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Influence of Diamond and Silver as Cavity Resonator Wall Materials on Resonant Frequency

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ABSTRACT In this paper, the effect of diamond material and silver material as the cavity resonator walls on the resonant frequency has been analyzed. A closed rectangular waveguide can be used as a resonator with a source circuit inside it. The walls of the cavity are made from materials that adequate the dielectric and conductive losses. It is found that the rectangular waveguide frequency resonance decreases with increasing the relative permeability and relative permittivity of diamond and silver. The effect of magnetic susceptibility on the frequency resonant $f_{mn\ell}$ can be found based on relative permeability where $\chi = \mu_r - 1$.

Keywords: Rectangular Waveguide, Cavity, Electromagnetic, Resonant Frequency, Diamond, Silver.

I. INTRODUCTION

A cavity resonator is a hollow closed conductor containing electromagnetic waves (radio waves) that reflect back and forth between the cavity's walls, such as a metal box or a cavity within a metal block. When a radio wave source at one of the cavity's resonant frequencies is used, the opposing waves generate standing waves, and the cavity stores electromagnetic energy. Material property measurements are needed for a variety of applications in industry, medicine, and pharmaceuticals [1,2]. Chen et al. [3] are interested in exploring microwave electronics, specifically measurement and material characterization, and waveguide, dielectric, and coaxial cavity resonators have traditionally been used to characterise materials. Jha and Akhtar [4] investigated a generalized rectangular cavity technique for determining the complex permittivity of materials. A Guide to the Characterization of Dielectric Materials at RF and Microwave Frequencies was studied by Clarke et al. [5]. The electromagnetic field theory of guided waves was addressed by Collin [6]. Saeed et al. [7] are studied the complex permittivity characterization of materials within the waveguide cavity resonators. Konefal et al. [8] investigated the EM coupling between wires inside a rectangular cavity using multiple mode similar transmission line circuit theory. To determine the frequency that would be dependent on permeability, Miura et al. [9] utilized the harmonic resonance cavity perturbation approach. Hameed et al. [10,11] investigated the triple-mode wide-band band pass filter utilising both a triangular waveguide cavity and a simple perturbation in a rectangle waveguide cavity loaded with metallic particles. For a $\boldsymbol{60 - GHz}$ cavity-backed wide slot antenna, Gong et al. [12] found an empirical cavity dominant mode frequency formula. The magnetically tunable Ferrite loaded substrate integrated waveguide cavity resonator was studied by Adhikari et al. [13]. The study of waveguide and electromagnetic wave propagation has been studied in [14,15]. Frequency resonant for silver is showed [16,17]. The relative permeability and relative permittivity for some materials are shown in [18]. In this work, the influence of diamond and silver material as cavity resonator walls on the resonant frequency is investigated. This paper is structured as follows. Section 2 provides the problem formulation of the rectangular waveguide cavity resonator. Section 3 is devoted to the results and discussion. Section 4 summarizes the concluding remarks.

II. PROBLEM FORMULATION

Rectangular Waveguide Cavity Resonator can be used using a waveguide, where the source circuit (s.c.) is placed inside the dimensions. The waveguide cavity is closed on both sides and has dimensions of a in the x-axis, b in the y-axis, and d in the z-axis. The total electromagnetic energy may be stored at a resonant frequency in this cavity, like the electromagnetic wave characteristics of nanotubes **[19]**, and the metallic walls are dielectric/conductive losses. The frequency of the resonators is determined, as well as the resonator's quality.

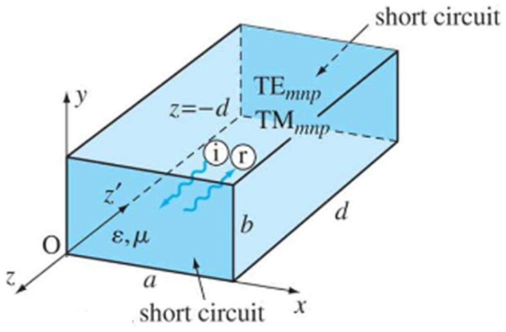

FIGURE 1. **Rectangular wave guide cavity resonator.**

With constant amplitudes A^- and A^+, the transverse electric field $E_t(x,y,z)$ can assume the following shape **[20]:**

$$E_t(x,y,z) = e^-(x,y)\left(A^+e^{-iz\beta mn} + A^-e^{+iz\beta mn}\right) \quad (1)$$

where the transverse component (x,y) is denoted by $e^-(x,y)$. The phase constant for β_{mn} modes in a rectangular waveguide is

$$\beta_{mn} = \sqrt{k_{mn\ell}^2 - k_c^2} = \sqrt{k_{mn\ell}^2 - \left(\frac{m\pi}{a}\right)^2 - \left(\frac{n\pi}{b}\right)^2} \quad (2)$$

where $k_{mn\ell}^2 = \omega^2\mu_r\varepsilon_r$ is the cavity's wave number, μ_r and ε_r are the relative permeability and permittivity of the material from which the waveguide was formed, respectively. Here m, n and ℓ indicate that only discrete solutions for the transverse wavenumber are allowed, and the electromagnetic field corresponding to $(m,\ n,\ \ell)$ is the $TE_{mn\ell}$ mode. E_x and E_y are the source circuits of the transverse field.

and boundary conditions:

$$E_t = 0 \text{ at } z = 0, \quad (3)$$

$$E_t = 0 \text{ at } z = d. \quad (4)$$

Substituting from (3) into (1), we obtain

$$e^-(x,y)(A^+ + A^-) = 0 \quad (5)$$

$$\Rightarrow A^- = -A^+. \quad (6)$$

Similarly, by substituting (4) into (1), and using (6), we obtain

$$e^-(x,y)\left(-A^+\left(e^{id\beta mn} - e^{-id\beta mn}\right)\right) = 0 \quad (7)$$

$$e^-(x,y)\left(-A^+(2i\,sin(d\beta_{mn}))\right) = 0 \quad (8)$$

$$\Rightarrow \beta_{mn} = \left(\frac{\pi\ell}{d}\right),\ \ell = 1,2,\ldots \quad (9)$$

Then, the cavity's wave number:

$$k_{mn\ell} = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{\ell\pi}{d}\right)^2},\ m = 0,1,2,\ldots$$

$$,\ n = 0,1,2,\ldots,\ \text{and } \ell = 1,2,\ldots,\ \text{but } (m,\ n) \neq (0,0). \quad (10)$$

So, the frequency resonant

$$f_{mn\ell} = \frac{ck_{mn\ell}}{2\pi\sqrt{\mu_r\varepsilon_r}} = \frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{\ell\pi}{d}\right)^2}. \quad (11)$$

Because it is the dominant waveguide mode for rectangular waveguide **[21]**, the lowest dominant resonant frequency for TE_{101} mode will be f_{101}. As a result, when $\ell = 1$, the guide wavelength will be $d = \frac{\pi\ell}{\beta_{mn}}$, then

$$d = \frac{\pi}{\beta_{mn}} = \frac{\pi}{2\pi/\lambda g} = \frac{\lambda g}{2}. \quad (12)$$

III. RESULTS AND DISCUSSION

1- DIAMOND EFFECT ON FREQUENCY RESONANT

If we consider that the cavity is made from diamond material with relative permittivity and relative permeability as $\varepsilon_r = 5.5 - 10$ and $\mu_r = 0.585 - 1.063$ respectively. In Fig. 2, the frequency resonant $f_{mn\ell}$ decreases by increasing the relative permettivity, where the tangent line decreases with increasing the relative permeability μ_r from $\mu_r = 0.585$ to $\mu_r = 1.063$.

The frequency resonant $\boldsymbol{f_{mn\ell}}$ decreases when the relative permeability $\boldsymbol{\mu_r}$ increases from $\boldsymbol{\mu_r = 0}$ to $\boldsymbol{\mu_r = 1.063}$ as shown in Fig. 3. The curve enhancing has occurred at low values of permittivity, $\boldsymbol{i.e.}$, the behaviour of $\boldsymbol{f_{mn\ell}}$ depends on the value of $\boldsymbol{\varepsilon_r}$, where the $\boldsymbol{\varepsilon_r}$ was $\boldsymbol{\varepsilon_r = 5.5}$ and then $\boldsymbol{\varepsilon_r = 10}$. Physically, that is true because the dielectric losses or permeability decreasing must lead to enhancing or increasing the frequency resonant. The importance of this relationship lies in the manufacture of the resonance cavity, where the material for the manufacture of its wall is carefully selected to reduce the loss from leakage of electric or magnetic fields. If we take a part of this effect when $\boldsymbol{\mu_r = 0.585 \to 1.063}$, it is possible to observe the decreasing relationship and the difference between the two curves at different values of electrical permittivity, as shown in Fig. 4.

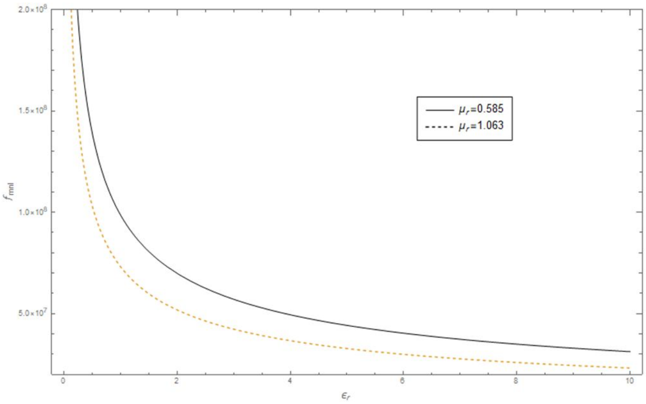

FIGURE 2. **Frequency resonant $f_{mn\ell}$ versus the relative permittivity ε_r of diamond at $l = 1,\ m = 2,\ n = 3,\ a = 5,\ b = 10,\ d = 15$ and $\varepsilon_r = 0 \to 10$.**

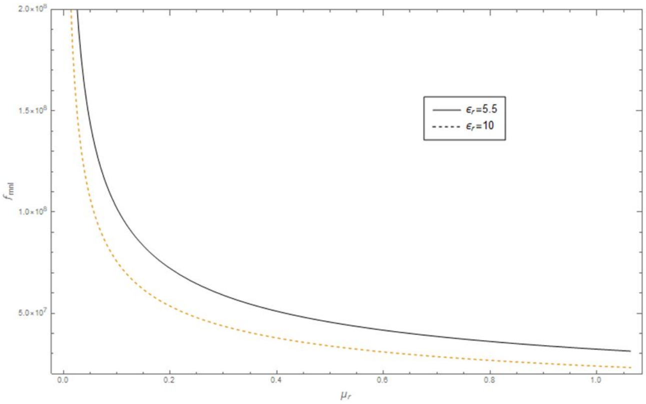

FIGURE 3 **Frequency resonant $f_{mn\ell}$ versus the relative permeability μ_r of diamond at $l = 1,\ m = 2,\ n = 3,\ a = 5,\ b = 10,\ d = 15$ and $\mu_r = 0 \to 1.063$.**

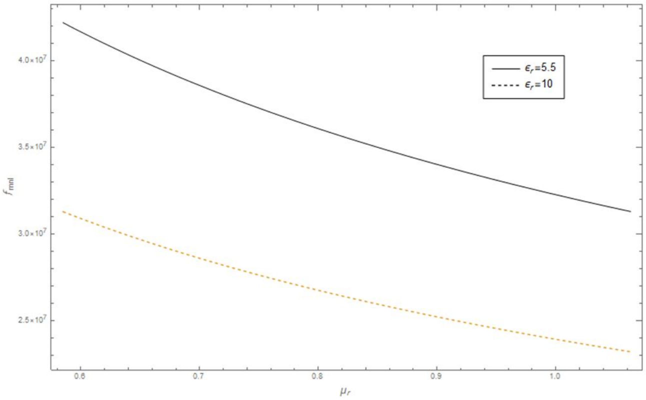

FIGURE 4. **Frequency resonant $f_{mn\ell}$ versus the relative permeability μ_r of diamond at $l = 1,\ m = 2,\ n = 3,\ a = 5,\ b = 10,\ d = 15$ and $\mu_r = 0.585 \to 1.063$.**

What if the manufacturing material was changed from diamond to silver?

Only the electrical permittivity and permeability change, but the change in the horizontal and vertical scale of the behavior will be observed as the values of these materials converge.

2- SILVER EFFECT ON FREQUENCY RESONANT

The silver material with relative permittivity $\varepsilon_r = 5.25974$ and relative permeability $\mu_r = 0.99998$ has been discussed in Figs. 5 and 6.

Fig. 5. displays the influence of the frequency resonant $f_{mn\ell}$ versus the relative permeability μ_r , while Fig. 4. shows the relationship between $f_{mn\ell}$ and the relative permittively ε_r. It is found that by increasing both relative permeability and relative permittivity, the frequency resonant $f_{mn\ell}$ decreases, as shown in Fig. 5. And 6 respectively. The extent to which the effect behaves depends on the values of permeability and permittivity. Based on the relative permeability, we can also check the effect of magnetic susceptibility where

$$\chi = \mu_r - 1.$$

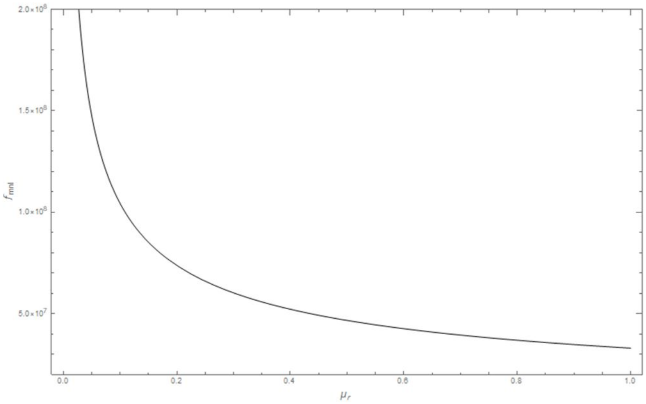

FIGURE 5. **Frequency resonant $f_{mn\ell}$ versus the relative permeability μ_r of silver at $l = 1,\ m = 2,\ n = 3,\ a = 5,\ b = 10,\ d = 15,\ \varepsilon_r = 5.25974$ and $\mu_r = 0 \to 0.99998$**

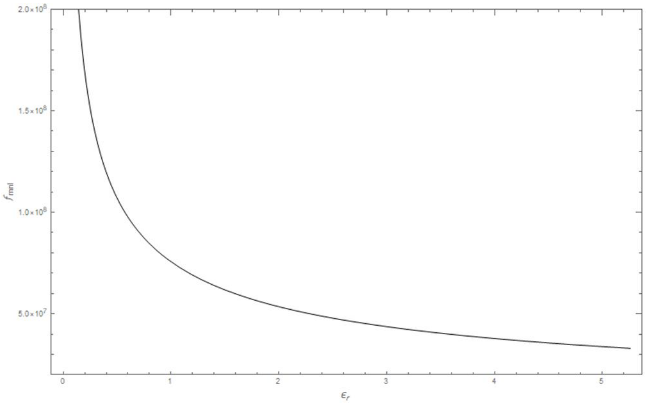

FIGURE 6. **Frequency resonant $f_{mn\ell}$ versus the relative permeability μ_r of diamond at $l = 1$, $m = 2$, $n = 3$, $a = 5$, $b = 10$, $d = 15$ and $\mu_r = 0.585 \rightarrow 1.063$**

IV. CONCLUSION

This paper investigates the effect of diamond material and silver material as the cavity resonator walls on the resonant frequency and it is found that the rectangular waveguide frequency resonance decreases with increasing the relative permeability and relative permittivity of diamond and silver. The tangent line decreases as the relative permeability μ_r increases. The behavior of $f_{mn\ell}$ depends on the value of ε_r . As dielectric losses or permeability decrease, the frequency of resonance increases, or enhancing, and finally, the electromagnetic wave causes the frequency resonant $f_{mn\ell}$ to behave dependently on the values of permeability and permittivity.

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