Development of High Current LaB6 hollow Cathode

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Abstract: Deep-space missions requires higher thrust and longer life to Electric propulsion system to achieve future cargo and manned-missions. For the cathodes of this class thrusters must be able to sustain discharge currents up to 50 amperes with lifetimes in excess of 10 khrs. To this purpose，a 100A lanthanum hexaboride (LaB6) hollow cathode has been developed and test at Lanzhou Institute of Physics. The LaB6 offers the capability of larger emission current, and lower gas purity requirements to propellant and can be exposed longer in the atmosphere than conventional dispenser cathodes. The hollow cathode design features a refractory metal tube and a graphite keeper to reduce sputtering by ion bombardment on this electrode. A prototype of the hollow cathode was experimentally characterized using xenon as propellant. The hollow cathode was tested at the current of 100 A for a total of about 300 hours of continuous operation and 2000 times ignition test.

I.Introduction

THE high-power electric propulsion spacecraft are being pursued to reduce launch vehicle size and facilitate in-space transportation of large masses in support of the manned space program. It is of great importance in applications such as deep space exploration and space station cargo spacecraft. With the in-depth demonstration of deep space exploration missions and asteroid exploration missions, the higher requirements are put forward on electric propulsion such as power, thrust, specific impulse and other performance [1, 2, 3]. The next generation high-power electric propulsion are being developed for these application in the range of 20 to 100kW with lifetimes in excess of 10 kh[1]. These thrusters will use the hollow cathode as an electron source and neutralizer and require it that can produce discharge current of 50 to over 500A, while the hollow cathode life of more than 40,000 hours required.

A high-current version of this LaB6 hollow cathode concept based on the mature product 5A LaB6 insert hollow cathode. Up to now 5A LaB6 insert hollow cathode has been completed more than 20,000 hours of continuous discharge test and 16,000 times ignition test. During the life test, hollow cathode emission current is 5.2A[7]. Until now high current hollow cathode has been completed more than 300 hours of continuous discharge test and 500 times ignition test. It was not find anything significant sputtering top corrosion before and after the test, and the discharge was stability during the test.

II. High Current Hollow Cathode and Structure

The high current cathode has been redesigned and configured to mount directly to the 20 kW Hall thruster. The new version of this cathode uses a refractory metal cathode tube welded to the tungsten orifice plate. This geometry provides a heat conduction path for the orifice plate that lowers the orifice plate temperature to mitigate evaporation issues. The hollow cathode using lanthanum hexaboride (LaB6) as insert material, compared with the barium-oxide (BaO-W) dispenser cathode insert lanthanum hexaboride has a larger emission current density and lower gas sensitivity. Because LaB6 tends to chemically react with most materials, the cathode tube can be made directly from graphite or can be fabricated from a refractory metal such as molybdenum [1]. High current hollow cathode is used tantalum as cathode tube. So the boron atoms in the lanthanum hexaboride will penetrate into the cathode tube at high temperatures, leading to the cathode tube expansion and fracture. Therefore, the tantalum carbide is used to interface with and provide electrical contact to the lanthanum hexaboride insert and cathode tube to avoid “boron brittleness” [4]. But compared with the graphite liner, the tantalum carbide separator can better contact with the cathode tube, increasing the thermal efficiency of the heater, thereby increasing the heater life [5]. However, tantalum carbide isolation process is relatively complex, the thermal losses also larger than graphite liner. This cathode design used a graphite keeper to minimize sputtering by the ions in the cathode plume [8]. Compared to refractory metal, high-density graphite materials have a larger sputtering threshold [6].

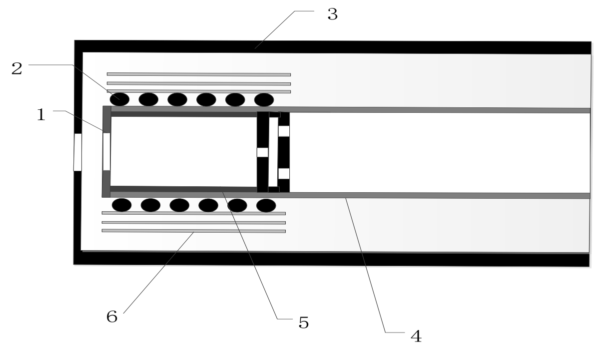

Figure 1 Schematic of high current hollow cathode

1-cathode orifice plate, 2-heating wire, 3- keeper, 4-cathode tube,5-LaB6 insert, 6-heat shield

High current hollow cathode demonstrated stable discharge currents of 20 to 150 A in a cathode test facility at the Lanzhou Institute of Physics. The structural schematic diagram was shown in Figure 1, high current hollow cathode main components includes the insert, heater, heat shield, graphite keeper, cathode orifice plate and so on.

High current hollow cathode heater is still assembled structure, using the rhenium tungsten wire heating wire, cathode tube is using tantalum, tungsten as cathode orifice plate. The High current hollow cathode is designed as a discharge cathode for 20kW thruster, the maximum discharge current is 150A.

III. Experimental Configuration

High current hollow cathode test facility shown in Figure 2. The facility has a 1.5-m-diam by 1-m-long vacuum system with 2000 l/s xenon pumping speed from two molecular pump. The cathode test electrical connection diagram is shown in Fig. 3. The background of the vacuum equipment better than 10-5Pa, working vacuum is better than 10-3Pa.

Figure 2 Test apparatus for hollow cathode test

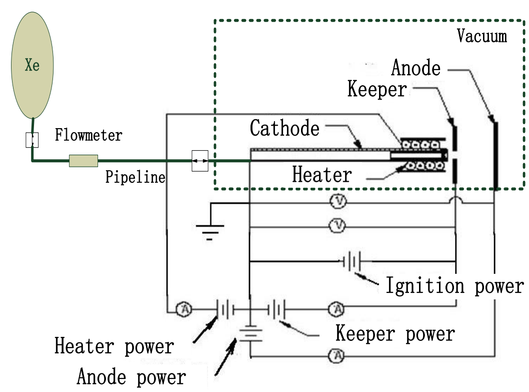

Figure 3 hollow cathode experimental schematic

The anode of the TS-3 device consists of a water-cooled cylinder of relatively large area to handle the high-power discharge. This test configuration produces discharge voltages in the 10to 30V range, depending on the current and gas flow rate. In addition, Cathode flow rate are controlled through the computer control system, beyond that the anode current during the experiment, the keeper current, the keeper voltage, anode voltage all control through the computer automatic acquisition system.

Heater power, ignition power supply, anode power supply is used constant voltage/ constant current supply, and all power supply are working in constant current mode. The experiment uses xenon as working gas, with a purity of about 99.9995%. High current hollow cathode heater power is less than about 220W, when the emission current of 100A when the power is less than 1.5KW.

IV.High Current Performance Test Results

The high-current LaB6 hollow cathode based on the mature product 5A LaB6 insert hollow cathode, expounding for the optimization as follows [9, 10]:1. sputtering corrosion problem of keeper (tantalum); 2. sputtering corrosion problem; 3. thermal design problem after cathode power increase. The above problems will affect the cathode performance and life expectancy. In response to these problems, not only test hollow cathode current performance, but also recorded its ignition time and cathode orifice plate temperature after the stability of the work.

Figure 4 Lanthanum hexaboride hollow cathode assembly

The anode consists of a water-cooled cylinder of relatively large area to handle the high-power discharge. Temperature measurements of the cathode orifice plate are made using a disappearing filament optical pyrometer calibrated by a tungsten filament reference in the vacuum system. A comparison of the measured temperature of the filament to that derived from simple radiation theory was used to obtain a calibration curve to correct the readings of the orifice plate temperature through the vacuum system window [9].

After installation of the cathode, the vacuum system is typically pumped down into the 10−4 Pa range and the cathode heater turned on for 60 min. at the same time the xenon gas flowing through the cathode, applying 50 V to the keeper electrode and turning on the anode power supply. The keeper current is typically regulated to 3 A, and the keeper voltage falls to values from 5 to 15 V range depending on the gas flow rate and discharge current. Once the keeper current exceeded 1 A, the heater power supply is turned off. The cathode is normally run at 20 A for a minute or two until the discharge voltage stabilized, and then it can be turned up to full current in a matter of tens of seconds.

Figure 5 shows the discharge voltage vs discharge current for the high current cathode measured for currents of 20 to 150 A for three xenon gas flow rates through the cathode. At discharge currents below about 80 A, the discharge voltage was observed to increase as the cathode cooled off. The cathode would stop operating completely at discharge currents below 20 A.

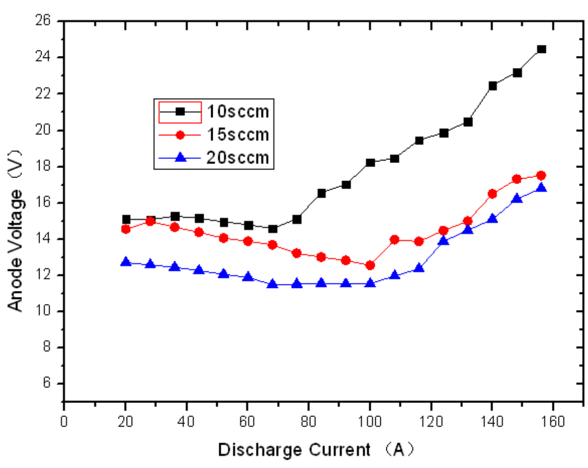

Figure 5 Discharge voltage vs current for three xenon flow rates

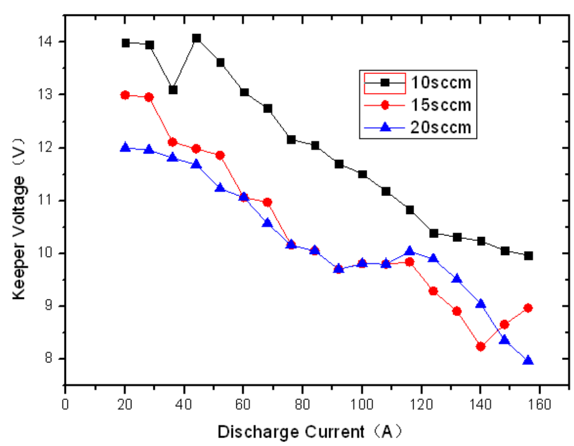

Figure 6 Keeper voltage vs current for three xenon flow rates

It can be seen from Fig. 5 that the anode voltage does not change much when the discharge current of the hollow cathode is below 60A at a working gas flow rate of 10sccm, but increases rapidly when the anode current is greater than 60A. By contrast when gas flow rate is 15sccm, 20 sccm, the anode voltage change is relatively flat.

Figure 6 is show that the keeper voltage vs discharge current for the high current cathode measured for currents of 20 to 150 A for three xenon gas flow rates through the cathode, the keeper voltage decreases as the anode voltage increases. Because of the selfheating mechanism in the hollow cathode depends on the discharge current level and the lower discharge currents provided insufficient heating in the cathode to maintain the insert temperature. Currently the keeper voltage shows a gradual increment trend in Figure 6. In the case shown at low current, the voltage drop in the cathode plasma increases to provide enough heating, which increases the measured discharge voltage. Higher cathode gas flows reduced the discharge voltage at any given current and permitted operation at up to 150 A for the maximum 20 sccm of cathode flow rate tested. It could not operate the cathode at discharge currents above 160 A in this facility.

The temperature of the cathode orifice was measured by the optical pyrometer during the high-current discharge testing. The uncertainty in the measurement is about 50°C.

Figure 7 shows the tungsten orifice plate temperature as a function of discharge current for the nominal case of 15 sccm in the cathode. As the discharge current is increased, the orifice plate temperature is observed to exceed 1800°C. This temperature is much higher than the LaB6 insert due to the high orifice plate heating from the high-current plasma discharge [11]. it does determine the maximum current capability of the cathode. The heater was assembled included a rhenium tungsten alloy foil around the tantalum tube to act as a barrier to this eutectic formation [12]. This cathode was successfully tested to 155 A of discharge current to date without any melting.

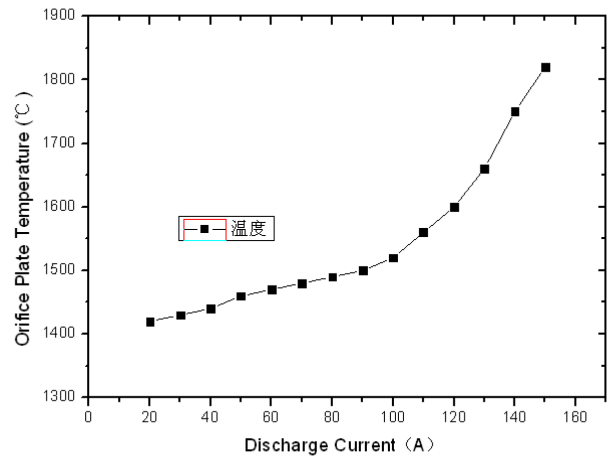

Figure 7 Orifice plate temperature vs discharge current for the nominal 15 sccm cathode flow

In the test, the cathode top temperature was changed to about 1850 ℃ at the full current of 150 A, under this condition orifice plate was quickly sputter-eroded. In the early high current hollow cathode used cerium tungsten as the cathode tip, when the hollow cathode work at 100A, after 100 hours the tip of the cathode was completely sputtering. After optimized the structure of the hollow cathode, the gas flow rate of the working fluid and tungsten was used as the cathode tip. The hollow cathode showed almost no change after 300 hours of continuous operation at the emission current of 100A.

V.Short-term Life Test Verification

High current hollow cathode has completed 300 hours life test, during this which also completed 500 times ignitions. During the life test, hollow cathode was operated at the anode current of 100 A, the keeper current of 3A, and the xenon gas flow of 15 sccm. During the experiment, the discharge voltage of the hollow cathode was stable and no obvious corrosion was observed on the orifice plate and keeper.

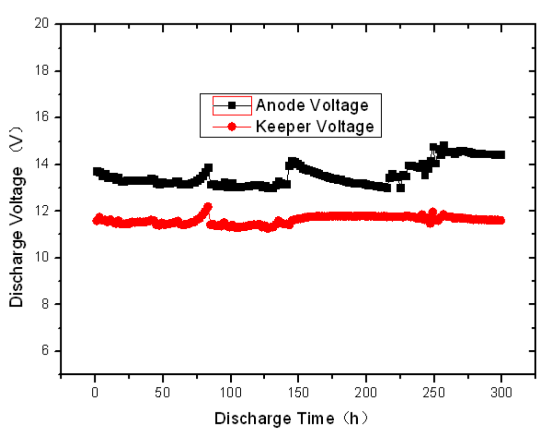

Figure 8 Variation of discharge performance during hollow cathode test

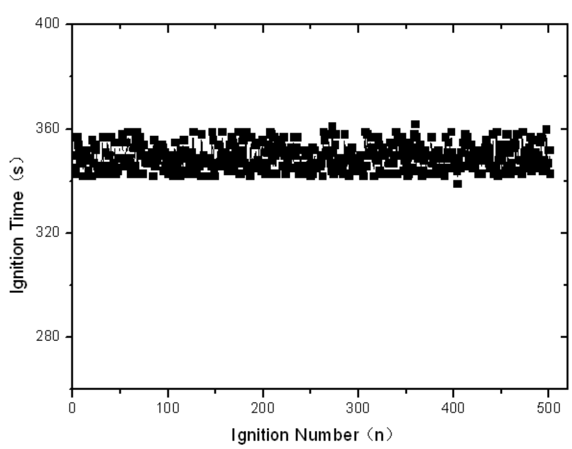

Figure 9 Changes in ignition time during life test

During the life test, the anode voltage of the hollow cathode was monitored. Figure 8 shows the change of the anode voltage of the hollow cathode during the life test.

It can be seen from Figure 9, the ignition time during the life test is distributed between 340 and 360 seconds, and the ignition time is stable. Before and after the test, the change of the cold resistance of the heating wire is less than 5%, which means that the heater basically does not change.

VI.Conclusion

Lanzhou Institute of Physics successfully developed High current hollow cathode, the maximum discharge current is 150A. The discharge performance of the hollow cathode and the temperature of the cathode tip were tested, When the cathode current was 100A, the cathode tip temperature was about 1550℃, and the cathode was operated within a reasonable working temperature range. Combined with the change of the cathode tip and keeper during the life test, high current hollow cathode can achieve 30,000 hours. The test result of the ignition time test also shows that the hollow cathode ignition time is stable, and the assembled heater structure currently used is reliable. However, if the working time of the hollow cathode exceeds 120A, the lifetime of the hollow cathode will drop drastically. For instance, the hollow cathode needs to be re-optimized when the electric power exceeds 20KW.

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