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THE EFFECT OF MAGNETOELECTRIC COUPLING ON ATTENUATION CONSTANT OF SURFACE POLARITONS IN MULTIFERROICS

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Abstract: In this study, we analyse the attenuation constant in magneto electricmultiferroics. The attenuation constant is an important parameter since it determines the frequency region for surface or bulk modes. This parameter is also illustrating the confinement of surface polaritons on the materials surface. The attenuation constant is derived by solving Maxwell constant using the appropriate form of surface modes. In magnetoelectricmultiferroics, there are magnetic and electric susceptibility components which are interrelated by magnetoelectric coupling. Since the attenuation constant is depended on the susceptibilities, then the properties of the attenuation constant are affected by magnetoelectric coupling. We found that the existence of magnetoelectric coupling shift the frequency region where the surface modes of polaritons may exist.

Keywords: Magnetoelectric effect; Attenuation constant; Surface Modes; Polaritons; Multiferroics;

I. INTRODUCTION

The attenuation constant is an important parameter for surface modes of polaritons[1.2]. This parameter is an imaginary propagation vector component which is directed perpendicular and opposite to the surface of the materials. It reflects the confinement of surface polaritons at the involved material's surface. The high value of attenuation constant is illustrating the high confinement of surface polaritons. However, the imaginary value of attenuation constant describes the existence of the propagation vector component, which is perpendicular to the surface. It means that the propagation of the surface modes is not purely parallel to the surface. The frequency region with the purely real attenuation constant determines that the surface polaritons may exist. The purely imaginary attenuation constant leads to the bulk modes of polaritons.

Since the attenuation constant is representing the response of the materials to the external fields,especially electromagnetic fields, then this parameter is affected by the permittivity and the permeability of the materials. Magnetoelectricmultiferroic materials have ferroelectric and ferromagnetismsimultaneously[3,4].This type of material possesses both the magnetization and polarization. The electric polarization dipole is related to the magnetization of the spin system through magnetoelectric coupling constant. It means that the application of an external electric field changes not only the electric polarization, but also the magnetization in the spin system. Vice versa, the electric polarization can be driven by the applied external magnetic field. It is illustrating that the magnetoelectric coupling influences the permittivity and permeability components of magnetoelectricmultiferroics. The polaritons in multiferroics materials had studied previously [5.6].It was reported that the surface modes of magnetic polaritons could be driven by an electric field[7]. The magnetic field can also be used to shift the magnetic polaritons in multiferroics film. However, the effect of magnetoelectric coupling on attenuation constant had not discussed yet. In this study, we analyse the attenuation constant based on the existence of magnetoelectric coupling.

II. RESEARCH METHOD

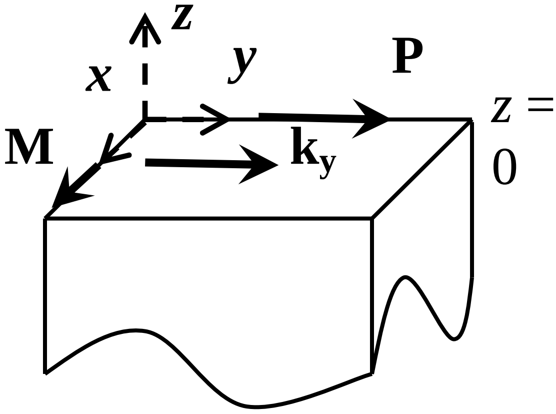

Figure 1.The geometry of this analysis. The multiferroic fills $z \leq 0$ with polarization in the z direction and the weak magnetization in the x direction. Here, the propagation of the surface mode is assumed in y direction.

In this study, The magnetoelectricmultiferroics is a ferroelectric-antiferromagnet with canted spin system. As illustrated in Fig.(1), the magnetoelectricmultiferroics fill a space with $z \leq 0$. The surface is placed on the$x - y$ plane at $z = 0$. Here, the multiferroic is ferroelectric-antiferromagnetic with canted spin system. We set the electric polarization $\vec{P}$ in the y-direction while the magnetization of weak ferromagnetism$\vec{M}$, which is resulted from the canted spin system, is directed in the x-direction. The plane of incidence is arranged in $y - z$ plane, then the surface mode propagates in they-direction.

Since the multiferroics have both electric polarization and magnetization simultaneously, then the phonon and magnetic polariton can be generated. Hence, we will focus on studying the attenuation constants related to these types of polaritons. Firstly, we discuss the attenuation constant of surface phonon polariton in this type of multiferroics. It is considered that the incoming electromagnetic waves have a magnetic component in x-direction (H_x). Hence, the involved electric components become E_y and E_z. Since the surface modes propagate along the multiferroic surface in the y-direction, then the surface modes can be assumed in the form

$$E, H \propto \exp(\beta z)\exp\left[i\left(k_y y - \omega t\right)\right] \quad \text{for } z \leq 0 \tag{1}$$

Where β represents attenuation constant of the magnetoelectricmultiferroics. Here, ω is frequency. If then, Eq.(1) is used in the curl forms of the Maxwell equations (Faraday and Ampere laws), the matrix equation is obtained as:

$$\begin{pmatrix} i\frac{\omega}{c}\mu_{xx} & \tilde{\beta} & -ik_y \\ \tilde{\beta} & i\frac{\omega}{c}\epsilon_{yy} & 0 \\ k_y & 0 & \frac{\omega}{c}\epsilon_{zz} \end{pmatrix}\begin{pmatrix} H_x \\ E_y \\ E_z \end{pmatrix} = 0 \tag{2}$$

where$\tilde{\beta} = \beta + i4\pi\chi_{xy}^{me}$ with χ_{xy}^{me} is magnetoelectric susceptibility. The solution of Eq.(2) for the case of phonon polaritons is obtained by setting the determinant of the constant matrix to zero which yields[6]

$$\epsilon_{zz}\left(\beta + i4\pi\chi_{xy}^{me}\frac{\omega}{c}\right)^2 = \epsilon_{yy}k_y^2 - \mu_{xx}\epsilon_{yy}\epsilon_{zz}\left(\frac{\omega}{c}\right)^2. \tag{3}$$

For the case of magnetic surface polaritons, the active field components are E_x, $H_y$and H_z. Here the electric field component E_x is perpendicular to the plane of incident. In this condition, the curl of the Maxwell equations result in the coupled equations as

$$\begin{pmatrix} i\epsilon_{xx}\frac{\omega}{c} & \beta & ik_y \\ \beta & -i\mu_{yy}\frac{\omega}{c} & \mu_{yz}\frac{\omega}{c} \\ ik_y & \mu_{yz}\frac{\omega}{c} & i\mu_{zz}\frac{\omega}{c} \end{pmatrix}\begin{pmatrix} E_x \\ H_y \\ H_z \end{pmatrix} = 0. \tag{4}$$

The solution is given by the relation as [6]

$$\mu_{zz}\beta^2 = \mu_{yy}k_y^2 - \epsilon_{xx}\left(\mu_{yy}\mu_{zz} - \mu_{yz}^2\right)\left(\frac{\omega}{c}\right)^2. \qquad (5)$$

The forms and determination of permittivity and permeability components of the material are derived and discussed in detail in Ref.[6]. It can be seen from Eq.(3) that the attenuation constant for surface phonon polaritons is directly related to the magnetoelectric interaction since there is an existence of magnetoelectric susceptibility. In surface magnetic polaritons case, the attenuation constant is related indirectly to the magnetoelectric interaction since the magnetoelectric susceptibility does not exist in Eq.(5). However, the susceptibility μ_{yz} appears from the canted condition, which is resulted from the magnetoelectric coupling. Hence, for the ferroelectric-antiferromagnetic with canted spin system, the attenuation constant β for surface magnetic polaritons is also affected by magnetoelectric interaction.

III. RESULTS AND DISCUSSION

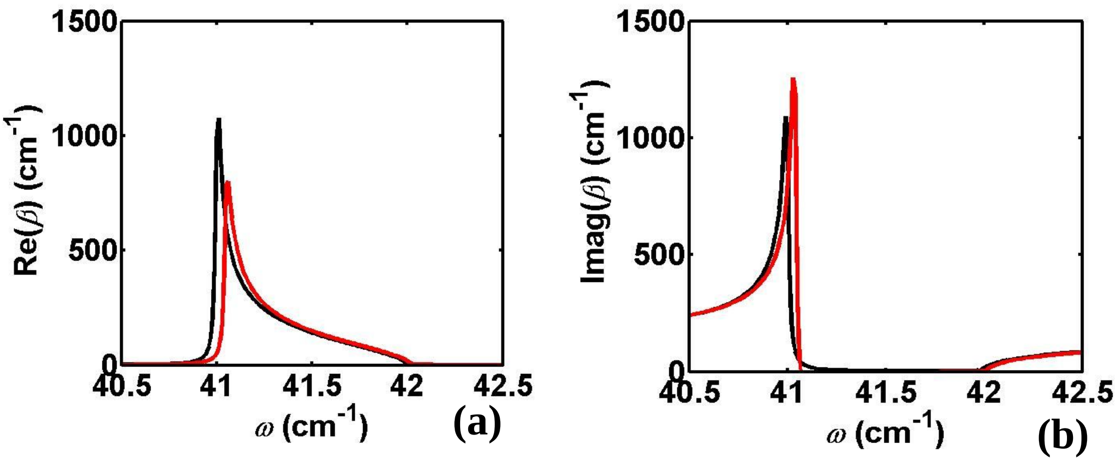

Figure 2.The attenuation constant for surface phonon polaritons. The real β is illustrated in (a) while imaginary attenuation constant is shown in (b). The black lines represent the attenuation constant with magnetoelectric coupling 1.47×10^{-5} cm^2/StatC while red lines are α with ME coupling 1.47×10^{-3} cm^2/StatC.

The attenuation constant for surface phonon polaritons is illustrated in Fig.(2) with the real parts in (a), and the imaginary part is shown in (b). In Fig.(2a), it can be seen that real attenuation constant is in the frequency interval between around 41 cm^{-1} to 42 cm^{-1} which illustrates that surface modes may be found in this frequency region. In the same frequency region, it is shown in Fig.(2b) that imaginary attenuation constant is nearly zero. It means that the propagation of surface modes is parallel to the y-direction.

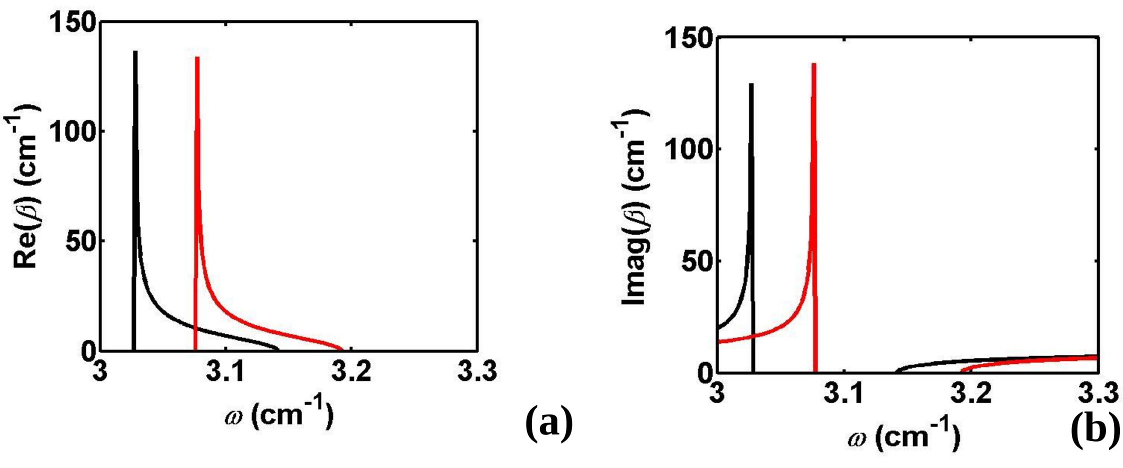

Figure 3.The attenuation constant for surface magneticpolaritons. The real β is illustrated in (a) while imaginary attenuation constant is shown in (b). The black lines represent the attenuation constant with magnetoelectric coupling 1.47×10^{-5} cm^2/StatC while red lines are α with ME coupling 1.47×10^{-3} cm^2/StatC.

The value of magnetoelectric coupling 1.47×10^{-5}cm^2/Stat C, which is represented by the black lines in Fig.(2) is weak. The resulted attenuation curve is similar to the attenuation curve without magnetoelectric coupling constant. We increased the magnetoelectric coupling constant to 1.47×10^{-3}cm^2/Stat C in the purpose to raise the magnetoelectric interaction effect.

The attenuation curves are illustrated by the red lines in Fig.(2).The magnetoelectricinteraction is directly affect the attenuation constant. The magnetoelectricinteraction leads to the existence of magnetoelectric susceptibility, and it is entering Eq.(3) as $i\chi_{xy}^{me}$. As a consequence, the real attenuation decreases and the imaginary βincreases near the resonance frequency when we set the attenuation constant at 1.47×10^{-3}cm^2/StatC. However, the magnetoelectric interaction also yields the magnetoelectric frequency as a part of resonance frequency. Since the magnetoelectric frequency is small compare to ferroelectric frequency, the shift of the frequency region is small for the magnetoelectriccoupling $\alpha=1.47 \times 10^{-3}$ cm^2/StatC.

The Attenuation constant for magnetic polaritons is shown in Fig.(3). The real part is illustrated in (a) while the imaginary part is drawn in (b). From the results above, itcan be seen that the surface modes for magnetic polaritons may be found in the frequency region between around 3.03 cm^{-1} to 3.15 cm^{-1} for magnetoelectric coupling 1.47×10^{-5} cm^2/StatC. Since in this frequency region the imaginary attenuation is zero, it illustrates that the surface modes propagate parallel to the surface in the y-direction.

The increase of magnetoelectric coupling to 1.47×10^{-3} cm^2/StatC shift up the frequency region (see Fig.(3)). It happens because the existence of magnetoelectric coupling leads to the appearance of magnetoelectric frequency in resonance frequency. Hence, it increases the value of resonance frequency which in turn shifts the frequency region. Since the magnetoelectric coupling in magnetic polariton in this study is directly affected the resonance frequency, then the frequency shift in this condition is broader than the frequency shift in the phonon polariton case.However, since the Eq.(5) does not have magnetoelectric susceptibility term, then the value of attenuation constant do not significantly change, as it can be seen in Fig(3a) for real βand Fig.(3b) for imaginary β.

IV. CONCLUSIONS

We had shown in this study, the effect of magnetoelectric interaction on attenuation constant in surface polaritons generated in multiferroics. It is found that magnetoelectric interaction results in the existence of magnetoelectric susceptibility in phonon polaritons, which in turn shift frequency region where surface modes may exist. In the case of surface magnetic polaritons, the magnetoelectric coupling generates the magnetoelectric frequency, which is then added to the resonance frequency. Then, this is also shifting the frequency region of surface modes.

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