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Resolving chemical states of p-GaN:Cs photocathodes with *in-situ* X-ray photoelectron spectroscopy (XPS)

Introduction

- New photocathodes with higher QE are desired for particle accelerator injectors (to provide higher beam currents)
- p-type GaN is able to produce a negative electron affinity (NEA) when cesium is deposited on the surface
- A thermal cleaning under vacuum was carried out to achieve an atomically clean surface

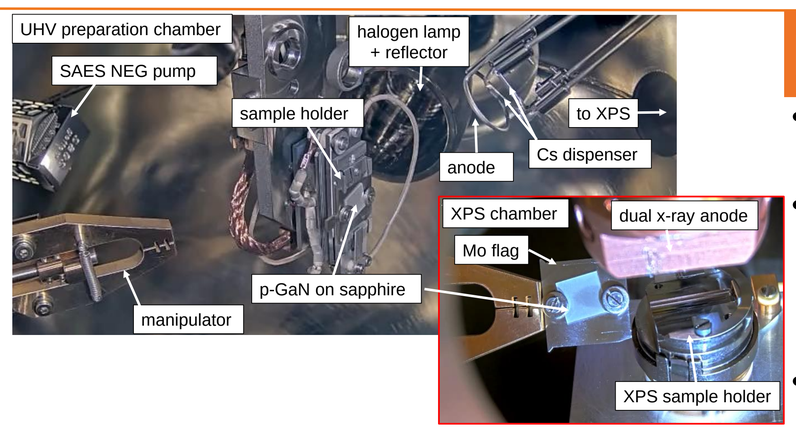

Fig. 1: The interior of the UHV preparation chamber (showing a sample holder, a halogen lamp, an anode, and cesium dispensers) and the XPS analysis chamber connected to the preparation chamber.

Methods and Material

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

Results

1) Thermal cleaning of p-GaN surface

- p-GaN was rinsed in 99 % pure EtOH
- EtOH solvent residues (C-OH) remained on the p-GaN surface
- After thermal cleaning: peak intensity of EtOH residuals was reduced

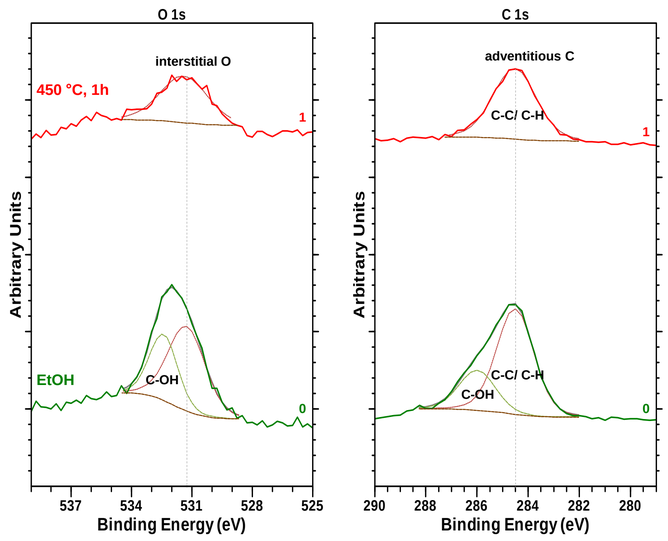

Figure 2: O 1s and C 1s photoelectron spectra for the p-GaN surface cleaned with 99 % EtOH (line 0) and after thermal cleaning (line 1).

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

→Derive from MOCVD ?

2) p-GaN:Cs photocathode

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

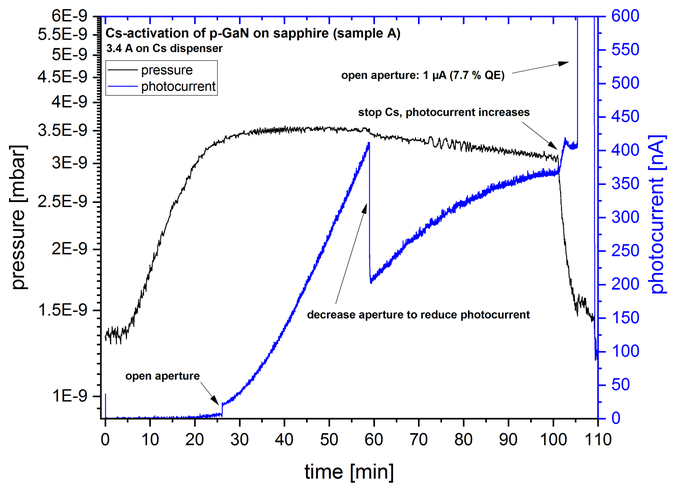

Figure 3: In-situ photocurrent and vacuum value during the cesium activation of the p-GaN surface.

$$\mathrm{QE} = \frac{h \cdot c}{q_e} \cdot \frac{I}{\lambda \cdot P_{\mathrm{Light}}}$$

- 7.7 % QE was achieved although C and O remained on the surface

3) Surface after Cs deposition (XPS)

- Cs caused a shift toward higher BE in Ga $3d_{3/2}$ and N 1s, but not in O 1s
- Peak intensities were normalized in their background
- N 1s had an overlap with Ga LMM Auger by Al excitation
- C remained at a BE of 284.6 eV

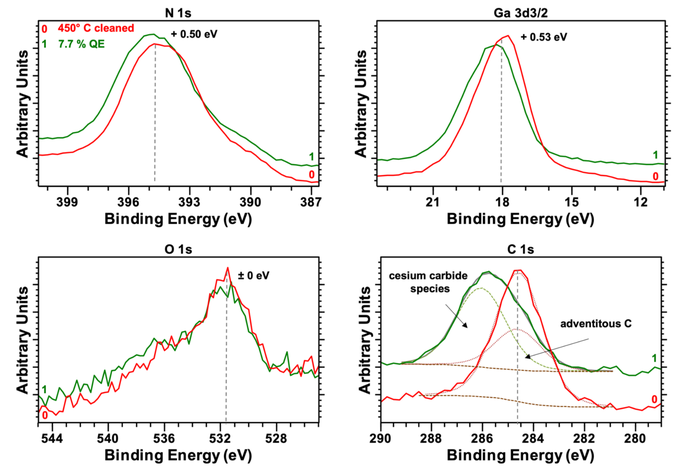

Figure 4: Ga $3d_{3/2}$, N 1s, O 1s, and C 1s photoelectron spectra for the p-GaN surface after thermal cleaning (line 0) and after Cs activation with 7.7 % QE (line 1).

- most influence was observed in C 1s peak: new component appeared at 286 eV
- → cesium carbide species

4) Photocathode degradation

- QE decays 1/e, but X-ray accelerated the natural degradation
- Photoemission peaks shifted toward lower BE during degradation

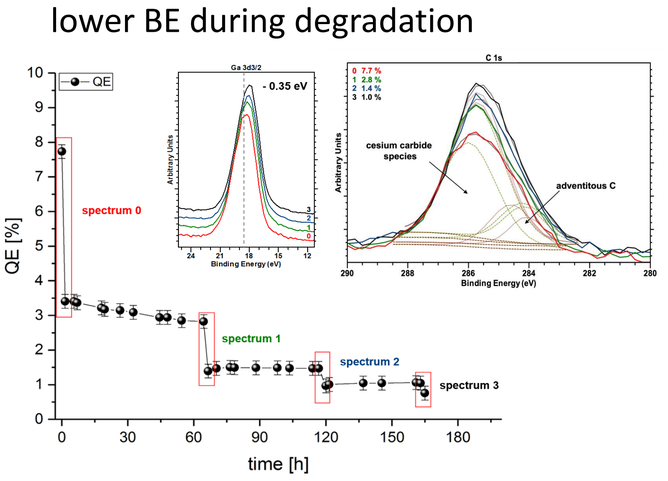

Figure 5: The QE decay of the p-GaN:Cs photocathode and the Ga $3d_{3/2}$ and C 1s photoemission spectra at different times during its decay. The C 1s spectrum showing the evolution of the cesium carbide species.

- C 1s showed a different behavior:
- peak intensity for cesium carbide species (286 eV) increased with ongoing degradation

5) Achieved QE values for p-GaN:Cs photocathodes on sapphire

- QE depended strongly on the applied temperature used in the thermal cleaning
- QE was influenced by the surface conditions

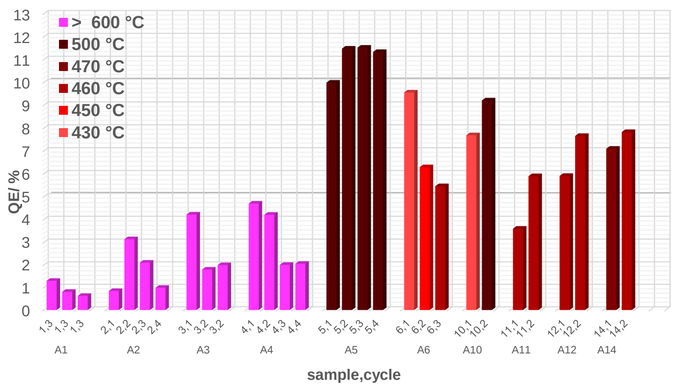

Figure 6: Achieved QE values of the p-GaN:Cs photocathodes depending on their surface conditions (applied T in thermal cleaning).

- High QE (max. 11.5 %) were achieved @ moderate temperature (400—500 °C)
- Less QE @ T > 600 °C

Conclusion

- p-GaN shows an enormous potential to be a new photocathode for particle accelerators
- Thermal cleaning cannot remove O and C contaminations entirely

→C and O were residuals from MOCVD ?

- Cs caused a shift toward higher BE
- But C 1s showed different behavior: new species was created
- Formation of cesium carbide species caused an external degradation +
- X-rays accelerated the photocathode degradation

Outlook

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

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