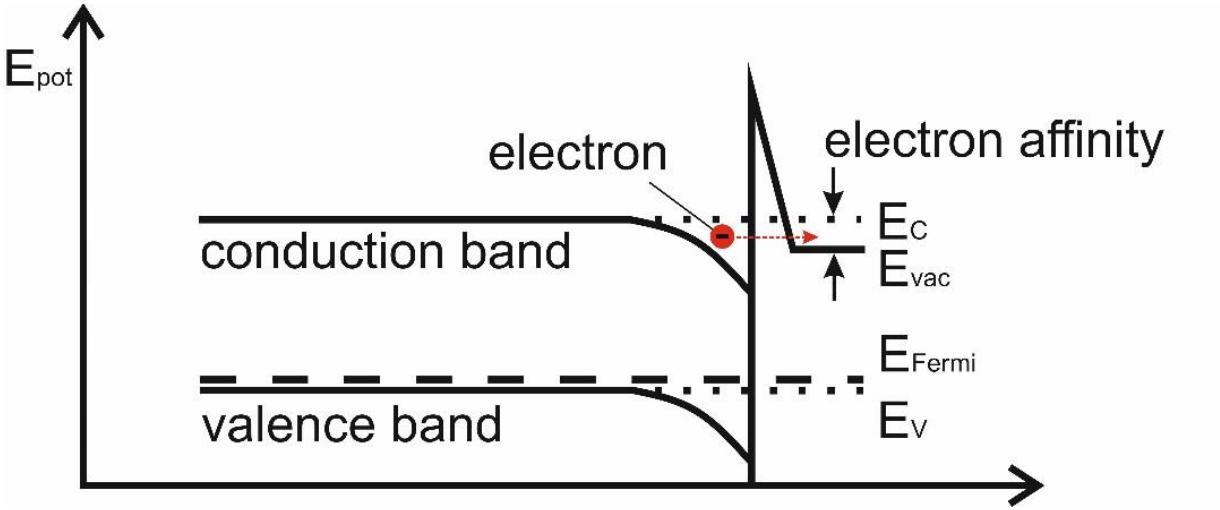
→ Enhancement of the electron diffusion length by **p-type doping with Mg**



Cs-deposition

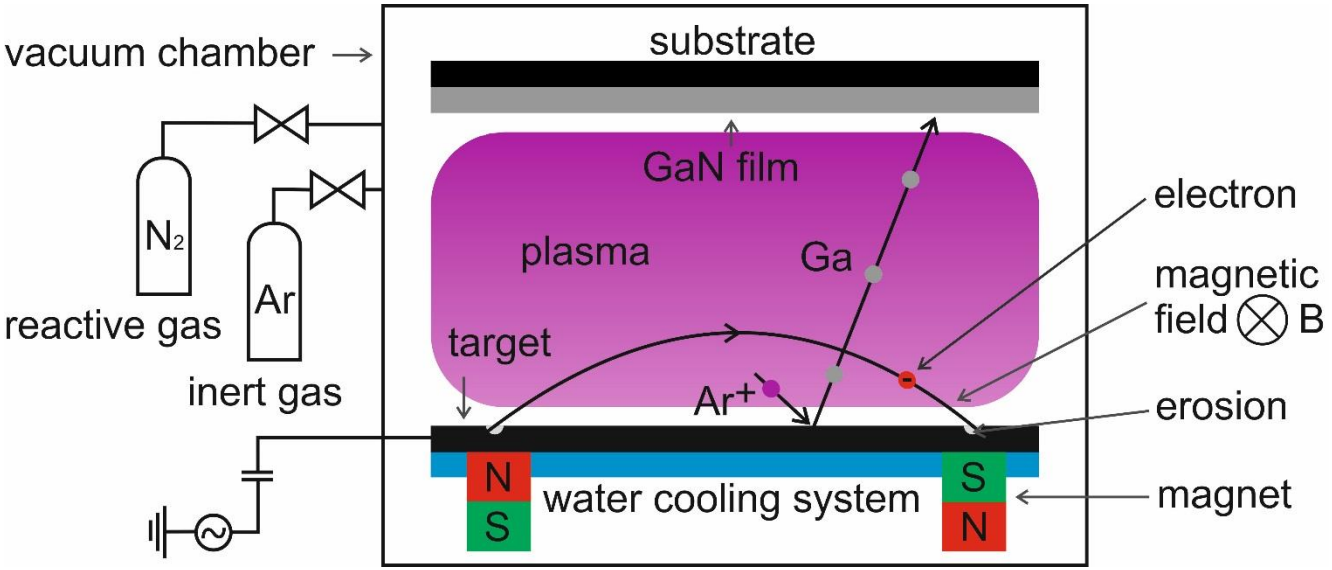
→ Achievement of a **NEA surface by a Cs-adsorption**

→ NEA = E_{vac} - E_c < 0



Synthesis of GaN films

RF magnetron sputtering

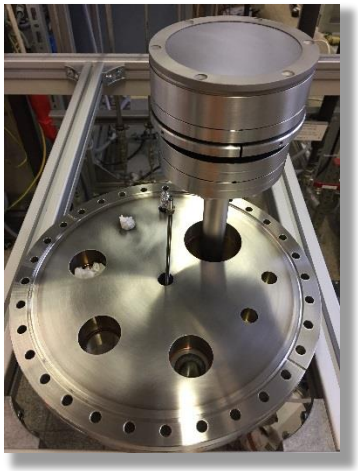


- Positive ions are accelerated to the negatively charged target and the gallium atoms will be sputtered
- Target-charging is avoided by an alternating potential

RF magnetron sputtering

- Potential targets: Ga, GaN and GaAs
  - → Low melting point of pure Ga (T_M = 29.76 °C)
  - → High purity is required (≥ 6N)

- Potential substrates: Si, Cu, Nb, Mo and Ta
- Potential interlayers : TiN, AlN, GaAs
- Modification of the band gap by adding In and Al

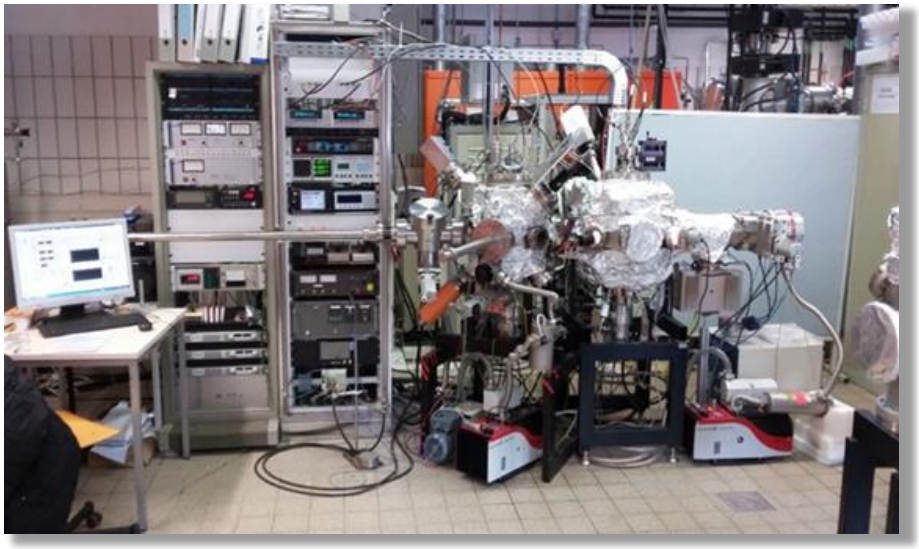


4 targets are required!

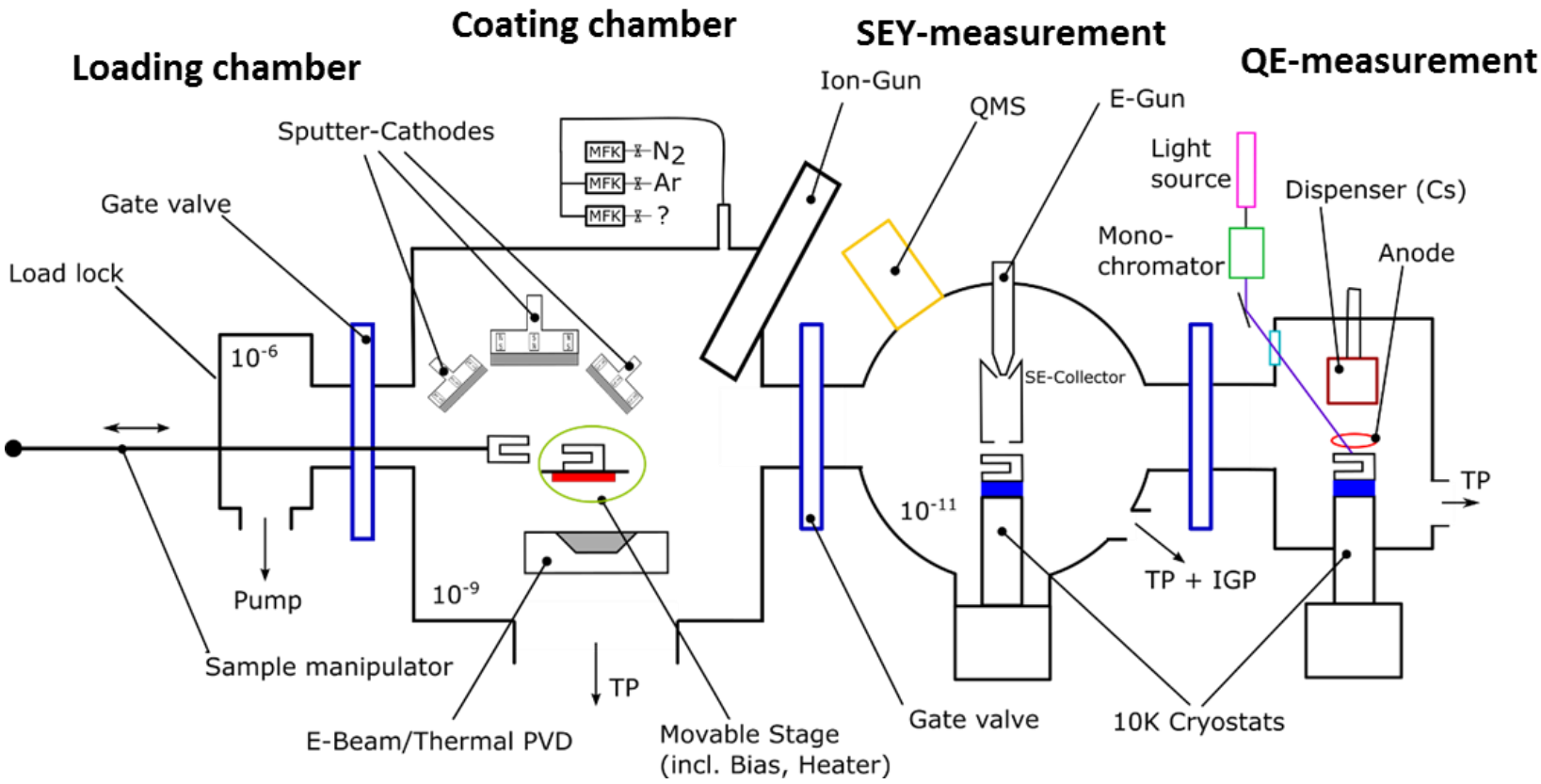
RF magnetron sputtering

Process parameters

- Cathode power
- Ar-pressure
- N_2- pressure
- Substrate temperature
- Bias-voltage



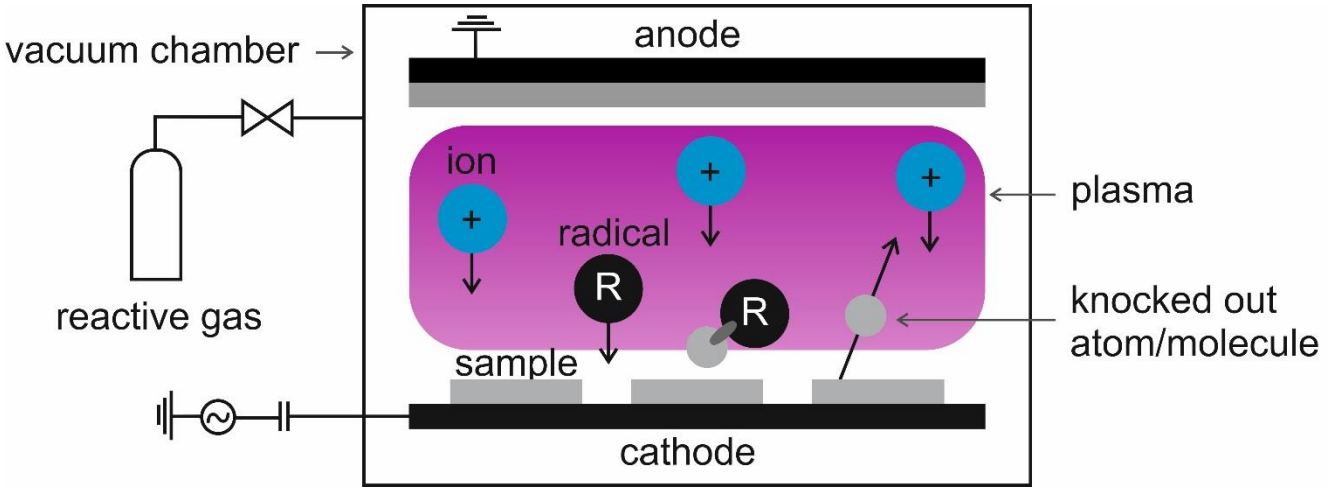
Experimental setup



- In situ QE-measurement

Surface modification of GaN films

Reactive ion etching - RIE

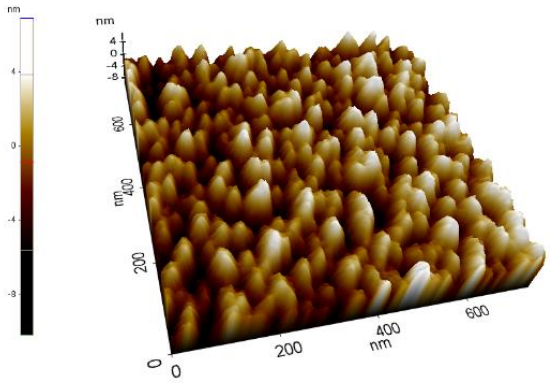


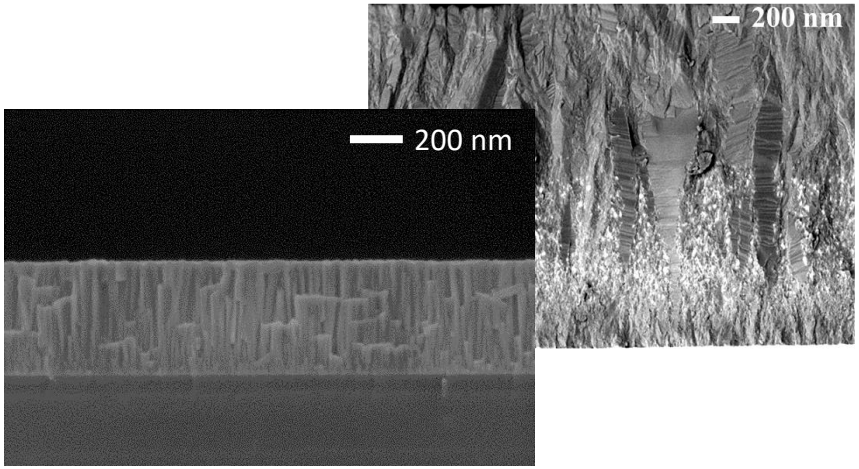
- Combination of physical- and chemical etching
- Aim of the RIE is the formation of various GaN film topographies, subsequently correlated with the QE

Characterisation of GaN films

Thin film analysis

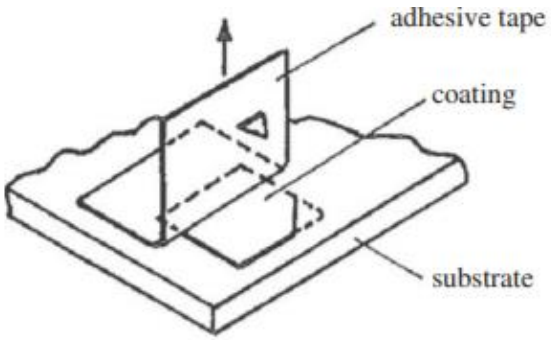
- Morphology and crystal growth:
  - → AFM
  - → SEM
- Crystal structure:
  - → XRD
- Chemical bonding structure:
  - → XPS
- Film/substrate adhesion:
  - → Tape test
  - → Scratch-Test
  - → Nanoindentation



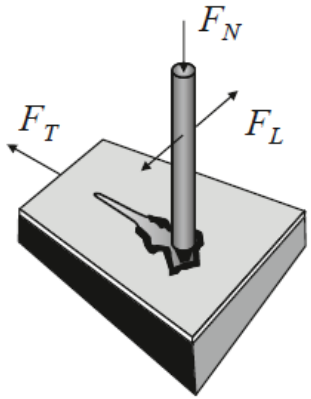


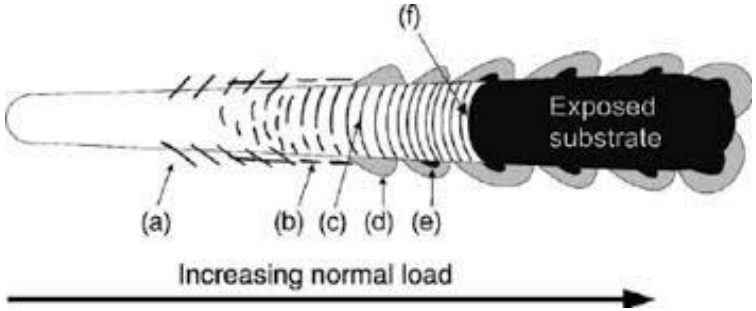
Film-substrate adhesion

- **Tape Test** (ASTM D3359 – 17)
  - → Applying and removing a tape
  - → Adequate level of adhesion?



- **Scratch-Test** (DIN EN ISO 20502)
  - → Linear increasing normal load
  - → Critical load depends on the adhesion
  - → Nanoindentation (low load regime, µN; small areas)



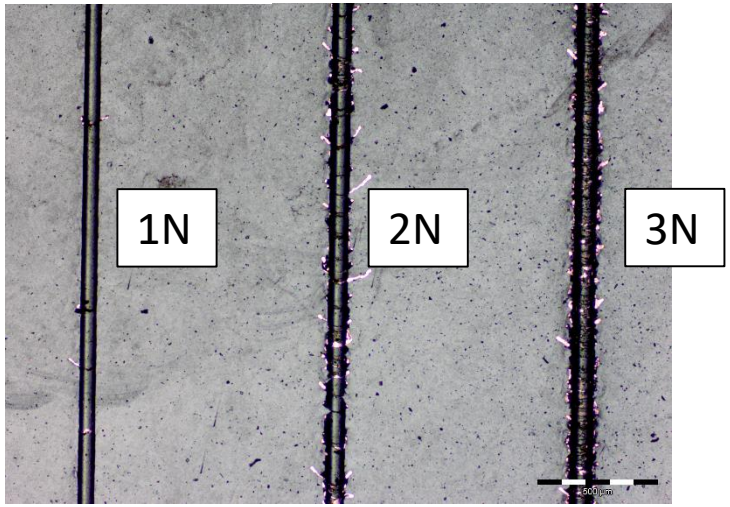


Film-substrate adhesion

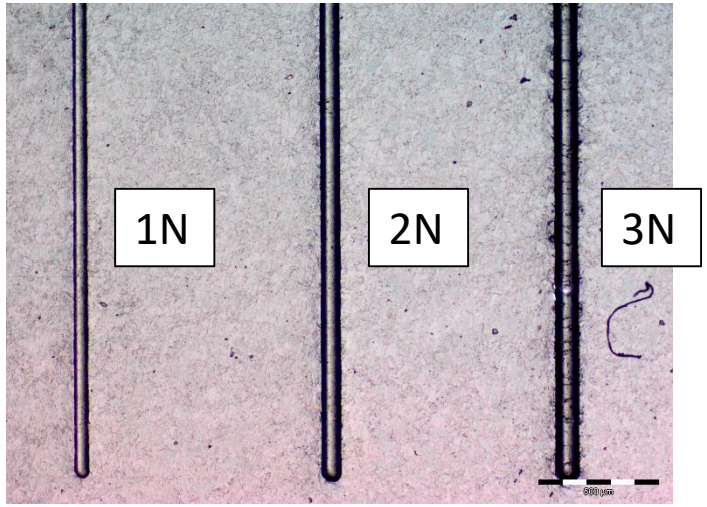
- Higher critical load for Ti interlayers

  → Higher Film/interlayer adhesion

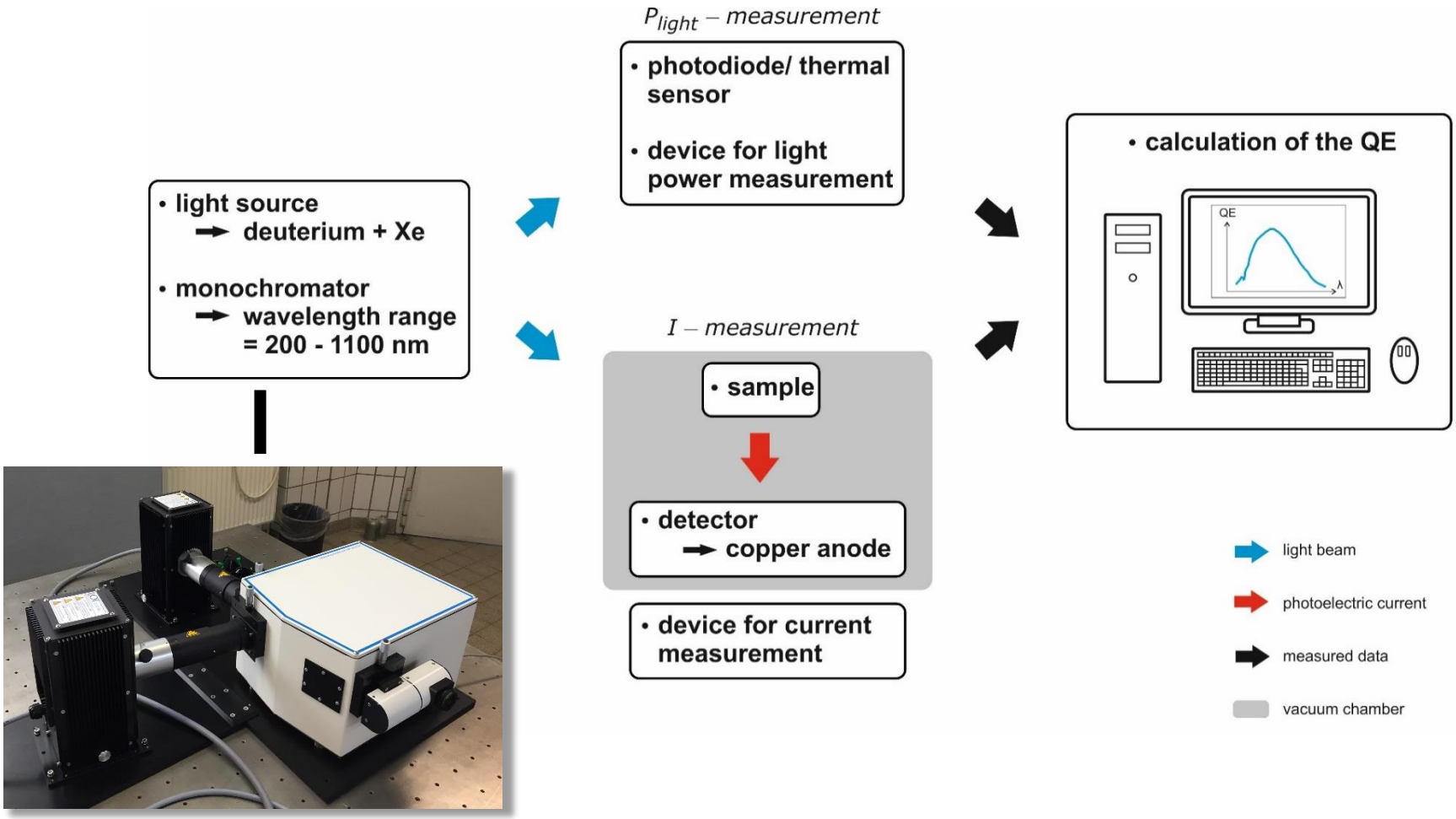
GaN/TiN/Cu



GaN/Ti/Cu



QE-measurement



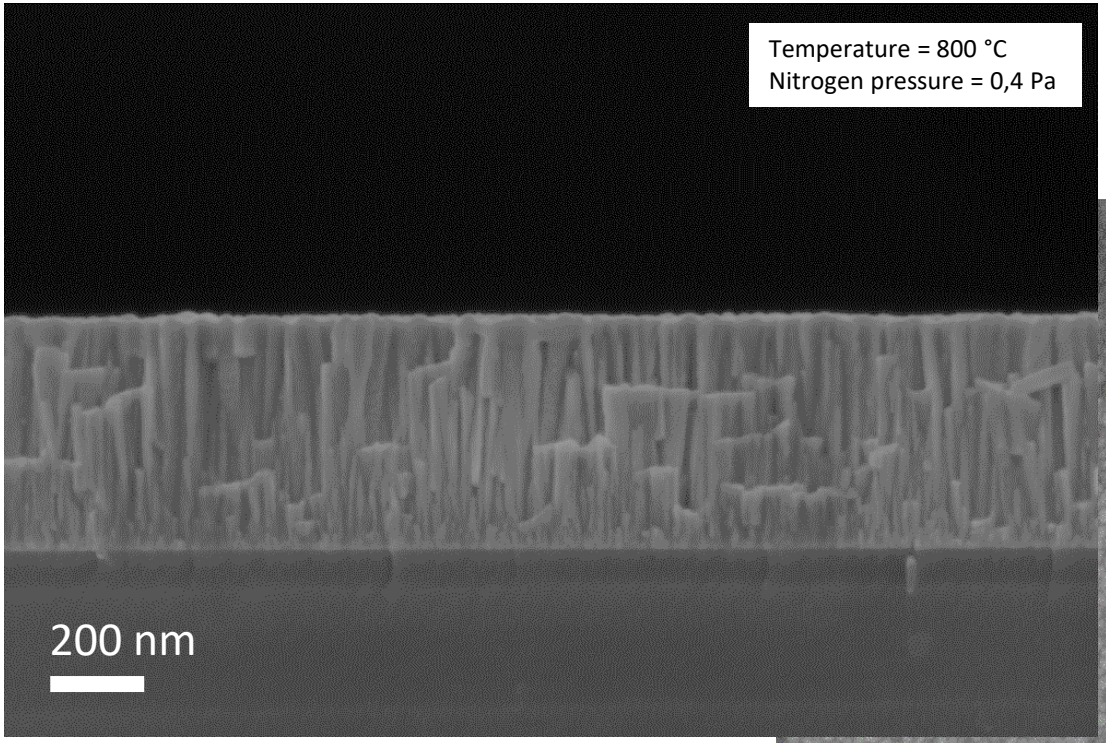
First experimental results

Synthesis of GaN films

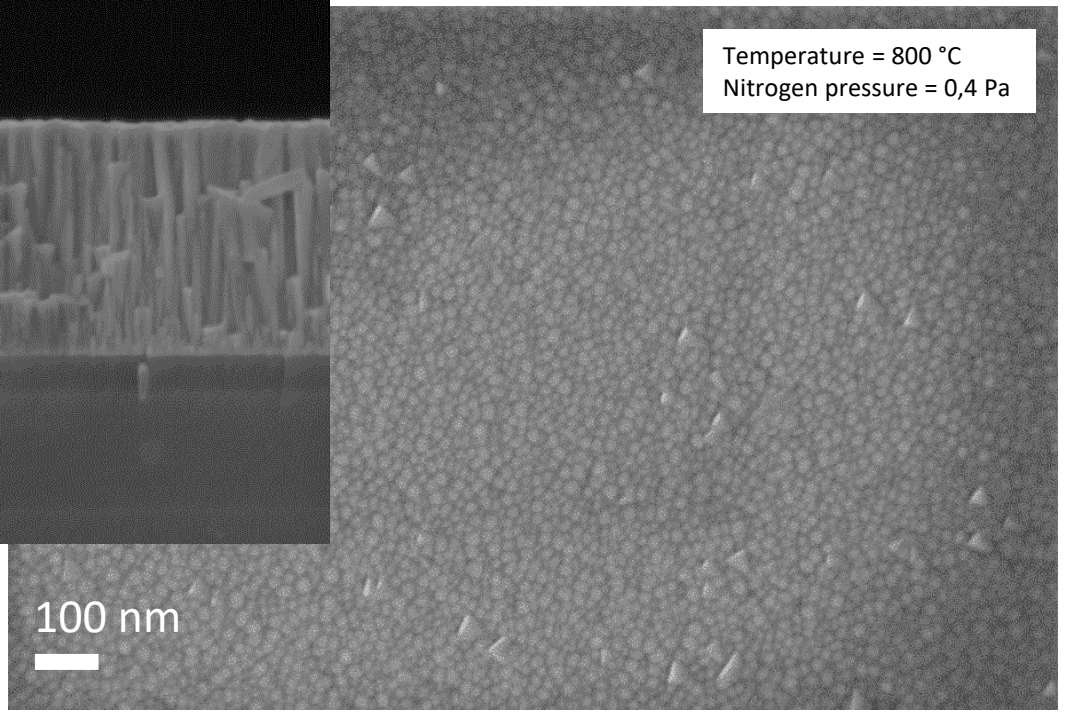
- GaAs target (purity = 99,9999 %)
- Sputtered in a pure N_2 plasma discharge
- RF power of 100 W is applied for 1 h
- Substrates: Si (111) and Cu
- Paramater variation
  - → Substrate temperature (RT – 800 °C)
  - → N_2 pressure (0,2 – 1,6 Pa)

1“ Cu substrate

Crystal growth

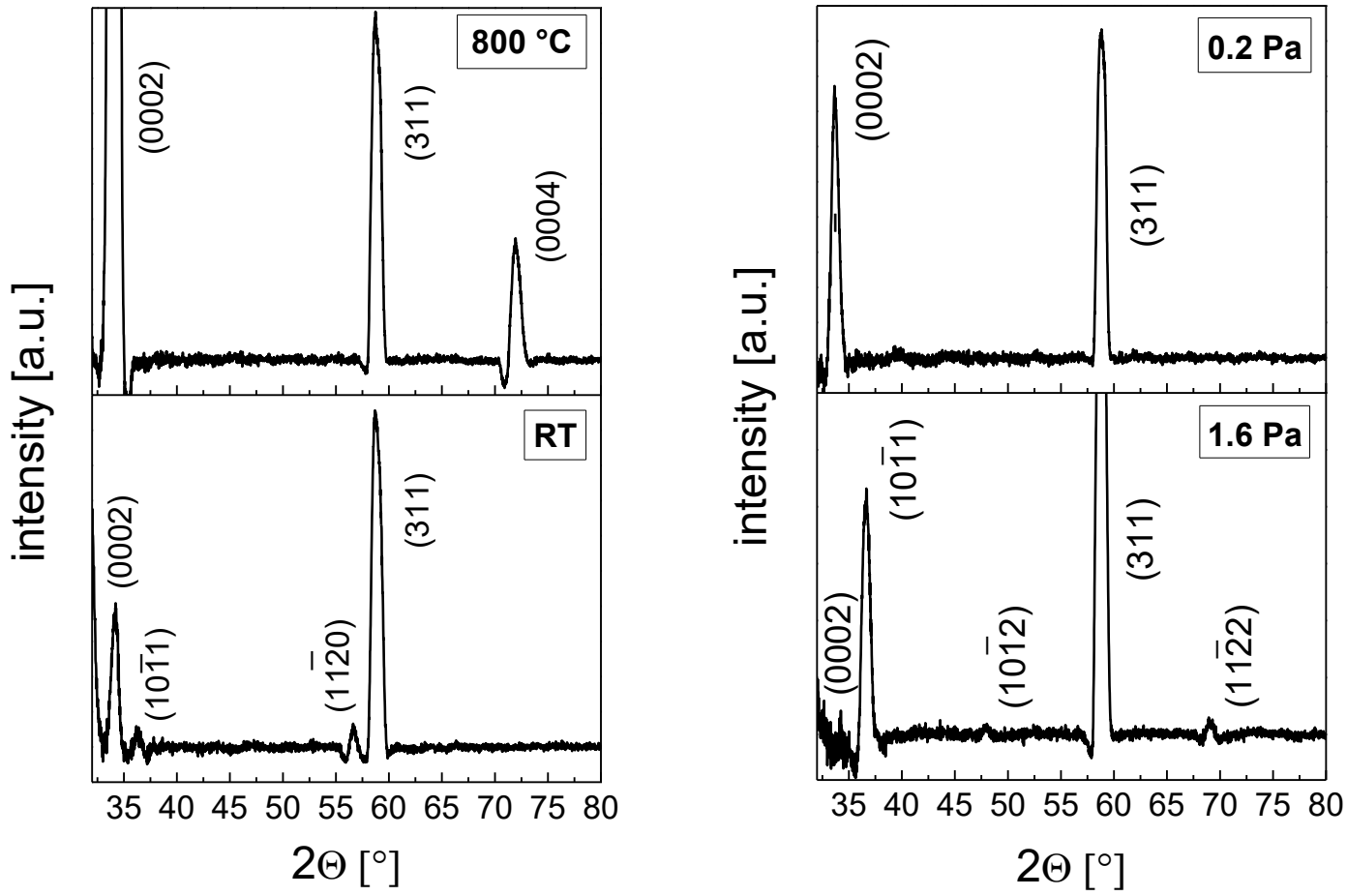


→ Columnar growth mechanism



→ Small columnar grain size (10 – 20 nm)

Crystal structure



→ (0002)-orientation at high substrate temperature and low N_2 pressure

Chemical bonding structure

- Aim is to synthesize GaN films without As

- Higher negative enthalpy of formation of GaN (-109,5 kJ/mol) than that of of GaAs (-81,5 kJ/mol)

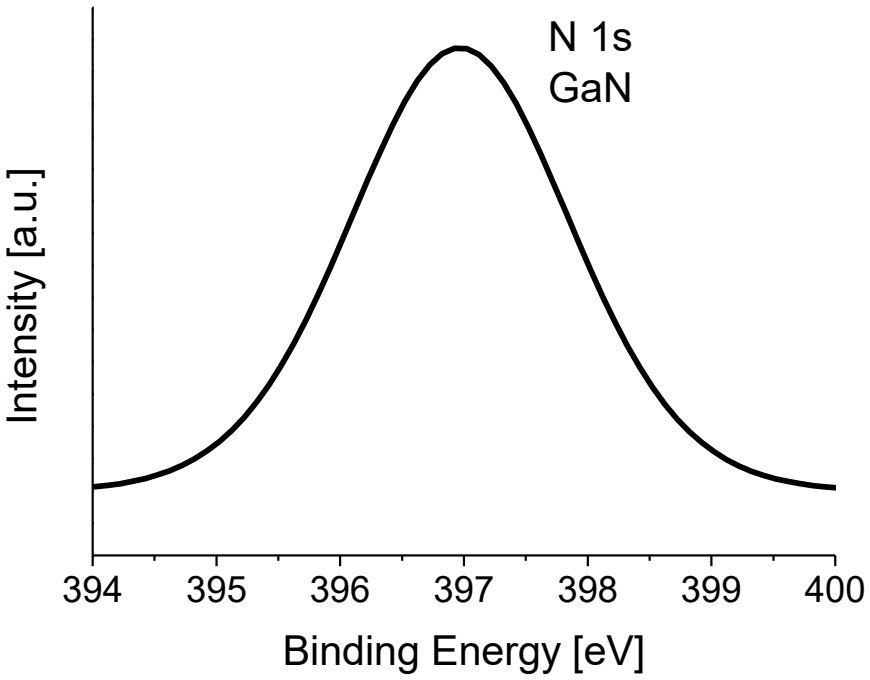
- 100 % N_2

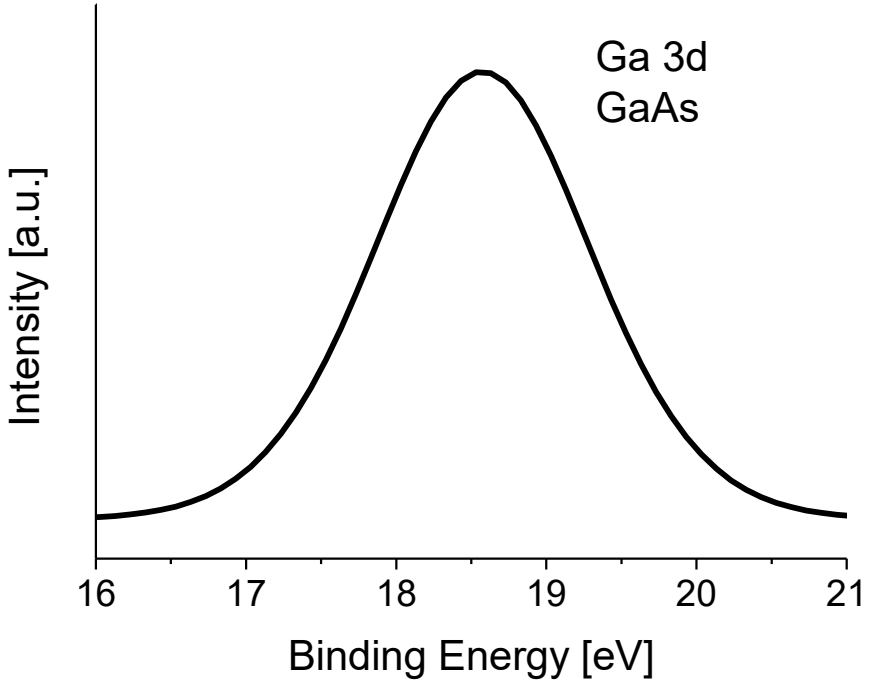
  → Higher concentration of N_2 containing species in the plasma compared to As species

- High substrate temperatures

  → Decreasing As-content

Chemical bonding structure





- As-atoms within all samples

  → With the abovementioned parameters, it is not possible to synthesize GaN films without As by using a GaAs target

Outlook

- Identify an ideal… → Target (Ga, GaAs, GaN)
  → Substrate (Si, Mo, Cu, Nb and Ta)
  → Interlayer (AlN, TiN, ZnO)

- Implementing of the QE measurement setup

- 4 targets → Ga source → p-type doping
  → Band gap modification → Interlayer

- Surface modification

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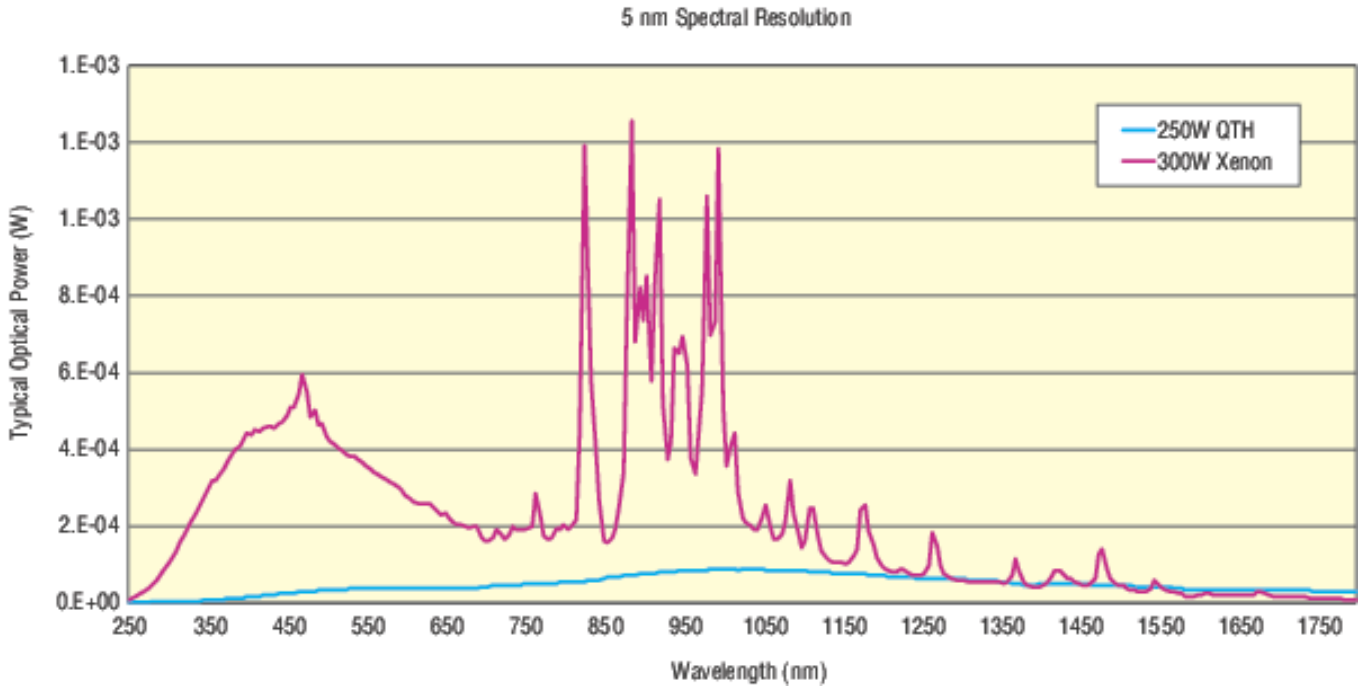
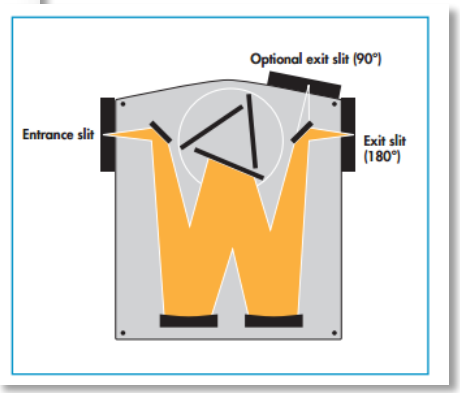
Thank you for your attention!

Light source



Monochromator

Specifications	
Configuration	Czerny-Turner
Slits	10 µm to 10 mm variable, manual or motorized
Slit height	20 mm
Number of gratings	1, 2 or 3
Grating size	68 mm x 84 mm
Aperture ratio	f/4.1 (at all grating angles)
Resolution	0.1 nm at reduced slit height, 0.3 nm with full slit height of 20 mm, both measured with 1200 l/mm grating
Wavelength acquisition speed	1000 nm/s
Wavelength accuracy	±0.2 nm over full range of 1200 l/mm grating
Wavelength reproducibility	±0.05 nm (1200 l/mm)
Weight	14 kg



Ordering information gratings			
Partnumber	Lines per mm (l/mm)	Blaze wavelength (nm)	Theoretical resolution for 1 mm slit (nm)
High-resolution UV gratings			
MSG-T-1800-250	1800	250	2
MSG-T-1800-500	1800	500	2