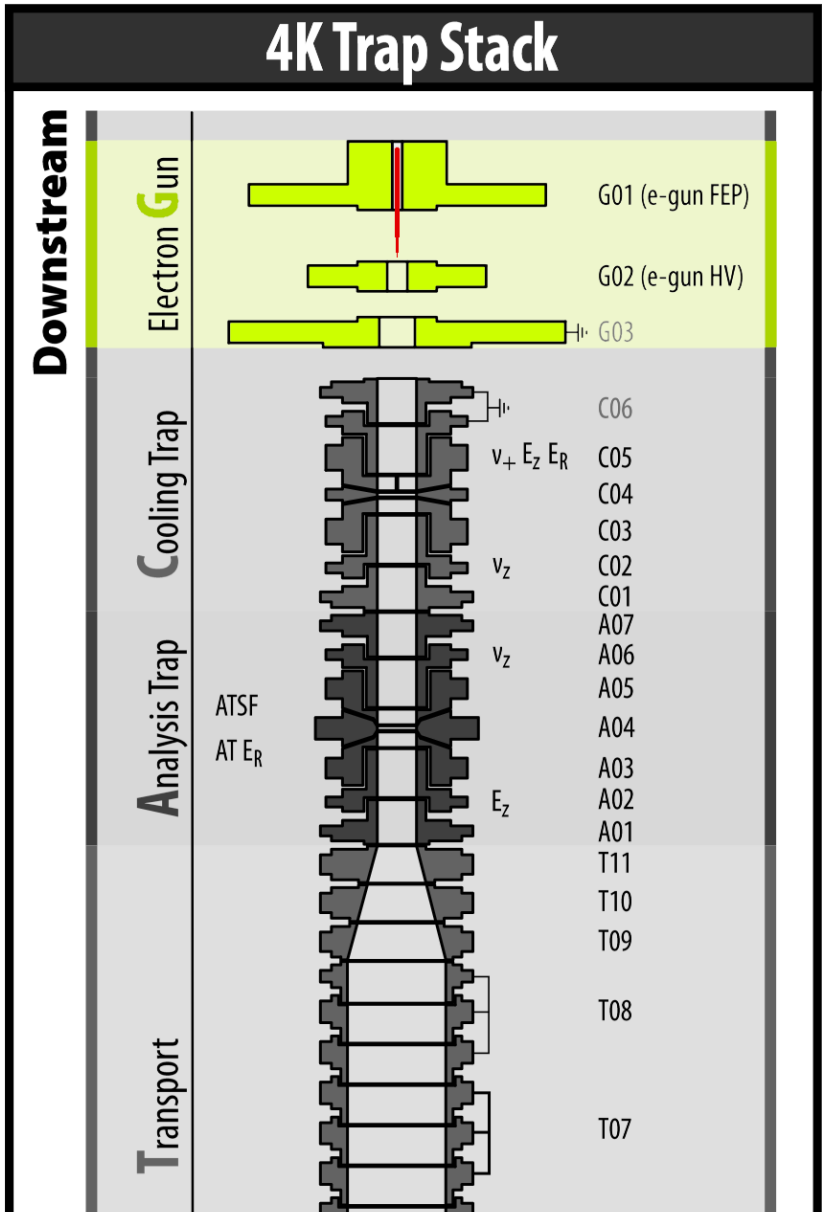
Production of new E-gun tips

Philip Geißler, 13.09.2021 – 12.12.2021

Deutscher Akademischer Austauschdienst
German Academic Exchange Service

Motivation



- BASE E-gun
  - H^- / p^+ creation via target collision of electrons and copper mesh with adsorbed hydrogen

$$[\mathrm{Cu}]_n \cdot \mathrm{H}_{(\mathrm{ads})} \xrightarrow{\mathrm{e}^-} [\mathrm{Cu}]_n + \mathrm{H}$$

$$\mathrm{e}^- + \mathrm{H} \longrightarrow \mathrm{H}^-, \qquad \mathrm{e}^- + \mathrm{H} \longrightarrow 2\mathrm{e}^- + \mathrm{p}^+$$

  - Electron cooling

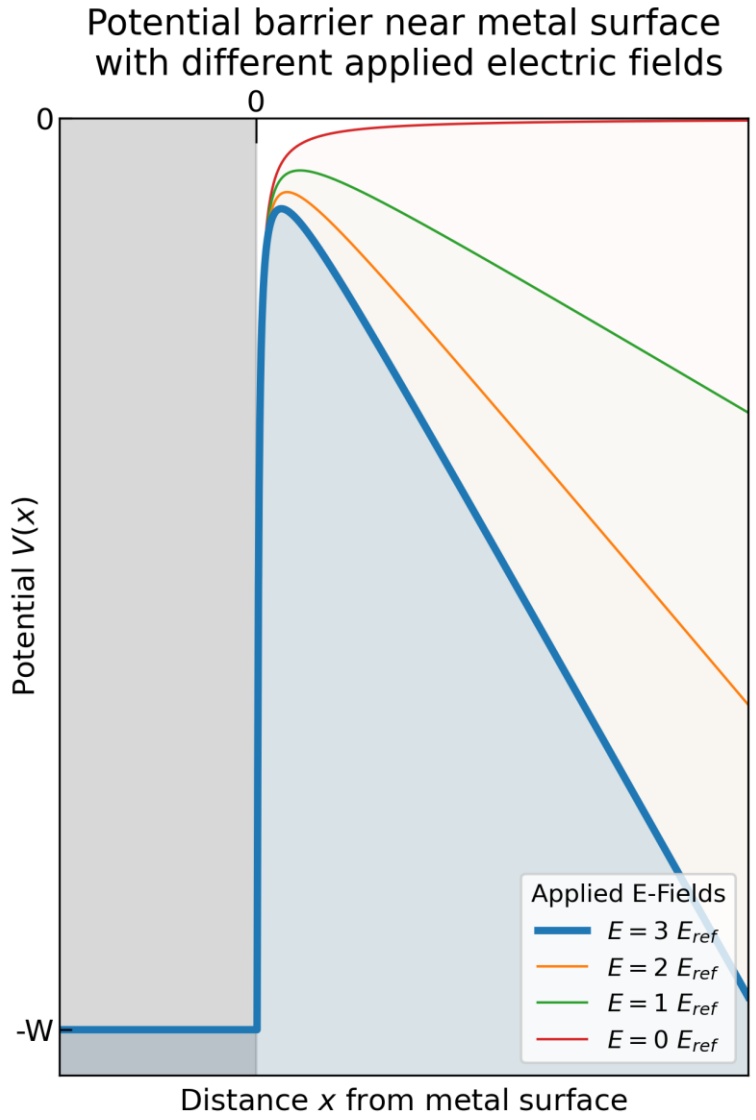
    H^- / $\bar{p}$ energy transfer to electrons,

    energy emission via synchrotron radiation

- Tips become dull over time

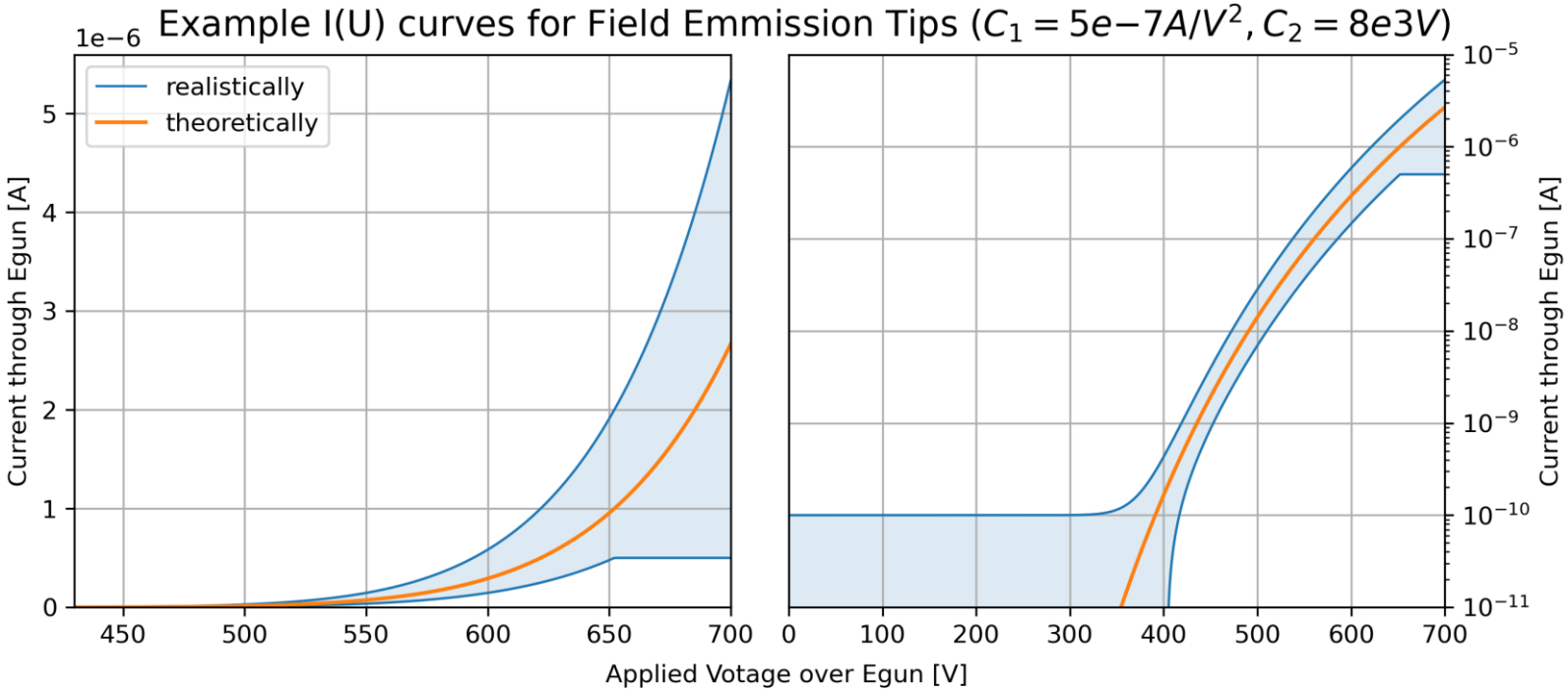
  → need replacement

Intro to Field Emission Tips



- Free electrons may tunnel through surface
- Stronger fields → greater tunnelling chance

$$I(U) \propto C_1 \cdot U^2 \cdot e^{-\frac{C_2}{U}}$$



Intro to Field Emission Tips

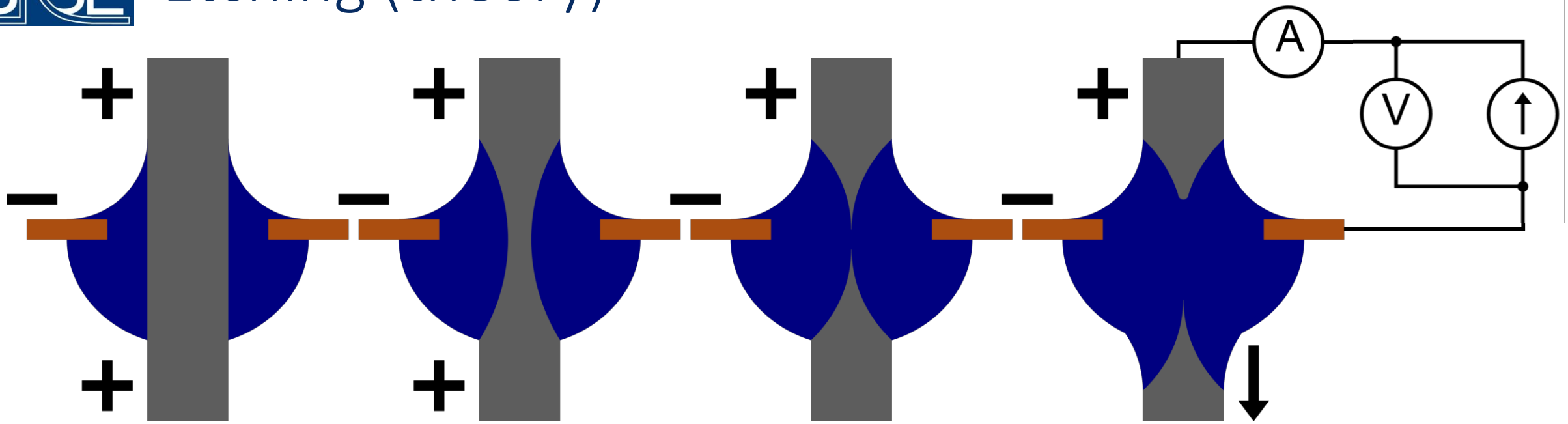
COPYRIGHT [1]

- We can increase voltage and decrease electrode distance to increase E-field

- Sharper tips increase E-field as well
  → Goal: produce sharpest possible tips

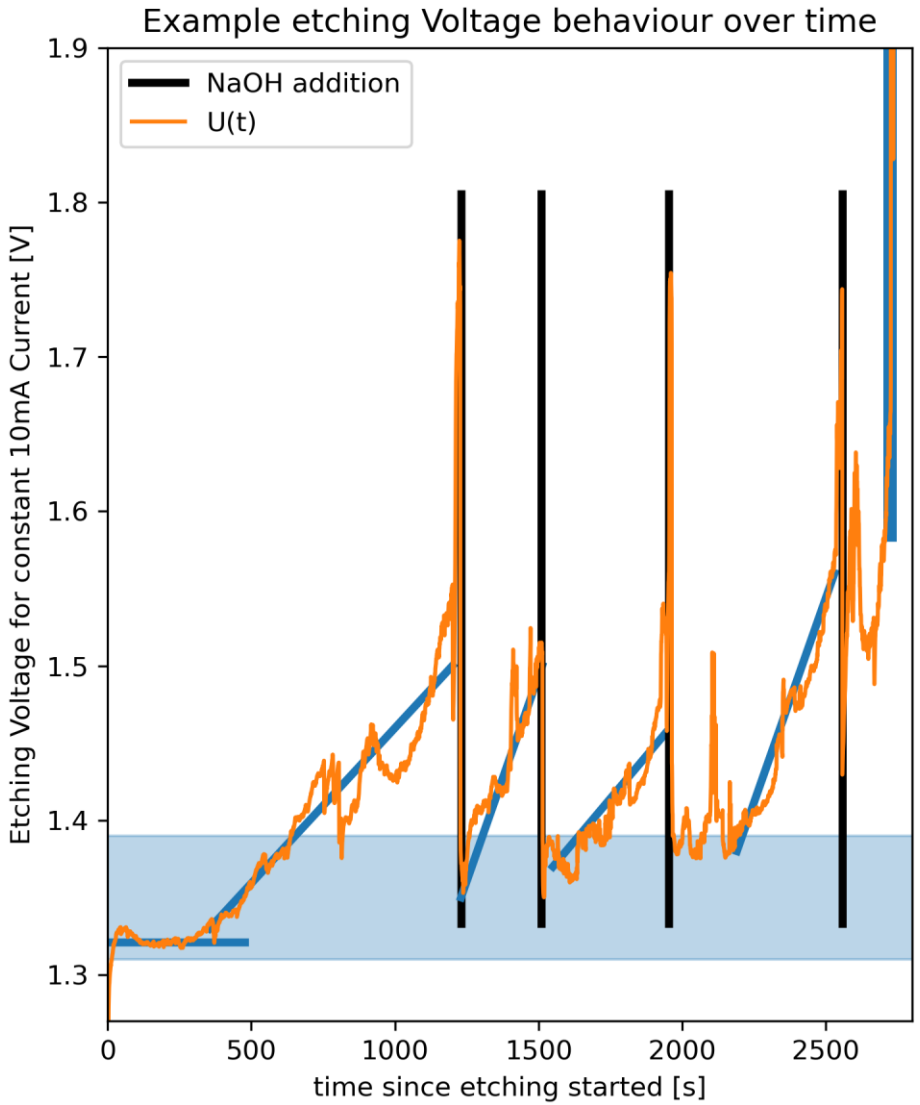
COPYRIGHT [2]

Etching (theory)



- Idea: inverse galvanization of tungsten wire to produce nm-sharp FE-tips
- Constant current application to etch tungsten near hole
- Separation of wire leaves lower part on floating potential
  → etching stops, tip stays sharp

Etching (implementation)



- $NaOH$ used as electrolyte (3M/l, 14.5pH)
  - Three consecutive behaviours:
    stable, slow increase & explosion in resistance
  - $NaOH$ is probably getting used up in electrolysis
    → refilling needed before explosion,
    otherwise the electrolysis stops
  - Also explosion in resistance after tip falls down
  - High resistance voltage oscillations

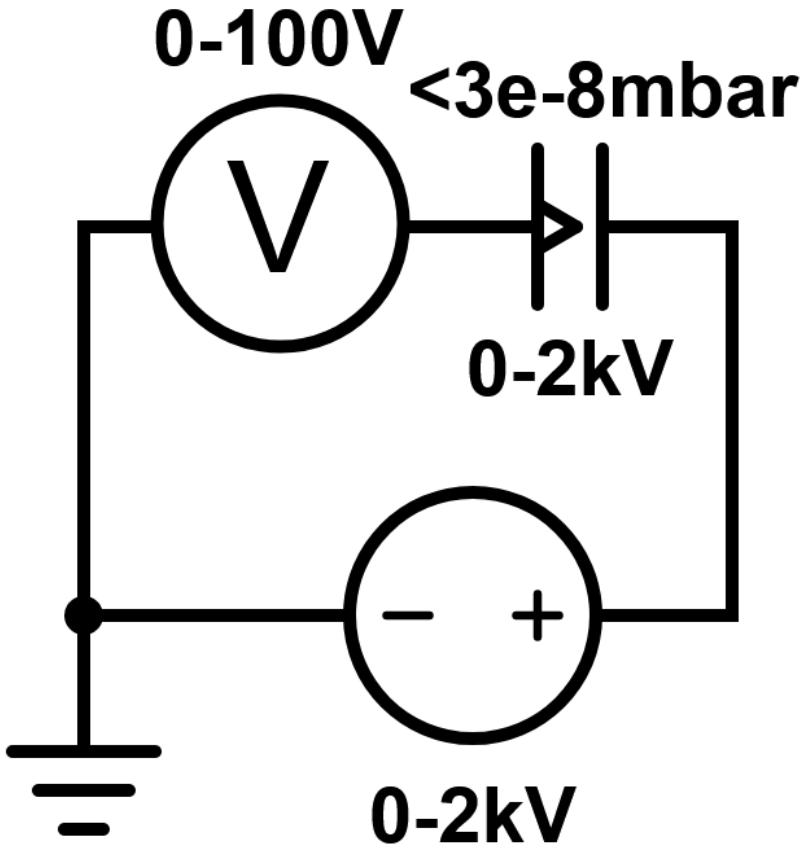
($Cu \leftrightarrow NaOH \cdot H_2O \leftrightarrow W$ is effectively a battery with ≈0.44V cell voltage.
This makes resistance measurements without current useless)

Etching (implementation)

A B

- Etching setup (see B):
  - Tungsten wire Source Measure Unit + connection
  - Guiding Rod to stabilize
  - Copper Plate with etching holes (1-6mm) and Source Measure Unit – connection
- $R_{\mathrm{Plateau}}(I) \approx 25\Omega + \frac{1V}{I}$
- Reliably produces FE-Tips (see A), but not with reliable shapes

Characterization (theory)



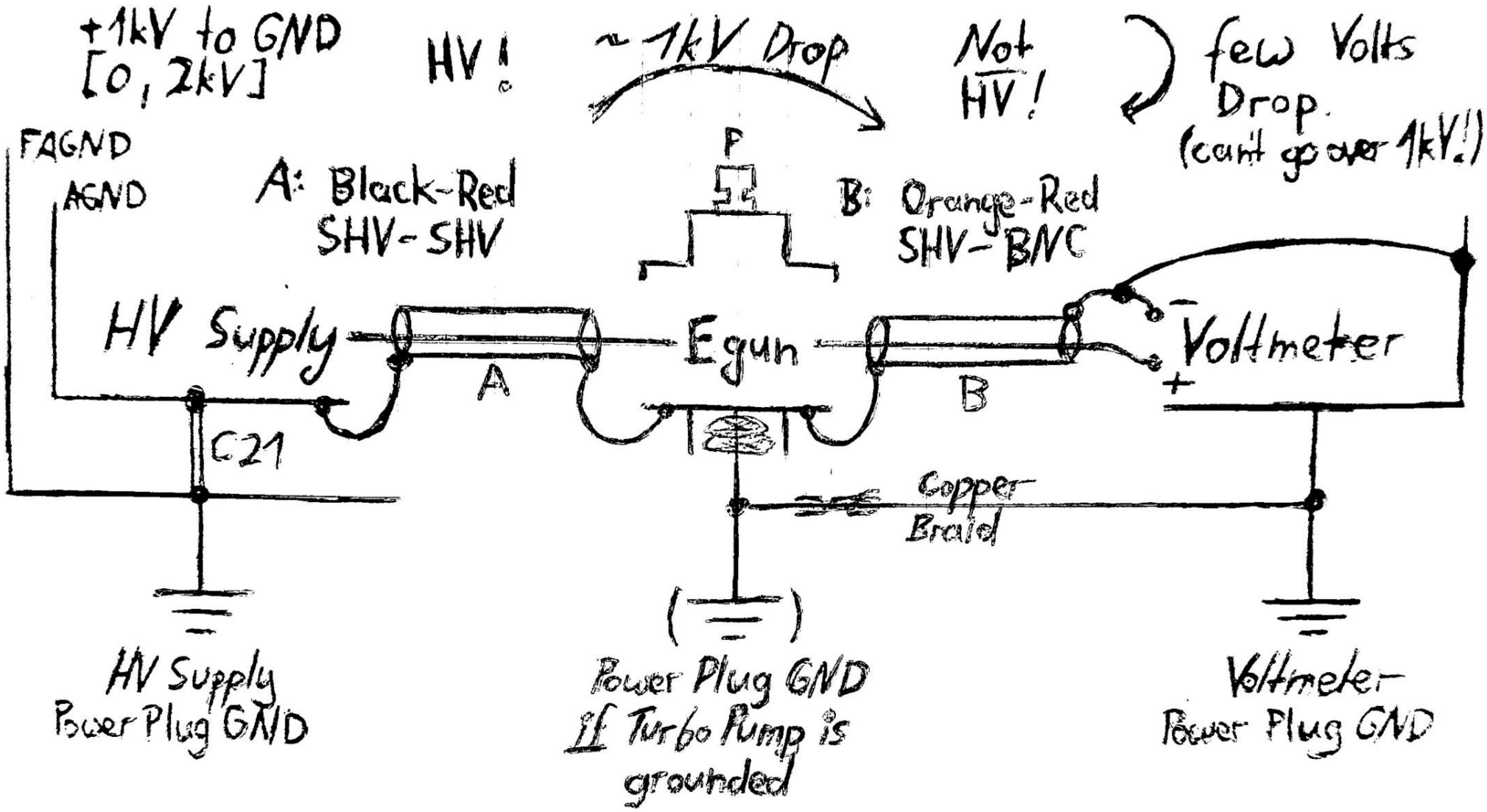
- Sweep over $U_{\mathrm{HV-Supply}}$,
- Calculate $I_{\mathrm{E-gun}}\left(U_{\mathrm{E-gun}}\right)$ from $U_{\mathrm{Voltmeter}}$

$$R_{\mathrm{Voltmeter}} = 10M\Omega$$
$$U_{\mathrm{HV-Supply}} = U_{\mathrm{E-gun}} + U_{\mathrm{Voltmeter}}$$
$$I_{\mathrm{Total}} = I_{\mathrm{E-gun}} = I_{\mathrm{Voltmeter}}$$

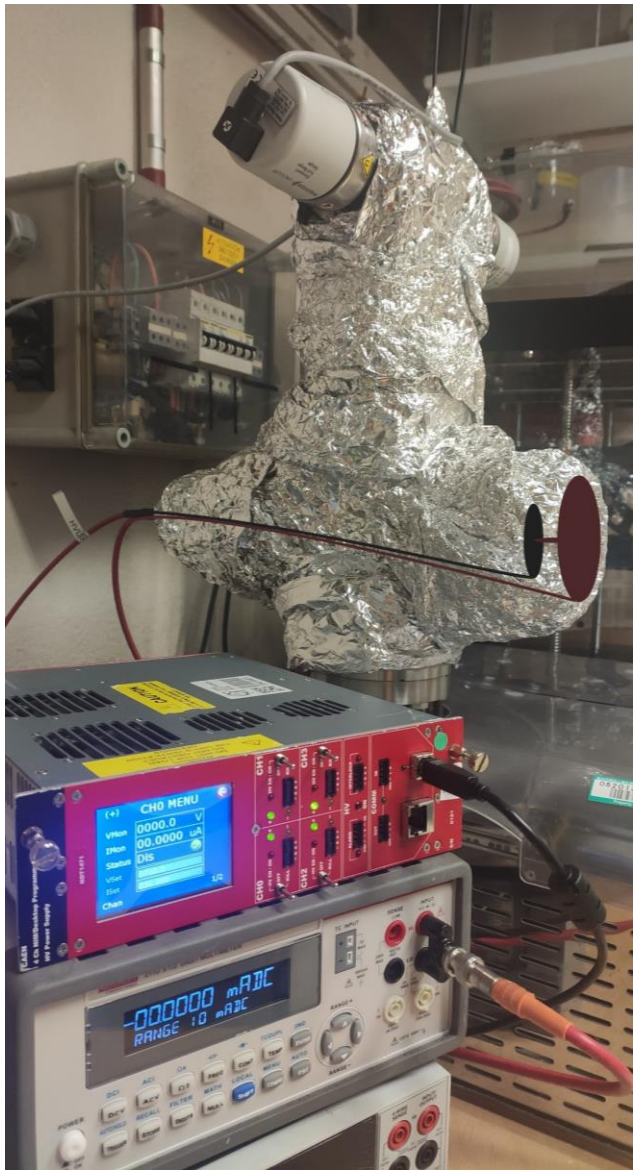
$$\rightarrow U_{\mathrm{E-gun}} = U_{\mathrm{HV-Supply}} - U_{\mathrm{Voltmeter}}$$

$$\rightarrow I_{\mathrm{E-gun}} = \frac{U_{\mathrm{Voltmeter}}}{10M\Omega}$$

Characterization (implementation)

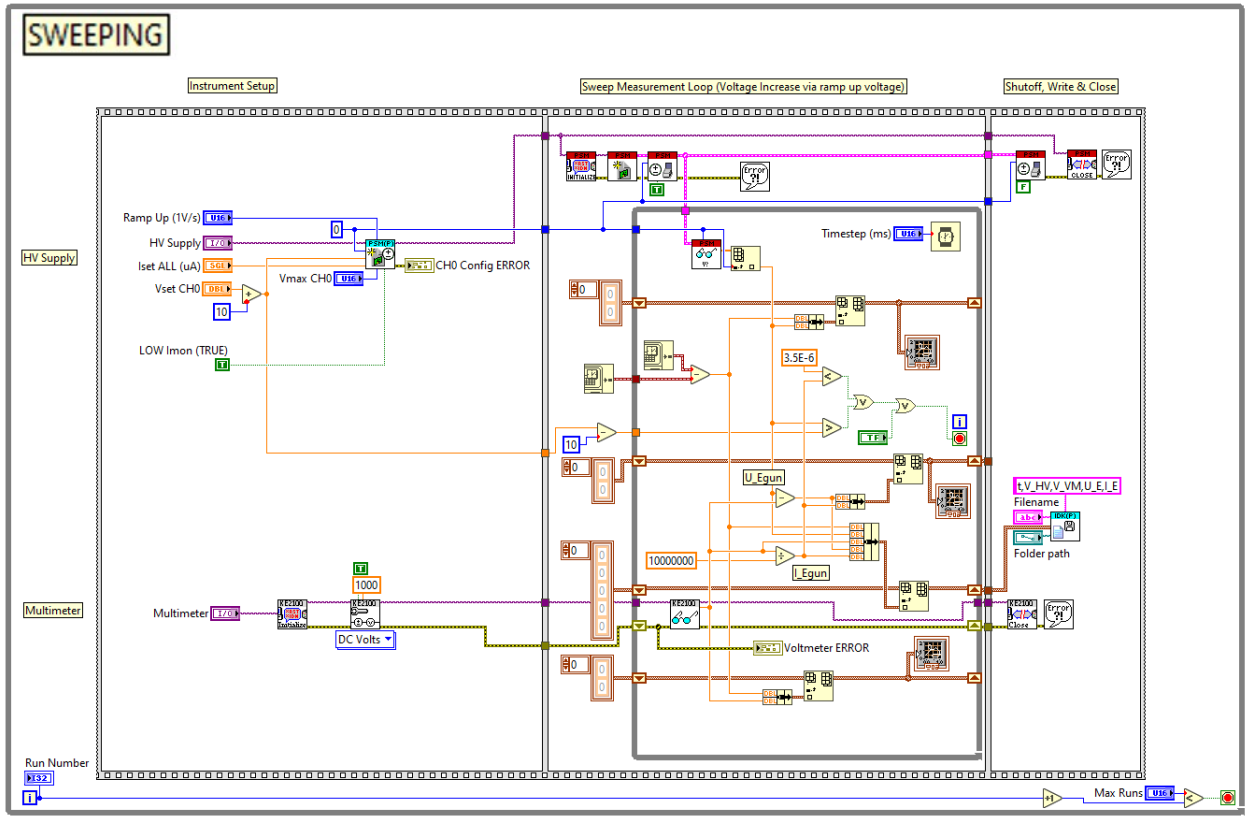


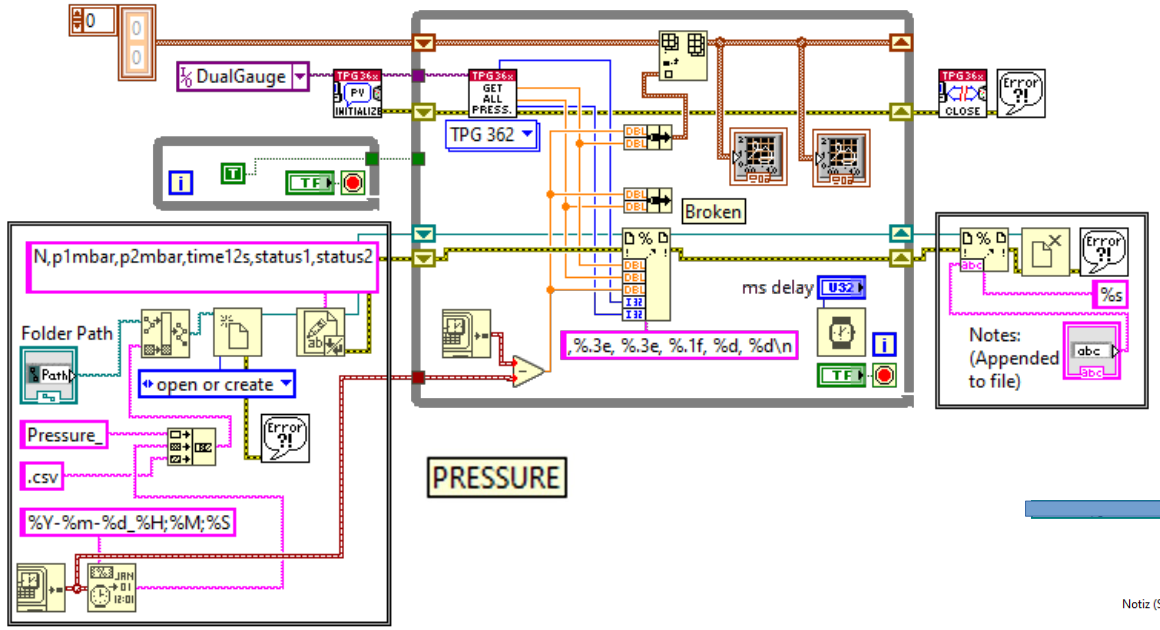
Characterization (implementation)

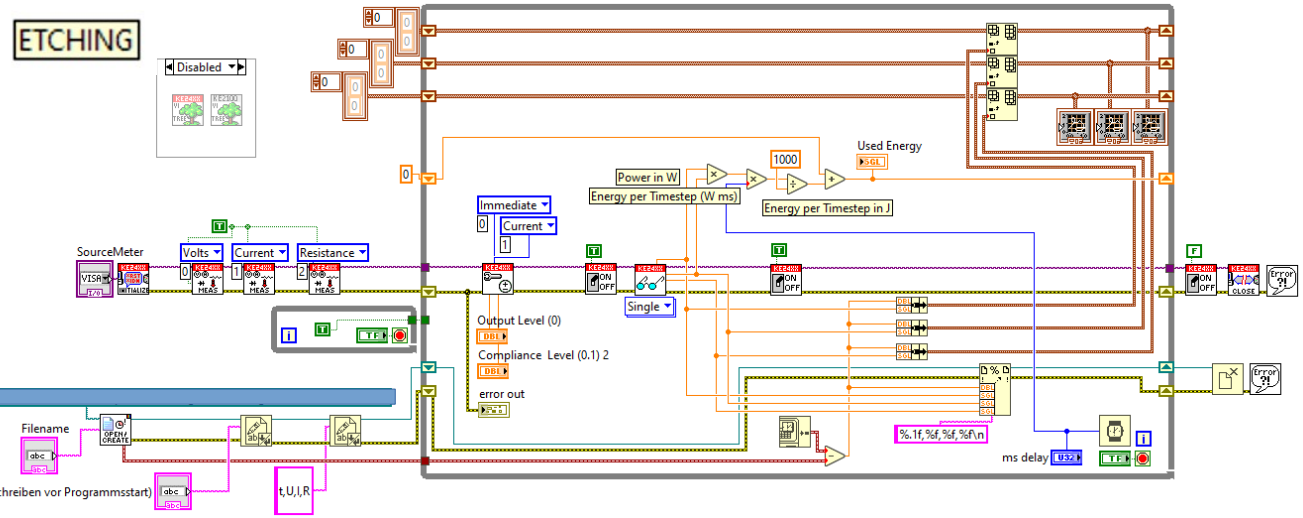


Code

- Measurement and Logging VI's
  - Pressure, Etching, Characterization
- Data Analysis in Python
  - 2D, 3D, Fitting, Allen deviation





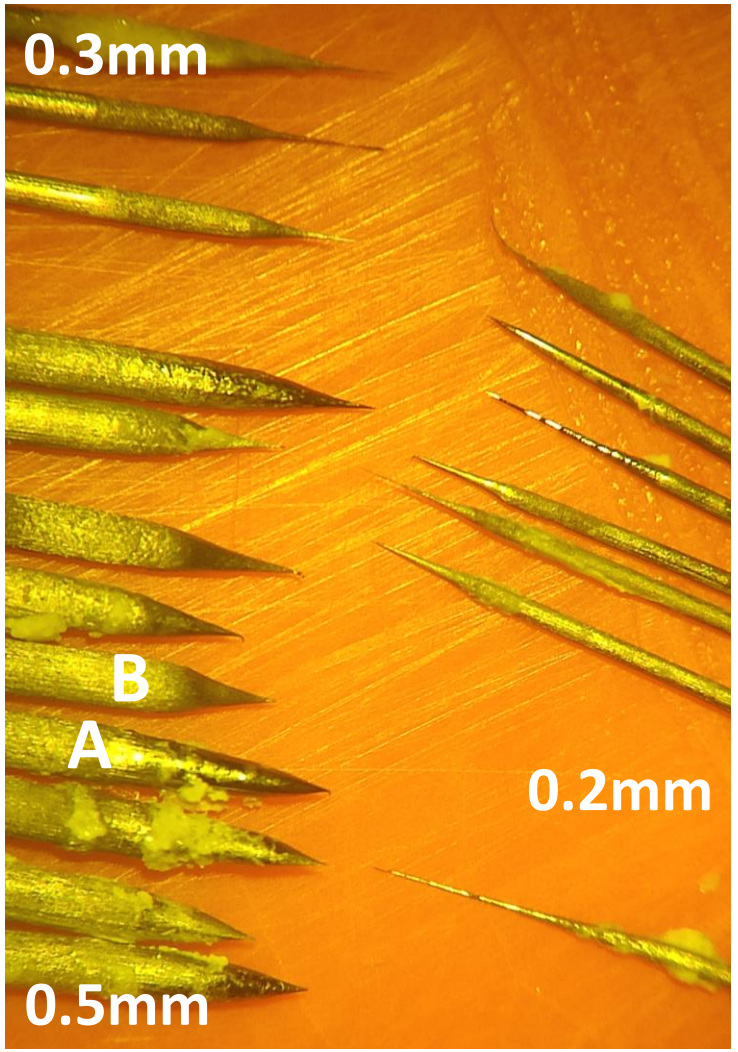


Results

- Tested and stored Tips:

Ø µm	500	500	500	500	300	300	500	500
V@1nA	500(50)	420(30)	450(50)	215(15)	145(15)	300(50)	450(30)	???
V@10nA	575(25)	475(25)	500(50)	235(15)	175(15)	320(50)	510(30)	???
V@100nA	700(50)	575(25)	575(25)	275(25)	195(25)	375(75)	600(50)	???
V@1µA	850(50)	650(50)	700(50)	325(25)	≥190(?)	≥350(?)	650(50)	???
Comment						Noisy!		(P23)

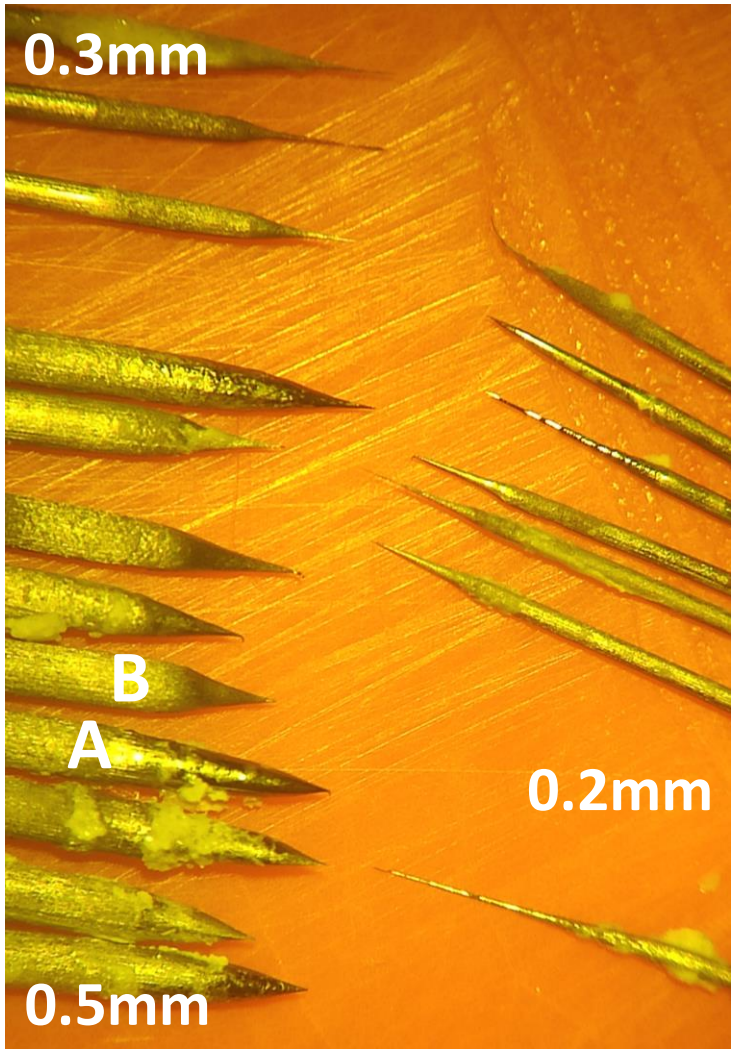
- Dependence on Parameters
  - Hole size/shape: - may change taper length
    - bent down hole keeps drop at wire
  - Concentration: - slower increase in resistance
    - crystallization on wire
  - Current: - changes finish (mirrored->matte)
    - decreases etching time
  - Wire thickness: - leads to macroscopically duller tips
    - easier to handle and put in E-gun
    - increases etching time
  - Max Voltage: - [not tested, kept low]
  - Etching time: - result of other parameters



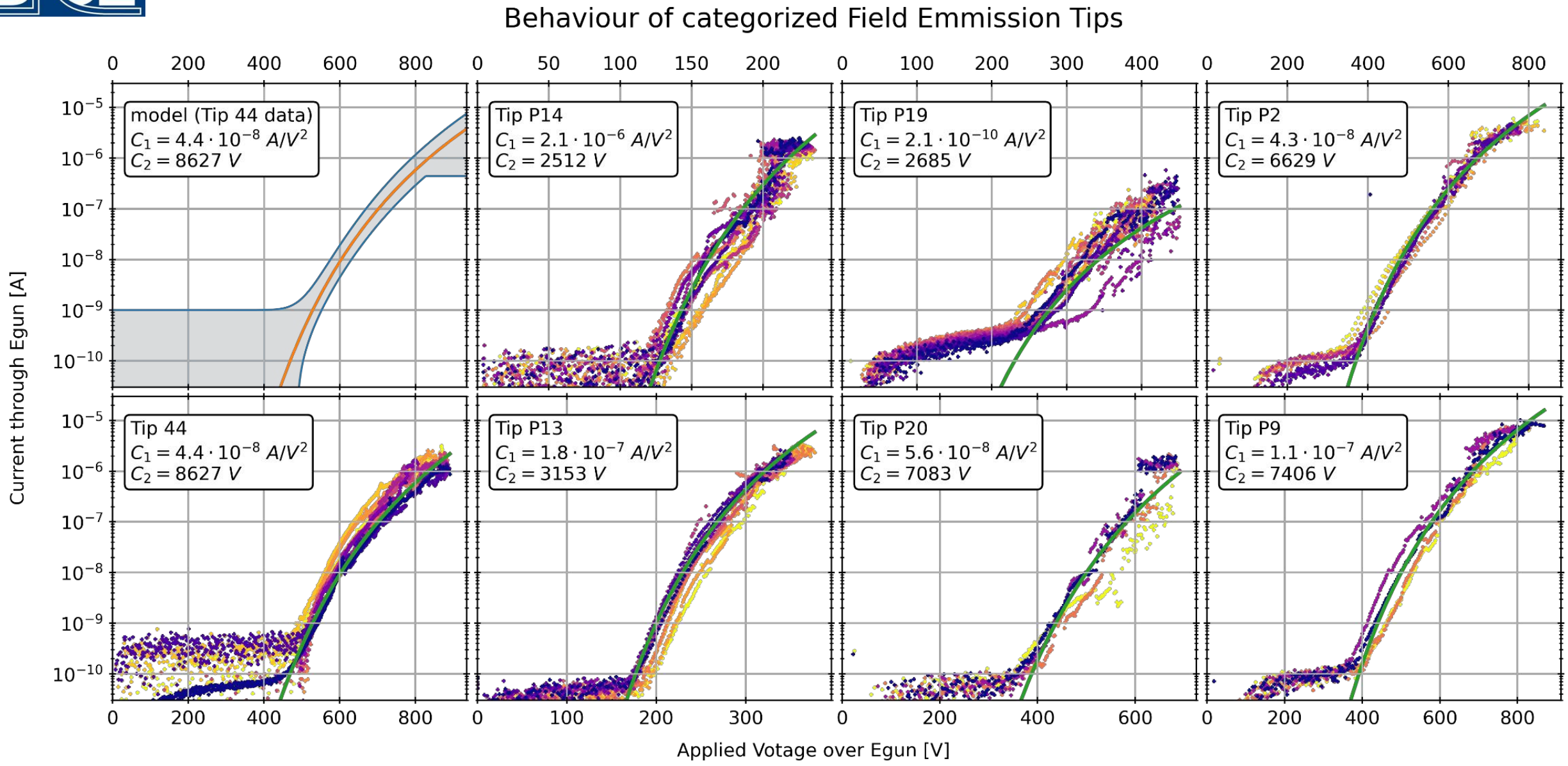
Results

Ø µm	500	500	500	500	300	300	500	500
V@1nA	500(50)	420(30)	450(50)	215(15)	145(15)	300(50)	450(30)	???
V@10nA	575(25)	475(25)	500(50)	235(15)	175(15)	320(50)	510(30)	???
V@100nA	700(50)	575(25)	575(25)	275(25)	195(25)	375(75)	600(50)	???
V@1µA	850(50)	650(50)	700(50)	325(25)	≥190(?)	≥350(?)	650(50)	???
Comment						Noisy!		(P23)

- Tested and stored Tips:
- Used and recommended Parameters
  - Hole size/shape: - $d_{\mathrm{hole}} \in \{1.7,1.8,2.3,2.8\}\mathrm{mm}$ all good
    - $2.8\mathrm{mm}$ bent down hole for production
  - Concentration: - $2\mathrm{M}$ R explosion after $\approx 10^{2.2(2)}\mathrm{s}$
    - 4M crystallized directly → 3M
  - Current: - $I \in \{5,10,50,100\}\mathrm{mA}$
    - $5\mathrm{mA}|_{0.2\mathrm{mm}}$, $10\mathrm{mA}|_{0.3\mathrm{mm},0.5\mathrm{mm}}$
  - Wire thickness: - $d_{\mathrm{wire}} \in \{0.2,0.3,0.5\}\mathrm{mm}$
    - mainly made $0.5\mathrm{mm}$ tips
    - $0.3\mathrm{mm}$ bent in E-gun, but usable
  - Max Voltage: - $V_{\mathrm{max}} < 20V$ $(5V, 3V, \cdots)$
  - Etching time: - $t(d_{\mathrm{wire}}, I) \approx 700 \left(\frac{d_{\mathrm{wire}}}{\mathrm{mm}}\right)^{2} \left(\frac{I}{\mathrm{mA}}\right)^{-0.8}$
    (very roughly, phenomenologically)



Results

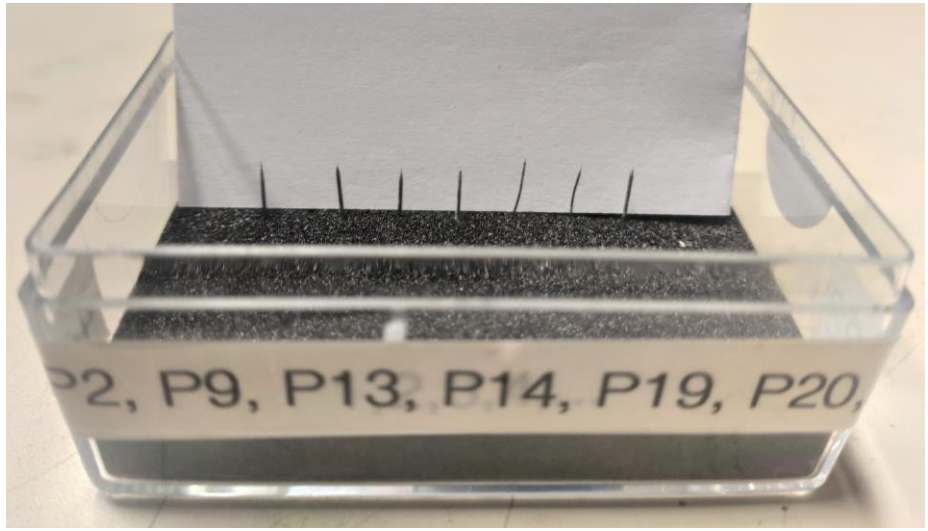

Behaviour of categorized Field Emmission Tips
Current through Egun [A]
Applied Votage over Egun [V]
model (Tip 44 data)
$C_1 = 4.4 \cdot 10^{-8}\ A/V^2$
$C_2 = 8627\ V$
Tip P14
$C_1 = 2.1 \cdot 10^{-6}\ A/V^2$
$C_2 = 2512\ V$
Tip P19
$C_1 = 2.1 \cdot 10^{-10}\ A/V^2$
$C_2 = 2685\ V$
Tip P2
$C_1 = 4.3 \cdot 10^{-8}\ A/V^2$
$C_2 = 6629\ V$
Tip 44
$C_1 = 4.4 \cdot 10^{-8}\ A/V^2$
$C_2 = 8627\ V$
Tip P13
$C_1 = 1.8 \cdot 10^{-7}\ A/V^2$
$C_2 = 3153\ V$
Tip P20
$C_1 = 5.6 \cdot 10^{-8}\ A/V^2$
$C_2 = 7083\ V$
Tip P9
$C_1 = 1.1 \cdot 10^{-7}\ A/V^2$
$C_2 = 7406\ V$

Conclusions & further work

- Tips now stored in closed box, stuck in foam with tip side up
- Code (python, LabVIEW), presentation and important logs in "`G:\[INTERNAL PATH]`"

- Explicitly characterize tip parameter dependencies
  - currently only done to the extend needed
- Solve NaOHdepletion / crystallization problem

Thanks for the Internship ^



Production of new E-gun tips

Philip Geißler, 13.09.2021 – 12.12.2021

Deutscher Akademischer Austauschdienst
German Academic Exchange Service