Technology Metals I Advanced Ceramics

Pushing Tantalum capacitors to the limit: A powder manufacturers view to 300 V anodizations and beyond

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High Voltage Market Trends: Focus High Reliability

Increasing demand for HV applications!

Data Storage (SSD)

Medical Devices

Aviation

Aerospace

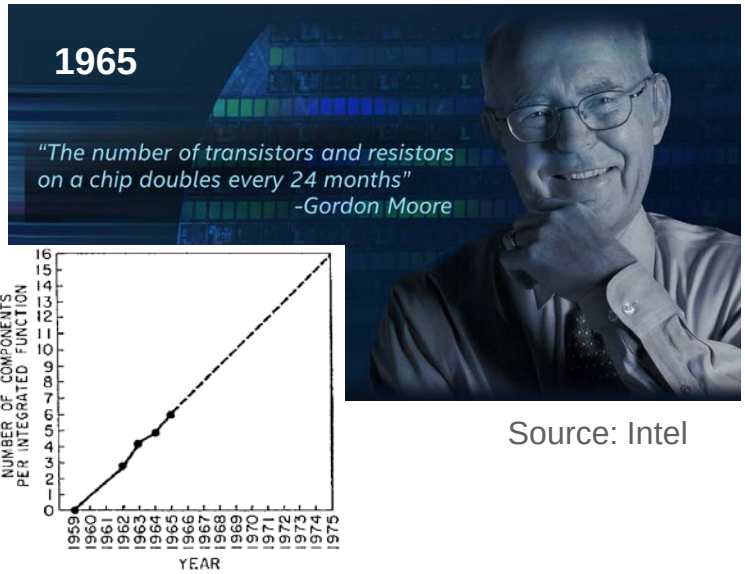
Transportation and Railroad

Automotive

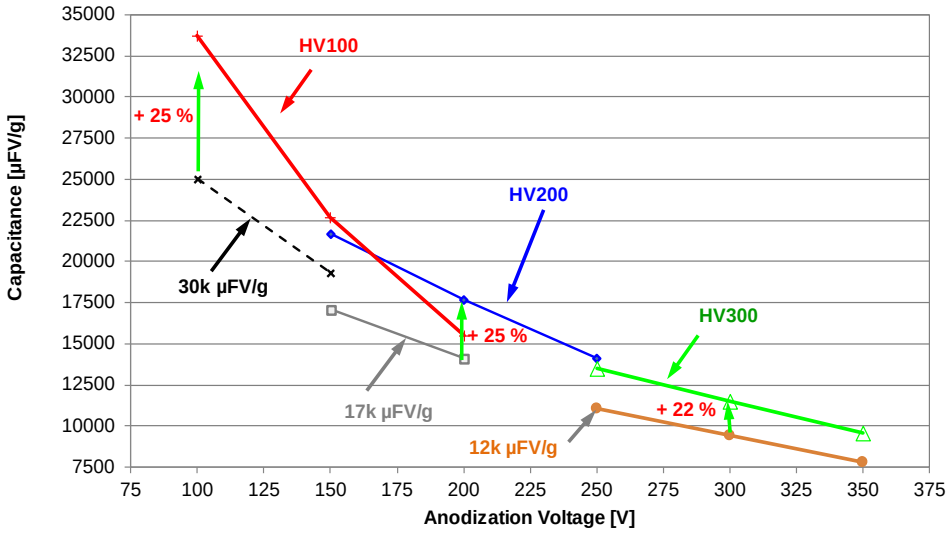
Defense

urce: Deutsch Bahn, Wikipedia

Moore's Law – Trends for High Voltage Applications



Source: Intel



Also continuous performance improvement for Ta capacitors!

Major trends for the recent years:

1. Increase capacitance at a given voltage e.g. 150 V_f
2. Increase forming voltage above 300 V_f ➔ More energy!

High Voltage Medium Capacitance = HVMC

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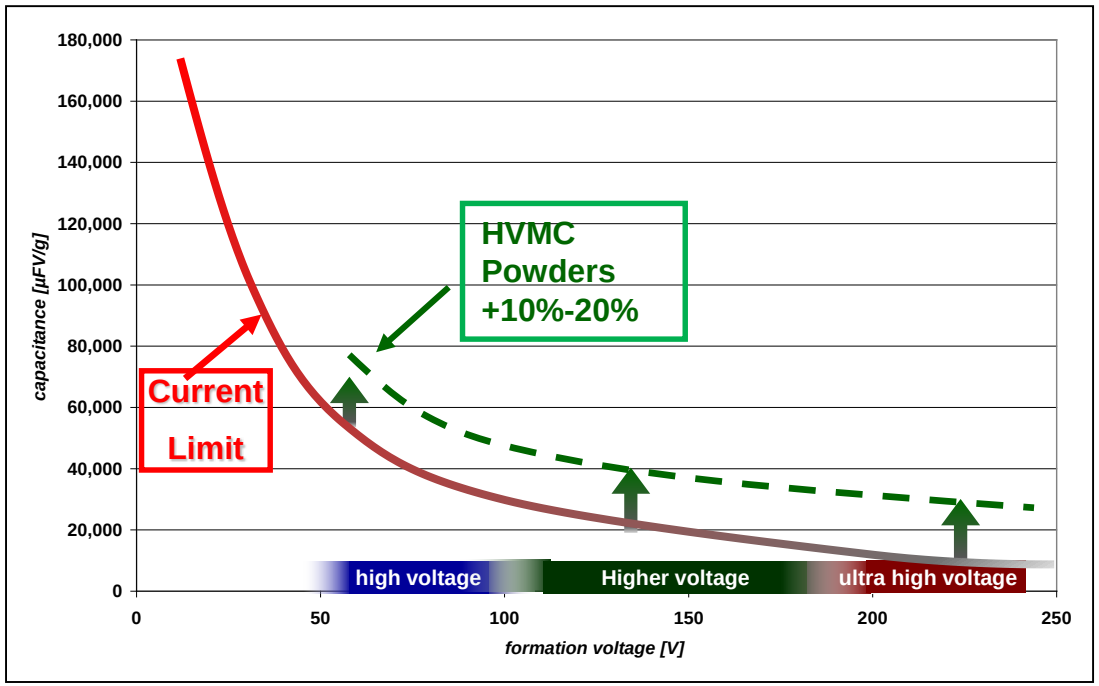
What Makes HVMC Powder so Unique

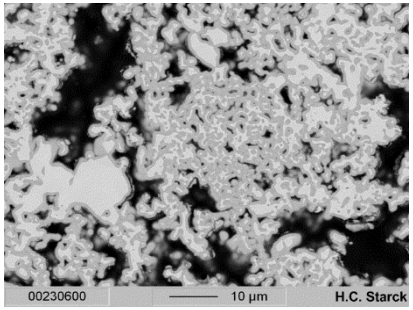
1. Superior microstructural homogeneity of pores and particles
2. Pore and primary particle structure can be tailored to application needs
   - ➔ Primary particle size can be varied from 0.3 µm – 3 µm
   - ➔ Pore size distribution can be tailored within a specific powder charge category
3. Provides higher purity than Na powder (Fe, Cr, Ni < 10 ppm, and K, Na <1ppm)



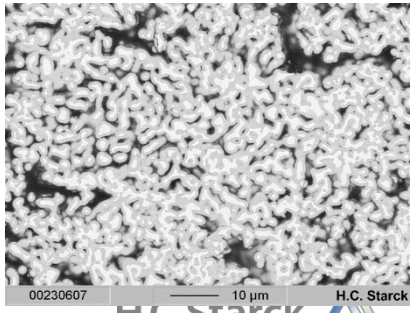
300 V_f Anode

Standard

Powder



HVMC



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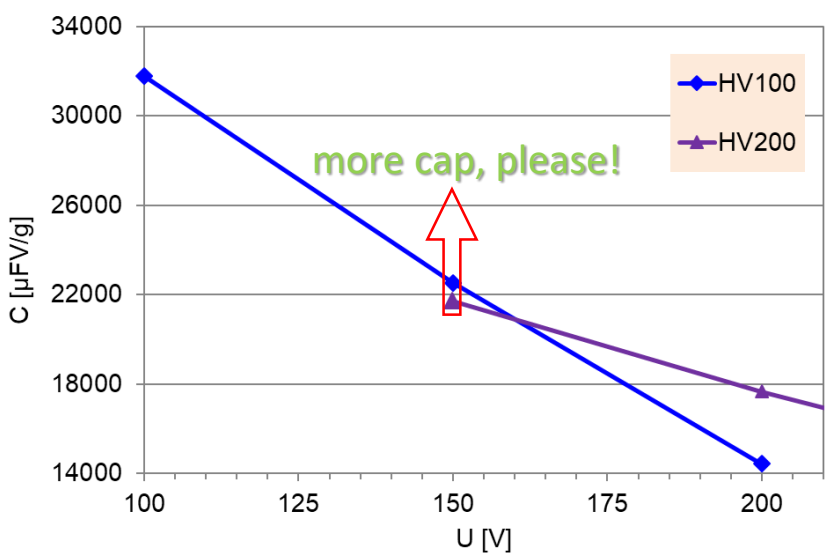
1. Trend: How to Provide More Capacitance?

Powder Naming
"**H**igh **V**oltage"
HV 200
target formation voltage

- New capacitors for U_f ~150 V_f highly requested
- Task: Provide more cap than existing HVMC powders (HV100/HV200)



- HV100: pores too small ➔ worse ESR
- HV200: better pores but lower cap

Develop new powder by improving particle and pores size distribution!

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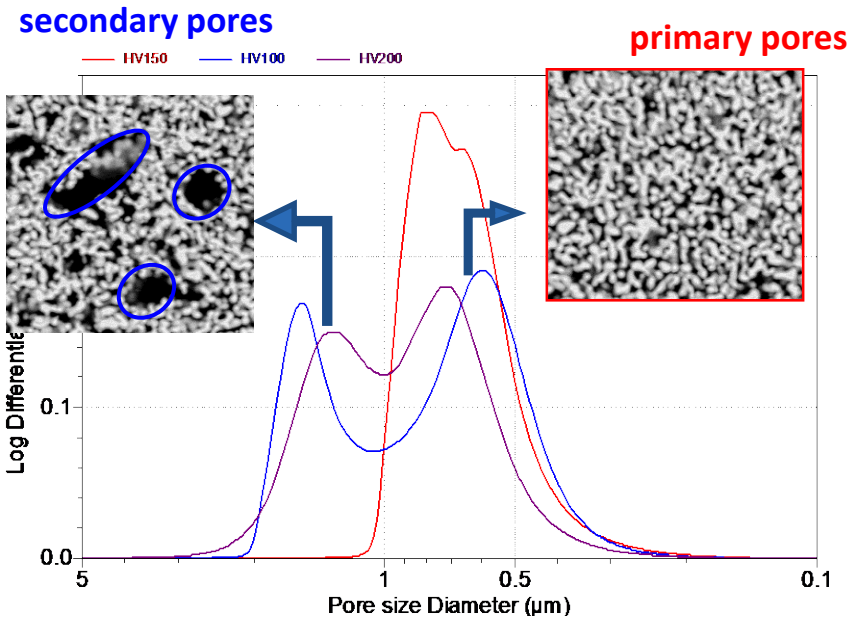
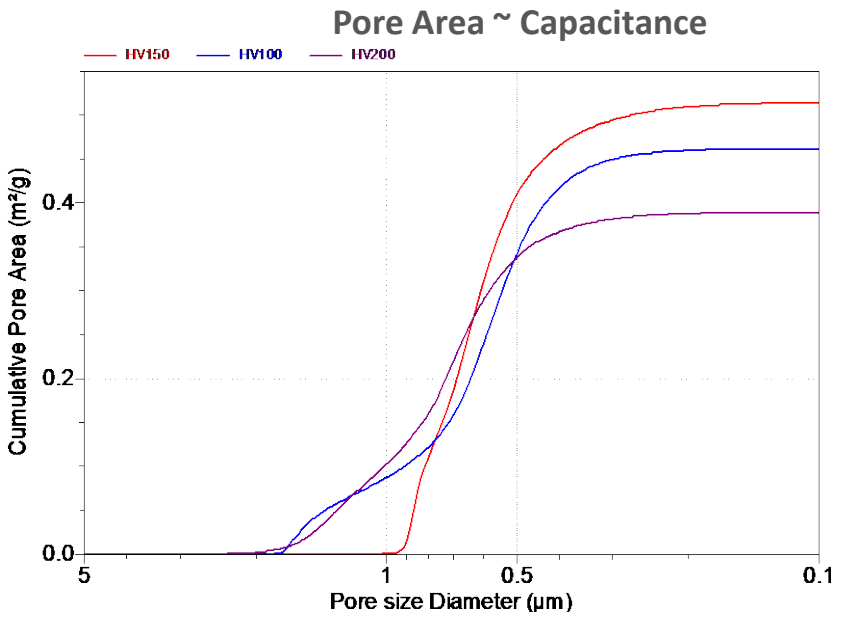
1. Trend: How to Provide More Capacitance?

- Production parameters optimized according to microstructure!
- Anode pore size + primary particle distribution was improved ➔ nearly monomodal

Anode Pore Size Distribution (PD 6,0 g/cm³, ~10 % shrinkage)





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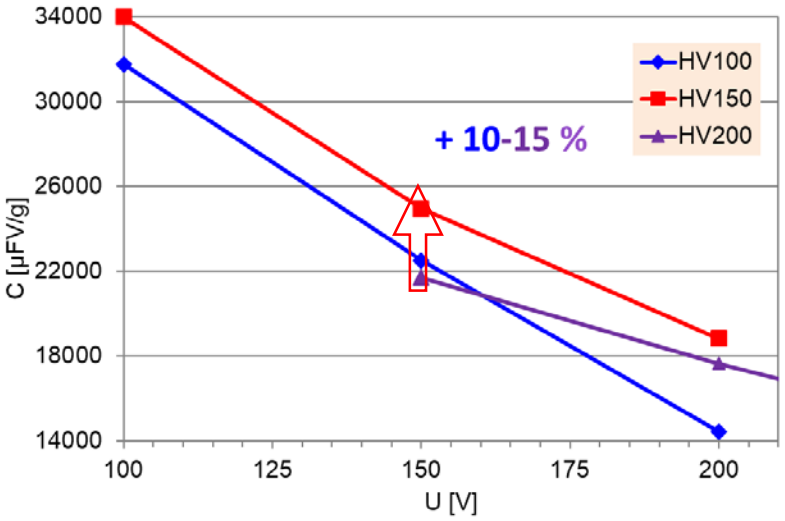
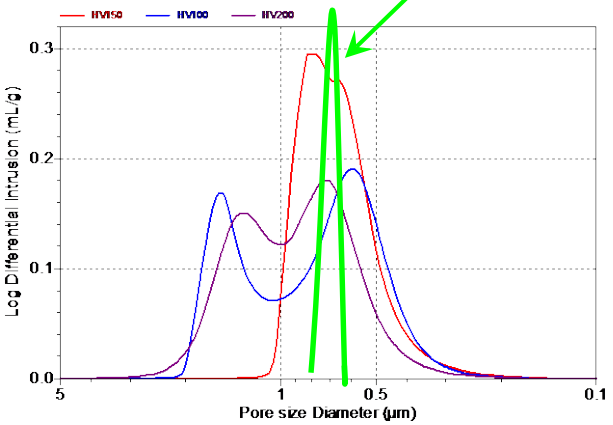
Structure Impact on Capacitance

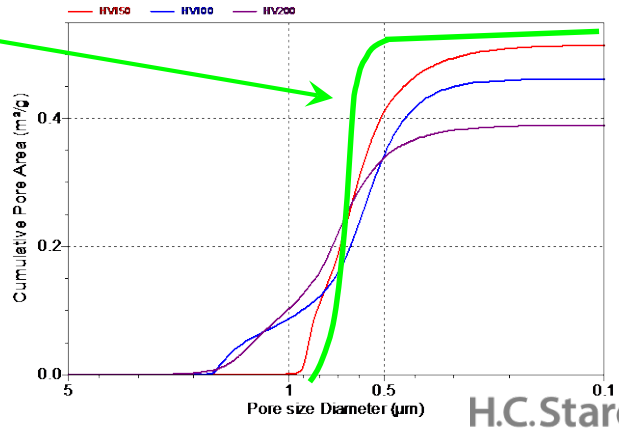
- New powder provides 10 -15 % more capacitance than other HVMC powders
- More cap over wide range: 100 – 200 V



Showcase for future developments !

Make anode pore/particle size distribution narrower!





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2. Trend: Increase Forming Voltage

- Currently, HV300 provides highest energy density @ 250-300 V
- Task: Provide more energy W by increased forming voltage U

$$W = C \int_0^U u \, \mathrm{d}u = \frac{C U^2}{2}$$

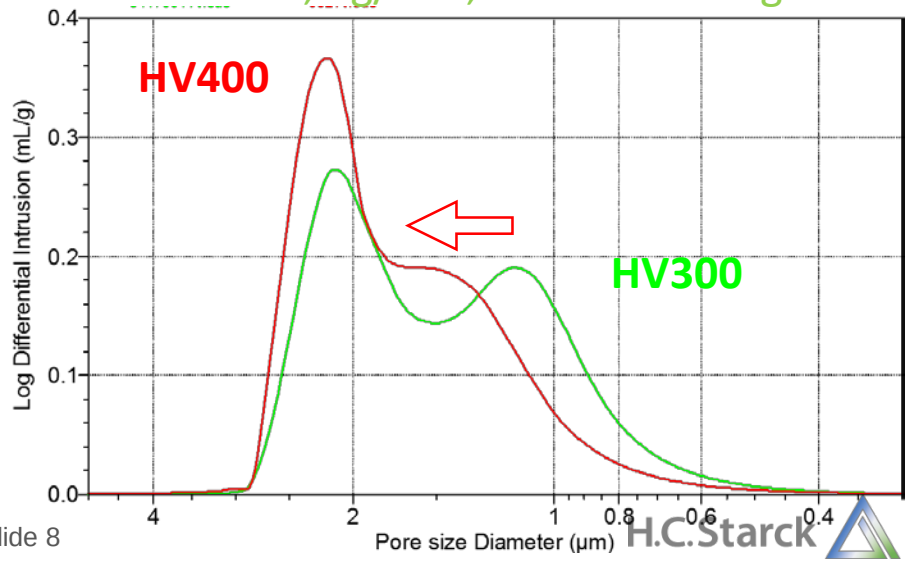
➔ Powder microstructure has to be adapted:

1. Increase primary particle size
2. Increase pore size
3. Improve pore distribution

New HV400 developed

Anode Pore Size Distribution

PD 5,5 g/cm³, ~10 % shrinkage



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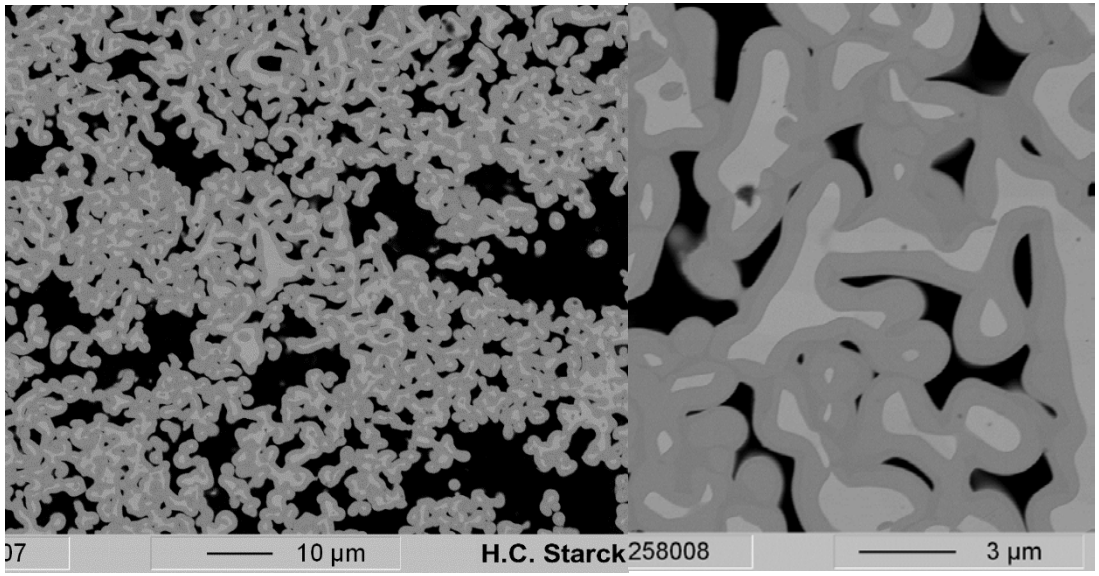
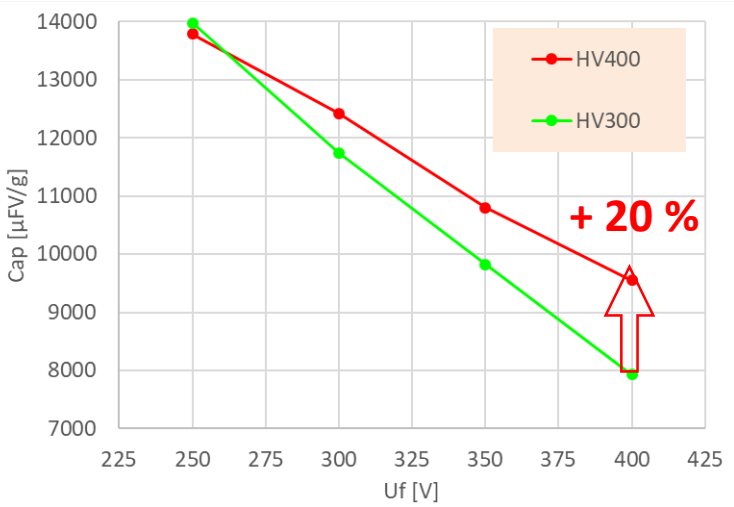
New HV400 - Properties

- Increased capacitance at 400 V_f: + 20 %
- Open pore structure, no macroscopic defects observed

Cross section of HV400 @ 400 V_f



Capacitance



- Could work until 450 V BUT: Increase of Leakage >10 nA/µC for higher voltages

Standard anodization process still sufficient?

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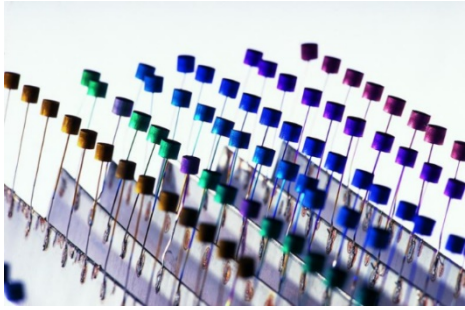
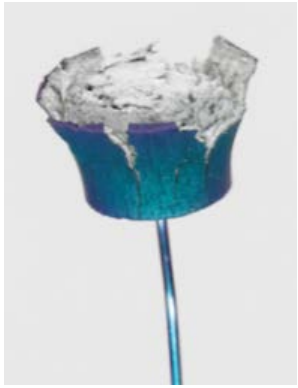
3. Impact of Anodization



- Anodization has an big impact on capacitance and LC
- Aqueous electrolyte systems not appropriate for U_f >200 V_f
- Additives are used to improve breakdown stability and LC:
  - Ethylene glycol, phosphoric, boric and citric aid

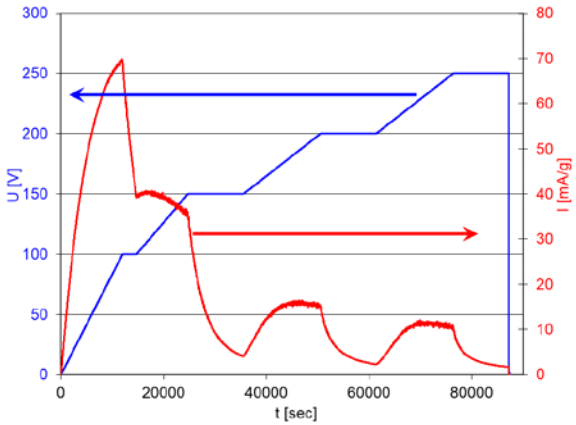


Task: Separate impact of anodization from powder modification

Experimental part

- HV200 large cylindrical anodes (∅ 8,0 mm, 2,2 g, PD 6.0, 10 % shr.)
- Forming U_f: 150 – 250 Vf at 60°C, water-glycol bath (2:3), 900 µS/cm by H_3PO_4
- Forming with „constant rate“ anodization

➔ Analyse anodes after forming



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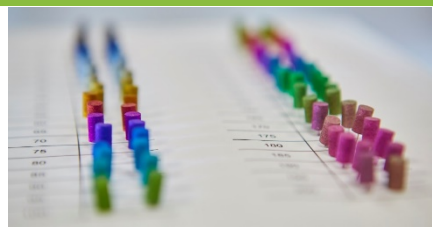
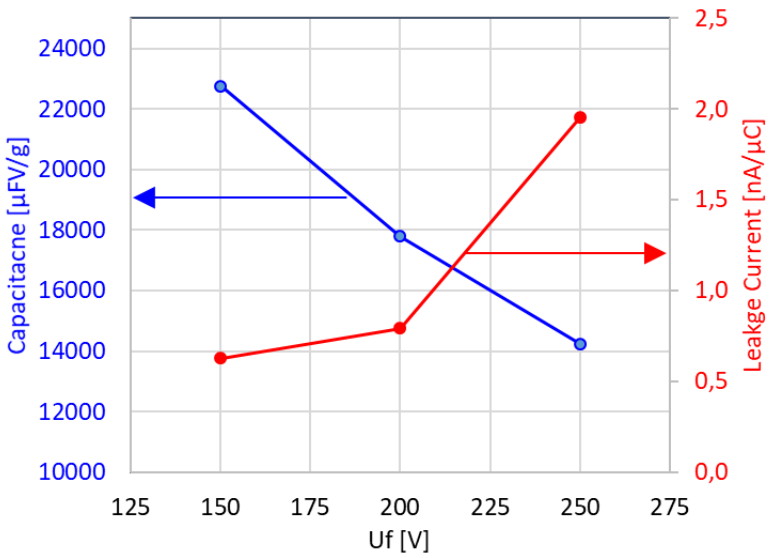
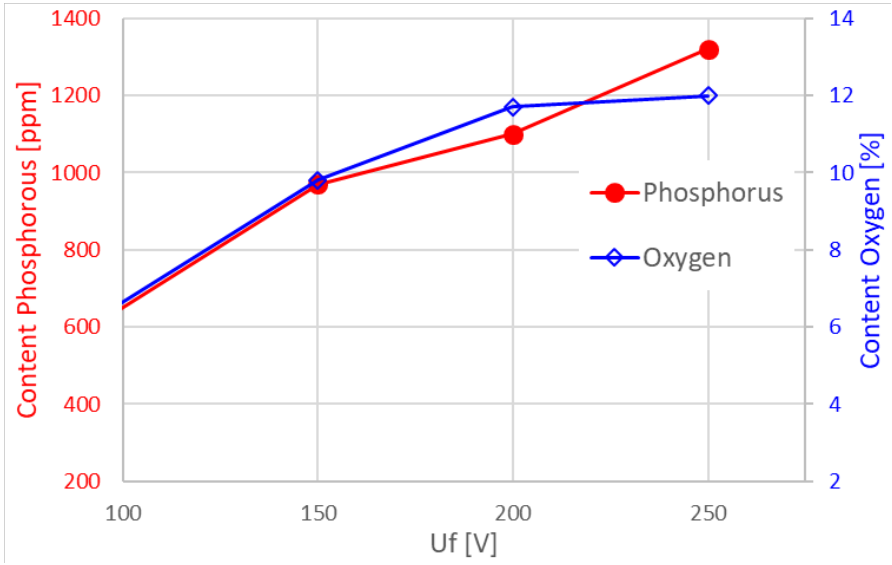
3. Impact of Anodization: Results



Capacitance



Chemical Analysis



- Increase of oxygen by forming
- Strong incorporation of phosphorus, probably as PO_4^{3-}
- Strong increase of LC at 250 V

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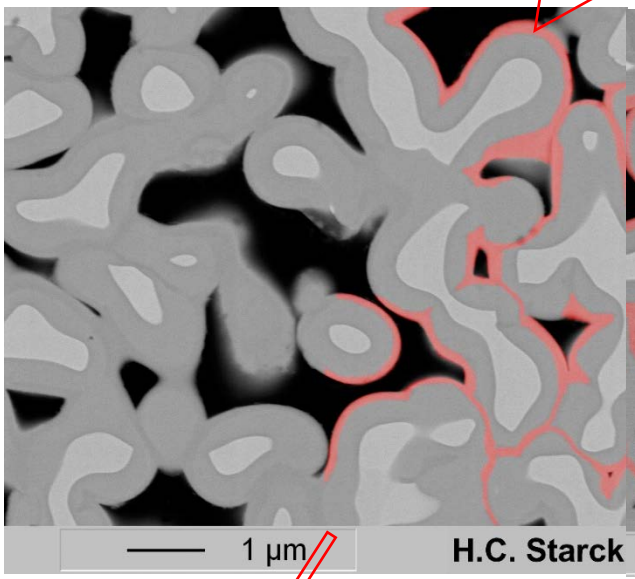
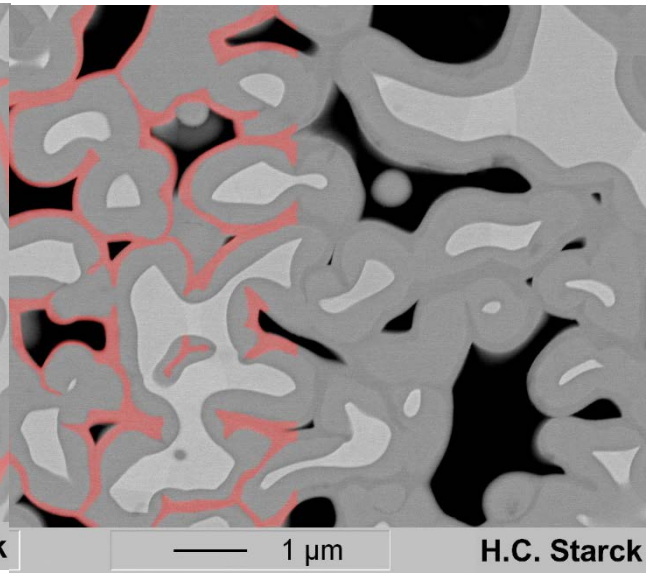
Incorporation of Phosphorous

- outer oxide layer: incorporation of PO_4^{3-}

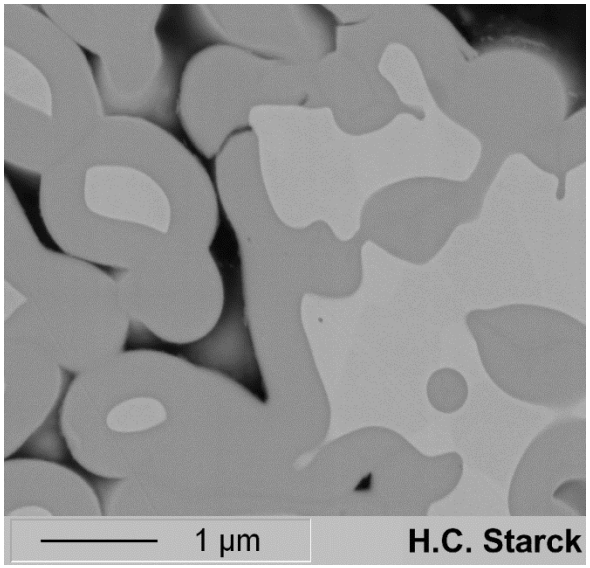
200 V_f



250 V_f



200 V_f formed in HNO_3



370 nm oxide

~85 nm outer PO_4^{3-} rich layer

1100 ppm P ➔ 3370 ppm PO_4^{3-} = 0,53 %

117000 ppm O ➔ 637280 Ta_2O_5

P is only found at the outer layer! Phosphate content is increased to 2,3 wt-.% = 9,9 mol%

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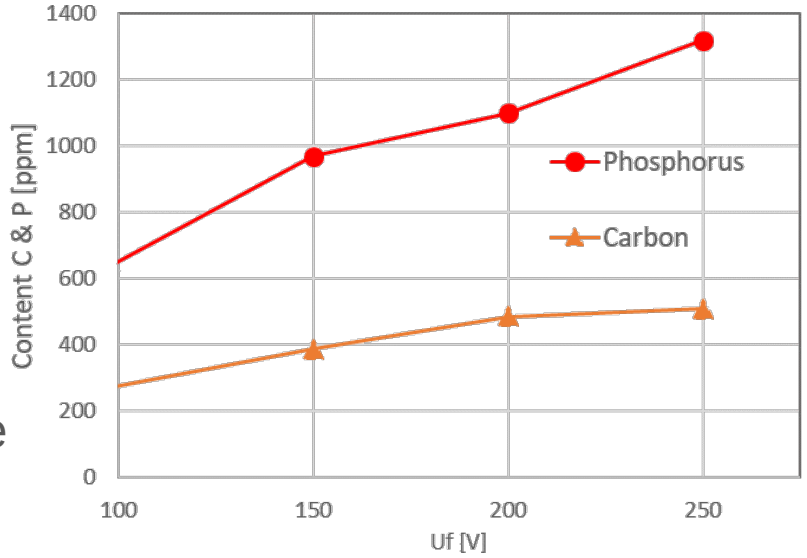
Incorporation of Carbon

- High carbon content found: 390 – 510 ppm
- Unclear how it is incorporated
- From decomposition of glycol?
- Powder with >60 ppm C is difficult to anodize for high voltage powder



➔ Not only carbon amount also how it is introduced has an big impact!

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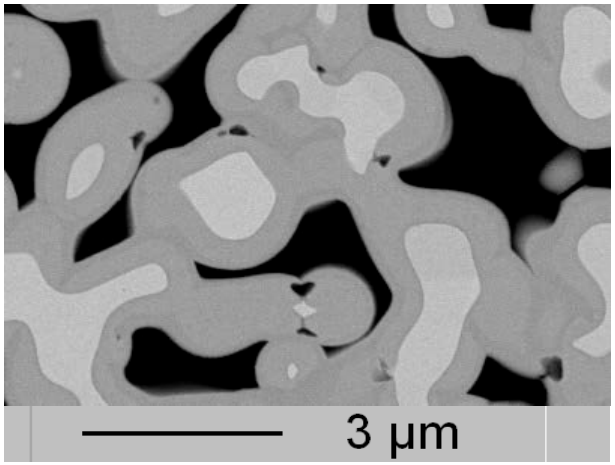
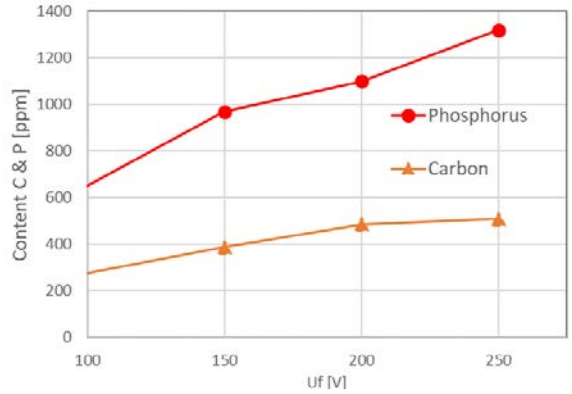
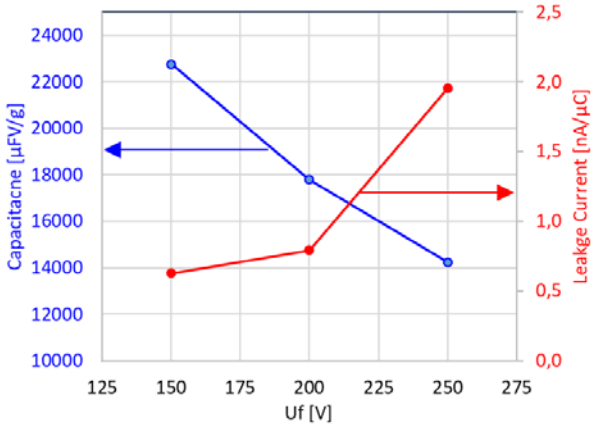
Effect of Incorporations

250 V_f







Defects can be found at the interface outer/inner layer

➔ caused by PO43-?

➔ Caused by gas formed during anodization (oxygen?)

➔ Caused by decomposed electrolyte (carbon)?

HV anodization has to be adapted!

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Summary

Powders Developments for more capacitance/energy

- New HV150 with increased capacitance by improve microstructure
- New HV400 available than can be formed to 400 V

Anodization

- Forming to 400 V is challenging
- Strong incorporation of P and C found
- Is Phosphorous really beneficial?

Search for perfect electrolyte has began. “Wish list”:

- Stable until 450 – 500 V, no decomposition
- No or limited incorporation of foreign ions
- Good heat conductivity


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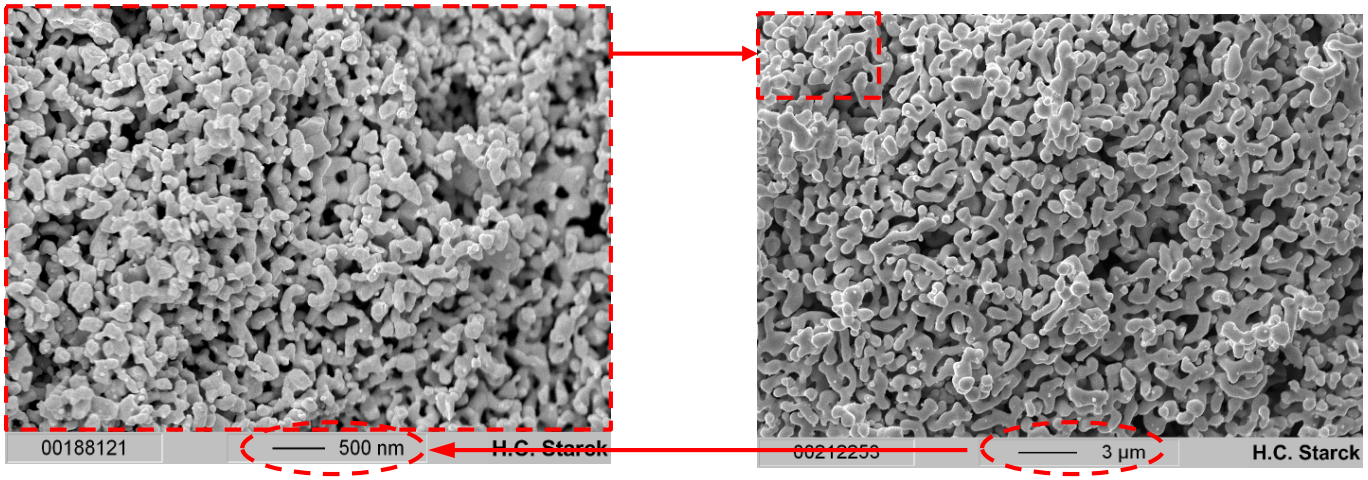
Microstructure of HVMC Anodes

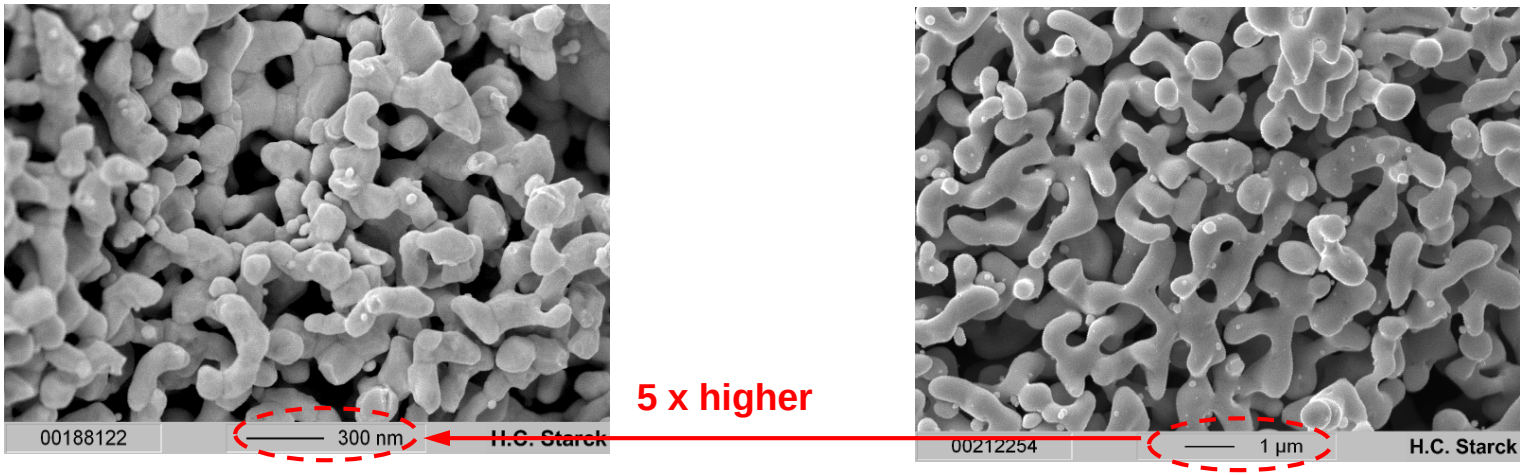
Increasing the dimensions but keep the structure homogeneous!

STA150KA
6 V-20 V



HVMC 20K
100 V-200 V

5 x higher magnification



5 x higher

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