OPEN LAB(part:1):Design of magnet for magnetron sputtering

haraprasad.dhal 1811074

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Abstract

In DC magnetron sputtering the presence of magnetic field perpendicular to electric field will give rise to $E \times B$ motion of electron in the plasma giving rise to azimuthal current.This helps in more ionisation and keeping electrons in the confinement which in turn will increase the efficiency of sputter system.The aim of this open lab project was to design a magnet(computer simulation) for magnetron sputtering.Searching for geometries of magnet that will give a uniform magnetic field perpendicular to electric field in the vicinity of substrate.It is also important to study the heating of magnets in the sputtering process but we have done only geometry simulation in this first part of open lab project.This will be addressed in the second part of project.

1 Sputtering Technique

It is a technique of thin film deposition.In 1852 ,Sir W.R .Grove[1] discovered surface coatings generated in the valve where he investigated a glow discharge.Sir W.Thomas called this phenomenon ,in analogy to the generation of drops out of a liquid surface by an impinging primary drop,SPLUTTERING.

In discharge tubes there is ejection of particles from the solid cathode surface after exposure to a bombardment with heavy particles(usually Ar ions generated from electric discharge) of sufficient energy.These ions then traverse to substrate plate and deposited there,making a thin film.In the bombardment process there is also ejection of secondary electrons which helps in sustaining the discharge by creating more ionization as the electrons are accelerated towards anode.

For a typical DC diode sputter system :Voltage $>$ 500V,mostly 1-5 kV.Current density:1-10 mA cm^{-2}.Target area: 10 cm^2.Distance between target and substrate:10cm.The most frequently used sputter gas is argon because of its inertness and low price.

2 Magnetron Sputtering

The lifetime of electrons in the vicinity of cathode target can be extended by applying a static magnetic field.Such a discharge, based on magnetic confinement of electrons is referred to as a magnetron sputtering discharge.This enclosure of plasma increases the efficiency of a sputter system as the number of atoms available for bombarding the target is highly increased. Figure 1 shows the typical setup.

3 Finite element Analysis(FEA)

We are trying to solve for magnetic field for particular magnet geometries.Theoretically one just needs to solve the partial differential equations concerning the magnetostatics.The magnetic field intensity(H) and flux density (B) must obey:

$$\Delta \times \boldsymbol{H} = \boldsymbol{J} \tag{1}$$

$$\Delta \times \boldsymbol{B} = 0 \tag{2}$$

[1] An introduction to Physics and Technology of Thin Films,Alfred Wagendristel,Yuming Wang

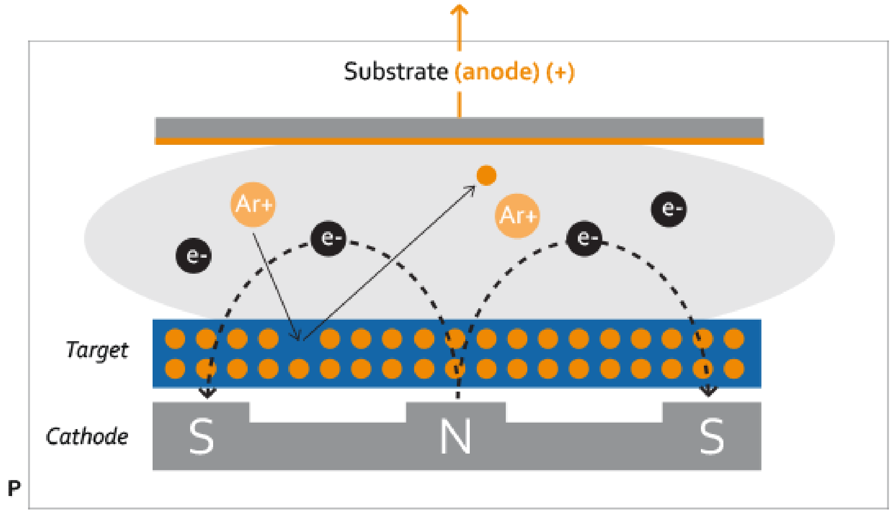

Figure 1: A schematic of magnetron sputtering setup

With relation between B and H for each material:B=μH. Flux density can be written in terms the vector potential A as:

$$\boldsymbol{B} = \Delta \times \boldsymbol{A} \tag{3}$$

Putting this in equation 1 and assuming coulomb gauge the new equation becomes

$$\Delta \times (\frac{1}{\mu}\Delta \times \boldsymbol{A}) = -\frac{1}{\mu}\Delta^2\boldsymbol{A} = \boldsymbol{J} \tag{4}$$

Equation 4 is the partial differential equation that needs to be solved given with boundary conditions.But typically it is very difficult to get a closed form solution.This is where FEA comes in.The idea of finite element is to break the problem into large number of regions,each with simple geometry e.g triangles.Over these simple regions ,the true solution for the desired potential is approximated by a very simple function.if enough small regions are used,the approximate potential closely matches exact solution.By breaking the domain down into a number of small elements the problem becomes transformed from a small but difficult to solve problem into big but relatively easy to solve problem.Through the process of discretization ,a linear algebra problem is formed with tens of thousands of of unknowns.However numerical algorithims solve them in short amount of time.

4 Software used:

1. FEMM
2. COMSOL Multiphysics

5 Magnet Designs:

5.1 A simple Planar magnetron magnet Assembly:

The schematic is shown in the figure 2.In FEMM software this magnetics problem is defined as shown in figure 3.The problem is deefined in axis symmetric mode.If one does a two pi revolution of the two rectangular boxes about the vertical axis one gets a magnet geometry of figure 2.N55 denotes the material type library used for the magnet.It is a NdFeB magnet of coercitivity give by 155319A/m*sqrt(55).The circular boundaries are the impedence boundary conditions defined by FEMM that allow a bounded domain to mimic the behaviour of an unbounded region.The solution is shown in figure 4.

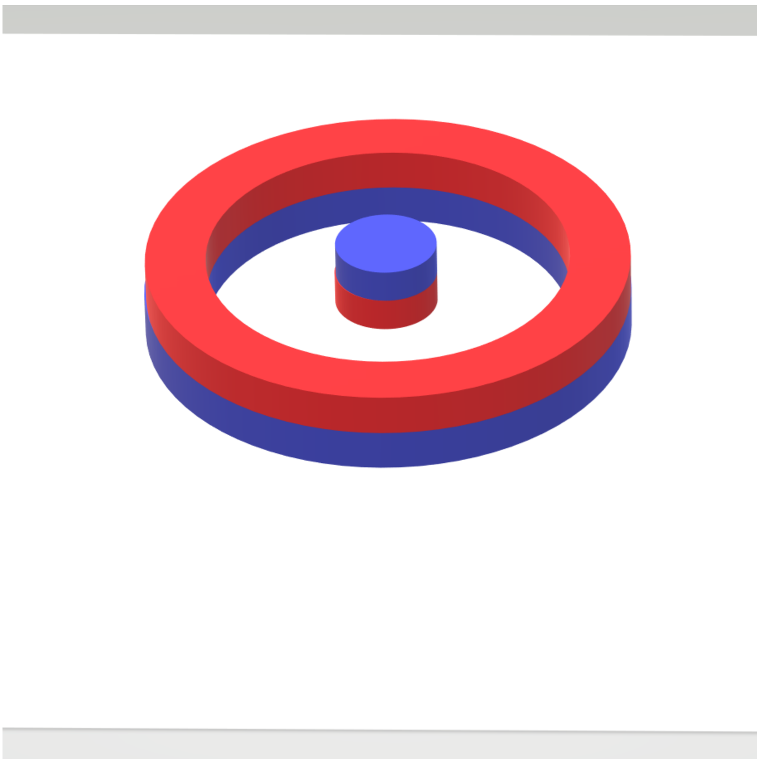

Figure 2: A schematic of plannar magnetron magnet assembly Red:south pole,Blue:North pole' radius of inner cylindrical magnet:1.5 cm ,inner radius of larger ring magnet:9.5cm,outer radius:11cm

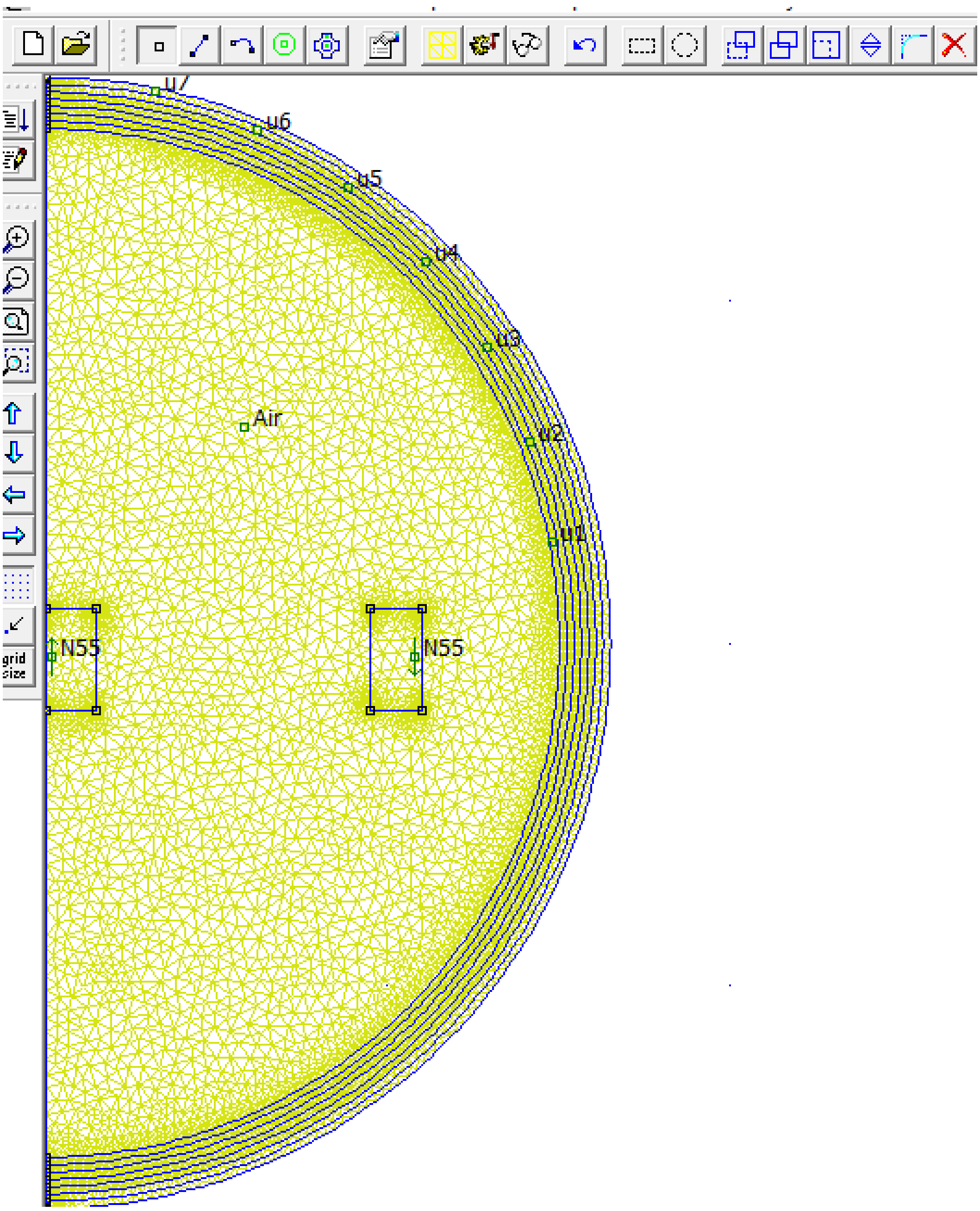

Figure 3: Magnet problem definition with meshing done by FEMM

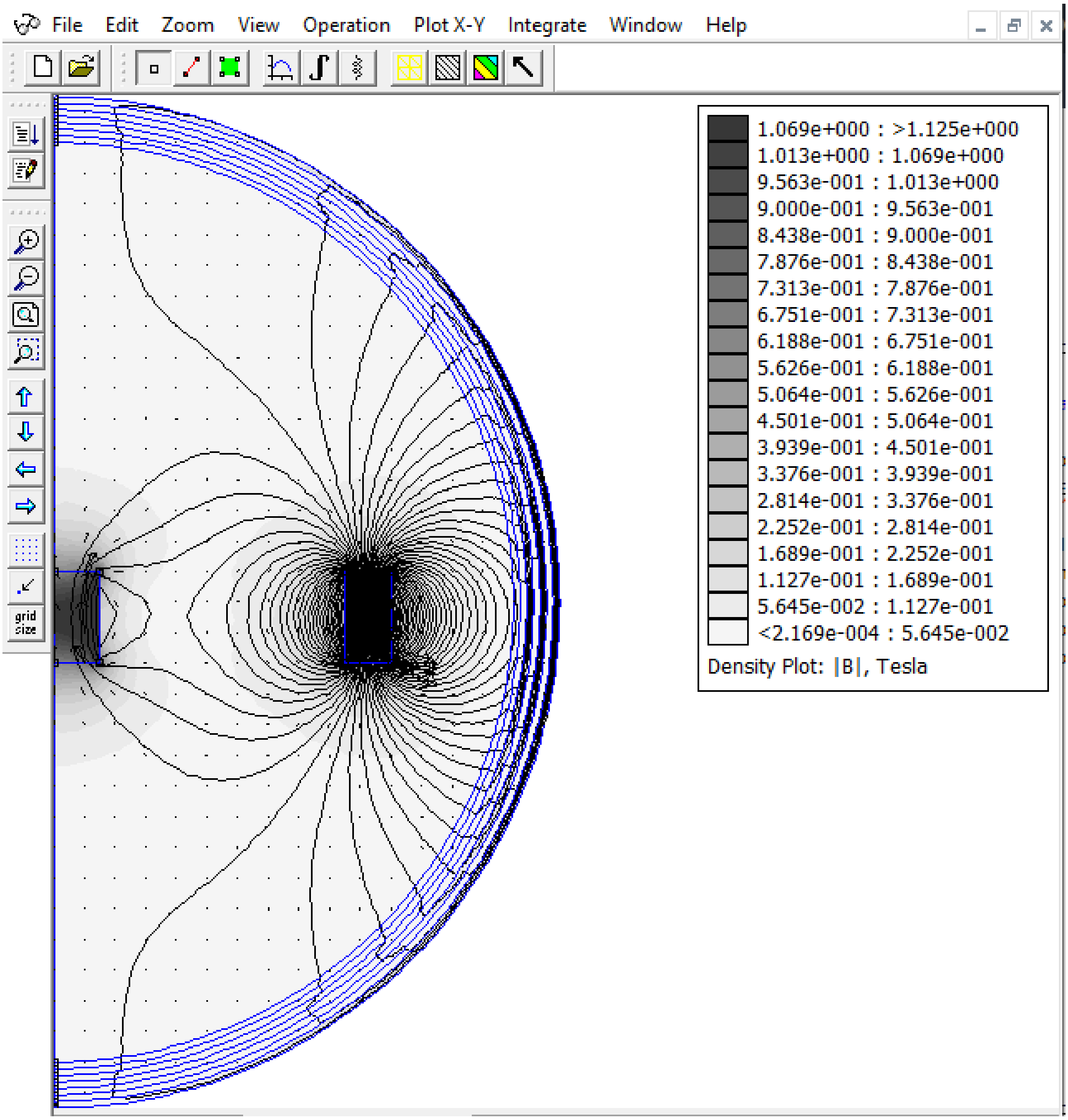

Figure 4: Contour plot of solution to problem defined in section 5.1

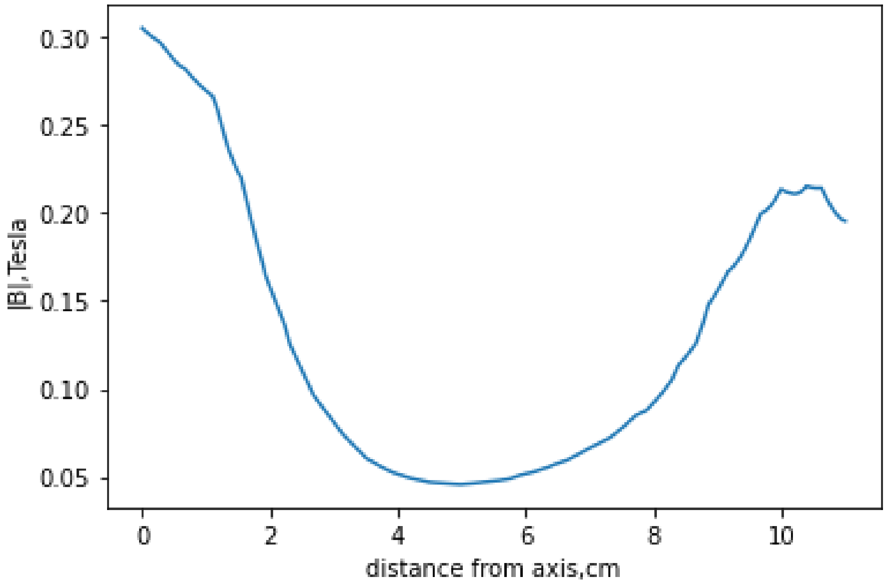

Figure 5: B at a height of 2 cm from magnet

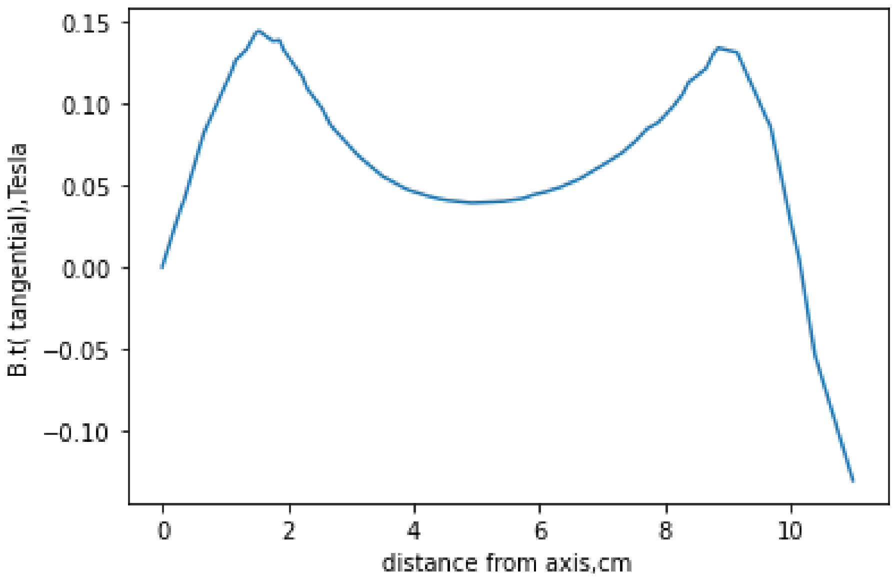

Figure 6: B.t at a height of 2 cm from magnet

Discussion: This design gives a uniformity in the magnetic field in some areas(2 cm to 8 cm) but at the center and edge the field is much higher than ,2 cm to 8 cm part.This will bring non uniformity in the thickness of deposited film. **Multiple Simulation with same problem definition:**I tried to run the above magnet geometry model with varying the two parameters as follows.

- radius of inner magnet(r1)
- inner radius of larger ring(r2)

So I wrote a script(submitted in separate file) which solved the same problem with different values of r1 and r2.At each value of r1 and r2 calculate the following function from the solution of magnetic field .

$$F = \frac{\sum B.t}{\sum |B.n|} \tag{5}$$

over the points given in the figure 7.So that higher the value of F for a particular value of r1 and r2 the better the field pattern for the sputtering because We want the field to be

- uniform in magnitude
- radial(i.e mostly tangential) B.t should be higher
- lesser component in vertical direction so B.n should be less.

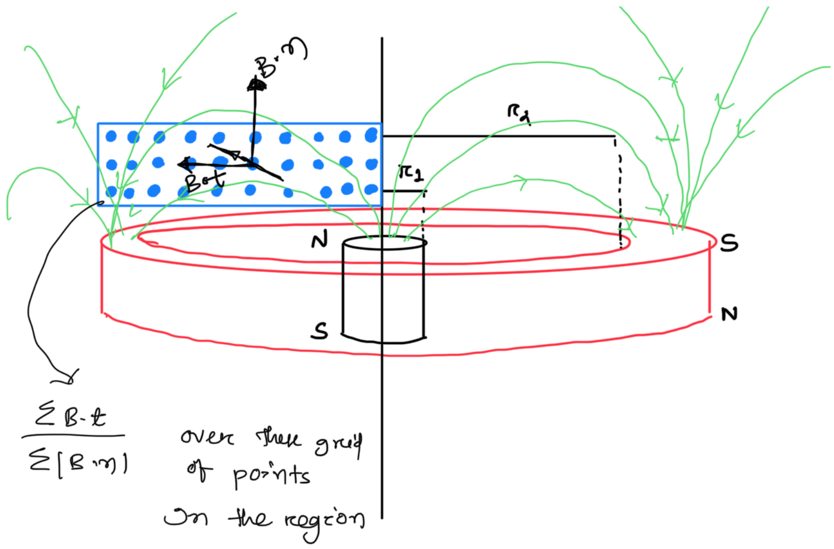

Figure 7:

Following palette(Figure 8) plot is the output of F for different r1 and r2(note always r1<r2).With an optimal value of 1.5 for r1 and 9.5 for r2.The outer radius of ring magnet is kept fixed at 11 cm.

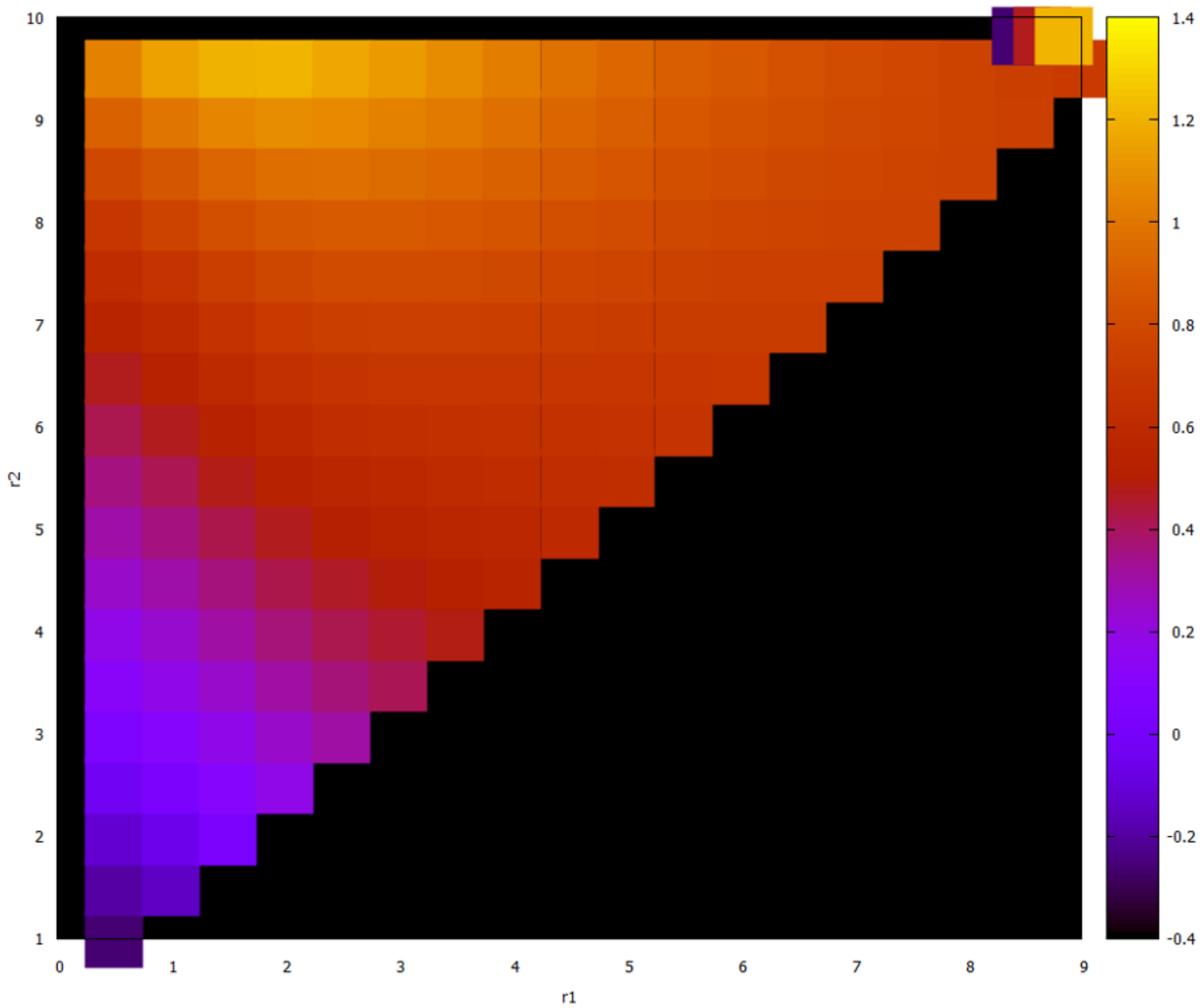

Figure 8: The color indicates value of F

5.2

Here is another design.

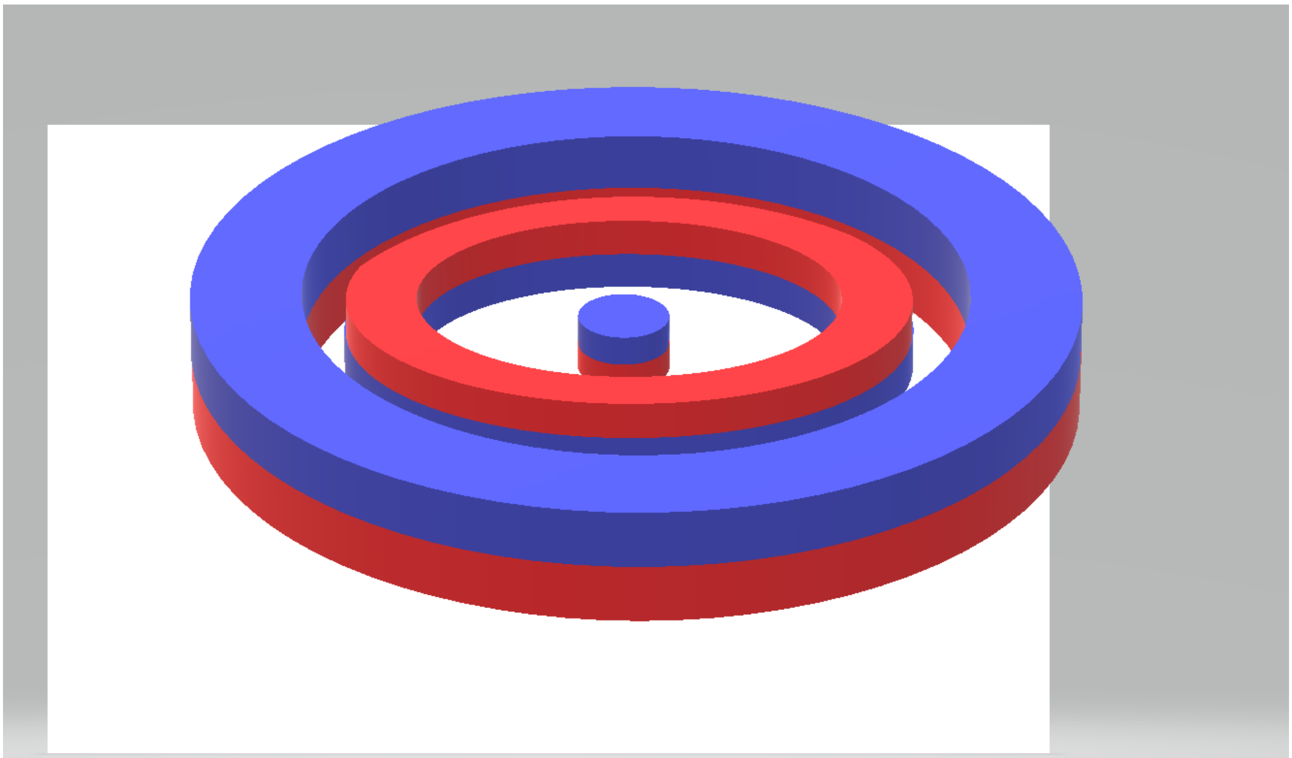

Figure 9: Blue:north pole,Red:south pole

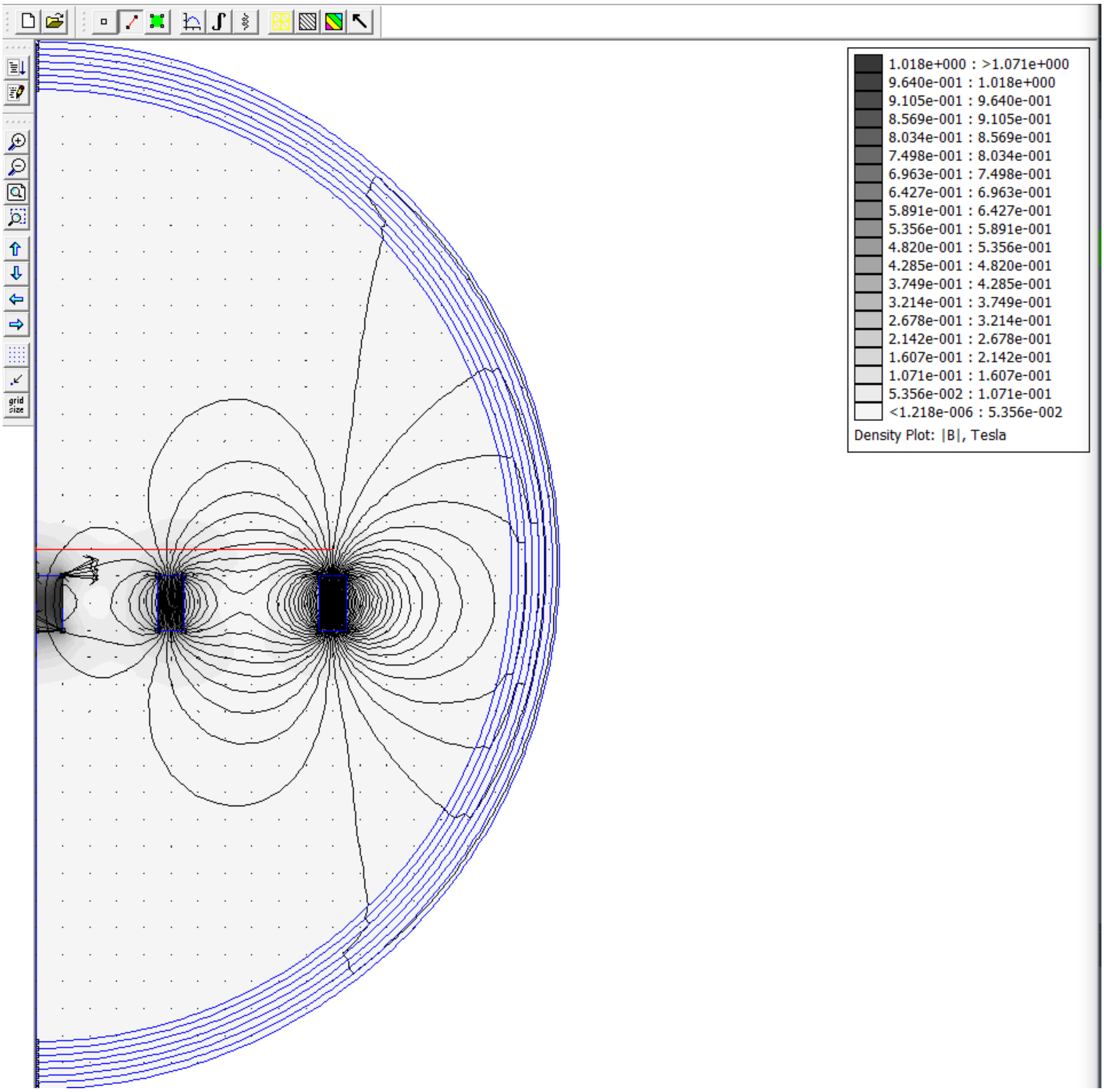

Figure 10: magnetics problem definition and solution

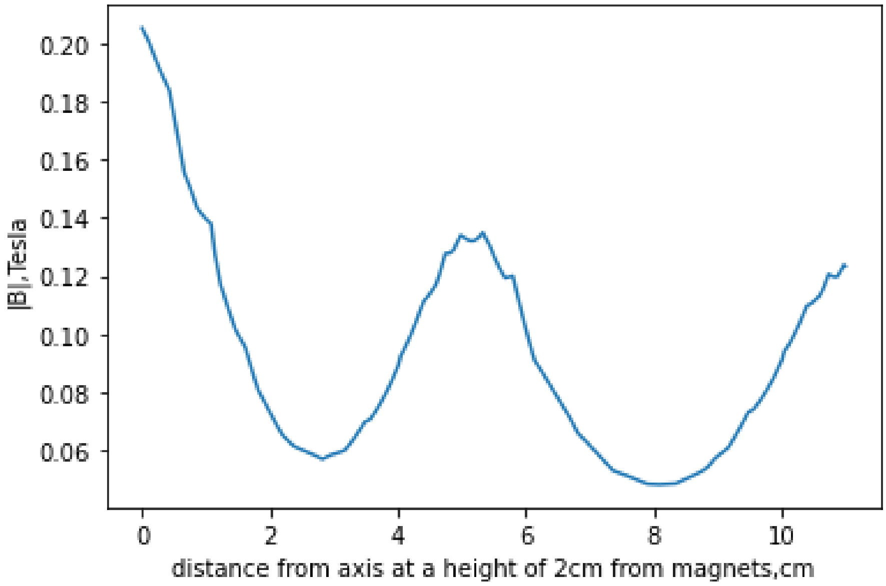

Figure 11: B at a height of 2 cm from magnet

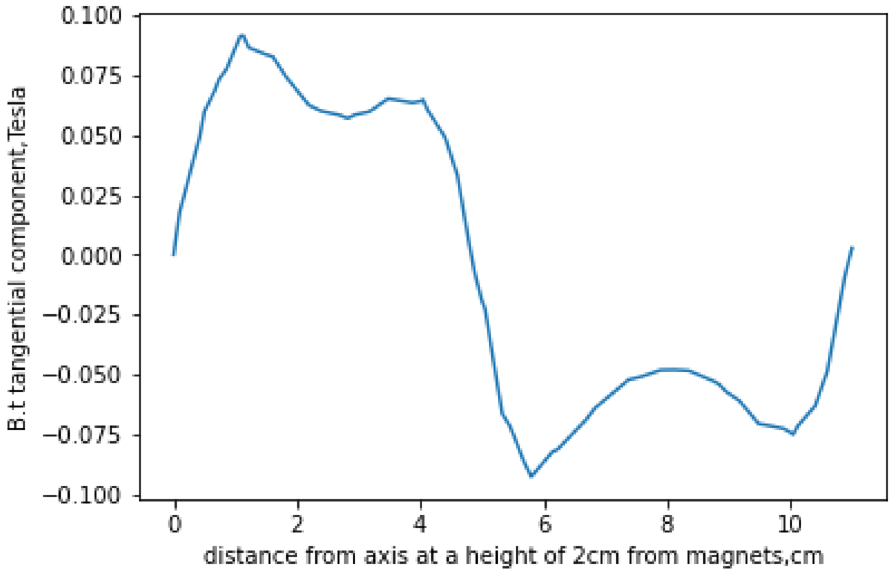

Figure 12: B.t at a height of 2 cm from magnet

Discussion: It may seem from figure 9 that if we increase the number of alternating north and south magnets in setup(in figure 7) we will increase the uniformity in the $|B|$.But the B.t (tangential) component of field will still keep fluctuating between positive and negative values due to presence of alternating poles.Hence this design is not good enough.

5.3

Here is another design but with no central magnet like previous sections[2].

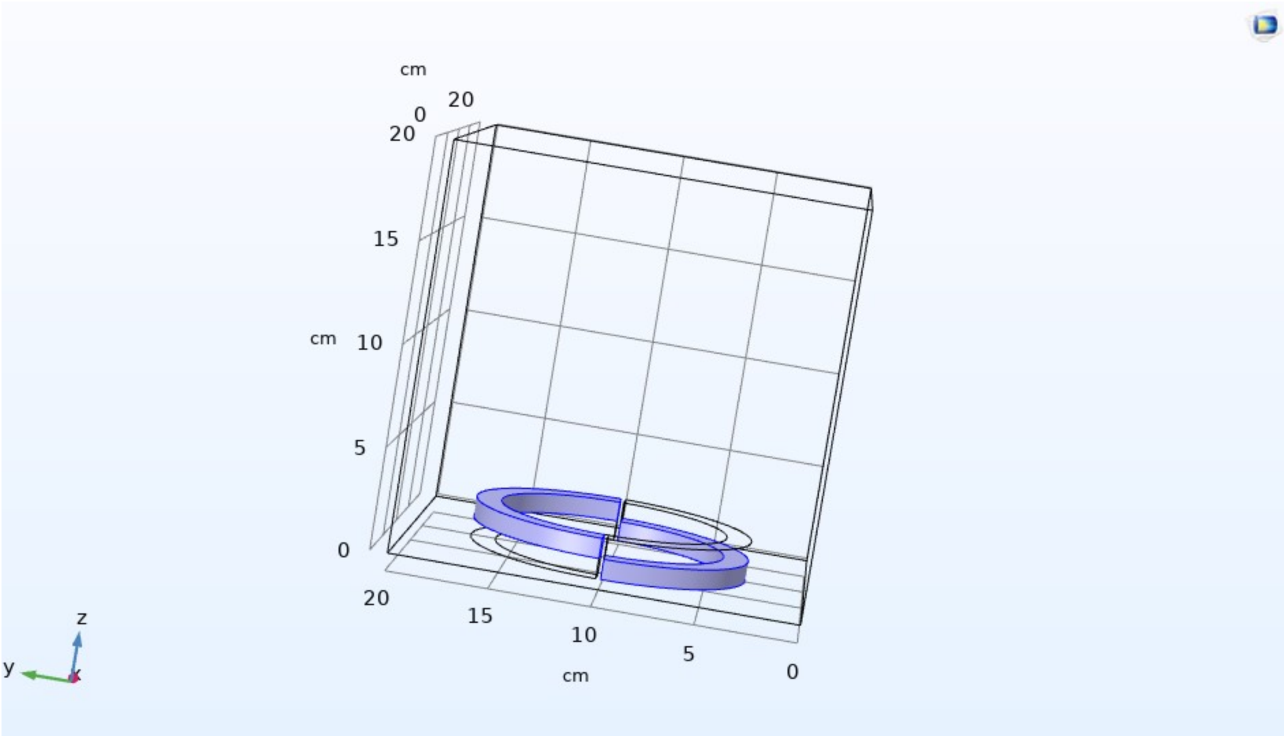

Figure 13: Semicircular ring magnets Blue and white color are different poles

[2]Idea from Anshuman,Debdoot and Swayang

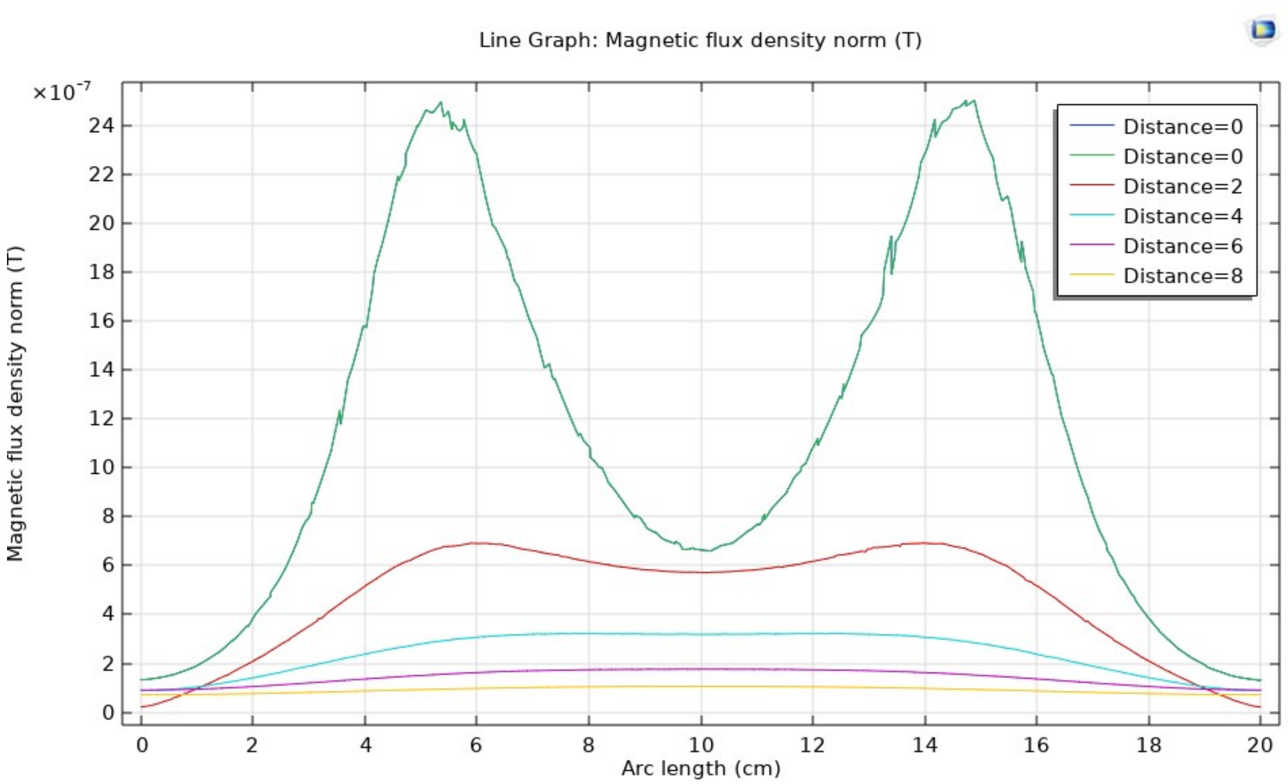

Figure 14: Flux density at different distances from magnets

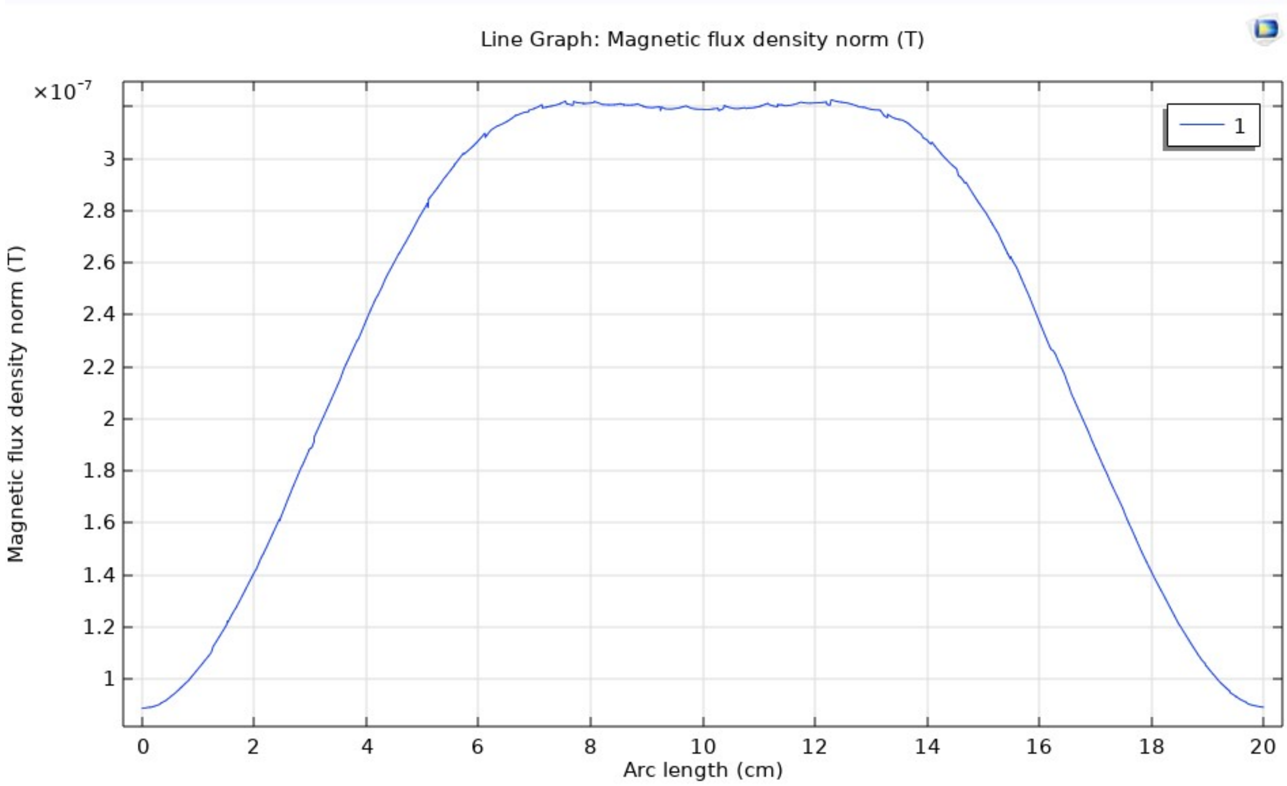

Figure 15: Flux density at a distance of 7 CM.

Discussion: So far This geometry has given the better uniformity in the magnetic field out of the 3 geometries discussed so far.But the limitation is that it is not uniform at all distances from magnet.Also the uniform region is far from the ionization region where plasma forms.