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THE PROFILE OF TRANSVERSE ELECTRIC (TE) SURFACE MODES IN MAGNETOELECTRIC MULTIFERROICS

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Abstract— We present the numerical analysis of the profiles of surface polaritons generated on magnetoelectric multiferroics. The study focuses on transverse electric (TE) modes where the non-reciprocal behaviour appears in surface polaritons. The amplitude and the attenuation constant are very important parameters in defining the profiles of surface modes. The attenuation constant is calculated by solving Maxwell equations while the amplitudes are obtained by considering the continuity of the fields. We found that the localisation is strong at the frequency near resonant frequency since the attenuation constant is big. We are also found that the profiles of surface modes for two directions of propagation, which is opposite each other, are not the same. This result is illustrating the non-reciprocal behaviour of the TE surface modes generated on magnetoelectric multiferroics.

Keywords— Multiferroics; magnetoelectric; surface polaritons; TE modes; profiles;

I. INTRODUCTION

The surface polaritons which are the surface modes of a modified electromagnetic wave resulted from the coupling between electromagnetic waves and elementary excitation of materials are interesting to be studied [1]. Transverse electric (TE) surface polaritons, where the electric component of the waves is perpendicular to the plane of incident, are usually found in magnetic materialsnear its resonance frequency [2],[3]. Hence this type of polariton can be categorised as magnetic polariton. TE surface modes are interesting due to their localized property at the surface of the materials. Also, TE surface polaritons may possess non-reciprocality feature where the condition based on the direction of the propagations is not symmetric compared to the condition in the opposite direction [2],[3].

In the last decade, it is reported that this type of mode can also be found in magnetoelectric multiferroics [4]-[9]. Since magnetoelectric multiferroics possess electricity and magnetism simultaneously through magnetoelectric coupling, then they have two types of resonant frequencies: the electric and the magnetic resonant frequencies. Recently, the TE mode of surface polaritons generated in magnetoelectric multiferroicswas studied based on the dispersion relation to show the non-reciprocality of this mode[4]-[8]. It is found that the non-reciprocity appears when the geometry of the sample is semi-infinite [2],[3],[6].

Surface polaritons were also studied by analysing the calculated attenuated total reflection (ATR) to investigate the localisation of these modes in the multiferroics films [9]. The flipping of localization can be performed by applying the large electric field with the direction opposite to the electric polarisation.

Motivated to complete the information from the previous researches, we perform the numerical study of the surface modes by analysing the profile of surface modes. Using Maxwell equations and the boundary conditions at the surface of multiferroics, the amplitude of the involved waves can be derived. Then, the profile of surface modes is calculated numerically.

II. RESEARCH METHOD

In studying the profile of surface modes in multiferroics materials, we set the surface of the material in *x-y* plane at $z = 0$ direction. Here, the multiferroics are ferroelectric-canted antiferromagnetic with the electric polarisation is in *y* direction while the canted antiferromagnetic yields weak ferromagnetism in *x* direction. We assume that medium outside the material is vacum and the surface modes propagate in *y* direction. The configuration of the research is sketched in Figure 1.

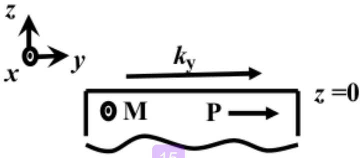

Fig.1 The sketched geometry used in the research, The surface of materials lied in *x-y* plane. Multiferroics possess weak ferromagnetism in *x* direction and electric polarisation in*y* direction. The waves are also set to propagate in y direction, parallel to electric polarisation

Based on the configuration in Fig.1,, the required solutions for TE modes with the localization at the surface of multiferroicsare assumed to be

$$\vec{E} = \begin{cases} \hat{\imath} E_0 e^{-\beta_0 z} e^{i(k_y y - \omega t)} & z > 0 \\ \hat{\imath} E_m e^{\beta z} e^{i(k_y y - \omega t)} & z < 0 \end{cases} \qquad (1)$$

whereβ represents the attenuation constant of the multiferroics inTE modes and$\beta_0$is attenuation constant for vacum. Both attenuation constants are easily derived from Maxwell equations as [6]

$$\beta = \left\{ \left[\mu_{yy} k_y^2 - \varepsilon_{xx} \left(\mu_{yy} \mu_{zz} - \mu_{yz}^2 \right) \left(\frac{\omega}{c} \right)^2 \right] / \mu_{zz} \right\}^{1/2} \qquad (2)$$

and

$$\beta_0 = \left[k_y^2 - \left(\frac{\omega}{c} \right)^2 \right]^{1/2}. \qquad (3)$$

Here, the attenuation constant β imposes surface waves to get weaker as the waves propagate down into the materials. Hence, parameter β ensures surface modes to be localized at the surface. In the formulation of attenuation constant above, variables ε_{ii} and μ_{ii} with $i = x, y, z$ represent permittivity and permeability components of the multiferroic material which are derived from the equation of motions using the suitable expression of an energy density (we refer to the previous report [6] for detailed calculation). The susceptibility components which are illustrating the transverse electric condition in multiferroic material with canted spin system are expressed as [6]

$$\chi_{yy}^m = \frac{2\omega_s(\omega_a \cos\theta + 2\omega_{me} \sin 2\theta)}{(\omega_M^2 - \omega^2)}, \quad (4)$$

$$\chi_{zz}^m = \frac{2\omega_s(\omega_{me} \sin 2\theta)}{(\omega_M^2 - \omega^2)} \qquad (5)$$

and

$$\chi_{yz}^m = -\chi_{zy}^m = \frac{i 2\omega_s \omega \sin\theta}{(\omega_M^2 - \omega^2)}. \qquad (6)$$

Here, the permeability is related by the relation $\overleftrightarrow{\mu} = \overleftrightarrow{I} + 4\pi\overleftrightarrow{\chi}$ with I is identity matrix. The frequencies are defined as follow: ω_s is a frequency from sub-lattice magnetization of the antiferromagnet phase, ω_a symbolise anisotropy frequency, ω_{me}represents a frequency from the magnetoelectric interaction and $\omega_M$is magnetic resonant frequency. An angle θ represents canting angle of the antiferromagnet. In analysing the profile of surface modes numerically, we use the values of frequency ω and propagation component $k_y$from the curve of surface polaritons from the previous study [6]. The amplitude E_0 and E_m are obtained by employing appropriate boundary conditions at the surface of the material($z = 0$). Then, Eq.(1) is used to calculate the profile of surface modes.

III. RESULT AND DISCUSSION

In the numerical calculation, we use the values of frequency as[9]: $\omega_s = 0.28$ cm^{-1}, $\omega_a = 0.09$ cm^{-1}, $\omega_{me} = 0.14$ cm^{-1} and $\omega_M = 3.02$ cm^{-1} which are illustrating multiferroic BaMnF$_4$. The canted angle of the sub-lattice magnetization is $\theta = 3$mrad.

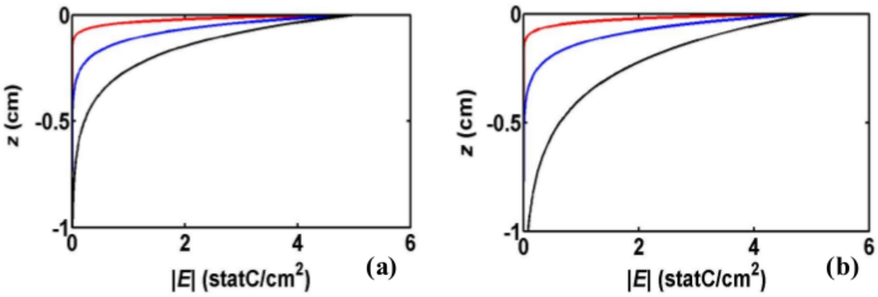

Fig. 2 The profile of TE surface modes is illustrated in three different frequencies. The black lines are profiles with frequency at 3.1 cm^{-1}, the blue lines are profiles with $\omega = 3.07$ cm^{-1} and the red lines are profiles with $\omega = 3.05$ cm^{-1}. Part (a) is illustrating the profiles of the surface modes with the propagation in $+k_y$ direction while part (a) is showing the profiles of surface mode which propagate in $-k_y$ direction.

The calculated profiles of TE surface modes which are resulted from Eq.(1) are presented in Fig.2. In each direction of propagation ($+k_y$ in fig.2a&$-k_y$in fig.2b) we analyse profile for three frequencies: 3.05 cm^{-1}, 3.07 cm^{-1} and 3.1 cm^{-1}. The related values of propagation vector$k_y$are obtained by solving dispersion relation which is formulated in previous report [6]. Each profile in Fig.2 describes that the value of surface mode, $|E|$, possesses maximum value at the surface ($z = 0$) and the value of $|E|$ decreases as it goes farther from the surface. This feature expresses the localisation of the surface modes at the surface of multiferroics. It is shown in both fig.2a and fig.2b that e profile with the frequency 3.05 cm-1 (red lines) goes to zero faster than other profiles with lower frequency (blue and black curves).

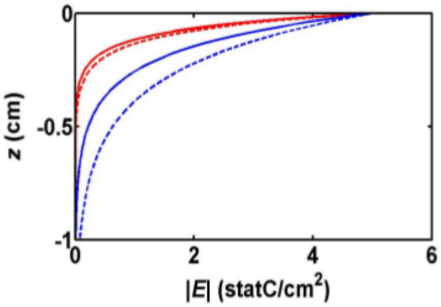

Fig. 3Difference between profile in $+k_y$ direction of propagation (thick solid lines) and the profile of surface mode which propagates in $-k_y$ direction(dashed lines). Red lines represent profiles with frequency3.05 cm^{-1} while blue lines illustrate profileswith frequency 3.07 cm^{-1}.

It can be understood by examining the attenuation constant β for the involved frequency using Eq.(1). Since attenuation constant involves is$E \sim e^{-\beta z}$, then the value of $|E|$ profile attenuates more rapidly when β increases. In $+k_y$ propagation,the frequencies 3.05 cm^{-1}, 3.07 cm^{-1} and 3.1 cm^{-1}yield β with values: 44.66 cm^{-1}, 13.72 cm^{-1} and 6.23 cm^{-1}. This agrees with the previous report [6], where it is stated that the attenuation constant increases as frequency is shifted approaching resonant frequency (here, the resonant frequency is around 3.02 cm^{-1}).

In figure 3, we compare the shape between profiles in $+k_y$ propagation (thick lines) and profiles in $-k_y$propagation (dashed lines) for frequencies 3.05 cm^{-1} (red lines) and3.07cm^{-1}(blue lines). It is shown that the profiles of the two opposite directions are different even though their frequencies are the same, ie: $+k_y(\omega) \neq -k_y(\omega)$. We argue that this feature is similar to the condition where the surface modes obey $\omega(+k_y) \neq \omega(-k_y)$. Hence, the condition of the profiles above is also illustrating non-reciprocal behaviour of TE surface polaritons in multiferroics.It can also be seen that the profile difference is increasing when the frequency is risen. It means that non-reciprocity is getting higher when the frequency is shifted further from resonant frequency.

IV. CONCLUSION

The surface modes with frequency near the resonant frequency of the materials have high value of attenuation constant which gives high locality at the surface. We have also shown that the profiles of surface polaritons can be used to determine the non-reciprocity of the surface modes. The non-reciprocity can be stated as $+k_y(\omega) \neq -k_y(\omega)$.

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REFERENCES

1. D. Mills and E. Burstein, “Polaritons: the electromagnetic modes of media,” *Rep. Prog. Phys.*, vol. 37, pp. 817, 1974.
2. A. Harstein, E. Burstein, A.A. Maradudin, R. Brewer and R. F. Wallis, “Surface polaritons on semi-infinite gyromagnetic media,” *J. Phys. C: Solid State Phys.*, vol. 6, pp. 1266, 1973
3. R. E. Camley and D. L.Mills, “Surface Polaritons on uniaxial antiferromagnets,” *Phys. Rev. B*, vol. 26, pp. 1280, 1982.
4. A.S. Savchenko, S. V. Tarasenko, T. N. Tarasenko and K. N. Primak, “Features of the reflections of a bulk TM electromagnetic wave on a nongyrotopicmultiferroics slab,” *Low TempPhys*, vol.32, pp. 61, 206.
5. A.S. Savchenko and S. V. Tarasenko, “Features of the reflections of TE waves from a nongyrotopicmultiferroics slab,” *Low TempPhys*, vol.33, pp. 412, 2007.
6. V. Gunawanand R Stamps, “Surface and bulk polaritons in a PML-type magnetoelectric multiferroics with canted spins: TE and TM polarizations,” *J.Phys: Condens Matter.*, vol. 23, pp. 105901, 2011.
7. V. Gunawan and R Stamps, “Mixed modes of surface polaritons in a PML-type magnetoelectric multiferroics with canted spins,” *J. Phys: Condens Matter.*, vol. 24, pp. 406003, 2012.
8. V. Gunawan and H. widiyandari, “TE and TM polaritons in multilayer system comprise of a PML-type magnetoelectric multiferroics and ferroelectrics,” *J. Phys: Conf.Ser.*., vol. 710, pp. 012037, 2016.
9. V. Gunawan and H. widiyandari, “Polaritons in magnetoelectric multiferroics films: switching magnonpolaritons using an electric field,” *Ferroelectrics*, vol. 510, pp. 16, 2017.

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