J. Schaber[1,2], R. Xiang[1], J. Teichert[1], P. Murcek[1], P. Zwartek[1], A. Arnold[1], A. Ryzhov[1], A. Hoffmann[1], S. Ma[1], P. Michel[1], N. Gaponik[2]

[1] Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
[2] Technical University Dresden, Dresden, Germany

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Surface studies of p-GaN:Cs photocathodes with *in-situ* X-ray photoelectron spectroscopy (XPS)

Introduction

- Higher beam currents and brightness are desired, therefore
- new photocathodes with higher QE are required
- p-type GaN is able to produce a negative electron affinity (NEA) surface when cesium is deposited on it
- A thermal cleaning under vacuum was carried out to achieve an atomically clean surface prior to the Cs deposition

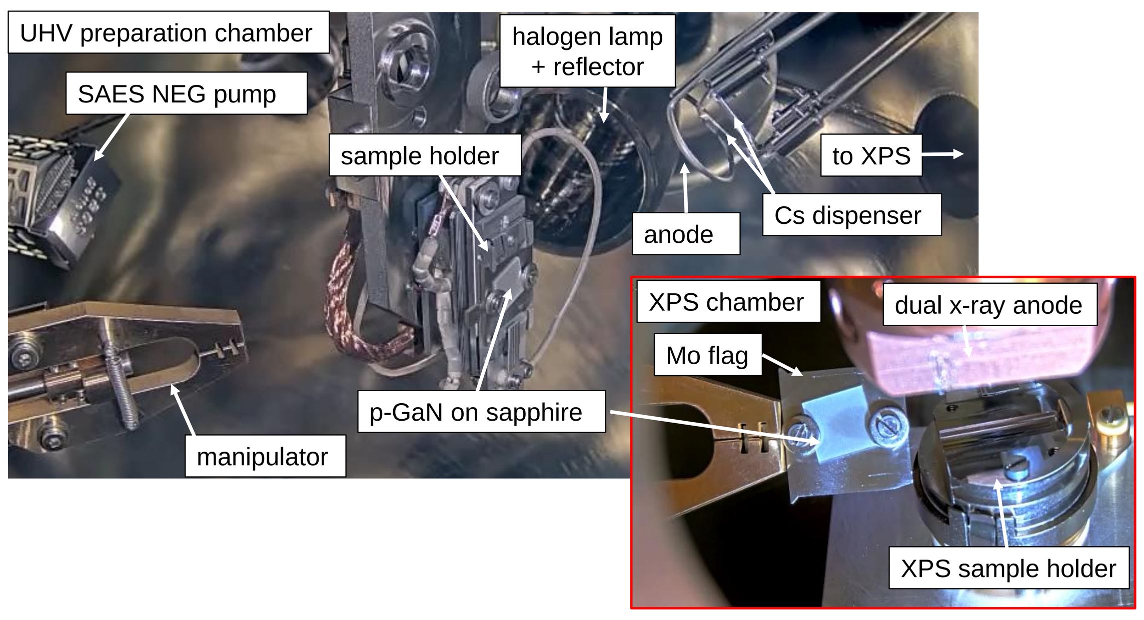

Fig. 1: The interior of the UHV preparation chamber (showing a sample holder, a halogen lamp, an anode, and cesium dispensers) and the XPS analysis chamber connected to the preparation chamber.

Methods and Material

- The p-GaN surface is studied with *in-situ* XPS without leaving the UHV environment
- A PHI 5600 spectrometer (average pressure of 4×10^{-9} Torr and Al Ka line (hv =1486.6 eV) from non-monochromatized x-ray source was used
- p-GaN (5 µm), grown on sapphire with metalorganic chemical vapor deposition (MOCVD) was used with a Mg conc.: $5 \times 10^{16} – 1 \times 10^{17}$ cm^{-3}

Achieved QE values for p-GaN:Cs

- QE depends on the surface conditions
- The QE values correlate with the temperature used in the thermal cleaning
- Samples were re-activated several times

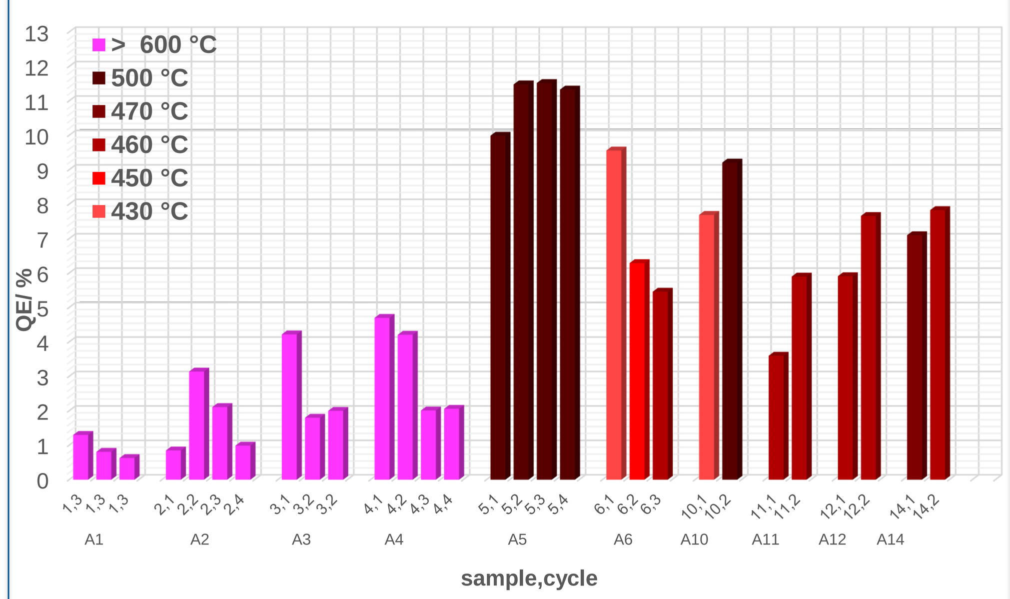

Figure 2: Achieved QE values of the p-GaN:Cs photocathodes depending on their surface conditions (applied T in thermal cleaning).

- Higher QE (max. 11.5 %) values were achieved @ moderate temperature (400—500 °C)
- Less QE values @ T > 600 °C
- During the first experiments from A1-A6 no *in-situ* XPS was available → no surface studies

Surface Studies of thermal cleaning

- p-GaN was rinsed in 99 % pure EtOH
- EtOH solvent residues (C-OH) attached to the p-GaN surface
- thermal cleaning of (450 °C, 1h) was applied: peak intensity of EtOH residuals was reduced

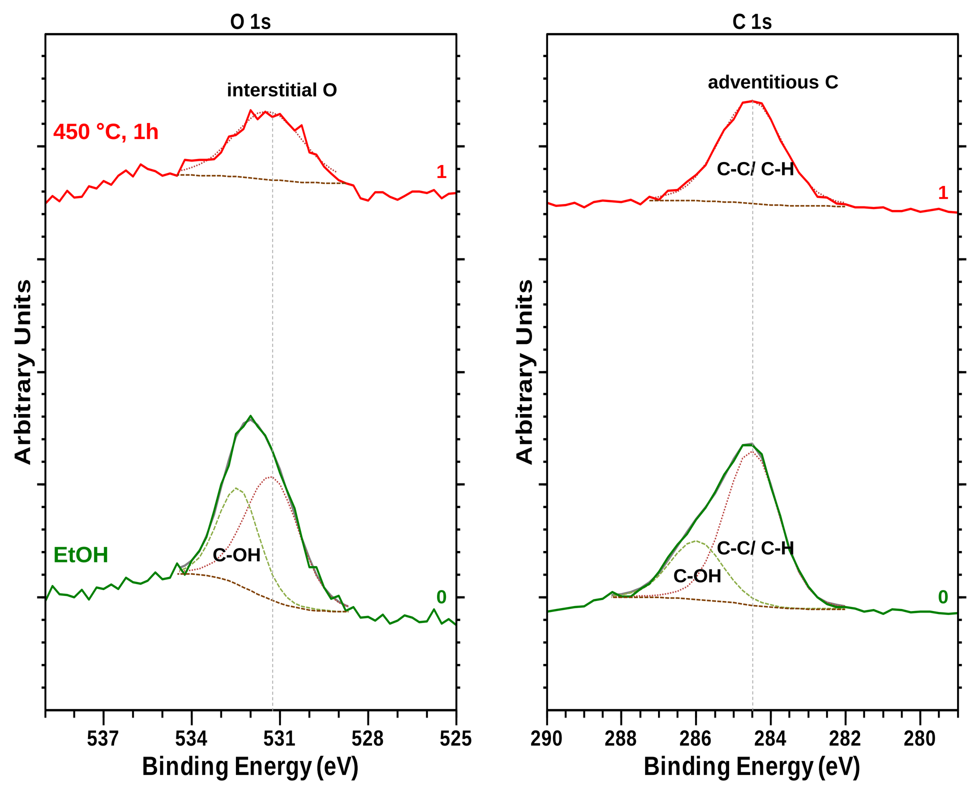

Figure 3: O 1s and C 1s photoelectron spectra for the p-GaN surface cleaned with 99 % EtOH (line 0) and after thermal cleaning (line 1).

- Thermal cleaning was not able to remove O and C entirely
- C and O contaminants remained

→Derive from MOCVD ?

p-GaN:Cs photocathode

- Cs was deposited on the p-GaN to achieve a NEA surface
- Cs current: 3.0 – 4.0 A (3×10^{-9} mbar)
- p-GaN was illuminated with 310 nm UV-light during the Cs deposition
- *In-situ* photocurrent was observed until a maximum was achieved

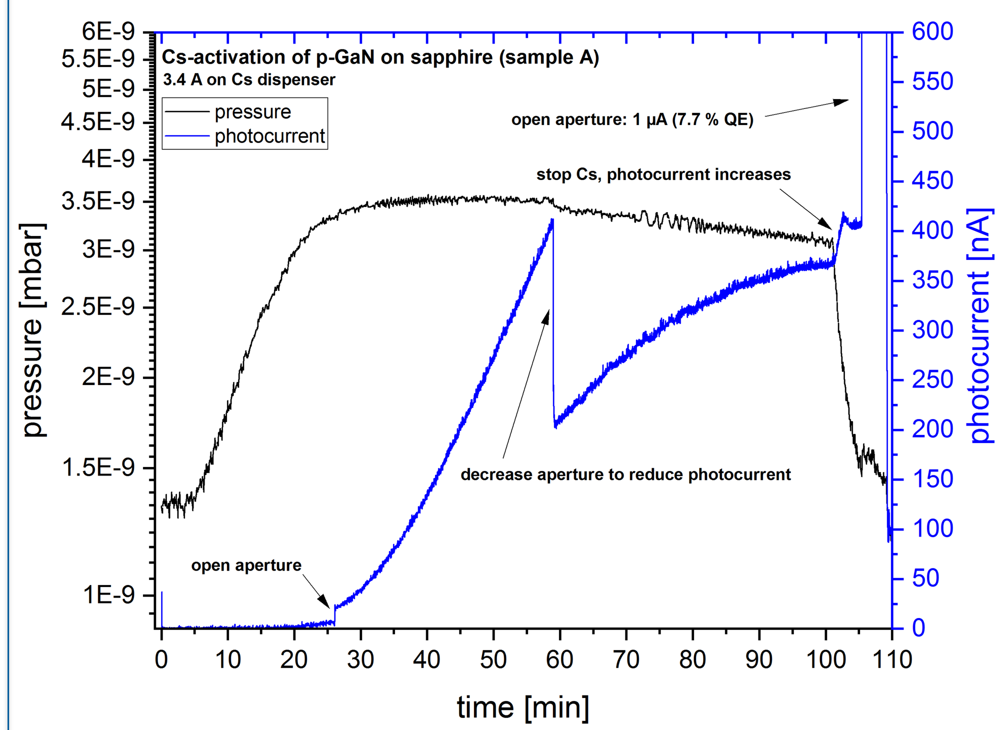

Figure 4: In-situ photocurrent and vacuum value during the cesium activation of the p-GaN surface.

- 7.7 % QE was achieved although C and O remained on the surface
- Simple and manageable preparation compared to other semiconductor photocathodes

Surface after Cs deposition (XPS)

- Cs caused a shift toward higher binding energies, but not in O 1s → O located in bulk, not at surface
- most influence observed in C 1s peak: new component appeared at 286 eV → cesium carbide species

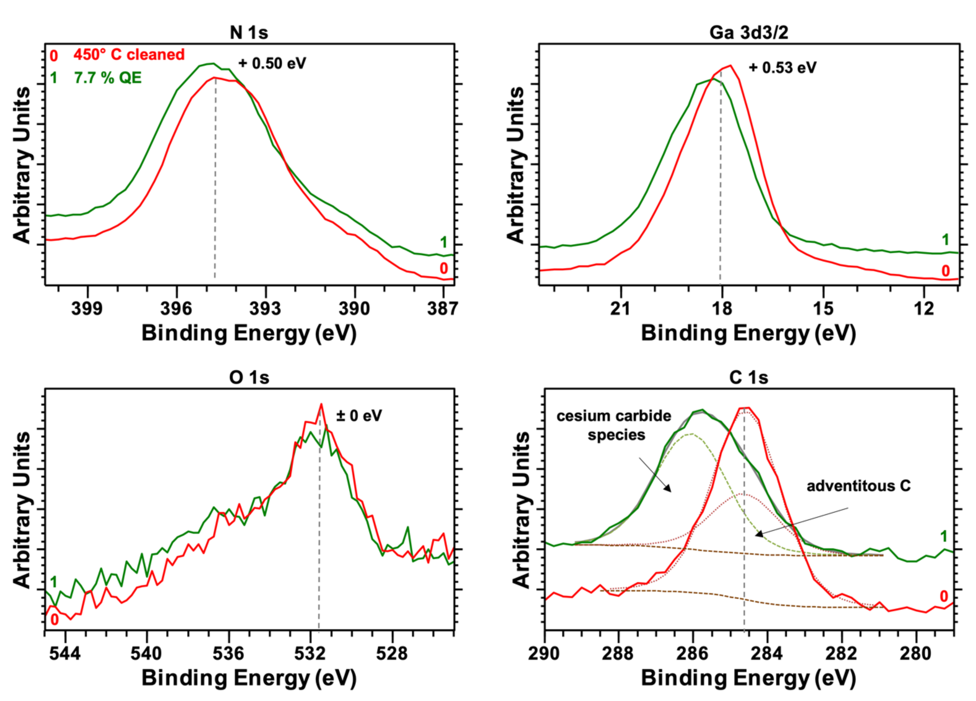

Figure 5: Ga $3d_{3/2}$, N 1s, O 1s, and C 1s photoelectron spectra for the p-GaN surface after thermal cleaning (line 0) and after Cs activation with achieved 7.7 % QE (line 1).

Photocathode degradation

- QE decays usually 1/e, but X-rays accelerated the degradation
- Photoemission peaks shifted toward lower binding energies

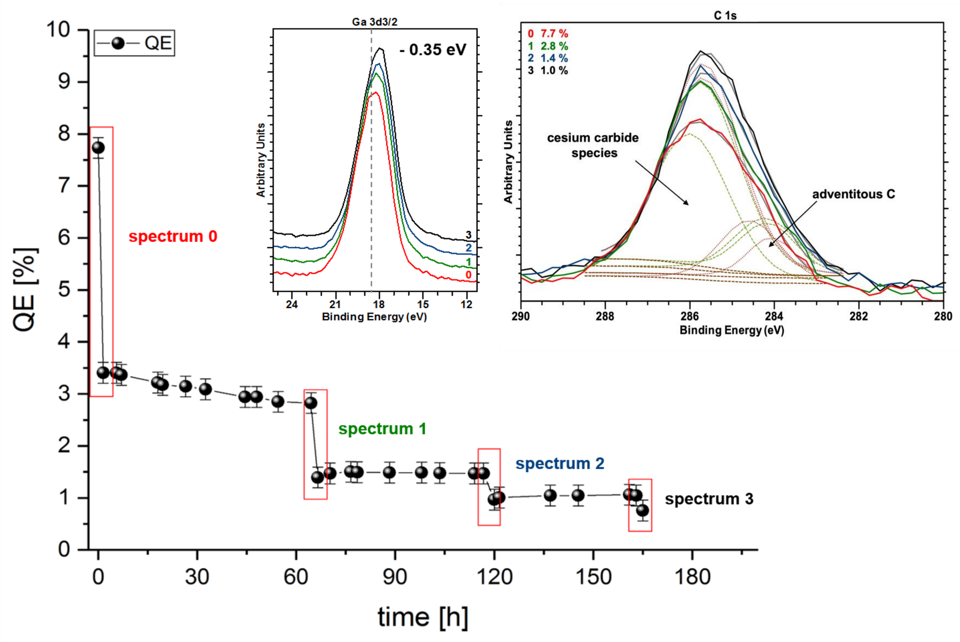

Figure 6: The QE decay of the p-GaN:Cs photocathode and the Ga $3d_{3/2}$ and C 1s photoemission spectra at different times during its decay. The C 1s spectrum showing the evolution of the cesium carbide species.

- peak intensity of the cesium carbide species (286 eV) increased with ongoing degradation

Conclusion

- Our study showed that p-GaN has an high potential to become a future electron source
- Thermal cleaning cannot remove O and C contaminations entirely

(→ C and O were residuals from MOCVD?)

- Cs caused a shift toward higher binding energy
- In C 1s: new species was created
- Formation of cesium carbide species caused an external degradation
- X-rays accelerated the photocathode degradation additional

Outlook

- p-GaN with higher quality (MBE or HVPE)
- On different substrates ? (SiC, Si)
- Remove C and O with low energy ions ?
- Influence of Mg concentration on QE ?

References related to p-GaN:Cs photocathodes

- J. Schaber *et al*. „Influence of Surface Cleaning on Quantum Efficiency, Lifetime and Surface Morphology of p-GaN:Cs Photocathodes". *Micromashines,* 2022, 13, 849. DOI: 10.3390/mi13060849
- R. Xiang and J. Schaber. „Review of Recent Progress on Advanced Photocathodes for Superconducting RF Guns". *Micromachines*, 2022, 13, 1241. DOI: 10.3390/mi13081241
- J. Schaber, R. Xiang, N. Gaponik. „Review of photocathodes for electron beam sources in particle accelerators". *J. Mater. Chem. C*, 2023,11, 3162-3179. DOI:10.1039/D2TC03729G
- J. Schaber *et al.* „Impact of various cleaning procedures on p-GaN surfaces". *Surf Interface Anal*. 2023;1–8. DOI: 10.1002/sia.7207
- J. Schaber *et al.* „Influence of surface carbon on the performance of cesiated p-GaN photocathodes with high quantum efficiency". *Scientific Reports,* 2023, 13:3188. DOI: 10.1038/s41598-023-30329-0

SCAN ME

EWPAA 2024 in Dresden

Bundesministerium für Bildung und Forschung

DRESDEN concept

Dr. Jana Schaber · j.schaber@hzdr.de · www.hzdr.de