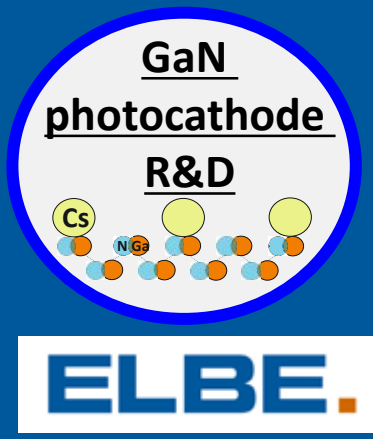

ELBE.

Institute of Radiation Physics

Radiation Source ELBE

The attempt of using GaN as a photocathode in SRF Gun II

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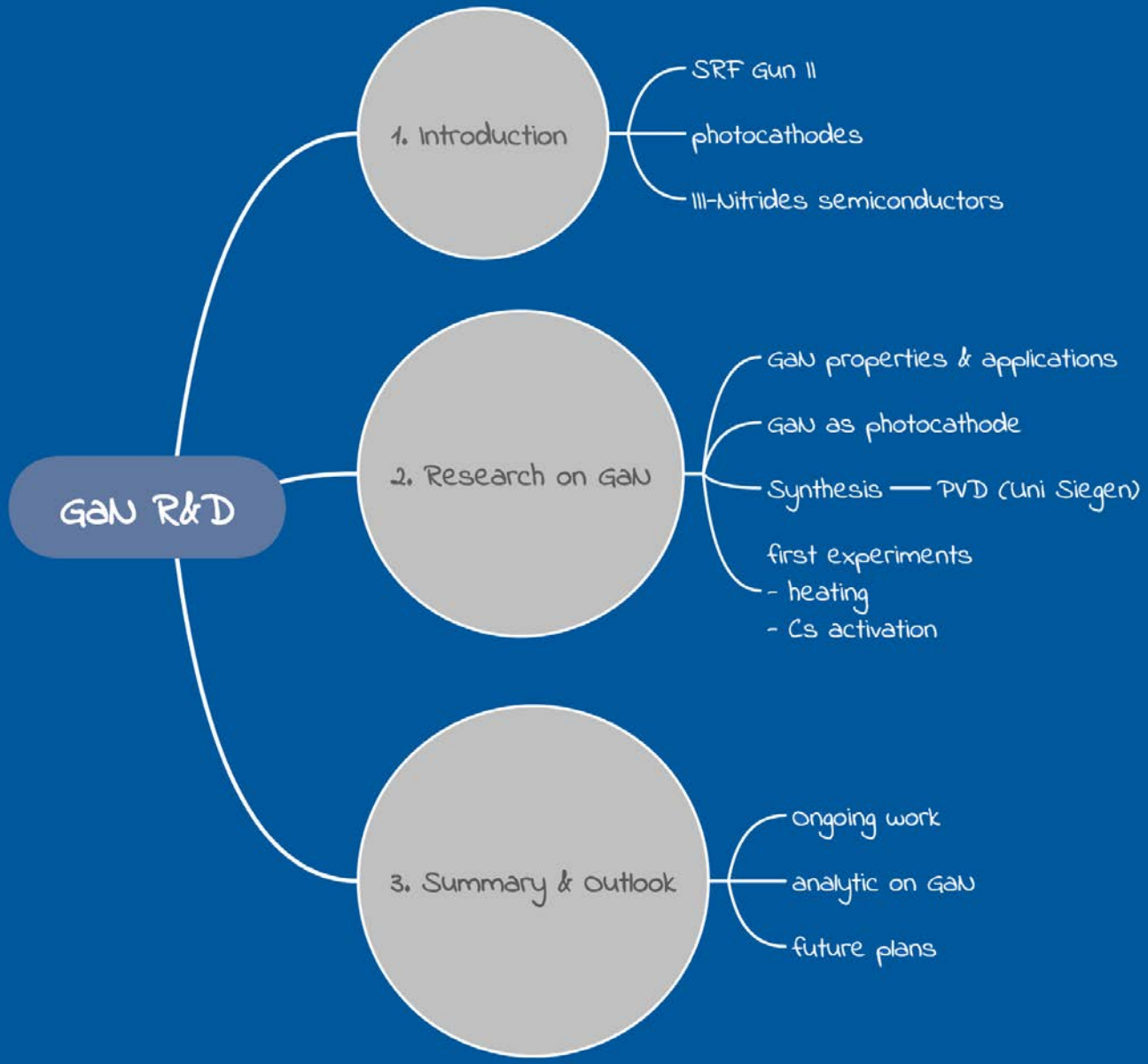
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

5th MT Meeting, Helmholtz-Institute Jena



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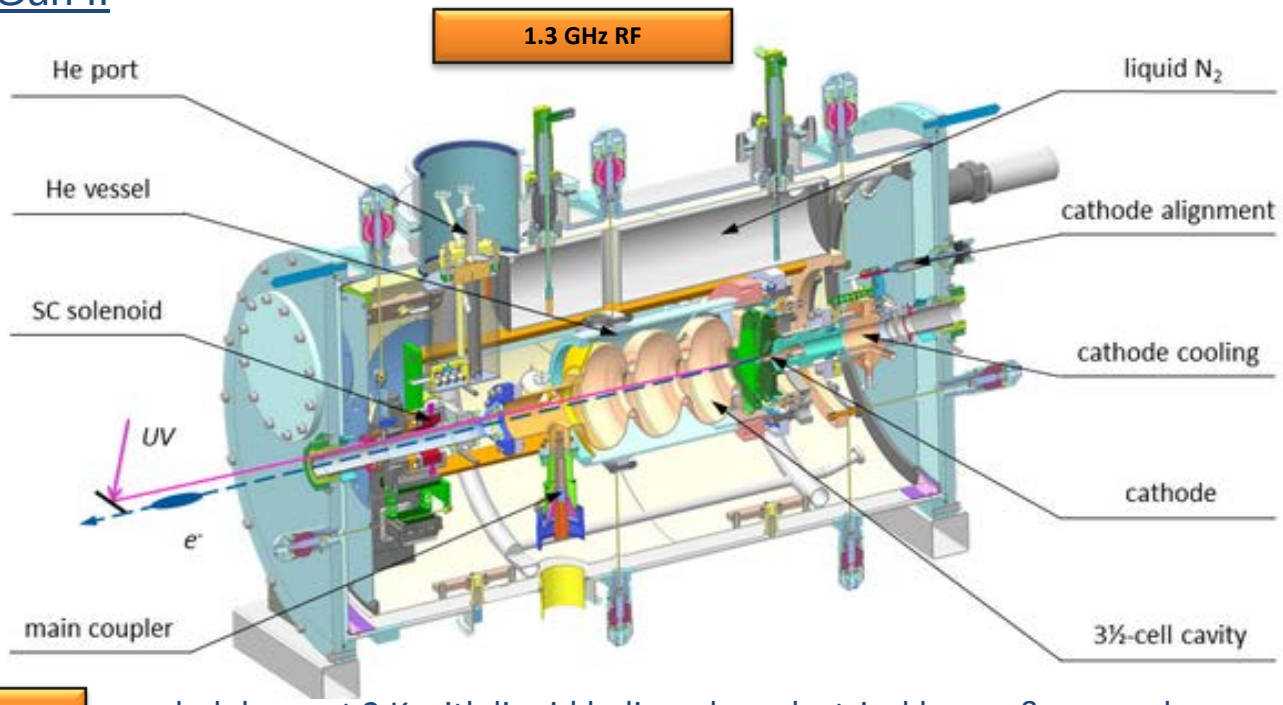
Introduction

Setup SRF Gun II



Core: 3.5 cell Nb cavity	cooled down at 2 K with liquid helium, low electrical losses & cw mode
SC solenoid	cooled down at 2 K, reduces the emittance
UV laser	illuminates the photocathode, max. power is 1 W

Development of photocathode plays an important role:

- Copper: used for demonstration of the working cavity and the first commissioning (QE of 10^{-5} with a bunch charge of several pC)
- Magnesium: mostly used for medium bunch charges of hundreds of pC (QE of 10^{-3} after cleaning)
- Cs_2Te: preparation and vacuum requirements are more complicated and higher (QE of 10^{-2})

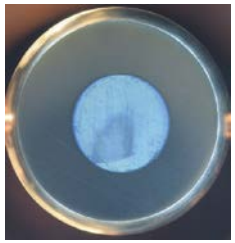
Lu, Pengnan. 2017. “Optimization of an SRF Gun for High Bunch Charge Applications at ELBE.”

Introduction

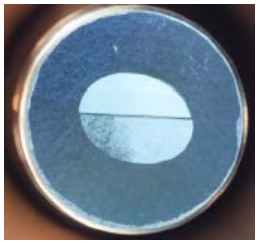
Photocathodes

Property [Unit]	K_2CsSb	Cs_2Te	GaAs	Cu	Mg	GaN
harmonic	2	4	2	4	4	3
λ [nm]	532	266	532	266	266	365
QE [%]	8	5	5	1.4E-2	0.5	~40
lifetime [hours]	4	> 100	58	> 1 year	> 1 year	several years (not in gun)
temporal response [ps]	prompt	prompt	< 40	prompt	prompt	prompt
vacuum tolerance	poor	very good	poor	excellent	excellent	excellent

- Drive laser: Nd:YAG, output at 1064 nm



Cs_2Te

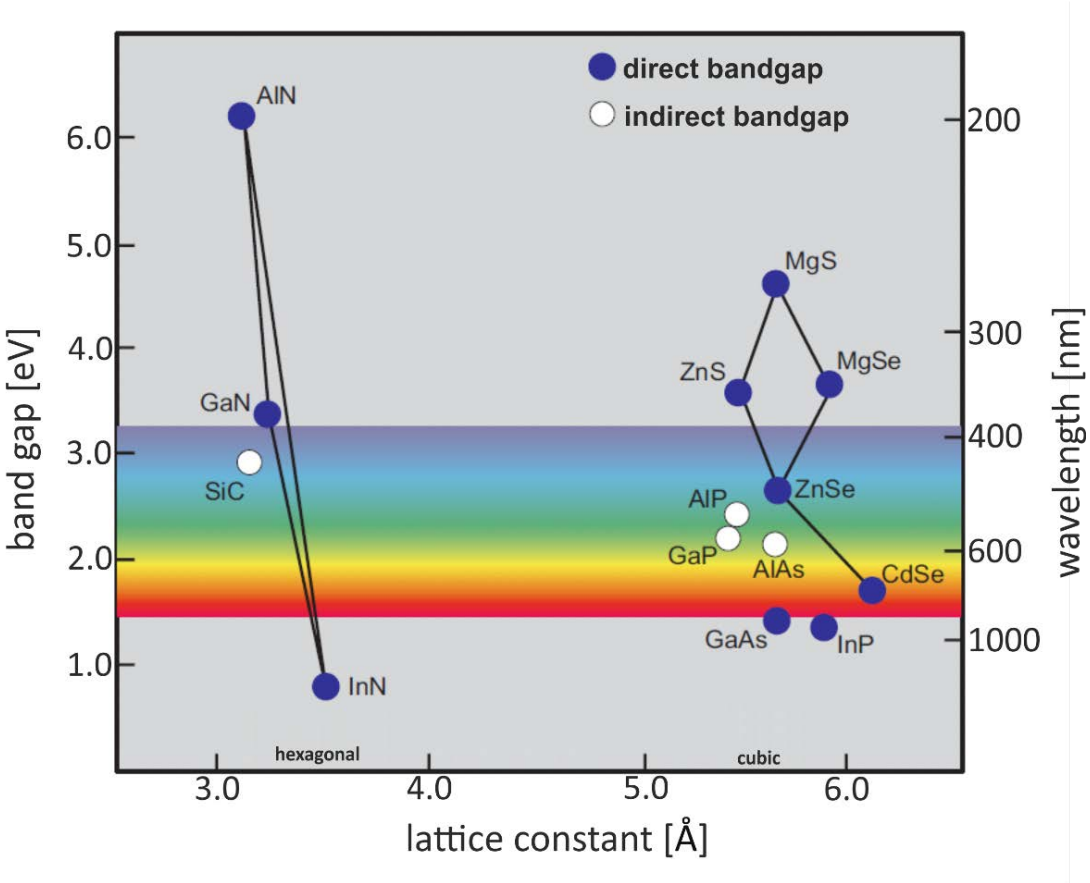


Mg

Introduction to the physics of electron emission, K.L.Jensen, 2017, p. 444 f.
Bazarov, Ivan V. et al. 2009. "Thermal Emittance and Response Time Measurements of a GaN Photocathode." Journal of Applied Physics 105(8).

Research on III-Nitrides

- high relevance for industry
- very good thermical, mechanical and electrical properties
- direct band gap: range from red to UV



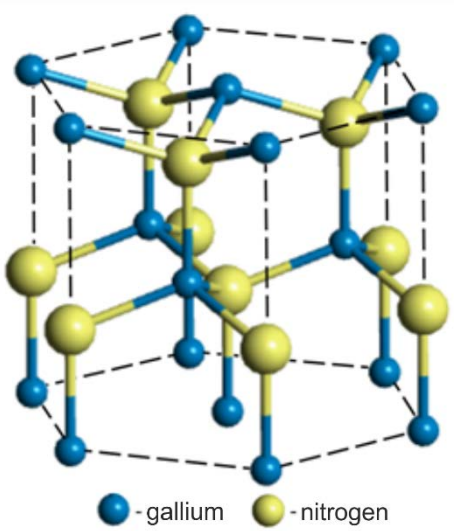
- especially used for short-wavelength devices in UV range (LEDs or LDs)
- based on thin semiconductor films with a large band gap
  → avoiding structural and point defects

Quay, Rüdiger. 2008. “Gallium Nitride Electronics.” in Springer Series in Material Science.

Focus on GaN

❖ Properties of GaN

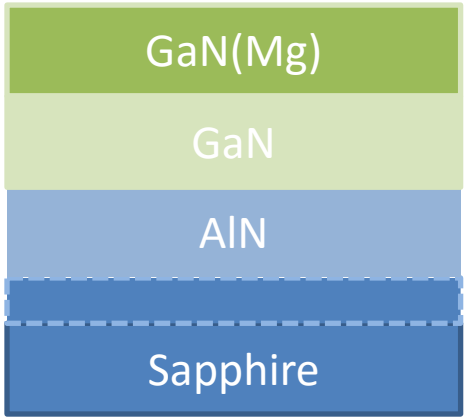
- direct semiconductor
- band gap of 3.37 eV @ 300 K
- Wurtztite structure:
  (hexagonal closed crystal structure: atoms have 4 neighbours (tetrahedrally coordinated)
  →alternating bilayers of Ga and N in c-direction (**ABAB**)



❖ Applications of GaN

- Light emitting diodes (LEDs)
- Laser diodes (LDs)
- UV detectors
- Data storage (Blu-Rays)

❖ GaN used as a photocathode

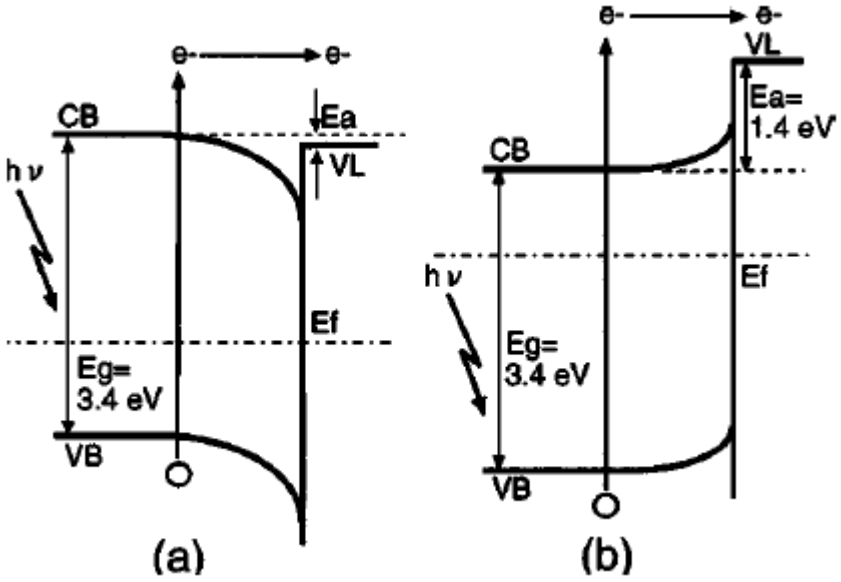


- substrate: sapphire, Si, SiC or metal
- high QE (~ 40%, up to 70%)
- working wavelength range of 150 nm~400 nm
- low thermal emittance and fast response
- negative electron affinity (NEA)
  → cesium lowers the conducting band minimum below the vacuum level
- High robustness: resitant to vacuum contamination
- Good storage: ~3 years under nitrogen atm.

Siegmund, O. et al. 2006. "Development of GaN Photocathodes for UV Detectors." 567:89–92.
Machuca, Francisco et al. 2011. "Prospect for High Brightness III – Nitride Electron Emitter Prospect for High Brightness III – Nitride Electron Emitter." 3042(2000):1–6.

Focus on Research on GaN

GaN band structure



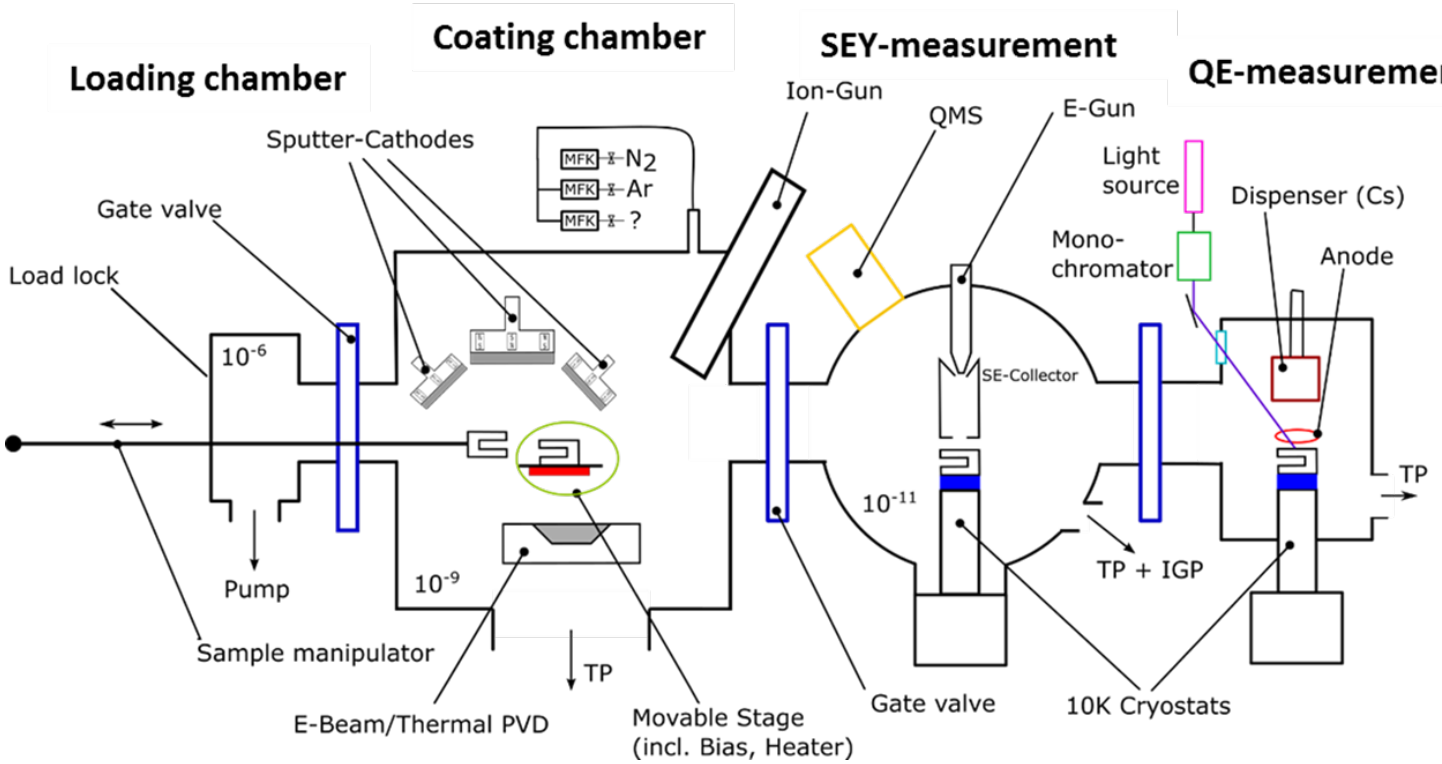
- Band gap of 3.4 eV → Laser wavelength of 365 nm
- (a) Mg GaN (Cs): Mg doping rate of $10^{16}cm^{-3}$ (minimum) to $10^{19}cm^{-3}$ (maximum)
  shift of vacuum level to lower energy than CB
  NEA: electron excite over the band gap and easily enter into vacuum
- (b) undoped GaN (Cs): high potential barrier, electrons cannot leave the surface

Problem of high doping: many trap sites and recombination centers

Uchiyama, Shoichi et al. 2011. "GaN-Based Photocathodes with Extremely High Quantum Efficiency GaN-Based Photocathodes with Extremely High Quantum Efficiency." 103511(2005):1–4.

Research on GaN

Setup PVD for GaN at University Siegen

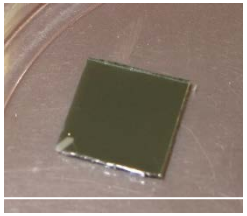


Courtesy of M. Sc. M. Schumacher

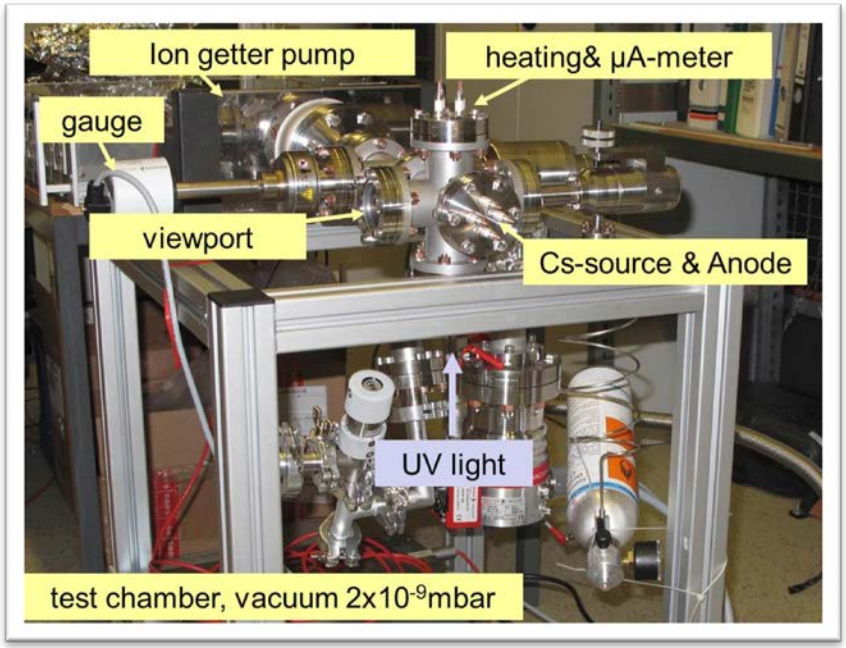
- coating chamber: samples/substrate can be cleaned utilizing an ion gun (H^+, He^+ or Ar^+)
- latter is done by sputtering cluster (In, Mg, Ti, GaAs as Ga source)
- last chamber: activation of sample and QE measurement

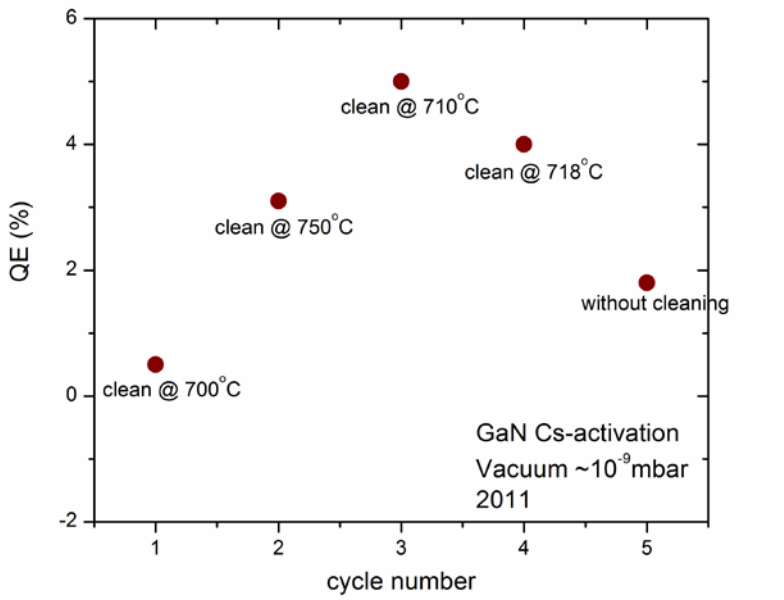
Focus on Research on GaN

First activation treatments


GaN on sapphire

- made on a sample of 10^{17}-level p-doped GaN grown on sapphire
- only cesium (SAES Cs-tube) is used in the test to achieve the NEG surface
- background vacuum is usually $2 \cdot 10^{-9}$ mbar in the small test chamber
- during the heat treatment at~700°C : vacuum droped down to $2 \cdot 10^{-6}$ mbar
- After heating: stable again at $5\text{-}6 \cdot 10^{-9}$ mbar, also during activation process

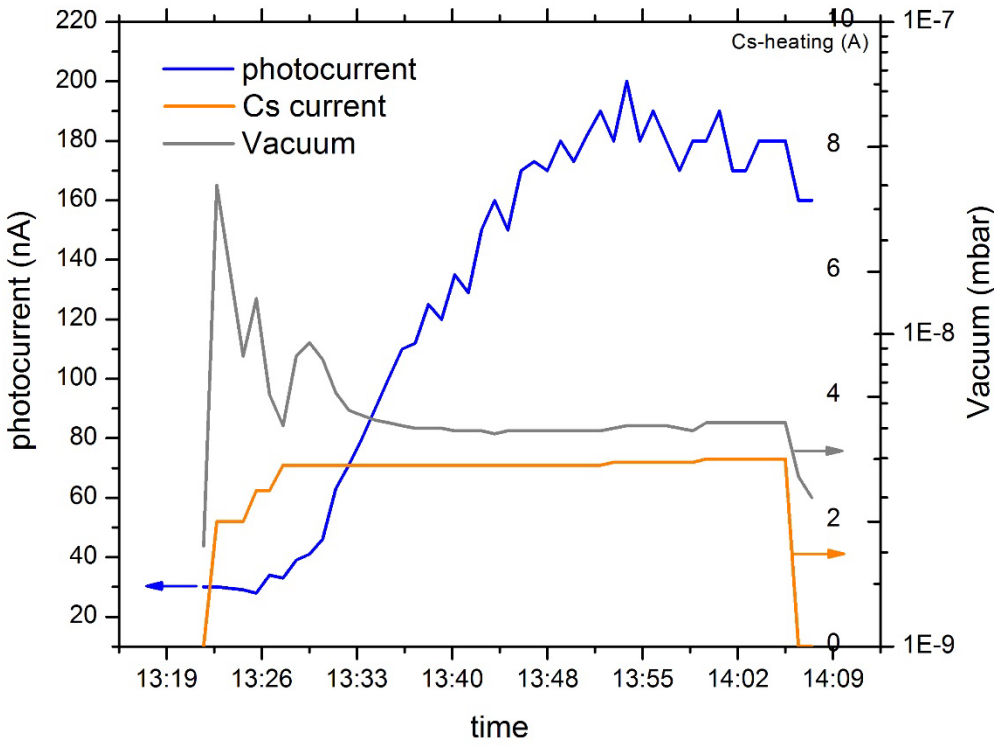




- 710°C seems suitable for the heat cleaning of GaN
- 5% is the best QE in the activation tests on the same sample

Focus on Research on GaN

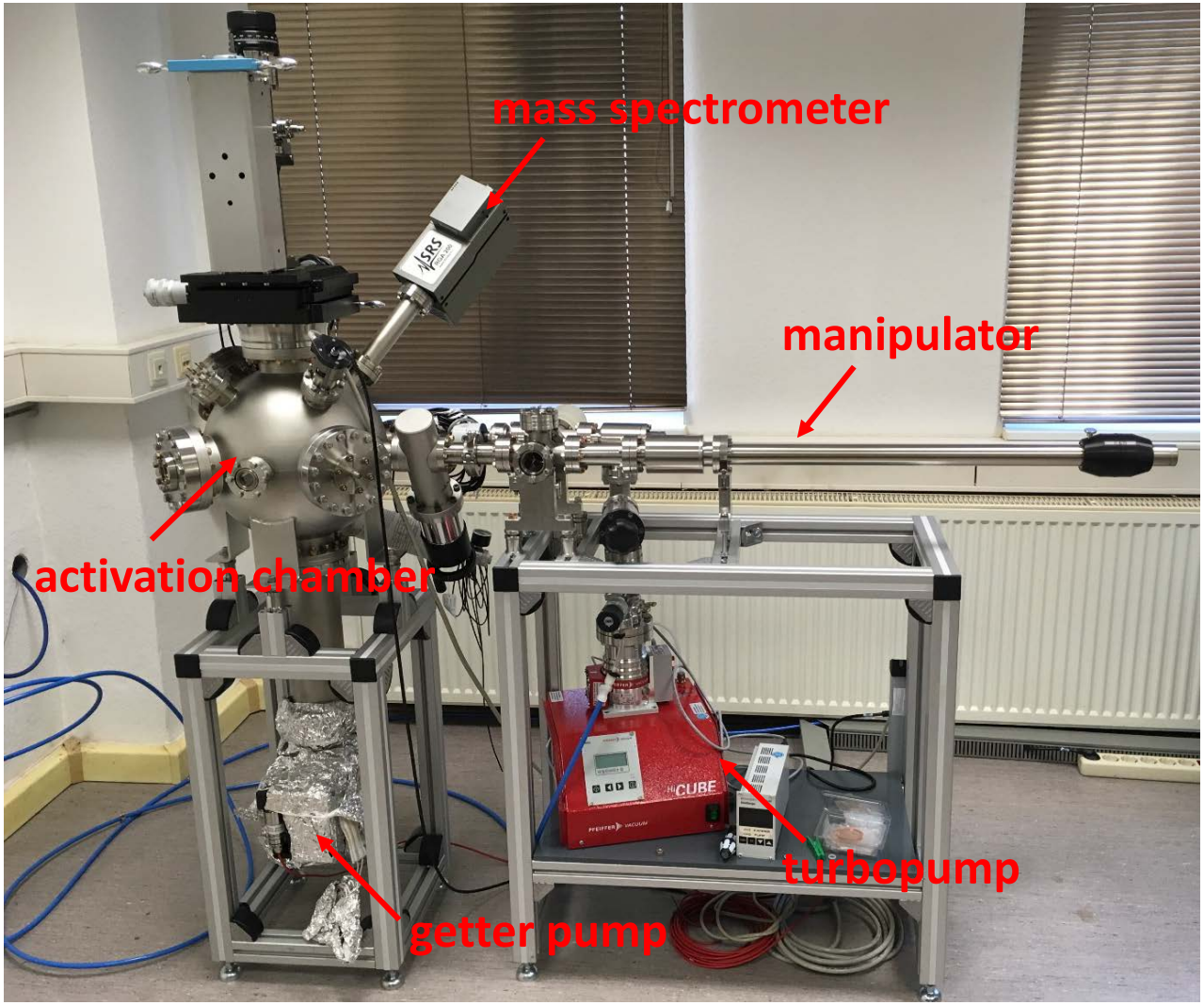
First activation treatments



- thermal cleaning of the surface (710°C: oxides disappear)
- cathode has to cool down on room temperature
- applying a Cs layer with a Cs dispenser
- QE is controlled via laser during the preparation

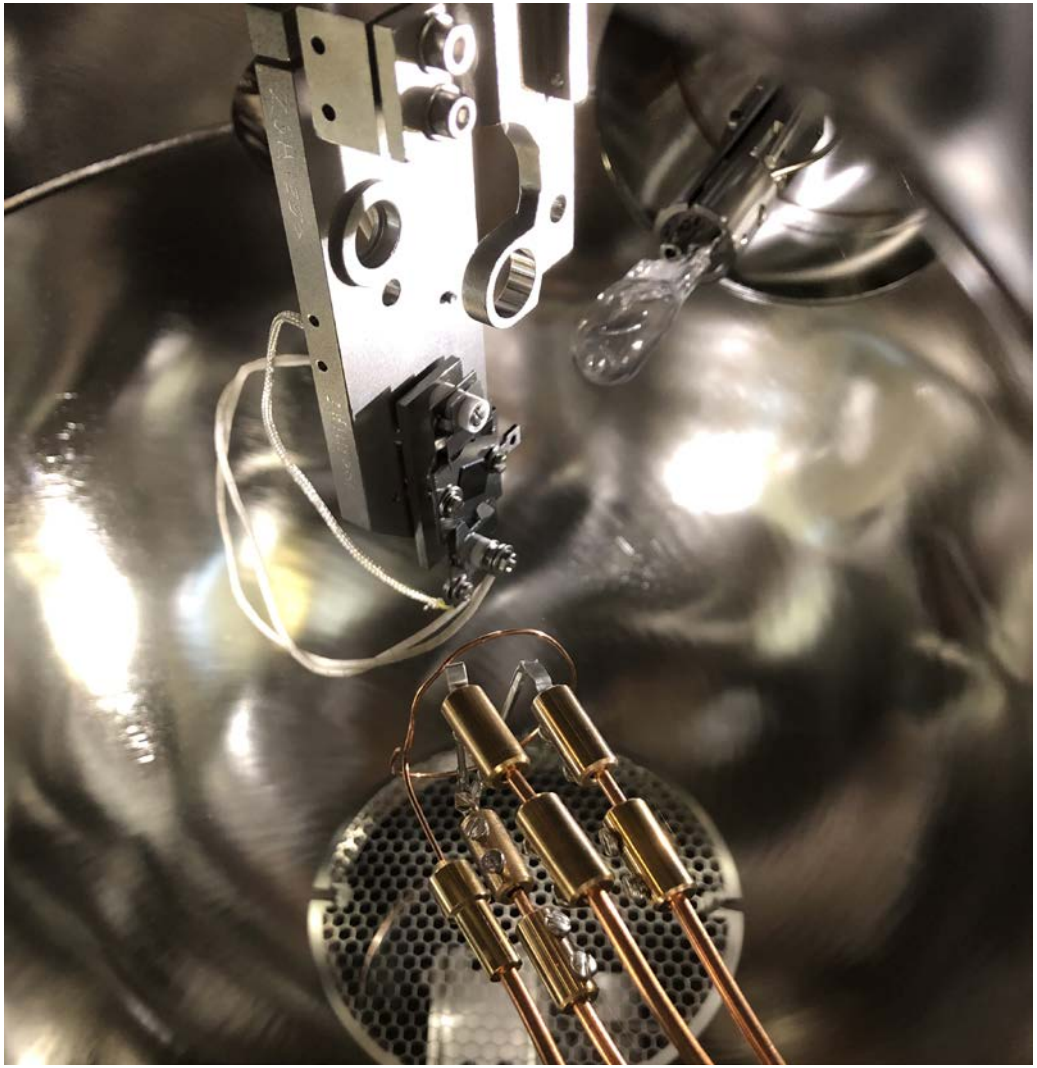
Focus on Research on GaN

OnGoing work- GaN(Cs)



Focus on Research on GaN

OnGoing work- GaN(Cs)

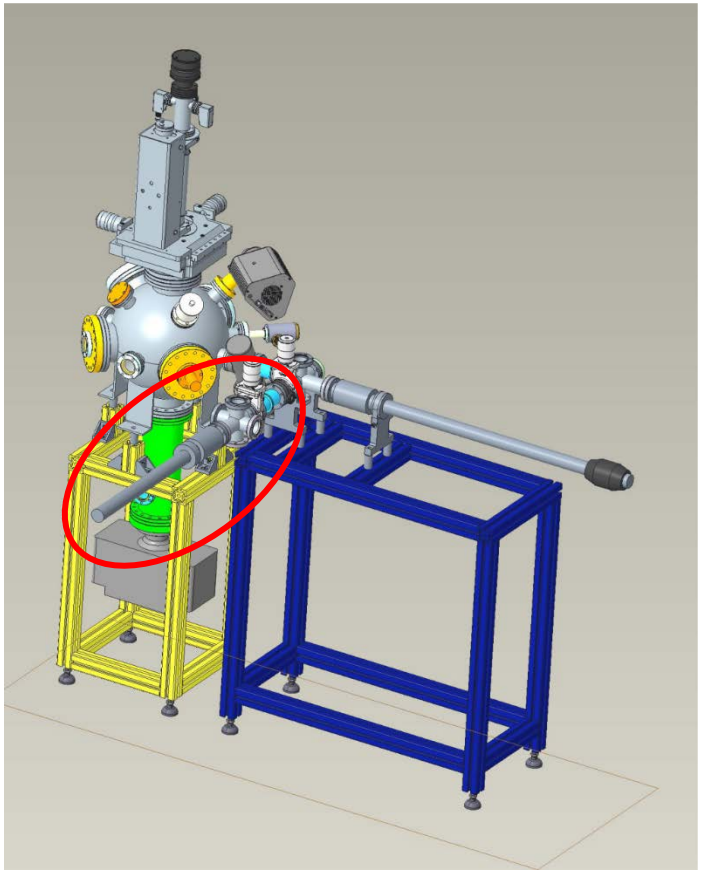


Focus on GaN

OnGoing work- GaN(Cs)

Sample changement

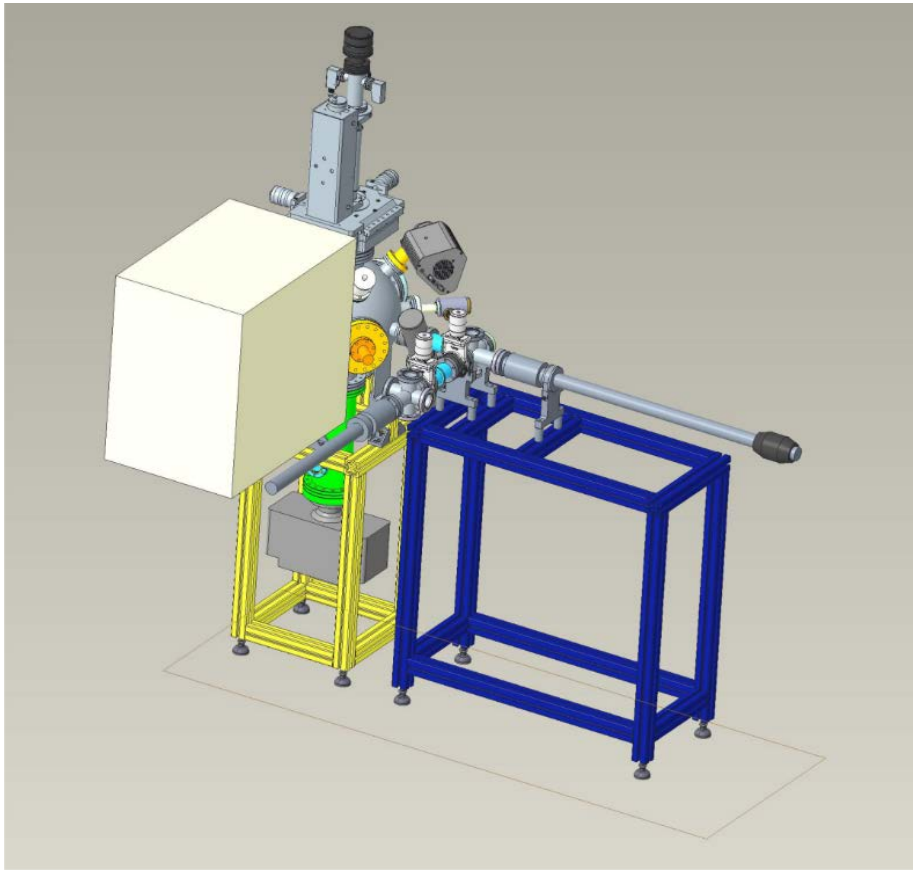
→ easy handling



Combination of activation chamber with SEM/EDX

→ easy measurement of activated GaN

→ detect contaminations/ lattice impurities

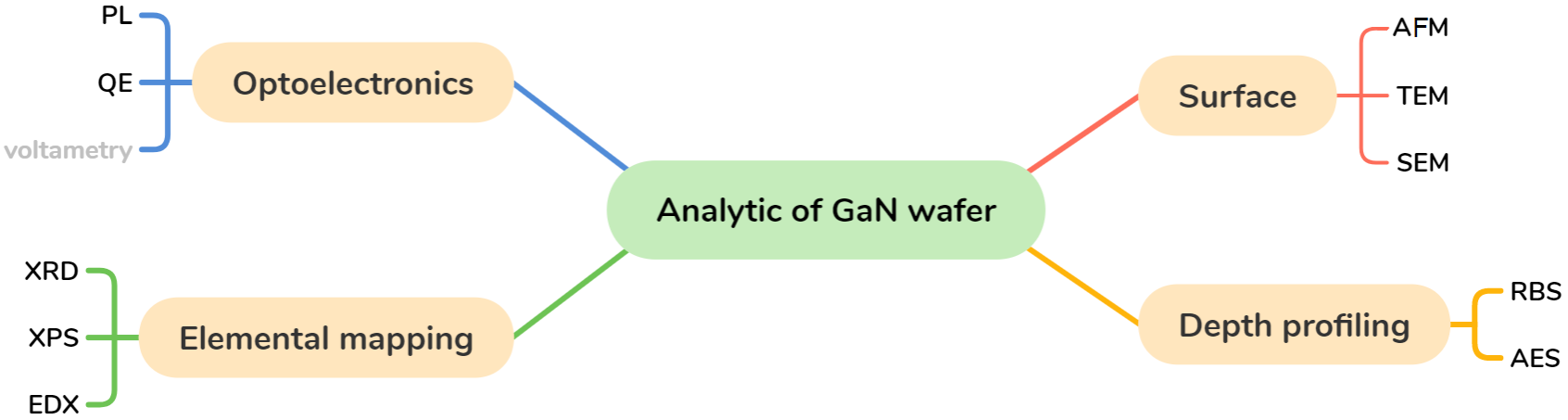


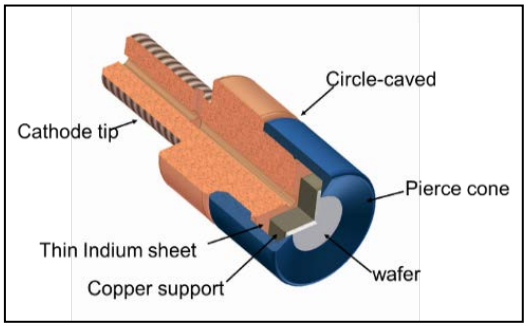
Focus on Research on GaN

OnGoing work

open questions???

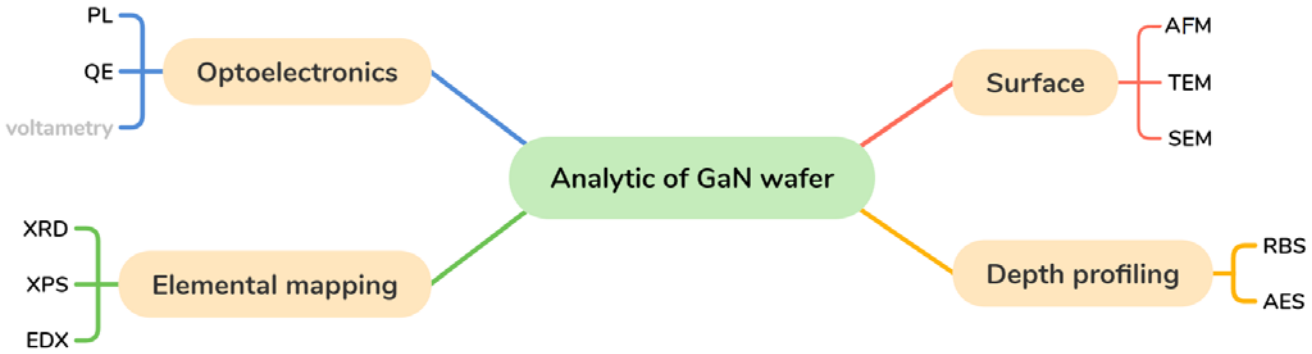
- proper substrate material and its influence
- thermal emittance
- field emission from NEA surface
- chemical stability under intensive laser

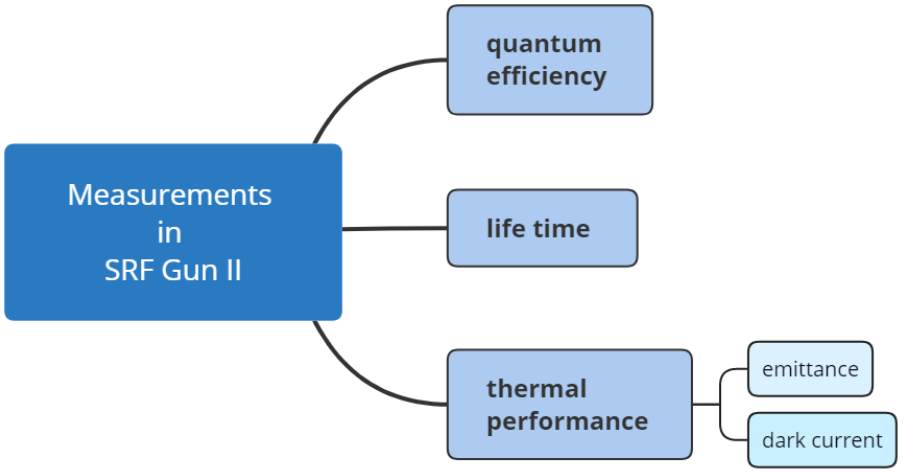




Summary and Outlook

- Characterization and comparison of commercial available GaN wafer (surface parameters, depth profile, elemental mapping, cleaning process, QE)
- Activation of GaN wafer with Cs and characterization of activated GaN
- Comparision to GaAs & selfmade sputtered GaN (Uni Siegen)
- Last phase: test in SRF Gun II as a photocathode for high brightness beam





Thank you for your attention!

Thanks to the ELBE team

J. Teichert, R. Xiang, P. Michel, A. Arnold, P. Murcek, P. Zwartek, M. Freitag, R. Steinbrück

and to our co-workers and partners

Universität Siegen

Johannes Gutenberg-Universität Mainz

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