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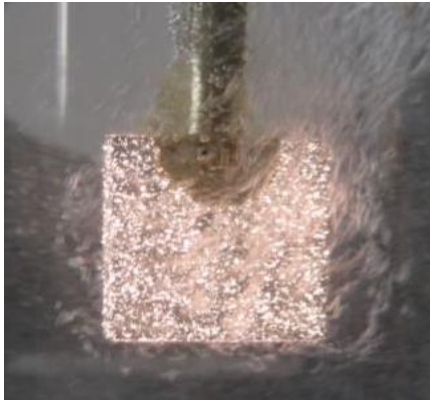
PLASMA ELECTROLYTIC OXIDATION (PEO) AT HIGH FREQUENCIES: CHARACTERIZATION AND CONTROL

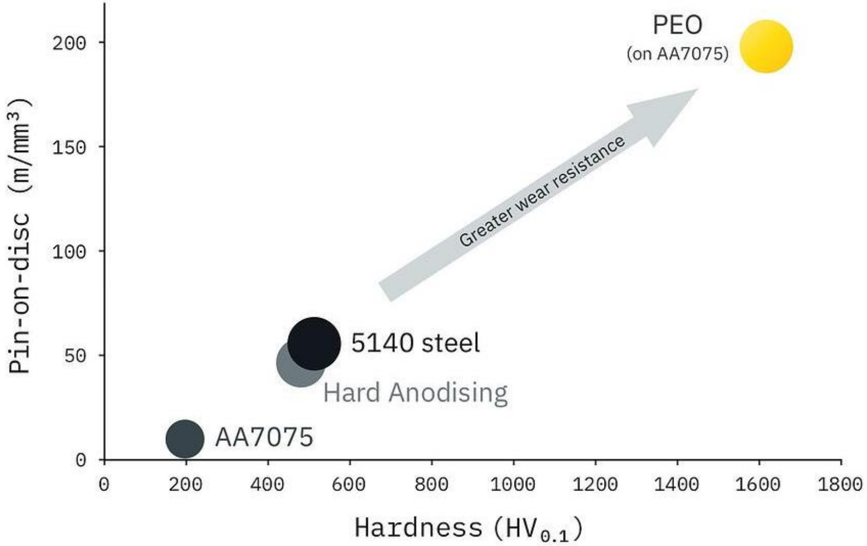
IOPS Presentation: Patrick Hermanns

Plasma Electrolytic Oxidation

Plasma (enhanced) Anodization

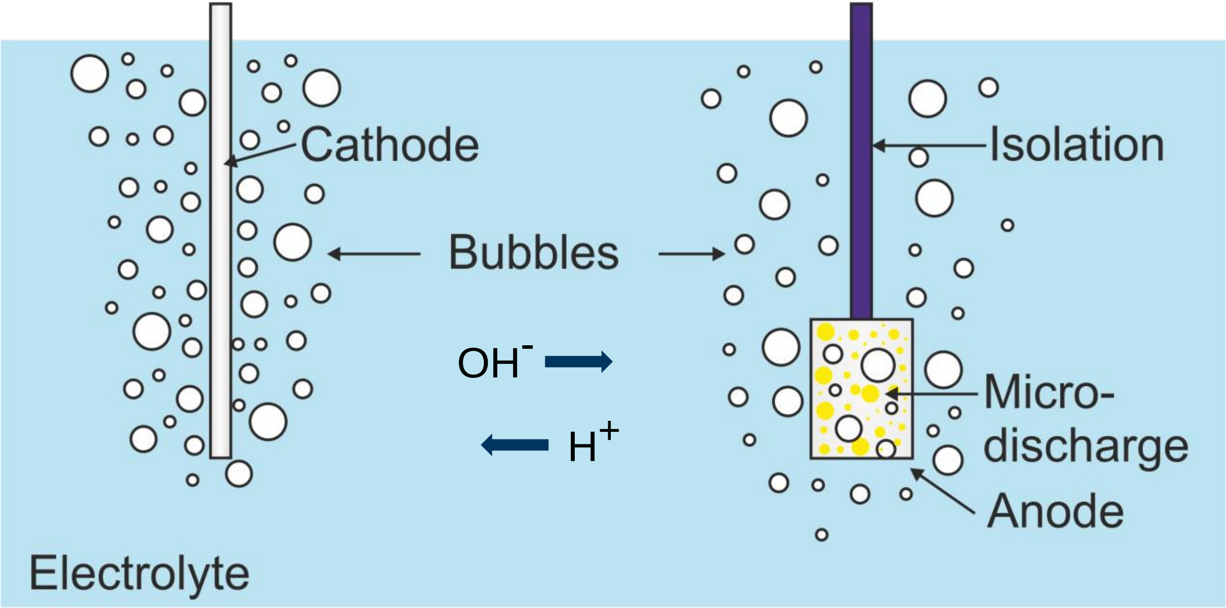


Al → Al_2O_3



Source: keronite.com

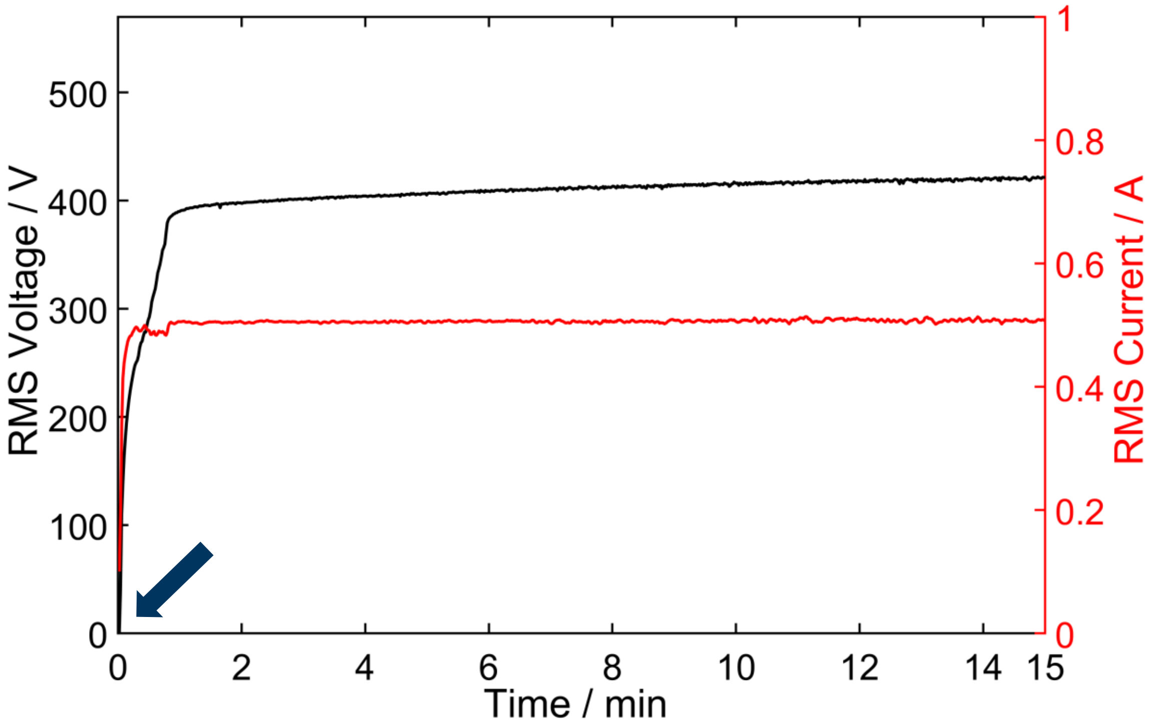
Electrochemical process

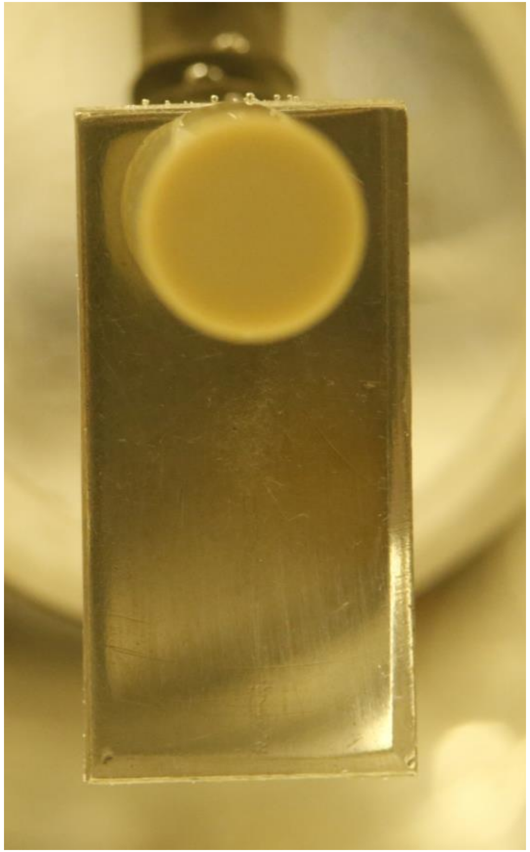


$$2Al^{3+} + 3OH^{-} \rightarrow Al_2O_3 + 3H^{+}$$

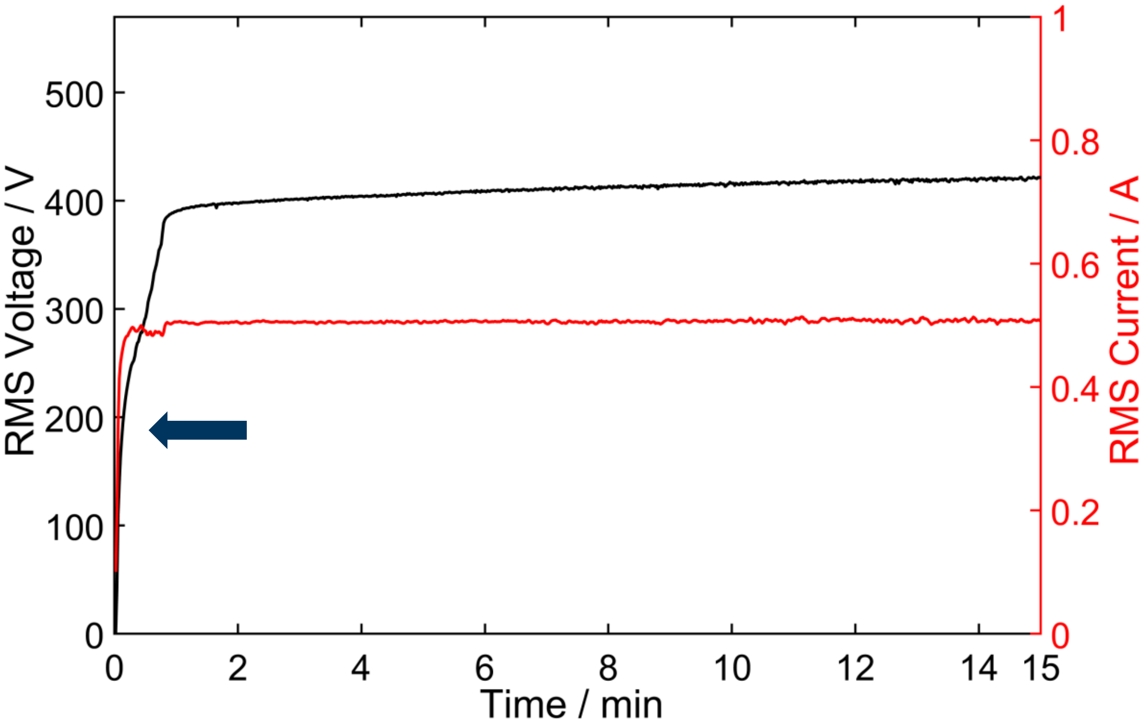
$$2Al^{3+} + 3O^{2-} \rightarrow Al_2O_3$$

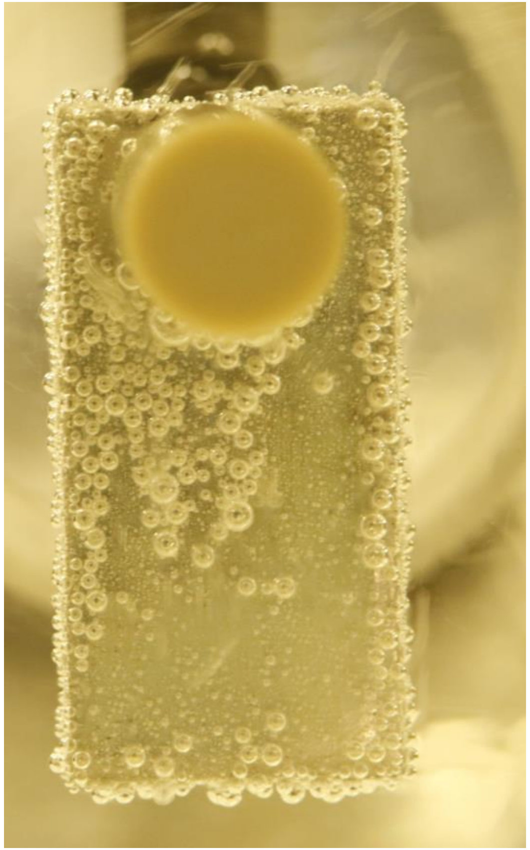
Time dependent process



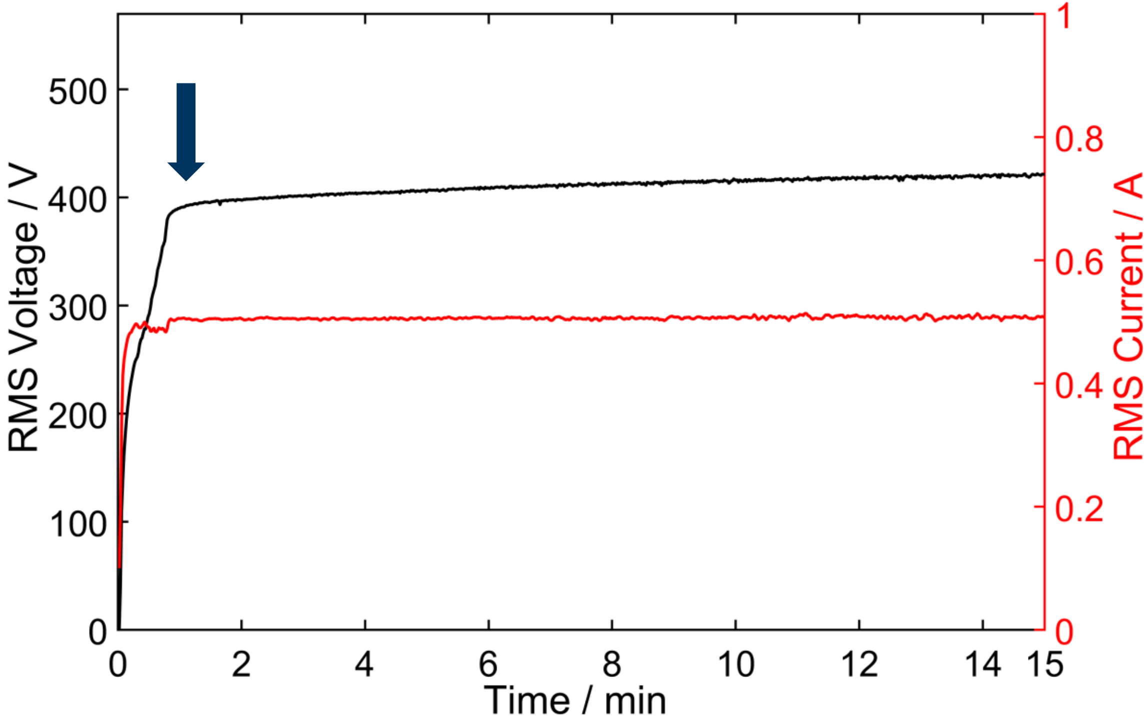


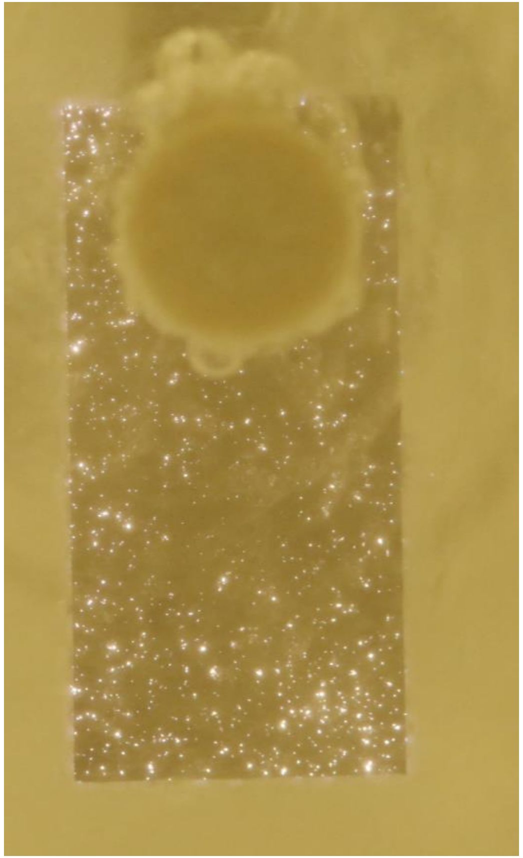
Time dependent process



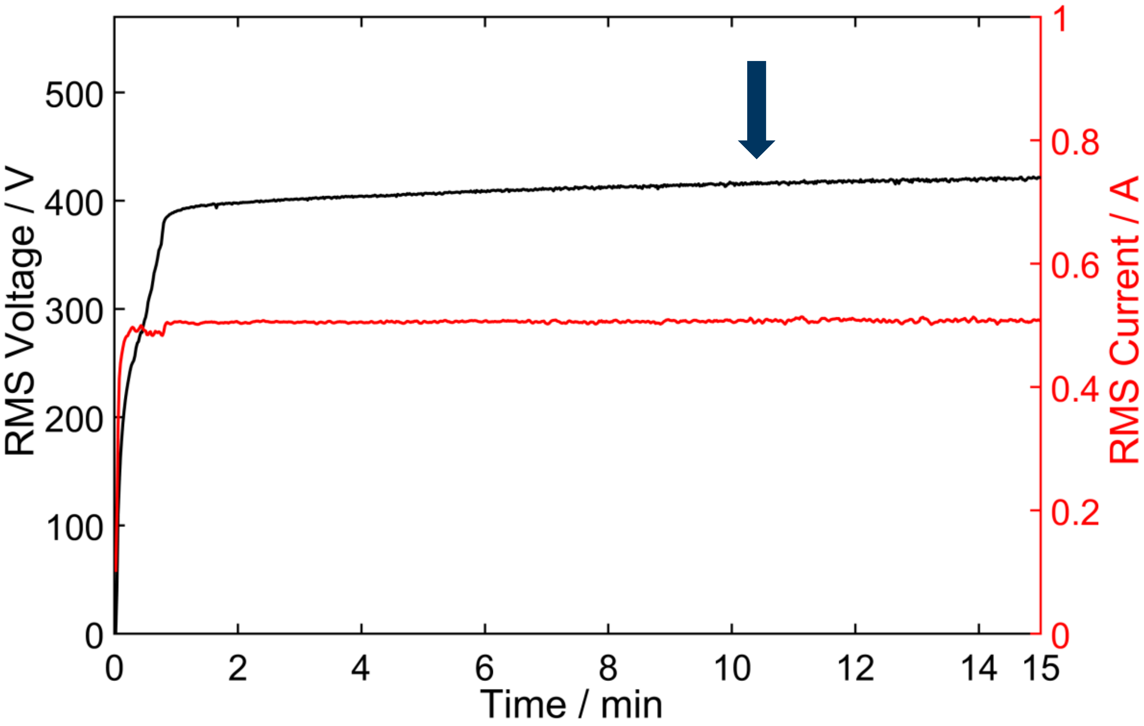


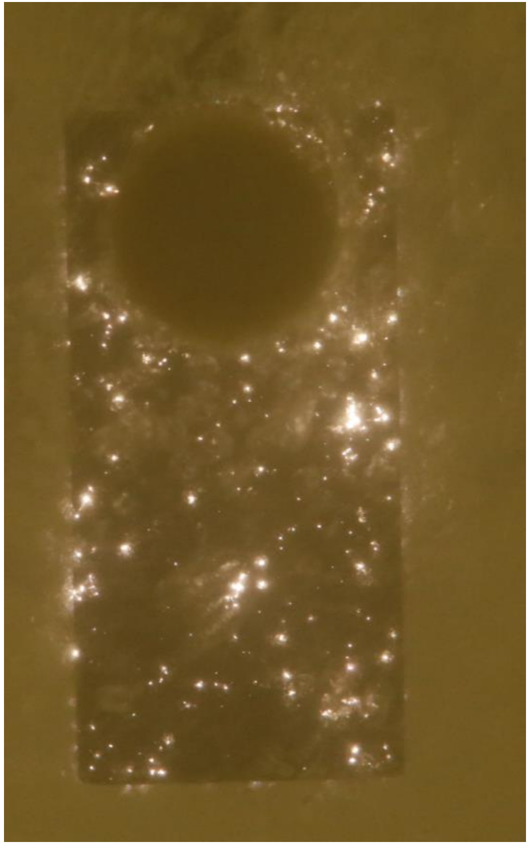
Time dependent process



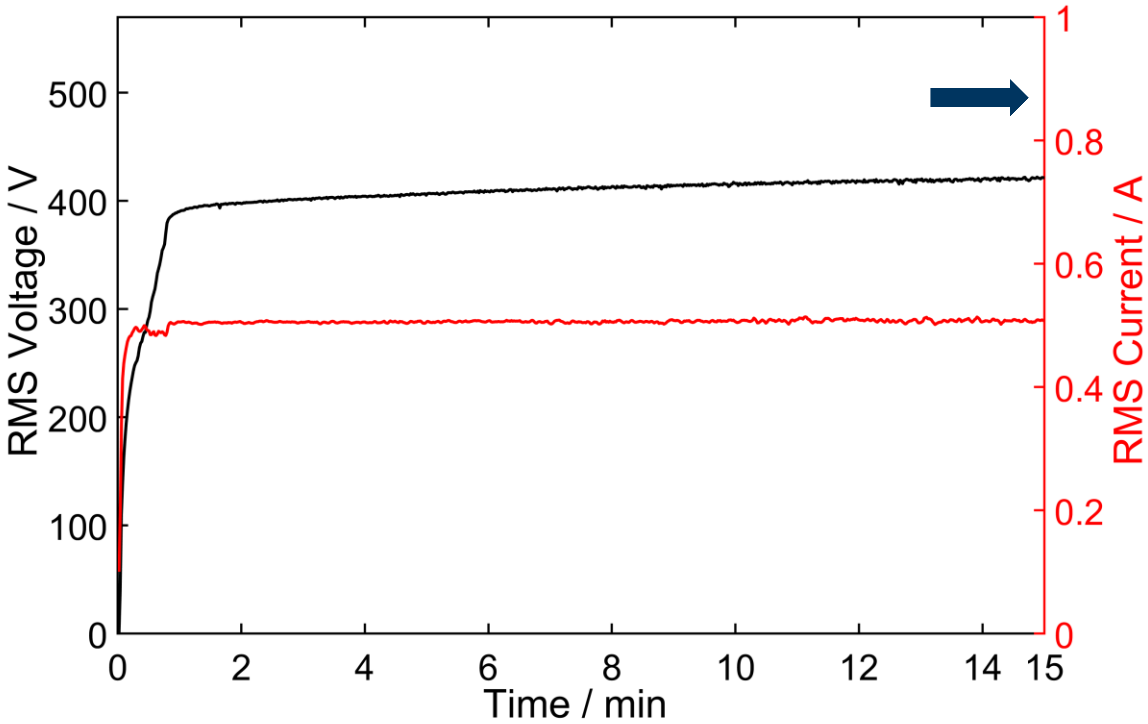


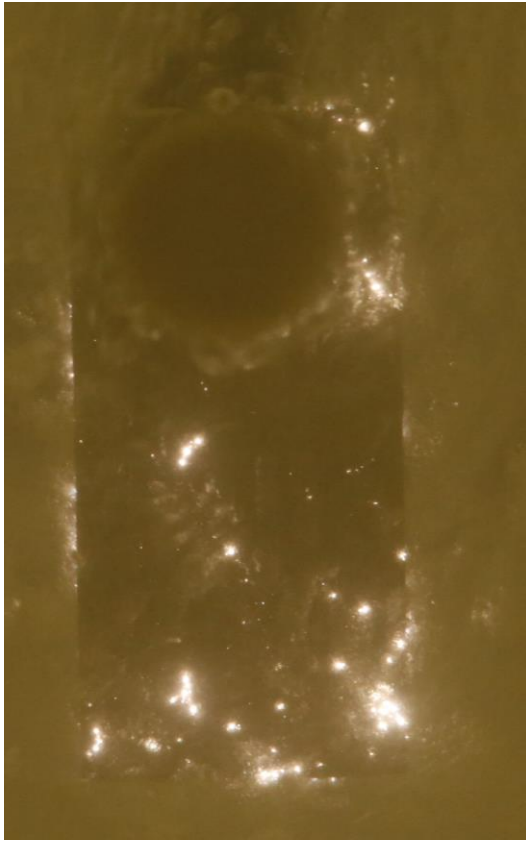
Time dependent process





Time dependent process





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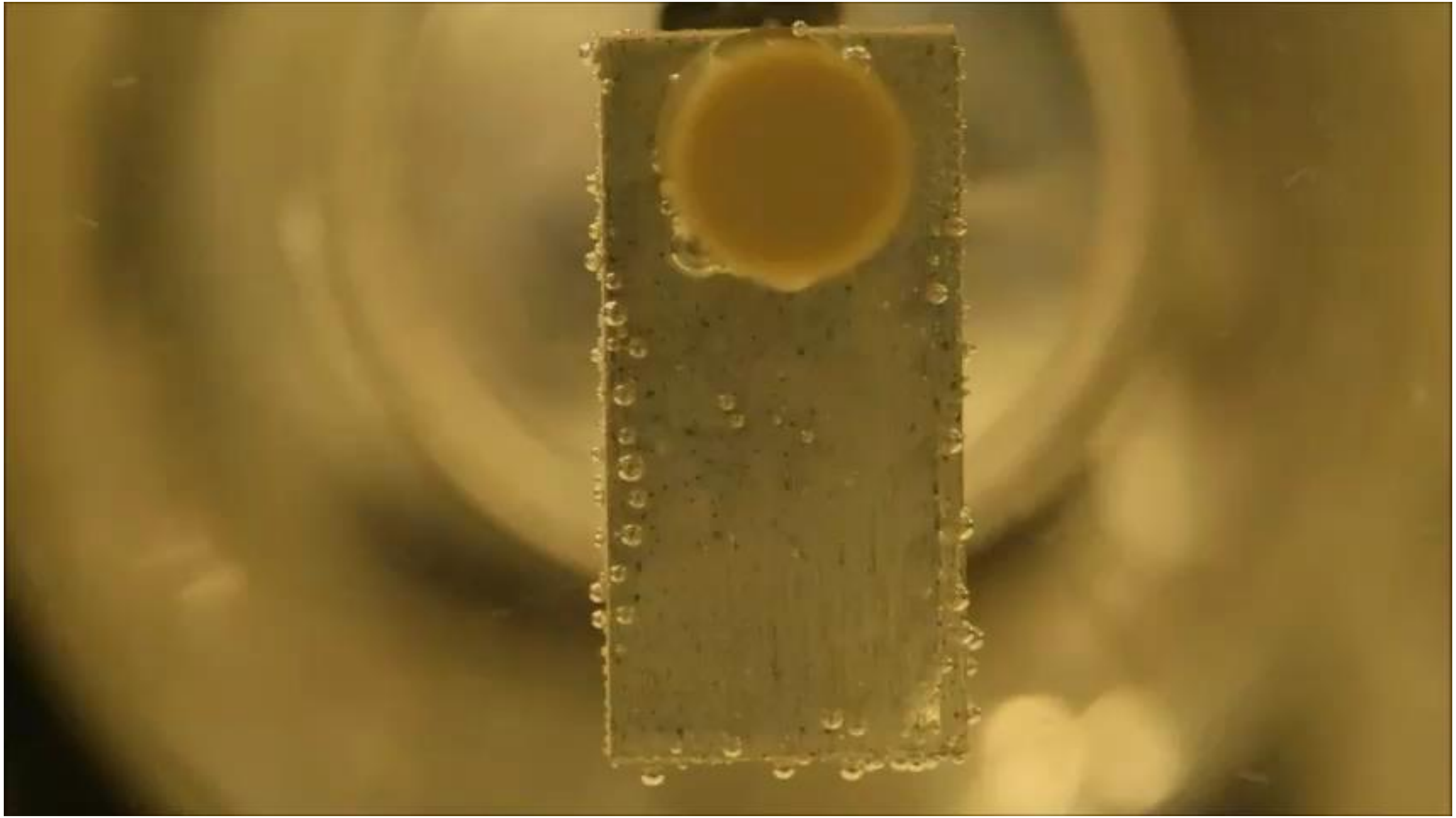

Porous surface

- Aluminum oxide melts and

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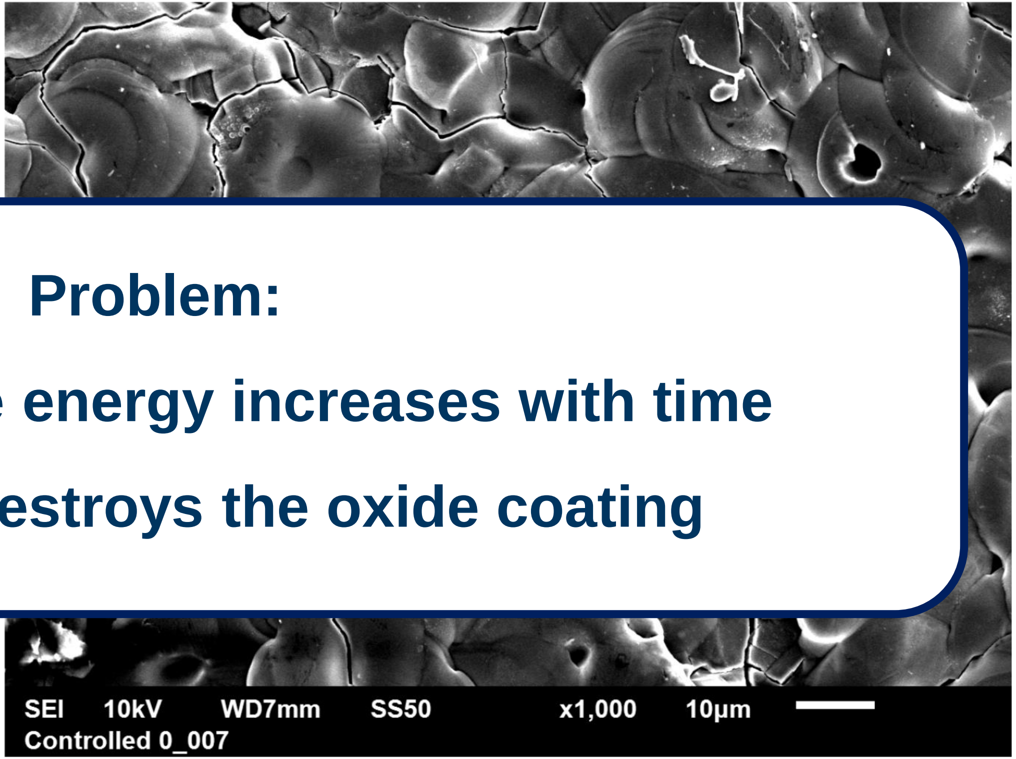
- Highly porous surface is established during coating

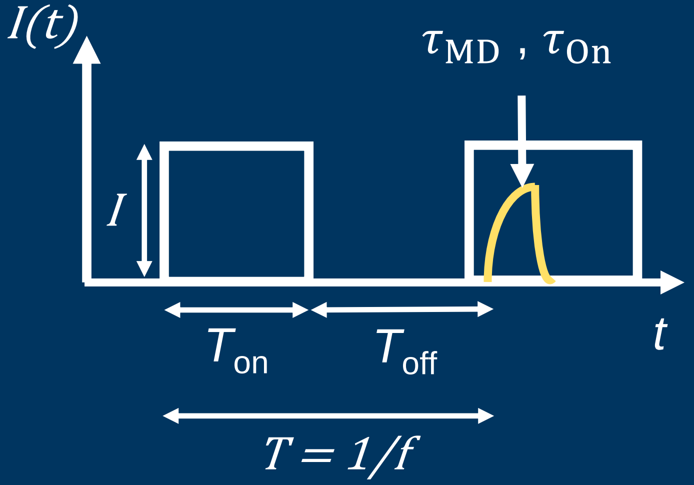


Problem:

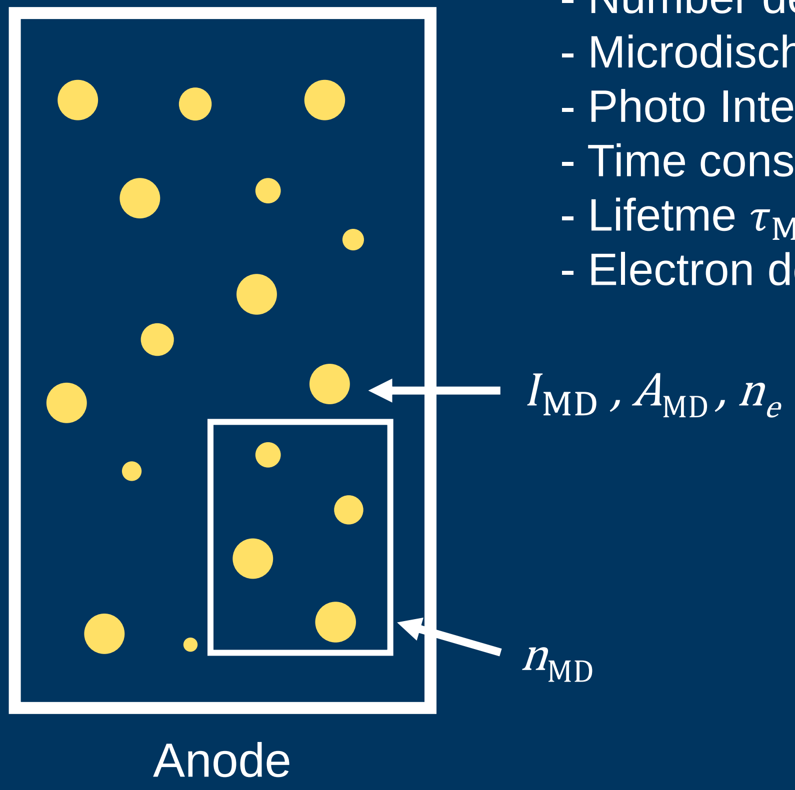
Microdischarge energy increases with time and locally destroys the oxide coating

Problem

Electrical parameters
- Current amplitude I
- Pulse On-time T_{on}
- Pulse Off-time T_{off}
- Duty-Cycle ϑ
- Pulsing frequency f

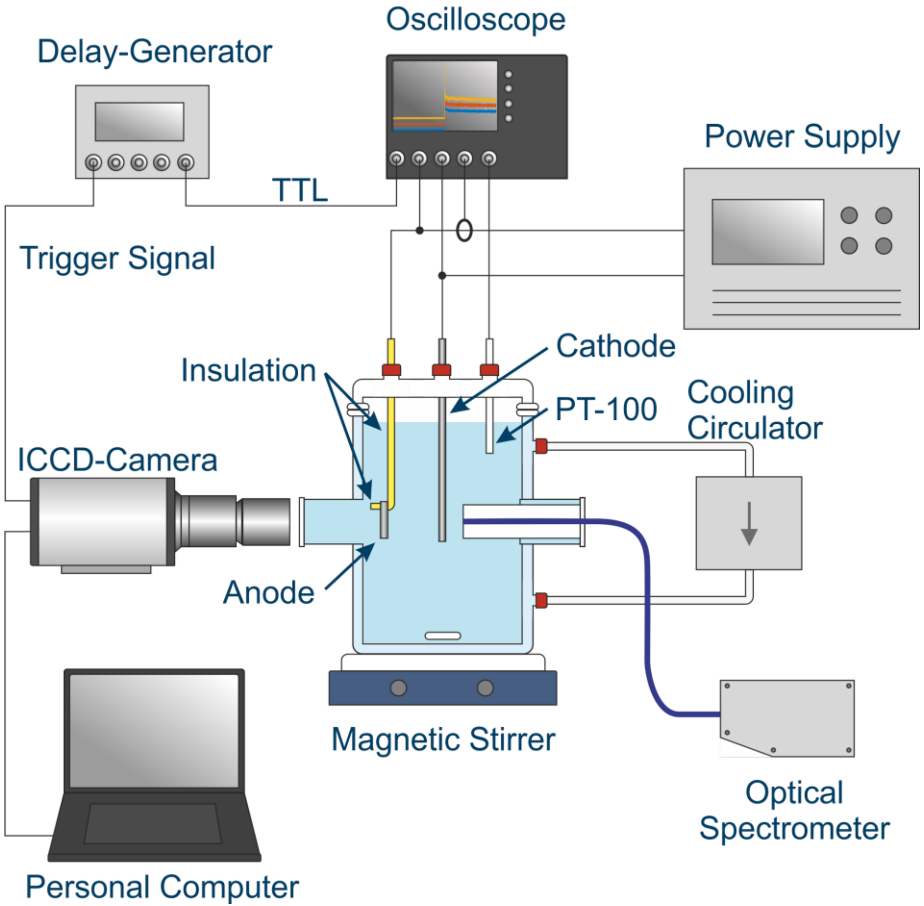


Microdischarge behaviour
- Number density n_{MD}
- Microdischarge size A_{MD}
- Photo Intensity I_{MD}
- Time constants τ_{On}
- Lifetme τ_{MD}
- Electron density n_{e}



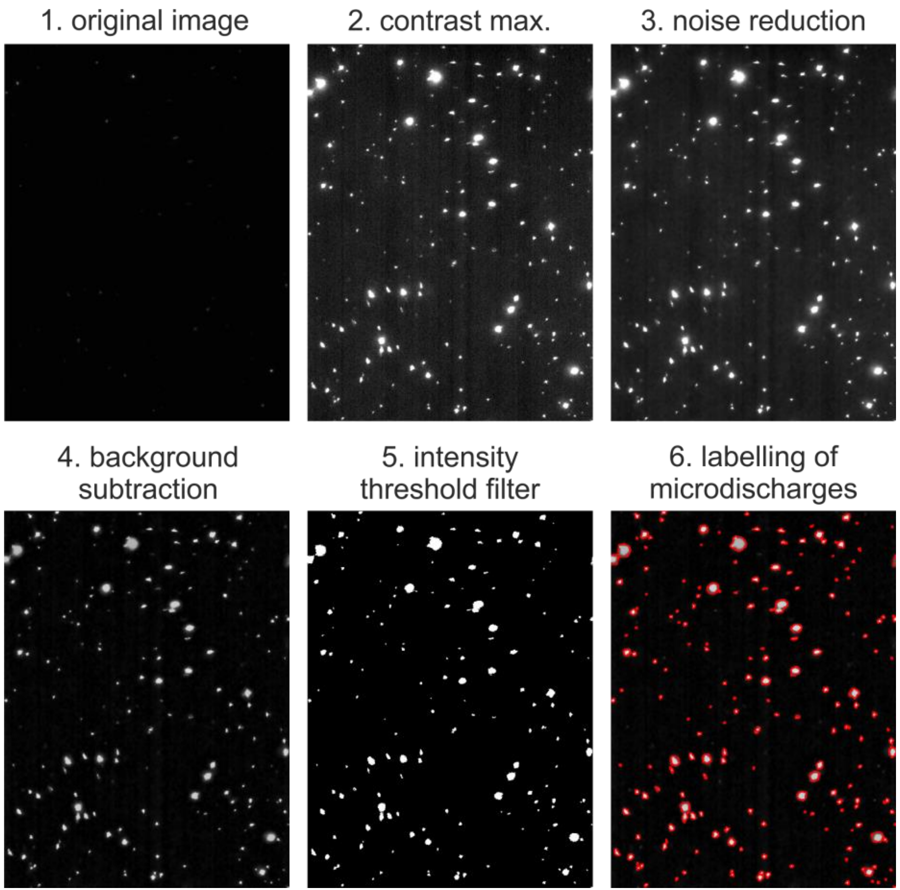
Experimental Setup

- Electrolyte:
  dest. water + $2\ \mathrm{g/l}$ KOH
- Anode material:
  Al 6061 alloy $(20 \cdot 10 \cdot 2\ \mathrm{mm})$
- Cathode material:
  stainless steel $(d = 4\ \mathrm{mm})$
- Generator:
  Magpuls MP2-30,
  galvanostatic mode,
  unipolar (rectangular) pulsing



MD Detection

- Image analysis during process
- Fast algorithm to enable *in situ* measurements
- Threshold filter regarding photo-intensity to create binary image
- MD size, number density and photointensity are calculated
- Time for processing of one image: $t_{tot} < 90\ \mathrm{ms}$



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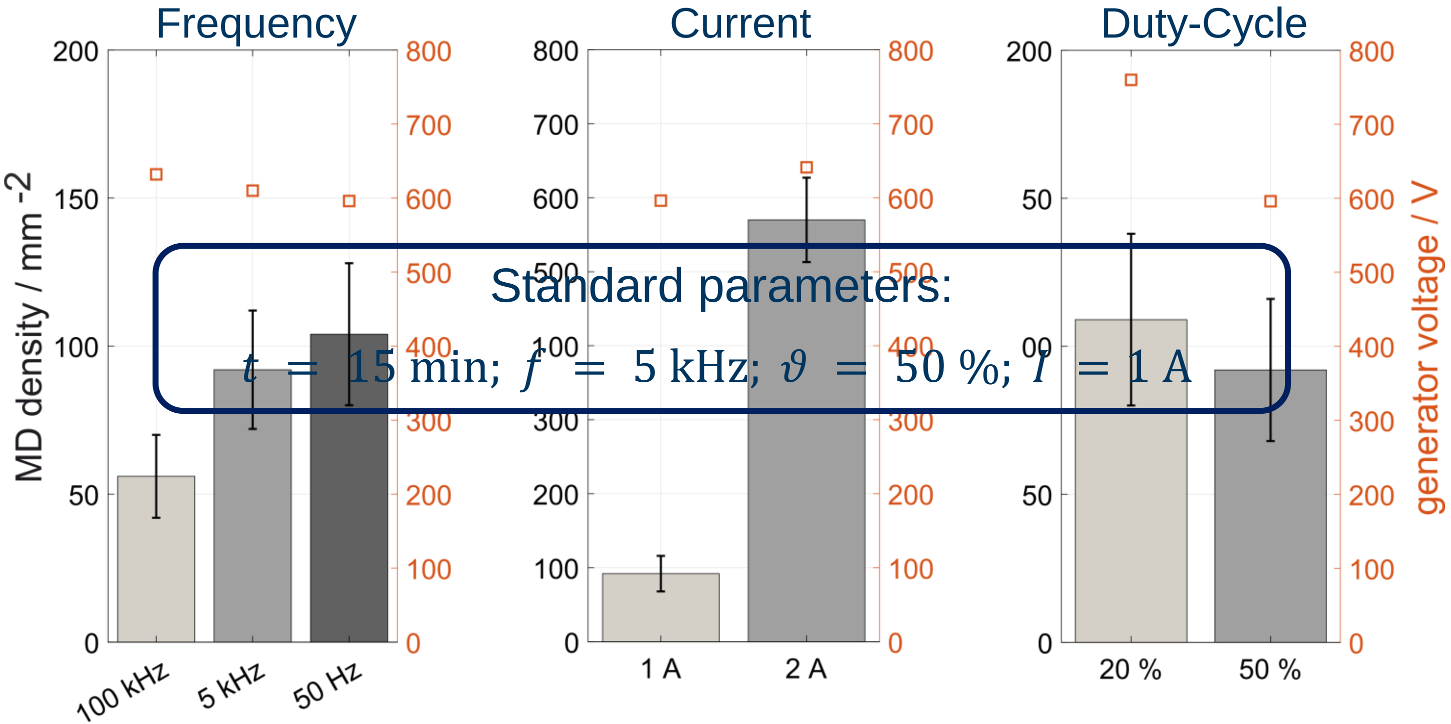
Parameter variation

Standard parameters:

$t = 15\,\mathrm{min};\ f = 5\,\mathrm{kHz};\ \vartheta = 50\,\%;\ I = 1\,\mathrm{A}$



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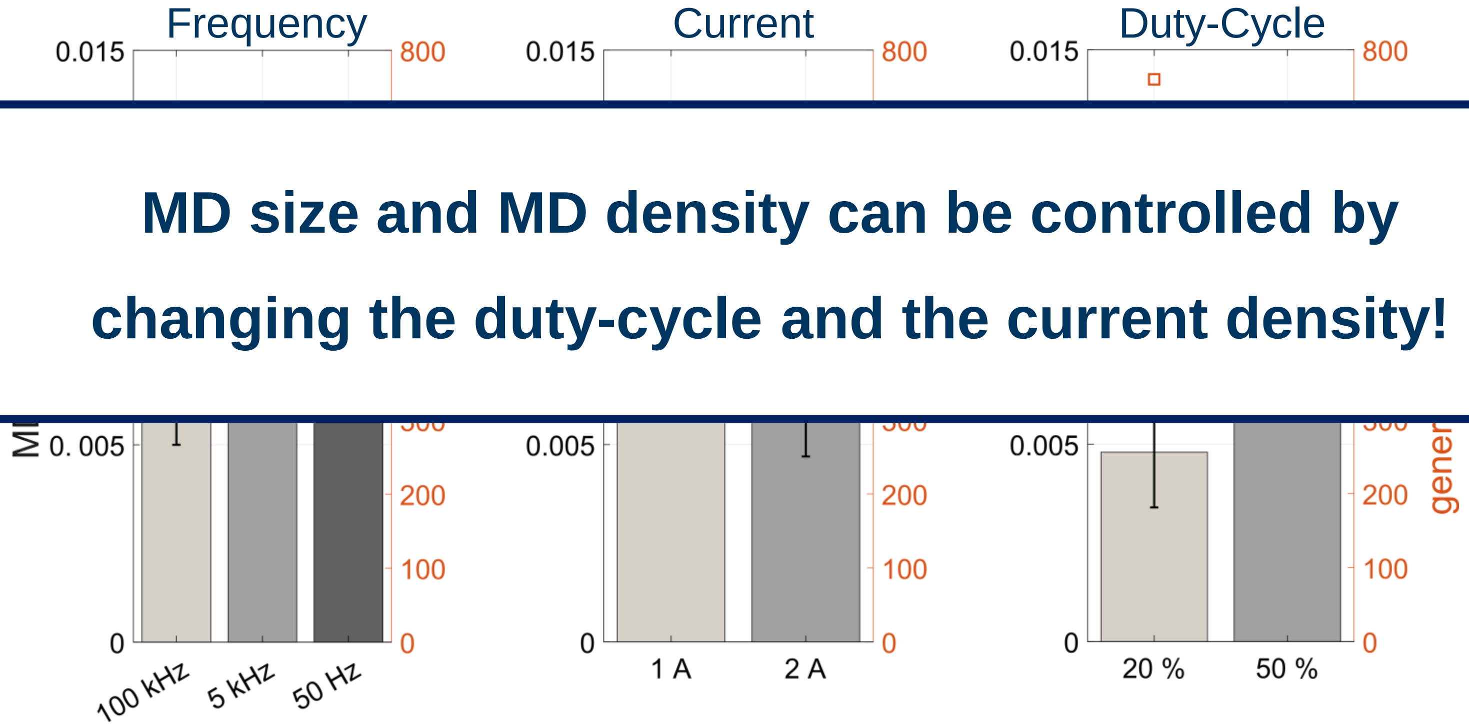
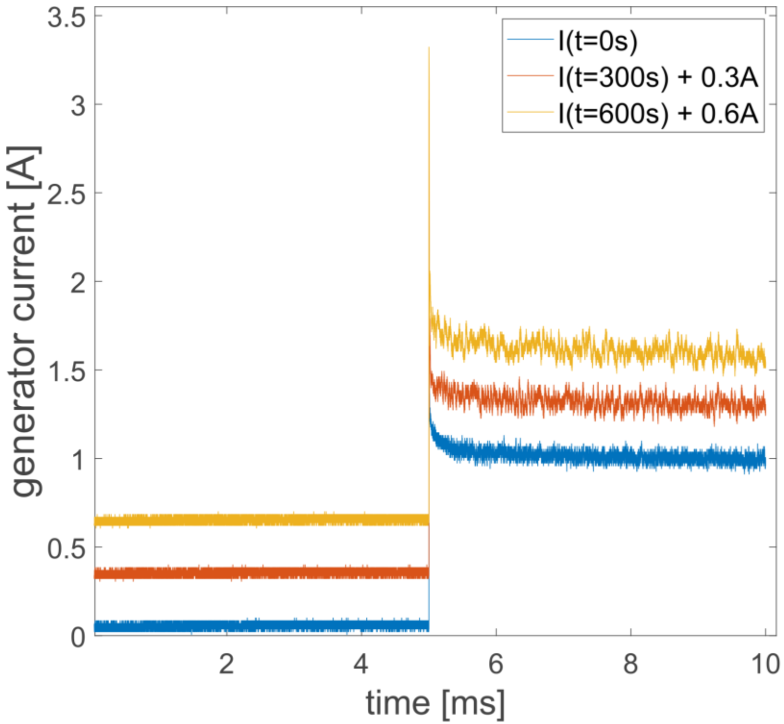
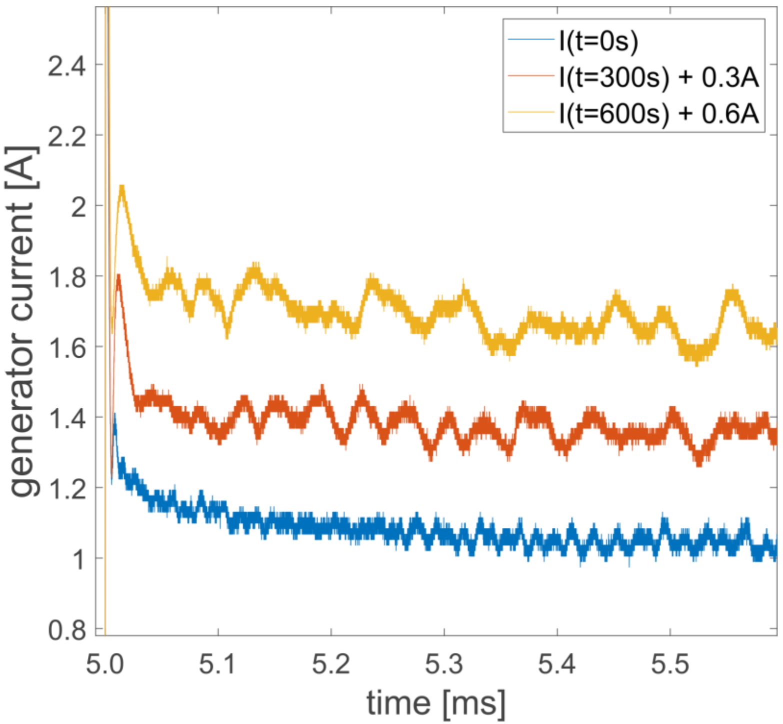


MD size and MD density can be controlled by changing the duty-cycle and the current density!

Lifetime of MDs (current pulses)





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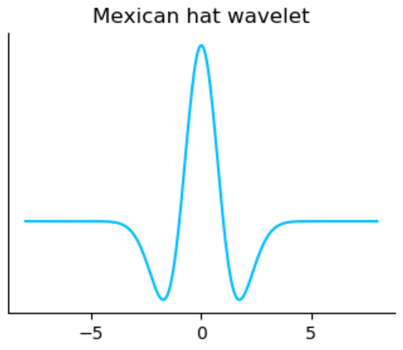
Lifetime of MDs

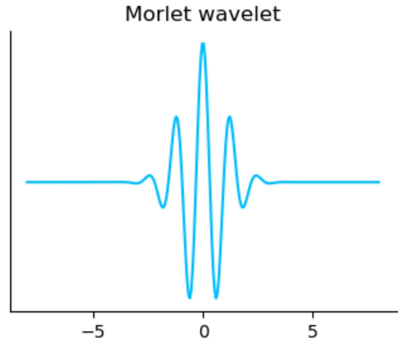
- Analysis of current pulses by wavelet transform
- Fitting of wavelet function by translation *b* and dilation *s:*

$$\Psi_{s,b}(t) = \frac{1}{\sqrt{s}} \Psi\left(\frac{t-b}{s}\right)$$

- Wavelet coefficients (like fourier coefficients):

$$W_{\Psi}(s,b) = \frac{1}{\sqrt{s}} \int_{-\infty}^{\infty} x(t) \cdot \Psi\left(\frac{t-b}{s}\right) dt$$





Source: towardsdatascience.com

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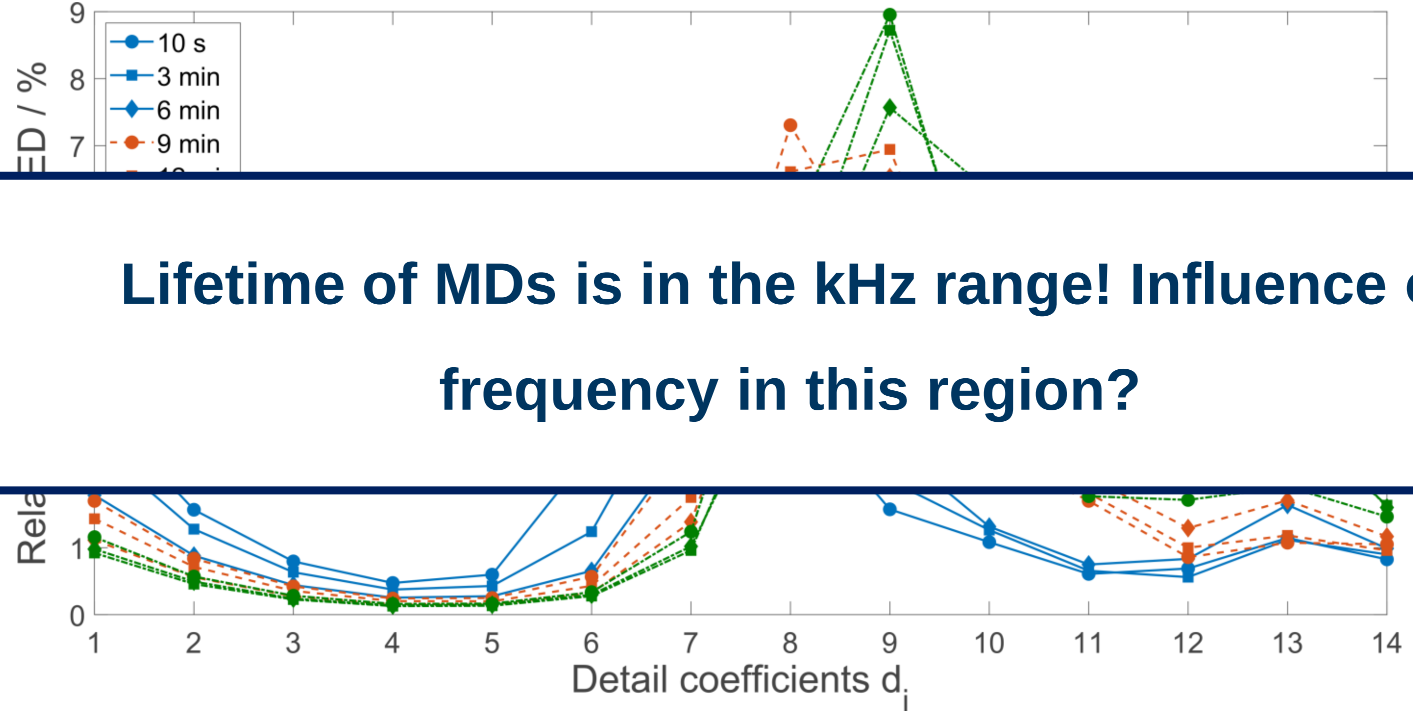
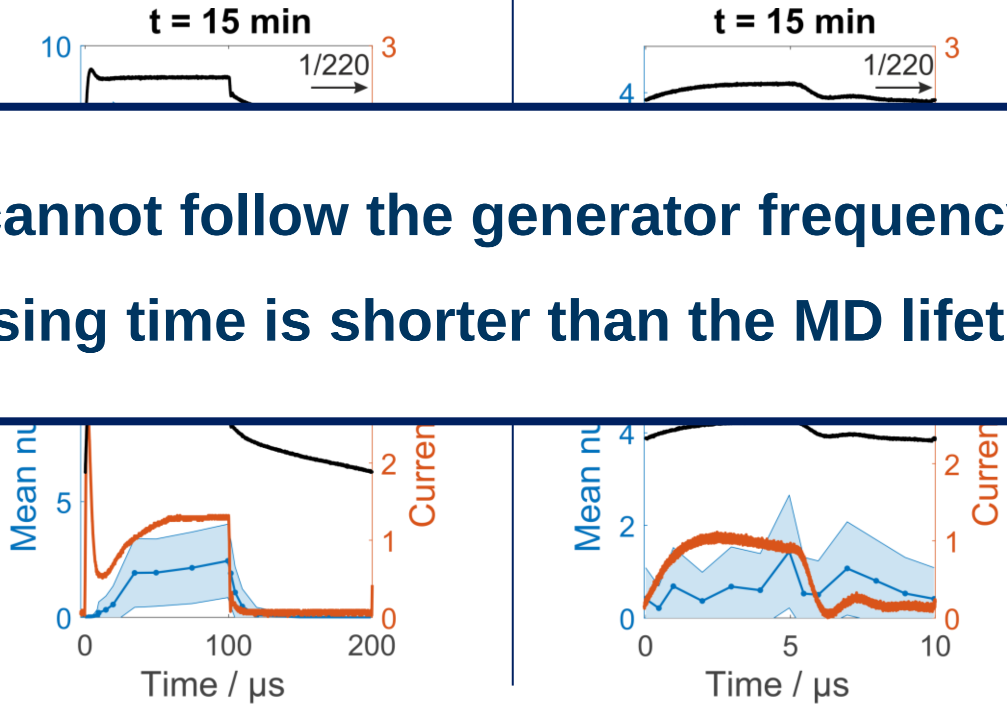
Results wavelet transformation



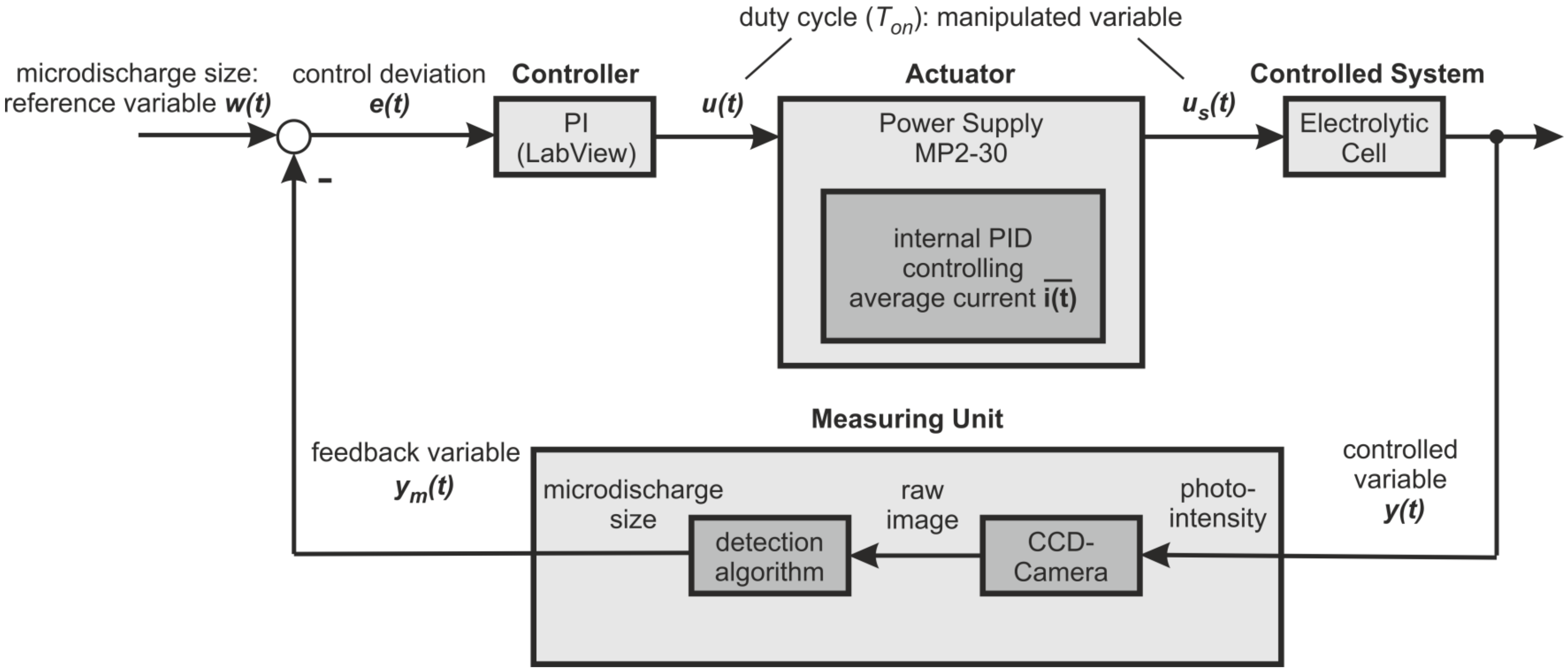
Lifetime of MDs is in the kHz range! Influence of frequency in this region?

Phase resolved MD dynamics



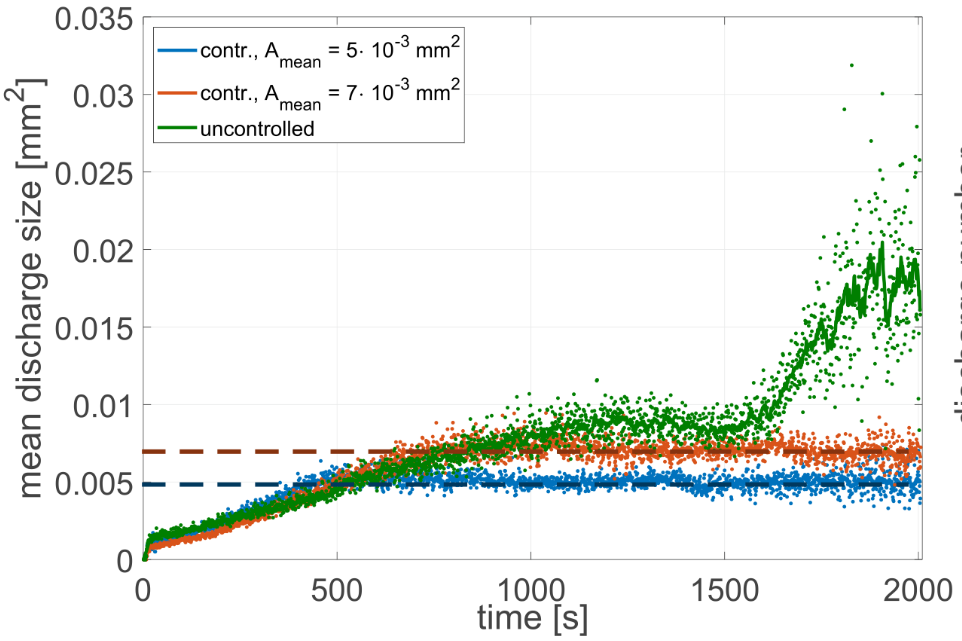
MDs cannot follow the generator frequency if the pulsing time is shorter than the MD lifetime!

In situ MD control scheme

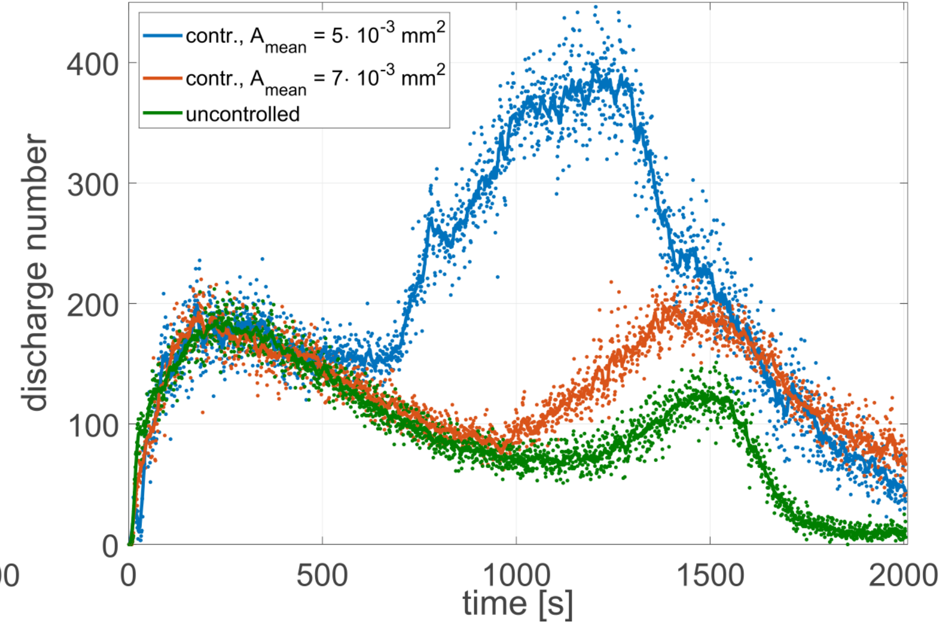


Results MD control (camera)

MD size



MD number



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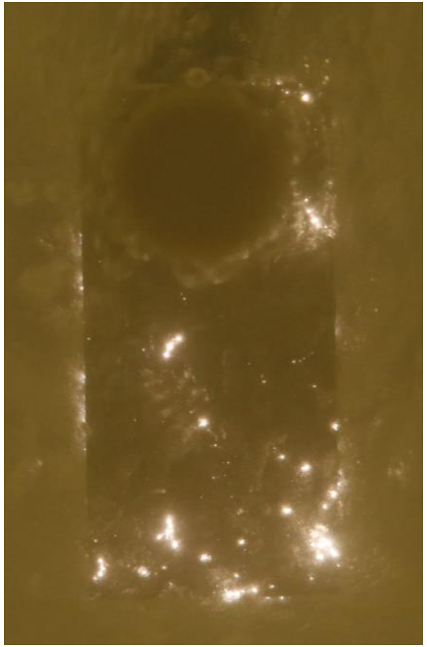
Results MD control (pictures)

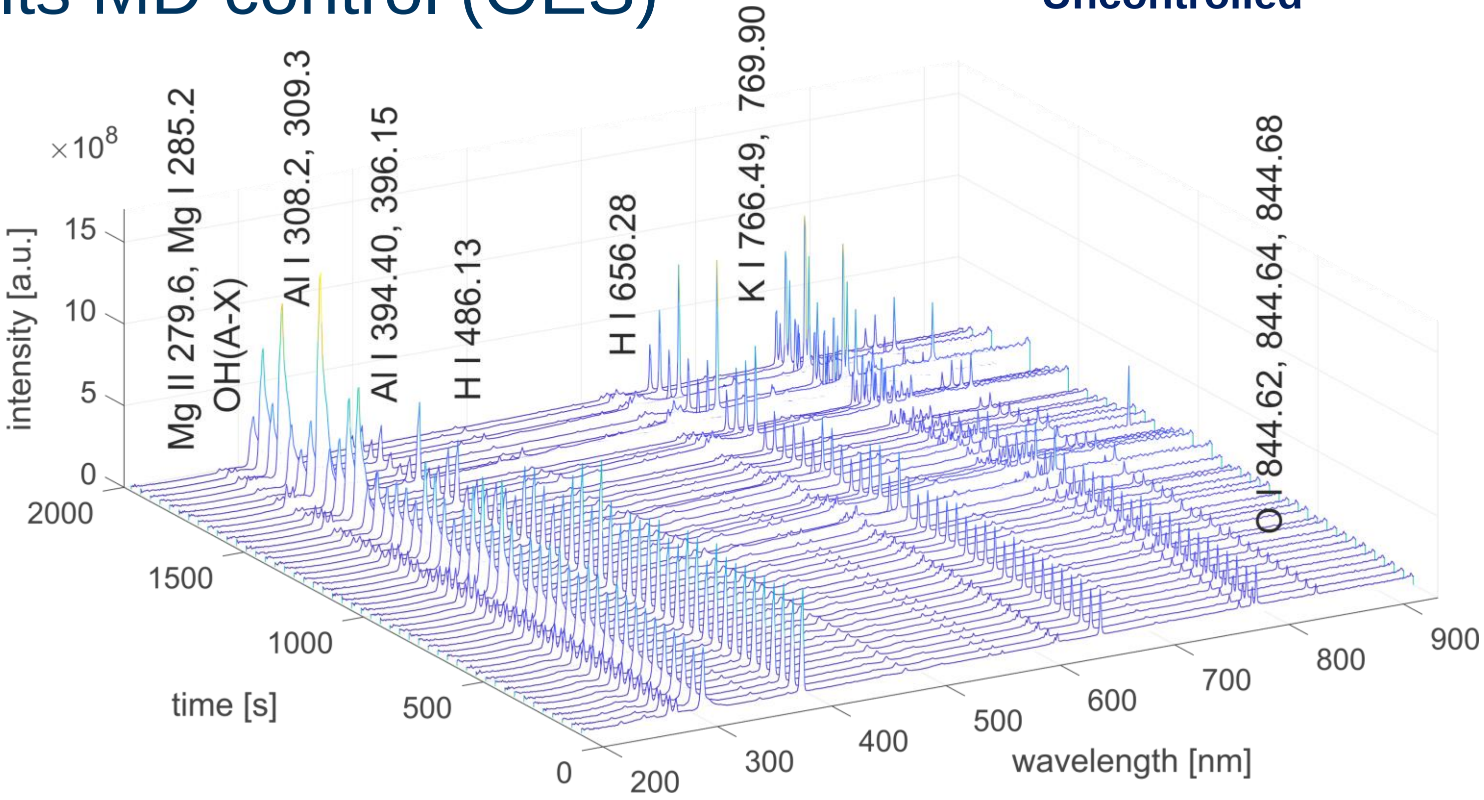
Uncontrolled



Controlled

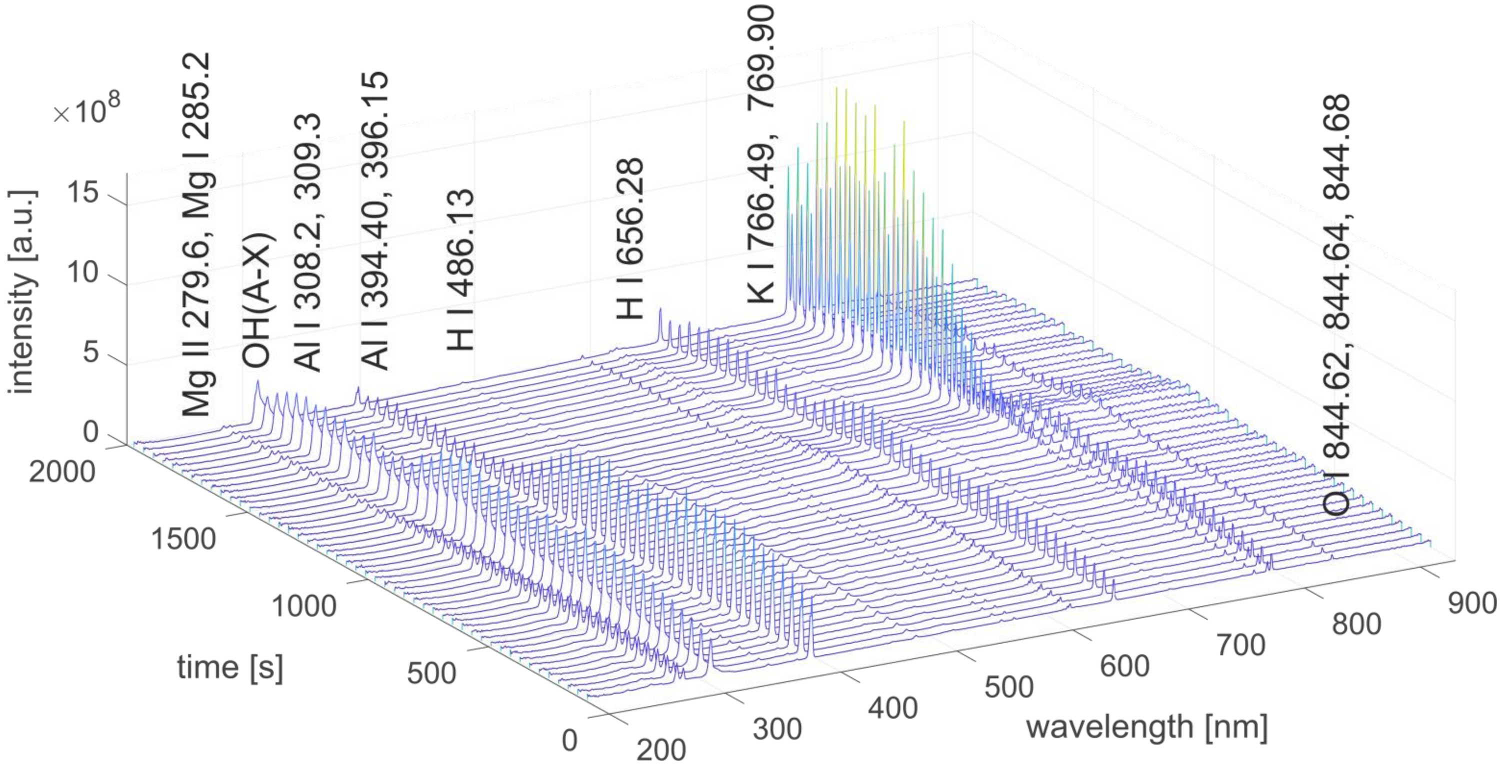
Results MD control (OES)

Uncontrolled



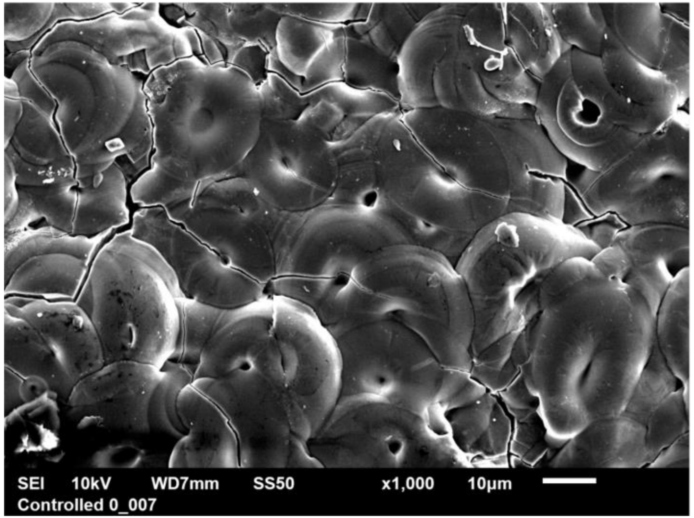
Results MD control (OES)

Controlled

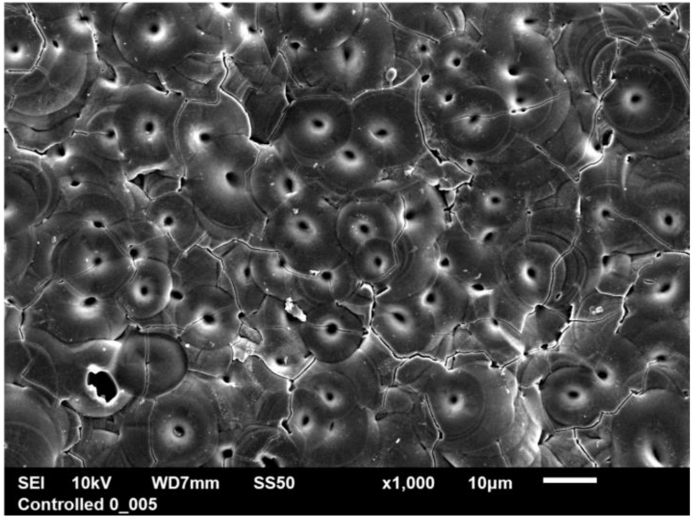


Results MD control (SEM)

Uncontrolled



Controlled



Conclusion

- MD lifetime is in the range between 6 µs and 1600 µs
- Current density and duty-cycle can adjust the MD number density and size
- Pulsing frequency has to be in the range of the microdischarge lifetime to control microdischarges
- Microdischarge properties can be controlled to distinct values with an *in situ* closed-control loop. By this the microdischarge energy can be controlled indirectly
- Outlook: Further material characterization of produced oxide coatings

Thank you for your attention!

Special thanks to people from:

[1]Hermanns *et al.* 2020 J. Phys. D: Appl. Phys. **53** 435204
[2]Hermanns *et al.* 2021 J. Phys. D: Appl. Phys. **54** 045205