Institute of Radiation Physics

Radiation Source ELBE

Resolving Surface Chemical States of p-GaN:Cs Photocathodes by *in-situ* X-ray Photoelectron Specctroscopy (XPS)

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p-GaN as a potential photocathode

Agenda

- Short overview of GaN chamber (Set-up)
- Activation cycle
- Achieved QE values vs. temperature

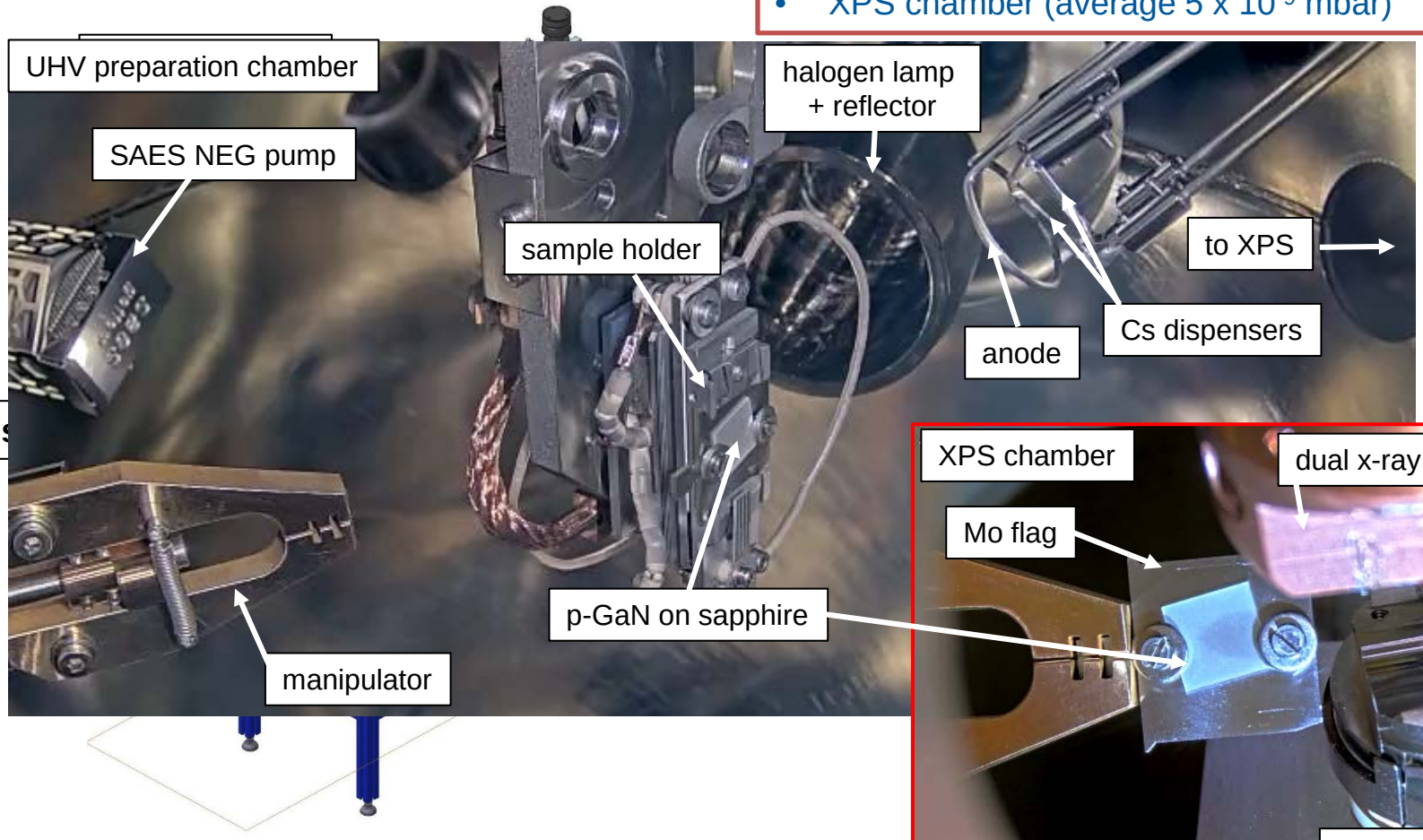
- Surface composition with XPS:
  - After thermal cleaning
  - After Ar^+ sputtering
  - After Cs activation
  - Degradation (+ X-ray influence)

- Summary & Outlook

p-GaN as a potential photocathode

Set-up

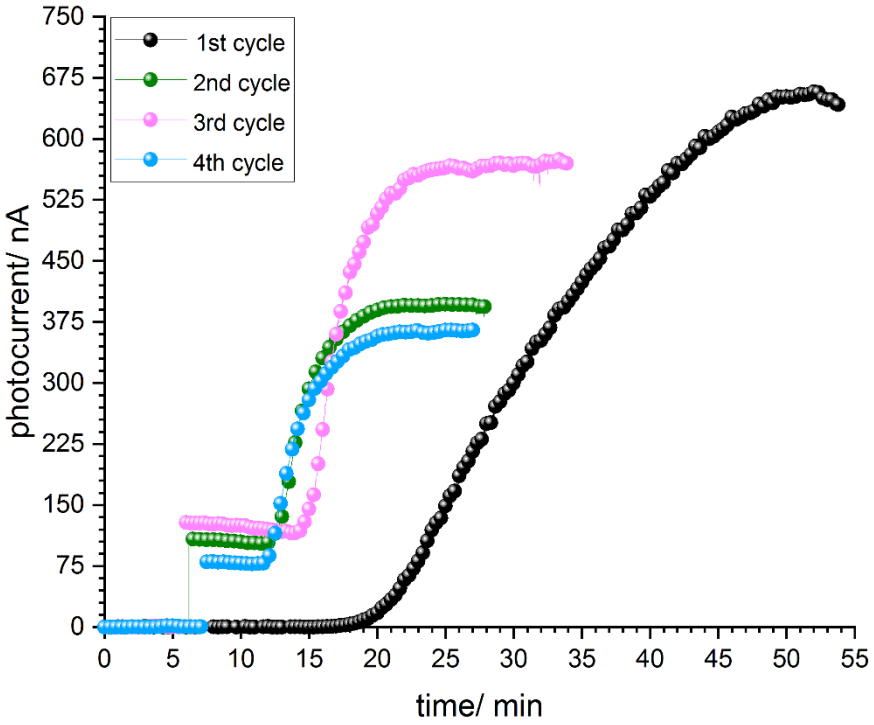
- UHV preparation chamber (average 3 x 10^{-10} mbar)
- 310 nm UV-LED with 50 µW
- halogen lamp for thermal cleaning
- Backside heating by manipulator
- external IR sensor for temperature measurement
- XPS chamber (average 5 x 10^{-9} mbar)



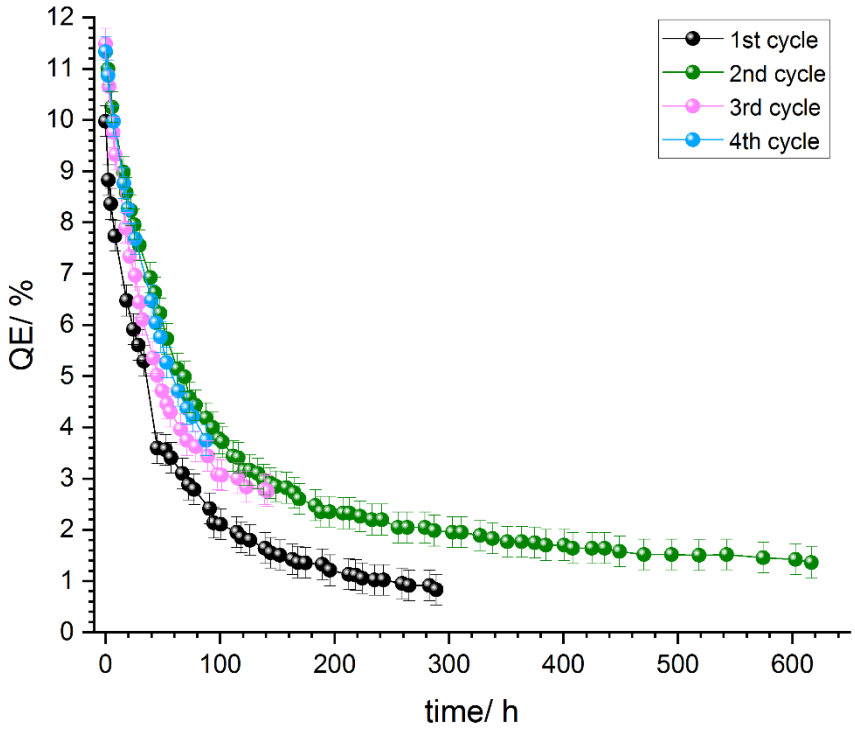
with courtesy of P. Murcek

p-GaN as a potential photocathode cycle

2. Cs activation



3. QE decay

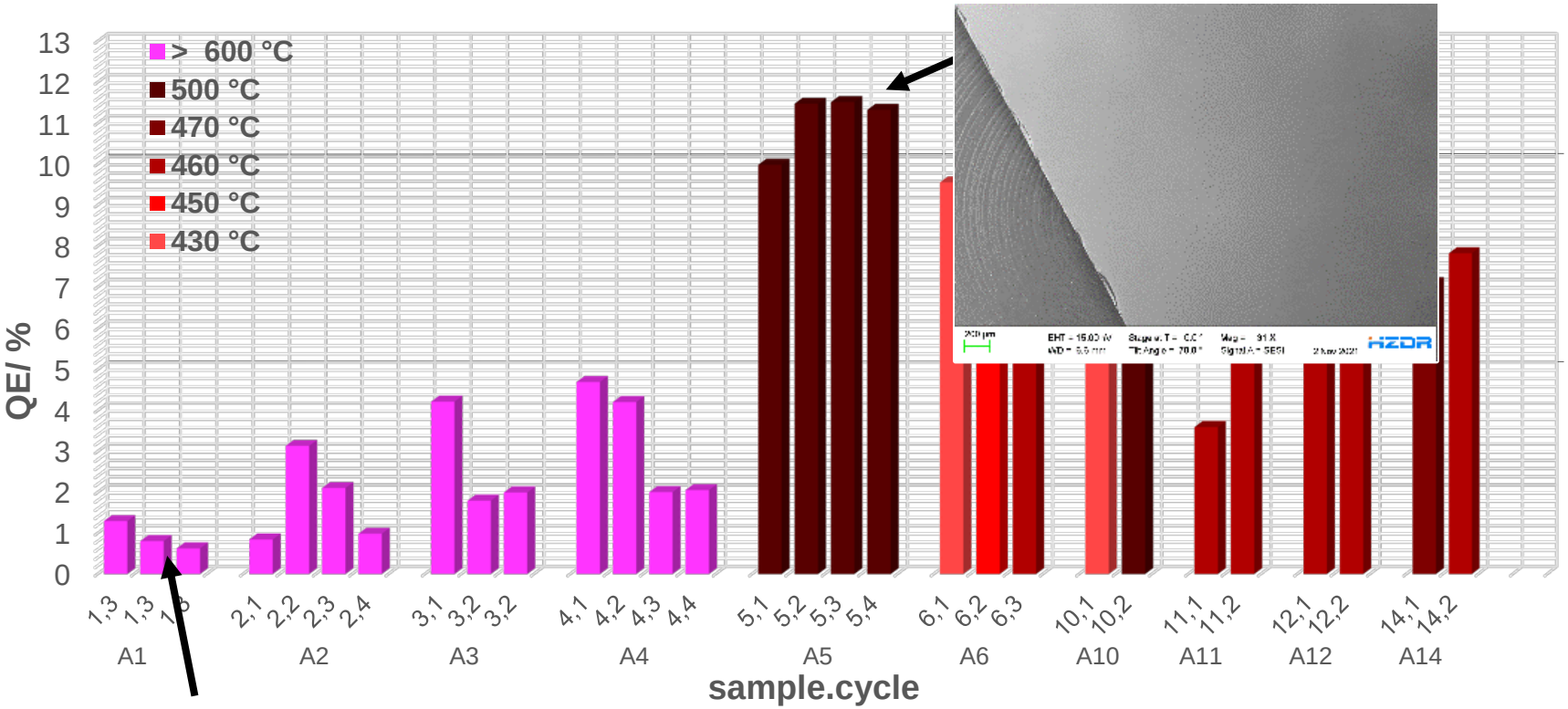


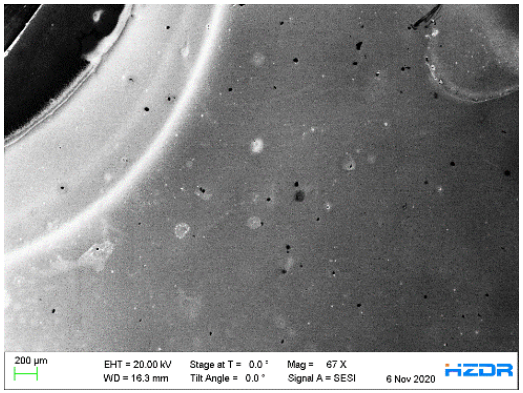
→ **Thermal cleaning, Cs activation and QE decay are defined as one cycle**
→ **p-GaN can be used several cycles**

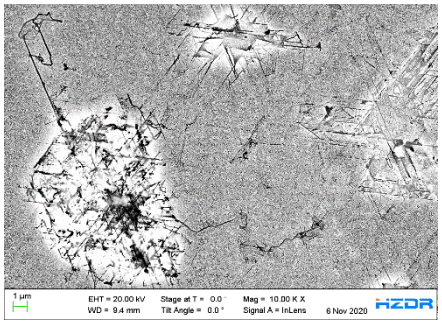
Schaber, J.; Xiang, R.; et al. Influence of Surface Cleaning on Quantum Efficiency, Lifetime and Surface Morphology of p-GaN:Cs Photocathodes. Micromachines **2022**, 13, 849. https://doi.org/10.3390/mi13060849

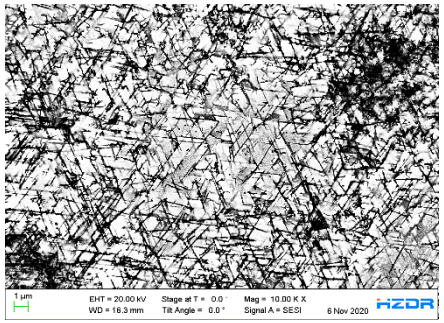
p-GaN as a potential photocathode

QE vs. T









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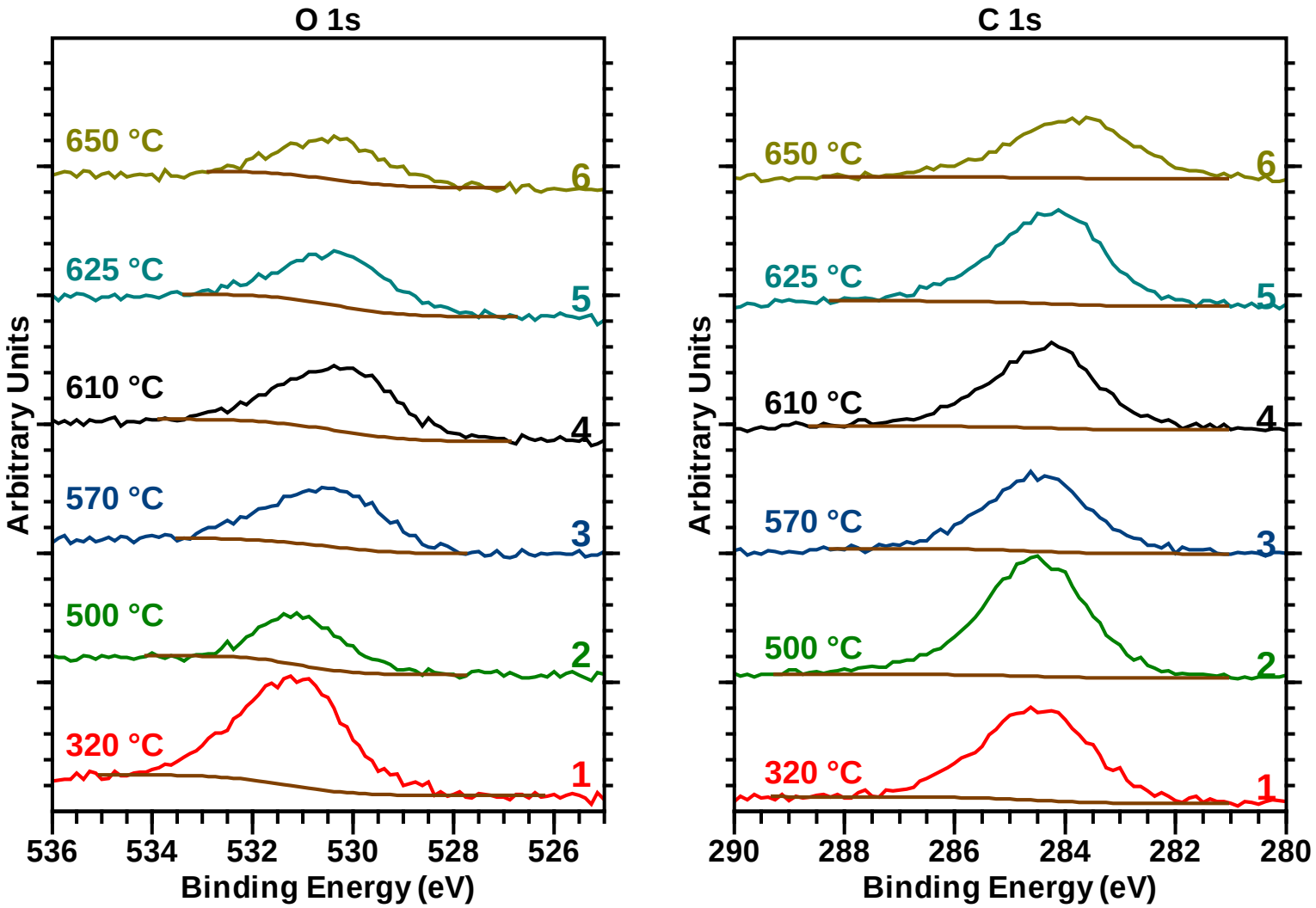
p-GaN as a potential photocathode

in-situ XPS

Surface composition after the thermal cleaning (backside)

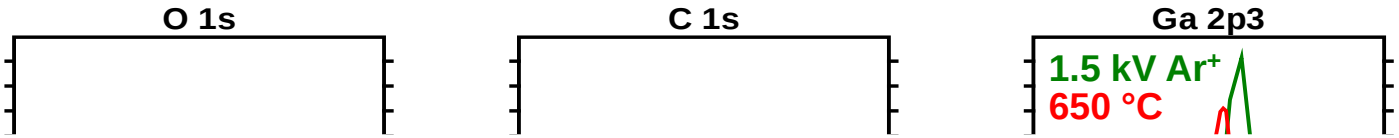


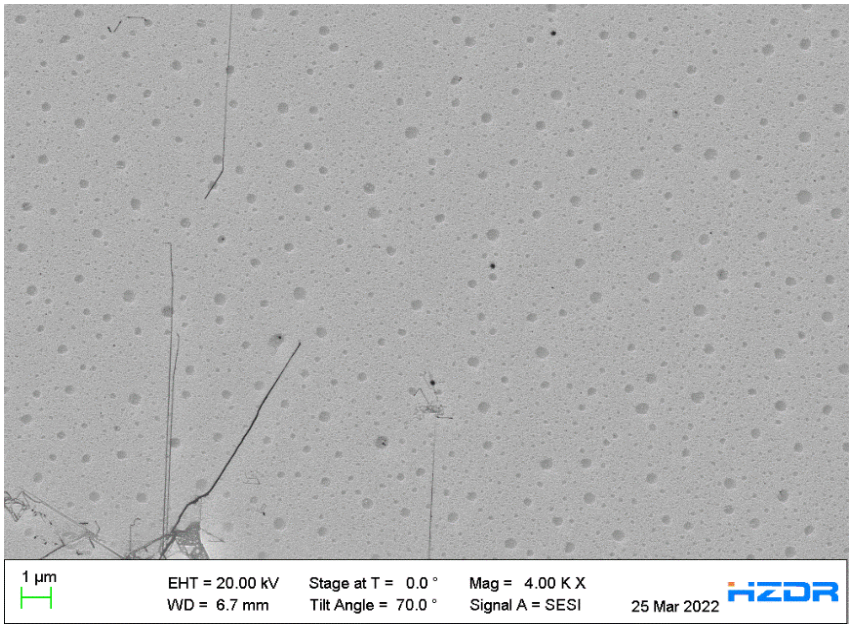
→ C and O are not removed by thermal cleaning

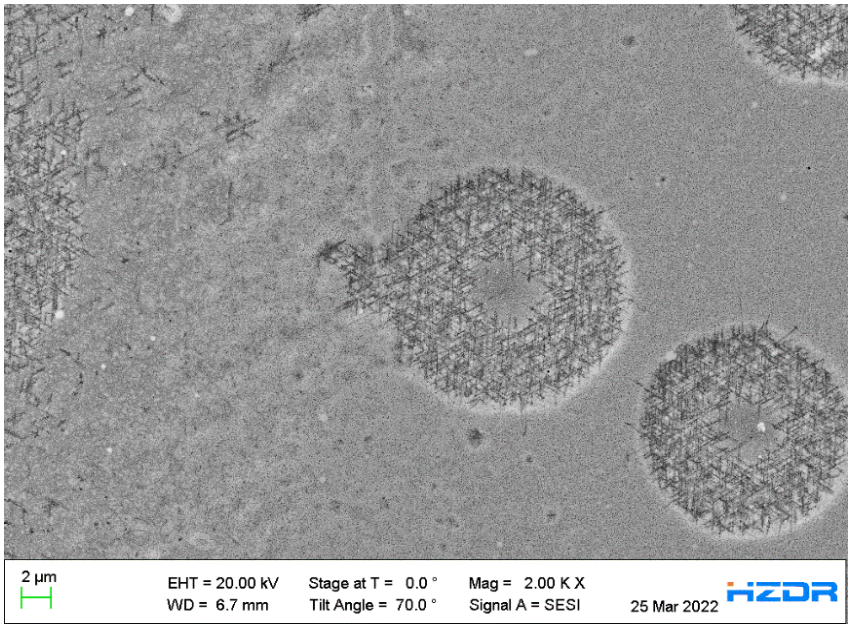
→ Might be incorporated into the crystal lattice

p-GaN as a potential photocathode

Ar^+ sputtering







536 534 532 530 528 526
Binding Energy (eV)

291 288 285 282 279
Binding Energy (eV)

1125 1119 1113
Binding Energy (eV)

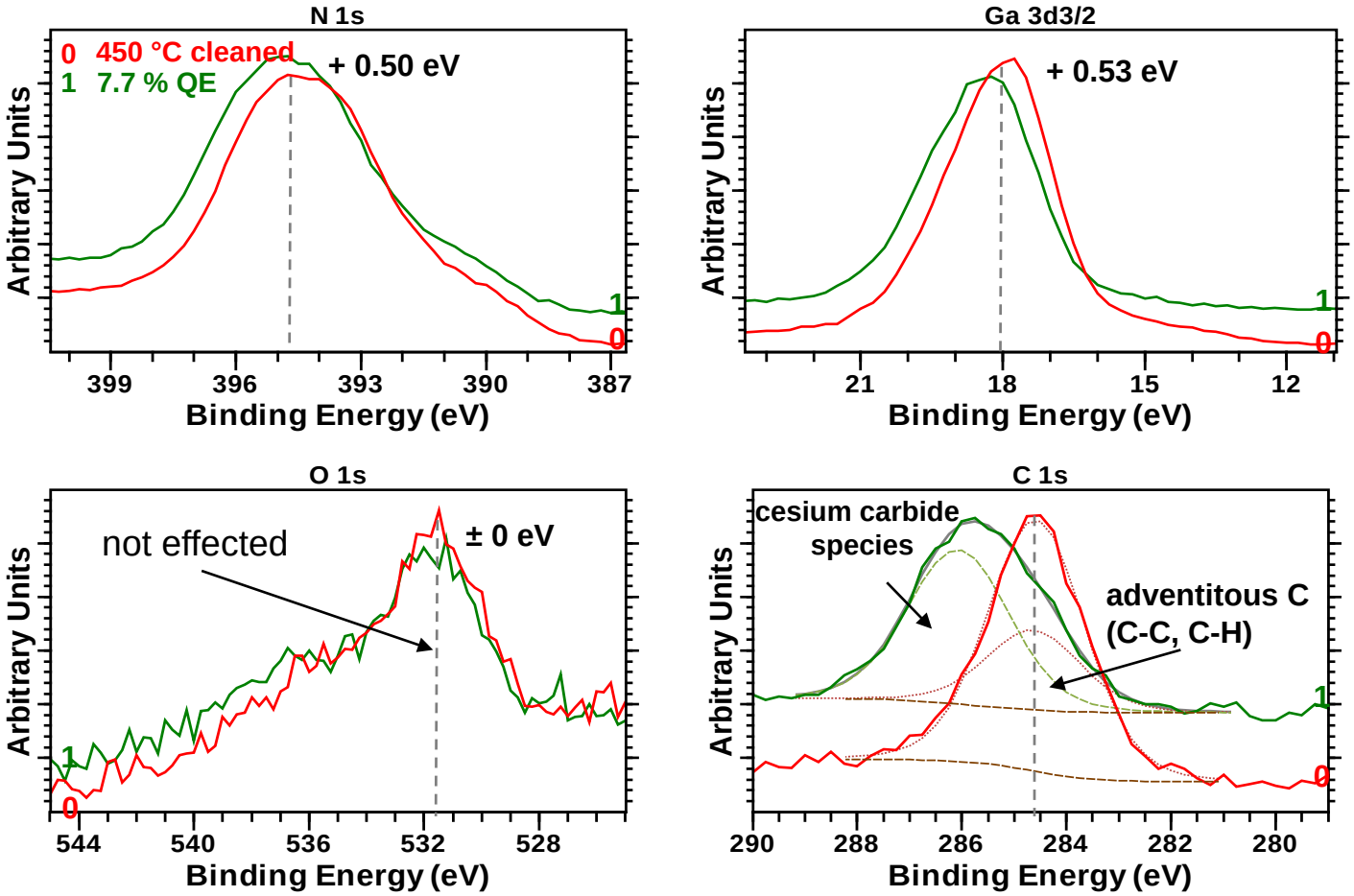
→ Ar^+ irradiation caused surface damage

→ depletion in N atoms → Ga:N ratio is not 1 anymore !

→ No NEA surface was achieved in Cs activation !

p-GaN as a potential photocathode

Cs activation

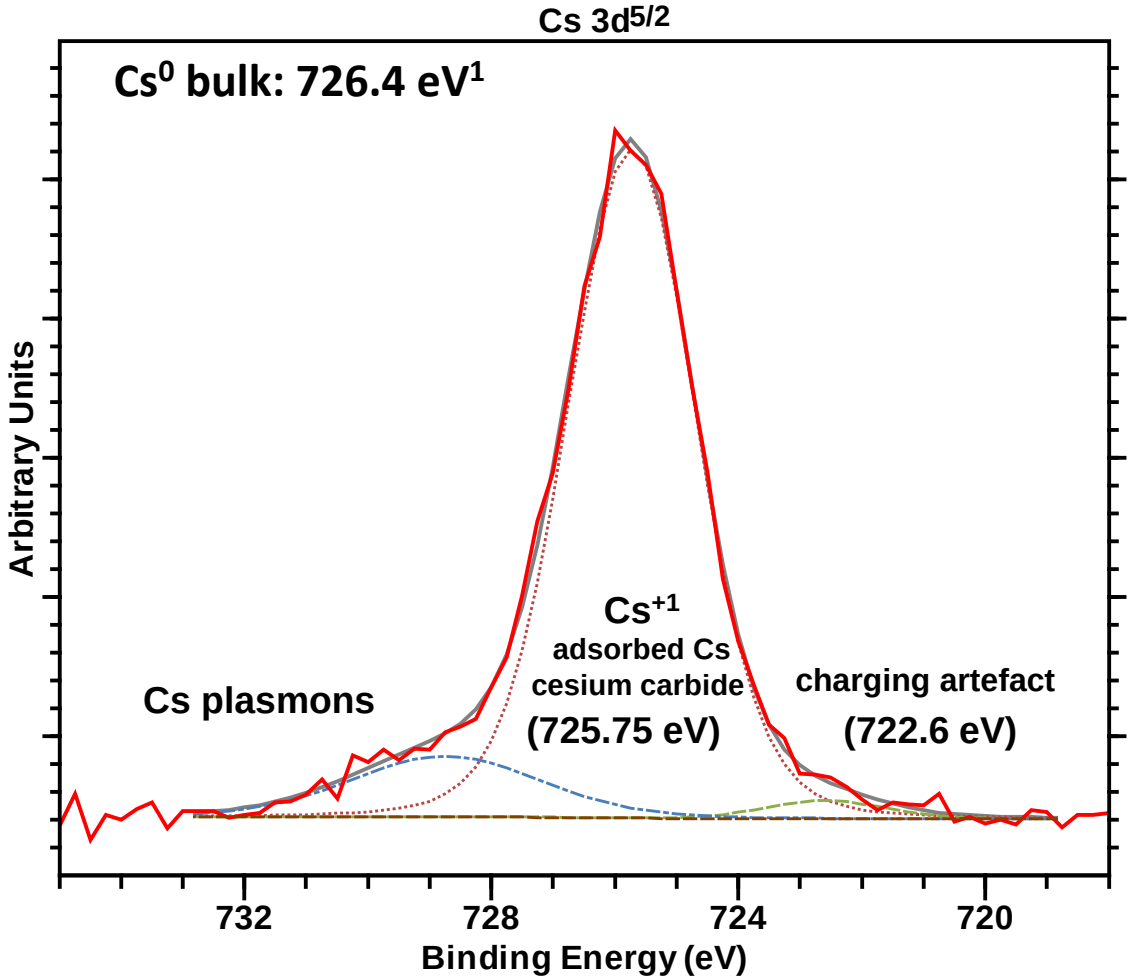


- **Deposition of Cs: shift towards higher BE**
- **No shift in O 1s → oxygen is not at the surface → derive from sublayers/ incorporated**
- **Significant influence on C 1s peak: new component is fromed**

Schaber, J.; Xiang, R.; et al. Influence of Surface Carbon on p-GaN:Cs photocathodes with high quantum efficiency, publication in progress

p-GaN as a potential photocathode

Cs $3d_{5/2}$ peak



- Cs $3d_{5/2}$: at lower BE than Cs^0

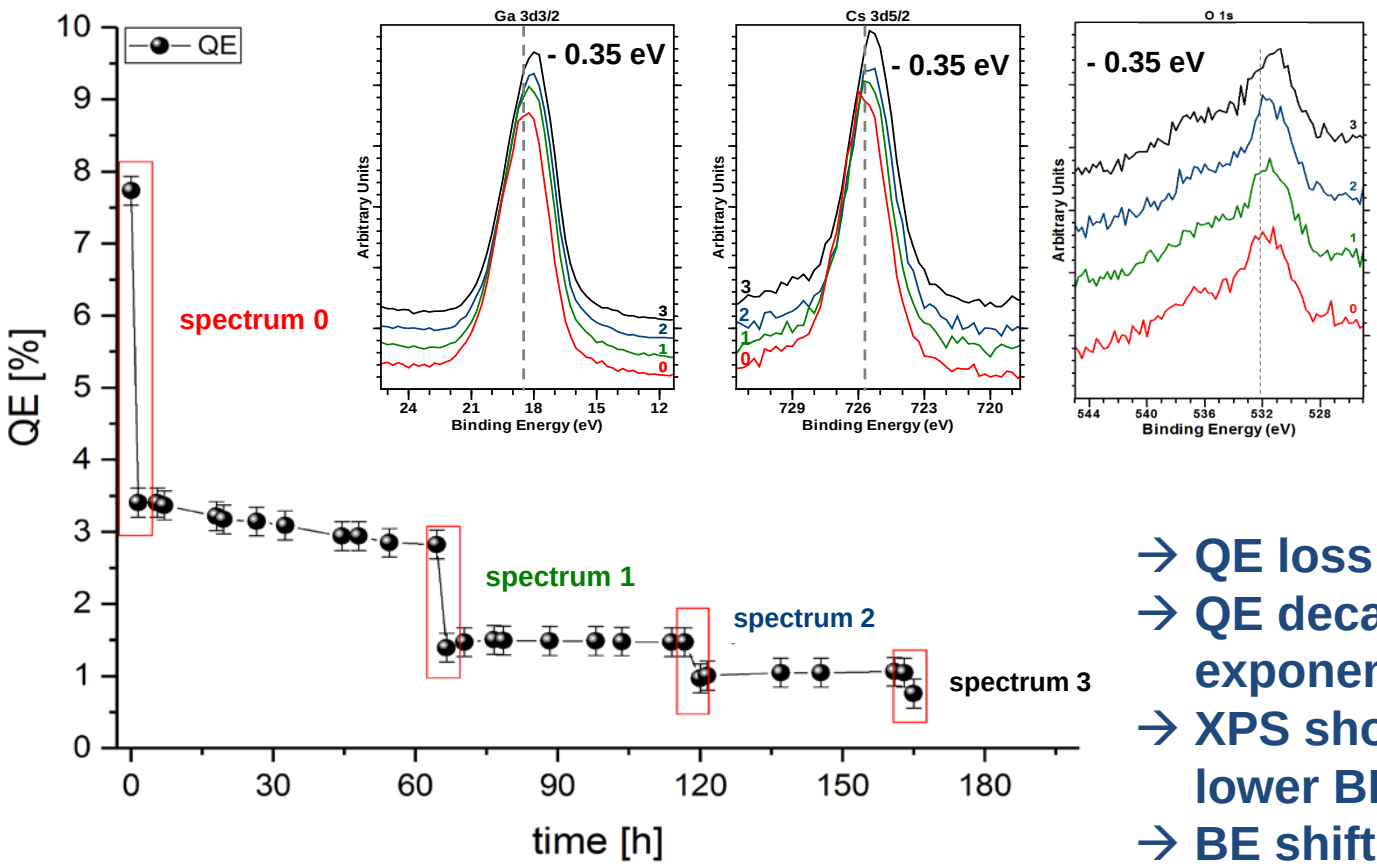
→ Cs must be Cs^{+1}
→ No bulk Cs
→ Cs plasmons with low intensity

→ BUT: X-rays from dual anode has also an influence on degradation

1) Moulder, J. F.; Jill C. Handbook of x-ray photoelectron spectroscopy: a reference book of standard spectra for identification and interpretation of XPS data. Physical Electronics Division, 1992, Perkin-Elmer Corp.
2) Schaber, J.; Xiang, R.; et al. Influence of Surface Carbon on p-GaN:Cs photocathodes with high quantum efficiency, publication in progress

p-GaN as a potential photocathode

photocathode degradation



→ QE loss after XPS analysis

→ QE decay should be exponentially

→ XPS shows a shift towards lower BE during degradation

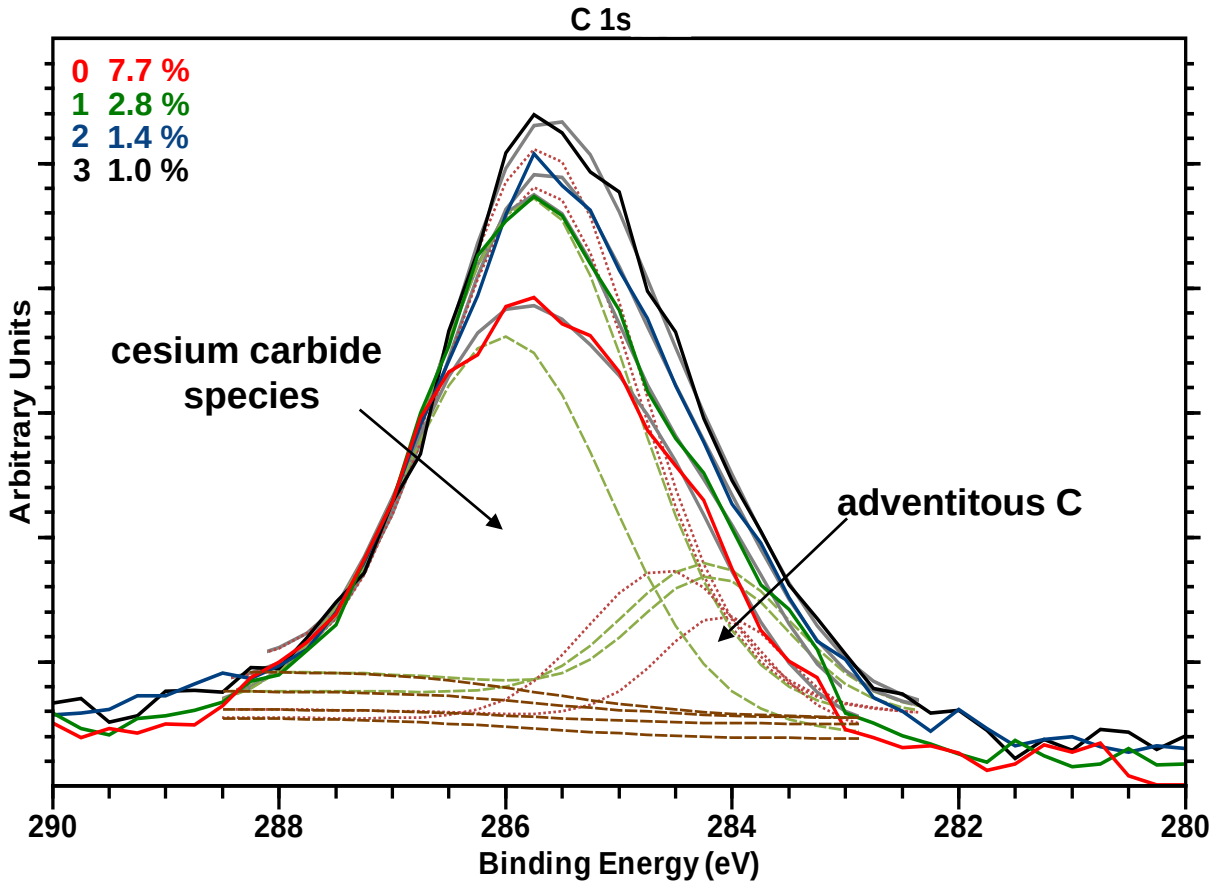
→ BE shift also observed in O 1s

X-rays accelerate the degradation as external source

Schaber, J.; Xiang, R.; et al. Influence of Surface Carbon on p-GaN:Cs photocathodes with high quantum efficiency, publication in progress

p-GaN as a potential photocathode

cesium carbide species



- → Carbon is always at the surface
- → Incoorperated into the crystal
- → Cesium carbide species increase in peak intensity

Increase in peak intensity is caused by:

- → Carbon atoms that form a new species with Cs
- → Carbon atoms that diffuse from sublayers to the surface
- → Is there a cesium carbide island formation?

Schaber, J.; Xiang, R.; et al. Influence of Surface Carbon on p-GaN:Cs photocathodes with high quantum efficiency, publication in progress

p-GaN as a potential photocathode

Summary

- QE values (7-12 %) @ 400-500 °C
- above 600 °C: surface morphology was destroyed
- *in-situ* XPS capability:
- C, O: incooperated during the MOCVD growth
  - ➢ removeable by Ar irradiation

  BUT: ion sputtering damage

- easy activation with exclussively cesium
- → photoemision peaks towards a higher BE
- Chemical state of Cs: no bulk Cs^0 but Cs^{+1}
- C 1s peak was influenced
  - ➢ Cesium carbide species
  - ➢ Cesium carbide peak intensity increased with degradation
  - ➢ Shift back towards lower BE

- X-rays of dual anode accelerated the QE decay !

- Higher p-GaN quality (MBE or HVPE) → No C on the surface
- Different Mg concentrations

- P-GaN on other substrates (Si, Cu, SiC, TiN, ….)

- Sputtering with helium ???

- P-GaN behaviour in the SRF Gun ???

Thank you for your attention !