Design and Testing of Different Insert Region Heaters of a Lanthanum Hexaboride Hollow Cathode

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Some of the space electric propulsion devices, such as ion engines and Hall effect thrusters, use hollow cathodes as the electron sources for providing the necessary electrons for the ionization of the propellant and to neutralize the ion beam leaving the thruster. Most of the hollow cathodes used in space applications have used Barium-oxide impregnated Tungsten (BaO-W) inserts as the thermionic emission material. However, recent studies have shown the advantages of using Lanthanum-hexaboride (LaB6) insert material as the thermionic emission source [1-3]. However, due to its higher work function, the LaB6 inserts have to be heated to a much higher temperature compared to the BaO-W inserts. In this paper, design, thermal modeling and testing of three different heater models of a prototype hollow cathode with an LaB6 insert as the thermionic emission material is presented. The built hollow cathode will be used as a neutralizer electron source of a 8 cm diameter laboratory RF ion thruster running on Xenon propellant.

The hollow cathodes used in modern electric propulsion systems usually have a thin, long, hollow cylindrical conductor pipe in which an insert material with low work function is placed. The basic operation mechanism of a hollow cathode is as follows: The insert (LaB6) is heated by an external heater coil to an elevated temperature where sufficient electron emission per unit area is achieved. The electrons which are emitted from the insert hit Xenon gas that is allowed to flow in the hollow region of the cathode tube and cause the Xenon neutral gas to be ionized. Then, with the application of a electric potential to the keeper electrode, which is placed external to the cathode electrode, elctron emission to outside is achieved. The cathode insert can maintain its emission temperatures with the heat flux from the plasma to the insert surface. This is called the self-sustaining mode of operation. The heater is required only to provide first heating of the insert.

BaO-W and LaB6 have been used as the most common hollow cathode insert materials due to their low work functions. The work function of BaO-W is 2.06eV at a temperature of around 1000 ^{o}C and the work function of LaB6 is 2.67 eV around 1650 ^{o}C [2]. Due to its higher work function LaB6 cathodes require higher operating temperature compared to BaO-W cathodes [4]. However, BaO-W cathodes are very sensitive to impurity poisoning (water vapor, oxygen or other impurities in xenon gas) at high temperatures and the poisoning can shorten the lifetime or even prevent the cathode electron emission [1, 5]. For LaB6 cathodes, the propellant purity requirements are much relaxed due to its lesser sensitivity to poisoning [4].

Generally heaters are made by wrapping a wire around the cathode tube and then covering it by a reflective foil as shown in Fig. 1. Although it is a simpler method, this method may not be effective for heating the insert in small cathode tubes due to its weakness in uniform and efficient heating of the insert [1]. As an alternative, a threaded ceramic tube which is wrapped by the wire is used as the heater for providing better surface contact between the heater assembly and the cathode tube compared with insulated wire [1]. Also a different heater design study was made at the University of Michigan as shown in Fig. 2 [6]. Axial pattern is used instead of helical wire path to make the machining of the ceramic sleeve easier [6].

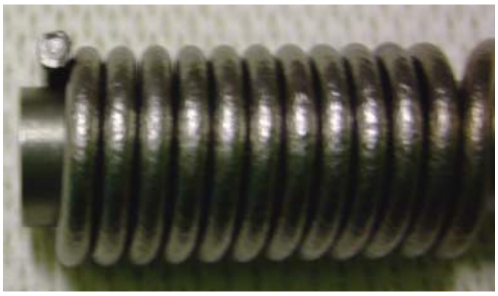

Fig. 1: Tantalum sheathed heater wire [3]

Fig. 2: Heater design of University of Michigan [6]

In this study, three different heater designs have been considered. These designs, shown in Fig. 3, are inspired by the several other works mentioned in the literature. The considered heater designs will be called as design A, design B and design C. In design A, the heater wire is assumed to be a 1 mm thick insulated Tantalum wire making 15 turns around the tube. The heater is assumed to be approximately 15 mm long (5 mm longer than the insert). In design B, a Boron Nitrite ceramic tube with helical shaped grooves placed on the cathode tube in the insert region. A bare Tungsten wire is assumed to be wound inside these grooves. This shape will provide a more uniform heating of the insert as well as allowing a more compact wounding of the wire. In design C, similar to design B, a Boron Nitride ceramic tube is placed around the cathode tube, but this time vertical grooves, instead of the helical shaped, are machined on the ceramic. Again, a bare Tungsten wire provides the resistive heating. A cylindrical Tantalum sheet, placed around the cathode tube and the heater coils, is used as a refractory material to prevent the radiative heat loss and aid maintaining the self-heating of the hollow cathode. The cylindrical Tantalum sheet radiates heat back into the system so that the generated heat is encapsulated and higher temperature values are achieved.

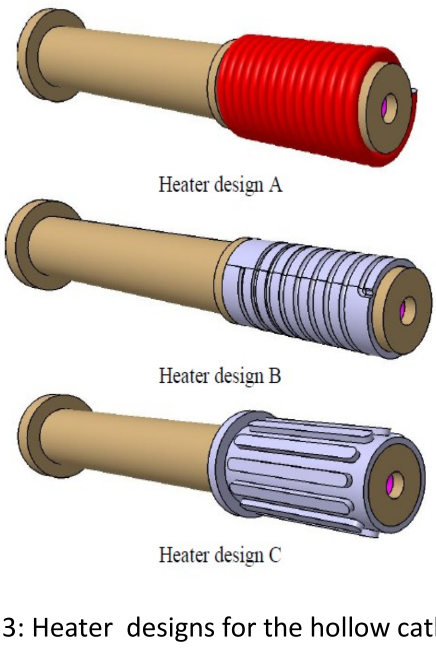

Fig. 3: Heater designs for the hollow cathode

In designs B and C it is assumed that Boron Nitride ceramic will be used for the heater. However, Boron Nitrite might decompose in vacuum (~10-6 Torr) at very high temperatures [7], thus this must be taken as a factor. Alumina or other high temperature ceramics could also be considered for this purpose. The design, thermal analysis using COMSOL multiphysics software, and experimental testing of the mentioned heater designs will be presented in the submitted final manuscript.

References

[1] D. G. Courtney, *Development and Characterization of a Diverging Cusped Field Thruster and a Lanthanum Hexaboride Hollow Cathode*, M. S. Thesis, Massachusetts Institute of Technology, May 2008

[2] D. M. Goebel and R. M. Watkins, *High Current Hollow Cathodes for High Power Ion and Hall Thrusters*, AIAA 2005-4239

[3] D. J. Warner, *Advanced Cathodes For Next Generation Electric Propulsion Technology*, M.S. Thesis, Air Force Institute of Technology, 2008

[4] K. R. Trent, M. S. McDonald, R. B. Lobbia, A. D. Gallimor, *Time-resolved Langmuir Probing of a New Lanthanum Hexaboride Hollow Cathode*, IEPC-2011-245

[5] D. M. Goebel, R. M. Watkins, K. K. Jameson, *LaB6 Hollow Cahodes for Ion and Hall Thrusters*, AIAA-2005-4239

[6] K. R. Trent, M. S. McDonald, R. B. Lobbia, A. D. Gallimore, *Timeresolved Langmuir probing of a new Lanthanum hexaboride hollow cathode,* 32nd International Electric Propulsion Conference, Wiesbaden, Germany, 2011, IEPC-2011-245

[7] L. H. Dreger, V. V. Dadape, J. L. Margrave, *Sublimation and decomposition studies of Boron Nitride and Aluminum Nitride*, Journal of Physical Chemistry, vol. 66, issue 8, p. 1556, 1962