June 2010 ISSN : 0974 - 7494 Volume 4 Issue 1

Trade Science Inc.

Nano Science and Nano Technology

An Indian Journal

Short Communication

NSNTAIJ, 4(1), 2010 [17-19]

# On optical bonding forces between light guides

Mark E.Perel'man

Racah Institute of Physics, Hebrew University, Jerusalem, 91904, (ISRAEL)

E-mail: m.e.perelman@gmail.com

PACS: 42.25.Ja, 42.50.-p, 42.81.Gs

*Received: 23rd December, 2009 ; Accepted: 2nd January, 2010*

## ABSTRACT

If through two parallel light-guides are passing monochromatic waves of identical frequency, the force, repulsive or attractive in dependence on phase difference, takes place between them. This recent experimental result can be described via occurrence of virtual dipoles induced by evanescent wave at processes of light propagation and reflection. So this effect can be considered as an original effect of high frequency polarization and must be taken into account at construction of optical nanostructures. The proposed description can be considered as a special variant of quasi-optics with simplified account of surface phenomena.



## KEYWORDS

Wave-guides;
Forces;
Polarization;
Dipoles.

Some of recent advances in nanoscale photonics and optomechanics are connected with forces that had been negligible in researches of bigger structures. So, in the articles[1,2] and several others were proposed the existence of optical force known now as the 'optical bonding force' (see, also, the general review[3]). The most evidently its existence and features are demonstrated in the recent article[4]. The often references to the Casimir effect for substantiation of its existence seem excessive: the Casimir forces are originated by vacuum fluctuations, but forces considered in the cited researches appear, as will be shown, as the result of substances polarization by light wave field.

Let us consider, as an initial qualitative review of examined effect, a quantum description of light propagation through a solid (transparent) strip. In accordance with the well-known Placzek theory[5] polarization of matter is executed by the dipole-dipole interaction, i.e. by the dipole absorption and further reemission by that or another dipole. In the case of standing light waves such picture must lead to formation of the 1D effective 'light lattice' or 'photon crystal', on which the interference and similar effects can be considered[6]; therefore two strips with such systems of virtual lattices can be, in general, attracted or repulsed in dependence on their relative positions and phases. Systems of such standing waves would lead to the 2D 'lattices' and several optical devices[6].

But what would take place in the case of flying waves with their fast displaced maxima? There is known the classic Zommerfeld–Brillouin suggestion about the wave front propagation with the vacuum speed $c$ before the polarization establishment[7], which however has not reliable experimental confirmations. The kinetic quantum theory of optical dispersion[8] shows absence of temporal lags for establishing of polarization: it corresponds to processes of photons scattering, i.e. is nearly instantaneous. This conclusion can be supported by the gen-

Short Communication

eral theory of particles interaction durations[9]. Hence the instant interactions between light guides become completely analogical to the case of standing waves.

But the possibilities of forces manifestation will be mainly depended on near surface dipoles, e.g. on features of effective transient zones. Therefore we must consider the definite specification of light refraction and reflection laws caused by their existence on each optical surface. Their existence is governed by physical impossibility of the geometrical type sharp alteration of physical magnitudes at transitions between substances, i.e. by its incompatibility with quantum representations. The used method had been suggested in[10] and with more details is described in[11].

Our consideration is sufficiently wide and will show that the most phenomena of optical propagation can be considered via high frequency polarization with formation of virtual (evanescent) electromagnetic moments in medium by light waves. Thus, the interaction between optical guides can be described via the instant interactions of these moments.

However, almost classical description of these phenomena, that represents a variant of quasi-optics, is also possible.

Let's consider, for simplicity, an electromagnetic wave that falls from a free space ($z > 0$) onto flat medium surface ($z < 0$). In the method of Bremmer[12] (Appendix 6) each component of fields $E, D, B, H$ and $j$ is expressed at the border via sum of all components multiplied on the suitable unit step Heaviside functions $\theta(\pm z)$:

$$\mathbf{V(t,r) = (V_I + V_R)\theta(z) + V_T(-z)}, \qquad (1)$$

in which the incident $V_I$, reflected $V_R$ and transmitted $V_T$ waves are included.

If the gradual transitions from one substance to another must be regarded for them, the discontinuous step functions would be replaced, instead the consideration of quantum picture, by flattened functions[11], e.g. by the expressions of the type:

$$\vartheta(\mathbf{z}\,|\,\mathbf{a}) = \int_{\mathbf{a}}^{\infty} \mathbf{d}\xi\,\delta(\xi - \mathbf{z}\,|\,\mathbf{a}) = \frac{\mathbf{1}}{\pi}\int_{\mathbf{a}}^{\infty} \mathbf{d}\xi \frac{\mathbf{a}}{(\xi - \mathbf{z})^2 + \mathbf{a}^2} = \frac{\mathbf{1}}{\mathbf{2}} - \frac{\mathbf{1}}{\pi}\tan^{-1}(\mathbf{1} - \mathbf{z}\,|\,\mathbf{a}) \qquad (2)$$

with $\alpha \to 0+$ and the term $V_s$ describing near-surface or evanescent waves in this stratum must be added.

Hence instead of (1) we shall write

$$\mathbf{V(t,r) = (V_I + V_R)\vartheta(z|a) + V_T\vartheta(-z|b) + V_s\varsigma(a|z|b)}, \qquad (3)$$

with $\varsigma(a|z|b) = 1 - \vartheta(z|a) + \vartheta(-z|b)$ describing the gradual field penetration in both substances, and the expression (3) returns to (1) at $a, b \to 0$. At the total reflection the term $V_T$ will be omitted, but it does not prevented the general consideration.

If the falling wave is of the frequency $\omega$ and is incident under the angle $\alpha$, both parameters can be expressed via the uncertainty principle $\Delta z \Delta k_z \sim 1$. For the down plate can be taken $\Delta k_z \sim \varepsilon_1 (\omega/c) \cos\alpha$, where $\varepsilon_1$ is the corresponding dielectric susceptibility, for the upper plate its dielectric susceptibility must be taken into account. Thus, approximately,

$$\boldsymbol{\alpha \sim c/\varepsilon_1\omega\cos\alpha;\ b \sim \alpha\sqrt{\varepsilon_1/\varepsilon_2}}\,. \qquad (4)$$

Such simplest estimation seems completely adequate for the phenomenon of frustrated total internal reflection (FTIR)[13] and can be improved for more realistic or complicated cases with taking into account different parameters of medium. So, the evanescent spatial shift of reflected and transmitted rays may be taken into account: if $V_I = V_I(t; x, y, z)$ then for reflected waves in x-z plane by the series expansion can be taken that

$$\mathbf{V_R = V_R(t; x + \Delta_R, y, z) \to V_R(t; x, y, z) + i\Delta_R\partial_x V_R(t; x, y, z)}, \qquad (5)$$

where $\Delta_R$ depends on the initial angle and refraction indices, and analogical for transmitted waves. For monochromatic waves $\partial_x V_R \to -ik\cos\alpha\, V_R$ and just these two additions form surface waves phenomenologically introduced into (3):

$$\mathbf{Vs \propto k(\Delta_R \cos\alpha \cdot V_R + \Delta_T \cos\beta \cdot V_T)}, \qquad (6)$$

after substitution of which all fields in (3) will be considered in one point.

For their consideration the general form of fields equations,

$$\mathbf{\nabla V = 4\pi(\rho + \rho^{(evan)})}; \qquad (7)$$

$$\mathbf{\nabla \times V = \frac{\imath\omega}{c} W + \frac{4\pi}{c}\left(j + j^{(evan)}\right)}, \qquad (7')$$

with additional, evanescent or virtual charges and currents, can be used (in accordance with the Maxwell equations $V$ in (7) represents $D$ or $B$; the pair $V, W$ in (7') represents $H, D$ or $E, B$).

Let's describe the TE wave in the (x, z) plane that is entering into an electrically neutral and optically passive substance at such angle that $V_T$ can be negligees. Since all fields, except $V_s$, satisfy the equation $\nabla V = 4\pi\rho$, the operations of divergence of (3) with $V \to D$ leads to the relation:

$$\nabla D(z) = D_{sz}(\delta(z,a) - \delta(z,-b)) + 4\pi\rho^{(evan)}(z)\varsigma(a|z|b) = 0. \quad (8)$$

Hence the intermediate layer represents an oscillating double electric layer of strength $D_{sz}$ with induced charges of density $\rho^{(evan)}$.

For the case of TM wave in the incident plane, we apply (3) to the magnetic field, $V \to B$, that leads to an analogical representation with density of "magnetic charges" inducing in a near-surface zone by transition effects.

The similarity of such expressions demonstrates not only a resemblance of both results, but also the difference of their possibilities at description of higher moments, etc.

The expression (8) can be rewritten as

$$D_{SZ}K(a,b) = 4\pi\rho^{(evan)}(z) \text{ with } K(a,b) = \frac{d}{dz}\ln\varsigma(a|z|b) \quad (9)$$

Physically it can be supposed that $1/\kappa$ would be of the order of a generalized "skin layer" thickness and $\varsigma(a|z|b)$ can be considered as the response function of this stratum.

The substitutions of (3) into other Maxwell equations (7') describe the evanescent, oppositely directed currents in this layer. Thus, oscillating "dipoles" and "currents" on frequencies of incident fields absorb falling radiation and emit reflected and refracted waves.

Hence at process of monochromatic light passage through light-guide, oscillating electromagnetic moments, in considered case virtual electric dipoles, can be excited; their density depends on field strengths. Such formations must lead to the forces between nearby light-guides.

Let's estimate these forces between two thin parallel dielectric strips of thickness $\delta$ and the distance between them $l \gg \delta$ (they can be considered as parallel double electric layers with alternating charges, but we can use more simple representations). If on both surfaces of strips are, correspondingly, dot charges $\pm q_1$ and $\pm q_2$, the force between strips $F \propto \pm q_1 q_2 (\delta^2/l^4)$ and $q_i\delta$ represent corresponding dipoles. By transition to surface densities and then to strengths of light waves $E_1 = E_{01}\sin(\omega t - kx)$ and $E_2 = E_{02}\sin(\omega t - kx + \phi)$ with their subsequent averaging the estimation of force density can be written:

$$f \sim E_{01}E_{02}S(\delta^2/l^4)\cos\phi, \quad (10)$$

where $S$ is the square of strips interaction. (The forces between such surface with the double electric layer and single dipole are considered in[14], they can be naturally generalized on forces between two surfaces.)

Hence, Eq. (10) shows possibility of both interaction types in dependence on phase difference.

In conclusion must be mentioned that the considered case with the coherent monochromatic waves seems the most elementary one, since in more complicated cases this method requires the averaging over phases, but on the other hand it represents an evident and unusual approach to the general problem. Similar consideration can be useful in other problems of optics and optomechanics. It must be underlined that at more thin guides magnetic dipoles, electric quadrupoles and so on can be excited instead of electric dipoles (cf.[10]).

## REFERENCES

[1] M.L.Povinelli, et al; Opt.Lett., **30**, 3042-3044 **(2005)**.
[2] A.Mizrahi, L.Schachter; Opt.Express, **13**, 9804-9811 **(2005)**.
[3] T.J.Kippenberg, K.J.Vahala; Science, **321**, 1172-1176 **(2008)**.
[4] Mo Li, W.H.P.Pernice, H.X.Tang; Nature Photonics, **3**, 464-468 **(2009)**. (arXiv:0903.5117)
[5] G.Placzek; Rayleigh Streeung und Raman Effekt, V.Berestetski, E.Lifshitz, E.Pitaevski; 'Quantum Electrodynamics'. Ch. VI, Pergamon, Oxford, **(1982)**.
[6] M.E.Perel'man, et al; Bull.Georgian Ac.Sc., **95**, **(1979)**.
[7] L.Brillouin; 'Wave Propagation and Group Velocity'. NY, Academic Press: **(1960)**.
[8] M.E.Perel'man, G.M.Rubinstein; 'New Research on Lasers and Electro Optics' (Editor: W.T.Arkin), Nova Sc. Publ., NY, 229-267 **(2006)**.
[9] M.E.Perel'man; Int.J.Theor.Phys., **47**, 468-491 **(2008)**.
[10] M.E.Perel'man; Phys.Lett.A, **370**, 528-532 **(2007)**.
[11] M.E.Perel'man; Int.J.Theor.Phys., **48**, 2579-2591 **(2009)**; arXiv: 0903.2780.
[12] M.Born, E.Wolf; 'Principles of Optics'. 4th Ed. Pergamon, NY, (Appendix 6) **(1968)**.
[13] M.E.Perel'man; Phys.Lett.A, **373**, 648-652 **(2009)**.
[14] M.E.Perel'man, G.M.Rubinstein, V.A.Tatartchenko; Phys.Lett.A, **372**, 4100-4103 **(2008)**.