

# Design Improvements and Experimental Measurements of BURFIT-80 RF Ion Thruster

Ugur Kokal\*, Nazli Turan†, Murat Celik‡

*Bogazici University, Istanbul, 34342, Turkey*

Huseyin Kurt §

*Istanbul Medeniyet University, Istanbul, 34700, Turkey*

BURFIT-80, a prototype radio-frequency ion thruster, is designed, built and tested at the Bogazici University Space Technologies Laboratory. This paper presents the design parameters and numerous design improvements of this thruster. Three different versions of the thruster, with the same discharge chamber inner diameter of 80 mm, have been built and tested. The latest version of this prototype thruster presents significant improvements of the DC electrical connections to the grids and RF electrical connections to the RF antenna. For the second version of the thruster, plume ion energy distribution measurements are conducted using an indigenously developed retarding potential analyzer, and some of the measurement results are presented.

## I. Introduction

Among the various types of plasma thrusters developed over the last few decades, Hall effect thrusters and ion engines are the most studied ones. These two types of plasma thrusters have also been deployed as a test-bed or for actual use in various satellites and spacecraft. In ion engines, the propellant (neutral gas) is first ionized by being stripped off an electron, and the generated plasma ions are then ejected out of the thruster at high velocities, using the high electric field created between a pair of grids, to create the desired

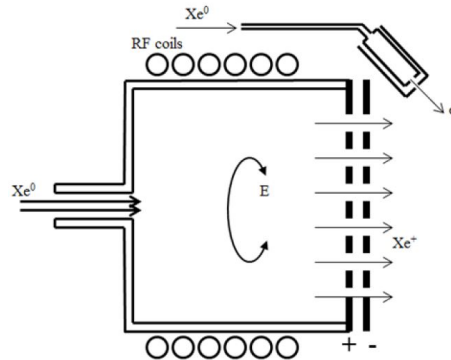


Figure 1. Schematic of an RF ion thruster<sup>1</sup>

thrust. Based on the ionization mechanism inside the ionization chamber, the ion thrusters are categorized as the electron-bombardment (Kaufman type) ion engines, RF (radio-frequency) ion engines, or microwave (electron-cyclotron resonance (ECR)) ion engines. Although today the ion thruster research is conducted in many different countries, historically electron-bombardment ion engines are developed in the United States,

\*M.S. Student, Department of Mechanical Engineering, ugurkokal@boun.edu.tr

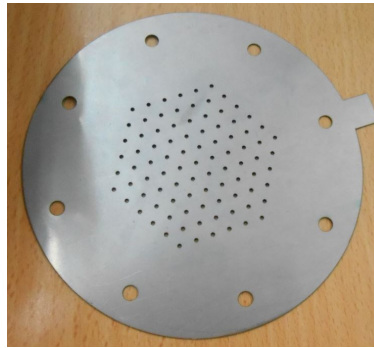
†M.S. Student, Department of Mechanical Engineering, nazli.turan@boun.edu.tr

‡Assoc. Prof., Department of Mechanical Engineering, murat.celik@boun.edu.tr

§Assoc. Prof., Department of Engineering Physics, kurtphys@gmail.com

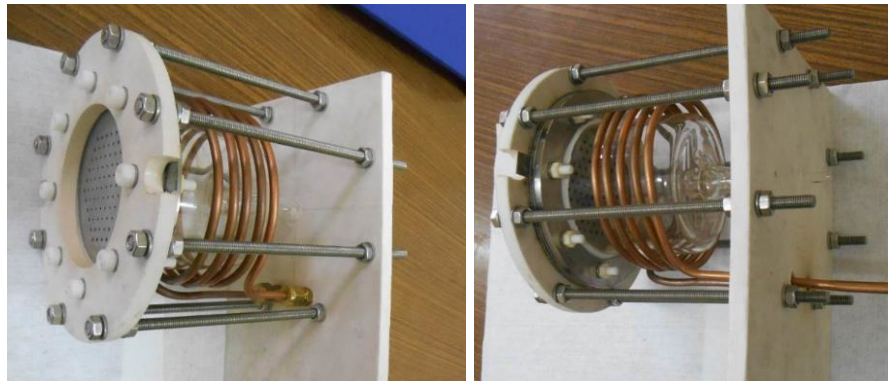
radio-frequency ion engines are developed in Germany, and the micro-wave ion engines are developed in Japan.

In a radio frequency (RF) ion engine, which is also known as RF ion thruster, the ionization is provided by the energy carried by the RF waves into the discharge chamber. A simplified schematic of an RF ion thruster is shown in Figure 1. The RF ion thrusters are first studied in the 1960s at Giessen University in Germany.<sup>2</sup> Later, Astrium GmbH, a private German company, has adopted this development and managed to build thrusters which were used in space missions. One of the advanced products of these early efforts was RIT-10, an RF ion thruster with discharge diameter of 10 *cm*. RIT-10 is space tested in 1992 on the EURECA carrier. RIT-10 was incorporated into the European ARTEMIS satellite, which was sent to space for geostationary communication purposes. RIT-10 is lifetime tested for 15000 hours in 2000. The commercially available RIT-10 package is also called as RITA.<sup>3</sup> After the development of the RIT-10 ion thruster, German Space Agency (DARA) has started a project in 1995 for RIT-15, which has a 15 *cm* chamber diameter and a planned specific impulse of more than 4000 seconds at 50 *mN* of thrust.<sup>2</sup> This level of thrust enables the application of such a thruster on larger satellites and space platforms.



**Figure 2. Molybdenum grid for the first version of the prototype RF ion thruster**

Research on the miniaturization of RF ion thrusters are conducted in the late 2000s. Astrium GmbH and their partners in the academia developed RIT-X, which is built for micropropulsion applications.<sup>4</sup> In addition to the miniaturization effort, studies in building high power RF ion thrusters for deep space applications have been carried out. Researchers from Giessen University and Moscow Aviation Institute designed a very large ion thruster, RIT-45, which had a discharge chamber diameter of 46.5 *cm*.<sup>5</sup> RIT-45 thruster designed to operate at a power level of 35 *kW* and is expected to provide a specific impulse of 7000 *s*.<sup>5</sup>

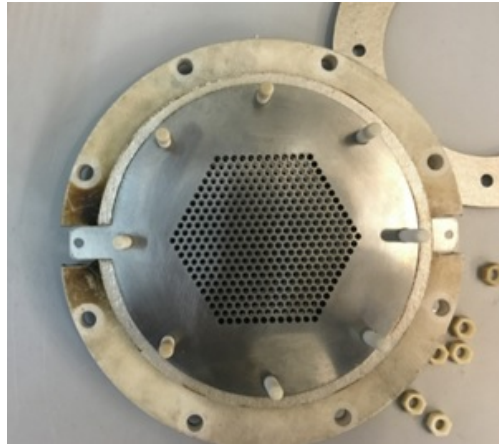


**Figure 3. First version of the prototype RF ion thruster**

## II. RF Ion Thruster Development at BUSTLab

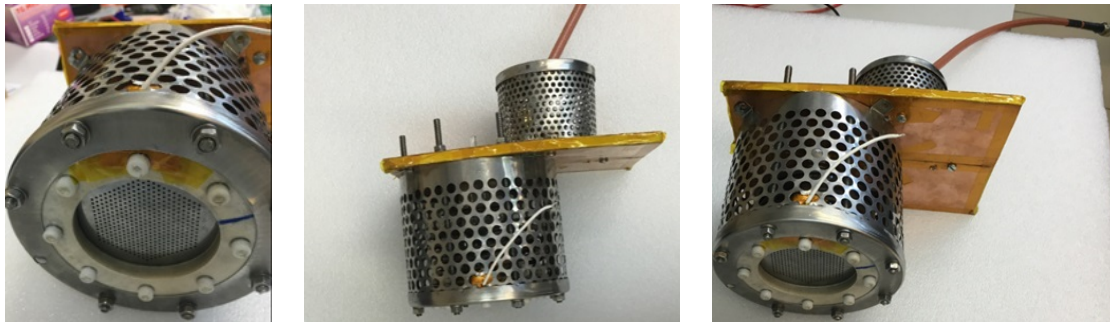
At the Bogazici University Space Technologies Laboratory (BUSTLab), several prototype RF ion thrusters have been designed, built and tested. The very first prototype ion engine had a cylindrical discharge chamber

of 80mm in diameter and 70mm in length. This ion thruster utilizes two parallel flat grids. For the first version of thruster, grids with 91 holes, packed in a hexagonal shape, are manufactured of molybdenum sheet of 0.5mm thickness using laser micromachining. A picture of one of the produced grids is seen in Figure 2. The diameter of the screen grid holes are 2.2 mm, and the diameter of the accelerator grid holes are 1.2 mm. A 1 mm thick dielectric insulation plate that is made of macor is used to separate the grids. ICP plasma is generated inside a Pyrex discharge chamber with a radio-frequency antenna that is wrapped around the chamber. The antenna is made of 4 mm diameter copper tube. The discharge chamber is 80 mm in diameter and 70 mm in length. A Pyrex diffuser, is placed inside the discharge chamber, provides propellant gas into the chamber. Grid structure is assembled with Zirconia ceramic screws and a Teflon outer cover. The entire structure is attached to a Teflon backplate. During the tests 13.56 MHz RF power is carried to the RF antenna through RG393 coaxial cables. Pictures of the first version of the prototype RF ion thruster are shown in Figure 3.



**Figure 4. Molybdenum grid for the second version of the prototype RF ion thruster**

In the second version of the thruster, molybdenum grids with 397 extraction holes have been used. A dielectric insulation plate that is made of micanite is used to separate the grids. The entire structure is attached to an aluminum backplate. A perforated shroud that is made of 304 grade stainless steel is used to cover the thruster body to prevent the radio wave leakage. The entire structure is attached to a Teflon backplate covered with copper sheet. Pictures of this second design are shown in Figure 5.



**Figure 5. Second version of the prototype RF ion thruster**

The tests of the prototype ion thrusters are conducted inside the BUSTLab vacuum chamber, which is 1.5 m in diameter and 2.7 m in length.<sup>6</sup> During the tests, the pressure inside the vacuum chamber is kept at  $5 \times 10^{-5}$  torr. Argon propellant is used. Pictures from the tests of the first and second versions of the thruster are shown in Figure 6.

An indigenously built retarding potential analyzer (RPA) probe is used to measure the ion energy distribution in the near plume region of the second version of the prototype RF ion thruster. A picture of the BURFIT-80 RF ion thruster in operation with the RPA in its plume is shown in Figure 7.

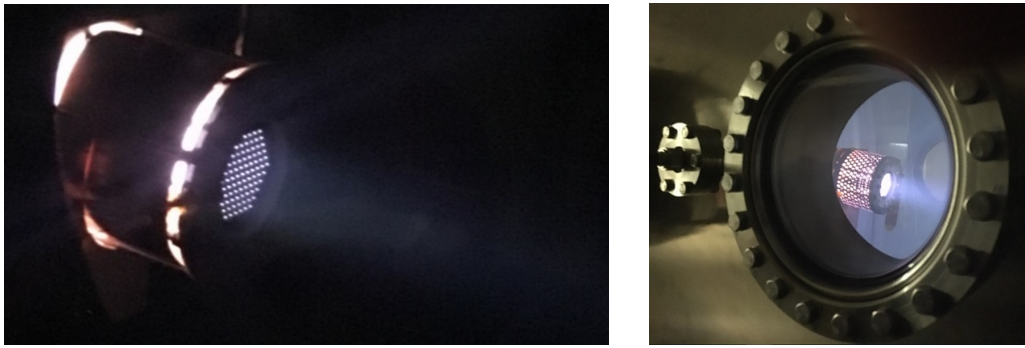


Figure 6. First version of the prototype RF ion thruster (left) and second version of the prototype RF ion thruster (right) in operation inside the BUSTlab vacuum chamber

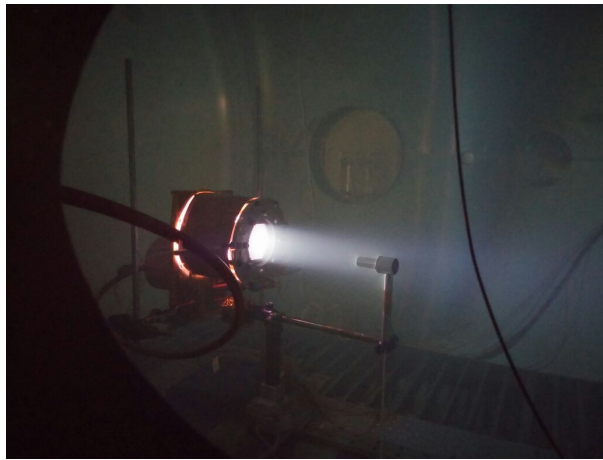


Figure 7. Second version of the prototype RF ion thruster during RPA measurements inside BUSTLab vacuum chamber

For a propellant mass flow rate of 15 *sccm* Argon, and for a screen grid potential of 400 *V* and acceleration grid potential of 0 *V*, the I-V curve measured by the RPA and the corresponding non-normalized ion energy distribution are shown in Figure 8.

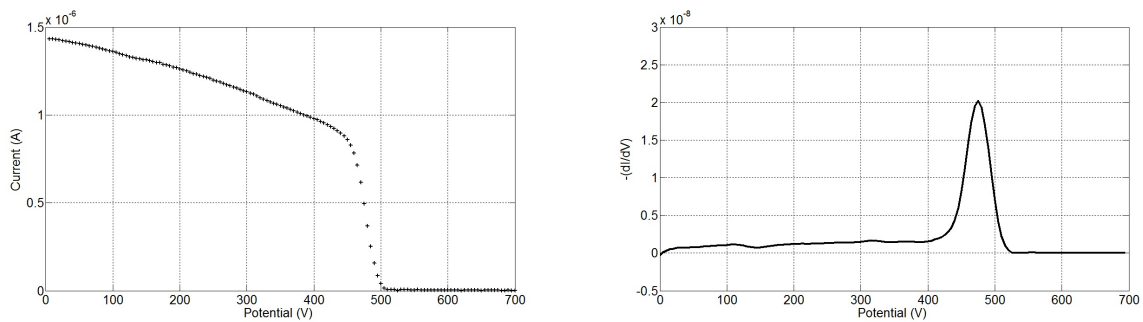


Figure 8. Measured I-V curve (left) and corresponding ion energy distribution (right)

In a separate set of measurements, the RPA probe is placed on a translation stage, and the probe measurements have been conducted by sweeping the angular location of the probe at a constant distance of 200 *mm* from the center of the thruster. The RPA ion energy distribution function measurements for angles of 0, 5, 10, 15 and 20 degrees are shown in Figure 9.

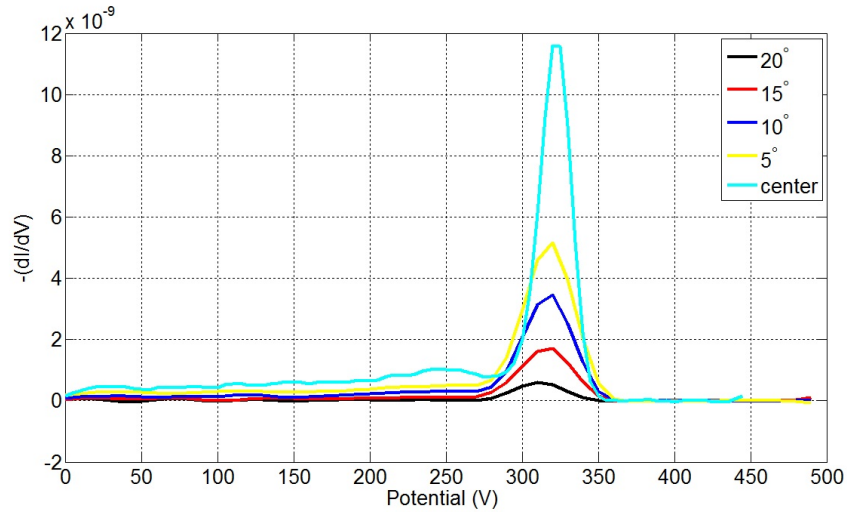


Figure 9. Measured ion energy distribution at different angles

### III. Advanced RF Ion Thruster Design

During the tests of the first and second versions of the prototype thruster, some problems are observed; such as the arcing problems at the grid connections. Therefore a new and more advanced RF ion thruster is designed and built, and further tests have been conducted. A 3-D technical drawing of the latest design is shown in Figure 10. In this design, each grid is attached to a metal ring. DC voltages are applied to

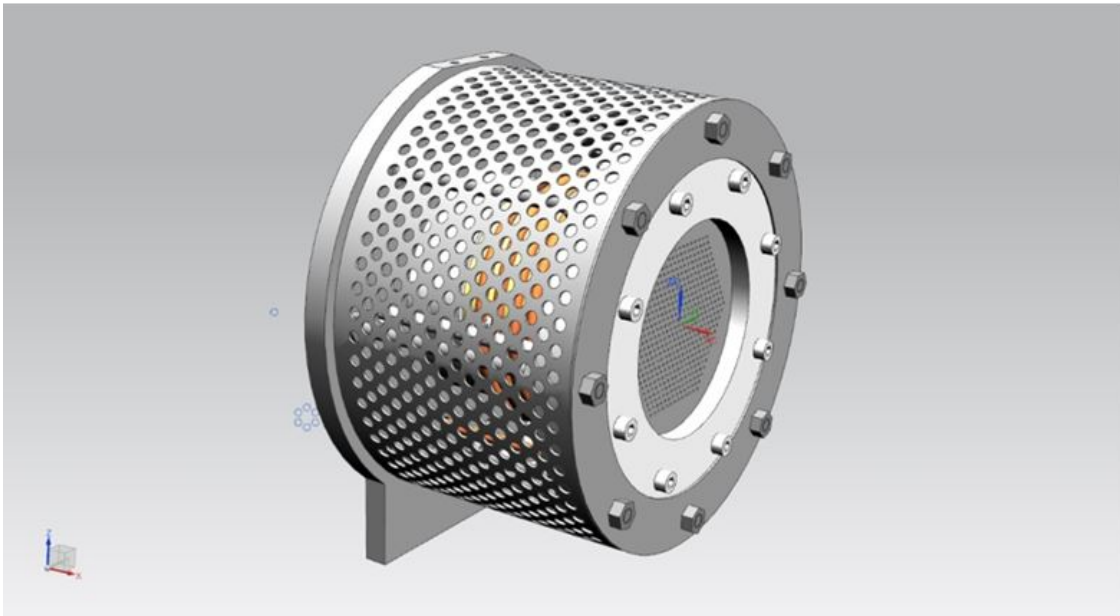


Figure 10. New RF ion thruster design

the grids through these rings. Each grid has 469 holes. Grid plates are separated with a micanite separator disc. The grids and the metal rings are covered with two Teflon parts. The grid assembly is fastened with zirconia screws. An alumina discharge chamber with 80 mm diameter and 70 mm length is used. In order to improve the propellant injection inside the discharge chamber, a macor diffuser is designed and machined. Inductive heating of the backplate is avoided by separating the discharge chamber and the backplate with a Teflon part. A cross-sectional drawing of the latest design is shown in Figure 11 and an exploded view of

the components are shown in Figure 12.

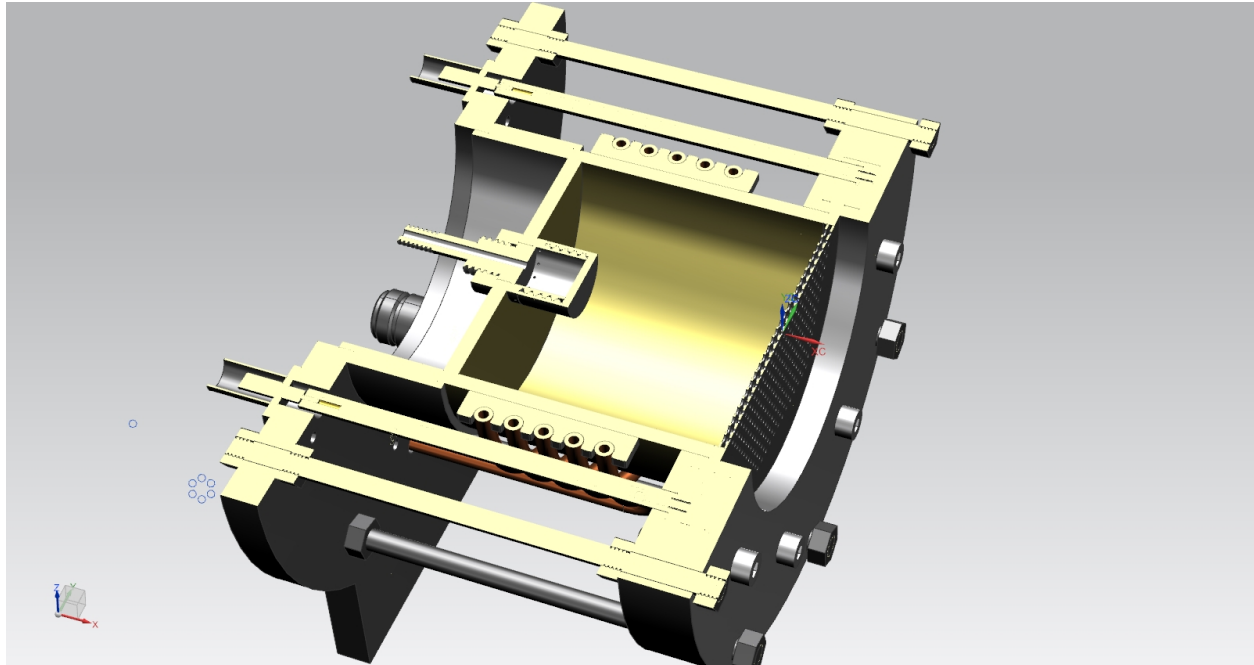


Figure 11. Section view of the new RF ion thruster design

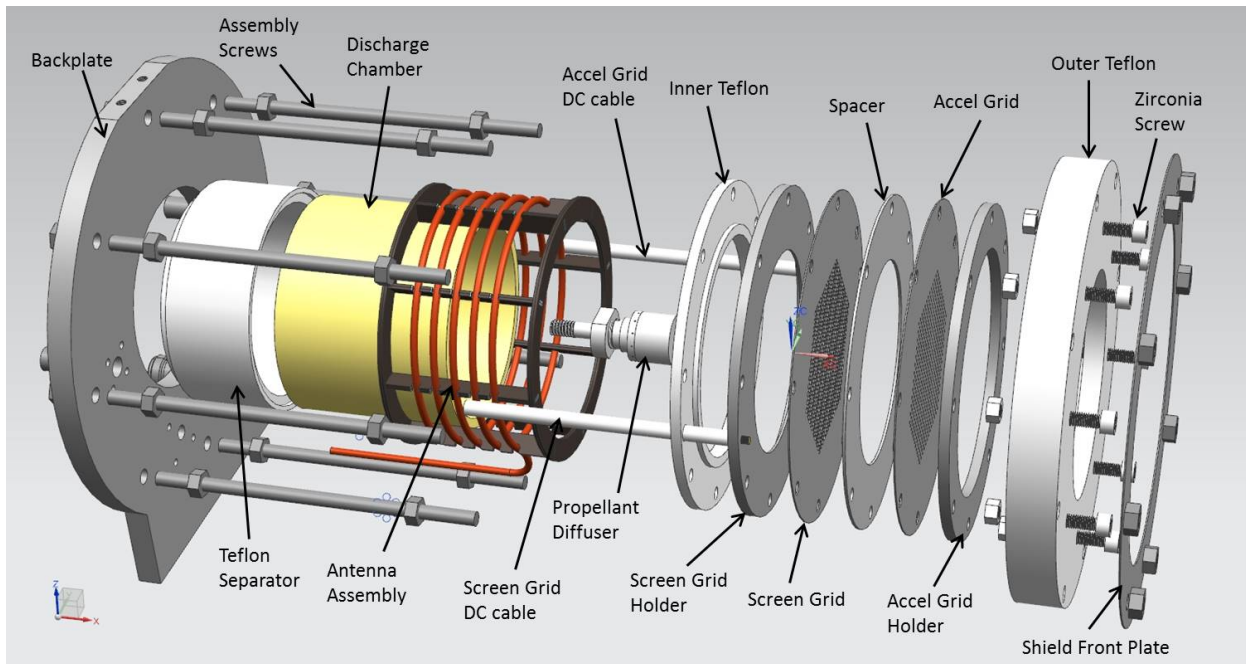
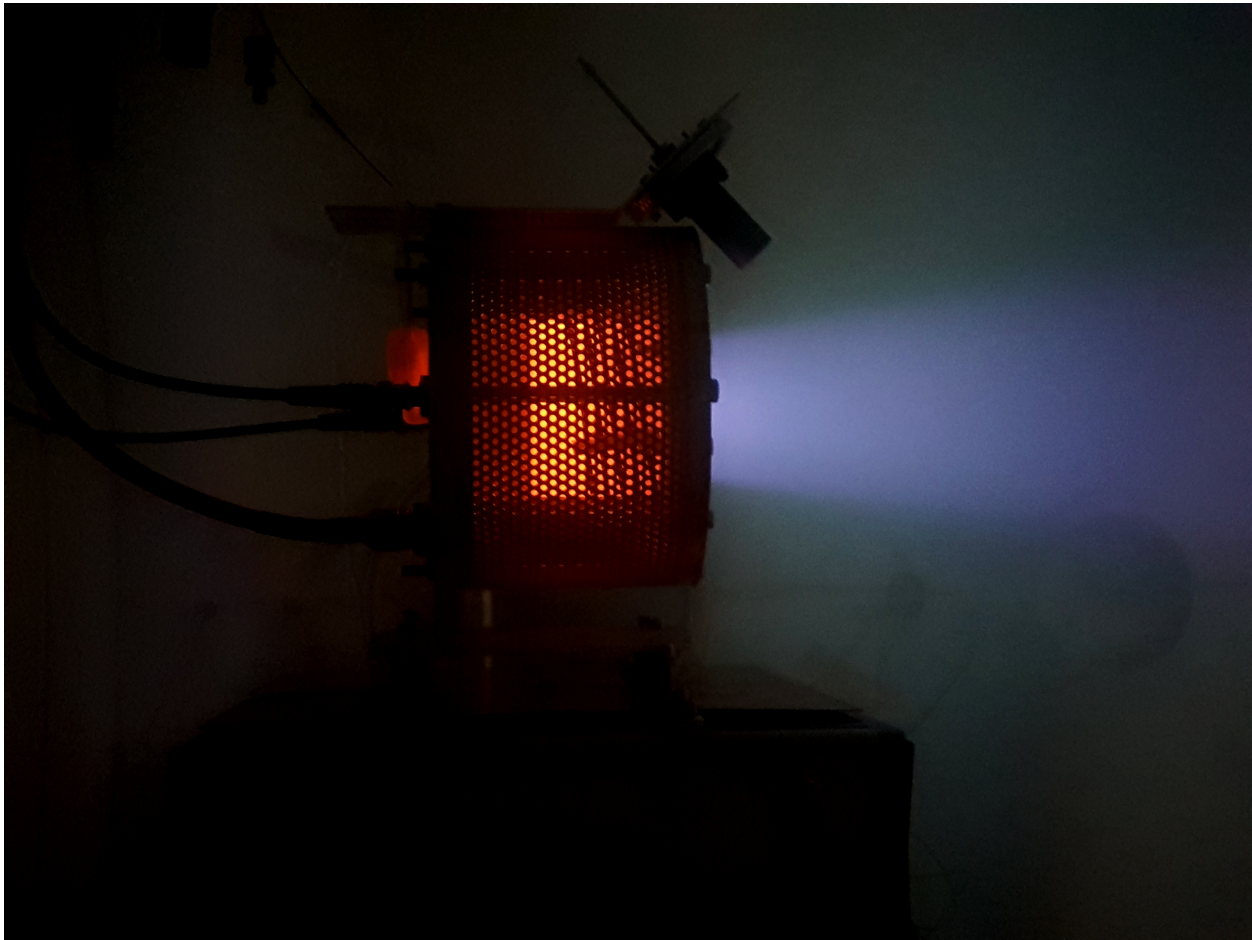


Figure 12. Exploded view of the new RF ion thruster design

#### IV. Conclusion

A prototype RF ion thruster with 80 mm discharge chamber diameter is designed, built and tested at Bogazici University Space Technologies Laboratory. Based on the problems encountered during the



**Figure 13. Latest version of the prototype BURFIT-80 RF ion thruster during operation**

preliminary tests, numerous improvements have been made to the thruster design. Ion energy distribution of the second version of the prototype thruster is measured with an RPA probe. Also, thrust measurements of the latest version of the prototype thruster are being conducted using the in-house built *BUSTLab thrust stand*. An image from these latest tests is shown in Figure 13. Characterization of the operational parameters of the latest version of the thruster are being conducted.

## Acknowledgements

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