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Surface polaritons at the interface of gyrotropic and nonlinear isotropic media

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Abstract. Surface polaritons at the interface of gyrotropic and non-linear isotropic media are investigated. Dispersion equation and existence conditions for TE surface polariton modes are obtained.

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Surface polaritons being the electromagnetic excitations localized near the interface at a distance of the order of wavelength can be tentatively divided into three classes. First of them represents well studied surface waves at the interface of isotropic media with opposite signs of dielectric permittivities and strong frequency dispersion (see [1]). Surface polaritons at the interface of nonlinear media can be referred to the second class. They may be exited even in spectral range, where permittivity and permeability of adjoining media are positive. Thus, in work [2] it was shown, that for exciting surface polaritons at the interface of nonlinear and isotropic media it is necessary to exceed some threshold value of field intensity.

Not long ago the third class of surface polaritons was theoretically predicted [3, 4], which appear owing to anisotropy of contacting materials and which are called singular surface electromagnetic waves. Unlike surface electromagnetic waves of the first class, singular surface polaritons can be excited in bianisotropic linear materials with positively definite dielectric permittivity and magnetic permeability tensors ε and μ when dispersion is little.

Today's there are studied only surface polaritons in several types of anisotropic media. So, surface electromagnetic waves at the interface of an uniaxial crystal and an isotropic medium were studied in papers [3, 4]. Later surface polaritons ware studied at the interface formed by different cuts of the same uniaxial crystal [5, 6, 7]. Such interface can be formed if uniaxial crystal is divided in half by a plane passing through its optical axis and then parts of the crystal are turned around each other. Recently surface polaritons at the interface of gyrotopic media was investigated [8].

Surface polaritons at the interface of nonlinear and anisotropic (gyrotropic) media are not enough examined.

In this paper we study TE mode of surface polariton at the interface of nonlinear and gyrotropic media (electric field vector in TE wave is perpendicular to the plane formed by the normal to the interface and the propagation direction).

Let nonlinear medium with permittivity tensor $\varepsilon_n = \varepsilon' + \beta \boldsymbol{E}^2$ is situated in the upper half-space $z > 0$ and gyrotropic medium is characterized by the following dielectric permittivity and magnetic permeability tensors ε and μ, and the gyrotropy tensor α

$$\varepsilon^{-1} = a + (b-a)\boldsymbol{q} \otimes \boldsymbol{q}, \qquad \mu = \mu 1, \qquad \alpha = ig\boldsymbol{q}^{\times}, \tag{1}$$

where $a = 1/\varepsilon_\perp$, $b = 1/\varepsilon_{||}$, $\boldsymbol{q}$ being unit vector of optical axis. Gyrotropic is situated in lower halfspace $z < 0$. Medium characterized by tensors of classes (1) corresponds to the symmetry crystal types 3 m, 4 mm and 6 mm. In this work we consider case when optical axis perpendicular to the boundary (unit vector $\boldsymbol{b}$, $\boldsymbol{a}$, $\boldsymbol{q}$ are directed along Cartesian coordinate axes x, y, z with beginning in the interface plane).

In nonlinear medium ($\beta > 0$) solution of Maxwell equations can be found through hyperbolic function:

$$\boldsymbol{E}^n = \boldsymbol{a}\sqrt{\frac{2\eta}{\beta}}\cosh^{-1}\left[\frac{\omega}{c}\sqrt{\eta}\,(z - z_0)\right]\exp\left[i\,(\omega t - kx)\right],$$
$$\boldsymbol{H}^n = \left(-k\frac{c}{\omega}\boldsymbol{q} - i\sqrt{\eta}\tanh\left[\frac{\omega}{c}\sqrt{\eta}\,(z - z_0)\right]\boldsymbol{b}\right)\sqrt{\frac{2\eta}{\beta}}\cosh^{-1}\left[\frac{\omega}{c}\sqrt{\eta}\,(z - z_0)\right]\exp\left[i\,(\omega t - kx)\right],$$

where $\eta = \frac{1}{\nu^2} - \varepsilon'$, z_0 being some constant, and reduced frequency $\nu = \omega/(ck)$ represents the phase velocity of the surface wave in units of c (velocity of light in vacuum). In gyrotropic medium characterized by tensors (1) it is possible to split surface polariton onto TE and TM mode (usually for anisotropic media such splitting is impossible). Using results obtained in work [8] we can write solution of Maxwell equations for TE wave:

$$\boldsymbol{E}^g = \boldsymbol{a}E_0\exp\left(-\frac{\omega}{c}\eta_1 z\right)\exp\left[i\,(\omega t - kx)\right], \tag{2}$$
$$\boldsymbol{H}^g_\tau = i\frac{1 - \varepsilon_\perp\nu^2}{\nu}\frac{1}{\sqrt{1 - (\varepsilon_\perp - g^2)\,\nu^2} - g\nu}\boldsymbol{b}E_0\exp\left(-\frac{\omega}{c}\eta_1 z\right)\exp\left[i\,(\omega t - kx)\right], \tag{3}$$

where E_0 being wave amplitude at the boundary. Now we using boundary conditions $\boldsymbol{H}^g_\tau = \boldsymbol{H}^n_\tau$, $\boldsymbol{E}^g_\tau = \boldsymbol{E}^n_\tau$:

$$E_0 = \sqrt{\frac{2\eta}{\beta}}\cosh^{-1}\left[\frac{\omega}{c}\sqrt{\eta}\,(-z_0)\right], \tag{4}$$
$$\tanh\left[\frac{\omega}{c}\sqrt{\eta}\,(z_0)\right] = \frac{1 - \varepsilon_\perp\nu^2}{\nu}\frac{1}{\sqrt{1 - (\varepsilon_\perp - g^2)\,\nu^2} - g\nu}. \tag{5}$$

Then we eliminating hyperbolic functions from equations (4), (5) (sign before the root depend on the sign of z_0):

$$\mathrm{sgn}(z_0)\sqrt{\frac{1}{\nu^2} - \varepsilon'}\sqrt{1 - E_0^2\frac{\beta}{2\left(\frac{1}{\nu^2} - \varepsilon'\right)}} = \frac{1 - \varepsilon_\perp\nu^2}{\nu}\frac{1}{\sqrt{1 - (\varepsilon_\perp - g^2)\,\nu^2} - g\nu}. \tag{6}$$

Equation (6) connects material parameters of adjoined media and wave number $k = \omega/(c\nu)$. Therefore equation (6) is dispersion equation the surface polaritons.

Solution of dispersion equation (6) $\nu = f(\beta, E_0, \varepsilon_\perp, \varepsilon', g)$ can be found analytically

$$\nu^2 = \frac{64\,g^2}{\beta^2\,{A_0}^4 + 8\,\beta\,{A_0}^2\,\left(2\,g^2 - \varepsilon + \varepsilon'\right) + 16\,\left(\left(\varepsilon - \varepsilon'\right)^2 + 4\,g^2\,\varepsilon'\right)}. \tag{7}$$

Value ν (7) satisfy equation (6) only in case when following conditions are fulfilled:

$$\beta > 0, \quad \varepsilon' < \varepsilon_\perp, \quad 0 < g < \frac{1}{2}\sqrt{2\varepsilon - 2\varepsilon' - \beta E_0^2}, \quad \beta E_0^2 < 2\,(\varepsilon_\perp - \varepsilon'). \tag{8}$$

Let us examine particular cases. If $g = 0$ then we comes to the case described in work [2]. In this case equation (6) does not depend on ν, and existence condition of surface wave takes the form

$$\frac{\beta E^2}{2} = (\varepsilon_\perp - \varepsilon') \,, \tag{9}$$

and consequently, the field value at the interface must be equal $E^2 = 2\,(\varepsilon_\perp - \varepsilon')\,/\beta$. In other words necessary condition of surface wave excitation is in that field value at the interface exceed some threshold value.

When case $\beta = 0$ is considered, then from the boundary conditions (4), (5) one can obtain dispersion equation for surface polariton mode at the interface of linear gyrotropic and isotropic media. As it was shown in [8] at this interface there exists only surface polariton TM mode.

Conclusion

Dispersion equation and existence conditions for TE surface polariton modes at the interface of gyrotropic and nonlinear medium are obtained. It is shown that for existing such surface polaritons the field intensity is not necessary to exceed some threshold value.

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