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A. LOYAN[1], N. KOSSELEV[1], T. MAKSYMENKO[1], N. PELLERIN[2], E. VÉRON[2], S. PELLERIN[3], T. GIBERT[3], L. BALIKA[3], F. GAFARI[4], J-B. LEFEVRE[4], M .DUDECK[4]

[1]*National Aerospace University "KhAI", Kharkov, Ukraine*
[2]*CEMHTI, CRNS, 1D Avenue de la Recherche scientifique, Orléans, France*
[3]*GREMI, University of Orléans-CNRS, Bourges cedex, France*
[4]*Institut Jean Le Rond d'Alembert, Université Pierre et Marie Curie, Paris, France*

ENERGY DEPOSITION AND SURFACE ANALYSIS OF THE SPT20-M7 HALL EFFECT THRUSTER

As a way to analyse the plasma-wall interaction, the electron energy deposition has been calculated at different points of the ceramics delimiting the plasma discharge of a Hall effect thrusters. The calculation takes into account the potential sheath but without secondary electron emission. The energy deposed by the ions is commented. The visible surfaces by the plasma of the SPT20-M (KhAI) ceramic have been analyzed at CEMHTI (CNRS Orléans) by GSEM (Gaseous Scanning Electron Microscope) and by EDX (Energy Dispersive X-ray) spectrometry. A large microstructural change is observed in the channel, with regions exhibiting erosion or deposit phenomena.

Key words: *plasma, Hall effect thruster, surface analysis.*

Hall Effect Thrusters

Hall effect thrusters (HET are now used on board geostationary satellites and interplanetary probes. In HET, a partially magnetized plasma discharge is sustained in a coaxial channel. A gas flow (xenon) is uniformly injected down the channel generally through holes in the anode. The electrons entering in the channel come from an external hollow cathode (set outside the channel). The pressure inside the channel is typically of a few mTorr, then the electron-atom collisions mean free path is on the order of 1 m, greater than the total channel length (~ cm), an external magnetic field generated by inner and outer magnetic coils is applied in order to increase the transit time of the electrons. This effect permit the ionisation of the neutral flow. The ions are not magnetized and they are accelerated by the discharge voltage between the anode and the cathode to provide the thrust. This axial electric field is generated by the decrease of the electron mobility due to the radial magnetic field. They are neutralized in the plume by a fraction of the electrons ejected from the external cathode source.

SPT-20M

The SPT-20M7 Hall Effect Thruster he Electric Propulsion Department of the National Aerospace University "KhAI" Kharkov in Ukraine was manufactured at the middle part of 2007. The annular channel of the SPT-20 is constructed with two successive diameters. The outer diameter of channel on exit plan is 23 mm and the inner one is 15 mm. The magnetization coil is set behind the first chamber containing the anode-gas distributor. The maximum value of the radial magnetic field is obtained near the channel exit with a value of 20 mT (experimental data and modelling results). The SPT-20M7 thruster is a low power thruster running with an input electric power lower than 100 W, a Xenon mass flow rate of 0.1 - 0.35 mg/s injected in the chamber (the total mass flow rate is 0.48 mg/s) and a discharge voltage of 220-310 V between an anode and an external hollow cathode. The axial thrust is from 1 mN to 4.5 mN for an electric input power from 40 to 90 W. The efficiency is in the range 25% - 40% and the anode discharge current is in the range 0.15 - 0.4 A [1].

Energy deposition on the ceramics

The annular channel of the SPT is made of insulator ceramics, generally with BN-SiO2. The plasma-surface interactions play an important role in the discharge: electron energy deposition, secondary electron emission with sheath saturation effect, variation of the low frequency "breathing mode", discharge current and global efficiency. Morever, electrons and ions strike the inner and the outer ceramics, especially on the last mm of the channel where stands the acceleration zone of the ions and the lense of electric potential. Then, the surface can reach a maximum of temperature around 800°C and

the surface is eroded with a “normal” erosion effect and an ‘ab-normal” erosion effect (axial scores). During the first 1000 h of run the erosion velocity is around 1 E/h and after the value is smaller due to the decrease of angle between the surface wall and the velocity of the ions.

The electron energy distribution function is non-Maxwellian. Two or three populations are experimentally measured by electrostatic probes in the channel with a doubt on the existence of the third population. In fluid [2, 3] and hybrid [4] codes the electron distribution is assumed to be Maxwellian. The electron temperature reaches around 20 eV at the channel exit. As the channel is insulated the surface is at the floating potential. The existence of a potential sheath is taking into account. Then the electron energy flux at different points of the wall has been evaluated using the electron properties calculated by L.Garrigues [5]. However, the saturation sheath effect due to the secondary emission rate is not taken into account. This emission induces an increase of the electron energy deposition. The electronic impacts are suggested as a possible way to explain the “ab-normal” erosion.

The energy of the ions striking the walls depends of the location of the ionisation zone, of the lense of the electric potential, of the surface inclination and of the potential sheath. The ion velocity has been measured in the channel by Fluorescence Induced by Laser [6] and the energy flux deposition has been evaluated by IR measurement [6]. The assumption of a Bohm velocity is often assumed in literature [E.Ahedo] for 1D fluid model or 2D model with a Bohm layer.

Analysis of the insulated surfaces

The insulated surfaces of the SPT-20M7 have been analyzed by GSEM (Gaseous Scanning Electron Microscope) after one hundred hours of running. Chemical analysis has been carried on by EDX (Energy Dispersive X-ray) spectrometry in the CEMHTI laboratory (CNRS Orléans). Ceramics are constituted with boron nitride - aluminum nitride as major phase (BN-Al), and with an oxide phase containing boron and aluminum, as minor part. The ceramic reference microstructure is homogeneous and dense. A large microstructural change is observed in the channel, with regions exhibiting erosion or deposit phenomena.

At the top of the inner cylinder, microstructure study shows the presence of areas slightly enriched with metals by deposition: Fe, Si, Ni, Cu (< 1 at.%) extract from the chamber or from the electrodes. On the inner and outer surface of the channel, small grains are formed from columnar growth oriented toward the cylinder axis (surface enriched with metals: Fe, W, Ni, Cu (< 7 at.%) – Cr, Si (< 3 at.%)), and oxidized. Boron is not detected in this deposit, and nitrogen rate is much reduced. Finally, xenon is also analysed on the channel wall (less than 1 at.%).

Erosion involves a strong modification of the external ceramic at the channel exit, forming a bevel on the surface perpendicular to the cylinder axis. This area is also covered with oxidized grains enriched with metals similarly to the channel surface, but also enriched with silicon (< 20 at.%). The erosion of the inner ceramic is slight.The peripheral area of the bevel is slightly affected by erosion, with a strong decrease of B and N content, but no metal deposit has been observed in this area.

The ceramic surface facing to the channel bottom is strongly altered. Microstructure exhibits melting signs with large modifications of the microstructure and cracks formation. This area is enriched with B but metal rates are rather low.

Various metals (in particular Fe) are present on the channel surface, due to electrodes and metallic pieces erosion, vacuum chamber or partial vaporization. The nitrogen and especially boron contents are strongly reduced in the channel, in agreement with optical emission spectroscopic measurements [7].

Conclusions

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References

1. Loyan A.V., Performance investigation of SPT-20M low power Hall effect thruster 30th Int. Electric Propulsion Conf / A.V. Loyan, T.A. Maksymenko // IEPC 2007 16-20 September 2007. – Florence, Italy.

2. Effect of wall material in stationary plasma thrusters / S. Barral, K. Makowski, Z. Peradzynski, N. Gascon, M. Dudeck // Near-wall and in-all conductivity Physics of Plasma. – Vol. 10, n° 10, Oct. 2003. – P. 4127-4152.

3. Gascon N. Wall material effects in stationary plasma thruster I: Parametric studies of an SPT-10 / N. Gascon, M. Dudeck, S. Barral // Physics of Plasma, vol. 10, n° 10, Oct. 2003. – P. 4123-4136.

4.Garrigues L., Modélisation d’un propulseur a plasma stationnaire pour satellite / L.Garrigues //- Thesis in French, Université Paul Sabatier de Toulouse, 28 Oct. 1998. – Toulouse, France.

5. Mazouffre S. A calibrated infrared imaging study on the steady state thermal behaviour of Hall effect thrusters / S. Mazouffre, P. Echegut, M. Dudeck // Plasma Sources Sci. Technol. 16 (2007).

6.. Ahedo E. Fulfillment of the Bohm condition on the HPHall fluid-PIC code”// E. Ahedo & F. Parra // AIAA 2004-3955 (2004).

7. Pagnon D. Ukrainian SPT-20 Hall Effect Thruster: Analysis of the Plume by Optical Emission Spectroscopy / D. Pagnon, S. Pellerin, M. Dudeck, A.V. Loyan, T.A. Maksymenko, N.N. Koshelev // J. of Technical Physics. – 2008. – 49(2). – P. 129-142.

8. Loyan A.V. Analysis of the plasma plume of the SPT-20M low power Ukrainian Hall Effect Thruster / A.V. Loyan, N.N. Koshelev, T.A. Maksylmenko, S. Pellerin, A. Leufroy, T. Gibert, D. Pagnon, M. Dudeck // 3rd European Electric Propulsion Conf., Versailles, 6-9 July 2009.

9. Bouchoule A. Spectroscopic studies of XeI and XeII emission in UHF discharge / A. Bouchoule, T. Gibert, S. Mazouffre. – ICPIG, Einhoven, 2006.

10. Leufroy A., Micropropulsion et diagnostics pour la propulsion spatial / A. Leufroy // PHD thesis in French, university of Orléans, Feb. 15, 2010.

11. Leufroy A. Laser Induced Fluorescence (LIF) and Retarded Potential Analyser (RPA) measurements of XeII in the plume of small Ukrainian Hall Effect Thruster SPT20-M7 / A. Leufroy, T. Gibert, A. Bouchoule, A. Loyan, N. Koshelev, T. Maksymenko, M. Dudeck // 6th Int. Spacecraft Propulsion Conf., Space Propulsion2010, 3-6 May 2010,- San Sebastian, Spain.

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Рецензент: д-р техн. наук, проф. А.И. Оранский, Национальный аэрокосмический университет им. Н.Е. Жуковского "ХАИ", Харьков.

ЭНЕРГЕТИЧЕСКИЕ ВОЗДЕЙСТВИЯ И ПОВЕРХНОСНЫЙ АНАЛИЗ РАЗРЯДНОГО КАНАЛА ХОЛЛОВСКОГО ДВИГАТЕЛЯ СПД-М7

А.В. Лоян, Н.Н. Кошелев, Т.А. Максименко, Н. Пелерин, Е. Верон, С. Пелерин, Т. Жиберт, Л. Балика, Ф. Жафари, Дж. Лефевре, М. Дудек

Для анализа воздействия плазмы на стенки разрядного канала (РК) СПД была рассчитана энергия электронов, приходящаяся на разные точки керамики в границах разряда с учетом пристеночного потенциала, однако без учета вторичной электронной эмиссии. Описана энергия ионов приходящаяся на стенки РК. Поверхность РК СПД-20М («ХАИ») была проанализирована в CEMHTI (CNRS Орлеан) при помощи газового сканирующего электронного микроскопа и при помощи энергорассеивающей рентгеновской спектрометрии. Отмечены значительные изменения микроструктуры канала с эродироваными и запыленными участками.

Ключевые слова: плазма, холловский двигатель, поверхностный анализ.

ЕНЕРГЕТИЧНІ ВПЛИВИ ТА ПОВЕРХНЕВИЙ АНАЛІЗ РОЗРЯДНОГО КАНАЛУ ХОЛОВСКОГО ДВИГУНА СПД-М7

А.В. Лоян, М.М. Кошелєв, Т.О. Максименко, Н. Пелерін, Е. Верон, С. Пелерін, Т. Жиберт, Л. Баліка, Ф. Жафарі, Дж. Лефевре, М. Дудек

Для аналізу впливу плазми на стінки розрядного каналу (РК) СПД було розраховано енергію електронів, що приходиться різні точки кераміки в межах розряду з врахуванням пристінкового потенціалу, але без врахування вторинної електронної емісії. Описано енергію іонів що приходиться на стінки РК. Поверхня РК СПД-20М («ХАІ») була проаналізована у CEMHTI (CNRS Орлеан) за допомогою газового скануючого електронного мікроскопа та за допомогою енергорозсіювачої рентгенівської спектрометрії. Відмічено значні зміни мікроструктури каналу з еродованими та запиленими ділянками.

Ключові слова: плазма, холовський двигун, поверхневий аналіз.

Лоян Андрей Витальевич – канд. техн. наук, с.н.с. кафедры двигателей и энергоустановок Национального аэрокосмического университета им. Н.Е. Жуковского «ХАИ», Харьков, Украина, e-mail: a.loyan@khai.edu.

Кошелев Николай Николаевич – старший научный сотрудник кафедры двигателей и энергоустановок ЛА Национального аэрокосмического университета им. Н.Е. Жуковского «ХАИ», Харьков, Украина.

Максименко Тарас Александрович – н.с. кафедры двигателей и энергоустановок Национального аэрокосмического университета им. Н.Е. Жуковского «ХАИ», Харьков, Украина, e-mail: taras@d4.khai.edu.

Pellerin N. – Assistant Professor , CEMHTI laboratory, University of Orléans, 45071 Orléans, France.

Véron E. – Engineer, CEMHTI laboratory, University of Orléans, 45071 Orléans, France.

Pellerin Stephane – Professor, GREMI laboratory, University of Orléans, 45067 Orléans, France.

Gibert Titaina– Assistant Professor, GREMI laboratory, University of Orléans, 45067 Orléans, France.

Balika L. – Doctorant, GREMI laboratory, University of Orléans,45067 Orléans, France.

Gafari F. – studient for DES, Institut Jean Le Rond d'Alembert, University of Paris, 75252 Paris, France

Lefevre J-B. – studient for Master, University of Paris, 75252 Paris, France.

Dudeck Michel – professor, Institut Jean Le Rond d'Alembert, University of Paris, 75252 Paris, France.