THE BEHAVIOR OF HOLLOW THERMO-EMISSION LANTHANUM HEXABORIDE ELEMENTS IN SPT CATHODES IN CONNECTION WITH THE MANUFACTURING METHOD

B. Arhipov*, V. Paderno**, Y. Paderno**, V. Filippov**

* - Experimental Design Bureau "Fakel", Kaliningrad, Russia
** - Institute for Problems of Materials of National Academy Sciences of Ukraine, Kiev, Ukraine

ABSTRACT

This report presents integrated researches of influence which method of manufacturing of initial compact lanthanum hexaboride material of thermo-emission element has on SPT cathode-neutralizer life; demonstrates changes during usage of various duration and various thermocycle number (firing-shutdown) regarding exterior, geometry and microtexture of working part of the channel of hollow cathode elements made of lanthanum hexaboride, obtained by different ways:

- cold pressuring followed by vacuum sintering;
- hot pressuring in graphite moulds and
- zone smelting with simultaneous zone cleaning.

The USSR patent #607435 of 20/01/78 concerning thermal processing of hot punched lanthanum hexaboride cathodes was issued and the USSR patent #883011 of 21/01/81 was attributed to the method of monocrystal borides reception (lanthanum hexaboride) with zone smelting and simultaneous zone cleaning. Cathodes, in which, in particular, the lanthanum hexaboride thermo-emission elements are used get the protection by Russia's patent #2012946, Europe patent #048438381 and USA patent #5350254.

INTRODUCTION

Currently lanthanum hexaboride is well known as one of the most efficient thermo-emission materials which are widely used as a powerful source of electrons. LaB₆ is characterized by a low electron output activity (2.7eV), high resistance to ion bombardment, poor poisoning while functioning in low vacuum or long exposed to air. In this connection lanthanum hexaboride is successfully used as hollow cathode material for ignition and maintenance of SPT plasma. It is known that lanthanum hexaboride hollow tubular cathode can provide 800A current [1] in channel outlet or more at the respective size of simulating surface.

Our experience showed that lanthanum hexaboride thermoemitter operation performance, stability and reliability depend significantly on the method of material production which determines its real structure and level of cleanliness.

A more pure and applicable for further compacting lanthanum hexaboride powder can be produced by borothermal reduction of lanthanum oxide with boron [3].

The more dense, pure and perfect is the material of thermoemission element, the more important and stable is its emission performance and the longer is its life [2].

Various method of compact synthesized powder material production for further manufacturing of cathode elements are known: a vacuum sintering of powder of previously cold punched blocks [4]; hot pressuring of powder at regular [5] and ultra-high pressure [6], zone smelting [7] and growing of monocrystals [8].

TEST PROCEDURE. CATHODE CHANNEL CONDITION ANALYSIS.

On the purpose of studying channel geometry distortion effects and microstructure changes in its operational part due to high temperature and ion bombardment, studied samples have been cut using electrospark method along the centerline of channel. Microstructure investigations have been performed by
As it's known the process of hollow cathode starting goes in several stages: previous heating by external tungsten radiation and then feeding plasma forming inert gas followed by discharge. Subsequently the cathode temperature maintenance is provided by plasma discharge (independent cathode operation).

During operation channel configuration changes mainly due to cathode material evaporation in the most stressed zones and to hexaboride vapour condensation on less hot channel zones. Primary factor of the channel configuration change is ion bombardment.

When delivered cathode elements have work piece configured as cylindrical channel with 0.5-0.8 mm diameter and 9 mm length.

Hollow cathode channel is electroerosion made that slightly affects integrity of surface layer, makes grains finer making their structure amorphous, confirmed by X-ray inspection. After milling the parts go through high temperature anneal which relieves internal stresses and takes the manufacturing induced impurities (hydrocarbons, graphite, etc.) out. At the same time channel surface structure is made more coarse and the uniform grain structure is formed characteristic for lanthanum hexaboride cathodes independent of the material production method.

Usage test showed that such hollow cathode life is limited mainly by erosion and channel destruction, channel narrowing due to filling it with erosion and evaporation products of both thermoemission element and other parts of cathode assembly (diaphragms, holders, etc.) and growth of gas phase transferred new grains inside the channel.

Maximal sintered hollow cathode life is 500-1000 hours [9] while providing the electron component of current about 5 A. Hot pressured - 3000 hours at the same electron component [10], while those made by smelting with simultaneous zone cleaning allow usage for more than 5000 hours at the output current 4.5 A [11, 12] corresponding to current density about 100 A per 1 cm² of emitter compared to 26.7 A per 1 cm² of cold pressurizing made one.

**ELECTRON MICROSCOPE INSPECTION**

Electron microscope inspection revealed some characteristic zones on the channel inside surface, eroded and destroyed differently and significantly differing from each other in microstructure.

It is known that outlet portion of the channel 1-3 mm from the edge is most heavily bombarded. Already after 100-200 hours of operation configuration of this channel edge zone is changed under intense erosion and thermal emitter sputtering forming characteristic cone-shaped outlet expansion, which dimensions, length and form depend significantly on operation time and mode and primarily on material production method (Fig. 1).

The most intensive form changes occur in channel outlet and on sintered emitter walls (Fig. 1a). Hot pressured emitter is characterized by forming an outlet cone of more regular form and more uniform channel surface erosion (1b) notwithstanding longer operation (700 hours compared to 320 hours of sintered emitter operation).

Zone smelting provides for fabrication of cathode element capable to work satisfactorily for longer than 5000 hours and over 6000 cycles, while the channel form is almost unchanged (Fig. 1c).
The initial structure of hot pressed element can be distinguished, yet it is also heavily covered by evaporation and oxidising products, signs of smelting are visible (Fig.2b).

Zone smelted element is more plasma erosion resistant and channel edge smelting and significant grain growth occur in the most arduous conditions (operation longer than 2000) (Fig.2c).

Thermoemission element material production method and life:

a) sintering, 320 hours at 320 cycles (x60);
b) hot pressing, 700 hours at 4800 cycles (x50);
c) zone smelting, 142 hours at 1696 cycles (x24).

After interaction between plasma and emitter in this channel edge zone large number of externally introduced fine irregularly shaped flakes and microstructure is distorted up to signs of smelting (Fig.2).

The initial grain structure of sintered element almost cannot be distinguished, nearly entire channel surface is covered by external particles which are mostly (after X-ray analysis of microstructure) products of cathode parts oxidising and thermal emitter sputtering (Fig.2a).
Fig. 2c

Fig. 2. Hollow cathode’s lanthanum hexaboride channel offer operation 1mm off the edge. Element material production method:

a) sintering, 342 hours at 456 cycles (x600);
b) hot pressuring, 313 hours at 914 cycles (x750);
c) zone smelting, 2010 hours at 2194 cycles (x410).

Farther from the channel edge (3-7mm) microstructure trend change from erosion to new crystal growth by recrystallization and growth through gas phase.

Significant porosity and crystal growth are seen in sintered material (Fig.3a).

Porosity and crystal growth decrease in hot pressed material, crystal form is more regular, close to perfect (Fig.3b).

More regular grains form in zone smelted material, however, erosion on subcluster boundaries is seen (Fig. 3c).

Surface material evaporation signs and condensation and growth from gas phase of separate regular crystals are seen in places of contact among remaining material grains (Fig.3d). Material surface is decorated with plasma generated evaporation products (most probably lanthanum hexaboride). polygonal subboundary structure is clearly distinguished, dislocation grid is seen (Fig.3e), which together with other factors is the most probable reason of higher resistance of such cathode element.
Fig. 3. Microstructure of the hollow cathode's lanthanum hexaboride channel after operation 5-6mm off the edge.
Thermoemission element material production method:

a) sintering, 658 hours at 853 cycles (x600);
b) hot pressing, 700 hours at 1800 cycles (x560);
c-e) zone smelting, 825 hours at 50 cycles c (x410), 336 hours at 527 cycles, (d, e) (x7900, x16000)

At the very long operation and long life higher current density results in intensive channel filling with sputtered material and its growth from gas phase during operation forming separate dendrites on the inside channel surface, in some cases achieving such size that they completely fill and plug the channel leading to failure of the cathode element (Fig. 4).

Fig. 4. Microstructure of the hollow cathode's lanthanum hexaboride zone smelted channel after operation in arduous conditions (2010 hours at 2194 cycles).

a) general view of plugged channel zone, (x11);
b-c) detains grown in channel (x90, x940)
Even farther from the edge (over 6 mm) a zone of large regularly shaped grains, formed by recrystallization, is distinguished. Similar structure is kept to the end of the channel. This indicates that plasma discharge in this channel zone is absent.

It may be presumed that some increase in channel diameter (while preserving the outside diameter of thermal emission element) would lengthen its emissive zone (decreasing the required current density and sputtering speed), decrease the speed of plugging it with sputtered material and eventually lengthen the cathode assembly life.

**CONCLUSION**

The investigation led to the following conclusions:

- Material production method significantly affects the operation test results. The cleaner and more dense is material, the less impurities it contains, the more its resistance to plasma sputtering, the longer life and the higher performance are provided for a cathode element.

- There is a correlation between lanthanum hexaboride cathode element structure and performance when used as the SPT hollow cathodes. This allows to recommend the manufacturing method providing for optimum structure and the longest life. Such method is zone melting with simultaneous cleaning, providing for obtaining material almost free of pores and impurities, structurally close to monocrystal, and in limit use providing for forming monocrystal bars without microcracks: cavities, with zero porosity, little structure divergence (less than 10°), comparatively low dislocation density 10^-6-10^-4 1/cm², which could be further used in manufacturing the respectively configured and sized cathode elements. Usage of such hollow thermal emission elements would significantly increase cathode operation performance, stability and reliability.

- The appropriate SPT cathode thermo-emission element fabrication method should be selected depending upon the specific SPT task and development and manufacturing cost.

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