Investigation of the Boron Nitride based Ceramics Sputtering Yield Under it's Bombardment by Xe and Kr ions*+

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Results of the ceramics sputtering yield under its bombardment by Xe and Kr ions are represented in a paper.
To realize this study there was used the special test facility and methodology.
The sputtering yield under normal impingement of ions with target surface was determined within the range of mean ion energies $\varepsilon_i \approx (100\text{-}400)$eV. There was determined also the dependence of sputtering yield on the ions incident angle at the target surface. Obtained results show that dependences of sputtering yield on ion energies and incident angle are similar for the Xe and Kr ions but the sputtering yield under target bombardment by Kr ions is by (30-50)% lower than under bombardment by Xe ions.

Introduction

In connection with possibility to use Krypton (Kr) in SPT-based propulsion system (PS) [1] it is interesting to study the ceramics sputtering yield under its bombardment by Kr ions. To compare Kr data with Xe case all experiments were made with usage of the same test facility, accelerated ion source, measuring instrumentation and methodology. Such study was made at RIAME MAI within the frames of the INTAS 99-01225 project and under support of the Russian Basic Research Fund (project No 00-15-99025). Obtained results are represented below.

1. Methodology of investigation

As it is known to manufacture the discharge chamber of the modern Russian *SPT's* there is used the so-called borosil (or BGP) ceramics consisting of the following main components: *BN and* SiO_2. The possibility to use this material in SPT design was verified by many tests of this material in a different thruster designs and operation conditions. And this material is the candidate for usage in SPT, operating with other than *Xe* gases. Taking into account the necessity to ensure large SPT lifetime it is important also to obtain the mentioned ceramics sputtering yield data under its bombardment by ions of alternative gases. One of possible alternative propellants is Krypton [1]. Therefore there was made the comparative study of borosil ceramics sputtering by Kr and Xe ions.

To realize the sputtering yield determination there was used the test facility consisting of a vacuum chamber with diameter *~0,8m* and *~l,5m* in length pumped out by diffusion pumps equipped by liquid nitrogen traps. Before test starting the pressure inside the vacuum chamber was typically at the level of $(6\text{-}7)\cdot 10^{-6}$ *Torr* by air and did not exceed the value $1\cdot 10^{-}$

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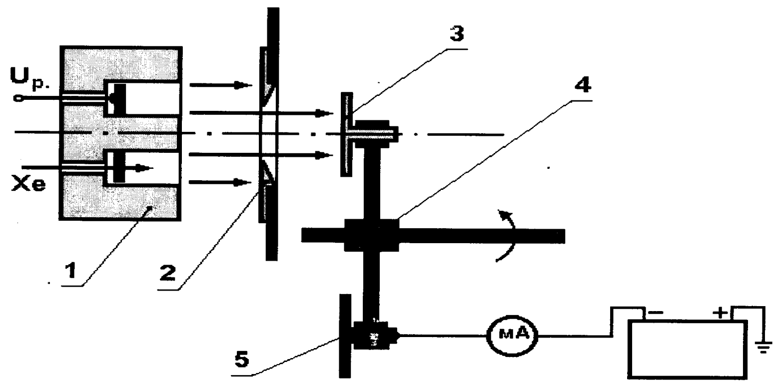
^{4} *Torr* during the test.

Inside the vacuum chamber there was positioned an experimental unit (Fig. 1) consisting of a plasma source 1 generating the accelerated ion flow. The ceramics target 3 was positioned on the rotating holder *(*see Fig. 1) behind diaphragm 2 collimating the ion beam getting a target. To measure an ion



1. Plasma unit
2. Diaphragm
3. Borosil sample
4. Rotating holder
5. Ion probe

Figure 1 - Experimental unit.

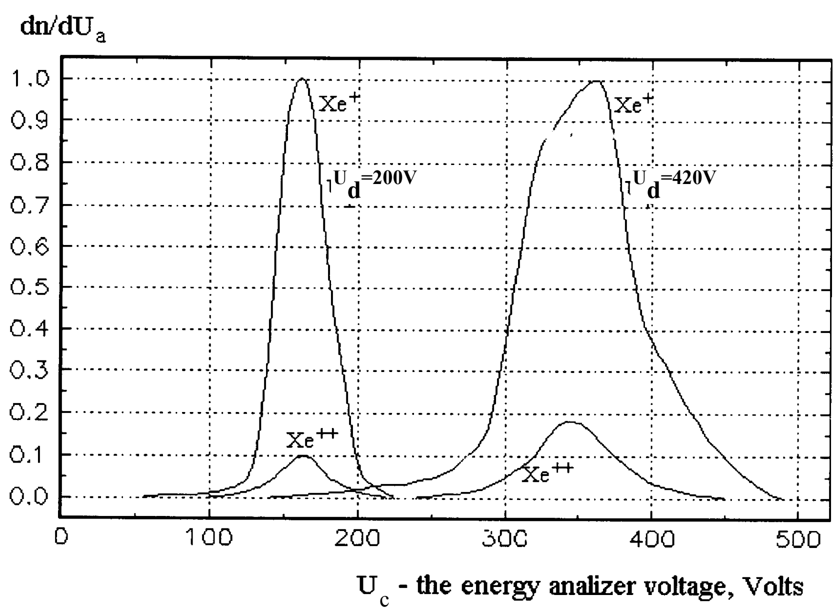


Figure 2 - The energy spectrum of ion flow.

current getting the target surface there was used an ion probe 5. It was possible to use several targets *(till 5)* and to test them during one experiment, positioning them in turn via diaphragm 2 by rotation of target holder.

As an plasma source there was used the *SPT-35* model able to provide ions with energies within the range *(100-400) eV* and ion current density $j_i=(15\text{-}30)mA/cm^2$ at target surface.

The accelerated ion flow exhausting SPT consist of not only single charged ions but also doubly charged ions at least (Fig. 2) and wide enough their distribution in energies.

For this source the mean ion energy ε_i was by (40..50)eV lower than eU_d under variation of U_d (see Fig. 2), where U_d is the discharge voltage. So, varying U_d it was possible to vary ε_i. The fraction of doubly charged ions under discharge voltage $U_d \approx 200V$ was *~11%* and ~15% under $U_d=400V$ in a Xe case. Now it is difficult to devide impact of multiple ions on the sputtering yield. But for relatively narrow range of energies till several hundred *eV* the sputtering yield dependence is close to linear one. Therefore it is possible to assume that impact of one doubly charged ion is equivalent to impact of two single charge ions. It is difficult also to devide impact of low energy and high energy ions. But again taking into account almost linear character of sputtering yield dependence it is supposed that mean ion energy could characterize the resulting sputtering yield. So, SPT is not the best instrument for the sputtering yield determination. But it has one significant advantage: the accelerated ion flow parameters in its plume are similar to that ones for other SPT's. Therefore results obtained with such accelerated flow could be directly used for estimation of the sputtering intensity in other SPT's.

Analysis and experimental data show also that sputtering yield depend on target surface coverage by adsorbed atoms. The equilibrium surface coverage depend on ion current density and pressure inside the vacuum chamber during the sputtering test. For the typical test conditions to eliminate the adsorbed atoms impact on sputtering yield it is necessary to have ion current density at target surface $j_i>10mA/cm^2$ (Fig. 3). This conclusion is valid for the *"pure"* enough vacuum conditions. For the described above test facility the vacuum *"purity"* was ensured by usage of traps cooled by liquid air or nitrogen and located between pumps and vacuum chambers.

Mass spectrum analysis of background atmosphere inside the vacuum chamber confirms that under trap temperature $T<130K$ there are significantly less value of impurities with high molecular weight produced by diffusion pumps.

Before tests the ceramics samples were exposed to atmosphere at least during one day and weighed. Then they were mounted on a holder, positioned inside the vacuum chamber. After the vacuum chamber pumping out the plasma source of SPT type was switched on and the ion current was measured to check a source operation mode and current value. Then targets were positioned in turn via diaphragm and exposed to the ion beam for definite time (around 1 hour). Before replacing of target the ion current was measured again. After sputtering of all targets mounted on the holder the test was stopped, vacuum chamber was opened and targets were weighed several times during *1-3 days,* because due to the air absorption their weight was changed. When this change becomes small enough the final weight was fixed and difference between initial sample weight and the final one was fixed as sample sputtered mass. The mentioned sample mass reduction Δm was devided by the charge Q_K coupled by sample surface during the test number *"K"*. Q_K value is determined by the evident expression

$$Q_K=J_i \cdot \tau_K,$$

where J_i is the ion current value to target surface during the test,

τ_K- duration of the given sample exposition to the ion beam in a *K-th* test.

This procedure allows determination of the sputtering yield

$$S_{mK} = \frac{\Delta m_K}{Q_K} \left(\frac{mg}{Coulomb}\right)$$

The S_m value depends on total charge Q coupled by target:

$$Q = \sum Q_K$$

It is necessary to note that there is layer of material at the target surface disturbed by mechanical processing at least. Then there is change of the surface microgeometry and component content in a sample surface layer in time. Therefore it is necessary to determine S_m values for the great enough Q values. And such determination was done.

2. Results of borosil sputtering yield study under its bombardment by Xe and Kr ions

Obtained results show that under normal ions impingement with target surface the sputtering yield S_m is decreased approximately by an order of magnitude with increase of Q magnitude (Fig. 4) and it is stabilized at Q values ~200 Coulomb/cm^2. Under current density J_i≈20mA/cm^2 such charge could be coupled by surface in ~10^4 seconds that is in a ~3 hours. Surely, the sputtering yield depend on material type (see BGP and BGP-10 data in Fig. 4),

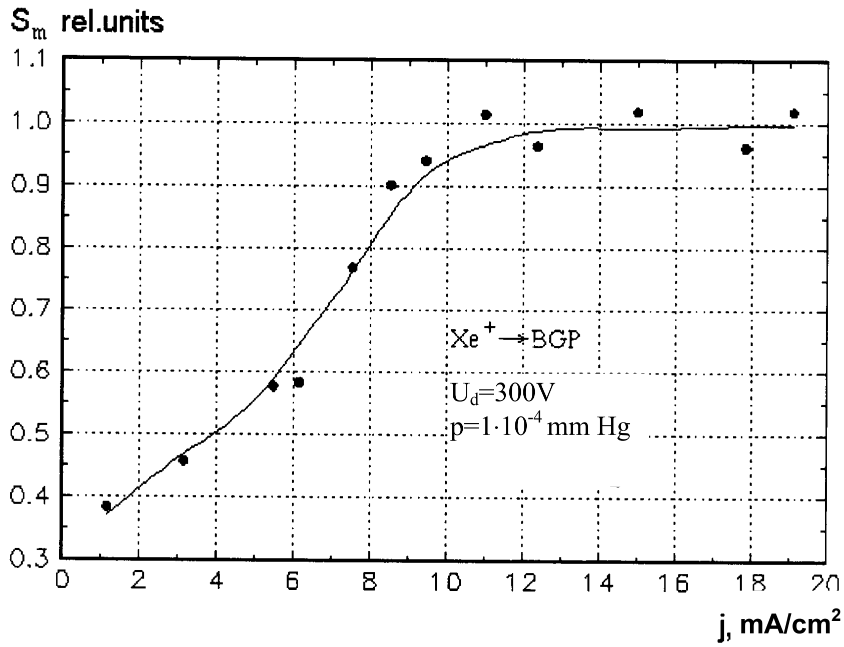


Figure 3 - The sputtering yield dependence on ion current density.

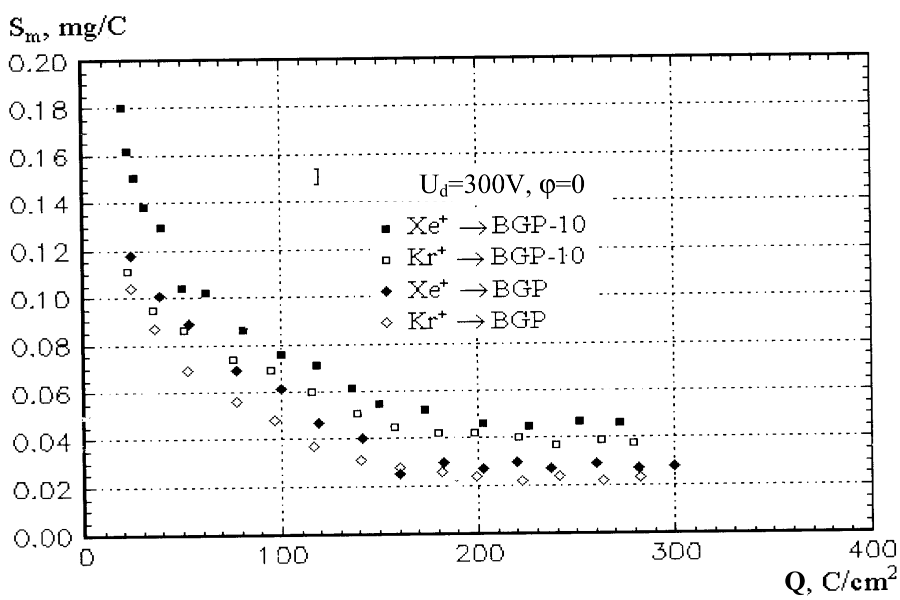


Figure 4 - The sputtering yield dependence on the type ion charge Q.

on ion energy (Fig. 5) and type of ions (see Fig. 4, Fig. 5).

According to obtained data the sputtering yield under ceramics surface bombardment by Kr ions is by (30-50)% lower than in Xe ion case. At the same time the angular sputtering yield distributions are very close for Kr and Xe cases (Fig. 6).

From applied point of view it is important that the lower ceramics sputtering yield simplifies solution of problem of large SPT life time ensurance in Kr case, which is more complicated than for Xe case due to necessity to operate under higher power densities in this case [1].

Conclusion

Obtained results give chance to simplify the problem of large SPT life time ensurance what is significantly more complicated in a Kr case.

Reference

[1] V. Kim et al. Investigation of SPT performance and operation particularities with Kr an Kr/Xe mixtures – paper IEPC 01-65.

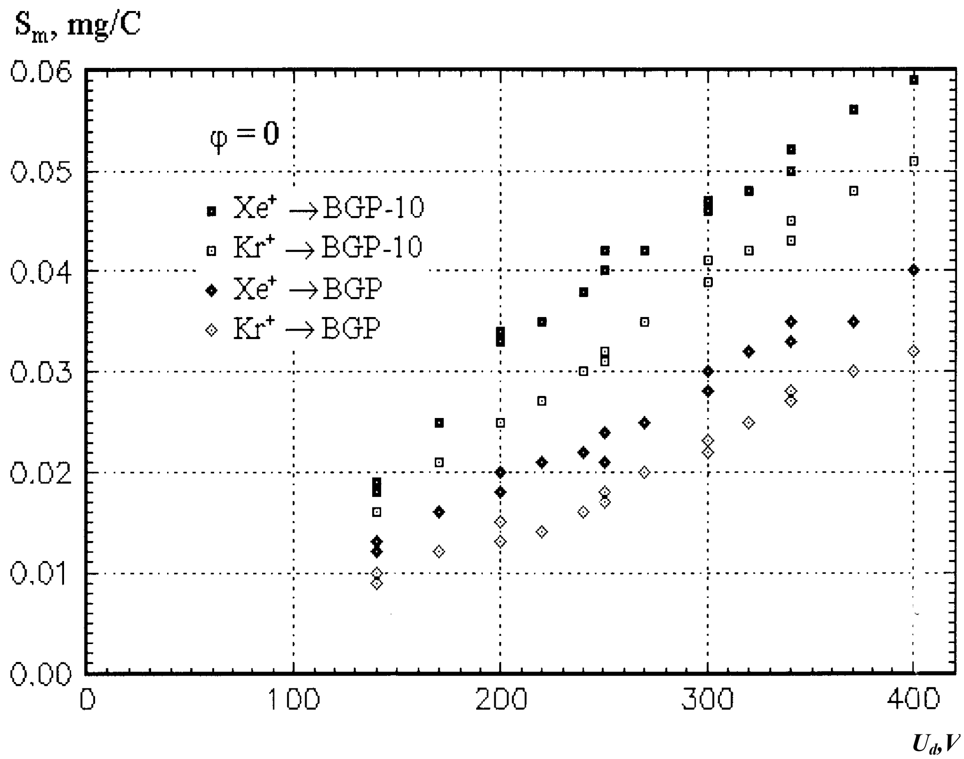


Figure 5 - The sputtering yield dependence on discharge voltages (ion energy).

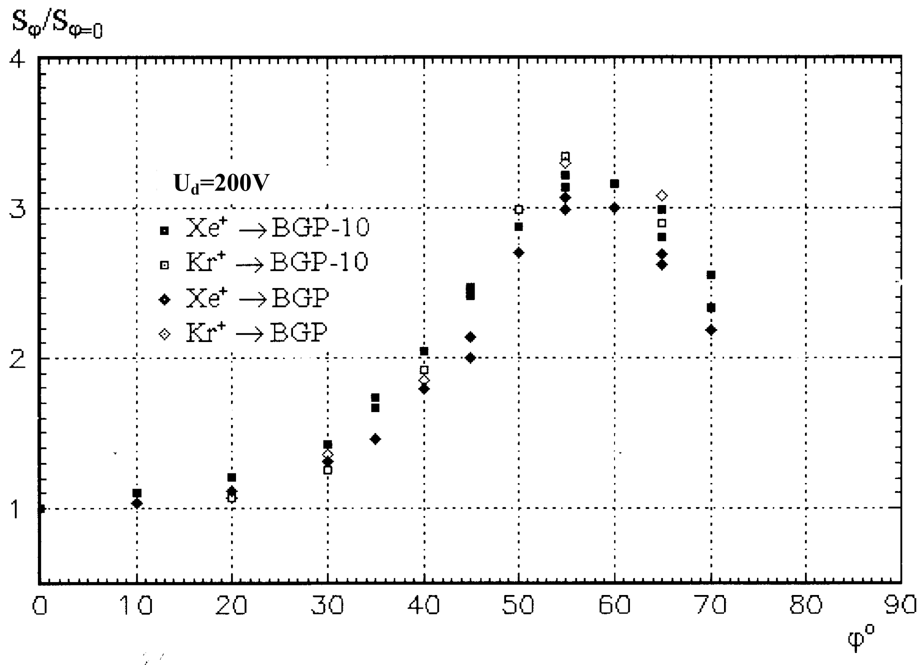


Figure 6 - The sputtering yield dependence on the incident angle.