National Cheng Kung University

Institute of Space and Plasma Sciences

107 Annual Report

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Abstract

Electric thruster is a device that uses electromagnetic fields to control and accelerate ions. An ion thruster using a metal target as the propellant has been development. Different from inert gas used in conventional plasma thrusters, the metal target is in solid state, high density, easy to be stored and cheap. The design is divided into three parts: metal evaporator and ion accelerator and neutralizer. The principle of E-beam evaporation, where metal target is evaporated and ionized by thermal emission electrons, is used. The working condition is independent to the vacuum condition so that it also works in the ultra-high vacuum space. A focus magnet with a magnetic field about 0.2~0.3T between the target surface and the filament, is used to guide electrons so that the metal is evaporated and ionized. A prototype has been built and is under testing. Metal targets were heated to more than 230 °C by electrons bombardment. A mass flow rate of $8*10^{-6}$ (g/s) using Zn was measured. Therefore, the estimated thrust is β*1mN with a power of 630W assuming 5kV accelerating voltage is used. The parameter β is the ionization rate of the metal vapor and will be measured experimentally. The thrust is much larger than those provided from existing thrusters with similar powers to date. The project is supported by Ministry of Science and Technology (MOST) project under Award Number 107-2628-E-006-006-MY2.

Contents

1. Future work

After finish evaporation rate measurement. I will build a full version ceramic thruster to do full power testing. Until then we can know more detail about Metallic Ion Thruster using Magnetron Electron-beam Bombardment (MIT-MEB), which includes thrust, Isp, ionization rate.

2. Summary

I build a metal evaporator first, and to measure evaporation rate. The evaporation rate about (8.0±1.3)x10^{-6}g/s, its very small value. I suspect it is because the metal is thermal conducting too fast. So I built a ceramic thruster again. And got evaporation rate about (2.5±0.1)x10-4g/s. And we want to know if the electron beam is bound by the magnetic field. So I used simulation to prove that the electrons can be focused by the magnet.

3. Evaporator built

I need to build evaporator to prove that MIT-MEB works. After 2018 Annual Meeting of Physical Society of Taiwan (TPS), I build the first evaporator to do evaporation rate measurement.

3-1 The Design

The evaporator is used to hold a metal target and a focusing magnet. Its shape is a cylinder and it has a chamber containing cooling water. Cooling is required to keep the temperature of the magnet below the curie temperature. There is a groove on the top for holding a metal target. The cylinder is made of aluminum alloy to withstand high temperatures(550˚C melting temperature). As shown in Fig. 1-3 the outer diameter is 7 cm and the height is 3 cm. The bottom plate has a groove for placing the O-ring for sealing. Lathe was used to build the evaporator because the evaporator is axisymmetric.

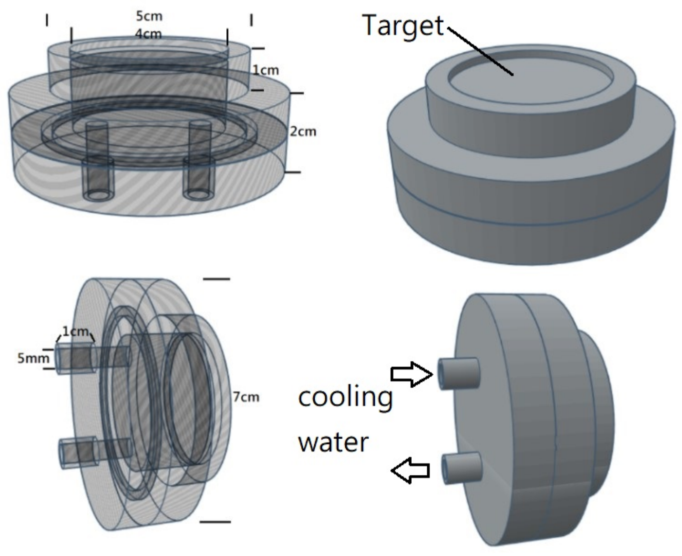

Figure 1: Blueprints of the evaporator

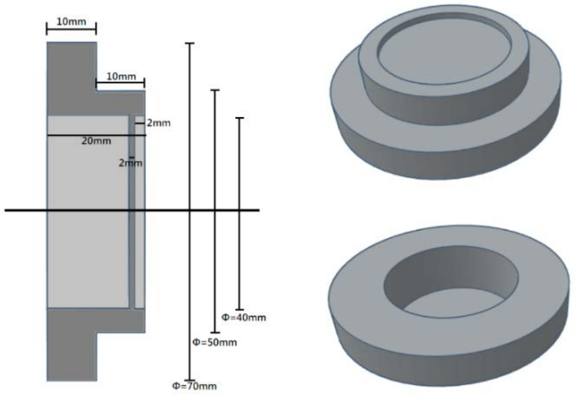

Figure 2: Blueprint of the top part of the evaporator

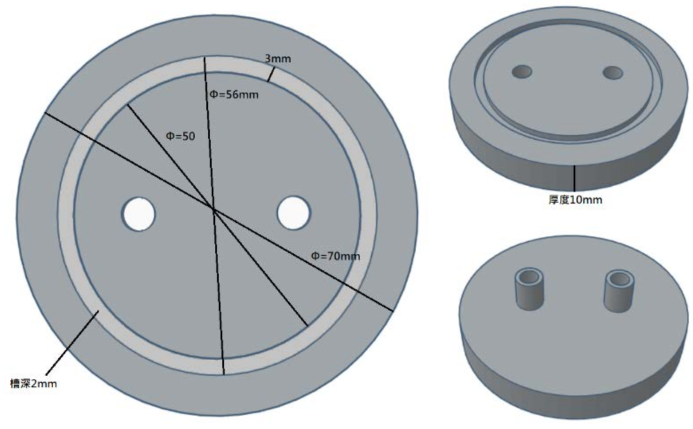

Figure 3: Blueprint of the bottom plate of the evaporator

3-2 The filament holder

The filament for emitting electrons and its connectors are attached to the filament holder. I use a plastic cylinder to build filament holder. There are two holes to hold two clips. As shown in Fig.4 Clips are used to hold the tungsten filament.

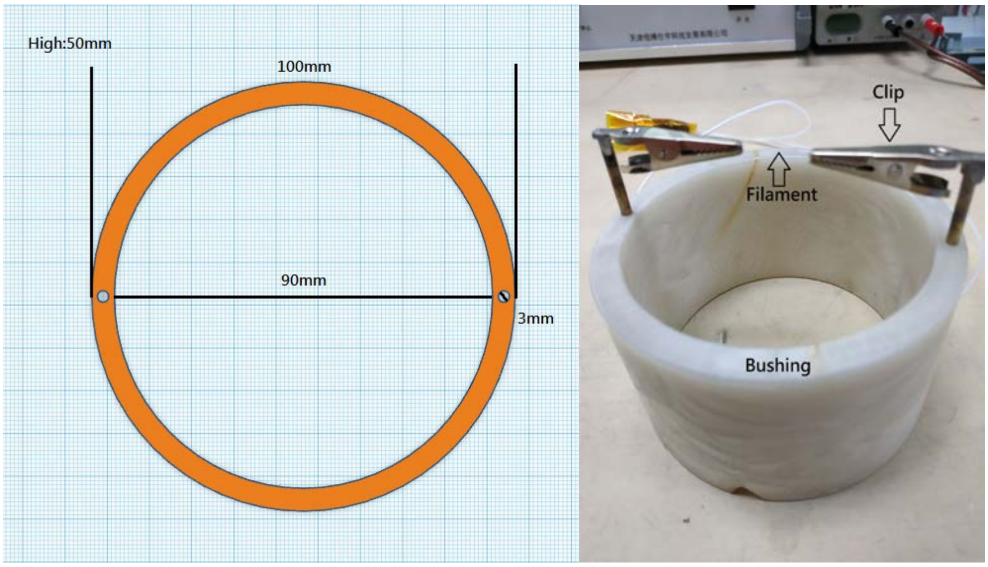

Figure 4: Filament holder uses to fixed filament.

4. Using ceramic to make new evaporator

4-1 The second Evaporator

The ceramic (Al_2CO_3) is used to build the second evaporator. Because Al_2O_3 has very high melting point, 2,072°C, and low thermal conductivity, the metal can be heated very efficiently. This makes it ideal for making evaporators. On the other hand, the magnet will not be heated due to loss of contact. One ceramic tube is used to carry the filament and the other is used to place the target as shown in Fig.5.

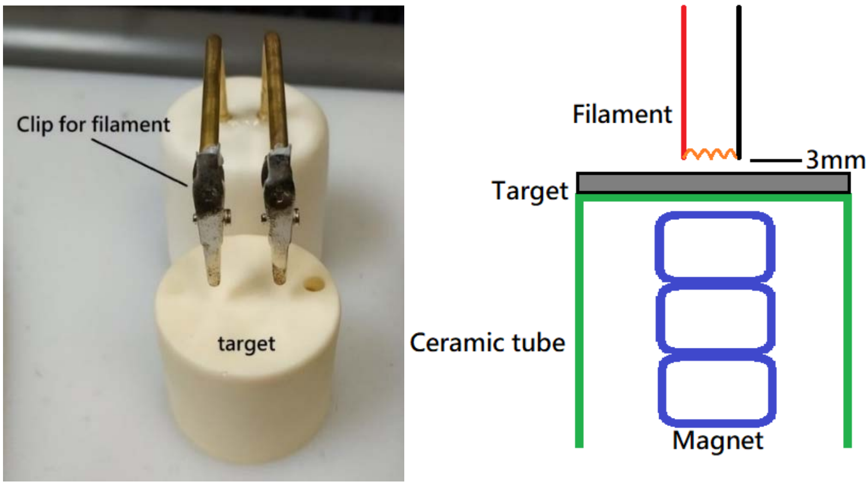

Figure 5: ceramic evaporator and clip

The ceramic evaporator is working well, the magnet is no longer heated. The filament was heated by 2-V DC power supply with current 1.8-2 A. The voltage between the filament and the target was 5kV White the electron current that heat the target was 3mA. Evaporation rates increased from $(8.0\pm1.3)\text{x}10^{-6}$g/s to $(2.5\pm0.1)\text{x}10^{-4}$g/s, using the first and second evaporator. In only ten minutes, the quartz chamber was obviously coated by the zinc. The mass difference of the target was 0.17±0.03g.

5. Measurement of mass flow rates of MIT-MEB

5-1 The experimental method

For the mass flow rate measurement, I recorded the weight of metal targets Mi before experiments, and the weight Mf after experiments. The mass flow rate is $\frac{Mi-Mf}{\Delta t}$ (g/s) where Δt is the time difference before and after the experiment. Typical mass difference are 0.1 to 0.001 g. The precision of the scale must be 0.0001g. The model of the scale we used is Sartorius TE124S as shown in Fig. 6.

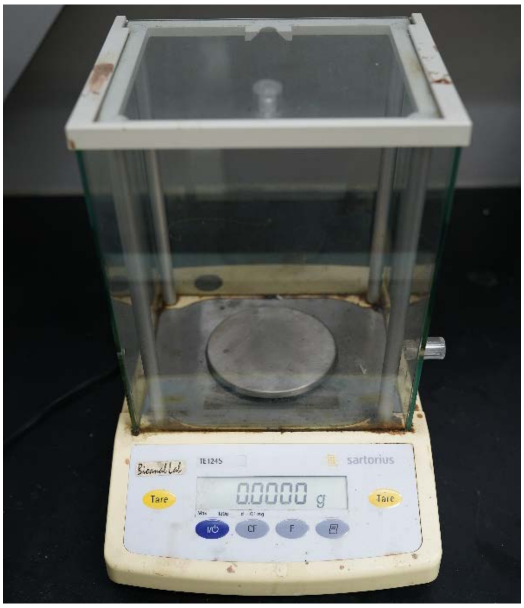

Figure 6: The scale Sartorius TE124S

5-2 Results

The mass flow rate of using Zn and aluminum alloy evaporator is $(8.0\pm1.3)\times10^{-6}$ g/s. The mass flow rate of using Zn and ceramics evaporator is $(2.5\pm0.1)\times10^{-4}$ g/s.

Figure 7: aluminum alloy evaporator(left) and ceramics evaporator(right)

6. Magnetic field profiles of focus magnets

6-1 The single magnet

In my original design, the focusing magnet consisted of a ring and a cylindrical magnet. They are used to guide electrons from the heated filament to the target. Electrons supposed to hit within a ring on target surface. After testing the evaporator, we found that the design was not able to guide electrons to the ring region. I suspect that it was because the position of the filament was too high causing the electrons being reflected by the magnetic field. Therefore, I replaced a single magnet cylindrical for focusing electrons. The system is even easier to build.

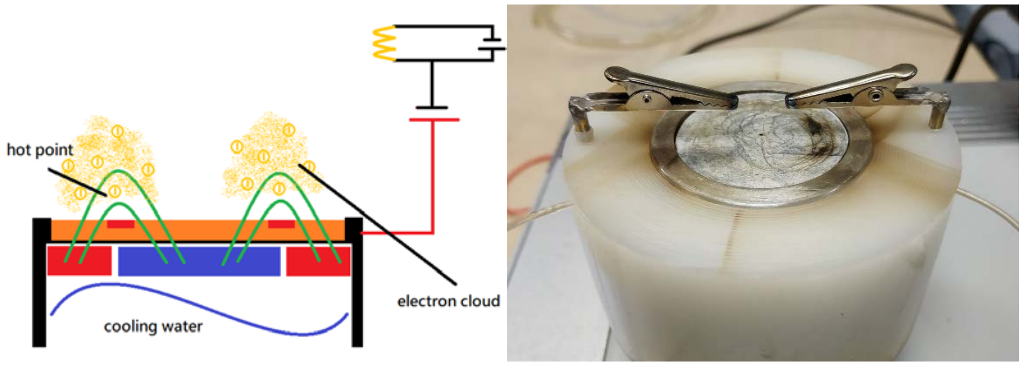

Figure 8: original focus magnet(left) and the experimented result(right)

6-2 Magnetic field measurement for the ring and cylindrical magnets

A gauss meter and a 3-axis linear stage were used to measure magnetic fields of magnets. Since the magnet is axisymmetric, I only measured magnetic fields in the X and Z directions as shown in Fig. 9.

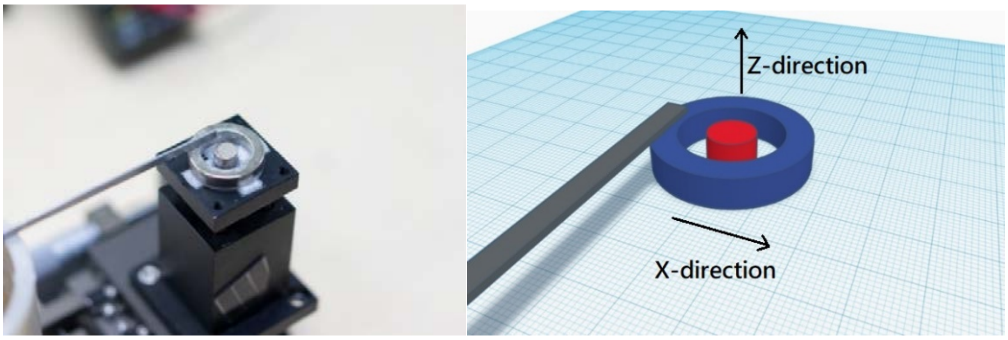

Figure 9: measure the magnetic field of ring and cylinder magnet

6-2 Results

Shown in Fig.10 are the experimental results. Because the magnet is axisymmetric, only one side was measured.

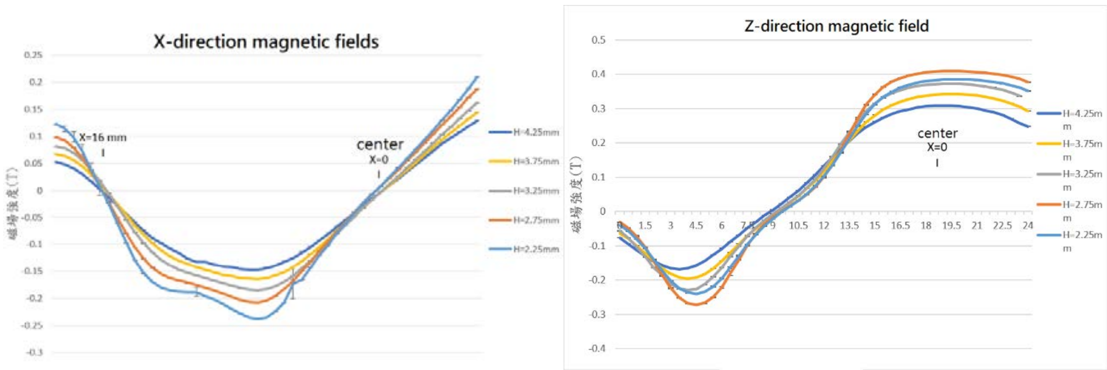

Figure 10: magnetic field of ring and cylinder magnetic

7. Field Simulations

Comsol was used to simulate both Electric and magnetic fields of MIT-MEB. Electron gyro radius were also calculated to verity that they are guided to the target..

7-1 The electric field

I used Comsol AC/DC Module to solve poisson equation for calculating electric fields. The MIT-MEB has a filament at ground and a metal target at +5 kV. The filament length is 1 cm. The diameter of the target is 5cm. The filament is 3 mm above the target. Shown in Fig.11 is the simulation result. The color contour is the electric potential in volt while arrows represent the electric field.

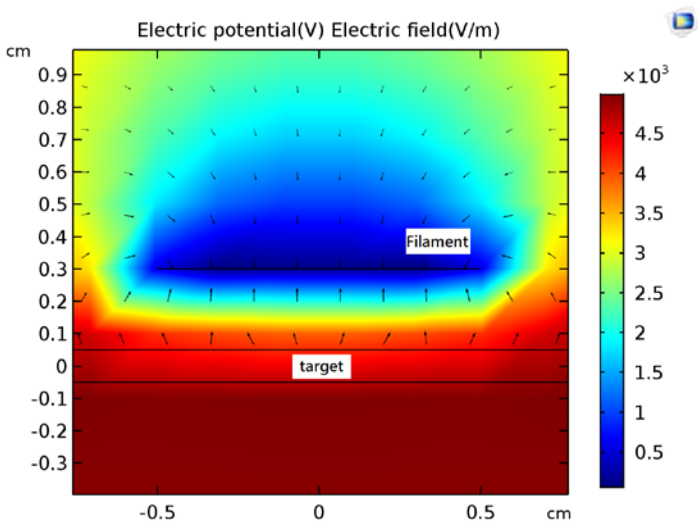

Figure 11: Electric fields and Electric potential simulation result. Arrows are electric fields while the color contour is electric potential.

7-2 The magnetic field

Comsol magnetic module was used to simulate magnetic fields of MIT-MEB. We change the magnetic flux density in the magnet toll the simulated magnetic fields match the data. Shown in Fig.12 are the contour of the simulated magnetic field in tesla. Magnetic field is 0.1~0.2 T between the target surface and the filament located 3 mm above the target.

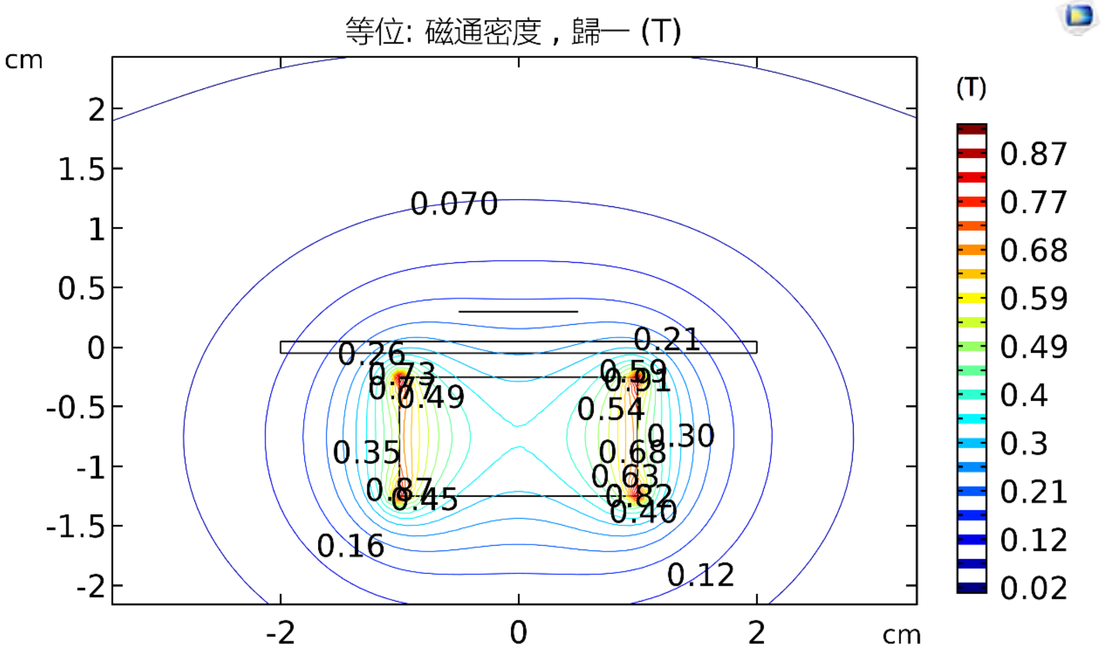

Figure 12: magnetic contour lines of MIT-MEB

Magnetic field lines are shown in Fig.13. Magnetic field lines can help us predict how electrons move in the space.

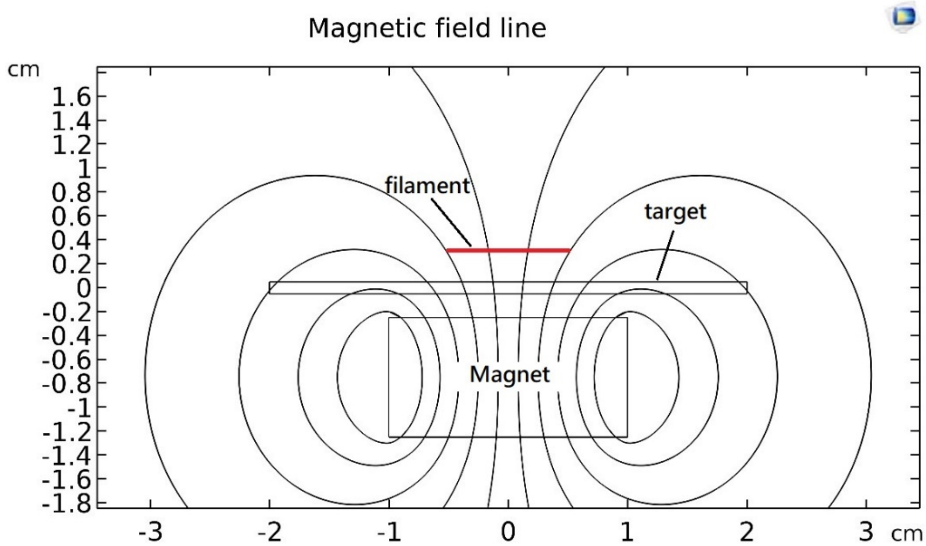

Figure 13: Magnetic field line

7-3 Electron gyro radius

To ensure that electrons are magnetized and follow magnetic field lines, gyro radius at different locations were calculated. When we get the distribution of electric potential shown in Fig.11, the speed of electrons v is determined. Therefore, with the magnetic fields B in different locations as shown in Fig.12, we can calculate electron gyro radius $r_L = \frac{mv}{eB}$ at different location. The result is shown in Fig.14. The gyro radius is much smaller than the system size indicating that electrons do follow magnetic field lines and hit the center of the target surface (dark red area in Fig.14)

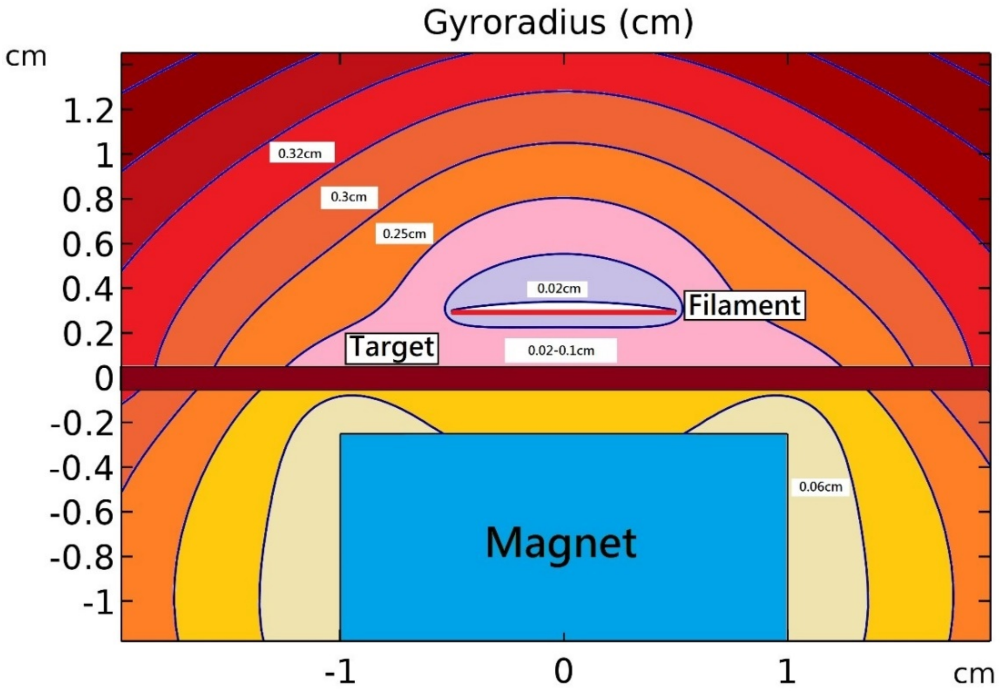

Figure 14: Distribution of Gyro radius