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

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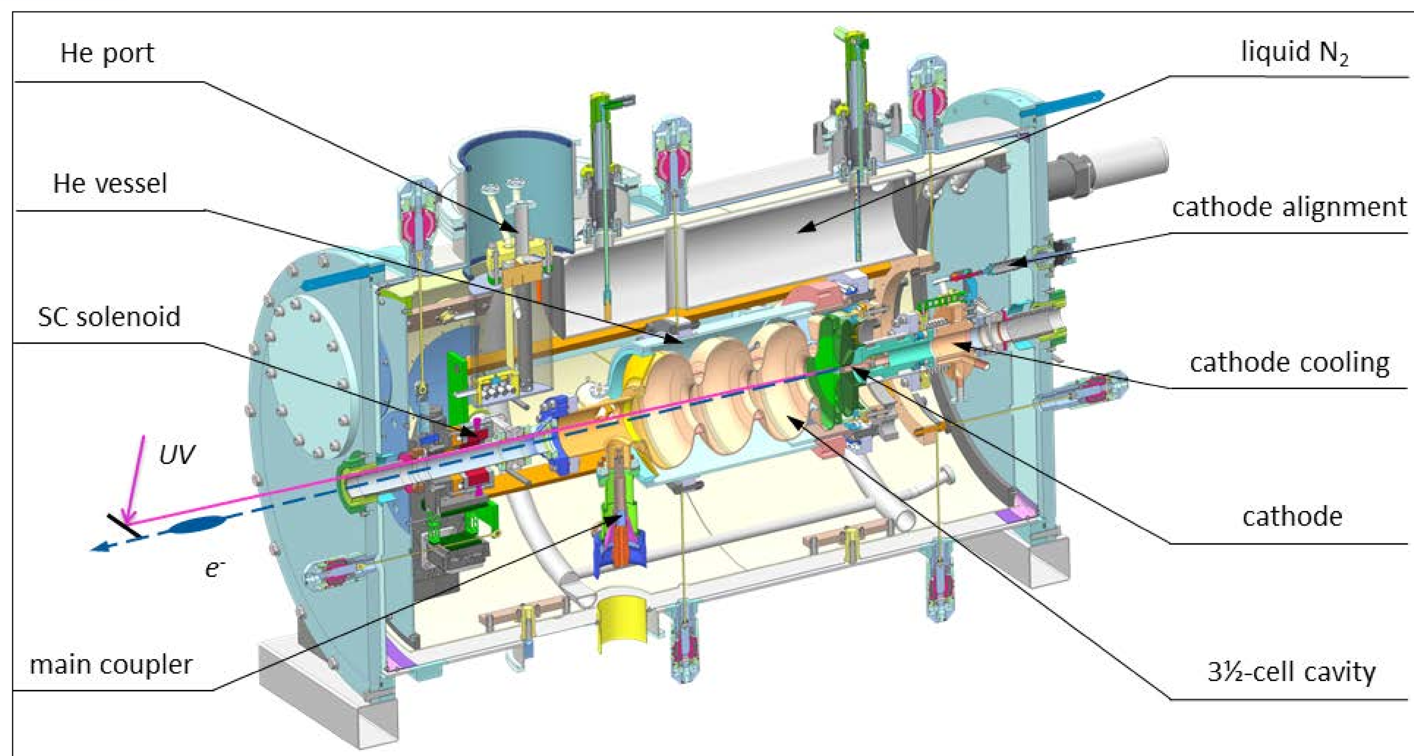
1. Introduction

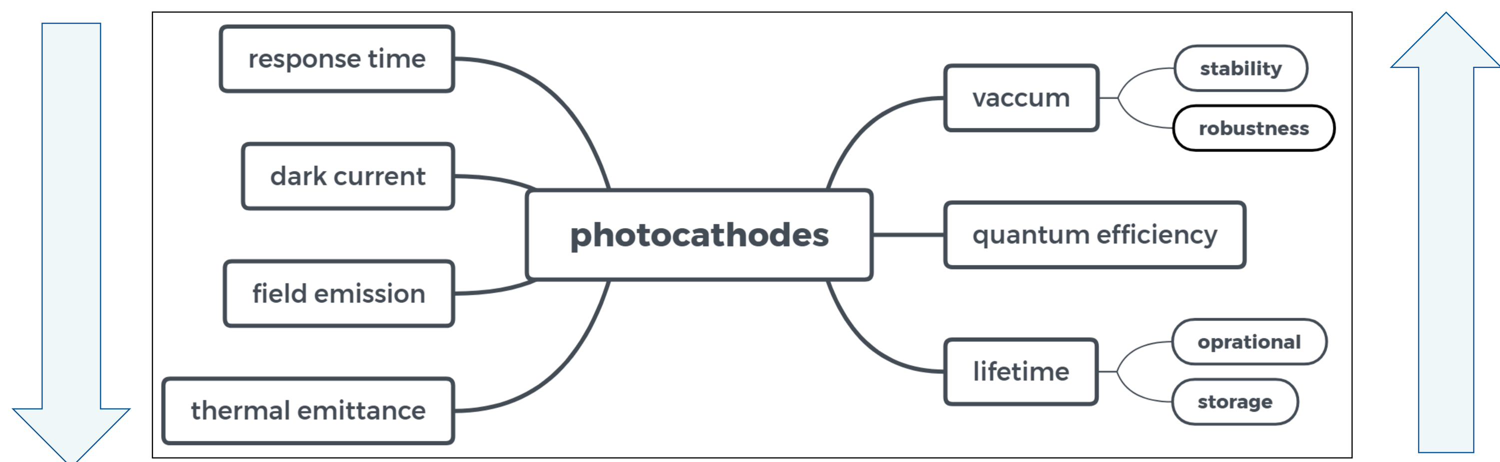
SRF Gun II



superconductive accelerator electron source in HZDR

desireable requirements for photocathodes

- searching for better photocathodes is one of the principle challenge for photoinjectors
- using photoemission effect
- novel III-V semiconductor with direct & wide band gap (3.4 eV)



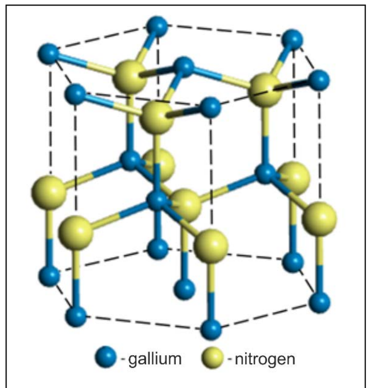
requirements for photocathodes used in accelerators

2. GaN (Cs)

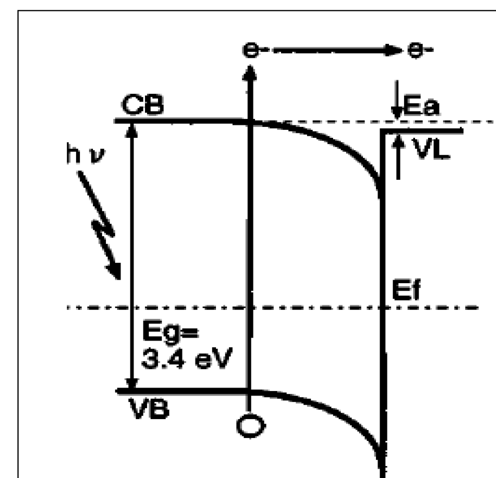
$$QE = \frac{N_{generated\ electrons}}{N_{incident\ photons}}$$

GaN & its characteristics

- high QE (~40%)
- working wavelength range of 150 nm- 400 nm
- negative electron affinity (NEA) → only with Cs
- High robustness: resitant to vacuum contamination
- Good storage: ~3 years under nitrogen atmosphere



wurtzite structure of GaN



[S. Uchiyama., et al., APL 86, 103511 (2005)]

band structure of GaN (Cs)

cesium activation & NEA

- Mg doping is necessary
  → increases diffusion length of e- to surface
- activation with monolayer of Cs
  → work function near surface is lowered below vacuum level

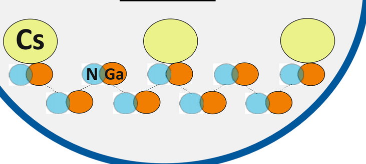
Table 1: Comparison of different photocathodes for SRF Guns

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
response time [ps]	prompt	prompt	< 40	prompt	prompt	???
vacuum tolerance	poor	very good	poor	excellent	excellent	excellent

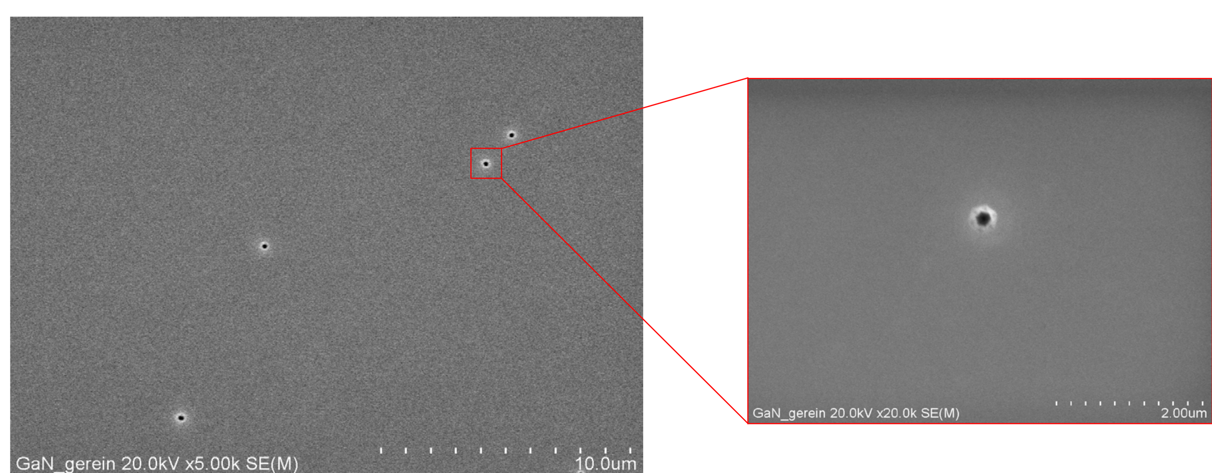
* For drive laser: Nd:YAG, output at 1064 nm

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).

GaN photocathode R&D



3. SEM/EDX



SEM image of GaN with etching pits

- Etching pits are from dislocations, can be found in cleaned and not cleaned GaN

Further research is required:

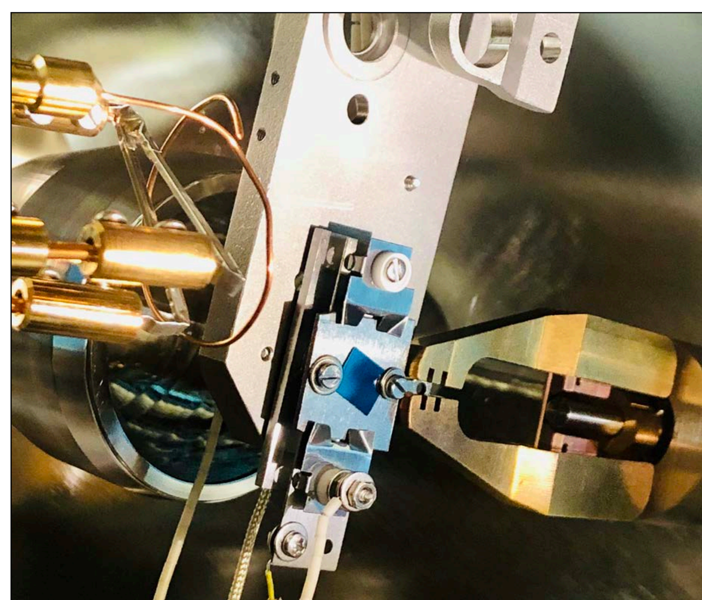
- Which cleaning porcess has an influence on this etching pits?

4. Ongoing working plan

analytical chemistry

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

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



view inside in activation chamber

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

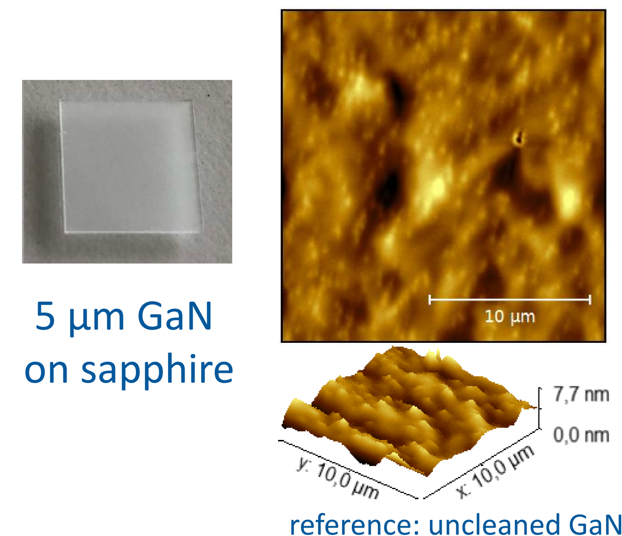
SEM/EDX measurments were performed by REM Hitachi S-4800

3. AFM images

Table 2: different wet chemical treating

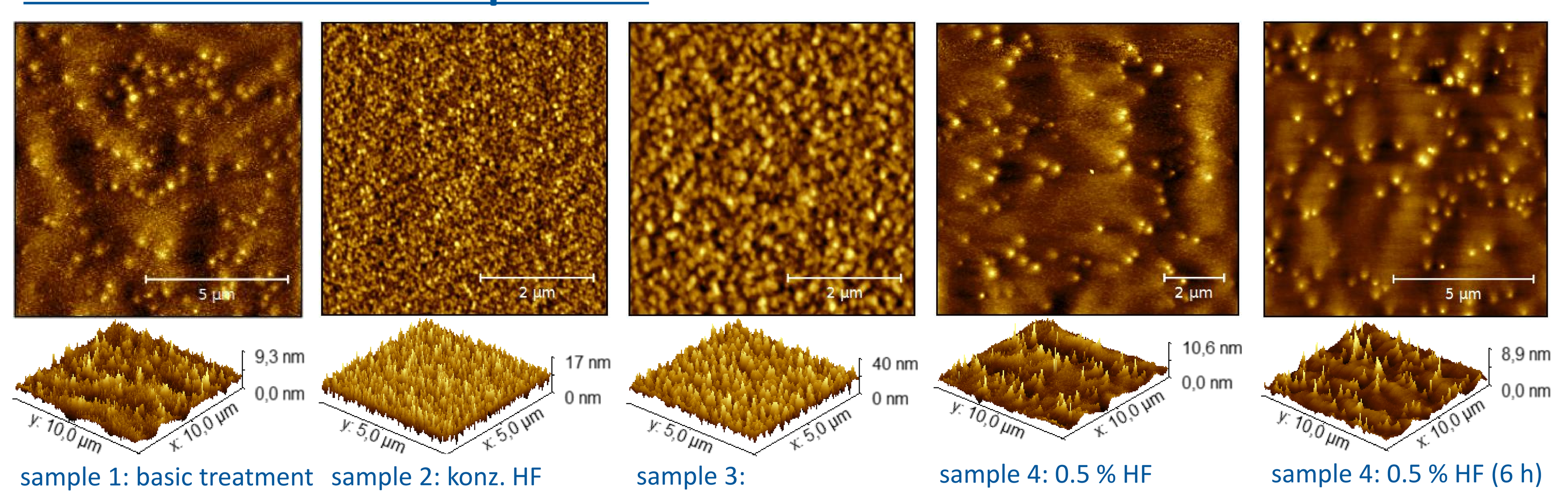
	sample No.	1	2	3	4
basic treatment	H_2SO_4:H_2O_2 (1:1), T ~140°C (15 min)	✓	✓	✓	✓
	rinsed 2 x H_2O	✓	✓	✓	✓
	Konz. HF (30 s)	-	✓	✓	-
	0,5% HF (2 min)	-	-	✓	✓
	H_2O rinsing tank (10 min)	-	-	✓	✓
post-treatment	EtOH & Benzol/Isopropanol (3:1) (1 min)	✓	-	✓	✓

5 µm GaN on sapphire



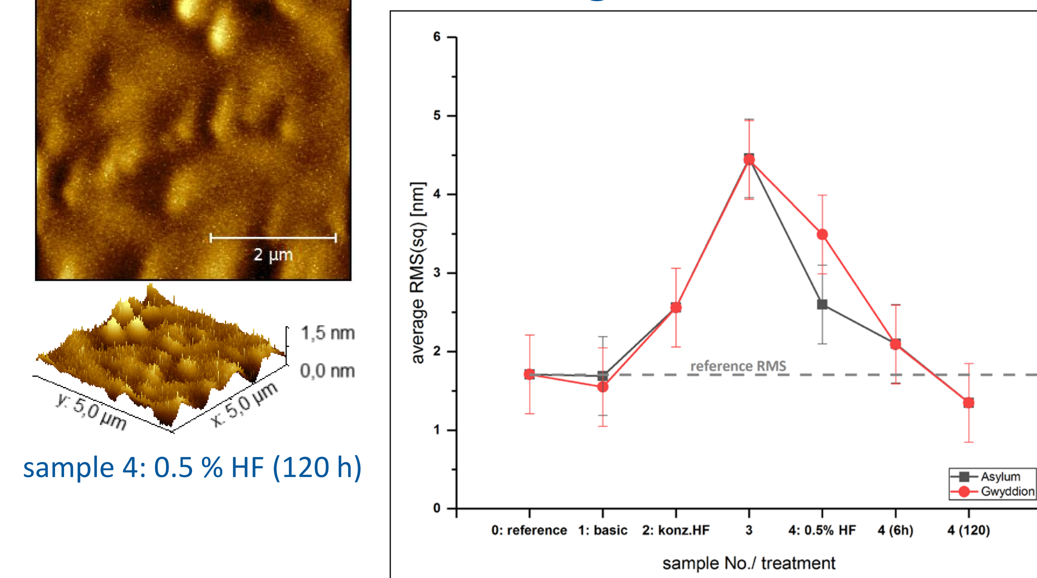
reference: uncleaned GaN

2Ds & 3Ds of GaN samples 1-4



sample 1: basic treatment · sample 2: konz. HF · sample 3: konz. HF & 0.5% HF · sample 4: 0.5 % HF · sample 4: 0.5 % HF (6 h)

RMS Roughness



sample 4: 0.5 % HF (120 h)

Graph 1: comparison of the average RMS

- basic treatment = reference
- using HF acid: increases roughness
- using konz. & 0.5% HF: maximum
- sample 4: surface reoxidizes after several hours & reached the same as reference

AFM images were made by Asylum Reasearch Cypher AFM microscope in AC mode

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