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The Conditions of Maximum Increase Evanescent Waves near the Surface of the 1D Magnetic Photonic Crystal

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It has been shown that the condition of the maximum increase of the intensity of TM or TE evanescent electromagnetic waves at the interface between the 1D magnetic photonic crystal and non-magnetic insulator are exist.

Keywords: Magnetic photonic crystal, Evanescent electromagnetic waves, Maximum increase of the intensity.

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1. INTRODUCTION

Evanescent waves in electrodynamics of photonic crystals have a special role as responsible for the formation of a number of abnormal wave properties of these media. Such properties primarily include the negative effect of optical refraction [1] and the formation of photon tunneling zones [2, 3]. Therefore the search for possibility to increase the intensity of this type of waves is of special interest. However, most of the studies that are devoted to this subject, exclusively related to the non-magnetic photonic crystals. At the same time in recent years, the study of various aspects of the propagation of electromagnetic waves in one-, two- and three-dimensional magnetic photonic crystals (MPC) is one of modern magnetooptic sections, which actively developing. This, in particular, due to the possibility of purposeful and effective influence on the propagation and localization of electromagnetic waves in such media using external parameters: field, pressure and temperature which are easily realizable in practice. This fact is important for the development of nano-optics, tunneling spectroscopy and electrodynamics of metamaterials. Special interest from the point of view of practical applications in this respect are the MPC, which by their electromagnetic characteristics are bianisotropic media. This is due to the fact that in this case a considerable part of the coefficients in the material equations will have resonance characteristics, depending on frequency.

The aim of this work is to determine the conditions under which the maximum (fourfold) increase in the intensity of TM or TE evanescent waves can be achieved inside total internal reflection region for interface between the semi-infinite 1D two-component MPC type "non-magnetic insulator - antiferromagnet with compensated antisymmetric magnetoelectric interaction".

It should be noted that such structure of magnetoelectric interaction can be is also characteristic for one-dimensional magnetic photonic crystals type "ferromagnetic - nonmagnetic with antiferromagnetic interlayer ordering" of tangentially magnetized ferromagnetic layers.

2. BASIC RELATIONS

The presence in the antiferromagnetic (AFM) antisymmetric magnetoelectric interaction leads to the fact that spin wave excitations, not only magnetic but also the electric type can propagate in the AFM layers . As an example of MPC, we consider a one-dimensional magnetic superlattice of alternating layers with antiferromagnetic structure $4_z^- 2_x^+ I^-$ [4, 5] and the non-magnetic layers of dielectric. We consider the case the compensated magnetic ground state (OZ -easy magnetic axis $\vec{L}_0 || OZ$, $\vec{L}_0$ - the equilibrium antiferromagnetic vector) and magnetic are not compensated, formed in the constant external magnetic field orthogonal OZ (eg. $\vec{H}_0 || OX$). Calculations show that in this case the material equations for easy axis (EA) AFM with a structure can be represented as

$$\vec{M} = \begin{pmatrix} \chi_{xx}(\omega) & 0 & 0 \\ 0 & \chi_{yy}(\omega) & \chi - i\chi_*(\omega) \\ 0 & i\chi_*(\omega) & \chi_{zz}(\omega) \end{pmatrix} \cdot \vec{H} + \begin{pmatrix} 0 & \beta_4(\omega) & -i\beta_1(\omega) \\ \beta_3(\omega) & 0 & 0 \\ i\beta_2(\omega) & 0 & 0 \end{pmatrix} \cdot \vec{E},$$

$$\vec{P} = \begin{pmatrix} \alpha_{xx}(\omega) & 0 & 0 \\ 0 & \alpha_{yy}(\omega) & -i\alpha_*(\omega) \\ 0 & i\alpha_*(\omega) & \alpha_{zz}(\omega) \end{pmatrix} \cdot \vec{E} + \begin{pmatrix} 0 & \beta_3(\omega) & -i\beta_2(\omega) \\ \beta_4(\omega) & 0 & 0 \\ i\beta_1(\omega) & 0 & 0 \end{pmatrix} \cdot \vec{H}. \qquad (2.1)$$

Where for magnetically compensated state

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$\beta_3(\omega) = \beta_4(\omega),\ \beta_1(\omega) = \beta_2(\omega)$.

For non-magnetic medium:

$$\vec{M} = \tilde{\chi} \cdot \vec{H}, \qquad \vec{P} = \tilde{\alpha} \cdot \vec{E}. \qquad (2.2)$$

We consider the interface for two half-spaces $\eta = 0$, where η - is the current coordinate along the normal to the phase interface $\vec{n}$, assuming that the lower half space is occupied by the one dimensional MPC. We restrict ourselves only to analysis of magneto-optical configurations that admit the independent propagation of the TM-type ($\alpha = p$) and TE-type ($\alpha = s$) polaritons in the MPC. In this case, the expression for surface impedance (admittance for TE-wave) Z_α can be represented in the form

$$Z_p = \frac{T_{21}^P}{e^{ik_p d} - T_{22}^P}$$
$$Z_s = \frac{T_{21}^s}{e^{ik_s d} - T_{22}^s}, \qquad (2.3)$$

where T_{ik}^α is the transfer matrix relating the tangential components of the vectors of magnetic $\vec{H}$ and electric $\vec{E}$ fields in the beginning and at the end of the elementary period d of the 1D MPC under consideration. In the discussed case, it has the following structure (k_α ($\alpha = p,s$) – Bloch number):

$$\hat{T} = \begin{pmatrix} T_{11}^p & T_{12}^p & 0 & 0 \\ T_{21}^p & T_{22}^p & 0 & 0 \\ 0 & 0 & T_{11}^s & T_{12}^s \\ 0 & 0 & T_{21}^s & T_{22}^s \end{pmatrix} \qquad (2.4)$$

If the MPC is a two component (medium A and medium B) superlattice, then

$$T_{ik}^\alpha = A_{il}^\alpha B_{lk}^\alpha,\ (i,\ l,\ k = 1,\ 2) \qquad (2.5)$$

where A_{lk}^α and are B_{il}^α the transfer matrices relating the tangential components of vectors for the layer of medium A with thickness d_A and the layer of medium B with thickness d_B, respectively, that form the elementary period of the binary MPC under consideration ($d = d_A + d_B$):

$$\hat{A} = \begin{pmatrix} \mathrm{ch}\left(q_A^\alpha d_A\right) + \frac{Z_{A+}^\alpha + Z_{A-}^\alpha}{Z_{A+}^\alpha - Z_{A-}^\alpha}\mathrm{sh}\left(q_A^\alpha d_A\right) & -\frac{2}{Z_{A+}^\alpha - Z_{A-}^\alpha}\mathrm{sh}\left(q_A^\alpha d_A\right) \\ \frac{2Z_{A+}^\alpha Z_{A-}^\alpha}{Z_{A+}^\alpha - Z_{A-}^\alpha}\mathrm{sh}\left(q_A^\alpha d_A\right) & \mathrm{ch}\left(q_A^\alpha d_A\right) - \frac{Z_{A+}^\alpha + Z_{A-}^\alpha}{Z_{A+}^\alpha - Z_{A-}^\alpha}\mathrm{sh}\left(q_A^\alpha d_A\right) \end{pmatrix}; \qquad (2.5)$$

$$\hat{B} = \begin{pmatrix} \mathrm{ch}\left(q_B^\alpha d_B\right) & -\frac{1}{Z_B^\alpha}\mathrm{sh}\left(q_B^\alpha d_B\right) \\ -Z_B^\alpha \mathrm{sh}\left(q_B^\alpha d_B\right) & \mathrm{ch}\left(q_B^\alpha d_B\right) \end{pmatrix};$$

where Z_{A+}^α and Z_{A-}^α are the surface impedances of the TM-type ($\alpha = p$) or the surface admittances of TE-type ($\alpha = s$) normal polariton wave at the upper and lower boundaries of the layer of AFM (eg. [4] for $\vec{L}_0 \,||\, \vec{n} \,||\, OZ,\ \vec{k} \in YZ$), and q_i^α i ($i = A, B$), is the inverse propagation depth of the wave into medium i in direction $\eta < 0$, Z_B^α - is the surface impedance (admittance) of nonmagnetic medium of MPC.

3. RESULT AND DISCUSSION

Analysis of the amplitude transmission coefficient [6] showed that the condition maximum increase evanescent wave TM ($\alpha = p$) or TE ($\alpha = s$) type is defined by

$$T_{21}^\alpha = 0, \qquad (3.1)$$

which leads to, $|W_\alpha| = 2$ i.e. a fourfold increase of the evanescent wave intensity.

It is easy to convince that, due to (3.1), we can write for the normal component of the energy flow of wave $\vec{P}_\alpha$ with polarization $\alpha = p, s$ on the external surface of the MPC ($\eta = 0$) for any time instant in this case:

$$\left(\vec{P}_\alpha \vec{n}\right) = 0,\ \phi_\alpha = 0, \qquad (3.2)$$

where ϕ_α is the phase incursion for the TM-type or TE-type polarized body wave reflected from the MPC surface in total internal reflection conditions. For the conventionally considered Tamm surface polaritons at the PC spatially uniform medium interface [7,8], we can write relations

$$\left(\left\langle \vec{P}_\alpha \right\rangle \vec{n}\right) = 0,\ \phi_\alpha \neq 0, \qquad (3.3)$$

where $\left\langle \vec{P}_\alpha \right\rangle$ is the flow averaged by the oscillation period.

The combination of condition (3.2) and the collective character of formation of surface wave under consideration allowing for [9] makes it possible to call it a Tamm surface wave with TM-type or TE-type polarization.

4. CONCLUSION

Thus in this report, as an example of 1D two-component MPC type "non-magnetic insulator - antiferromagnet with compensated antisymmetric magnetoelectric interaction", it is shown, that there exist conditions under which the maximum increase of evanescent waves on surface of 1D MPC are possible at total internal reflection.

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REFERENCES

1. J.D. Joannopoulos, R.D. Meade, J.N. Winn, *Photonic Crystal* (Singapore: Princenton University Press: 2008).
2. Liang Wu, Sailing He, Linfang Shen, *Phys. Rev. B.* **67**, 235103 (2003).
3. D. Bria, B. Djafari-Rouhani, A. Akjouj, L. Dobrzynski, J.P. Vigneron, E.H. El Boudouti,. A. Nougaoui, *Phys. Rev. E.* **69**, 066613 (2004).
4. D.V. Kulagin, G.G. Levchenko, A.S. Savchenko, A.S. Tarasenko, S.V. Tarasenko, and V.G. Shavrov, *J. Exp. Teor. Phys.* **141**, 540 (2012).
5. V.D. Buchel'nikov, V.G. Shavrov, *J. Exp. Teor. Phys.* **109**, 706 (1996).
6. L. Brehovskikh, *Wave in Layered Media* (Academic: New York: 1980).
7. F.G. Bass, A.A. Bulgakov, and A.P. Tetervov, *High Frequency Properties of Semiconductors with Superlat tices* (Nauka, Moscow, 1988) [in Russian].
8. a) A.P. Vinogradov, A.V. Dorofeenko, A.M. Merzlikin, V.I. Alshits, V.N. Lyubimov, and A. Radowicz, *J. Exp. Teor. Phys.* **104**, 9 (2007), b) A.P. Vinogradov, A.V. Dorofeenko, A.M. Merzlikin, A.A. Lisyanskii, *Phys. Usp.* **53**, 243 (2010).