SPT CERAMIC ISOLATOR SURFACED LAYER COMPOSITION CHANGE WITH LIFETIME

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The experimental results of SPT ceramic isolator surfaced layer composition change with lifetime are represented in the paper. The SPT-70 with segmented isolator made of BGP (BOROSIL) was used in the experiments. The thruster operated under nominal mode (300 V, 2.2 A). Every 8 - 10 hours of thruster operation the segment of isolator is taken away from the thruster and was tested with RBS method. Simultaneously the wall profile was measured. Four tests were carried out. The total time of thruster operation was 40 hours. As the results of the experiments it was found out that surfaced layers of a ceramic are changed greatly in the thickness 2.5 µm. It was found out that Xe is presented in under-surfaced layers and also that ceramic's stoichiometric composition is changed.

INTRODUCTION

One of the factors limiting an SPT lifetime is a process of ceramic isolator sputtering. For the future long time space missions it is necessary to choose a ceramic with sputtering resistance at least in 1.5 – 2.0 times higher that traditional BOROSIL has. In order to solve this problem it is necessary to know in details what is happening with ceramic in the SPT channel. In this paper the conditions of ceramic operation in the SPT channel are just examined.

Experimental procedure

The aim of the experiment is to determine an elemental composition and a profile of an operating surface of the SPT ceramic isolator. Standard plasma thruster of the SPT-70 type is used in the experiment. The isolator is made of ceramic of BGP-10 type. The thruster operated under nominal mode: discharge current – 2.2 A; accelerating potential – 300 V; the propellant – Xe. The experiment was carried out in the vacuum chamber with volume 2.5 m^3. The vacuum chamber is pumped by two turbo-molecular pumps of BMH 2500 type. The pressure inside the vacuum chamber during thruster operation was not more than $6 \cdot 10^{-5}$ torr.

Elemental composition and erosion profile change were determined using information about isolator mass losses. As far as it is impossible to control continuously such parameters during SPT operation in our experiment, total time of operation was divided into four equal cycles (over time). The main parameters were measured between experiments. Elemental composition was measured with RBS method. Due to specific of this method (it was possible to use only small-size samples), it was difficult to analyze an isolator as a whole. So, the SPT was modified as it is shown in the fig. 1 and 2. Four diametrically located slots were done in external isolators. In the slots the inserts made of BGP-10 are mounted. In order to overcome spurious discharges, inserts and slots had trapezoidal form. The inserts are fixed in the slots with the help of spring split ring made of tungsten wire. Inserts amount and position were selected in such a way that jet symmetry was secured and also we were able to obtain additional statistic information.

The experiment was carried out by the following way: before first ignition elemental composition of the insert's material were analyzed; inserts' profiles were measured; inserts were weighted. After that, the inserts were placed to the selected position and the SPT was ignited. Then when SPT operation cycle was finished, the inserts were taken out, their profiles were measured, inserts were weighted and insert #1 elemental composition was analyzed. Then the samples were put to their places again and the next cycle of SPT operation was carried out. It was carried out four cycles with duration 8 – 12 hours. In this case total lifetime of the SPT was 44 hours.
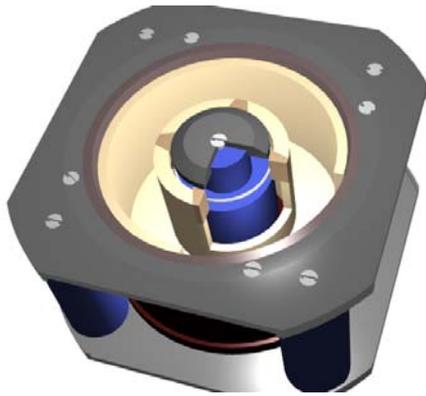
Figure 1: Inserts position in the SPT isolator

Figure 2: Modified SPT-70

Ceramic isolator composition study

In order to clarify how elemental composition of SPT isolator is changing, elemental composition of ceramic isolator made of BGP-10 was tested. For examination it was chosen an isolator's point located on insert external generatrix at the distance 1 mm from thruster exit. Sample analytical diagnostic was done with the help of RBS method permitting to determine absolute content of atoms in a structure. The measurements were carried out in the IPTM PAS ion-beam complex. RBS spectrums are recorded with standard double-detector scheme of measurement with angles of dispersion $\upsilon_1=160^0$, $\upsilon_2=120^0$ under $E_0=1$ MeV [1]. RBS spectrums are processed with the help of approximate interactive software RUMP [2].

In the fig. 3 one can see experimental RBS H$^+$ spectrums ($E_0=1$ MeV) of initial ceramic and for the same ceramic after 44 hours of thruster operation in a vacuum chamber. In this case spectrums approximation was done approximately as far as hydrogen atoms dispersion on B^{11}, C^{12}, O^{16}, F^{19} atoms have sufficiently non-Rutherford type [2]. Due to this phenomenon an estimation of ceramic composition change should be assumed as semi-qualitative.

As far as H$^+$ ions have sufficiently lower (relatively helium ions) energy losses under retarding, its thickness of penetration into insert material is higher approximately on an order. Spectrums represented in the fig. 3 characterize sample diagnostic approximately up to 50 μm.

a)   *b)*
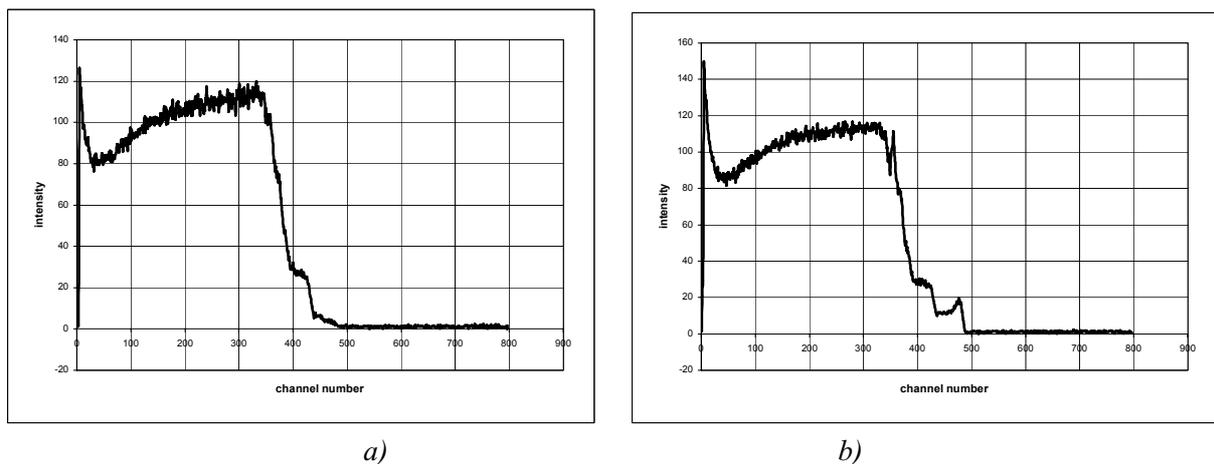
Figure 3: Experimental RBS spectrums ($E_0=1$ MeV) of initial ceramic (a) and for the same ceramic after 44 hours of thruster operation (b)

Spectrums processing is represented in the table 1. From the table one can see, that initial material is made of **C-B-N-Si-O-Sr**. **Xe** appearing in surfaced layers may be due to propellant diffusion into porosity structure of isolator.

Table 1: Spectrums processing

Before run									
Layer thickness, Å	∞								
C	0.270								
B	0.300								
N	0.280								
Si	0.060								
O	0.150								
Sr	0.001								
Cycle #1 (8 hours)									
Layer thickness, Å	600	1600	3400	7400	16400	26400	36400	∞	
C	0.1466	0.1649	0.1829	0.2033	0.2420	0.2796	0.2797	0.2797	
B	0.4203	0.3977	0.3754	0.3485	0.3098	0.2596	0.2597	0.2597	
N	0.2835	0.2813	0.2791	0.2711	0.2614	0.2596	0.2597	0.2597	
Si	0.0244	0.0339	0.0433	0.0484	0.0581	0.0599	0.0599	0.0599	
O	0.1173	0.1164	0.1155	0.1258	0.1258	0.1398	0.1399	0.1399	
Sr	0.0029	0.0029	0.0029	0.0029	0.0029	0.0015	0.0010	0.0010	
Xe	0.0049	0.0029	0.0010	-	-	-	-	-	
Cycle #2 (12 hours)									
Layer thickness, Å	600	1600	3400	7400	10400	16400	21400	36400	∞
C	0.0877	0.0968	0.1441	0.1971	0.2418	0.2517	0.2669	0.2797	0.2797
B	0.4386	0.4356	0.4323	0.3549	0.3095	0.3001	0.2768	0.2597	0.2498
N	0.3411	0.3291	0.2594	0.2661	0.2611	0.2614	0.2570	0.2498	0.2498
Si	0.0244	0.0339	0.0432	0.0493	0.0580	0.0581	0.0593	0.0599	0.0599
O	0.0975	0.0968	0.1153	0.1281	0.1257	0.1258	0.1384	0.1499	0.1598
Sr	0.0049	0.0048	0.0048	0.0044	0.0039	0.0029	0.0015	0.0010	0.0010
Xe	0.0058	0.0029	0.0010	-	-	-	-	-	-
Cycle #3 (14 hours)									
Layer thickness, Å	600	1600	3400	7400	16400	20900	32900	46900	∞
C	0.1382	0.1566	0.1640	0.1902	0.2031	0.2034	0.2397	0.2597	0.2797
B	0.4146	0.3914	0.3763	0.3504	0.3578	0.3584	0.3096	0.2797	0.2498
N	0.2863	0.2838	0.2798	0.2703	0.2418	0.2421	0.2497	0.2498	0.2498
Si	0.0247	0.0342	0.0405	0.0450	0.0580	0.0581	0.0599	0.0599	0.0599
O	0.1283	0.1272	0.1351	0.1401	0.1354	0.1356	0.1398	0.1499	0.1598
Sr	0.0039	0.0039	0.0039	0.0040	0.0039	0.0024	0.0012	0.0010	0.0010
Xe	0.0039	0.0029	0.0005	-	-	-	-	-	-
Cycle #4 (10 hours)									
Layer thickness, Å	800	1600	3400	9400	18400	24400	32400	46400	∞
C	0.1399	0.0980	0.1257	0.1608	0.1801	0.2050	0.2405	0.2597	0.2597
B	0.4512	0.4608	0.4254	0.3819	0.3602	0.3416	0.3106	0.2797	0.2797
N	0.2256	0.2745	0.2707	0.2714	0.2701	0.2635	0.2505	0.2498	0.2498
Si	0.0564	0.0343	0.0387	0.0422	0.0470	0.0517	0.0571	0.0599	0.0599
O	0.1128	0.1275	0.1354	0.1407	0.1401	0.1367	0.1403	0.1499	0.1499
Sr	0.0068	0.0029	0.0029	0.0030	0.0025	0.0015	0.0010	0.0010	0.0010
Xe	0.0074	0.0019	0.0012	-	-	-	-	-	-

In the fig.4 it is represented a dependence of ceramic composition on the thickness at different moments of time. As one can see from this figure, composition stabilization is happened already for the first hours of thruster operation, after that profile of concentration is changing insufficiently. The great thickness of

changed layer can be explained by micro-relief presence on ceramic surface (micro-relief is formed under ion bombardment). According to RBS, typical size of the micro-relief is 3-5 μm and is increasing with thruster time of operation. Visual examination gives the same result.

a)   b)
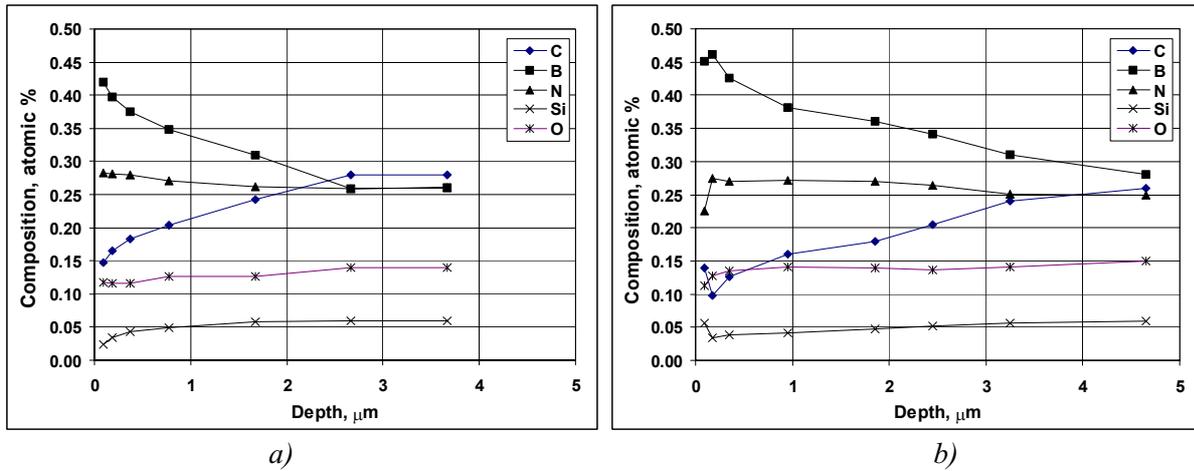
Figure 4: Ceramic elemental composition distribution over thickness at different moments of time a) after 8 hours of thruster ignition b) after 44 hours

Measurement of erosion profile and inserts mass

Erosion profile was measured with the help of universal optical microscope with contact-free method. Samples position on the microscope operation table is represented in the fig. 5. Back (non-operation) side of the tested sample was pressed to the based Johansson plate placed on the microscope frame. In order to minimize an error, appearing due to the fact that samples are placed a few differ in different serious of measurement, Johansson plate was fixed immovably at microscope frame. Before measurement the base plate projection was coincided with the lines of dotted mesh of the microscope. As a point of reference the most distant (relatively thruster cut) point on cylinder generatrix of the sample was chosen. Then sample was moved along measurement plate with a step 0.5 – 0.1 mm with the help of the frame and sample generatrix ordinate values (relatively base surface) were measured. In this case it was assumed that back (non-operation) side and initial point on the external (operation) side of the sample were not eroded. According to such method the summary error of measurement with the help of microscope taking into account all factors will be 3μm. The results of measurement for the sample #1 are represented in the fig 6. Some non-uniformity of erosion can be due to inaccuracy of inserts profile measurement.
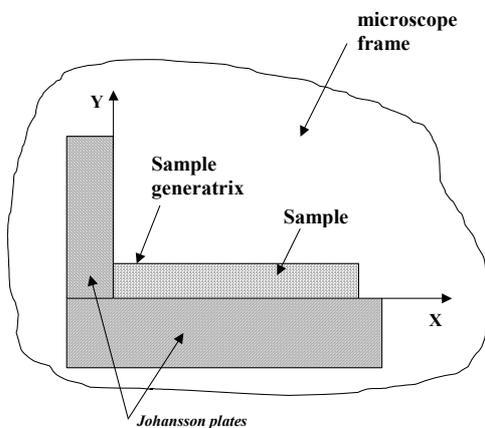
Figure 5: Samples position on the microscope table
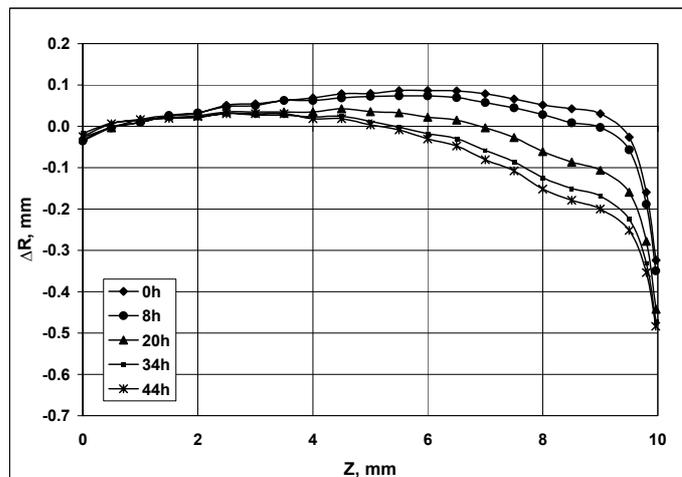
Figure 6: Sample 1 profiles at different moments of time

Samples mass was measured before and after every cycle of the SPT operation. Weighting was carried out with the help of mechanical balance, securing mass determination with the accuracy ±1 mg. In the fig.7 the dependence of samples mass on the SPT time of operation is represented.
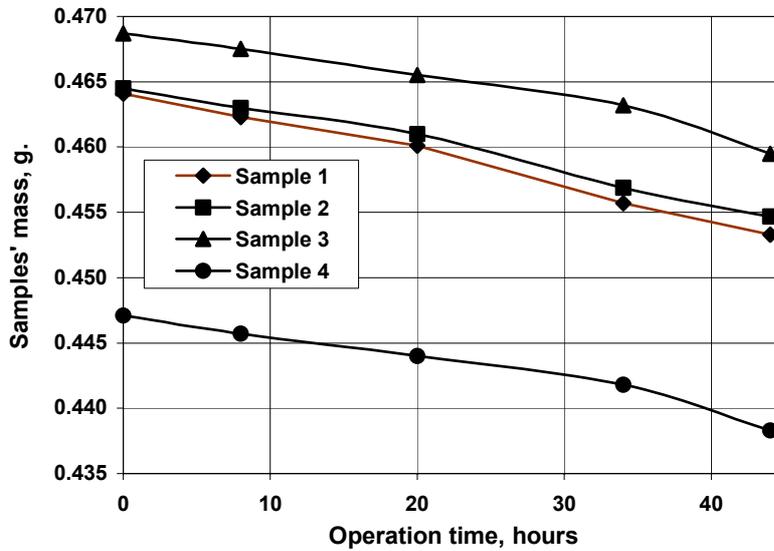
Figure 7: Samples mass change over the SPT time of operation

Average mass losses of the samples were 9.7 mg and this fact agrees with profile-metrical measurements. The dependences are linear and that confirms constant erosion rate of the samples.

Conclusions

Information about surfaced layer composition of the ceramic isolator during first 44 hours of operation was obtained. It is found out that the profile of concentration is stabilized during first 10 hours of operation and further is changing insufficiently. Ceramic composition is changing greatly with thickness. The thickness of the changed layer can be 3-5 μm and can be explained by diffusion and micro-relief presence on the sample surface. Visual examination confirms this fact. Inserts mass change with thruster time of operation is linear and this fact confirms that there is no any qualitative reorganization of samples structure.

References

1. L.R. Doolittle, Algorithms for the rapid simulation of the Rutherford Backscattering spectra. Nucl. Inst. and Meth, B9, 1985, pp. 344-351.
2. J.R. Bird, J.S. Williams, Ion Beams for Material Analysis, Acad. Press, Sydney, 1989, pp. 718.