The attempt of using GaN (Cs) as a photocathode in SRF injector

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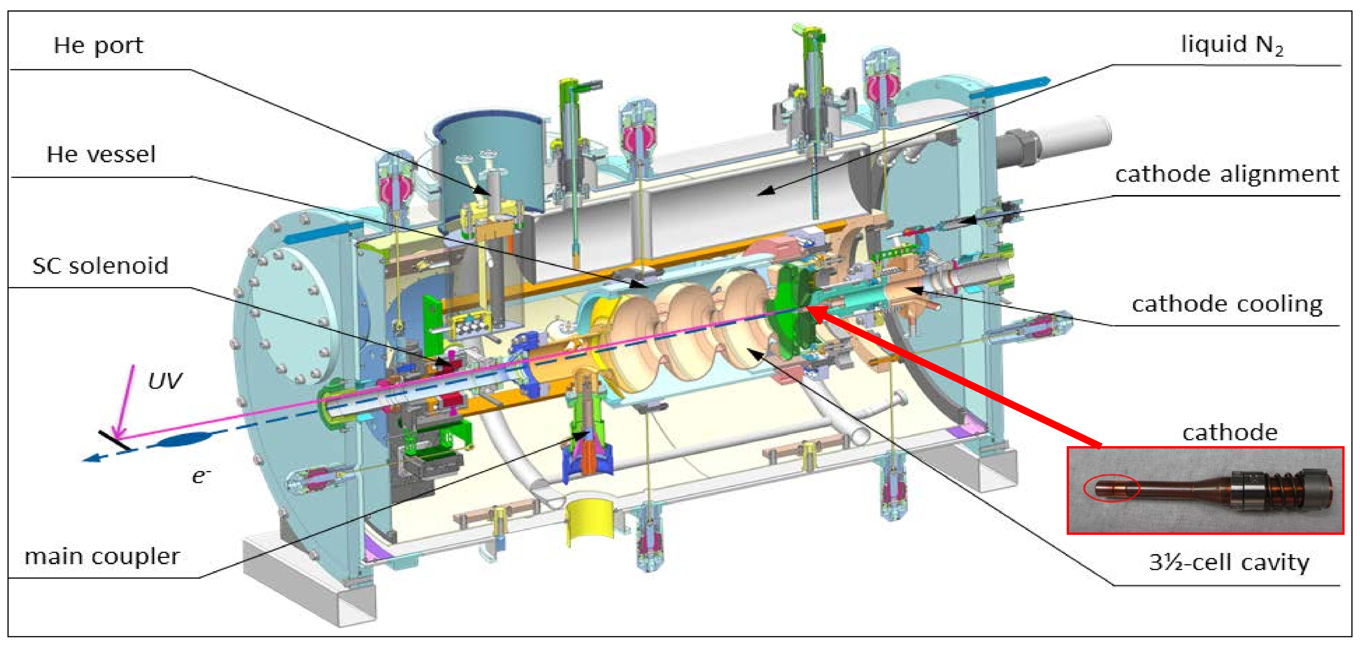
Introduction

The need of photocathodes providing low thermal emittance, low dark current, low field emission, a fast response time, good vacuum stability, high QE and a long lifetime are desirable.

At the moment a caesium telluride cathode is the material of choice so far for UV cathodes. But its disadvantage is a low efficiency and a limited wavelength range (cutting off at 300 nm).



Semiconductors such as GaN as novel materials for photocathodes showing an enormous potential.

The III-nitrides are widely used for UV, blue, green light-emitting diodes and for UV and blue laser diodes.

Usually a single crystal or heteroepitaxial thin film is grown on different types of substrates like silicon (Si), sapphire (Al_2O_3) or silicon carbide (SiC). The most commonly used substrate is sapphire, as in case of GaN.

GaN-Facts

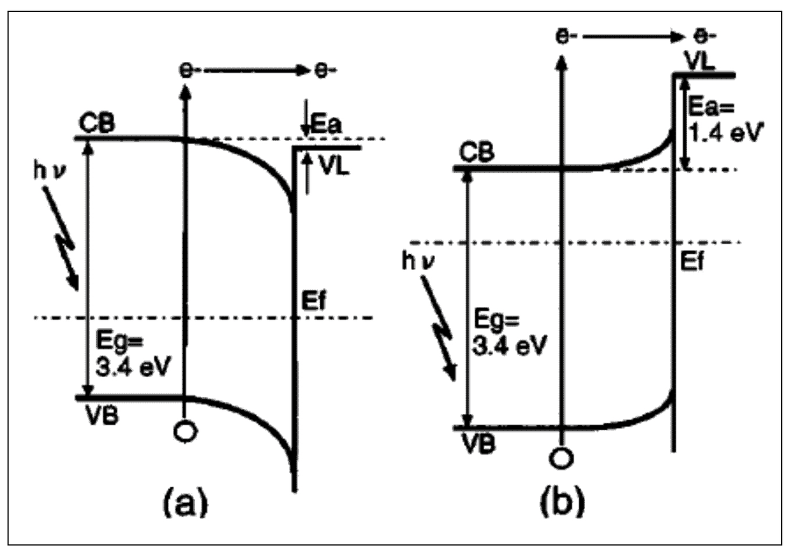
GaN is a semi-conductive material that is well known for high QE when lighted with UV light.

band structure of plain GaN (Figure b):

- e^- are not able to overcome the energetic barrier and leave the surface

band structure of Cs-activated p-GaN (Figure a):

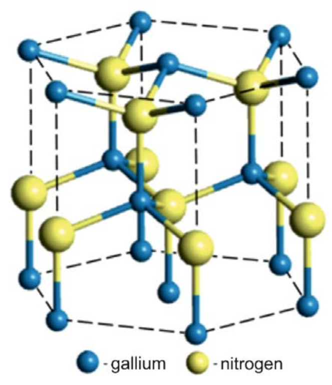
- Mg-dopant increases the e^- diffusion length
- activation only with Cs for achieving NEA surface
- band bending around the surface is lowered
  → vacuum level is shifted to lower energy than the CB
  → e^- can easily enter into vacuum



The equilibrium phase of GaN is wutzite, which means gallium atoms are tetrahedrically surrounded by nitride atoms in a hexagonal closed crystal structure. The tetrahedrons build alternating bilayers of Ga and N in c-direction.

The interesting characteristics of GaN(Cs):

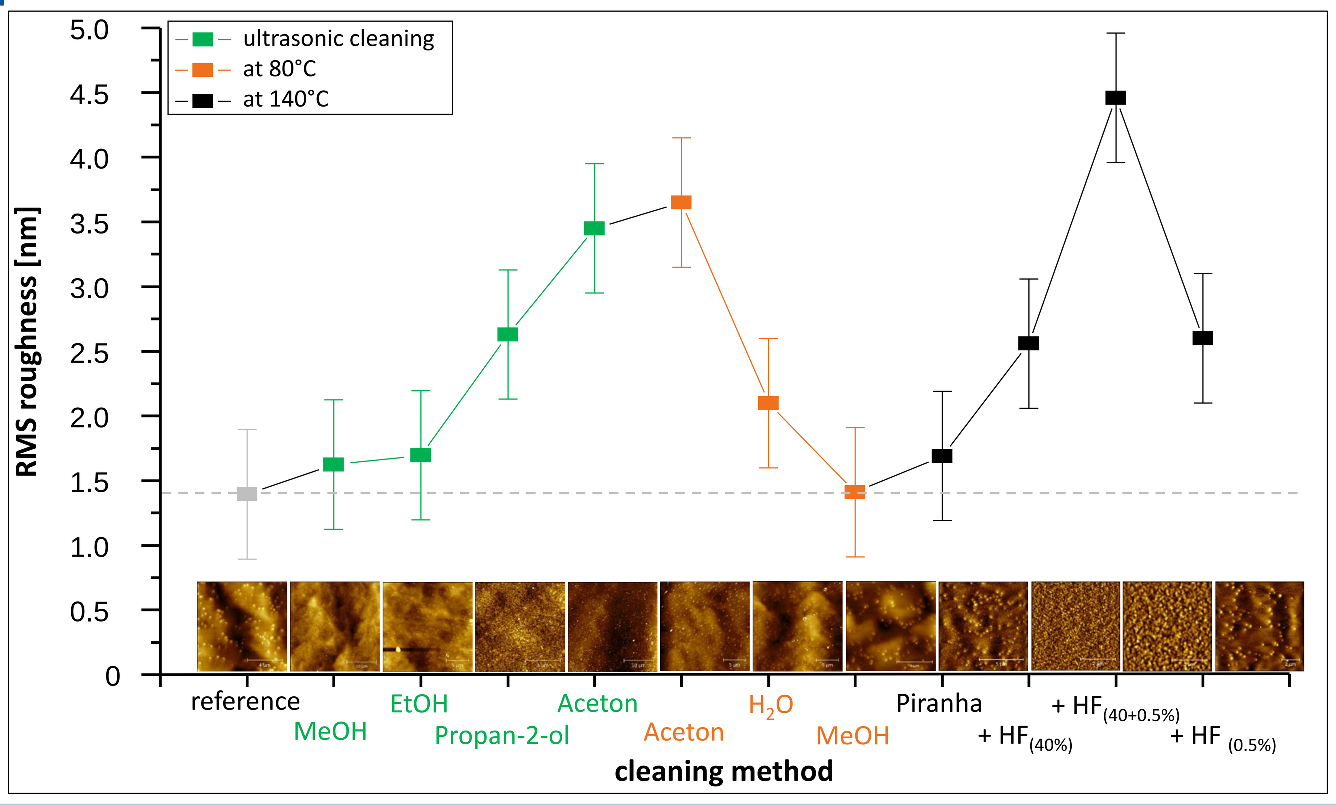
1. High QE: up to 40%
2. Robust against contamination & save storage
3. NEA surface can be achieved only with Cs
4. GaN sample on sapphire is commercially available

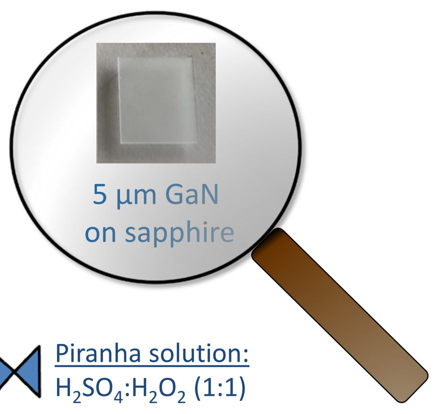


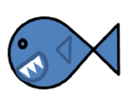
Analytic

AFM-Images

For achieving a good NEA surface a pre-chemical cleaning is necessary to remove all residual oxides from the surface. Several pre-cleaning processes are studied by AFM to identify which cleaning method provides the best surface smoothness.





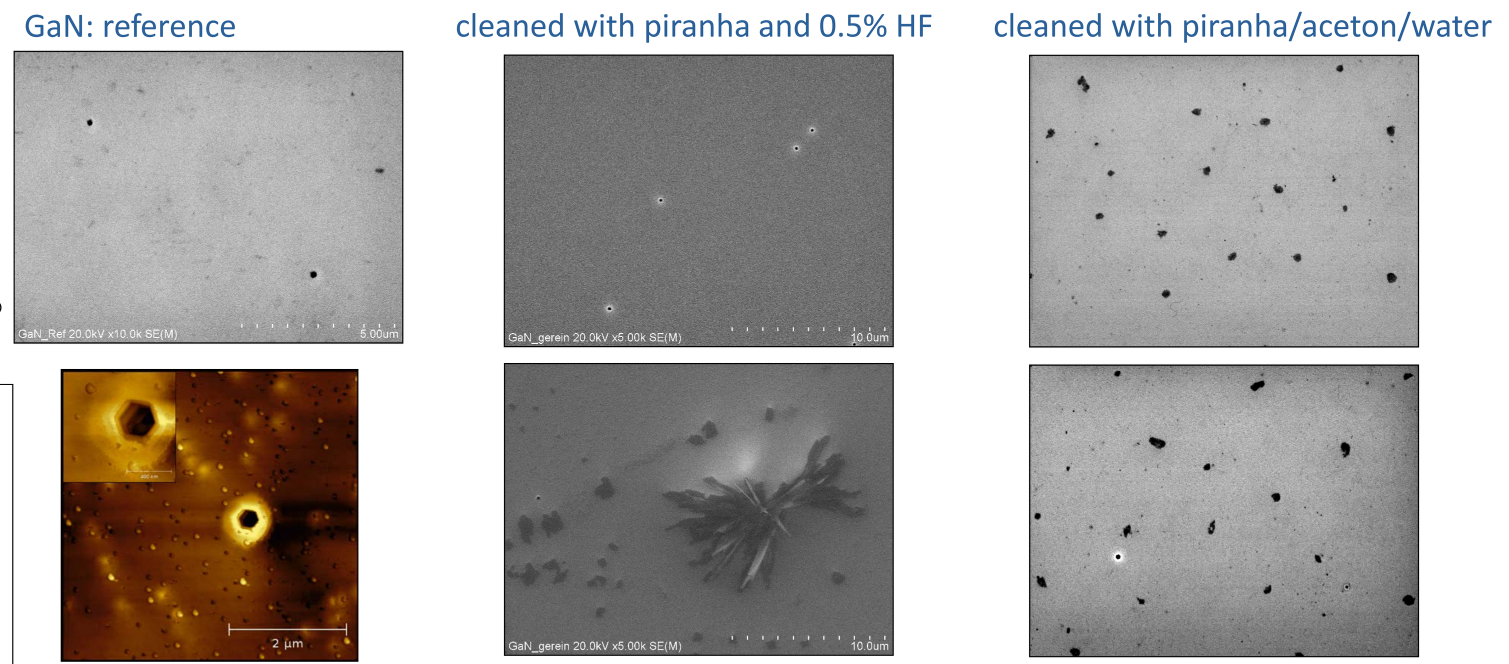


Piranha solution: H_2SO_4:H_2O_2 (1:1)

- ultrasonic bath (15 min)
- ultrasonic bath in aceton (15 min)
- piranha solution at 80°C (2min)
- dipped into HCl:H_2O (1:1)
- rinsed with…
- blown dry with N_2
- piranha solution at 140°C (15 min)
- dipped into…
- dipped into EtOH,
- benzene:isopropanol (3:1)
- blown dry with N_2

SEM Images

SEM images were made for better understanding of cleaned surface.

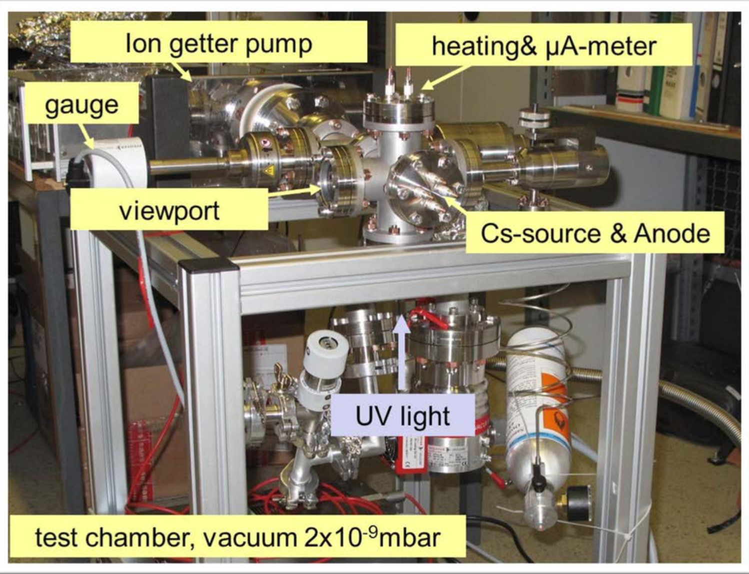


- untreated GaN shows a lot of etching pits (also seen in AFM)
- some cleaned GaN samples show contaminations, where crystals are growing onto the surface

→ need of AES/XPS measurements

1st activation

Test Chamber

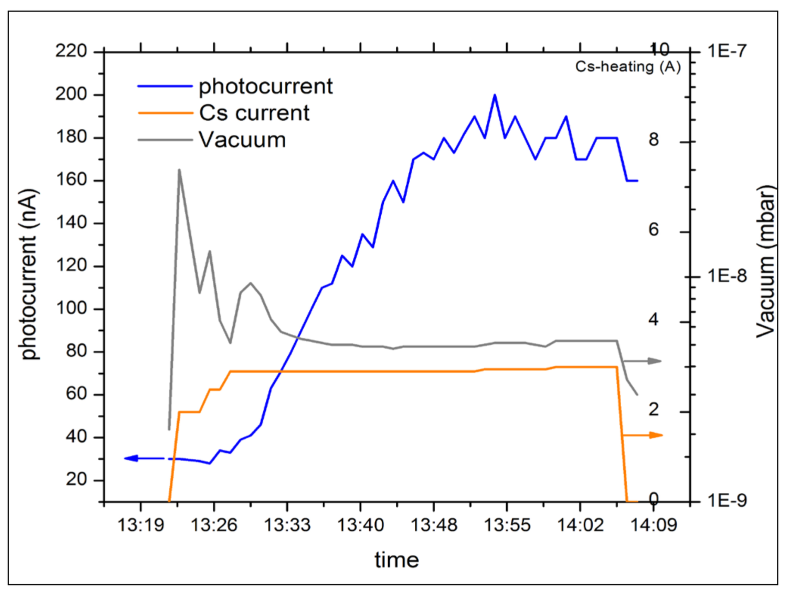


sample pre-treatment

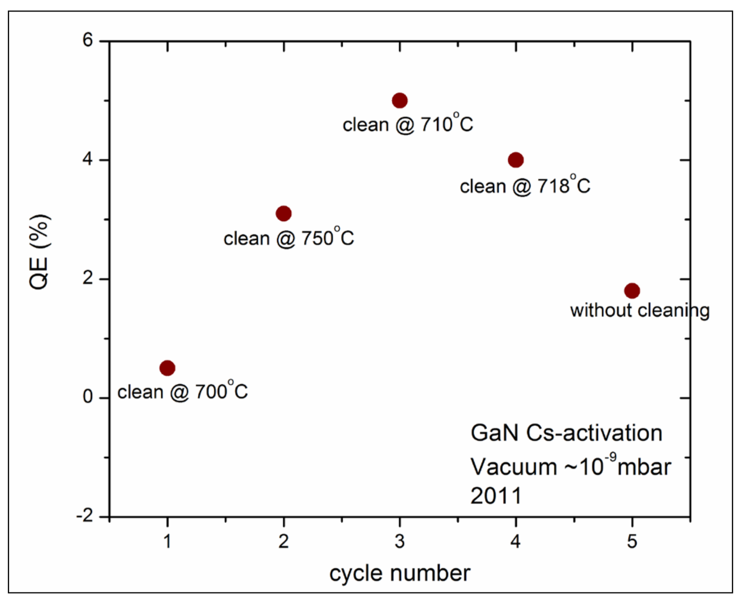
1. ultrasonic bath in MeOH (3 min)
2. dried with N_2
3. etch in H_2SO_4: H_2O_2 (4:1) (5 min)
4. rinse with deionized H_2O and MeOH
5. dried with N_2
6. deposition of Au layer (10nm) in corner (1 x 2 mm) & Ni Layer (20nm) on Au layer
7. annealing in N_2 at 450 °C for 5min

- sample of 10^{17}-level p-doped GaN grown on sapphire substrate
- pre-heat treatment at different temperatures
- activated with Cs-dispenser (SAES) to achieve the NEG surface
- background vacuum in the test chamber droped down during activation

Results-Test Chamber



The process steps of the NEA activation. A 262 nm laser was used for the process detection and a 500 V bias was supplied to the anode.



The sample was heated up to different temperatures and NEA activated with Cs. The QE of the activated samples was measured and the highest QE was detected at a cleaning temperature of 710° C.

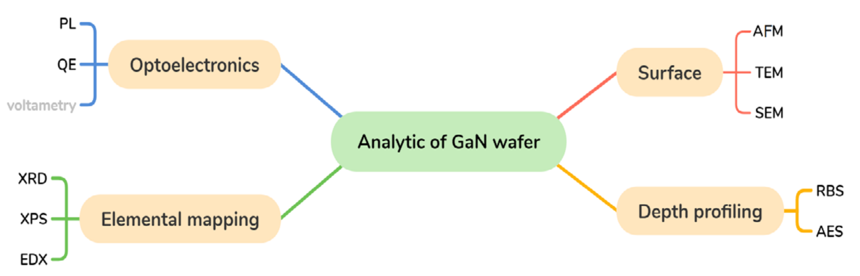
Future plans

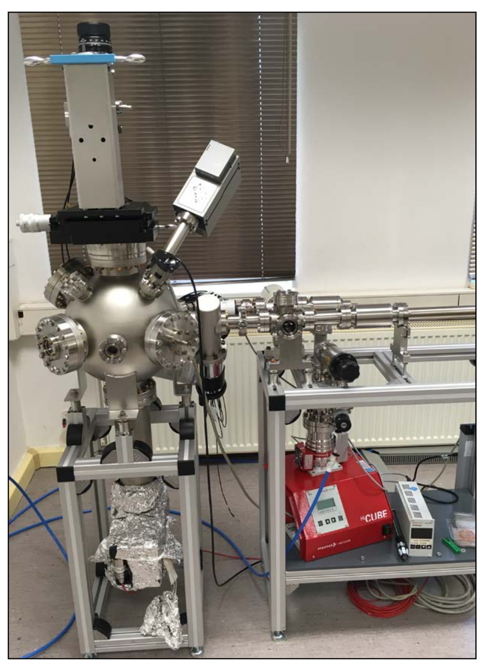
Outlook

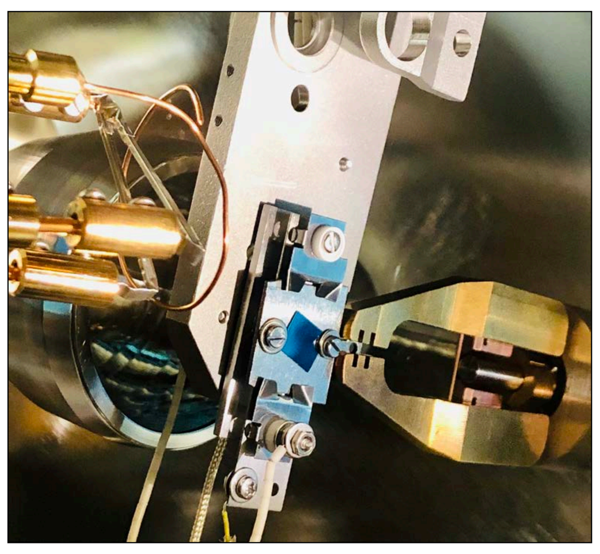
- cleaning process of GaN wafer? (analytic surface chemistry)
- compare GaN on different substrate material
- chemical stability under intensive laser?
- processing in SRF Gun II?

analytical chemistry

- SEM, TEM & AFM
- XRD, XPS & EDX
- RBS & AES
- PL & QE







Modification of activation chamber

combination with SEM/EDX

- easy measurement of activated GaN
- detect contaminations/ lattice impurities

sample changement

- easy handling
- transfer from glove box without air exposure

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HOPE II

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