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Optical phenomena on the interface between a conventional dielectric and a uniaxial medium with mixed metal-dielectric properties

E. G. Gamaly
Laser Physics Centre, Research School of Physical Sciences and Engineering, Australian National University, Australian Capital Territory 0200, Canberra, Australia
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Two optical effects are described at the interface of an isotropic conventional dielectric and a uniaxial medium with mixed metal-dielectric properties, when the specific matching of the dielectric constant in the homogeneous medium to that in the anisotropic one has been introduced. First, the reflection coefficient at the interface of these media is *independent* on the angle of incidence of a light beam. Second, this interface ideally supports (with zero attenuation) a surface wave with an exact matching of the phase velocity of a surface wave to the phase velocity of an electromagnetic wave in the isotropic medium. The possibilities for checking both effects in an experiment have been discussed.

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I. INTRODUCTION

It has been shown quite recently [1,2] that the interface between the homogeneous dielectric and an anisotropic plasma having nonlocal electric properties can support a surface wave. Moreover, it has become clear that by changing the degree of asymmetry of an electron distribution function one can change the phase velocity of a surface wave and its attenuation. The degree of asymmetry for the two-temperature Maxwellian electron distribution function may be characterized by the ratio of the transverse to the longitudinal temperature. For some particular degree of asymmetry it is possible to achieve the exact matching of a phase velocity of a light wave in a dielectric to the phase velocity of a surface wave propagating along the interface between the isotropic dielectric and anisotropic plasma. It seems obvious that the same arguments are applicable for the case of any anisotropic medium with local and nonlocal electric properties that may have the metal-like optical properties at least along the one optical axis. In this case the degree of asymmetry may be related to the ratio of complex dielectric constants along the optical axes. The propagation, reflection, and refraction of an electromagnetic wave in different layered (isotropic, anisotropic, and mixed) media has been calculated in many papers and described in the textbooks in a rather general form [3–7]. The goal of the present paper is to describe the proper conditions for the supporting of a surface wave on the boundary between a conventional homogeneous dielectric with positive real permeability and an anisotropic medium having a local relation of the current to the electric field and mixed metal-dielectric optical properties. The unusual optical properties of the interface of two such media in the case of exact matching (and a small mismatch) of the dielectric constant in an isotropic medium to the constant along one optical axis in a uniaxial medium are calculated and discussed. We will discuss also the possible conditions for the excitation of a surface wave in an experimental situation.

II. DISPERSION RELATIONS FOR THE SURFACE WAVE ON THE BOUNDARY OF AN ANISOTROPIC MEDIUM

Let us consider the interface between two semi-infinite media: the homogeneous dielectric with real positive dielectric constant $\varepsilon_1 > 0$ (at $z < 0$) and an anisotropic medium at $z > 0$, which is characterized by tensorial permeability $\varepsilon_{\alpha\beta}^{(2)}$. The x and y axes are in the plane of an interface. We assume that the relation of the electric field to the electric current is local,

$$j_\alpha = \sigma_{\alpha\beta} E_\beta \ . \quad (1)$$

Here $\sigma_{\alpha\beta}$ is a complex conductivity tensor related to the dielectric tensor through the familiar equation

$$\varepsilon_{\alpha\beta} = \delta_{\alpha\beta} + i(4\pi/\omega)\sigma_{\alpha\beta} \ , \quad (2)$$

where $\delta_{\alpha\beta}$ is the Kronecker symbol and ω is a frequency of an electromagnetic wave. The problem is described by the set of Maxwell equations,

$$\nabla \times \mathbf{B} = \frac{4\pi}{c}\mathbf{j} + \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t}, \qquad \nabla \times \mathbf{E} = -\frac{1}{\partial}\frac{\partial \mathbf{B}}{\partial t} \ . \quad (3)$$

Assuming that each component of $\mathbf{E}$ and $\mathbf{B}$ has a time dependence

$$\mathbf{E}, \mathbf{B} \sim \exp(-i\omega t) \ , \quad (4)$$

one can reduce the set (3) to one equation,

$$\mathrm{grad}_\alpha \mathrm{div}\mathbf{E} - \Delta E_\alpha = k_0^2 \varepsilon_{\alpha\beta} E_\beta \ , \quad (5)$$

where we denoted $k_0 = \omega/c$. Let us choose the coordinate axes to coincide with the main axes of the tensor $\varepsilon_{\alpha\beta}$, thus reducing the last one to the symmetrical form $\varepsilon_{\alpha\beta} = 0$ ($\alpha \neq \beta$),

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$$\varepsilon_{\alpha\beta}=\begin{bmatrix}\varepsilon_{xx},0,0\\ 0,\varepsilon_{yy},0\\ 0,0,\varepsilon_{zz}\end{bmatrix} . \tag{6}$$

Introducing (4) and (6) into (5) one can easily arrive at the familiar Fresnel equation [8]. Let us consider the case of a medium that is a uniaxial crystal, thus assuming that $\varepsilon_{xx}=\varepsilon_{yy}=\varepsilon_y$ and $\varepsilon_{zz}=\varepsilon_z$. In this case the Fresnel equation splits into two independent equations,

$$n^2=\varepsilon_y, \tag{7}$$

$$\varepsilon_y\varepsilon_z-n_z^2\varepsilon_z-\varepsilon_y(n_x^2+n_y^2)=0 . \tag{8}$$

Here we denote $n_\alpha=k_\alpha/k_0$. When both components of the dielectric tensor are real and positive Eqs. (7) and (8) describe the familiar birefringence phenomenon: splitting the wave refracted into the ordinary [Eq. (7)] and extraordinary [Eq. (8)] waves. This phenomenon becomes more complicated in a medium where one (or both) permeability components may be negative or (and) complex numbers, thus revealing metallic properties. In this case the interface between a homogeneous dielectric and an anisotropic medium can support a surface wave. We will study a surface wave excitation and propagation when an anisotropic medium has mixed metal-like and dielectric properties.

Let us choose the z axis direction to coincide with the direction of the normal to the interface between two media, and the y axis to be parallel to the interface plane. The field components are (p-polarized wave)

$$\mathbf{E}(0,E_y,E_z);\mathbf{B}(B,0,0)\sim\exp\{-i\omega t+ik_y y+ik_z z\} . \tag{9}$$

We are looking for a solution describing the surface wave propagation in the y direction as thus being evanescent to both sides of the interface. For the p-polarized incident beam (9) there is only an extraordinary wave in an anisotropic medium. From boundary conditions of continuity E_y and B_x at the interface, one can obtain the usual dispersion relation for the surface wave:

$$-\frac{k_{1z}}{\varepsilon_1}=\frac{k_{2z}}{\varepsilon_y} \quad \text{or} \quad \frac{n_{2z}^2}{\varepsilon_y^2}=\frac{n_{1z}^2}{\varepsilon_1^2} . \tag{10}$$

Assuming that the optical properties are independent of the direction in the x-y plane, it is easy to obtain from (8) the expression of n_{2z} in a uniaxial medium

$$n_{2z}^2=\frac{\varepsilon_y}{\varepsilon_z}(\varepsilon_z-n_y^2), \tag{11}$$

and the formula for n_{1z} in a homogeneous dielectric

$$n_{1z}^2=\varepsilon_1-n_y^2 . \tag{12}$$

Introducing (11) and (12) into (10) one obtains the dispersion relation for the surface wave in the final form

$$\frac{\varepsilon_z-n_y^2}{\varepsilon_y\varepsilon_z}=\frac{\varepsilon_1-n_y^2}{\varepsilon_1^2} . \tag{13}$$

Solving (13) for a normalized wave vector of the surface wave n_y, we have

$$n_y^2=\varepsilon_z\varepsilon_1\frac{(\varepsilon_y-\varepsilon_1)}{(\varepsilon_y\varepsilon_z-\varepsilon_1^2)} . \tag{14}$$

Making use of (14) one can express (11) and (12) in the form of the functions of dielectric permeabilities of both media,

$$n_{2z}^2=\frac{\varepsilon_y^2(\varepsilon_z-\varepsilon_1)}{(\varepsilon_y\varepsilon_z-\varepsilon_1^2)}, \tag{15}$$

$$n_{1z}^2=\frac{\varepsilon_1^2(\varepsilon_z-\varepsilon_1)}{(\varepsilon_y\varepsilon_z-\varepsilon_1^2)}. \tag{16}$$

Assuming $\varepsilon_z=\varepsilon_y=\varepsilon_2$ and $\varepsilon_2<0$, $|\varepsilon_2|>\varepsilon_1$ one obtains from (14), (15), and (16) the conventional dispersion relation and attenuation coefficients near the interface of a homogeneous dielectric and a homogeneous metal. It is clear from the previous formulas that the replacement of a metal by a uniaxial medium introduces the new parameter—the mismatch of dielectric constants $\varepsilon_z-\varepsilon_1$, which allows us to steer effectively the propagation of the electromagnetic waves (e.g., surface waves) along the interface.

III. DISPERSION RELATIONS AND MATCHING CONDITIONS

Let us consider the case when both permeabilities are positive and real numbers $\varepsilon_1>0$, $\varepsilon_z>0$, while ε_y is a complex number with the negative real part. The last assumption means that the uniaxial medium has metallic properties in the y direction. Analysis of (14), (15), and (16) for this case shows that the following conditions should be fulfilled on the interface between two media to support the surface waves:

$$\varepsilon_z>\varepsilon_1,\quad \mathrm{Re}\ \varepsilon_y<0,\quad |\varepsilon_y|>\varepsilon_1 . \tag{17}$$

Now we can express (14) in an explicit form, introducing ε_y as

$$\varepsilon_y=-|\varepsilon_y'|+i\varepsilon_y'',\quad \varepsilon_y'<0 .$$

After straightforward algebra one obtains

$$\mathrm{Re}n_y^2=\varepsilon_1\left\{1+\frac{\varepsilon_1(\varepsilon_z-\varepsilon_1)(\varepsilon_z|\varepsilon_y'|+\varepsilon_1^2)}{[(\varepsilon_z|\varepsilon_y'|+\varepsilon_1^2)^2+\varepsilon_z^2\varepsilon_y''^2]}\right\},$$
$$\mathrm{Im}n_y^2=\frac{\varepsilon_1^2\varepsilon_z\varepsilon_y''(\varepsilon_z-\varepsilon_1)}{[(\varepsilon_z|\varepsilon_y'|+\varepsilon_1^2)^2+\varepsilon_z^2\varepsilon_y''^2]}. \tag{18}$$

It is convenient to denote the real part of the wave vector of a surface wave as a propagation constant

$$\beta=k_0\mathrm{Re}n_y=k_0\left[\frac{|n_y^2|+\mathrm{Re}n_y^2}{2}\right]^{1/2}, \tag{19}$$

and the imaginary part of the wave vector as an attenuation coefficient

$$\gamma=k_0\mathrm{Im}n_y=k_0\left[\frac{|n_y^2|-\mathrm{Re}n_y^2}{2}\right]^{1/2} . \tag{20}$$

Equations (18), (19), and (20) reveal the distinctive features of this structure; the phase velocity ($V_{ph}=\omega/\beta$) and the attenuation coefficient of a surface wave, and the attenuation coefficients of the evanescent waves in both media are strong functions of the mismatch of the dielectric constants. In the case of the exact matching ($\varepsilon_1=\varepsilon_z$) the phase velocity of the surface wave equals the phase velocity of the incoming electromagnetic wave (from the homogeneous medium). Simultaneously, the attenuation coefficient for the surface wave as well as the coefficients for evanescent waves in both media are equal to zero. The last condition means that in this case the interface guides the surface wave without damping in both media. Let us note that along with the wave vector components in the z direction for both media, and the attenuation coefficient of a surface wave, the electric field component along the interface, E_y, is also proportional to the mismatch and turns to zero for exact matching. The last point means that there is no driving field in the y direction, and consequently no motion of the conductivity electrons, and no damping related to the resistance. Thus the surface wave propagates along the interface, being driven by the same dipole oscillators related to the same dielectric constant on both sides of the interface.

It is difficult to find real optical materials with exact matching of the dielectric permeabilities. Let us introduce the relative mismatch in the form

$$\delta=\frac{\varepsilon_z-\varepsilon_1}{\varepsilon_1} \ll 1<\varepsilon_1<\varepsilon_z \ .$$

Now one can present the ratio of the phase velocity in a homogeneous medium to the phase velocity of a surface wave and attenuation coefficient explicitly for the case of small mismatches

$$\frac{V_{ph}^{(1)}}{V_{ph}^{SW}}=1+\frac{1}{2}\frac{\varepsilon_1\delta(|\varepsilon_y'|+\varepsilon_1)}{(|\varepsilon_y'|+\varepsilon_1)^2} \ ,$$

$$\gamma=k_0 \mathrm{Im} n_y=k_0\frac{1}{2}\frac{\varepsilon_1^{3/2}\varepsilon_y''\delta}{(|\varepsilon_y'|+\varepsilon_1)^2} \ . \tag{21}$$

It is interesting to note that the attenuation coefficient is directly proportional to the product of a mismatch and the imaginary part of a dielectric constant in the y direction related to conductivity. Thus one can reduce the attenuation by either increasing the conductivity or decreasing the mismatch.

IV. REFLECTION AND REFRACTION ON THE INTERFACE OF TWO MEDIA WITH MATCHED PROPERTIES

Let us consider refraction and reflection of the p-polarized light wave (9) on the interface of a homogeneous dielectric and a uniaxial crystal, keeping in mind the possibilities of excitation of a surface wave. Following the conventional procedure, we present the electromagnetic field in a homogeneous dielectric as a sum of an incident (B_0) and a reflected (B_r) wave in the form

$$B=B_0\exp\{-i\omega t+ik_y y+ik_{1z}z\} +B_r\exp\{-i\omega t+ik_y y-ik_{1z}z\} \ ,$$

and a refracted wave in a uniaxial medium as

$$B_p=B_{0p}\exp\{-i\omega t+ik_y y+ik_{2z}z\} \ .$$

Making use of the boundary conditions and Eqs. (11) and (12) one easily arrives to the reflection coefficient in the conventional form as follows:

$$R=|B_r/B_0|^2=|(1-A)/(1+A)|^2 \ , \tag{22}$$

where

$$A=\frac{\varepsilon_1}{\varepsilon_y}\left[\frac{\varepsilon_y}{\varepsilon_z}\right]^{1/2}\frac{(\varepsilon_z-n_y^2)^{1/2}}{(\varepsilon_1-n_y^2)^{1/2}}=\frac{\varepsilon_1}{\varepsilon_y}\left[\frac{n_{2z}}{n_{1z}}\right] \ .$$

Here n_{1z}, n_{2z}, and $n_y^2=\varepsilon_1\sin^2\theta$ are the normalized components of a wave vector at the interface $z=0$, θ is the angle of incidence (measured from the normal to the interface). It is clear from the previous formula that in the case $\varepsilon_1=\varepsilon_z$ reflection coefficient is *independent* of the angle of incidence. It is also clear that this property relates to the angle dependence of n_{1z} and n_{2z}, which is exactly the same near the interface due to the continuity of n_y, and for this reason it cancels in (22) for the case of exact matching. This is another manifestation of the same microscopic properties of this particular structure as were explained for a surface wave. This effect will exist for a uniaxial crystal with any properties in the y direction (only matching of dielectric constants in the z direction is necessary).

It is convenient to consider separately the case when all dielectric constants in both media are real and positive and the case of the mixed metal-dielectric properties in a uniaxial medium. Introducing the mismatch one can express (22) for the first case in the form

$$A=\frac{A_0}{(1+\delta)^{1/2}}\frac{(\cos^2\theta+\delta)^{1/2}}{\cos\theta}$$

$$\text{where } A_0=\left[\frac{\varepsilon_1}{\varepsilon_y}\right]^{1/2}\equiv A(\delta=0) \ . \tag{23}$$

The simple analysis of (23) shows that the reflectivity has a minimum ($R=0$) at

$$\cos^2\theta=\frac{A_0^2}{(1+\delta-A_0^2)} \ ,$$

and it increases to $R\to 1$ at $\theta\to\pi/2$. For the second case let us introduce the metallic part of the dielectric permeability in the form

$$\varepsilon_y=\varepsilon_y'+i\varepsilon_y''=|\varepsilon_y|e^{i\Psi},$$

$$\cos\Psi=-\frac{|\varepsilon_y'|}{|\varepsilon_y|},$$

$$|\varepsilon_y|=\{(\varepsilon_y')^2+(\varepsilon_y'')^2\}^{1/2} \ .$$

Now one can express the reflection coefficient as

$$R=\frac{1+A_R^2-2A_R\cos\frac{\Psi}{2}}{1+A_R^2+2A_R\cos\frac{\Psi}{2}},$$

$$A_R=\frac{A_{0R}}{(1+\delta)^{1/2}}\frac{(\cos^2\theta+\delta)^{1/2}}{\cos\theta},$$

$$A_R(\delta=0)\equiv A_{0R}=\left[\frac{\varepsilon_1}{|\varepsilon_y|}\right]^{1/2},\tag{24}$$

$$\cos\frac{\Psi}{2}=\left[\frac{|\varepsilon_y|-|\varepsilon_y'|}{2|\varepsilon_y|}\right]^{1/2}.$$

In this case the minimum value of the reflectivity is nonzero:

$$R_{\min}=\frac{1-\cos\frac{\Psi}{2}}{1+\cos\frac{\Psi}{2}}\quad\text{at }\cos^2\theta_{\min}=\frac{A_{0R}^2}{1+\delta-A_{0R}^2}.\tag{25}$$

It is clear that the s-polarized incident wave should be totally reflected in the case of metallic properties in the y direction for an anisotropic medium (s polarization fits to the ordinary refracted wave $n^2=\varepsilon_y$). In the case of real and positive permeability in the y direction it would be usual reflection and refraction of the ordinary wave for the s-polarized incident wave.

Thus, it is possible to excite a surface wave along the interface of a homogeneous dielectric and a uniaxial crystal with metallic properties in the y direction and matched dielectric properties in the z direction by a p-polarized wave that is incident on the interface at a grazing angle. It is also possible to excite the surface wave in the same geometry by an unpolarized light. One should note that in the last case the efficiency of excitation will be lower due to the total reflection of the s-polarized part of the incident beam. The interface of these matched media serves as an ideal polarizer for an incident unpolarized light.

V. POSSIBLE STRUCTURES FOR AN EXPERIMENTAL OBSERVATION OF THE PROPOSED EFFECTS

(i) It is possible to measure the reflectivity dependence on the angle of incidence at least for two pairs of known materials with relatively small mismatches. The main difficulty of such a measurement relates to a small absolute value of the reflectivity.

The first combination consists of CsF as a homogeneous dielectric ($\varepsilon_1=2.340$) and familiar birefringent crystal $CaCO_3$($\varepsilon_y=3.1684$, $\varepsilon_z=2.3654$) for the wave length of 242 nm [11]. The relative mismatch for this case is 0.0105. One can easily calculate with the help of formulas (23) the angle dependence of the reflectivity. The reflectivity that corresponds to the exact matching equals 5.7×10^{-3} and coincides with the reflectivity at the normal incidence for this mismatch.

There is also the polymer-PPV [poly-(p-phenylene vinylene)] with a large optical birefringence. The reported optical properties of PPV for the wavelength of 632.8 nm are $n_y=2.17-2.22$ (TE mode) and $n_z=1.61-1.62$ (TM mode) [12]. There are also several optical materials to match PPV for the measurement of the reflectivity angle dependence. The smallest relative mismatch of 0.0125 is for GeO_2 ($n_1=1.6054$ [11]). For this case the reflectivity at the normal incidence (coinciding with the angle independent reflectivity for the exact matching) is 0.0244.

(ii) The most suitable material for the observation of the excitation and propagation of a surface wave along the interface of an anisotropic medium having mixed metal-dielectric properties is, of course, pure crystalline graphite. The electric properties of this material for the incident beam with the wavelength of 248 nm are $\varepsilon_z=3.28$, $\varepsilon_y'=-4$, $\varepsilon_y''=6$ [9]. The best matching dielectric for this case is CsCl with $n_1=1.77$ [11] giving the relative mismatch of 0.0469. For this mismatch the minimum reflectivity is 0.359 (at $\theta_{\min}=79.5°$) in comparison with 0.395 for the perfect matching (or for normal incidence in the case of this mismatch). The ratio of the phase velocities of a light wave in CsCl to that of a surface wave is 1.006, which is much better than for the familiar case of a surface wave along the air-silver interface ($V_{air}/V_{sil}=1.032$ [7]). On the other hand the attenuation in the considered case is larger due to poor conductivity of graphite along the basal planes. Another feature of the considered structure is the strong dependence of the attenuation coefficient of both evanescent waves in the z direction on the magnitude of a mismatch. If the mismatch is small the surface wave has almost a symmetrical space profile in the z direction. For the considered case of a CsCl-graphite interface the attenuation coefficients are

$$\alpha_{1z}=k_0\mathrm{Im}n_{1z}=0.207k_0,$$

$$\alpha_{2z}=k_0\mathrm{Im}n_{2z}=0.289k_0$$

(compare to the case of the air-silver interface $\alpha_{air}=0.25k_0$, $\alpha_{sil}=4.18k_0$ [7]).

VI. ROLE OF SPATIAL AND TEMPORAL DISPERSION

In the previous treatment we considered the medium properties as nondispersive. However, it is well known [10] that in the case of a metal the different relations between three characteristic spatial scales of the problem v_f/ω, l_{skin}, l_e are manifestations of different kinds of dispersion. Here v_f is the Fermi velocity, ω is the frequency of the incident light; l_{skin}, l_e are correspondingly the skin depth and electron mean free path. When $l_e\ll v_f/\omega, l_e\ll 1_{skin}$ there is no dispersion (normal skin effect). At higher frequencies the interaction enters into regime of the anomalous skin effect when $1_{skin}\ll l_e$, $1_{skin}\ll v_f/\omega$. These relations are clear conditions for the spatial dispersion. With further increase of frequency the interaction enters into the limiting regime of a high frequency skin effect when $v_f/\omega\ll l_{skin}$, $v_f/\omega\ll l_e$. In this case the prevailing effect is the temporal dispersion. For the case of an electromagnetic wave interacting with a uniaxial medium having mixed properties, at least electric properties in one direction may be affected by dispersion effects. Let us estimate the characteristic space scales for the typical metal ($n_e = 10^{23}$ cm^{-3}, $v_f = 1.3\times10^8$ cm/s; $l_e = v_f/\nu_{\rm eff}$; $\nu_{\rm eff} \sim kT/h$ is the effective frequency of phonon-photon interaction). It is easy to see that for a laser wave length comparable or less than a micron, laser-matter interaction falls into the frames of the high frequency limits for skin effect. Thus the conductivity in this case depends on the form of the Fermi surface and on the interaction function between conductivity electrons [10].

VII. DISCUSSION AND CONCLUSION

The explicit description of a surface wave propagating along the interface of an isotropic conventional dielectric and a uniaxial crystal having mixed (metalliclike along one optical axis and dielectric along the other) electric properties has been formulated. It is shown that in the case of the exact matching of the dielectric constants in a homogeneous medium and in uniaxial crystal along one axis, the interface serves as a perfect (with nonzero attenuation) guide for the surface wave. In this case, it is also possible to achieve exact matching of the phase velocity of an electromagnetic wave in an isotropic medium to the phase velocity of a surface wave. At the same time the attenuation coefficient of the surface wave is zero for exact matching conditions. For the general case of a plane wave propagation in an anisotropic medium the direction of the Pointing vector does not coincide with the direction of the wave vector of a wave. For the k vector lying in the y direction the tangent of the angle between two vectors is proportional to the ratio E_y/E_z and consequently it is proportional to the mismatch of the dielectric constants. Thus for the considered case of the exact matching this angle is zero, and the wave (energy flux) is driven along the y axis by reemission of the same dipole oscillators related to the same positive dielectric constant on both sides of the interface. Due to the absence of the field component along the y axis there is no conductivity current in this direction and consequently no attenuation due to resistivity. One can consider such nondissipative propagation of a surface wave as a wave propagation along the optical axis in a single anisotropic medium because the exact matching means that near the interface the wave "sees" the same optical constants on both sides of the interface.

The interface between such matched media reveals also another unusual optical property, namely, the reflection coefficient at this interface is independent on the angle of incidence of the light beam from the isotropic medium. The explanation of this effect is as follows. The absorption (reflection) coefficient depends only on the ratio of the wave vector components perpendicular to the interface. For the case of the exact matching the angle dependence of these vectors is the same near the interface due to continuity of n_y on the interface. By this reason the angular dependence cancels in the formula (22) for the reflectivity just leaving the reflectivity dependence only on the ratio of the different dielectric constants. The last property allows the effective excitation of the surface wave by oblique incidence of the light beam on the interface. The combination of two materials with such specifically matched properties may be used as a wave guide or polarizer. It is worth noting that for a small mismatch the polarization of the surface wave is elliptical, which is usual, but in the case of exact matching it becomes plane polarized. The using of new materials (for example, graphitic nanotubes filed by high conductivity metals [13]) may allow us to reduce the attenuation of a surface wave by order of magnitude even for the case of a small mismatch of the dielectric constants. It seems plausible that by choosing the different combinations of materials it is also possible to find different applications of these effects. It is also possible to use the materials with anisotropy induced by laser light (as pointed out by Dr. W. Krolikowski). We will present elsewhere the studies of analogous effects in media with nonlocal properties.

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