Update NOVALIS

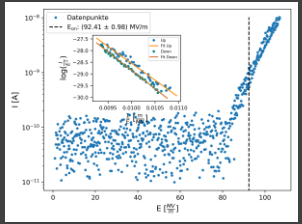
Frederic Braun
fbraun@uni-wuppertal.de
Dirk Lützenkirchen-Hecht
dirklh@uni-wuppertal.de

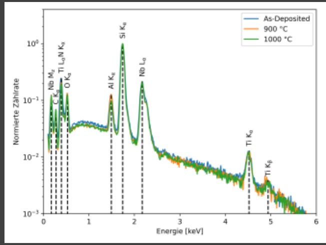
BERGISCHE UNIVERSITÄT WUPPERTAL

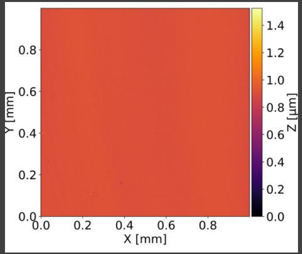
NbTiN Samples

- Samples system
  - Si(100)-Wafer
  - 15 nm AlN
  - 60 nm $Nb_{0.75}Ti_{0.25}N$
- Three samples
  - As-Deposited
  - Annealed at 900 °C (1 h)
  - Annealed at 1000 °C (1 h)

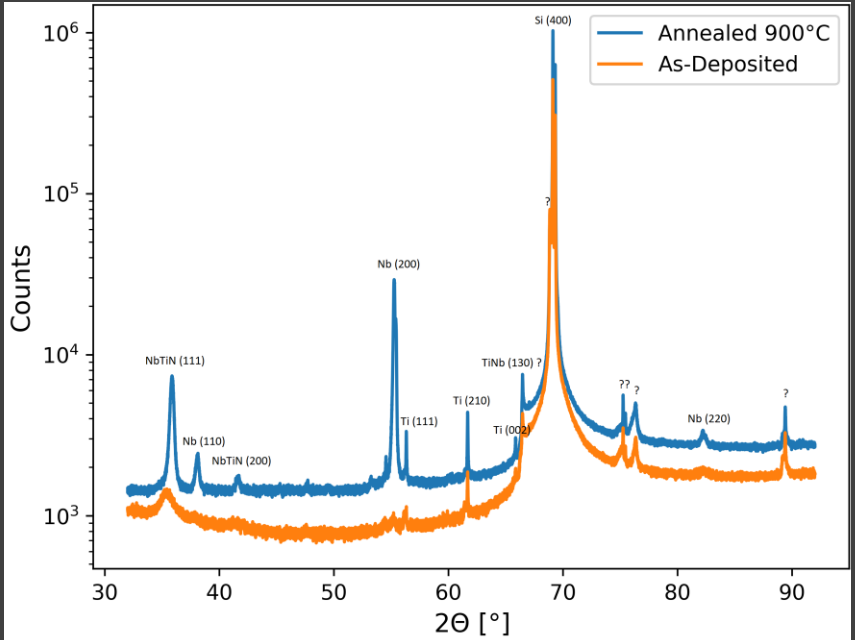
Analysing with
- FESM
- XRD
- EDX
- SEM
- OP



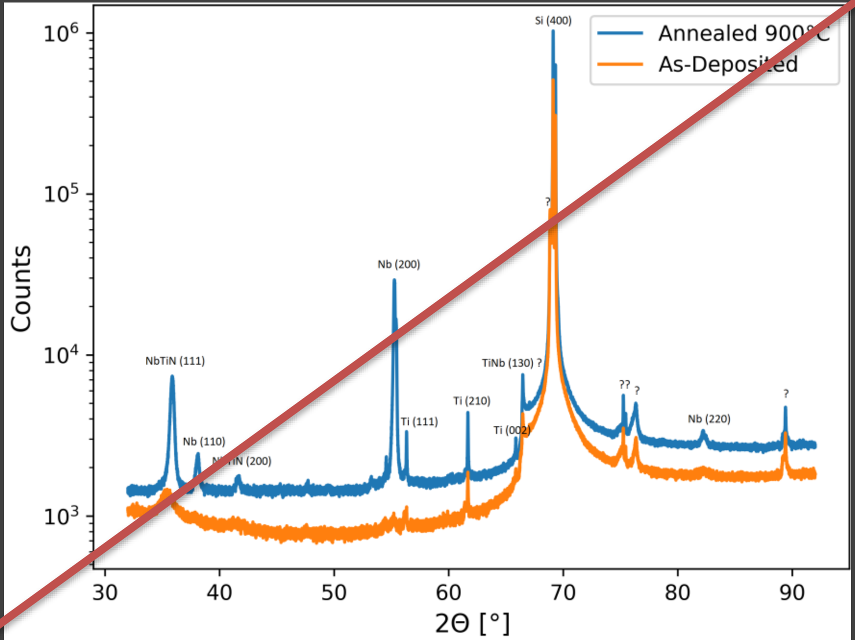




Results of XRD Measurement



Results of XRD Measurement



Characterisation of NbTiN multilayer-systems
Frederic Braun

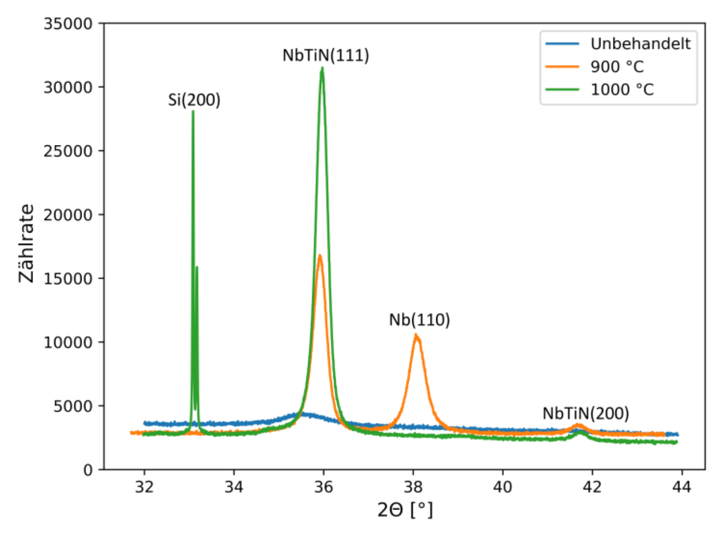
BERGISCHE UNIVERSITÄT WUPPERTAL

Results of XRD Measurement

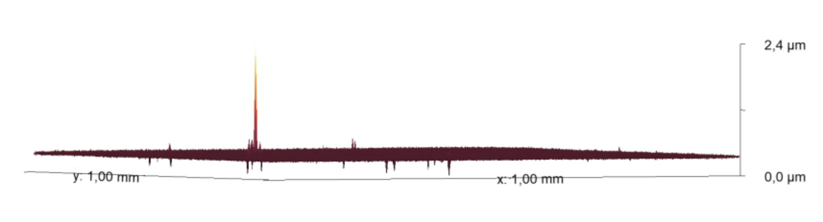
- Only NbTiN and Si Peaks visible
  - Nb(110) belongs to sample holder
- As-Deposited NbTiN under heavy microstrain
  - high fwhm and bragg angle is lower
- Bragg-angle of NbTiN(111) increases
  - As-Deposited: $35.565 \pm 0.013\,°$
  - 900 °C: $35.916 \pm 0.001\,°$
  - 1000 °C: $35.960 \pm 0.001\,°$
- Grainsize of NbTiN(111) increases
  - As-Deposited: 75.297 ± 3.480 Å
  - 900 °C: 272.182 ± 1.532 Å
  - 1000 °C: 319.084 ± 1.631 Å

→ Annealing releases stress in the film

- NbTiN(200) is formed by annealing

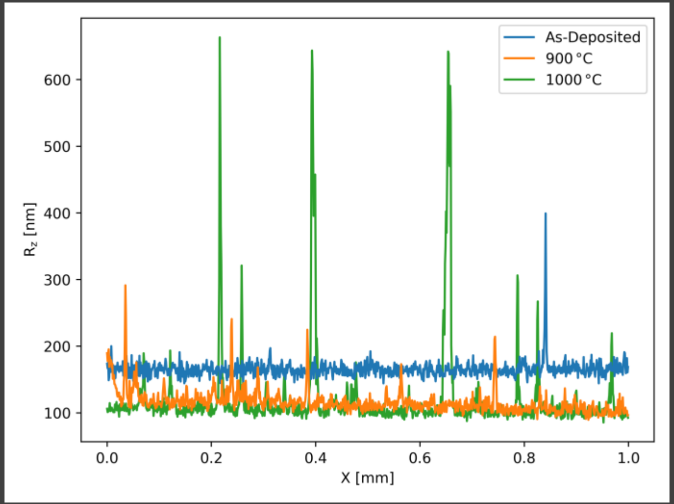


Results for the surface roughness

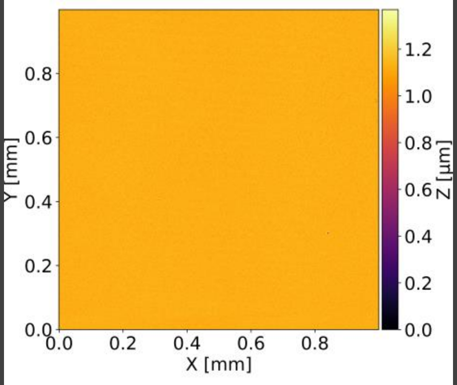


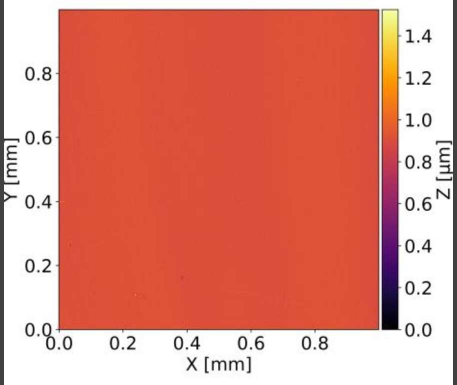
1000 °C

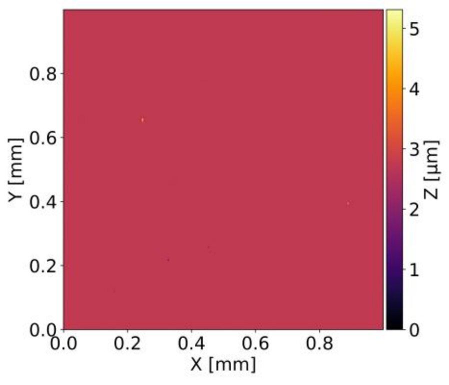
- A few deeper defects on the surface
- 3D-view shows distinction between defect types
    - Annealing promotes formation of defects
    - Wafer defects become visible
- Determination of R_z over a few subareas



Results for the surface roughness







As-Deposited
- R_a = (24.11 ± 0.76) nm
- R_z = (141.67 ± 3.06) nm

over 10 x 10 mm²

Annealed at 900 °C
- R_a = (15.93 ± 0.33) nm
- R_z = (94.59 ± 2.00) nm

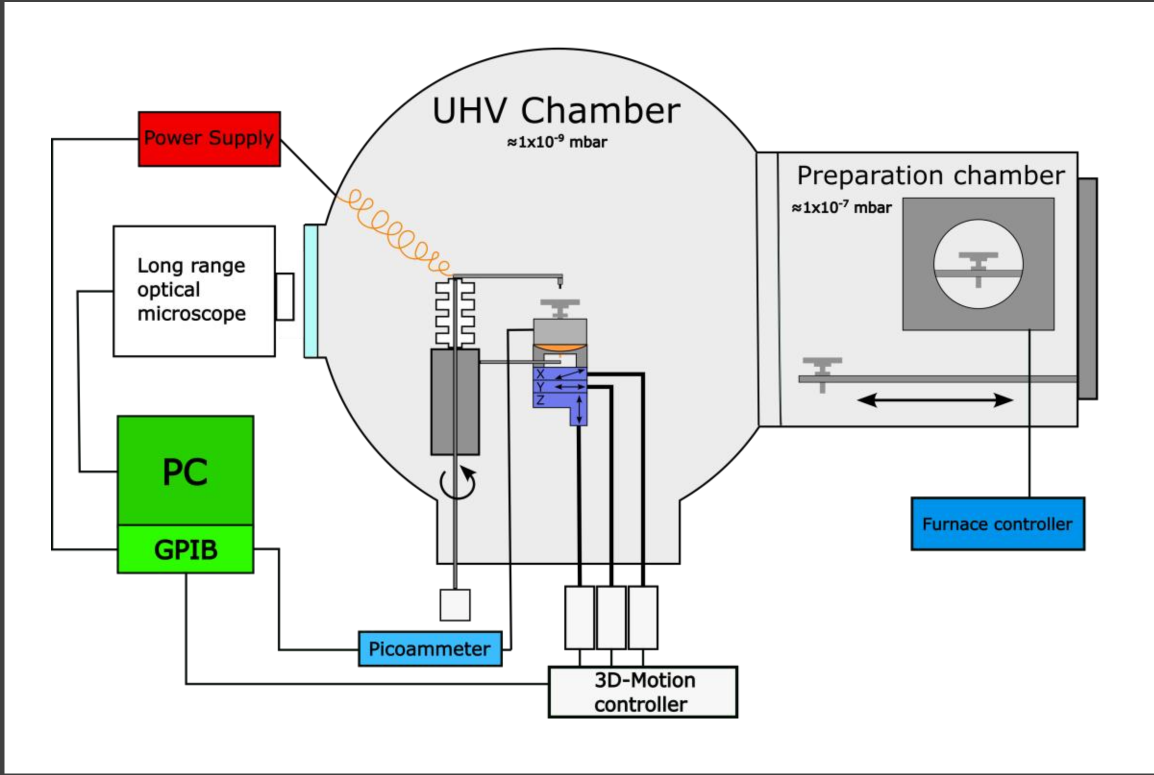
over 10 x 10 mm²

Annealed at 1000 °C
- R_a = (14.15 ± 0.82) nm
- R_z = (80.34 ± 0.13) nm

over 10 x 10 mm²

→ Annealing reduces R_a by 41.30 % and R_z by 43.29 %

Experimental Setup

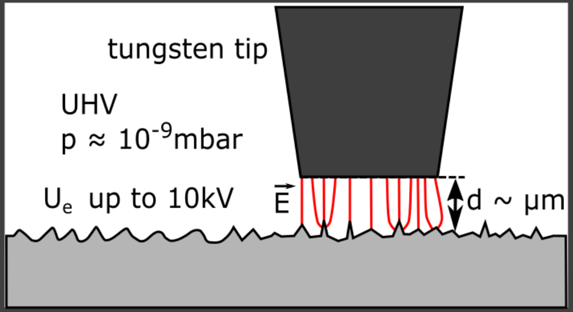


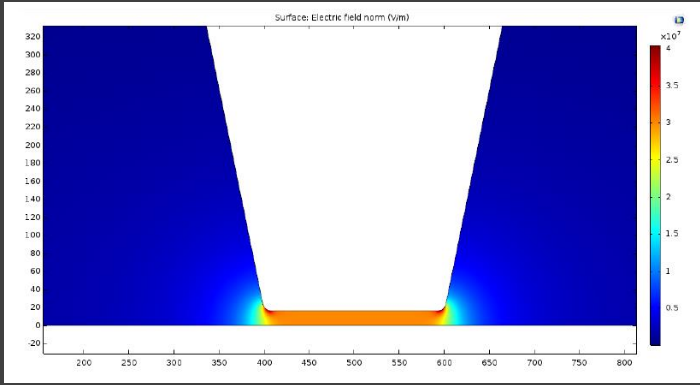
Working principle

Current flows after Fowler-Nordheim:

$$I(E) = \frac{AS\beta^2E^2}{\Phi}\exp\left(-\frac{B\Phi^{\frac{3}{2}}}{\beta E}\right)$$

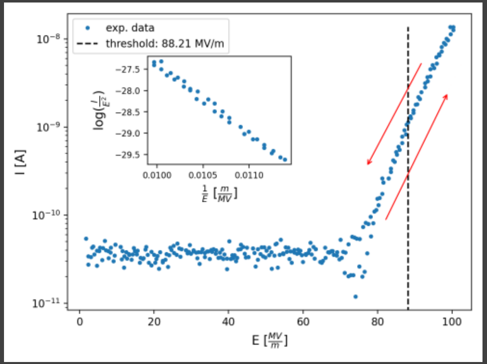
With A = $1.54 \cdot 10^6 \frac{\mathrm{AeV}}{(\mathrm{MV})^2}$, B = $6830 \frac{eV^{\frac{3}{2}}MV}{m}$, Φ as work function, β as geometric factor of the tip/surface and S as effective area of emittance

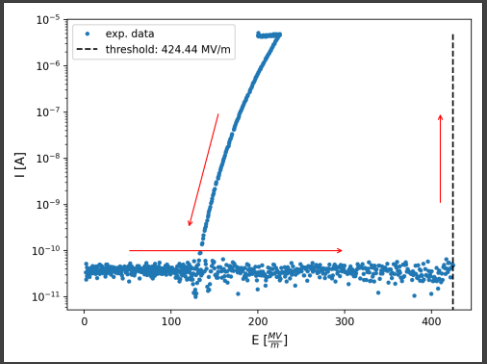




- Surface roughness leads to enhanced field emisson → lowers onset-field
- Tip radius and shape can vary heavily
  - Between a few nm and 1 mm
  - Sharper tips yield higher resolution
  - Truncated cone tips are more mechanical stable

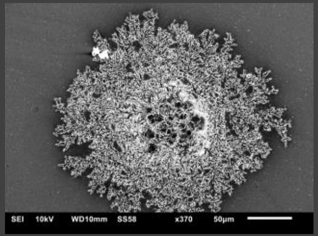
Current-Voltage-Curves (IV-Kurven)





- Increasing voltage until selected current, then decreasing voltage
- Onset-field threshold set to 1 nA
- Plotting and fitting $\mathrm{Log}\left(\frac{I}{E^2}\right)$ vs. $\frac{1}{E}$ yields $\boldsymbol{\beta}, \boldsymbol{S}$ and $\boldsymbol{\Phi}$

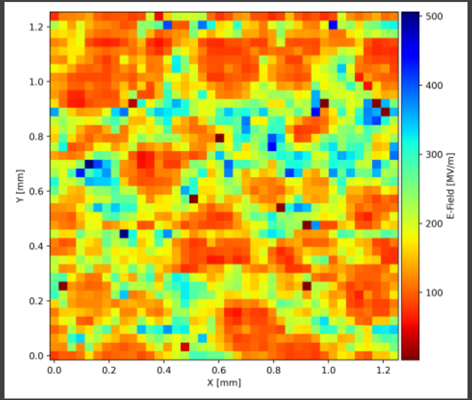
- On some measurements sudden jump to high currents
  - called **activation of surface**
  - activation irreversibly changes surface
- Onset-field threshold set at the highest field strength



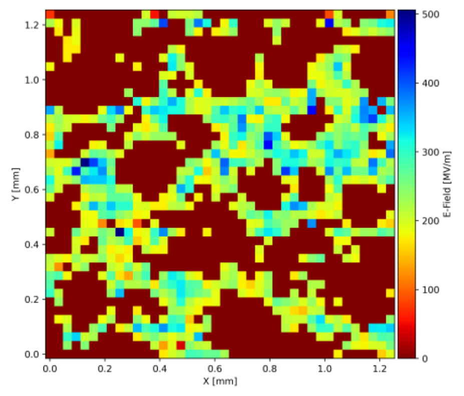
Measurement programm for the FESM

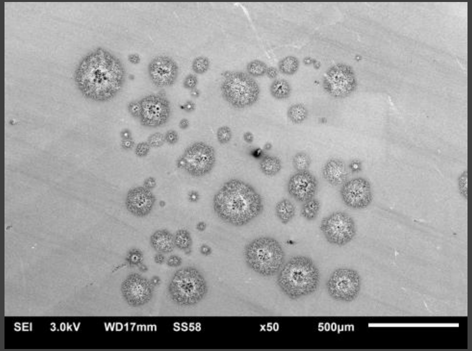
- Measuring I-V-Curves over 6.5x6.5 mm^2
  - 440I-V-Curves in total
  - Max. current 10 nA
- Stepsize 317.65 µm
  - No overlap with 250 µm tip
- Evaluation of I-V-Curves with
  - Constant Current Map
    - Determination of E_{on}
  - β ,ϕ und S

Constant Current Map – filtering of damaged areas



Damage threshold: 140 $\frac{\text{MV}}{\text{m}}$

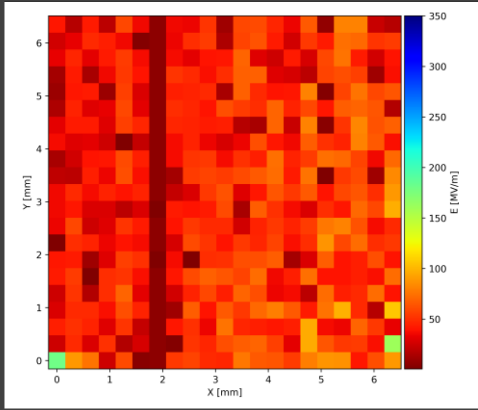




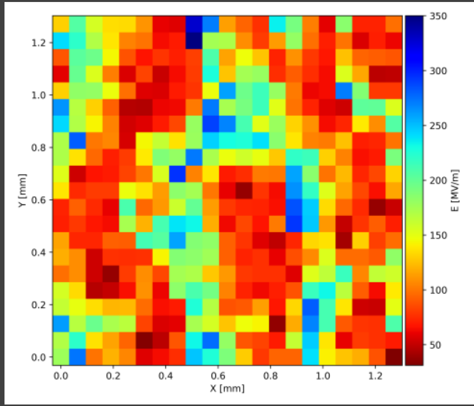
- Damages has to be filtered out

→ Setting individual threshold for each map

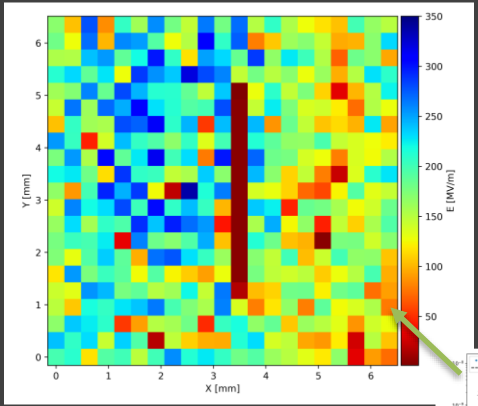
Results of Constant Current Map

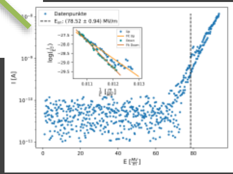


As - Deposited

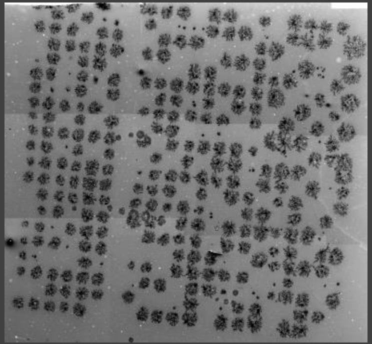


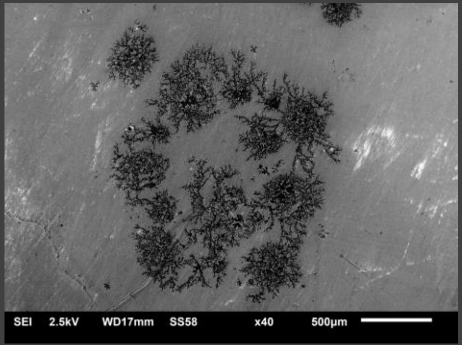
900 °C

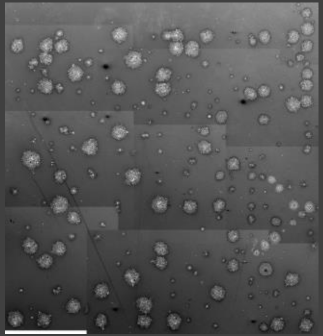




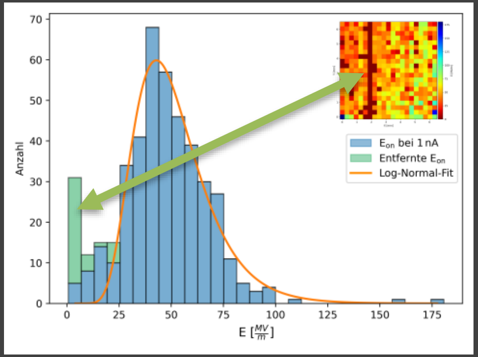
1000 °C





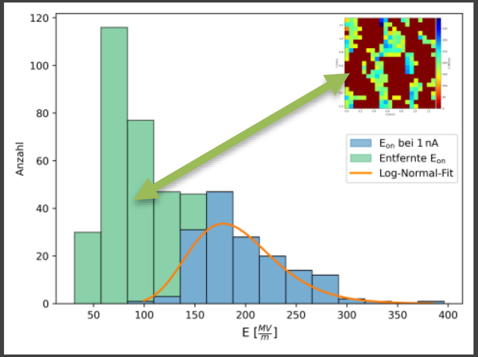


Results Constant Current Map



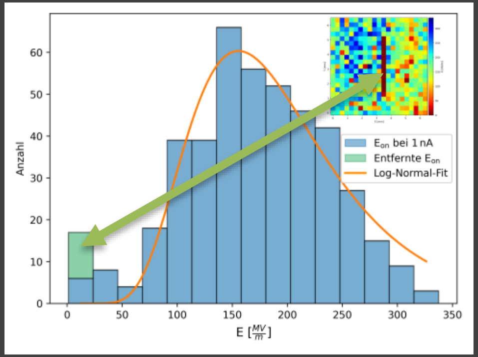
As - Deposited

$\bar{E}_{on}$: 51.53±1.03 $\frac{\mathrm{MV}}{\mathrm{m}}$



900 °C

$\bar{E}_{on}$: 192.37 ± 2.87 $\frac{\mathrm{MV}}{\mathrm{m}}$

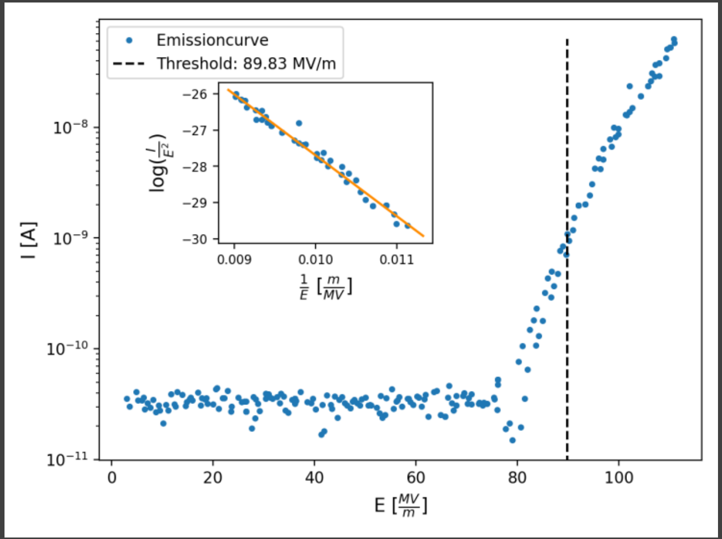


1000 °C

$\bar{E}_{on}$: 195.71 ±6.43 $\frac{\mathrm{MV}}{\mathrm{m}}$

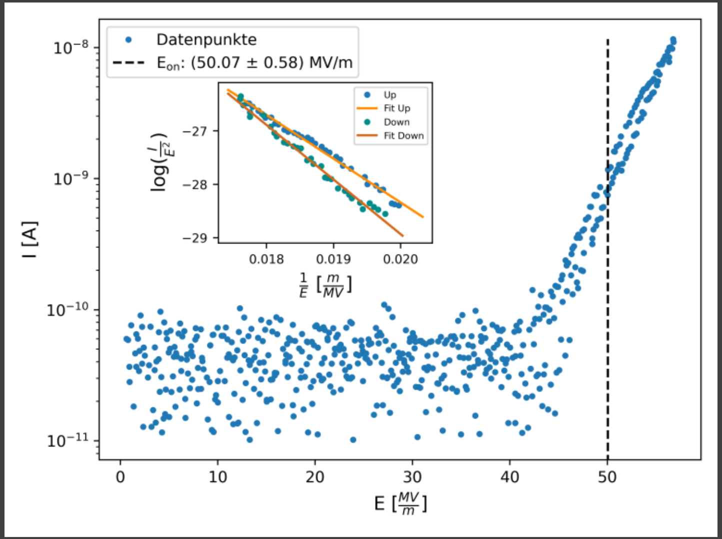
Analysis of I-V-Curves

- Determination of β ,ϕ and S separate over Up and Down direction
  - Altering the surface through FE
  - → β and S change
- Fits are done with varying β and keeping S and ϕ fix for several values of S and ϕ
  - Setting damage threshold
  - Work function between 2.5 eV and 5.5 eV
    - Stepsize 0.05 eV
  - S between 10^{-23} m² and 10^{-8} m²
    - Stepsize $0.1 \cdot 10^{x}$
  - Damaged areas will not be taken into account

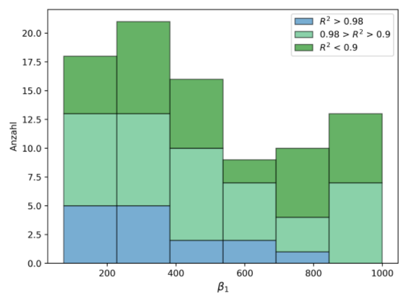


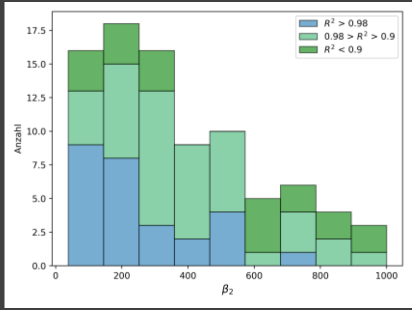
Analysis of I-V-Curves

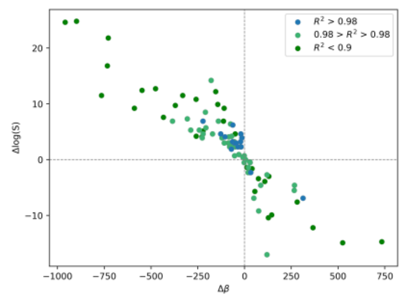
- Determination of β ,ϕ and S separate over Up and Down direction
  - Altering the surface through FE
  - → β and S change
- Fits are done with varying β and keeping S and ϕ fix for several values of S and ϕ
  - Setting damage threshold
  - Work function between 2.5 eV and 5.5 eV
    - Stepsize 0.05 eV
  - S between 10^{-23} m² and 10^{-8} m²
    - Stepsize $0.1 \cdot 10^{x}$
  - Damaged areas will not be taken into account

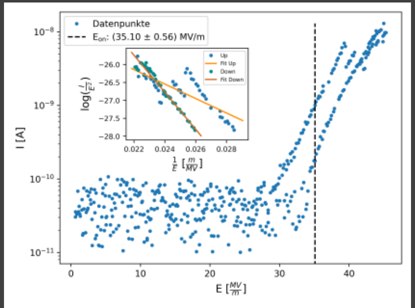


Results of the geometric factor – As - Deposited





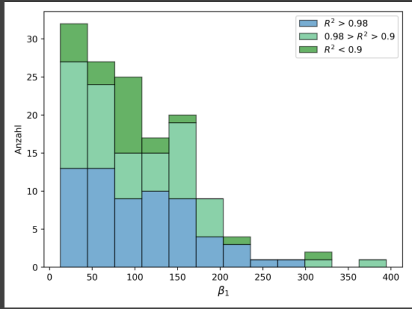


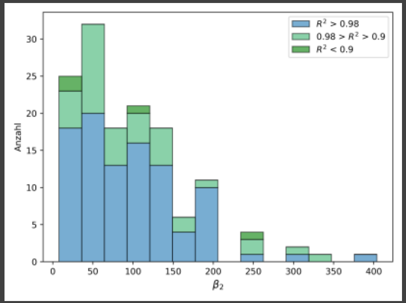


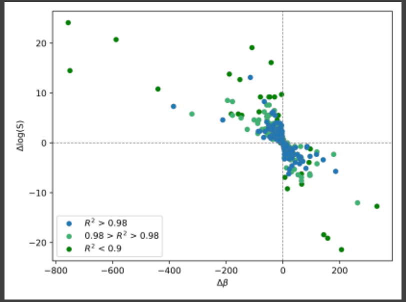
- Out of 440 Measurements only 92 were suitable for fitting
  - Data from activation of the surface is not suitable for fitting
- Quality of fits increases for β_2
- Comparison between β_1 and β_2
  - In 61 cases $\beta_1 > \beta_2$
  - In 26 cases $\beta_1 < \beta_2$
  - In 5 cases no change

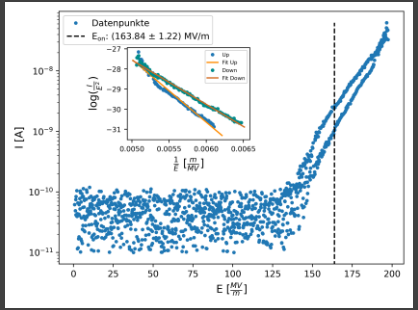
  → Microtips are destroyed
- Problem: damaged surface → bigger β_1
  - Film destruction during Up-Direction at currents as low as I ≈ 1 nA
- Negative correlation between log(S) and β_1

Results of the geometric factor– 900 °C Probe



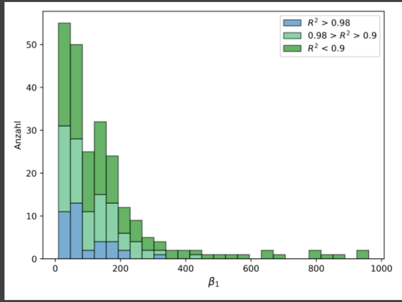


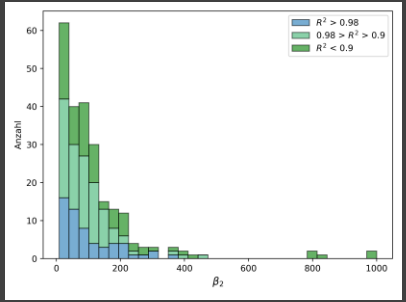


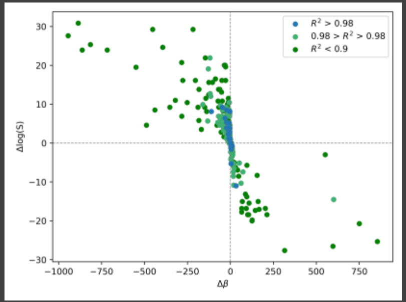


- Lots of damaged areas reduces data suitable for fitting
- Quality of fits increases for β_2
- No real changes between β_1 and β_2
- Negative correlation between log(S) and β_1

Results of the geometric factor – 1000 °C Probe





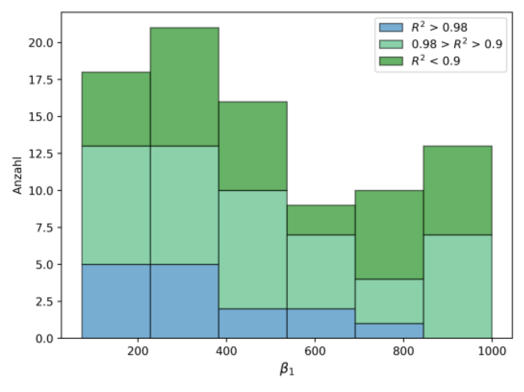


- Out of 440 Measurements 235 were suitable for fitting
  - Noticeable less surface damage
- Comparison between β_1 and β_2
  - In 111 cases $\beta_1 > \beta_2$
  - In 44 cases $\beta_1 < \beta_2$
  - In 80 cases no change

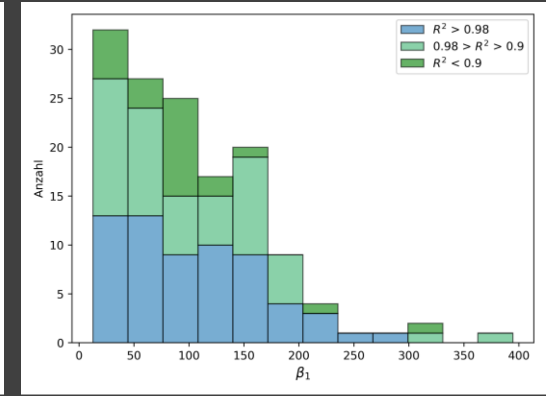
  → Microtips are destroyed
- Negative correlation between log(S) and β_1

Results of the geometric factor – comparison

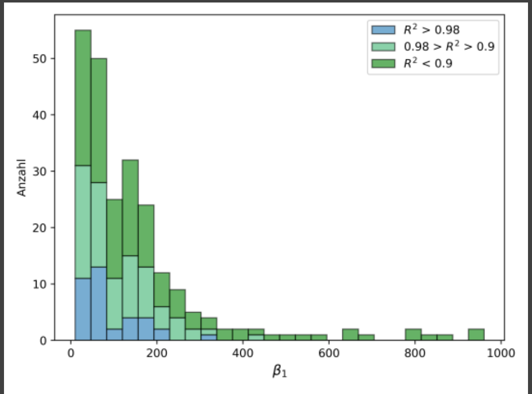
Annealed samples show lower β_1-values
→ Reduces surface roughness / less surface damage



As-Deposited

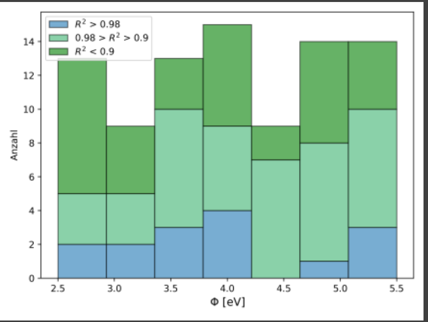


900 °C

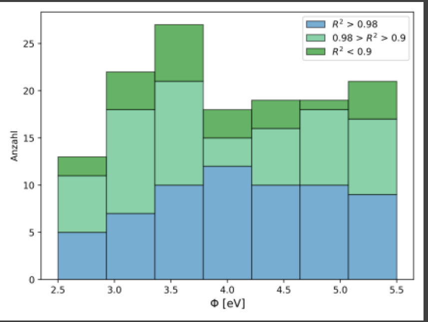


1000 °C

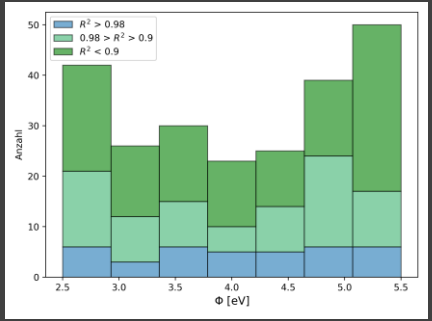
Results for the work function



As-Deposited



900 °C

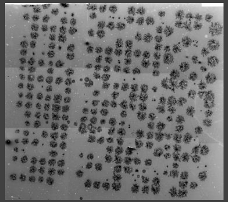


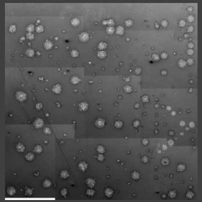
1000 °C

- Damage threshold is taken into account
- No clear conclusion about the work function can be drawn
    - Damage can influence the results for the work function
- UPS / Kelvin probe measurements will be done to determine Φ

Conclusion

- Annealing NbTiN sample has lots of advantages for FE
  - Increasing grainsize of NbTiN
    - from ≈ 75 Å to ≈ 320 Å
  - Releasing stress in the film
  - Reducing R_z by 43.29 %
    - Less/smaller microtips lowers β
  - Increasing onset-field significantly
    - from ≈ 50 $\frac{MV}{m}$ to ≈ 200 $\frac{MV}{m}$
  - Improved film adhesion due to reduced stress
    - Significantly reduced surface destruction after FE





Thank you for your Attention

Frederic Braun

BERGISCHE UNIVERSITÄT WUPPERTAL