Fast Warm Cathode – Practical Fielded Design

Dr Sabina Orlowska

TMD Technologies Ltd., Swallowfield Way Hayes Middlesex UB3 1DQ, UK

Abstract: This paper presents information about fast warm cathode for microwave tubes applications. Its mechanical profile and thermal characteristics are discussed.

1. Background

The idea of fast warm up cathode for microwave tubes has been originated by challenging demands of vacuum electronics market. The applications of the cathode reaching its maximum electron emission in several seconds are expanding. Electronic warfare, missile seekers or conventional radars are keen on implementing electron guns with fast switching cathodes in their core. The design of the fast warm up relies on the high thermal efficiency of the cathode package, which gives a Fast Warm Up Time. The key elements to this successful operation are cathode heater, potting material in which the heater is embedded and cathode button that is the emission surface. The heater operates under voltage and surge current conditions, which make it up to the very high temperature in a few seconds. The heat propagates in the potting material to the cathode button, which starts emitting electrons when its surface reaches temperature level overcoming the work function, which depends on the surface type.

The profile of the Tungsten-Rhenium heater must be such that it can stand enough power and release enough heat to the surrounding potting. Therefore its length, thickness and shape are essential factors to be considered. Potting material, which is alumina-based ceramics, has a heat-conduction role and its thermal conductivity is most important aspect in the fast warm cathode design. The whole bulk of the cathode package has to be most selected, and kept to the optimal mass, as any extra thermal mass would be a burden for the heat conduction and slow down cathode's operation.

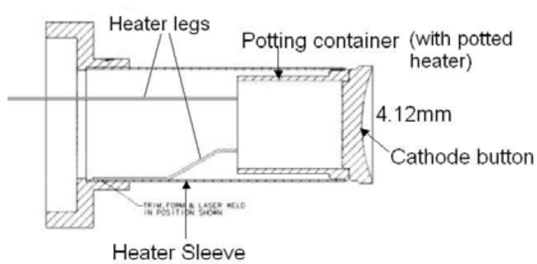

Figure1. TMD fast warm cathode

Dispenser (or impregnated) cathodes manufactured at TMD are impregnated with barium calcium aluminate and sputtered with Osmium/Tungsten layer and have work function of 1.9 eV at 1100deg C, the minimum temperature for desirable level of thermo ionic electron emission in this cathode being 1050degC. The temperature that has to be carried onto the cathode's emitting surface and getting it to the 1050deg C in the few seconds time constitutes a significant thermal stress to the cathode. Continued R&D works have been carried out at TMD towards obtaining a fast warm cathode package with high reliability and long lifetime.

2. Fast warm cathode practical profile and manufacture

On the way of computer simulations and experimental validation of results the optimal fast warm up cathode profile was chosen. Figure1 shows its general structure and main components.

The fast warm up time can be critical to cathode lifetime. But TMD have developed outstanding techniques and processes for the cathode manufacture so that its overall performance gave successful results. The cathodes go through a series of manufacturing processes, including: brazing, sintering, impregnation, cleaning, heating, pre-glow, and sputtering. Figure2 shows Auger characteristics of the impregnated and Tungsten/Osmium sputtered cathode button, measured at TMD. This type of cathode (CD-type surface layer) has been proven to have the longest life times versus highest emission current densities (Figure3), compared with cathodes that are not sputtered (B-Type) or sputtered with Osmium only (M-Type).

TMD has carried out intensive R&D works on research of alternative cathode potting materials - which had to be considered because standard alumina potting, with thermal conductivity, k, of 20- 25W/m.k, was limiting further progress. The challenge was to find the potting that would conduct heat faster and stand much higher thermal stress as a product of shorter warm up times in the fast warm cathodes. Tests and experiments resulted in selecting potting mixtures with higher thermal conductivities and more compactness: doped alumina ceramics and modifications to potting and sintering processes brought solution to fast warm up time requirement.

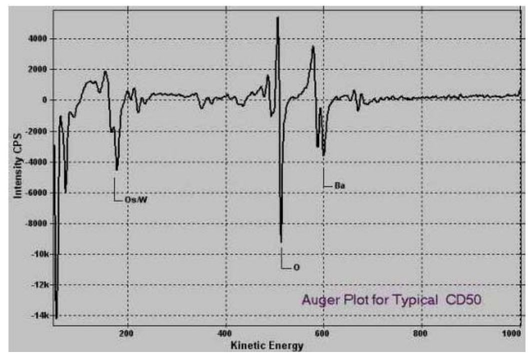

Figure2. Auger plot for typical CD cathode surface

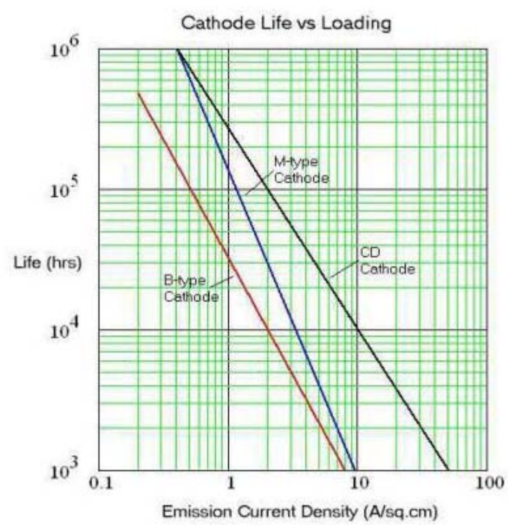

Figure3. Cathode life as a function of cathode loading

Production challenge consisted between other things in finding ceramic materials that would allow to make a solution liquid enough to start with for convenient potting process, but without the excess of liquid phase which would result in shrinkage and delamination of the ceramics while sintering, also finding optimum sintering temperatures that would allow good sintering of different materials together without harming fast warm results otherwise. The degree of sintering was assessed by optical microscopy of the particle sizes and from the change in density between the green and the fired state. Figure4 shows microscope photographs of two examples of ceramic samples and how they evolved from having porous structure with cavities to denser and firmer one, on the way of research. The small pores in the sintered material, even though it was hard, would limit thermal conductivity. Important design changes were equally introduced to the Tungsten heater profile, so that it would stand the peak power of the fast warm up cycle. Advanced techniques, including laser welding, were used to process heaters.

3. Fast warm up tests

Fast warm up cathodes, with modified alumina-based ceramic potting have been tested at different warm up time intervals. Figure5 shows plots of voltages and currents for 4.5s, 3.5, and 2.8s hotshots, at which cathodes C= and R= were tested. During that short time the inside of the cathode is exposed to severe thermal stress and only thanks to its exceptional design the cathode successfully survives that stage. The dependence of the current emission on the heater power is shown on Figure6 (cathode knee curve). After the hotshot cycle, volts and currents change into steady state, which is meant to maintain the temperature at the level granting desired electron emission. The shapes of the curves during the fast warm up time are caused by the rapid change in heater wire resistance.

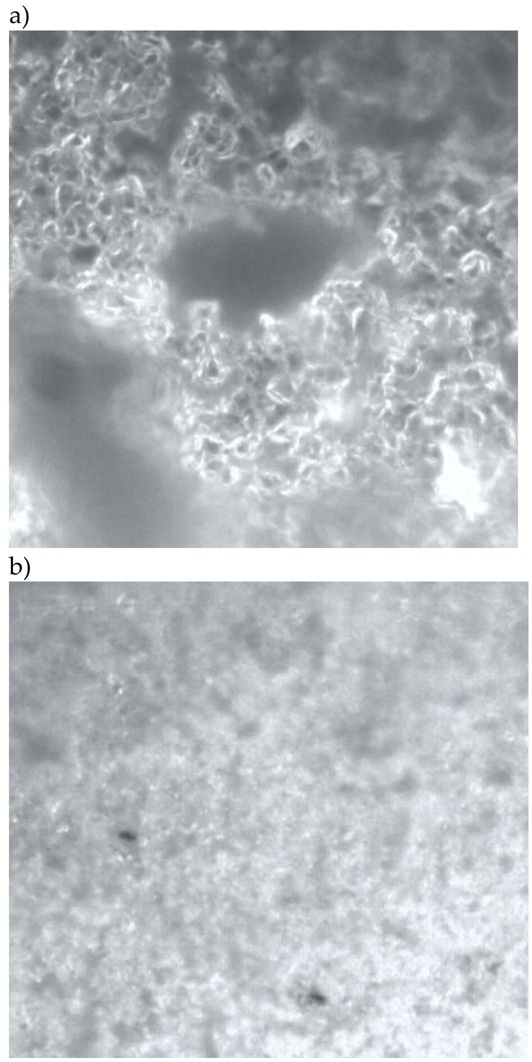

Figure4. Sintered ceramic potting a) Mix 15,1800C, x30obj, porous structure, b) Mix 19, 1850C, x50obj, modified mixture

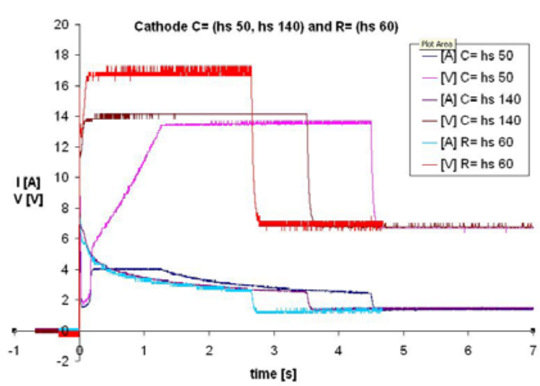

Figure5. Voltages and currents for 4.5s, 3.5, and 2.8s fast warm up times

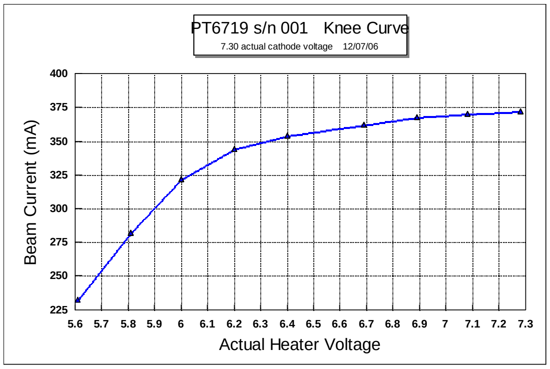

Figure6. Fast warm cathode knee curve - TMD

Figure7 shows the corresponding measured brightness temperatures of the cathode button, and Figure8 shows the glowing cathode button in the bell jar test. TMD's efforts have been concentrated on achieving short fast warm up times – Figure7b) shows the results of the latest trials with 2.8s fast warm up. Cathodes are expected to go through 200 fast warm up cycles and the set of temperature characteristics shown here represents some of those consecutive hotshots.

4. Conclusions

TMD have been running an intensive development programme aiming at shortening cathode warm up times and on achieving consistent results. The study on fast warm-up identified the critical area requiring attention and significant work was performed on research of the new potting material composition, on adjusting potting process and modifying the sequencing of cathode assembly to meet the requirement of fast warm up time. TMD's ability of the cathode design for fast warm up shot endurance has been demonstrated. Improvements have been made to the potting composition and processing technique, most promising potting materials for further study in fast warm up heater /cathode packages were selected, and the heater profile was adjusted to the new challenging requirement.

a)

b)

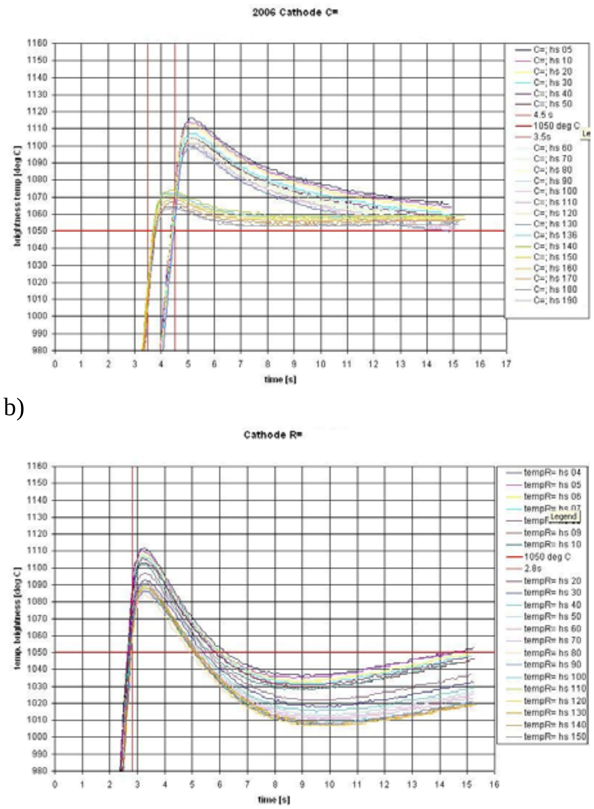

Figure7. Cathodes brightness temperatures on fast warm up tests a) 4.5s and 3.5s cycle, b) 2.8s cycle

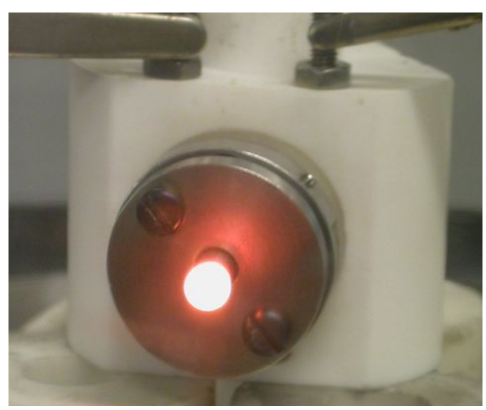

Figure8. Cathode glowing at 1050deg C – bell jar test