# Thruster Relevant Material Sputter Investigations

H. Neumann, R. Feder, C. Bundesmann

## Abstract

Sputtering is an important process in the application of electric propulsion devices. For instance, the extraction grids of gridded ion thrusters are subject to grid erosion by charge-exchange ions, which works towards an increase of the accelerator grid hole diameter and limits the thruster lifetime, or the acceleration channel walls of Hall Effect ion thrusters are suffering from strong erosion by ions from the discharge plasma itself.

One of the challenges facing further application of electric thrusters for space missions is the establishment of valid lifetime predictions. For the modelling, reliable sputter yield data are required, which, however, are often not available in the required energy and angular dependency for the ion-material combination under consideration. Especially sources of errors in sputter yield measurements like the influence of the background pressure, the roughness of the starting surface and the role of knowledge of the primary ion beam properties will be discussed in this short paper. Beside this an idea to surface modification of Titanium is given and assessed. Measurement strategy for isolating material like BN is short outlined and preliminary data are announced. More complete descriptions for metals and isolator sputter yield measurements of the Leibniz-Institut für Oberflächenmodifizierung (IOM) group are given in special papers [1, 2, 3].

## Keywords

sputtering; electric propulsion; Xenon low energy sputtering; titanium; carbon-carbon; BN; gridded ion thruster; Hall effect thruster; silver connectors; low energy broad beam ion sources

## 1. Introduction

Lifetime prediction for electric propulsion thruster is a primary requirement for its application in space missions. Ambitious missions increase the thruster requirements for total impulse and lifetime. Because of the tremendous duration and costs of a complete life-test it is essential to support the development and qualification by a validated simulation. Realistic lifetime estimates are of a high importance. Beside an intelligent modeling strategy [4] for life time calculation sputter data at the required energy range as well as for the incidence angle range of 0…90° for the materials of interest under Xenon bombardment are the basis for such predictions. The obtained sputter characteristics allow assessing the applicability of current and prospective new materials. Furthermore, on the basis of these data, simulation can predict reliable lifetime values if it is validated with measurements in former lifetime experiments on thrusters.

## 2. Experimental Setup

The sputter experiments were performed in a dedicated UHV-chamber (see Figure 1). The background pressure was about $2\times10^{-8}$ mbar and with the sputter ion source in operation $1\times10^{-5}$ mbar. During the sputtering process the residual gas composition was permanently controlled. Oxygen partial pressure was about six orders of magnitude lower than that of the ion source working gas Xenon. Under such conditions, additional chemical etching (particularly important for carbon materials) does practically not occur. Figure 2 shows a typical mass spectrum of the chamber working pressure conditions.

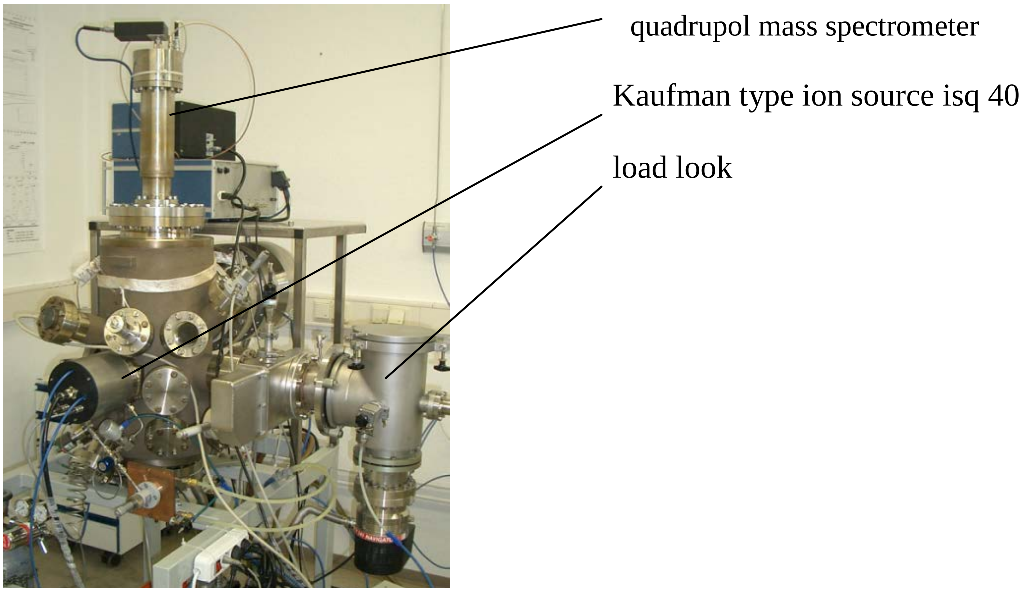


**Figure 1 – Sputter Test Facility of IOM**

The quasi-monoenergetic low-divergence xenon ion beam was produced by a 4 cm in house developed ion source ISQ 40 of Kaufman type. In the DC-discharge ions were generated inside an alumina discharge chamber fitted with a collimating graphite three grid system. Ion energy is adjustable between 20 and 2000 eV with an energy distribution width (FWHM) less than 10 eV. An ion beam density up to 2 mA/cm$^2$ can be produced. Figure 3 shows a picture of the ion source and three different energy spectra of the generated $Xe^+$ measured by an energy selective mass spectrometer HIDEN EQP 300.

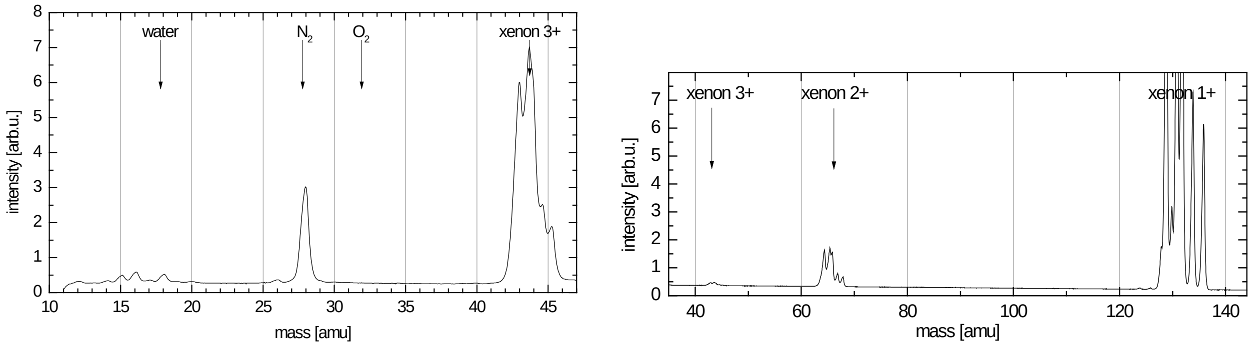


**Figure 2 - Typical mass spectrum of working conditions inside the sputter chamber. Oxygen partial pressure is lower than 6 orders of magnitude in comparison with the Xenon partial pressure**

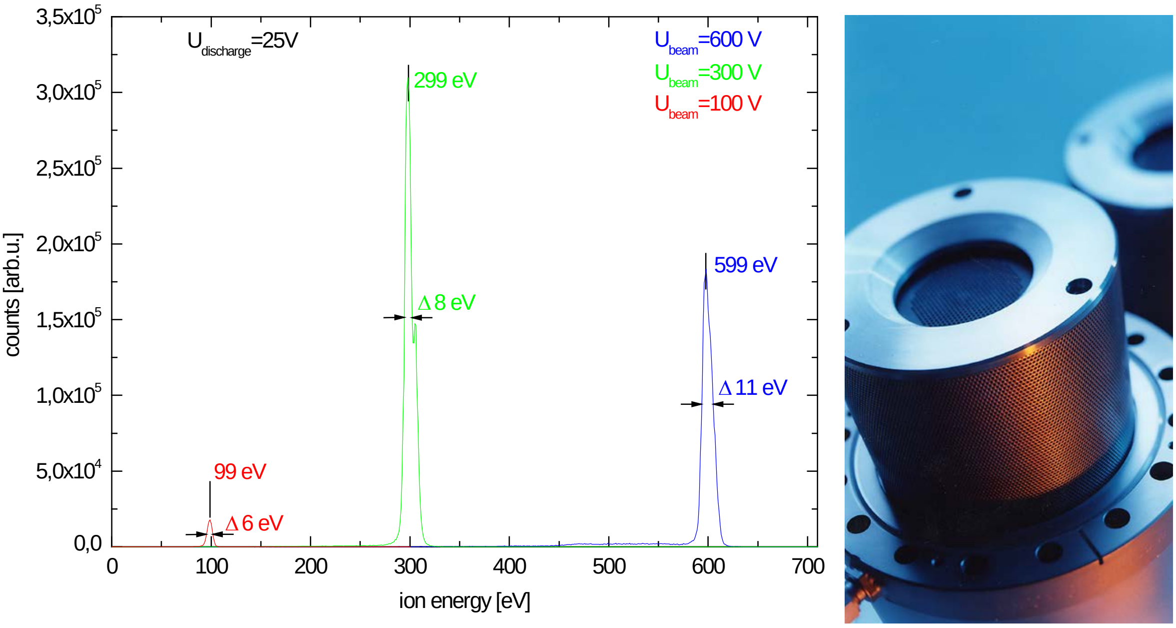


**Figure 3 - Energy spectra at different ion energies and a photo of the isq 40**

The sputter ion current density distribution is measured using two different methods: Faraday probe mappings over the beam diameter and sputter foot print measurements on a silicon wafer. A comparison of both showed a good compliance of the results. Half angle divergences of about 3° at 90 % of the density distribution at 500 eV and maximum densities of 2.5 mA/cm$^2$ are examples, this characterization was performed before etch sputter measurement.

The sputter targets (ca. 15×15 mm$^2$) were placed at a distance of 13 cm from the grids in the beam centre under various incidence angles in respect to the ion beam axis [2]. The target current was measured directly, integrated over the whole sputter time and corrected with the charge exchange loss by calculation with help of the well known cross sections. For the weight loss measurement of the samples while the sputtering time a high-precision microbalance with a resolution better than 10 µg is used. Target temperature is controlled during the sputter experiment too. Surface topography of the samples is investigated ex situ with help of REM measurements.

## 3. Experimental Results

In case of conductive monoatomic materials, sputter yield is calculated in (removed) atoms/(incident) ion. The charge exchange lost on the way of the ions from grid to the target is taken into account by using the charge exchange cross section of the sputter gas ions, the distance and the neutral gas pressure. The sticking of sputter gas ions are neglected by irradiation of target samples some 10 minutes in advance of yield measurement procedure.

For isolating compound materials like BN, the number of energetic particles is given by a pilot investigation of sputter yield on well known conducting material (mostly silver) at the same conditions and the sputter rate is given in $mm^3$/Coulomb because of the multicomponent targets and the preferential sputtering effect.

All results are compared with semi empirical formulae's of Bodansky (energy dependency) and Yamamura (angular dependency) [6, 7].

In our experience most important sources of errors in sputter yield measurements are the primary ion beam properties and the background pressure composition described in the experimental setup chapter of this paper, the target preparation before and after the experiments and the influence of its surface roughness.

An example for the influence of the surface roughness is given in the case of CC-material. The roughness is changing in the sputter process at which after a sputter time of some hours equilibrium is reached and the sputter yield becomes independent from the starting surface (see Figure 4). This surface development is taken into account for sputter yield measurements.

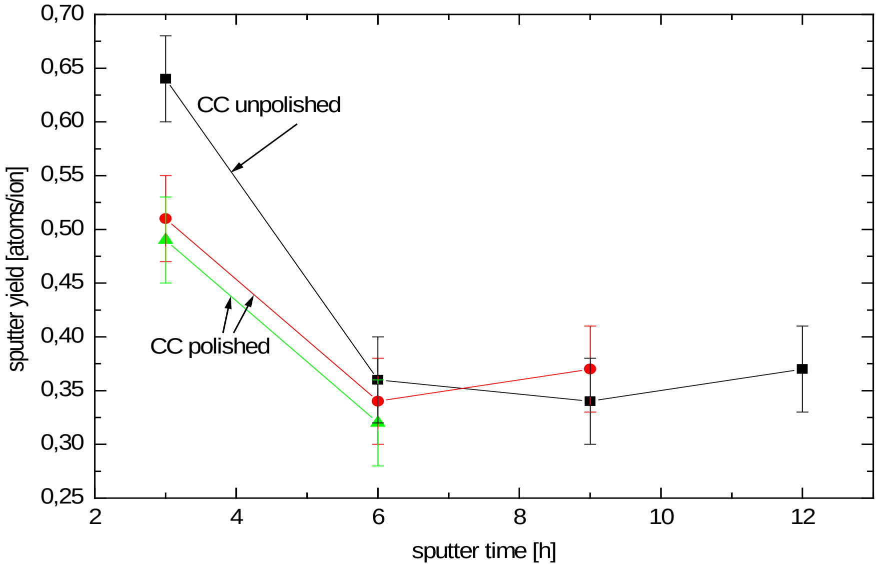


**Figure 4 - Time Dependent Sputter Yield of CC with Different Starting Roughness**

In Figure 5 preliminary sputter yields for BN at different energies under normal incidence angle Xenon bombardment are given in comparison to data from literature.

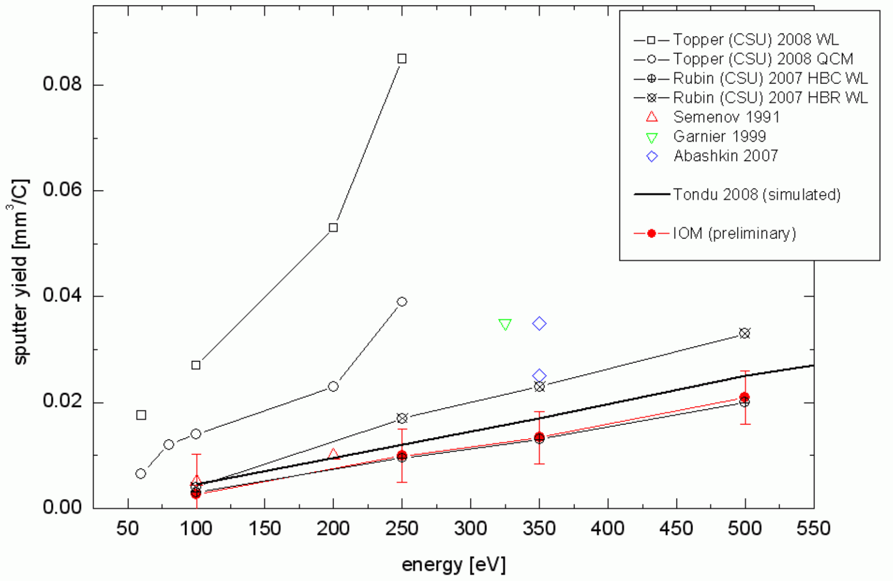


**Figure 5 - Sputter yield of BN in dependence on the Xenon-ion energy in comparison with results from literature**

In a further example (Figure 6) the influence of nitrogen surface preparation with two different methods on the titanium sputter yield evolution is demonstrated. Both methods - Plasma Imersion Ion Implatation PIII and plasma nitriding – are well known processes from surface modification of different materials for changing some of there properties [5]. A decreasing of the sputter yield of about 25 % inside the nitrided layer in dependence on the nitrogen content of the layer could be demonstrated. This effect illustrates new possibilities for grid preparation in gridded thruster technologies.

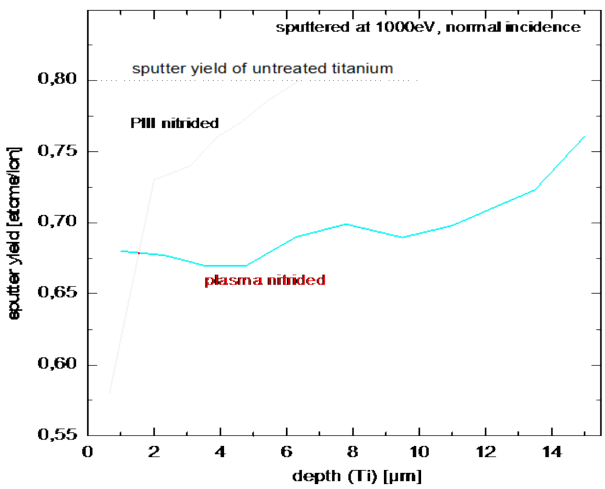


**Figure 6 – Xenon sputter yield of Titanium in dependence on the nitridation process and nitrogen depth, PIII-process at 700 °C for 30 minutes, plasma Nitriding at 900 °C for 6 hours**

In some cases, the s/c solar arrays are undesired hit by ions from electrical thrusters. This effect attacks especially silver interconnectors of these arrays. Therefore, the knowledge of the Xenon-sputter behaviour of silver is essentially for the life time calculation of the solar generators. Figure 7 and Figure 8 give a complete overview of the silver sputter yield under Xenon-bombardment.

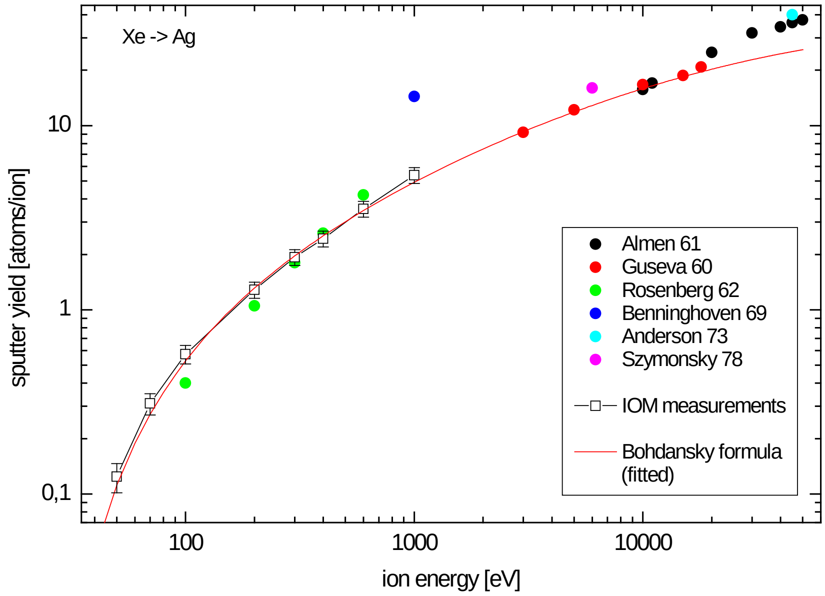


**Figure 7 - Energy dependence of silver sputter yield with Xe-ions and comparison with data from literature and semi empirical simulations with the Bohdansky formula**

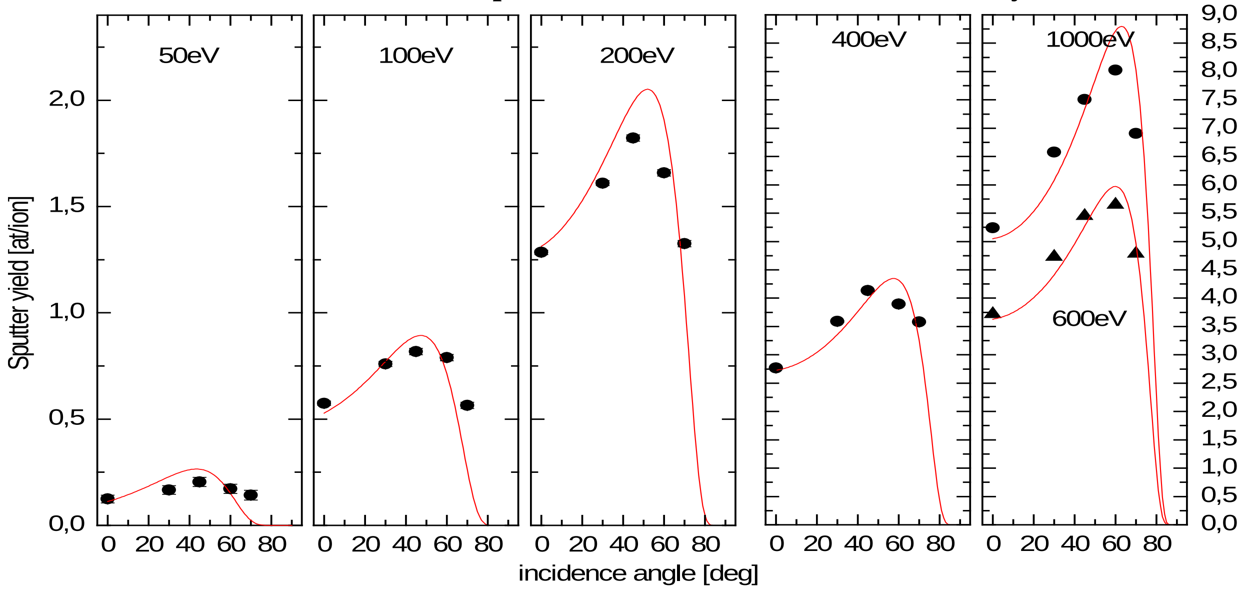


**Figure 8 - Energy and angular dependence of silver sputter yield with Xenon-ions in comparison with calculation with help of the semi empirical Yamamura formula**

## 4. Conclusions and Outlook

We have investigated the sputter behavior of electric thruster relevant materials by Xenon-ion bombardment. Some examples for sources of errors as well as some measured data are given in the paper. It should be proposed, that in special material combinations for electric thruster and/or s/c applications the sputter yield of the material/ion combination is to be measure in excellent characterized equipment under consideration of the experience described before.

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