Polymer (Tantalum) Capacitors

Design, Characteristics, and Manufacturing
Not All Tantalum Capacitors Burn

- All of the Caps on this board have failed.
  - They are measured as shorts

Test card with capacitors subjected to **2x Rated Voltage**, applied with reverse polarity and > 20 amperes current capability.
Design
Tantalum Construction

- Tantalum
- Ta$_2$O$_5$ Dielectric
- Ta Metal
- MnO$_2$ or Cond. Poly.
- Interconnected Tantalum Particles
- Counter Electrode Penetration into Pores (Manganese Dioxide (MnO$_2$) or Conductive Polymer)
- Carbon Ink
- Silver Paint
- Ta$_2$O$_5$ Dielectric Layer
Why use Tantalum?

- Stable $C(T,V)$, DCL($t$)
- Reliable
- Efficient($CV/cc$, $E/cc$)

$$C = \frac{kA}{d}$$

$k = 27$

$.01 < d < .1 \text{ um}$
Tantalum Construction

Interconnected Tantalum Particles

Tantalum Wire
Anode: Tantalum

• Pros
  – Resistant to chemical attack
  – High melting point (2996°C)
  – Relatively Dense

• Cons
  – Relatively expensive
  – Less conductive than Ni or Al
    • Ta 7.61 x 10^4 S/cm
    • Ni 1.43 x 10^5 S/cm
    • Al 3.77 x 10^5 S/cm

• Critical Characteristics
  – Specific surface area (CV/g)

• Chemical impurities
  – Oxygen
  – Carbon
  – Metallic impurities

• Physical characteristics
  – Powder flow
  – Crush strength
Sintering Tantalum into Pellet

Sintered Pellet - All tantalum in electrical contact

- Tantalum Wire
- Tantalum Particles
- Die Cavity Volume
Tantalum Construction

Interconnected Tantalum Particles

Ta$_2$O$_5$ Dielectric Layer

Tantalum Wire
Dielectric: Tantalum Pentoxide $\text{Ta}_2\text{O}_5$

- Critical Characteristics
  - Dielectric constant
    - 27.7
  - Dielectric breakdown
    - VBDV 470 volt/mm
  - Dielectric thickness:
    - 2.0 nm/volt
  - Resistant to chemical attack

<table>
<thead>
<tr>
<th>$V_R$</th>
<th>Ta</th>
<th>MLCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>20.7</td>
<td>600</td>
</tr>
<tr>
<td>4</td>
<td>27.6</td>
<td>600</td>
</tr>
<tr>
<td>6</td>
<td>36.8</td>
<td>600</td>
</tr>
</tbody>
</table>
Tantalum Construction

Interconnected Tantalum Particles

Tantalum Wire

Conductive polymer penetrates into channels and surrounds $\text{Ta}_2\text{O}_5$

$\text{Ta}_2\text{O}_5$ Dielectric Layer
Cathode: PEDT or MnO2

Cathode forms the negative connection:

- PEDT is a conductive organic polymer
- MnO₂ is Manganese Dioxide
Polymerization Techniques

**Insitu Polymer Process**

**Initial Polymerization**

**Slurry Polymer Process**

**BDV Comparison**

*US Patent #7,563,290*
Tantalum Construction

Interconnected Tantalum Particles

Conductive polymer penetrates into channels and surrounds Ta$_2$O$_5$

Carbon

Silver

Ta$_2$O$_5$

Dielectric Layer
**Terminations**

- **B** – Gold
- **C** – Hot Solder Dipped
- **H** – Solder Plated
- **K** – Solder Fused
- **T** – 100% Tin
Tantalum Surface-Mount Capacitor

- Polymer / Ta₂O₅ / Ta
- Silver Adhesive
- Silver Paint
- Washer
- Leadframe (- Cathode)
- Carbon
- Leadframe (+ Anode)
- Tantalum Wire
- Weld
Substrate Construction

Package Designs

Standard (T520/T521)

Facedown (T528)

Facedown (T527)

Substrate (T488/T529)
Production Flow
Electrical Conditioning

• IR Reflow
  – Place parts under an unbiased heat profile to precondition parts to surface mount conditions
  – Time, temperature

• Aging
  – Application of elevated temp. / voltage to improve DC leakage
  – 100% application
  – Temperature
  – Voltage
  – Resistance
Production Flow

Testing

- 100% Electrical screen
  - 85°C DC leakage
  - 25°C DC Leakage
  - Capacitance @ 120Hz
  - Df @ 120Hz
  - ESR @ 100kHz
  - *Surge capability available, 100% on KO CAP

- SMT (Surface Mount Testing)
  - Tollgate sampling of every batch
  - Simulates customer board-mount
  - A/R 0/1
Packaging

Different Package Options to meet the customer’s need.

Custom requests welcome!

**PHS** – Polymer Herm Seal  
- polymer cathode system  
- low ESR, stable cap at temperature and frequency.

**HVE** – Facedown is volumetrically efficient with low inductance

**MAT** – Low ESR with multiple anodes in a single package

**T560/BMC** – Approx 1in cube.

**Stacks** – Utilizing both cathode systems. 2, 3 and 2x2 configurations.

**Modules** – Targeting medical market
Characteristics
Standard vs. Polymer Tantalum

ESR vs. Freq. vs. Temp

ESR vs. Frequency

- Standard Tantalum
  (T491D227M004AT)

- Tantalum Polymer
  (T520D227M004ATE066)

Temperature Points:
- -55°C
- 25°C
- 125°C
Tantalum RC-Ladder

Surface Silver Termination

\[ t_{c1} = C_1 \times R_1 \]
\[ t_{c2} = C_2 \times (R_1+R_2) \]
\[ t_{cn} = C_n \times (R_1+R_2...+R_n) \]
Standard vs. Polymer Tantalum
Capacitance vs. Freq. vs. Temp

Capacitance vs. Frequency
Standard vs. Polymer Tantalum

-55°C
25°C
125°C

Tantalum Polymer
(T520D227M004ATE006)

Standard Tantalum
(T491D227M004AT)
Current through fault generates enough heat and oxygen for ignition.

Conductive polymer consumes oxygen preventing ignition.
Voltage Derating Guidelines

<table>
<thead>
<tr>
<th></th>
<th>Ta-MnO₂</th>
<th>Ta-Poly KO $V_R&gt;10VDC$</th>
<th>Ta-Poly KO $V_R\leq10VDC$</th>
<th>Alum-Poly AO</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 PPM FR % $V_{Rated}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@50% $V_{Rated}$ FR(PPM)</td>
<td>68%</td>
<td>126%</td>
<td>197%</td>
<td>235%</td>
</tr>
<tr>
<td>@80% $V_{Rated}$ FR(PPM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@90% $V_{Rated}$ FR(PPM)</td>
<td>458</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>@100% $V_{Rated}$ FR(PPM)</td>
<td>1,700</td>
<td>12</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6,310</td>
<td>35</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

- Typical derating guidelines:
  - Tantalum MnO₂: 50%
  - Tantalum Polymer: 20% (>10V), 10% (≤10V)
  - Aluminum Polymer: 0%!
Thank You!
Manufacturing
Anode Pressing

Powder, wire, and lubricant, to mitigate tool wear, are added to cavity.

Die Fill

Compaction

Pressed Anode

Testing and
Finishing
Lubricant removal
- Removes lubricant from tantalum powder compact (anode)
  - Temperature 100º-600ºC in vacuum or by water wash
  - Lubricant boils off at selected temp.

Sintering
- Employed to bond particles at temp. < M.P.
  - Typically 1300º-2000ºC in vacuum

Key post-operation properties:
Increased inter-particle connection (“neck size”) & physical strength porosity / surface area

Key post-operation properties:
Carbon & oxygen content
Product Flow Racking

Anode Manufacturing → Electro-Chemical Processing → Encapsulation → Testing and Finishing

Sintered anodes welded to an Al process carrier bar

*Key post-operation properties:*
- Weld strength
- Rack height
- Tight tolerances guarantee subsequent processing consistent for all anodes
Product Flow
Dielectric Formation

- Anode Manufacturing
- Electro-Chemical Processing
- Encapsulation
- Testing and Finishing

Interconnected Tantalum Particles

Electrolyte Solution

Ta$_2$O$_5$

Dielectric Layer

Tantalum particle

Ta$_2$O$_5$
Product Flow
MnO2 Impregnation / Polymerization

Key post-processing properties:
Capacitance recovery (coverage of dielectric surface)
Dissipation factor (continuity, conductivity of internal layer)
Equivalent series resistance (continuity, conductivity of cathode)
**Product Flow**

**Carbon Ink**

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**Anode Manufacturing** → **Electro-Chemical Processing** → **Encapsulation** → **Testing and Finishing**

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**Carbon Ink properties:**
- Conductive
- Isolates silver from MnO₂
- Critical for low ESR

**Moisture barrier properties:**
- Moisture resistant layer
- Inhibits ionic migration

**Silver paint properties:**
- Conductive
- Mechanical strength
- Stable through IR passes
Components

1) Silver Adhesive
2) Processed Anodes
3) Leadframe
**Product Flow Molding**

**Components**

1) Epoxy Pellets
2) Assembled Leadframe
Product Flow
Deflash / Print / Dejunk (DPD)

- Deflash
  - Remove excess epoxy from leads
- Print/Laser Marking
  - Laser-mark parts for identification
- Dejunk
  - Singulate the negative side of the lead frame strip
Product Flow
Electrical Conditioning

Anode Manufacturing → Electro-Chemical Processing → Encapsulation → Testing and Finishing

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Product Flow
Lead Form and Tape

Anode Manufacturing → Electro-Chemical Processing → Encapsulation → Testing and Finishing

1\textsuperscript{st} Lead Form

2\textsuperscript{nd} Lead Form

3\textsuperscript{rd} Lead Form

Formed parts are placed in carrier tape for packaging and shipment
Thank You!