Cylindrical Cavity Simulation for Searching Axions

Doyu Lee[1], *Woohyun Chung*[2], *Yannis Semertzidis*[1,2]

[1]Korea Advanced Institute of Science and Technology(KAIST), Daejeon, Republic of Korea,
[2]Center for Axion and Precision Physics(CAPP), Insititute for Basic science(IBS), Daejeon, Republic of Korea,

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The axion is an excellent candidate for cold dark matter. In 1983, Sikivie [1] proposed the scheme to detect axions using a resonant cavity inside a high magnetic field. In order to detect axions in his scheme, we need to scan a range of resonant frequencies of the cavity where the converted photon signal gets enhanced. This poster presents the ways to design a frequency tuning system with conducting and dielectric materials inside the cavity. The simulation software package COMSOL Multiphysics was used to evaluate the effects on the Q-factor and the form factor with different configurations and materials.

1 Introduction

The axion to photon conversion signal is extremely weak. To catch this signal, we need a ‘good’ cavity. ‘Good’ means with a broad frequency tuning range, high quality factor and form factor. We could optimize these conditions by real experiment but it would need a lot of resources. Here we want to find the optimal conditions for our microwave cavity using the COMSOL multiphysics simulation program.

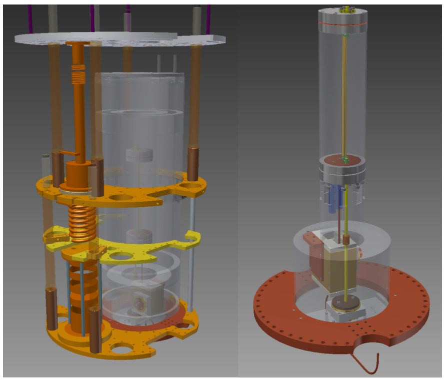

Figure 1: Drawing of the cavity tuning system. Drawn by Dr. Harry Therman(CAPP/IBS).

2 Methods

The resonant frequency of the cavity could be changed by putting a different material inside. For a cylindrical cavity with TM010 mode, a conductor or dielectric rod inside the cavity could be used to tune the resonant frequency. The quality factor and form factor of the cavity are also changed according to the material and the position of the tuning rod. The simulation was performed to explore the best combinations for the axion search using the COMSOL Multiphysics program [2].

Figure 1 shows the cavity with a tuning system and when it was installed in the dilution refrigerator.

3 Results

3.1 Resonant frequency, quality factor and form factor

Figure 2 below shows the E-field distributions (cross sectional view) of TM010 mode with a tuning rod inside the cavity. The conductor rod pushes E-field and the dielectric rod pulls E-field. Based on these properties, we tune the resonant frequency of the cavity.

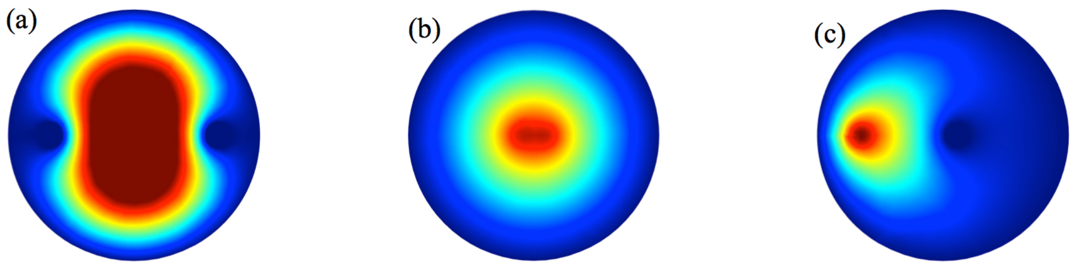

Figure 2: E field distribution in XY cross section for (a) two conductor rods (b) two dielectric rods (c) one conductor and one dielectric rod.

Depending on the position of the rod, the resonant frequency, quality factor, and form factor of the cavity are changed. In Fig. 3, the yellow horizontal line indicates an empty cavity. Introducing a conductor rod makes the resonant frequency go up and a dielectric rod makes it go down. The tuning range of the conductor rod is usually broader. Table 1 shows that the tuning range is about 1.7 GHz with two conductor rods, and 0.9 GHz with two dielectric rods. The quality factor and form factor vary with rod positions also.

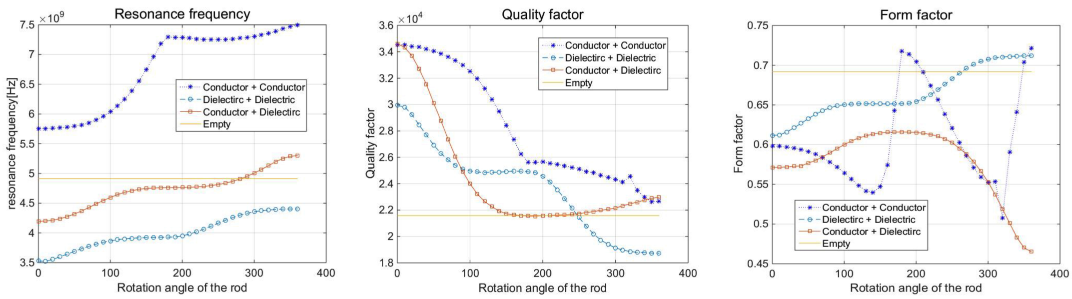

Figure 3: Resonance frequency, quality factor, and form factor of the cavity with different rod conditions.

	Frequency range	Quality factor	Form factor
Conductor + Conductor	5.8 GHz ∼ 7.5 GHz	$2.2\times10^4 \sim 3.4\times10^4$	0.59 ∼ 0.72
Conductor + Dielectric	4.2 GHz ∼ 5.3 GHz	$2.1\times10^4 \sim 3.4\times10^4$	0.46 ∼ 0.61
Dielectric + Dielectric	3.5 GHz ∼ 4.4 GHz	$1.8\times10^4 \sim 3.0\times10^4$	0.61 ∼ 0.71

Table 1: Resonance frequency, quality factor, and form factor range of the cavity with different rod conditions.

3.2 Gap problem in conducting rod case

When there is a gap between the rod and the cylinder, mode localization happens. Figure 4(a) shows the normal TM010 mode, but figure 4(b) shows a strange mode generated when a gap between the top or bottom of the cavity and the rod is introduced in the simulation model. In figure 4(c) we can see the location where mode localization shows up. One possible solution to solve this problem is changing the length of the cavity. The TM010 mode does not depend on the length, however the other strange mode depends on it. Figure 4(d) shows a mode crossing point according to the length of the cylinder. We can move the mode crossing points through this property, but cannot solve the, completely.

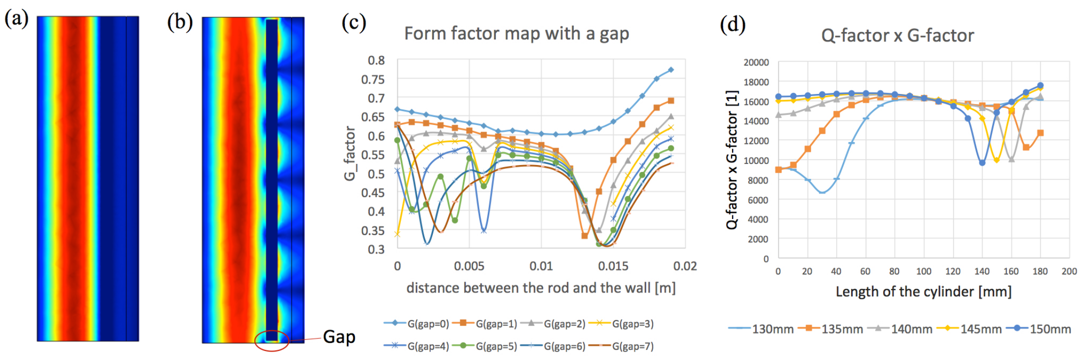

Figure 4: (a),(b) E-field norm of Y-Z cross section of the cylindrical cavity with conducting rod (a) without a gap, (b) with a gap. (c) Form factor graph with a cylindrical cavity which has various gap sizes (0mm-7mm). (d) Form factor and quality factor graph according to the length of the cylinder.

3.3 Cylindrical cavity with dielectric cap and high conductivity film

A high quality factor is required for higher axion conversion power. We change the conductivity of the cavity and introduce some dielectric material in the simulation to evaluate the effect. Figure 5 and Table 2 show results of many trials. If the conductivity of the cavity wall goes up, the quality factor goes up too. A dielectric cap at the top and bottom is harmful for the quality factor.

When the conductivity increase is N times larger, the Q factor is increase $\sqrt{N}$ times larger. To achieve a high Q factor, we consider the inner surface coating with superconducting film.

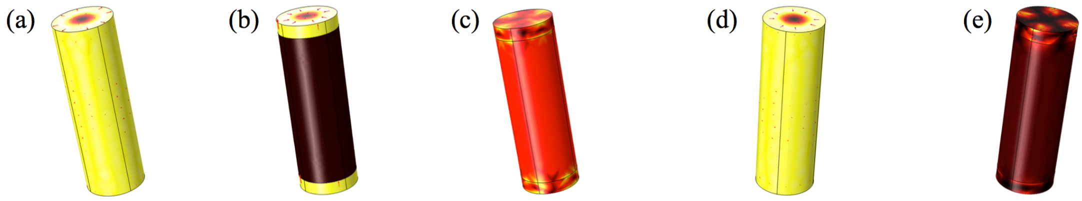

Figure 5: Heat map of surface loss for cylindrical cavity made with (a) copper only, (b) copper with high conductivity film on the wall side (the conductivity is 100 times higher than copper),(c) copper with high conductivity film on the wall side and dielectric cap on the top and bottom, (d) copper with high conductivity film on the whole cavity, (e) copper with high conductivity film on the whole cavity and dielectric cap on the top and bottom

	Quality factor
copper	21523.804
copper + high conductivity coating (wall)	66697.146
copper + high conductivity coating (wall) + dielectric cap	54158.212
copper + high conductivity coating (whole)	277928.43
copper + high conductivity coating (whole) + dielectric cap	247355.67

Table 2: Quality factor according to the various condition of the cavity.

4 Conclusion

The resonant frequency of the cylindrical cavity can be controlled by using the tuning rod. The use of a conductor rod can achieve wider frequency tuning range but has a mode localization problem. Employing one dielectric tuning rod seems a better option even with a bit narrower tuning range. The superconducting film coating looks very promising option to increase the quality factor of the cavity.

References

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