Gravitational Hertz experiment in dielectrics, excited by intense laser pulses

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Abstract. The possibility of generating and detection of high-frequency gravitational waves based on parametric optical processes in dielectric media excited by intense laser emission is analyzed. The theory predicts the feasibility of the Hertz gravitational laboratory experiment in dielectric media at the presence of strong constant magnetic field with illumination of this media by intense ultra short laser pulses of visible or ultraviolet ranges. Parametric conversion of ultra short intense laser pulses with frequency $\omega_0$ to a gravitational wave with frequency $\omega_g=2\omega_0$ and reconversion process of gravitational radiation to optical radiation at resonance condition for some dielectrics and photonic structures are predicted.

1. Introduction

The existence of gravitational waves, arising from cosmic objects, was predicted in the classical Einstein's works. The interest to gravitational waves generation and detecting has increased significantly after recently direct detection of gravitational waves [1]. The experimental results, presented in [1], are gravitational waves detection at relatively low frequencies (10-100 Hz), emitted by astrophysical bodies. This results based on laser interferometer technique with using of Michelson interferometer, first proposed and theoretically justified in [2]. In accordance with the theory, the gravitational wave emission intensity is proportional to the frequency of the sixth powered degree. So it is interesting to investigate the possibility of generating and detection of the high-frequency gravitational waves. The theory [3-5] predicts the opportunity of registration of emitted by astrophysical objects gravitational waves at high frequency at the presence of strong magnetic field. In this paper it is analyzed the new way, proposed in[6], of high-frequency gravitational waves generation and detection by means of dielectric media excitation by powerful laser pulses at visible or ultraviolet ranges, at the presence of strong constant magnetic field.

2. To the common theory of gravitational waves in space

The Einstein equations of gravitational waves in space may be written as [5]:

$$ R_{ik} = \frac{8\pi G}{c^4} \left( T_{ik} - \frac{1}{2} g_{ik} T \right) $$

Taking into account that at the presence of electromagnetic waves $T=0$, we have:
\[ R_{ik} = \frac{8\pi G}{c^4} T_{ik} \]  

(2)

After changing of energy-momentum tensor \( T_{ik} \) by Maxwell stress tensor \( \sigma_{\alpha\beta} \), this relation for spatial components may be presented as:

\[ (\nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2}) h_{\alpha\beta} = - \frac{16\pi G}{c^4} \sigma_{\alpha\beta}; \alpha, \beta = 1,2,3. \]

\[ g_{ik} = g^{(0)}_{ik} + h_{ik}; i, k = 0,1,2,3. \]

\[ \sigma_{\alpha\beta} = \frac{1}{4\pi} \left[ E_\alpha E_\beta + H_\alpha H_\beta - \frac{1}{2} \delta_{\alpha\beta} (E^2 + H^2) \right] \]  

(3)

Here \( g_{ik} = g^{(0)}_{ik} + h_{ik} \); \( i, k = 0,1,2,3 \) is the metric tensor at the presence of weak gravitational waves, described by \( h_{ik} \) and \( h_{\alpha\beta} \); \( G \) and \( c \) are fundamental constants; \( E \) and \( H \) are corresponding electric and magnetic field stresses value. Let us analyze the simple geometry, when flat gravitational wave corresponds along \( z \)-axis; constant magnetic field \( \vec{H} = \vec{e}_z H_0 \) is directed along \( x \)-axis; electromagnetic field with wave vector \( k_p \) is described as:

\[ \vec{E}_e = \vec{e}_z E_{0e} \cos(\omega t - k_p x); \vec{H}_e = \vec{e}_z (H_0 - H_{0e} \cos(\omega t - k_p x)). \]

(4)

In this case takes place:

\[ \sigma^{zz} = \frac{1}{8\pi} \left[ H_0^2 - \frac{1}{2} H_0^2 \Delta - 2H_0 H_{0a} \cos(\omega t - k_p x) + \frac{1}{2} H_{0a}^2 \cos(2\omega t - 2k_p x) \right] \]  

(5)

Taking into account only one term in (5), oscillating with frequency \( \omega \), we have;

\[ \left( \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{c^2 \partial t^2} \right) h_{zz} = \frac{4G}{c^4} \frac{H_0 H_{0a} \cos(\omega t - kx)}{d} \]  

(6)

After transition to complex presentation of the fields \((h_{zz} \rightarrow \tilde{h}_{zz} = h_{zz} \exp(\pm ik_g x - \omega t)); H_{0e} \cos(\omega t - k_p x) \rightarrow H_{0e} \exp(\pm i(k_p x - \omega t))\) we have:

\[ \left( \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{c^2 \partial t^2} \right) \tilde{h}_{zz} = g H_0 \tilde{H}_{0e}; g = \frac{4G}{c^4} \]  

(7)

The solution (4) may be presented as :

\[ h_{zz}^+ = \exp(-i\omega t) \int dx \frac{1}{4\pi} \frac{\exp[\pm ik_g (x - x')]}{(x - x')} g H_0 H_{0e} \]  

(8)

Accordingly it takes place:

\[ h_{zz}^+(x,t) = i H_0 \frac{g H_{0e} L}{2k_g} F(q) \exp(ik_g x - \omega t); F(q) = \frac{\sin q L/2}{q L/2}; q = k_p - k_g. \]  

(9)

Here \( k_g \) and \( k_p \) are the wave vectors of gravitational and electromagnetic waves correspondingly and \( L \) is the length of applied magnetic field. The relation (9) is close to the corresponding one for photon-axion conversion processes, described before in [7]. So we have for likelihood of \( N_g \) gravitons appearance as the result of \( N_p \) exciting photon emitted of light source and resulting photon-graviton conversion process:

\[ P_{p \rightarrow g} = \frac{N_g}{N_p} = \frac{1}{4} (g H_o L)^2 F(q)^2 \]  

(10)

Taking into account the wave vector conservation law in elemental photon – graviton conversion processes, \( F(q) \rightarrow 1 \), we have:
Here $N_p$ is the number of photons, falling at the unit square during 1 s.

3. Gravitational waves in dielectric media

Constant $g = \frac{4G}{c^4}$ is dramatically small for cosmic space objects. So photon–graviton conversion may be waited from the very large objects, surrounded by enormous strong constant magnetic fields. As it was proposed in [6], at the case of dielectric media $g$ constant in (11) may essentially increase because of the nonlinear property of dielectric media and due to even electron (quadrupole–type) states presence at visible or uv–regions. The additional opportunity for photon–graviton conversion enhance in dielectrics is the resonance excitation of dielectrics by laser emission, frequency of which is close to frequency of polariton wave, propagating with the very small group velocity (the case of so called “stopped” light).

As an example, we have analyzed the properties of polariton waves in uranil-type condensed media as $\text{UO}_2\text{Cl}_2$ or $\text{Na(UO}_2\text{)}_2(\text{CH}_3\text{COO})_3$. Dielectric constant in these case may be presented as:

$$\varepsilon(\omega) = \varepsilon_{\infty} \prod_j \frac{\omega_{lj}^2 - \omega^2}{\omega_{lj}^2 - \omega_{0j}^2 - \omega^2}$$

(12)

Here $\omega_{lj} = \frac{2\pi c}{\lambda_{lj}}$, $\omega_{0j} = \frac{2\pi c}{\lambda_{0j}}$ value correspond to longitudinal and transversal frequencies and wave lengths of electromagnetic waves, corresponding to numerous energetic levels of uranium ion. Dispersion law of polariton wave in this case may be written as:

$$\omega = \frac{ck_p}{\sqrt{\varepsilon_{\infty} \prod_j \frac{\omega_{lj}^2 - \omega^2}{\omega_{lj}^2 - \omega_{0j}^2 - \omega^2}}}$$

the corresponding group velocity may be calculated from relation: $V = \frac{d\omega}{dk_p}$.

Figure 1 illustrates the calculated uranyl polariton dispersion law $\omega = F(k_p)$ (thick curves). We can see a lot of resonances located at the absorption electronic levels. Thin line illustrates the light dispersion law in vacuum: $\omega = ck$. The intersections between vacuum and media curves correspond to so called unitary ($n=1$) polaritons positions, when refractive index is equal to unity.

**Figure 1.** The dispersion law of polaritons for the sodium uranyl acetate (thick lines). The thin line illustrates the dispersion law in the vacuum: $\omega = ck$. 
Figure 2. Polariton waves group velocities at two scales (a and b).

Figure 2 illustrates the calculated group velocity of the corresponding polariton waves in uranil compound.

As can see from figure 2 the group velocity V of polariton waves becomes very small (less 1 m/s) at some frequencies: i.e. we have “stopped” light in these cases. Accordingly constant $g = \frac{4\epsilon}{c^2}$ becomes large enough and the photon–graviton conversion efficiency $P_{p\rightarrow g} = \frac{N_g}{N_p} = \frac{1}{4} (gH_0L)^2$ should sharply increase. If $V=1\text{cm/s}$, $H_0\approx10^4$ CGS, $L\approx1\text{cm}$, we have $P_{p\rightarrow g} \approx 10^{-8}$. The detection of generated graviton may be realized with the help of the same uranil compounds, placed in magnetic field. So for initial falling photons $N_p\approx10^{19}$ 1/cm$^2$s we have at the exit of equipments, described in [6]: $N_p' \approx 10^7$/cm$^2$s. It is worth to notice, that the using of the powerful ultra short laser pulses for exciting of photon-graviton conversion in dielectrics may prove also the stimulated conversion process at high enough intensity of exciting emission. In this case the intensity at the exit should be compared with the initial one. The presented results show that Gravitational Hertz experiment in dielectric media is possible by means of stopped electromagnetic waves in uranil type or resemble dielectrics using, having a lot of electronic levels in visible or uv ranges. Strong magnetic field exploring, applied to dielectrics, opens the opportunity of gravitational wave generation with high frequency $\omega_0 = \omega_p$.

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