

# Investigations of Discharge Chamber Material Influence on Small Hall Thruster Parameters

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**Abstract:** The results of the study of the integral characteristics of small Hall Thruster depending on the ceramics used for the discharge chamber are shown. There are several samples of alumina mono-crystal and boron nitride ceramic with different silica content were investigated. Studies have shown that a change in the ratio of ceramic components change the ionization efficiency and the share of the ion current in the discharge. Studies erosion characteristics have shown that the rate of bulk erosion depending on the type of ceramics may vary in two and more times. Influence of ceramic porosity on thruster parameters was studied.

## Nomenclature

$E_e$	=	electron energy
$I_d$	=	discharge current
$I_i$	=	ion current
$U_d$	=	discharge voltage

## I. Introduction

RANGE of tasks to be solved by using microsattellites are greatly expands at present time. However, still unsolved problem of the development of active orbit correction systems for low-orbit micro-spacecraft in the absence of reliable and efficient propulsion systems with low power consumption. Hall thruster (or SPT) is a promising candidate as its specific impulse is about 1500 s. Besides the high specific impulse and efficiency of the thruster is to be met to ensure the lifetime on the level of a few thousand hours, that may provide only with application of the special materials for the discharge chamber of the thruster. There are known research results of sputtering for variety of materials [1] based on which can be recommend to use, in terms of lifetime, materials such as boron nitride and aluminium oxide.

In frames of the task of creating effective solutions of EP (electric propulsion) on the basis of a low power Hall thruster (LPHT), the question remains of raising the efficiency and lifetime characteristics.

The discharge chamber material has a significant influence on the characteristics of thruster. The main influencing factors are the secondary electron emission [2, 3], as well as the ratio of ion sputtering (directly determines the lifetime of the thruster).

According to the test results on the SPT-20m3 bulk sputtering of Al<sub>2</sub>O<sub>3</sub> mono-crystal in 14 times lower than that of aluminum-boron-nitride (ABN) [4]. However, it is also known that the material affects discharge characteristics of the thruster [5] is largely due to secondary electron emission [6]. Previous studies have shown that additives into Al<sub>2</sub>O<sub>3</sub> mono-crystal provide a bit performance is not worse than the ABN, in terms of the ion current to the discharge current ratio [4].

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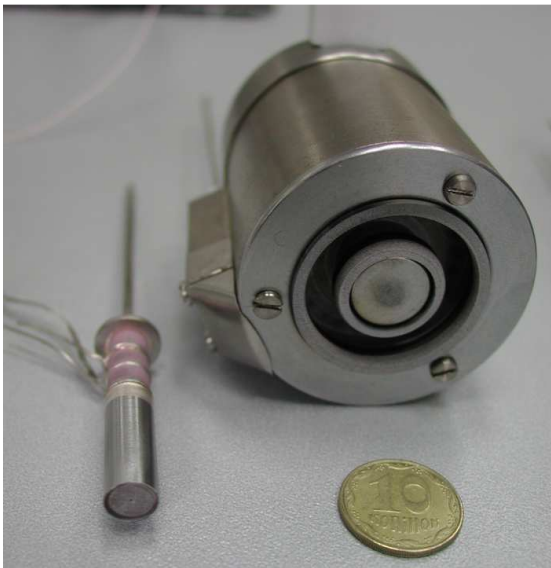
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Previous studies have shown that ceramics based on boron nitride with the addition of silica has a sufficiently low coefficient of secondary electron emission [2, 3] and low coefficient of ion sputtering [1]. Using such ceramics allow get well integral characteristics for the middle class HT [2] and for the LPHT [7]. Also it was noted the influence of silica content on the parameters of the thruster. In view of the above, it adopted the decision to explore in more detail the parameters of the thruster with the boron nitride compositions with different content of silicon oxide.

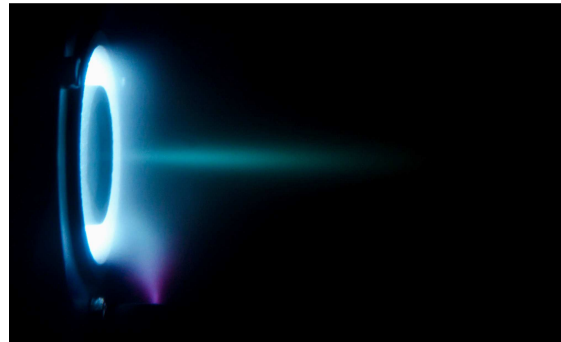
## II. The research results

### A. Facility

Studies of the influence of the material of discharge channel were carried out on the LPHT developed in the "KhAI" SPT-20M with gas-discharge hollow cathode BNK M0320M (Fig. 1, 2), which showed good conditions at power consumption level of 100 watts [4, 8].



**Figure 1. SPT-20M with the cathode BNK M03.**



**Figure 2. Running SPT-20M – low power Hall thruster.**

Tests were carried out on the test stand in the "KhAI". The volume of the vacuum chamber is  $2 \text{ m}^3$ , with the total capacity of the pumping  $7,000 \text{ l/s}$  oil-free vacuum limit is  $7 \cdot 10^{-6} \text{ Torr}$ . (for calibration by the air), at a total mass flow of xenon to  $0.4 \text{ mg/s}$ , a dynamic vacuum is reduced to  $5 \cdot 10^{-5} \text{ Torr}$ . Thrust was measured using a pendulum thrust-balance, the estimated error for measured thrust about  $4 \text{ mN}$  is not more than 3%. RPA was used for investigation of the parameters of the ion components of the plasma.

### B. Ceramics

At the 1st stage of experiments were selected for study various types of ceramics from alumina mono-crystal with  $\text{TiO}_2$  additive to reduce the secondary electron emission and mixtures of BN and  $\text{SiO}_2$  (Table 1).

At the 2nd stage of experiments walls of thruster was made of ceramics based on BN with  $\text{SiO}_2$  content from 0 to 50% (Table 2). The table also provides the density and porosity of used ceramic samples.

Table 1

№	Ceramic type
1	BN(65%)+SiO <sub>2</sub> (35%)
2	BN(50%)+SiO <sub>2</sub> (50%)
3	Al <sub>2</sub> O <sub>3</sub> (charge «-»)
4	Al <sub>2</sub> O <sub>3</sub> (99,5%)+TiO <sub>2</sub> (0,5%)(charge «-»)
5	Al <sub>2</sub> O <sub>3</sub> (99%)+TiO <sub>2</sub> (1%) (charge «0»)
6	Al <sub>2</sub> O <sub>3</sub> (99%)+TiO <sub>2</sub> (1%) (charge «+»)

Table 2

№	Composition, %	Density g/cm <sup>3</sup>	Porosity
1	BN – 100;	1,55	0,326
2	BN – 95; SiO <sub>2</sub> – 5	1,7	0,266
3	BN – 90; SiO <sub>2</sub> – 10	1,72	0,263
4	BN – 80; SiO <sub>2</sub> – 20	1,87	0,211
5	BN – 65; SiO <sub>2</sub> – 35	1,86	0,232
6	BN – 60; SiO <sub>2</sub> – 40	2,02	0,172
7	BN – 50; SiO <sub>2</sub> – 50	2,08	0,188

### C. The 1st stage of experiment

Investigations were carried out at series anode mass flow rates. The range of variation of the discharge voltage was 150 .. 450V (restriction on the discharge power - 150W). Magnetizing current in the coil has been fixed to provide reducing of the discharge current without significant loss for magnetization. We have measured discharge and thrust characteristics during the experiment (fig. 2, 3).

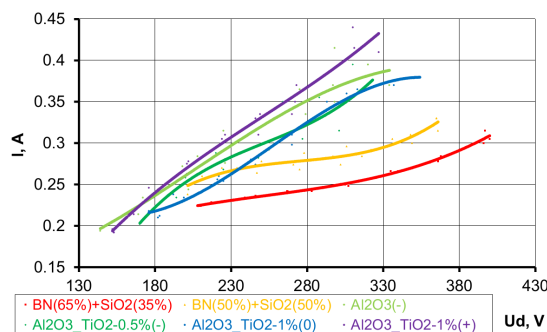


Figure 2. Discharge current vs discharge voltage (anode mass flow rate – 0.29 mgm/s).

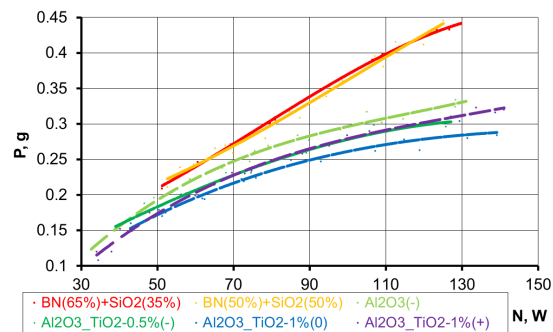


Figure 3. Thrust vs discharge power (anode mass flow rate – 0.29 mgm/s).

From these characteristics can be clearly seen that the application of mono-crystal Al<sub>2</sub>O<sub>3</sub> results discharge current rapidly increases with increasing voltage, and the rate of increase in thrust with increasing discharge power decreases. This indicates on significant electron current that resulting efficiency decreasing. When BN+SiO<sub>2</sub> used discharge current starts to increase significant only at higher voltages. It may be associated with increase in thermal power disposed on the walls.

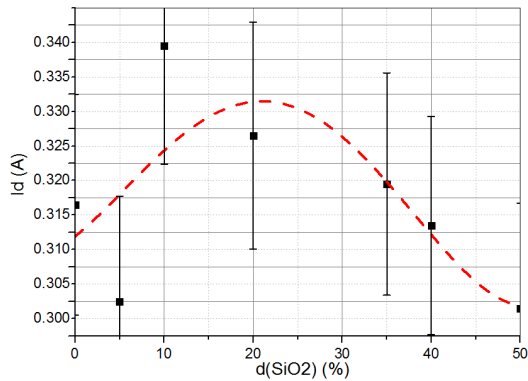
### D. The 2nd stage of experiment

At the next step series of BN ceramics with varies proportion of SiO<sub>2</sub>, were investigated (see Table 2). Following parameters were investigated for comparative analysis: current-voltage characteristics, thrust, plasma parameters with RPA, the weighting erosion characteristics.

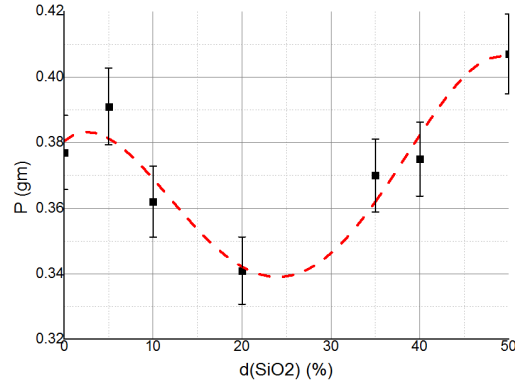
For comparison thruster performance tests were carried out in the main operating point:

- anode mass flow rate - 0.35 mg / s;
- maximum magnetic field strength in the center of the discharge chamber - 25 mTl;
- discharge voltage - 300 V.

In the experiment, for each type of ceramic discharge characteristics (Fig. 4) and thrust (Fig. 5) were measured.



**Figure 3. The discharge current.**



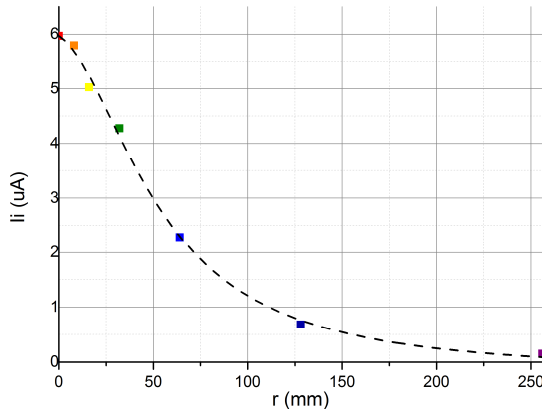
**Figure 4. Thrust characteristics.**

It is clearly seen that, depending on the applied ceramics type changing the discharge current for the same input conditions can be over 10%.

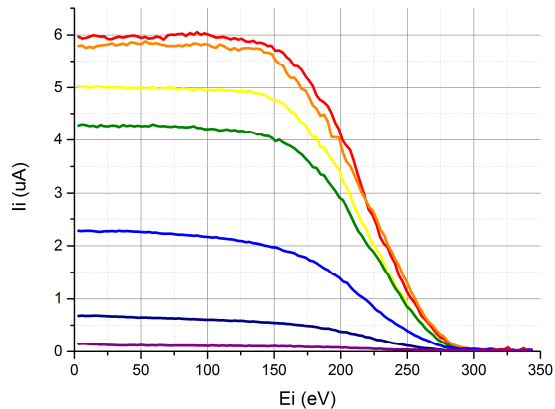
Thrust depending on the type of ceramics with the same input conditions may vary up to 20%.

Also with the help of the RPA measured ion current (Fig. 6) and retarded current-voltage characteristics, depending on the position of the probe relative to the axis of the thruster (Fig. 7).

The distance from the edge of the thruster to the probe - 140 mm. The maximum displacement of the probe from the axis - 256 mm. Also changed the angular position of the probe in order to maximize current signal in each point.



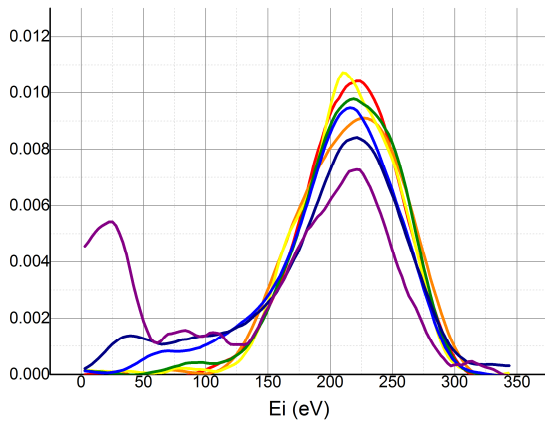
**Figure 6. Radial distribution of the ion current.**



**Figure 7. Retarded probe CVC.**

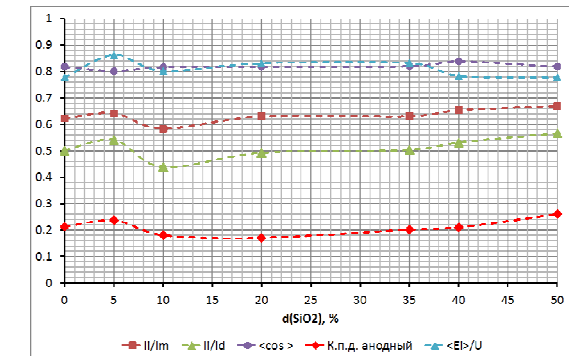
The functions of ion energy distribution as a result of differentiation derived retarded current-voltage characteristics (CVC) specified (Fig. 8).

From the obtained data were calculated ratio of the ion current to the discharge and the equivalence of mass currents, the fraction of the ion current in the discharge and ionization efficiency, respectively. Also, we calculated the ratio of the average energy of the ions (in eV) to the discharge voltage, which characterizes the efficiency of the use of the discharge voltage to accelerate the ions. The mean cosine of the angle of deviation of ions from the axis also been calculated. The measurement results are shown in Fig. 9. As figure shows the thruster anode efficiency depending on the used ceramic.



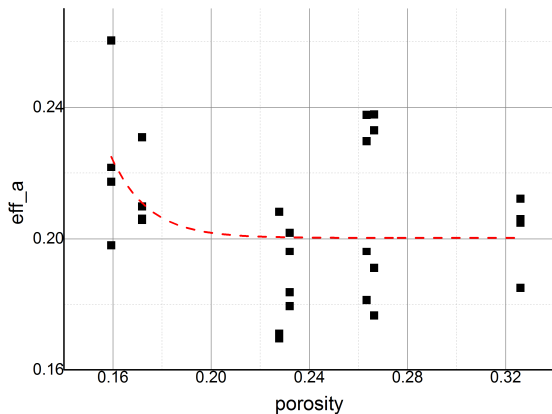
**Figure 8. The local ion energy distribution function.**

Analyzing the obtained data it can be said that the type of ceramic has a significant effect on the efficiency of ionization and the share of the ion current in the discharge.



**Figure 9. The specific parameters that characterize the efficiency of the thruster.**

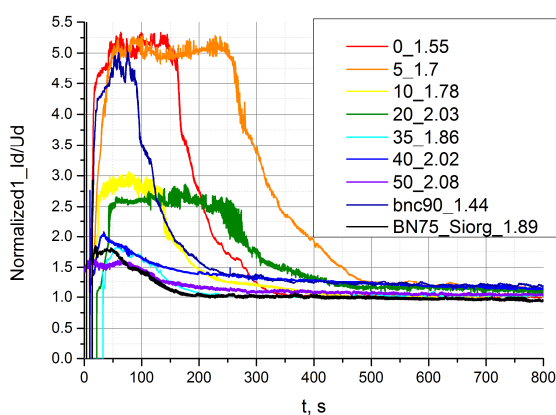
Due to these effects with ceramics on the basis of boron nitride containing silica from 0 to 50% anode efficiency may differ up to 9%. In the application of ceramics with SiO<sub>2</sub> content of 5% and 50% managed to get the greatest values of thruster efficiency: 23.8% and 26% respectively.



**Figure 10. Thruster anode efficiency vs. porosity**

Investigation of ceramic porosity influence on thruster anode efficiency was provided after repeated measurements. Main results are shown on fig. 10.

It is clear to see that when ceramic porosity increases up to 23% efficiency decreases. This effect may depend on parasite gas leaks from porous during discharge that affect conditions.



**Figure 11. Ratio of current to voltage vs. running time.**

Measuring discharge parameters during thruster firing and running until steady state reached has shown great dependence on ceramic density (porosity). The ratios of current to voltage normalized by steady state vs. running time for ceramics with different density are shown on fig. 11. Amplitude and duration of drops are in strong dependence on ceramic density. Dependence of drop amplitude vs. ceramic density is shown on fig. 12. It is obviously that ceramic with density lower than 1.8gm/cm<sup>3</sup> is too porous and absorb too much gas which leads to significant current drop on discharge start.

Studies of erosion characteristics were performed at thruster running within 8 hours when the speed of the sputtering significant. Fig. 13 shows the dependence of the speed of bulk erosion of the walls for each type of ceramic.

It can be seen that the rate of erosion depending on the type of ceramics may differ more than in 2 times. The ceramics with the content of SiO<sub>2</sub> 5% looks the most attractive from the point of view of lifetime characteristics.

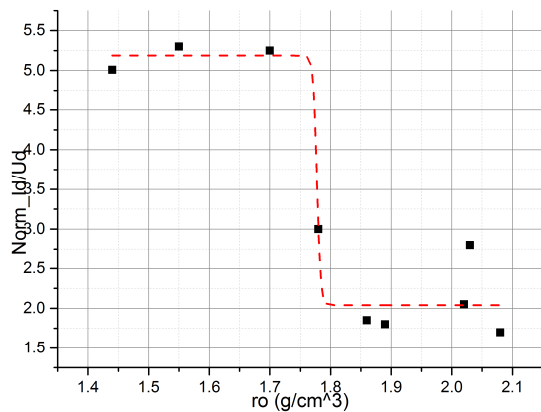


Figure 12. Drop amplitude vs. ceramic density.

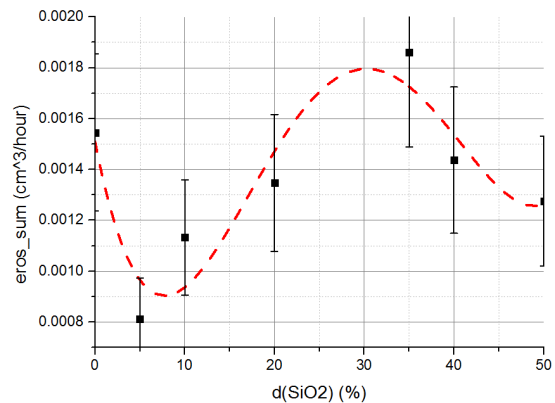


Figure 13. The bulk erosion Speed.

### III. Conclusion

The studies have shown great influence of the ceramic type on integral characteristics of small Hall Thruster. New types of mono-crystal Al<sub>2</sub>O<sub>3</sub> show discharge current fast increasing with increasing voltage probably due to high secondary electron emission (despite the additives). Content of silica in BN ceramic influence on the efficiency of ionization and the share of the ion current in the discharge so anode efficiency may differ up to 9%. Ceramic porosity influence on thruster anode efficiency: until ceramic porosity increases up to 23% efficiency decreases. Dependence of current drop amplitude vs. ceramic density is strong. Ceramic with density lower than 1.8gm/cm<sup>3</sup> is absorbing too much gas which leads to significant current drop on discharge start. The rate of erosion depending on the type of ceramics may differ more than 2 times. It is necessary to improve process technology to produce more dense compositions to obtain better efficiency and lifetime characteristics of LPHET.

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