Thermionic Cathodes Manufacturing

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3M Technical Ceramics

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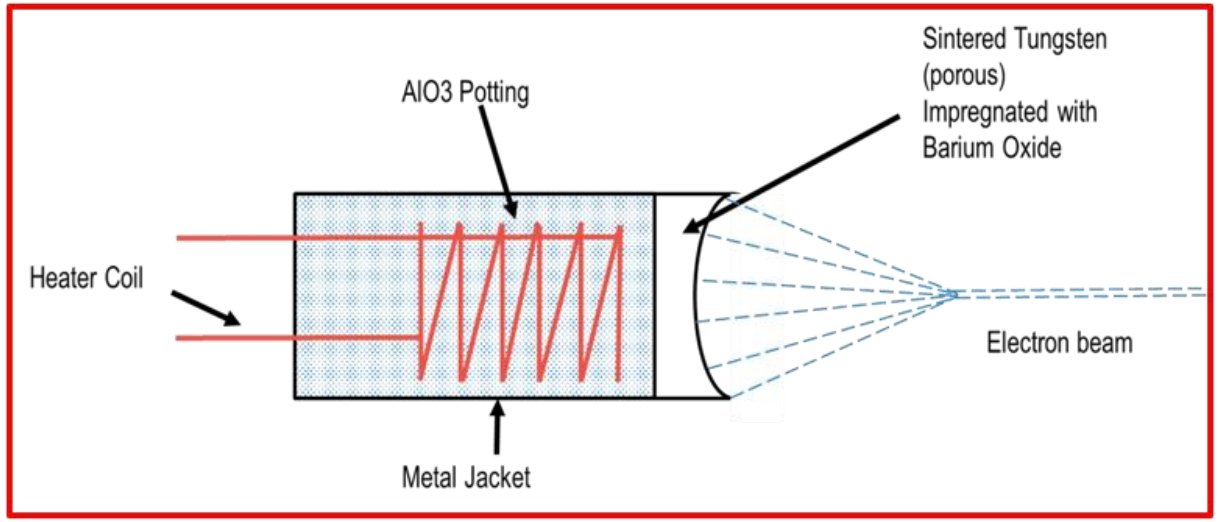
Introduction

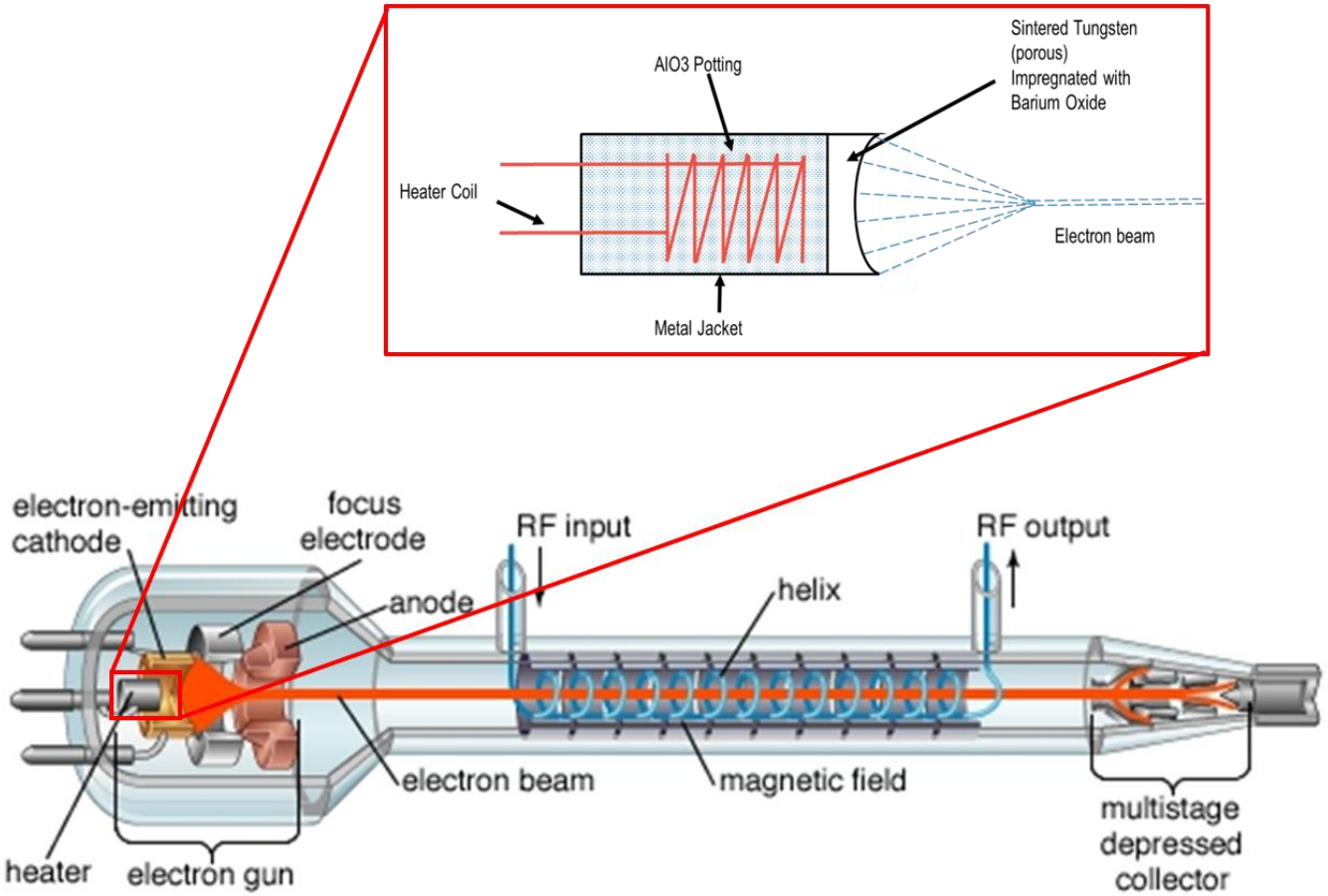
What is thermionic (dispenser) cathode?



- Dispenser cathode is the key component of a vacuum electron tube. It is as a source of electrons for the electron beam
- Electron gun is used to form the electrons from the cathode into a beam suitable for interaction with a microwave circuit.

Cathode types (based on tube type)?

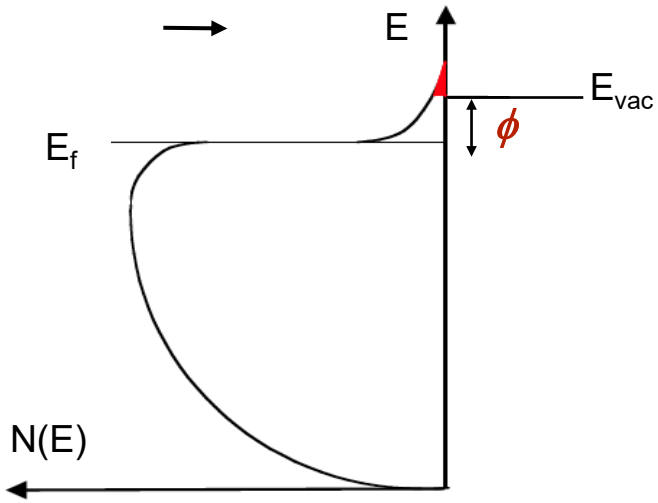
- TWT
- Klystrons
- Magnetrons
- Gyrotrons
- CRT
- Hollow cathodes for ion thrusters



How cathode works?

Thermionic Emission

Escape *over* barrier



Richardson Equation

$J \sim T^2 \exp(-\phi / kT)$

- lower work function is needed
- low operating temperature, higher J and longer life are desired

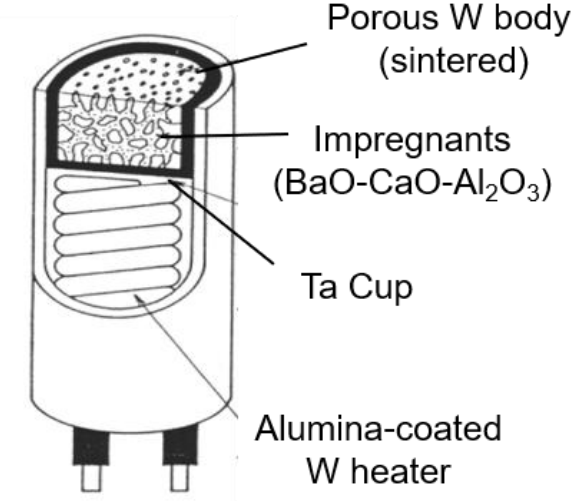
Thermionic emitter materials must be capable of **high-temperature operation**:

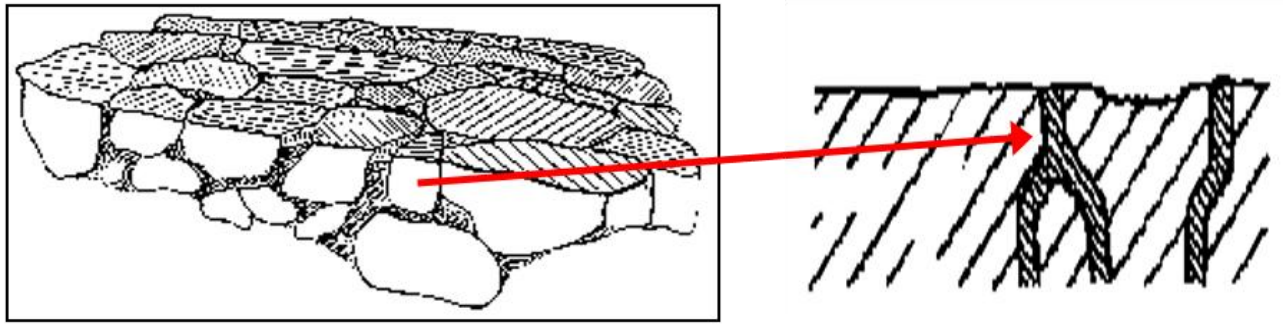
- **High melting point**
- **Robustness** (at operating T)
  - Low evaporation rate
  - High mechanical strength
- **High electrical conductivity**

Physics of Barium Dispenser Cathodes

- ✓ **W provides the electrical conductivity**
- ✓ **BaO lowers the work function**

Ba-O dipole is continuously maintained

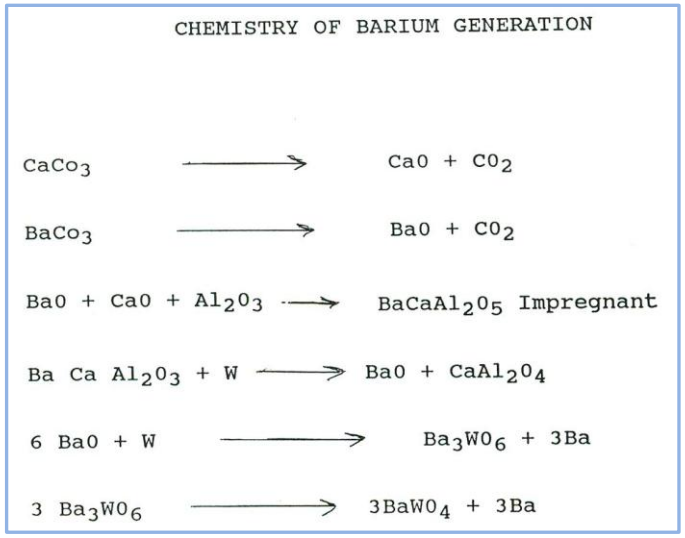


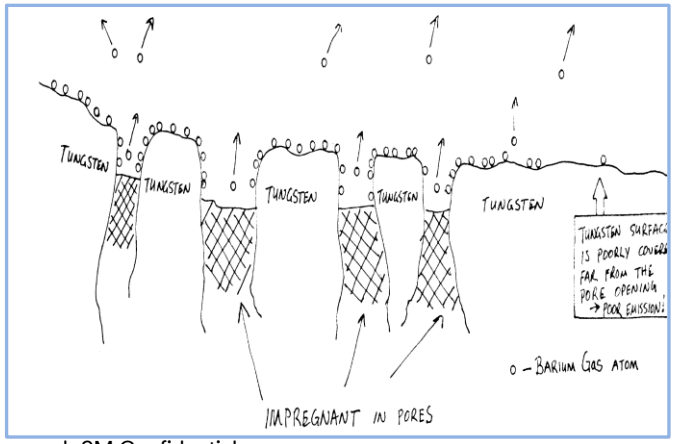


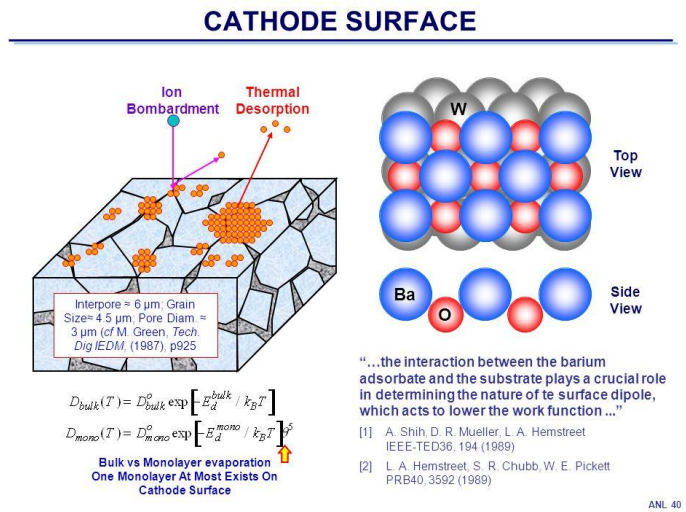
M. Green, Tech. Report RADC-TR-81-211 (1981)

- **Ba supply** via **diffusion** through the **pore structure**
- Low ϕ created by **Ba-O dipole** on W surface: **ϕ = 2.1 eV**
- **Addition of Os** lowers ϕ further: **ϕ = 1.95 eV**

Physics of Barium Dispenser Cathodes







Ba forms dipole

Ba
O
W or Walloy

Barium on oxygen on tungsten

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Cathodes Manufacturing

Expectations:

There are no practical and economically viable methods to test finished cathodes for emission performance.

Uncertainty of performance (not able to test) makes quality a priority

A significant effort and time are invested before cathode's emission can be verified. Cathode must be installed into a gun, sometimes in complete tube before can be tested and emission verified. At that time, if cathode fails cost of replacement is very high.

For that reason, it is reliability of cathode's performance and life is an imperative.

Manufacturing of Barium Dispenser Cathodes

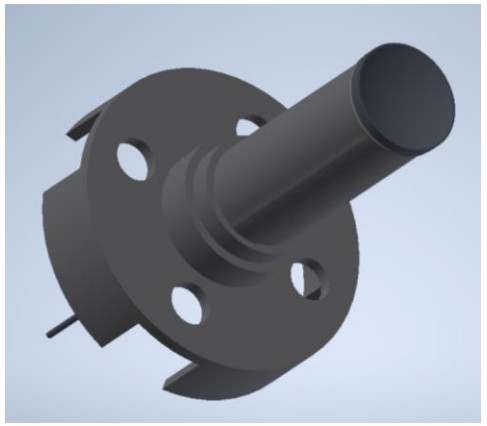
In order to manufacture a reliable cathode which will perform as designed and in accordance with the lows of physics, multiple factors must be considered:

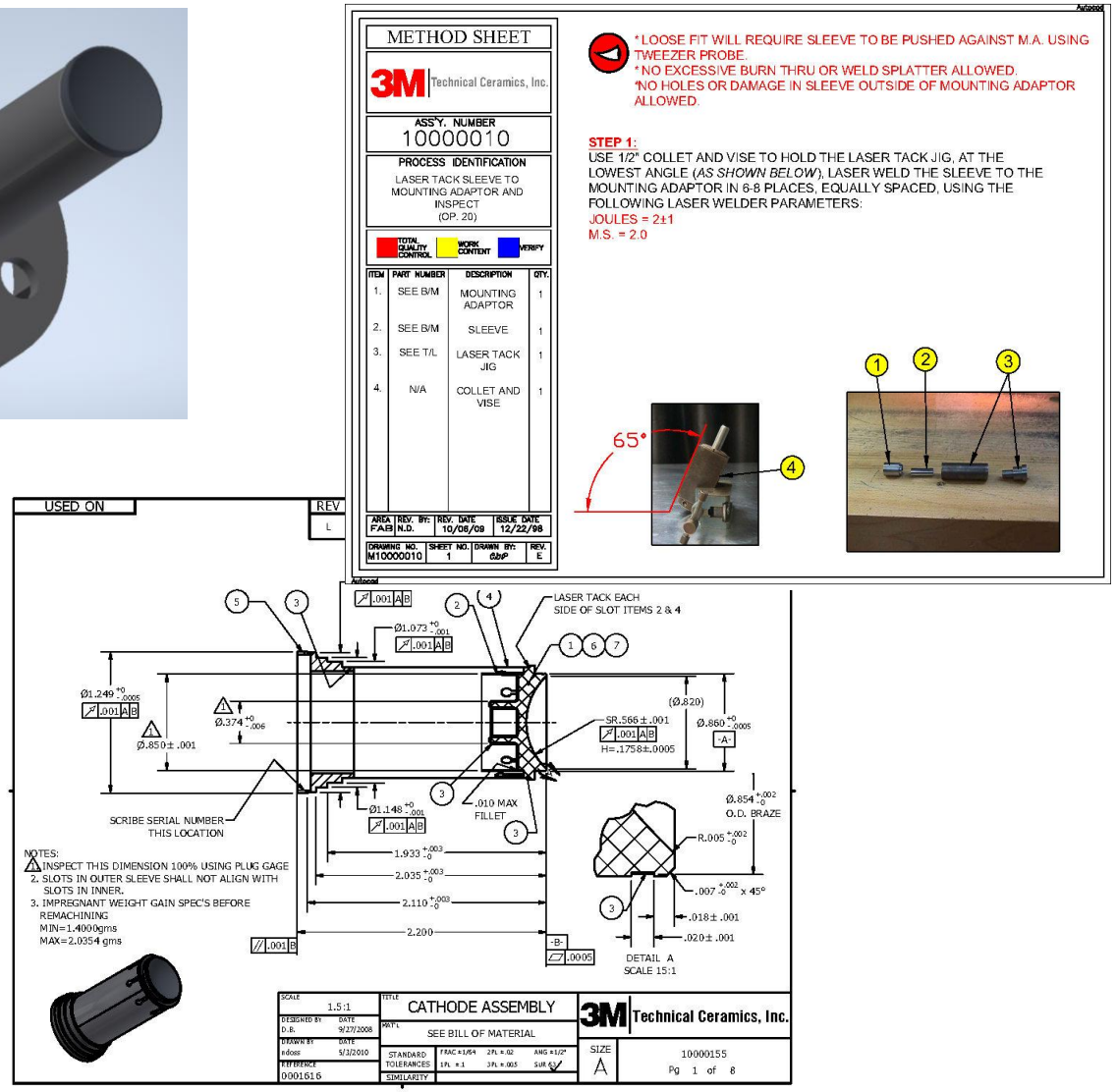
- Design
- Raw materials and components
- Process and process control
- Environment
- Handling
- Testing and documentation
- Packaging

Design

Design

- Meeting customer's requirements
- Meeting customer's expectations
- External and internal standards
- Manufacturability (components and assemblies)
- Materials (mechanical and thermal stability)
- Drawings and process instructions
- Supply chain





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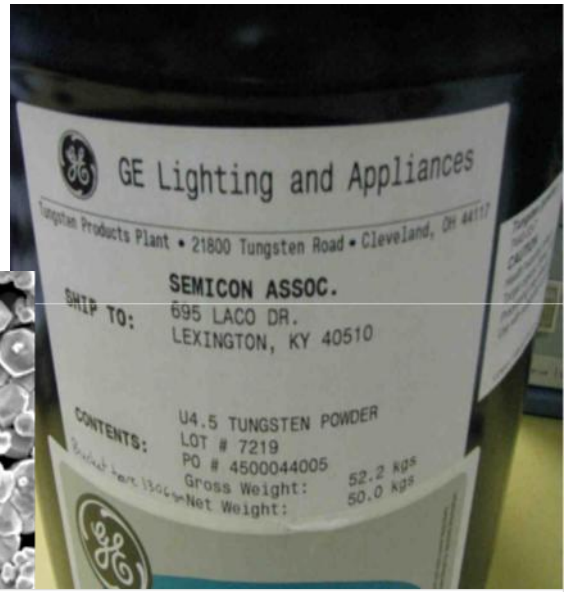
Materials

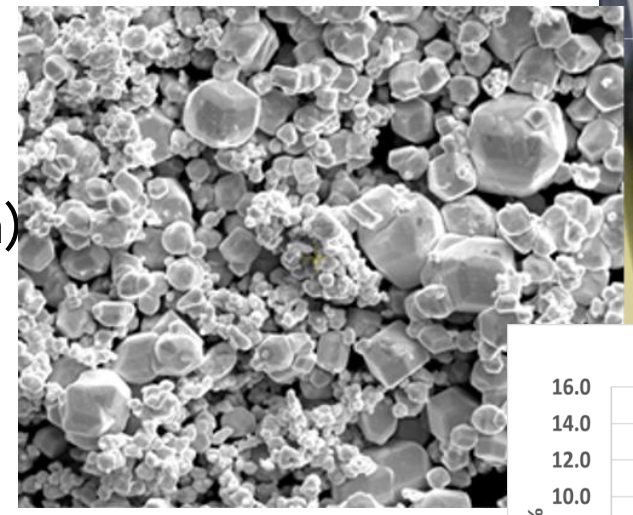
Raw materials and components

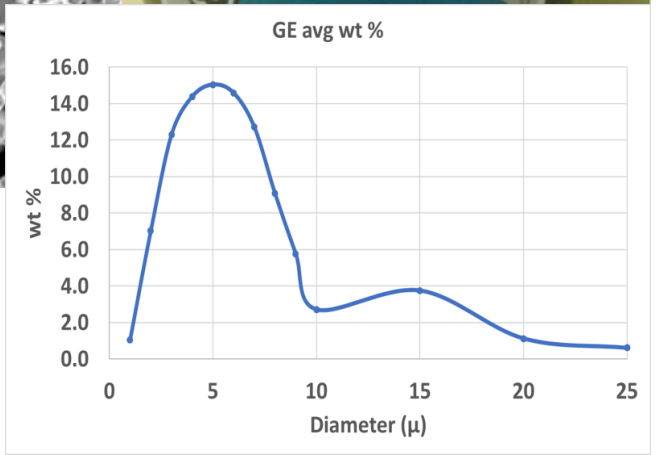
- Tungsten powder
- Tungsten rods
- Refractory metals
- Heaters
- Impregnant
- Braze and potting materials
- Requirements (external and internal)
- Diminishing sources
- In-house vs. purchased
- MOQ
- Storage

Tungsten powder

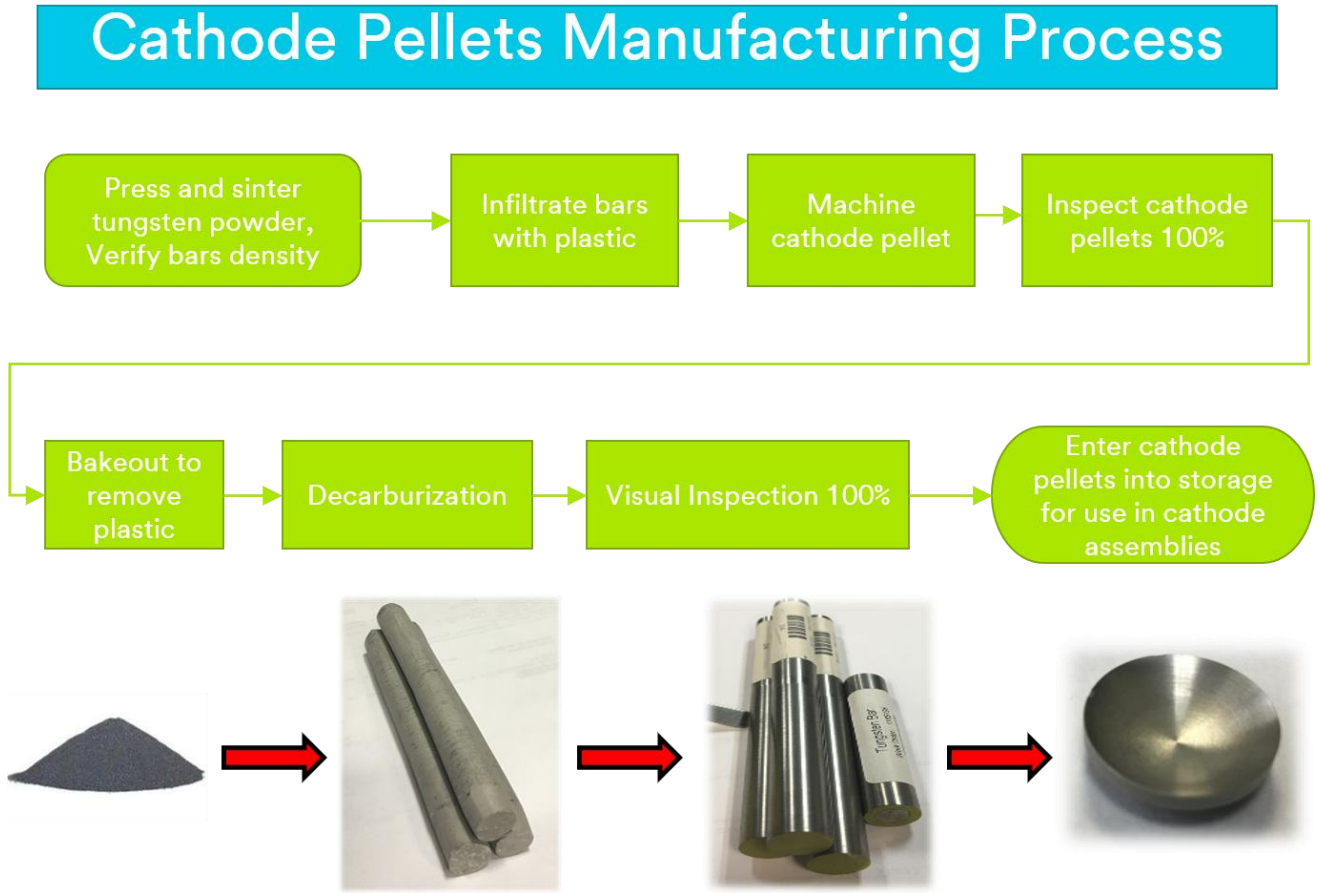
- This is the most critical material for cathode manufacturing
- Lot acceptance
- Purity (vendor or 3rd party certification)
- Particle size (vendor or 3rd party certification)
- Particle size distribution
- Screening
- Supplier selection and qualification





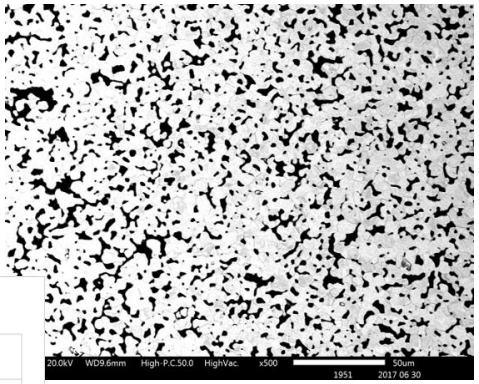


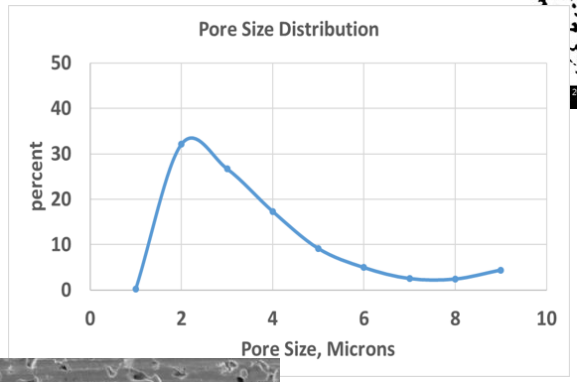
Tungsten rods

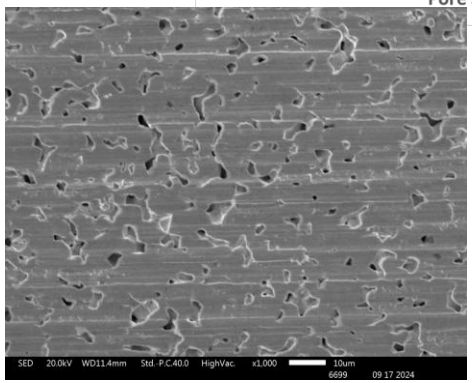


Tungsten rods

- Use only approved powder
- Green density
- Sintered density, density gradient
- Rod’s microstructure (pores and grains)
- Permeability (interconnection of the pore network)
- Impregnant absorption
- Machined surface porosity







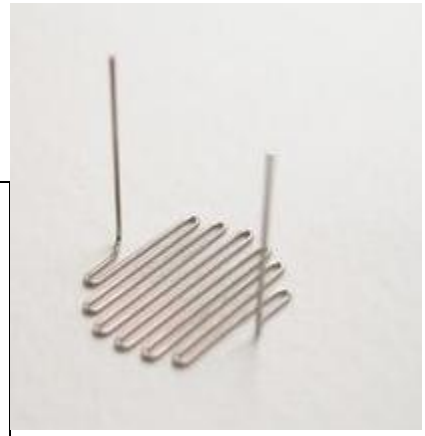
Other materials

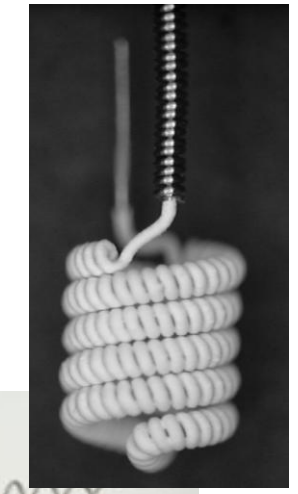
- Metal rods (molybdenum, kovar, SST, CuNi, rhenium, nickel,…)
- Metal sheets (molybdenum, MoRe, tantalum, hastiloy, hafnium…)
- Ceramics (Al2O3) – bare and/or metallized

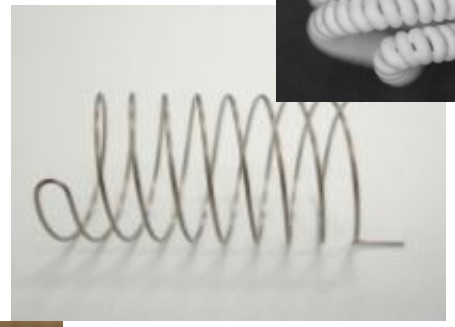
- Purity
- Dimensional conformity
- Cleanliness
- Electrical and magnetic properties
- Consistency is very important

Heaters

- Heater is another critical component
- Wire quality is the key
- Critical properties:
  - Chemical composition
  - Dimensional conformity
  - Electrical properties (conductivity and resistivity)
  - Surface condition
  - Ductility
  - Coating

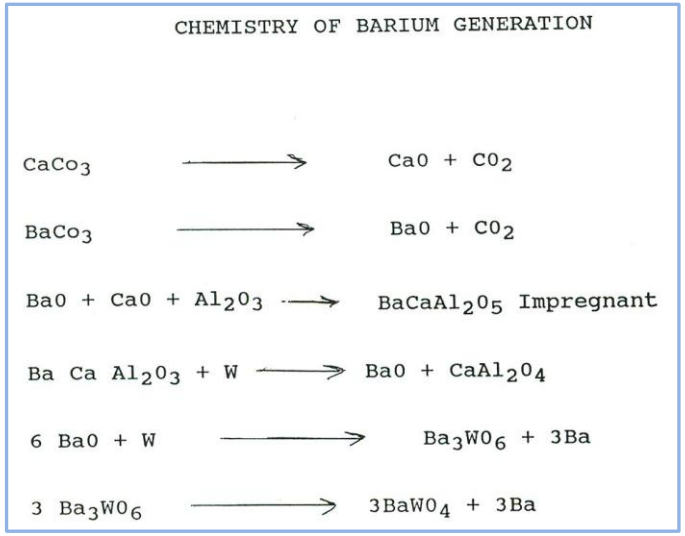






Impregnant

- Emission enhancing material – extremely critical for cathode performance
- Typical composition BaO-CaO-Al2O3 (in different ratios)
- Purity of each of the components and final material is very critical
- Shelf life and storage



Braze and potting materials

- In-house made materials
- Purity is critical to prevent cathode contamination and poisoning
- Mix ratio is also critical for melting point control
- Potting particle size mix and distribution is critical for good packing (avoiding voids)

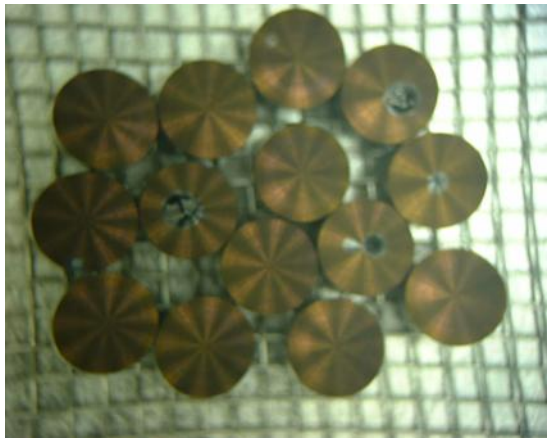
Process

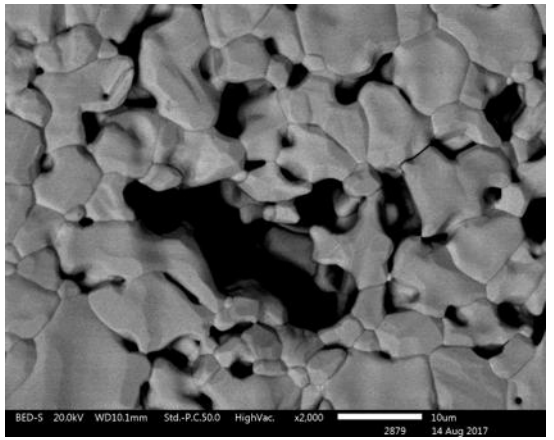
Process and process control

- Cathodes cannot be tested for performance prior to delivery to users
- Properly developed and consistently follow process is the key for a reliable cathode
- Key processes:
  - Tungsten bar fabrication
  - Impregnant, potting, braze manufacturing and storage
  - Brazing
  - Potting
  - Impregnation
  - Cleaning
  - Welding
  - Re-machining
  - M coating

Tungsten bar fabrication

- Density
- Consistency across the matrix (no voids or density gradient)
- Porosity
- Chemical purity (contamination, carbon residue….)





Impregnant, potting and braze manufacturing and storage

- Proper formulation and processing method
- Prevent contamination
- Moisture exposure
- Control of storage method and life

Brazing

- Mechanical integrity (poor integrity will result in parts falling apart or moving during operation)
- Proper selection (melting point and reactivity)
- Joint seal (impregnant/cleaning solution may penetrate, may result in virtual leak)
- Heat distribution (poor braze joint can compromise heat transfer)
- Flow control (penetration into tungsten matrix or overflow)
- Flow or vapor control (deposition on emitter or bridging between components)

Potting

One of the two most critical processes in cathode manufacturing

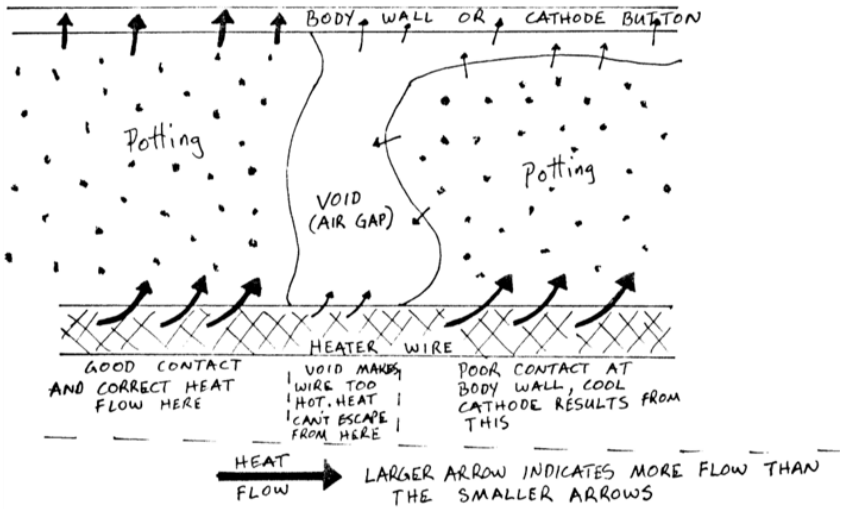
POTTING QUALITY

POTTING IS SUPPOSED TO

1. HELP TRANSFER HEAT FROM THE HEATER WIRE TO THE CATHODE BUTTON. A SOLID MATERIAL DOES THIS MUCH MORE CONSISTENTLY THAN AN AIR GAP OR VOID AND IS MORE PREDICTABLE.

2. PROVIDE RIGID SUPPORT TO THE HEATER WIRE SO THAT IT CAN'T MOVE AROUND. IF HEATER WIRE CROSSES OVER ITSELF (TOUCHES) OR CONTACTS THE BODY ANYWHERE BUT THE GROUND BRAZE JOINT IT WILL SHORT OUT AND MALFUNCTION. MANY CATHODES MUST OPERATE IN VIBRATING MACHINES.

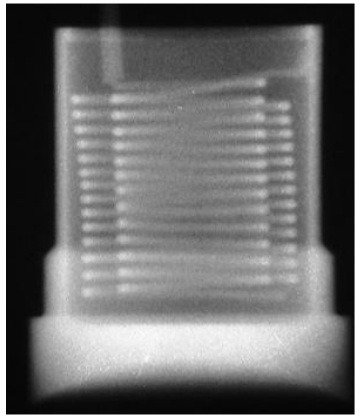
3. PROVIDE ELECTRICAL INSULATION BETWEEN THE CATHODE AND HEATER WIRE. DIRTY POTTING WILL ROB HEATER CURRENT AWAY FROM THE HEATER AND CHANGE THE CATHODE OPERATING TEMPERATURE.

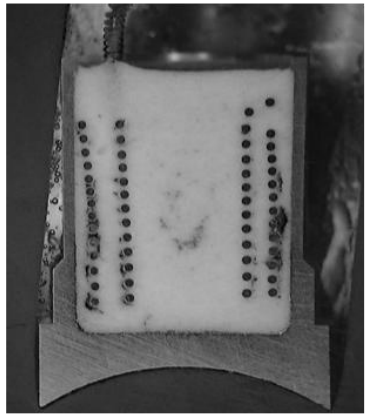


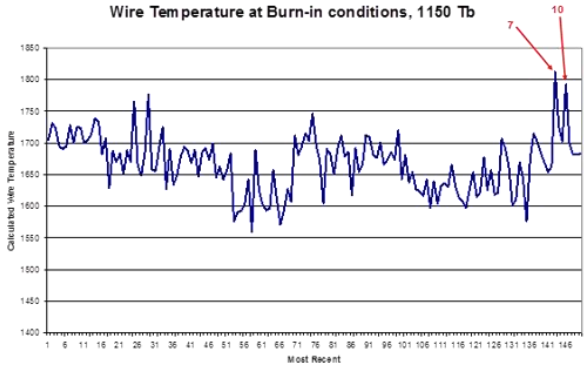
Poor potting can result in:

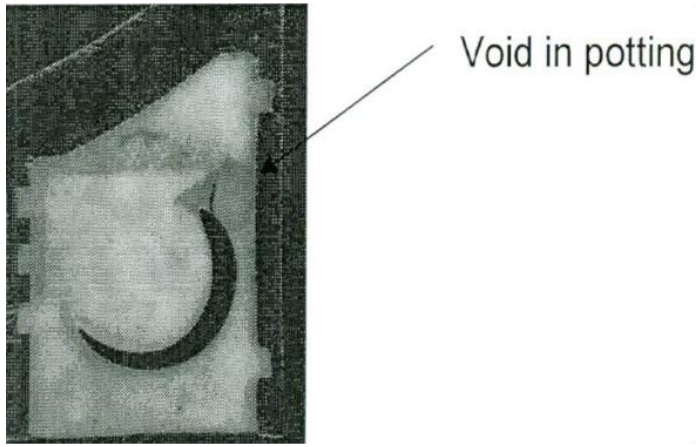
- Low temperature (poor emission)
- Heater burn-out
- Loose particle in tube
- Bad heater position in heater cavity

Potting









Impregnation

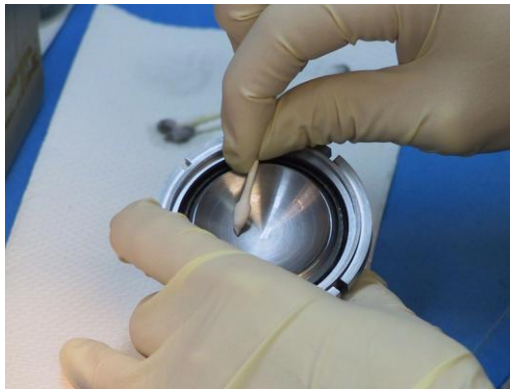
Impregnation process has to insure the following:

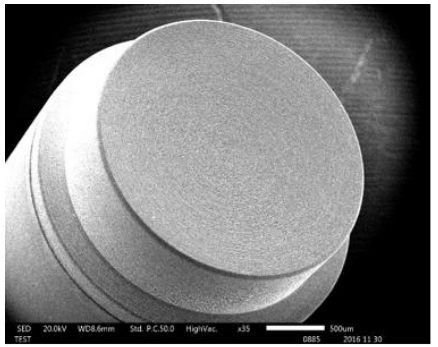
- Sufficient impregnant fill
- Correct impregnant mix is used
- Proper process temperature, atmosphere and dew point
- No contamination
- Proper location of cathodes within furnace heat zone
- Impregnant will not flow onto the potting

Bottom Line: any of this can affect cathode performance even if it visually looks completely normal. DO NOT CHANGE ANY PROCESS PARAMETER.

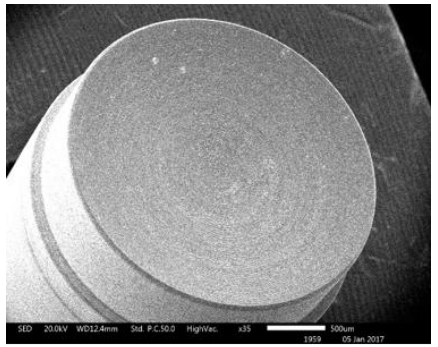
Cleaning

This is second of the two most critical processes in cathode manufacturing





Good cathode



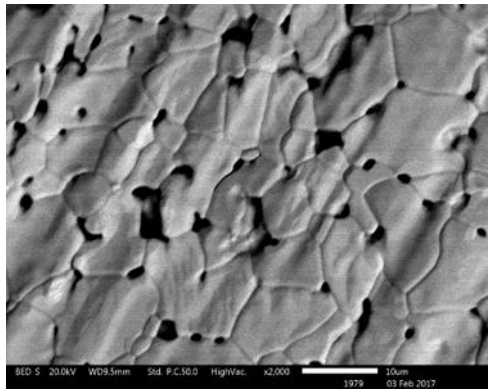
Bad cathode

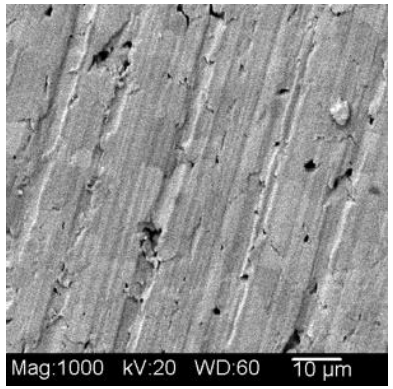
- Removes impregnant residue and/or any other contamination from cathode surfaces
- Enables formation of continuous Ba-O film on emitting surface
- Prepares emitting surface for successful M type coating

- Should remove all impregnant from surface
- Ideally should not remove much from pores to maintain balance from evaporation and supply
- Any contamination has to be removed as well
- All surfaces, not just emitter should be clean
- Prevent contact with potting
- Cleaning solution has to be removed

Final machining

This is THIRD of the TWO most critical processes in cathode manufacturing

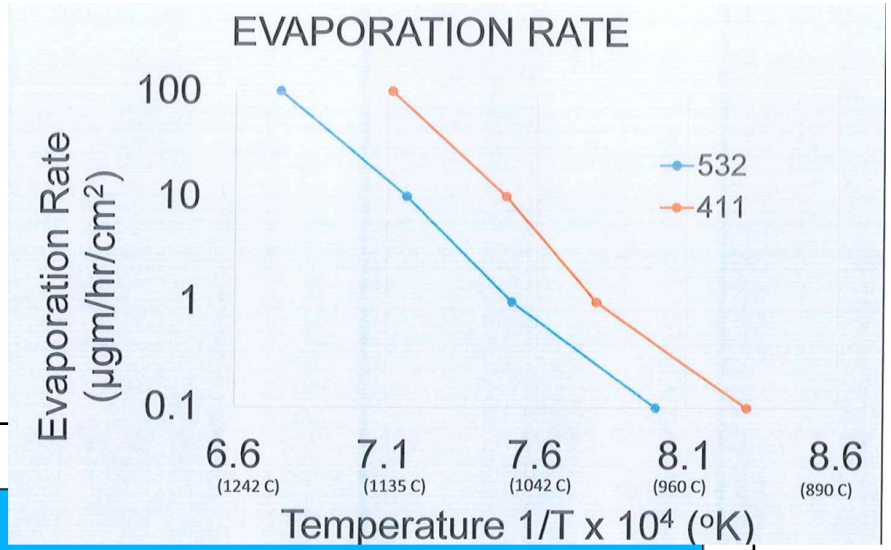


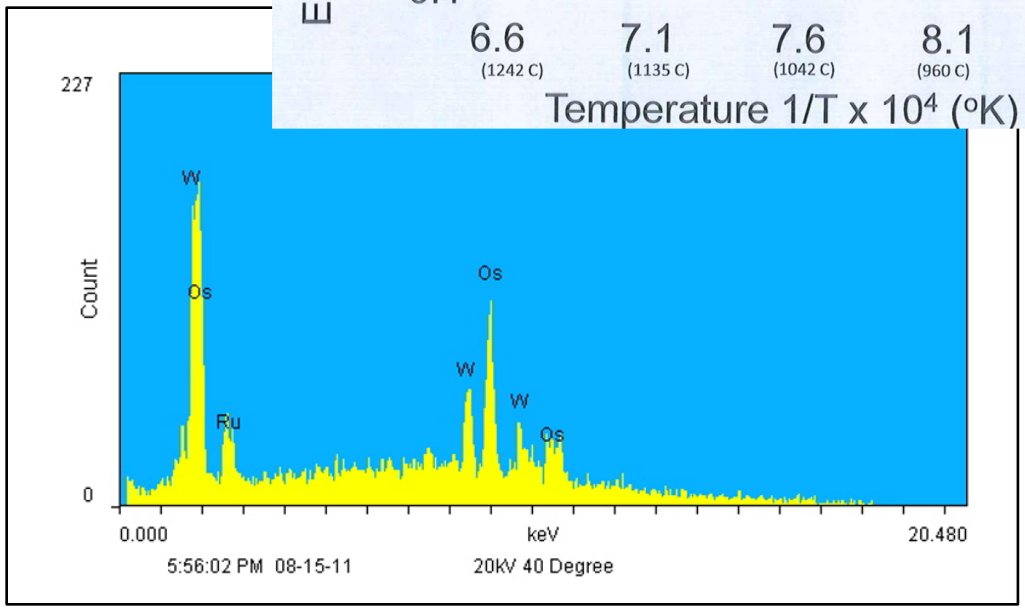


- Cathodes should be designed to allow machining after completion of assembly process
- Objectives of this machining:
    - To achieve dimensional and geometric requirements
    - To open pores smeared during initial emitter machining (SEM Inspection)
    - To remove any surface imperfection due to impregnation process and handling
    - No lubricant can be used, experience is critical
    - Tooling must be sharp

M coating

- Purpose of this process is to lower emitter work function
- It lowers operating temperature for 30-40°C (doubles the cathode life due to lower Ba evaporation)
- Has to be applied to a clean cathode surface
- Thickness uniform





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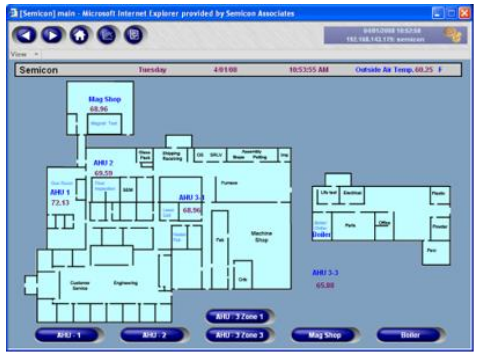
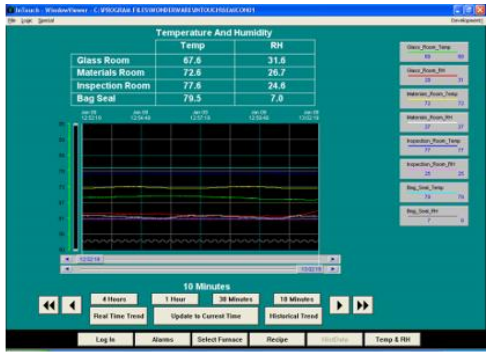
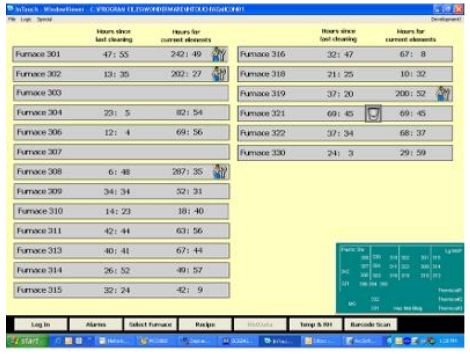
Environment and Equipment

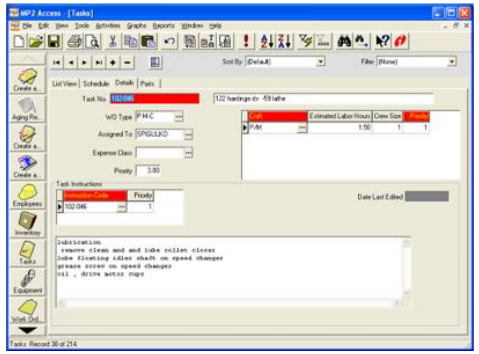
Environment

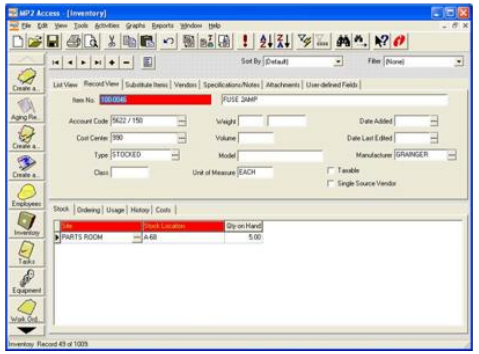
Environment conditions (temperature, humidity, cleanliness) have significant effect on quality of the products manufactured at 3M

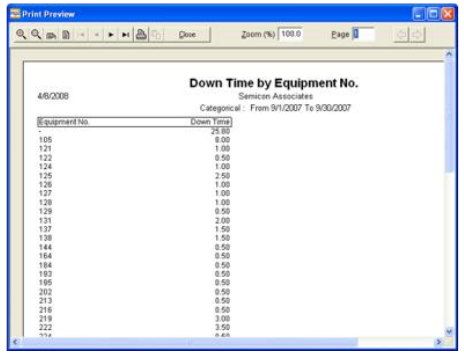










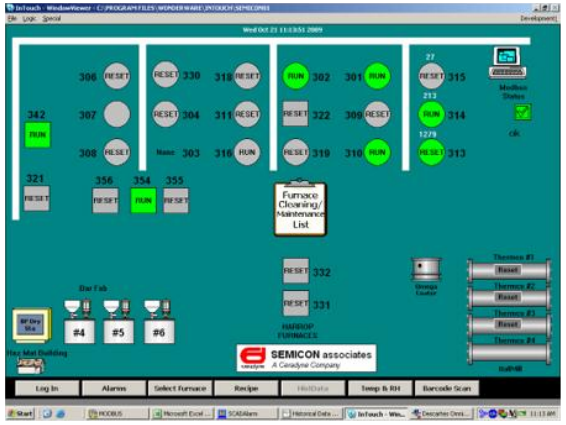


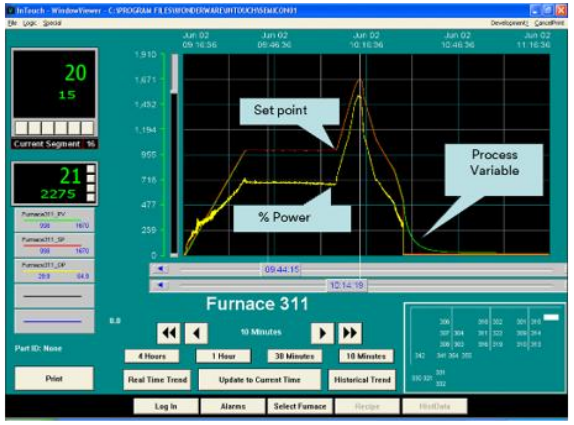
Equipment

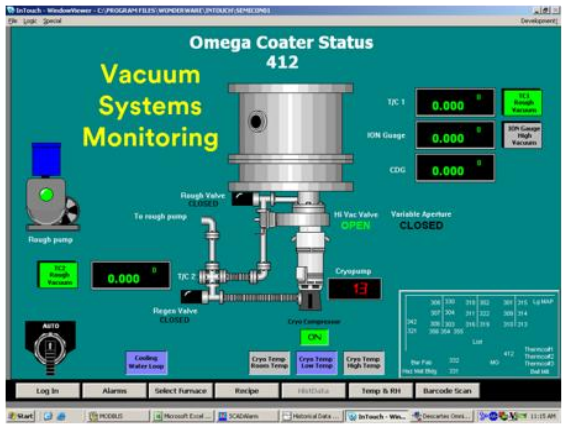
24/7 – Monitoring of equipment status in both static and run states. Alarms are displayed on computer monitor and depending on severity of deviation audible alarms, email, and pager notification levels have been established.

Run-Time Demand Maintenance

Notification is provided to the responsible party that some action is require based on a run time clock or process event.







Handling

Handling

Handling of the product during each of, and between the processing steps is critical for product quality and performance

- Maintain product cleanliness
- Prevent emitter contamination and poisoning
- Prevent physical damage to fragile components
- Properly store and pack cathodes for long shelf life

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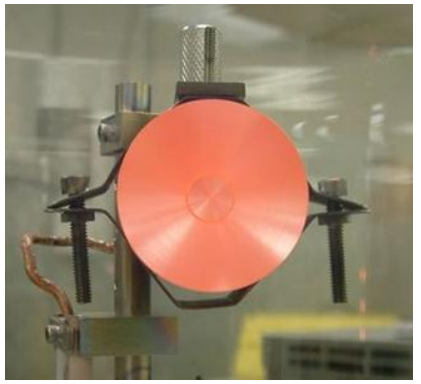
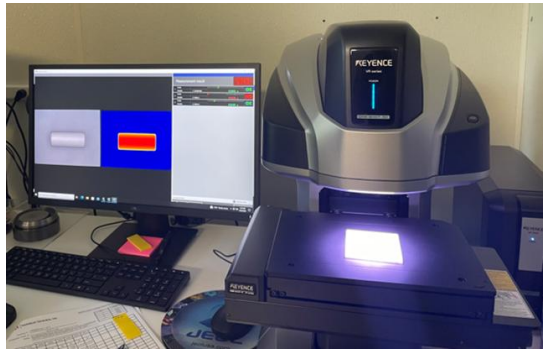
Quality Testing

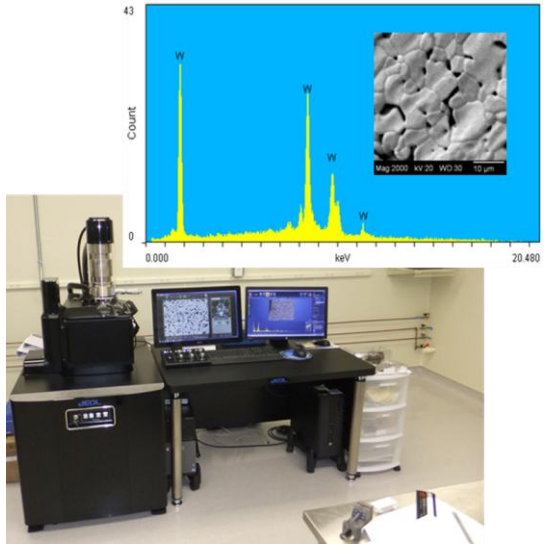
Testing

Since cathodes cannot be tested for emission, it is imperative to make sure all design aspects are met so the cathodes are capable of proper performance:

- Dimensional conformance
- Cleanliness
- Coating thickness and impregnant weight gain
- Heater V, I, T test
- No process deviation was done
- Proper storage and packaging
- Complete process documentation and test results are reviewed
- Data collection for full traceability





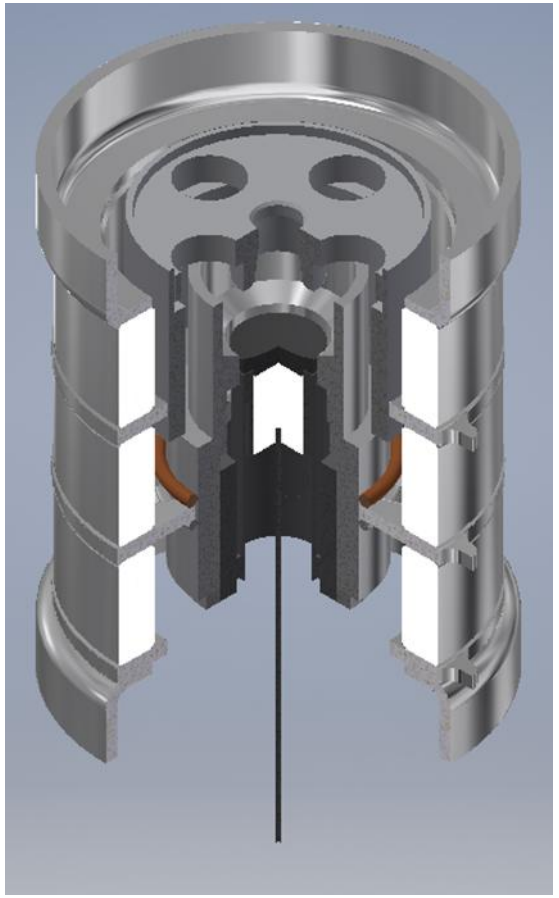


Packaging

Before shipment cathodes have to be packed in such a way to protect parts from damage during the shipment and in shelf life and from exposure to harmful environment

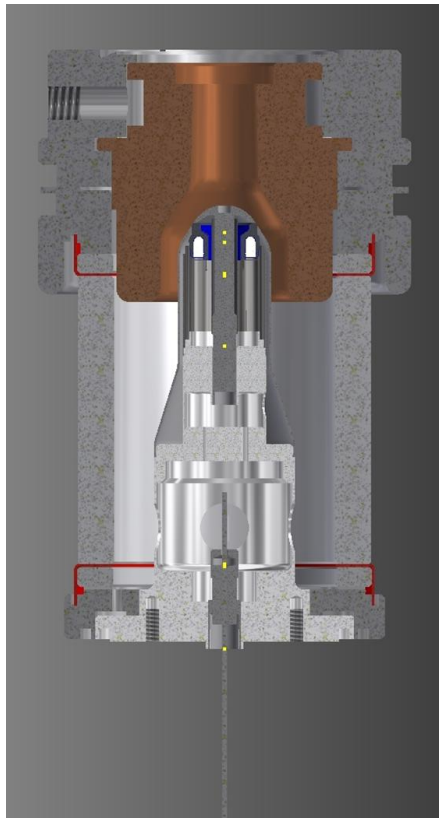
- Packing in evacuated glass vial
- Packing in mylar bags under inert atmosphere
- Installed into a special fixture for damage prevention
- Package is check for leak by tesla coil or in vacuum oven
- Activation instructions sent if requested
- All required documentation submitted
- All process and test results store for a required time (7-20 years)

Electron Gun Manufacturing



- Mechanical and thermal design
- Extensive experience in precision fabrication

- Ceramic to metal brazing capabilities
- Mechanical, thermal, electrical and vacuum integrity inspection capabilities



Science.
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Cathode Manufacturing Process Control

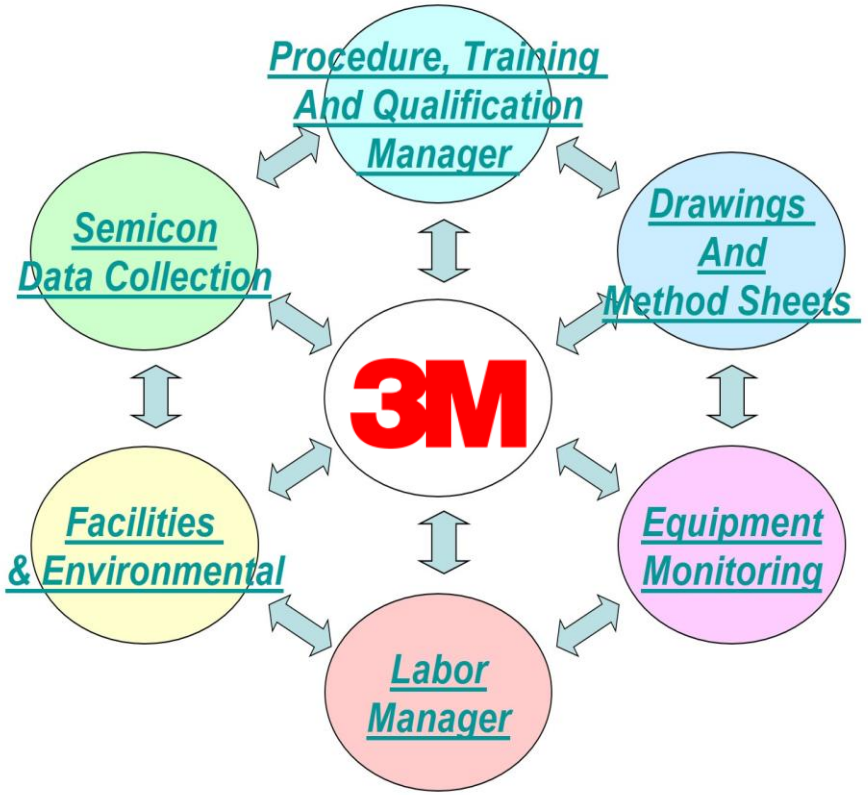
R.A.D.A.R.

(Remote Access Data Acquisition and Recovery)

…uncertainty of performance (not able to test) makes quality a priority….

…manufacturing of dispenser cathodes is not just a sale of product, but in essence sale of precisely controlled process….

R.A.D.A.R.



Specialty Cathodes

- All presented above is a standard process for standard products
- There are special types of cathodes that require more rigorous materials and process controls (space qualified cathodes, rapid response cathodes, ….)

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BUT THAT'S A STORY FOR ANOTHER DAY

Questions?