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

Source: Deutsch Bahn, Wikipedia
Moore’s Law – Trends for High Voltage Applications

“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!

Capacitance = HVMC

Source: Intel
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 < 1 ppm)
1. Trend: How to Provide More Capacitance?

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

- HV100: pores too small \( \Rightarrow \) worse ESR
- HV200: better pores but lower cap

Develop new powder by improving particle and pores size distribution!
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)**
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!
2. Trend: Increase Forming Voltage

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

\[
W = C \int_0^U u \, du = \frac{CU^2}{2}
\]

⇒ Powder microstructure has to be adapted:
1. Increase primary particle size
2. Increase pore size
3. Improve pore distribution

New HV400 developed
New HV400 - Properties

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

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

Standard anodization process still sufficient?
3. Impact of Anodization

- Anodization has a big impact on capacitance and LC
- Aqueous electrolyte systems are 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 ($\varnothing 8.0 \ mm$, $2.2 \ g$, PD 6.0, 10% shr.)
- Forming $U_f$: 150 – 250 $V_f$ at 60°C, water-glycol bath (2:3), 900 μS/cm by $H_3PO_4$
- Forming with "constant rate" anodization

⇒ Analyse anodes after forming
3. Impact of Anodization: Results

- Increase of oxygen by forming
- Strong incorporation of phosphorus, probably as $\text{PO}_4^{3-}$
- Strong increase of LC at 250 V
Incorporation of Phosphorous

- outer oxide layer: incorporation of $\text{PO}_4^{3-}$

200 $V_f$  
250 $V_f$

200 $V_f$ formed in HNO$_3$

370 nm oxide  
1100 ppm P $\Rightarrow$ 3370 ppm $\text{PO}_4^{3-}$ = 0.53 %

~85 nm outer $\text{PO}_4^{3-}$ rich layer  
117000 ppm O $\Rightarrow$ 637280 Ta$_2$O$_5$

P is only found at the outer layer! Phosphate content is increased to 2.3 wt-% = 9.9 mol%
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!
Effect of Incorporations

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!
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