Indian Journal of Pure & Applied Physics
Vol. 55, February 2017, pp. 104-112

Analytical and numerical investigation of the brightness of high power X- and gamma rays as a result of intense laser interacting with plasma mirrors in radiation pressure regime

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Received 28 June 2016; revised 14 November 2016; accepted 22 December 2016

At laser intensity in the range ~ 10^{22} –10^{23} W/cm^2, the radiation pressure starts to play a key role in the interaction of an intense electromagnetic wave with a dense plasma foil. In this radiation pressure dominant regime (RPD regime) we present our numerical results for the frequency and brightness of the reflected radiation from a uniformly moving plasma mirror. The interaction of the electromagnetic wave with an approaching plasma mirror results in the Doppler-shifted reflected radiation. The reflected photon frequency lies in the hard X-ray or gamma-ray range. For the source pulse energy ε_s = 12 J, $\lambda_s = \lambda = 0.8\mu\mathrm{m}$, n_e = 480 n_{cr} = $5.4\times10^{23}\mathrm{cm}^{-3}\times(1\mu\mathrm{m}/\lambda)^2$, there are approximately 9.6×10^{42} hard X-ray photons/ (mm^2-mrad^2 -s.-0.1% bandwidth) in the energy range ~ 10 keV. In the case when $2\gamma>\left(n_e\lambda_s^3\right)^{1/6}$ for the same parameters of source laser pulse and driver pulse normalized vector potential $a_d = 300$, λ_d = 0.8 µm the brightness is found to be 3.9×10^{34} photons / (mm^2 - mrad^2 - s. - 0.1% bandwidth) in the energy range ~100 keV. These radiations have broad range of applications in many areas of research e.g. medicine and material science.

Keywords: Plasma mirror, Laser ion acceleration, Brightness, X-ray, Gamma-ray generation

1 Introduction

With the availability of a new range of laser intensities by the development of the chirped pulse amplification (CPA) technique has revived interest in high harmonic generation (HHG) from plasmas[1]. The ultra-short and relativistically strong laser pulses provided by CPA turn a solid target almost immediately into over dense plasma[2]. Because of the huge radiation pressure associated with laser intensities ~ 10^{22} – 10^{23} W/cm^2, combined with ponderomotive force and Coulomb attraction of ions, the plasma electron fluid moves with relativistic velocity and acts as relativistically moving mirror[3]. Depending upon the incident laser intensity, polarization of the incident beam and also on the density of the thin plasma layer the mirror motion may be assumed to be uniform, accelerated, or oscillatory[4-6]. In the case if an accelerated dense thin plasma slab meets a counter-propagating intense laser pulse, the reflected laser pulse is compressed in the longitudinal direction, intensified, and its frequency is Doppler-upshifted[7] by a factor of $4\gamma^2$. This phenomenon is of great interest for developing compact sources of coherent radiation in the ultraviolet and X-ray range of photo energies[8,9]. X-ray sources have a broad range of applications from single-molecule imaging to medicine, oncological hadron therapy[10] and they are required in material science and for the investigation of fundamental science problems such as in nonlinear quantum electrodynamics (QED) and relativistic astrophysics[11].

In the present paper we consider analytically and numerically the interaction of a uniformly moving /accelerating plasma mirror with a counter-propagating intense plane electromagnetic wave (source wave) at normal/oblique incidence. The role of the mirror is played by a high density plasma slab which is accelerated as a whole by an ultra-intense laser pulse (the driver) in the RPD regime[12-14]. In the case of uniformly moving mirror the change in the frequency and amplitude of reflected electromagnetic wave occurs due to double Doppler effect. Frequency change due to double Doppler effect is also seen in

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the concepts of oscillating mirror[15] which can produce ultra-short pulses of XUV radiation and X-rays. In a less dense foil ($\omega_p \approx \omega$) the electrons can perform collective motion in the direction perpendicular to the foil, thus forming a mirror oscillating with relativistic velocity. A portion of an incident relativistically strong electromagnetic wave, driving the oscillating mirror, is reflected in the form of strongly distorted wave carrying high harmonics[15,16].

In this paper the numerical results of the brightness of a source have been analyzed which are measured by the light energy emerging from a portion of an illuminated surface of a solid. A light beam from a finite source can be characterized by its beam divergence $\Delta\Omega$, source size (usually surface area A) and spectral power density $P(\nu)$ (watts per hertz of bandwidth). From these parameters it is useful to determine the "spectral brightness β_ν" of the source, which is defined as the power flow per unit area, per unit band width, and steradian namely $\beta_\nu = \dfrac{P_\nu}{A\Delta\Omega\Delta\nu}$. The numerical results of the spectral brightness of the reflected radiation from a uniformly moving plasma mirror as a function of the photon energy are obtained under the assumption $2\,\gamma < \left(n_e\,\lambda_s^3\right)^{1/6}$ and also in the opposite case when $2\,\gamma > \left(n_e\,\lambda_s^3\right)^{1/6}$.

2 Reflected Electromagnetic Wave from an Infinitely Thin Plasma Foil

An electromagnetic wave incident on an infinitely thin plasma foil, representing a mirror moving along x-axis represented by the coordinate $X_M(t)$, satisfies the wave equation[4,17]:

$$\frac{\partial^2 A}{\partial t^2} - c^2\,\frac{\partial^2 A}{\partial x^2} + \frac{4\,\pi\,e^2\,n_e\,l\,\delta\left(x - X_M(t)\right)}{m_e\,\gamma}\,A = 0 \qquad \dots (1)$$

where, A is the vector potential, n_e is initial electron density, l is thickness of plasma slab, m_e is the mass of electron and $\gamma = \left[1 - \dot{X}_M^2\,c^{-2}\right]^{-\frac{1}{2}}$. Introducing the dimensionless variables $\bar{x} = k\,x$, $\bar{t} = c\,k\,t$ and new variables $\xi = \dfrac{\bar{x} - \bar{t}}{2}$, $\eta = \dfrac{\bar{x} + \bar{t}}{2}$, Eq. (1) becomes:

$$\frac{\partial^2 A}{\partial\eta\,\partial\xi} = 2\,n_e\,l\,\frac{e^2}{m_e\,c^2}\left(\frac{2\,\pi}{k}\right)\frac{\delta\left(\psi(\xi,\eta)\right)}{\gamma(\xi,\eta)}A \qquad \dots (2)$$

where, $\psi(\xi,\eta) = \left(\eta + \xi - X_M(\eta - \xi)\right)$. Solution of Eq. (2) with proper boundary conditions at the plasma interface can be written in the form of two differential equations[18]:

$$a_1'(\xi) = \chi\left(a_1(\xi) + a_0\,e^{2i\,\eta_0(\xi)}\right)F\left(\xi,\eta_0(\xi)\right) \qquad \dots (3)$$

$$2\,i\,a_0\,e^{2i\,\eta_0(\xi)} - a_2'(\eta) = \frac{\chi}{F\left(\xi_0(\eta),\eta\right)}a_2(\eta) \qquad \dots (4)$$

Here a_0, $a_1(\xi)$ and $a_2(\eta)$ are the incident, reflected and transmitted waves, respectively, plasma density parameter $\chi = 2\,n_e\,l\,r_e\,\lambda$, $\lambda = \left(\dfrac{2\pi}{k}\right)$, r_e is the classical radius of electron and $F = \sqrt{\dfrac{1 + X_M'(\eta - \xi)}{1 - X_M'(\eta - \xi)}}$.

2.1 Uniformly moving mirror

Solution of the Eq. (3) with proper boundary conditions at the plasma interface of the uniformly moving mirror gives the reflected wave amplitude[17,18]:

$$a_1 = -\,a_0\,\frac{\chi}{\chi + 2\,i\,F_0}\exp\left(-\,2\,i\,F_0^2\,\xi\right) \qquad \dots (5)$$

The expression for the reflection coefficient is given by:

$$R = \left|\frac{a_1}{a_0}\right|^2 = \frac{\chi^2}{\chi^2 + 4F_0^2}. \qquad \dots (6)$$

Similarly transmission coefficient can be calculated by the relation $R + T = 1$, where $\chi = 2\,n_e\,l\,r_e\,\lambda$, n_e= 480, n_{cr}=5.4×10^{23}cm$^{-3}\times(1\mu\mathrm{m}/\lambda)^2$, l=0.01 λ, r_e=2.8×10^{-13} cm, λ=0.8 μm, $F_0 = \left(\dfrac{1 + \beta_M}{1 - \beta_M}\right)^{1/2}$. Change in the frequency and amplitude of an electromagnetic wave reflected by a moving mirror occurs due to double Doppler effect. The frequency of a reflected wave depends on the incidence angle and the mirror velocity as:

$$\omega_r = \omega_0 \frac{1 + 2\,\beta_M \cos\theta_0 + \beta_M^2}{1 - \beta_M^2} \qquad \ldots (7)$$

The reflection angle θ_r is related to the incidence angle as[4]:

$$\sin\theta_r = \frac{\omega_0}{\omega_r}\sin\theta_0 = \frac{\left(1 - \beta_M^2\right)\sin\theta_0}{1 + 2\,\beta_M \cos\theta_0 + \beta_M^2} \qquad \ldots (8)$$

During the wave-mirror interaction, the ratio of the amplitude of the electric field to its frequency is constant: $\frac{E_r}{E_0} = \frac{\omega_r}{\omega_0}$, 0 and r denote the parameters of the radiation incident on the mirror and reflected in the lab-frame. Depending on whether the wave and mirror are co-propagating $(\beta_M < 0)$ or counter-propagating $(\beta_M > 0)$ in the lab-frame, we have either the frequency downshift or frequency up shift. In the simplest configuration of normal incidence of the wave on the mirror (θ_0=0), then $\omega_r = \omega_0 \left(\frac{1+\beta_M}{1-\beta_M}\right) = \omega_0\,(1+\beta_M)^2\,\gamma^2$, where $\gamma = \left(1-\beta_M^2\right)^{-\frac{1}{2}}$. In the ultra-relativistic limit $\gamma >> 1$, the reflected wave frequency is higher by a factor $\approx\ 4\,\gamma^2$. The reflected wave energy changes accordingly.

2.2 Accelerated mirrors

The reflected wave from an accelerated mirror in the case of normal incidence is described by the transverse component of the vector potential:

$$A\,(x,t) = A_0 \left(t - \frac{x}{c}\right) + A_r \left(t + \frac{x}{c}\right) \qquad \ldots (9)$$

The mirror coordinate at time t is determined by equation $M\,(x,t)$ = constant, i.e., the mirror is located at point $x = X_M\,(t)$. The solution of the wave equation with the boundary condition $A\,(X_M\,(t),t) = 0$ at $x = X_M\,(t)$ can be written in the form[4]:

$$A\,(x,t) = A_0 \left[\exp\left(-\,i\,\omega_0\,v\right) - \exp\left(-\,i\int^{u}\omega_r\,(u)\,d\,u\right)\right] \qquad \ldots (10)$$

where the coordinates u and v are: $u = t - \frac{x}{c}$, $v = t + \frac{x}{c}$. The reflected wave-phase $\psi_r\,(u) = \int^{u}\omega_r\,(u)\,d\,u$ is given by $\psi_r(u) = \omega_0\,(2\,t\,(u) - u)$. Differentiating this expression with respect to time, we find $\psi_r'\,(u) = \omega_0 \frac{1+\beta_M\,(u)}{1-\beta_M\,(u)}$, where $\beta_M\,(u) = \frac{d\,x_M\,(t\,(u))}{c\,d\,t}$ is the normalized mirror velocity. The derivative of the phase with respect to u is the frequency ω_r of the reflected wave. From the expression for the vector potential $A(x,\,t)$ we can find a relation between the electric field $E = -\,(\partial A/\partial t)\,/\,c$ in the incident and reflected waves:

$$E_r = -\,E_0 \frac{1+\beta_M\,(t)}{1-\beta_M\,(t)} \qquad \ldots (11)$$

where $\beta_M\,(t) \equiv \beta_M\,(u\,(t))$.

When the mirror moves with a uniform acceleration $w = g\,k\,c^2$, the dependence of its coordinate on time is given by[19]:

$$x_M\,(t) = \left(\frac{c}{w}\right)\left[\left(m^2\,c^2 + w^2\,t^2\right)^{1/2} - 1\right] \qquad \ldots (12)$$

In this case, the frequency of light reflected from the uniformly accelerated mirror is given by following equation:

$$\omega_r = \omega_0 \frac{\sqrt{m^2\,c^2 + w^2\,t^2} + w\,t}{\sqrt{m^2\,c^2 + w^2\,t^2} - w\,t} \qquad \ldots (13)$$

2.3 Oscillating mirror

When a wave is reflected from a relativistic mirror, its frequency spectrum extends to the high-frequency range and the wave breaks up into short wave packets. The wave frequency increases by a factor $\approx 4\,\gamma_M^2$. The maximum electric field increases by the same factor according to Eq. (11). We consider a thin electron layer oscillating under the action of a linearly polarized electromagnetic wave with the electric field parallel to the y-axis[4,19]:

$$E_y = E_0 \cos\left[\Omega\left(t+\frac{x}{c}\right)\right] \quad \text{... (14)}$$

The source pulse is reflected from the electron layer as from the mirror. To describe the electron layer motion, we use the results of an exact solution of the problem of the electric charge dynamics in the field of an electromagnetic wave as:

$$x = \frac{c}{\Omega}\frac{a_0^2}{4\left(2+a_0^2\right)}\sin 2\eta, \quad y = \frac{c}{\Omega}\frac{a_0}{\sqrt{1+a_0^2/2}}\cos\eta$$

$$t = \frac{\eta}{\Omega}+\frac{a_0^2}{4\Omega\left(2+a_0^2\right)}\sin 2\eta, \quad p_x = \frac{a_0^2\, m_e\, c}{\sqrt{1+a_0^2/2}}\cos 2\eta \quad \text{... (15)}$$

$$p_y = a_0\, m_e\, c \sin\eta, \quad z = 0, \quad p_z = 0.$$

Here normalized amplitude of the wave is $a_0 = e\,E_0 / m_e\,\Omega\, c$. Using these solutions, we can calculate the phase and frequency of the reflected wave and find the electric field $E_r(t) = E_0\ \omega_0^{-1}\,\psi_r'(t)\cos\left(\psi_r(t)\right)$.

The oscillating mirror model describes the case when the laser pulse interacts with the electron layer oscillating with the amplitude comparable to the light wavelength. As a result the reflected wave frequency spectrum is enriched with high order harmonic[13] (HOH): $\omega_0/4\gamma^2 < \omega_r < 4\gamma^2\,\omega_0$. In the coordinate space the reflected wave packet is comprised of extremely short (attosecond) pulse. The electromagnetic pulse width for optimal conditions scales[20] as $\delta t = \frac{1}{\omega_r\, a_0}$. The reflection coefficient in terms of the reflected photon number scales[4] as $\sim\gamma^{-3}$. Taking into account the volume change where the reflected laser pulse is localized, the intensity of the reflected EM wave is given by $I_r \approx 32\, I_0\left(\frac{D_0}{\lambda_0}\right)^2\gamma^3$, where D_0 is the reflected beam diameter[4].

3 Spectral Brightness

Here, we are concerned essentially with the brightness of a source which is measured with the light energy emerging from a portion of an illuminated surface of a solid. A light beam from a finite source can be characterized by its beam divergence $\Delta\Omega$, source size (usually surface area A), and spectral power density $P(\nu)$ (watts per hertz of bandwidth). From these parameters it is useful to determine the "spectral brightness β_ν" of the source, which is defined as the power flow per unit area, per unit band width, and steradian namely $\beta_\nu = \frac{P_\nu}{A\,\Delta\Omega\,\Delta\nu}$.

If dS denotes the elemental surface area of the source, the power dP emitted by dS into the solid angle $d\Omega$ around a direction making the angle θ with respect to the surface, can be written as $dP = B\cos\theta\, dS\, d\Omega$, where B is the brightness. Considering a diffraction-limited laser beam of power P with a circular cross section of diameter D and with a divergence θ_d, then $P = 2\pi\, S\int_0^{\theta_d} B\cos\theta\sin\theta\, d\theta \;=\frac{1}{2}\pi\, B\, S\left[1-\cos 2\,\theta_d\right]$, where the beam cross-section is given by $S = \frac{\pi\, D^2}{4}$. Since θ_d is small, we can express $P \approx \frac{1}{2}\pi\, B\, S\,\frac{(2\,\theta_d)^2}{2}$, where angle of diffraction $\theta_d = \frac{\beta\,\lambda}{D}$, β=1.22, for diffraction due to a circular aperture. This reduces to $B = \left(\frac{2}{\pi\,\beta\,\lambda}\right)^2 P$.

For mirror velocities greater than some critical value $(2\gamma) > \left(n_e\lambda_s^3\right)^{1/6}$, the wavelength of the reflected light from the moving mirror in the frame of the mirror becomes shorter due to relativistic Doppler effect. In this case the scattering of light from the plasma mirror electrons is incoherent. The intensity of the reflected wave is proportional to the number of electrons. The coherent scattering occurs when the condition $(2\gamma) < \left(n_e\lambda_s^3\right)^{1/6}$ is satisfied[4]. In both the cases one can get bright high frequency radiation source.

The expression for the brightness for the case of coherent reflection i.e. when $(2\gamma) < \left(n_e\lambda_s^3\right)^{1/6}$ is given by $B_M \approx \varepsilon_s\left(\hbar\omega_r\right)^3\lambda_s / 4\pi^5\hbar^4 c^3$, and in the case when γ is very large i.e. $(2\gamma) > \left(n_e\lambda_s^3\right)^{1/6}$ then the interaction becomes incoherent and corresponding brightness is given by $B_T \approx a_d\, \varepsilon_s\, (\hbar\omega_r)^2\, r_e\, \lambda_s^2 / 8\pi^4\, \hbar^3 c^2 \lambda_d^3$, where ε_s is source pulse energy, a_d is the dimensionless vector potential of driver pulse, λ_s is the source pulse wavelength and λ_d is the wavelength of driver pulse[4].

4 Results and Discussion

As a result of immense radiation pressure of the driver laser pulse incident on a thin plasma layer, we consider the simplest case of uniformly moving ultra-thin dense plasma sheet. When a counter-propagating source laser pulse meets this moving plasma layer normally, the reflected wave frequency is Doppler up shifted by a factor of $4\gamma^2$ and its amplitude gets accordingly modified as given by Eq. (3). Figure 1 shows the numerical results of the variation of normalized amplitude of reflected wave versus its phase ξ for plasma mirror velocity β = 0.95, 0.99. We find that the frequency of the reflected wave increases ~ 5 times when the plasma mirror speed increases from β = 0.95 to 0.99, which is ~ $4\gamma^2$ times increase in the frequency of reflected wave. However the amplitude of the reflected electromagnetic wave described by the Eq. (3) decreases by a factor of ~ 1.26. Figure 2 shows the variation of the frequency of the reflected wave (ω_r / ω_0) when the counter-propagating laser pulse from the source meets the plasma mirror at an angle θ for a given mirror velocity β = 0.99. Figure 3 shows the variation of reflection coefficient $R = \left|\frac{a_1}{a_0}\right|^2$ with normalized speed β of the mirror. The numerical results show that the reflection coefficient decreases with increase in the normalized speed of the mirror. This is due to the relativistic increase in the frequency of the incoming wave as seen by the plasma mirror. The incoming electromagnetic wave penetrates through the plasma layer and reflection of the wave is effectively reduced. This is an ultra-relativistic phenomenon in the sense that when the mirror speed is below some

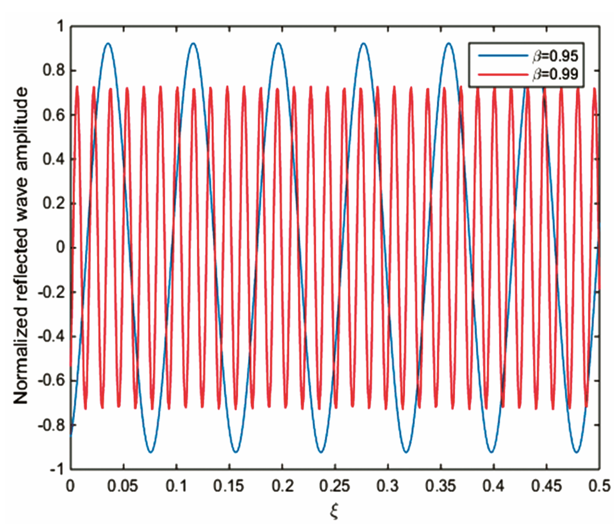

Fig. 1 — Variation of normalized amplitude of reflected wave versus normalized propagation factor when the normalized speed of the mirror is 0.95 and 0.99

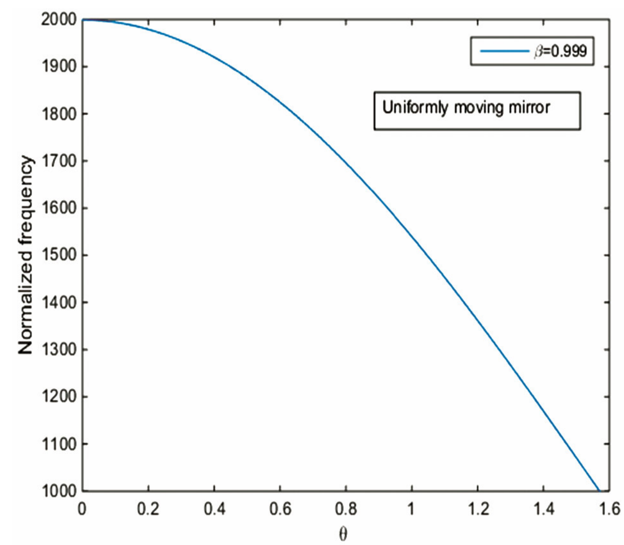

Fig. 2 — Variation of normalized frequency of the reflected radiation versus incidence angle of the mirror

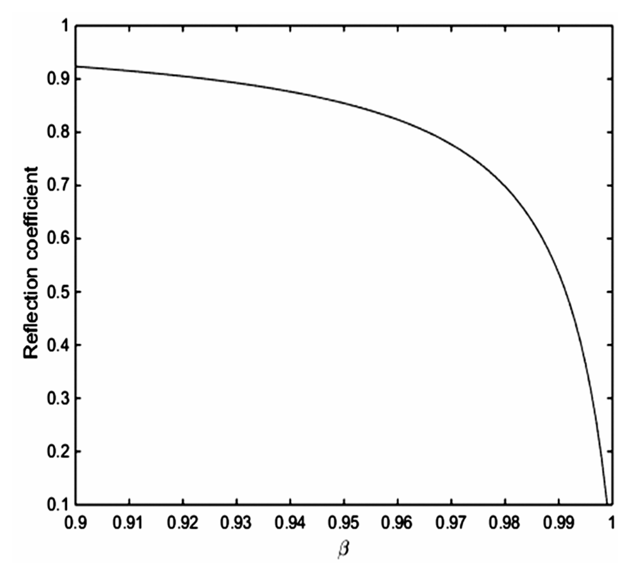

Fig. 3 — Variation of reflection coefficient versus normalized speed of the mirror

threshold value e.g. $\beta \le 0.90$, the reflection coefficient $R \sim 1$. However for $\beta \sim 0.99$, the reflection coefficient approaches zero. Figure 4 shows the variation of the reflection coefficient R with parameter χ of the plasma mirror for $\beta = 0.99, 0.999$. The reflection coefficient first increases and then attains a fixed value 1. Figure 5 shows the variation of transmission coefficient T of the uniformly moving mirror with parameter χ for fixed $\beta = 0.99, 0.999$. Figure 6 shows the variation of transmission coefficient versus normalized speed of the mirror. The results show that the transmission coefficient increases with increase in the normalized speed of the mirror.

Figure 7 shows the variation of brightness of the reflected radiation versus energy of the reflected photon in the case when $2\gamma < \left(n_e \lambda_s^3\right)^{1/6}$ for different values of source pulse energy ε_s. From this figure we see that in the coherent interaction for the parameters $\lambda_s = \lambda = 0.8\mu\text{m}$, $n_e = 480\, n_{cr} = 5.4\times 10^{23}\,\text{cm}^{-3}\times(1\mu\text{m}/\lambda)^2$, maximum brightness corresponding to 10 keV photon energy is approximately 4.82×10^{42} photons / (mm^2 - mrad^2 - s - 0.1% bandwidth) for $\varepsilon_s = 6$ J, 6.43×10^{42} photons / (mm^2 - mrad^2 - s - 0.1% bandwidth) for $\varepsilon_s = 8$ J, 8.03×10^{42} photons / (mm^2 - mrad^2 - s - 0.1% bandwidth) for $\varepsilon_s = 10$ J, and 9.64×10^{42} photons /

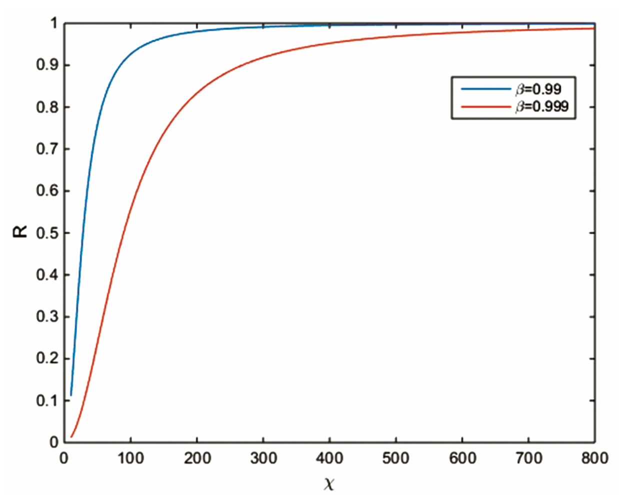

Fig. 4 —— Variation of reflection coefficient of the uniformly moving mirror versus dimensionless parameter.

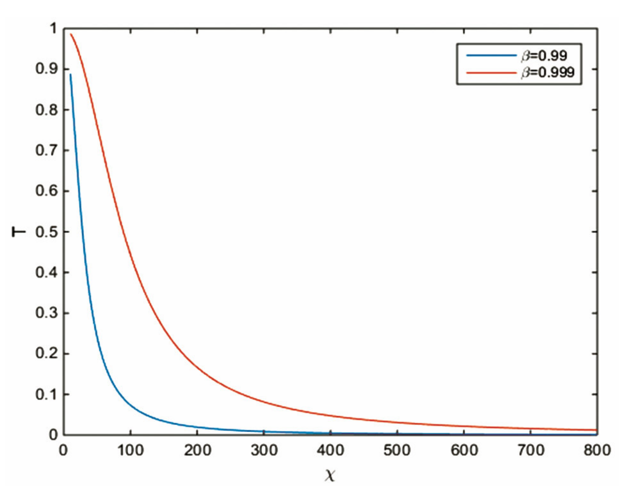

Fig. 5 — Variation of transmission coefficient of the uniformly moving mirror versus dimensionless parameter

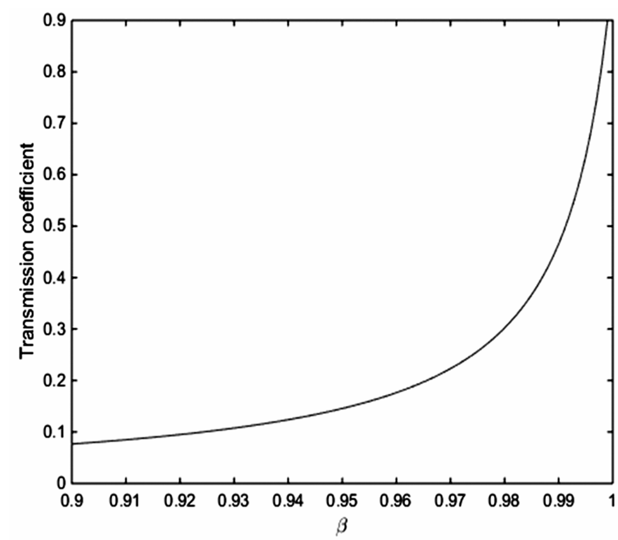

Fig. 6 — Variation of transmission coefficient versus normalized speed of the mirror

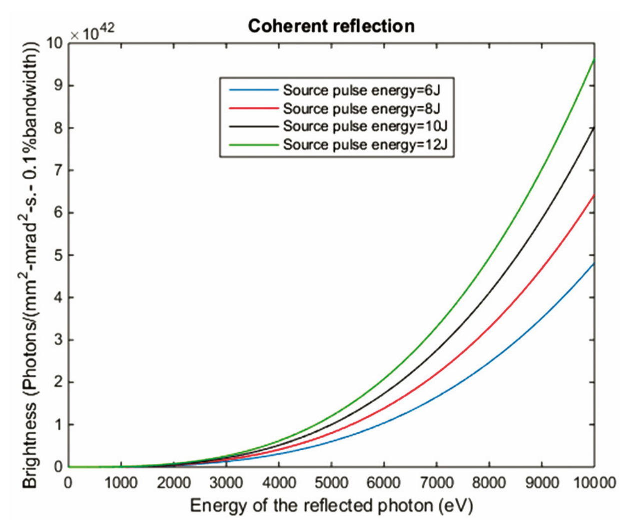

Fig. 7 — Variation of brightness of the reflected radiation versus energy of the reflected photon in the case $2\gamma \langle \left(n_e \lambda_s^3\right)^{1/6}$ when mirror is moving uniformly for different values of source pulse energy $\varepsilon_s = 6$ J, 8 J, 10 J, 12 J

(mm^2 - mrad^2 - s - 0.1% bandwidth) for ε_s = 12 J. This energy of the reflected photon is corresponding to the energy of hard X-ray source.

Figure 8 shows the variation of brightness of the reflected radiation versus energy of the reflected photon in the case when $2\gamma > (n_e \lambda_s^3)^{1/6}$ for different values of source pulse energy ε_s. In this case when the mirror is moving uniformly, the reflections of the photons are incoherent and corresponding scattering is Thomson scattering. From this figure we see that in the incoherent interaction using parameters $\lambda_s = \lambda_d = 0.8\mu$m, n_e = 480 n_{cr} = 5.4×10^{23}cm^{-3}× $(1\mu\text{m}/\lambda)^2$, $a_d = 300$, maximum brightness corresponding to 100 keV photon energy is approximately 1.96 ×10^{34} photons / (mm^2 - mrad^2 - s - 0.1% bandwidth) for ε_s = 6 J, 2.62 ×10^{34} photons / (mm^2 - mrad^2 - s - 0.1% bandwidth) for ε_s = 8 J, 3.27 ×10^{34} photons / (mm^2 - mrad^2 - s - 0.1% bandwidth) for ε_s = 10 J, and 3.93 ×10^{34} photons / (mm^2 - mrad^2 - s - 0.1% bandwidth) for ε_s = 12 J. This energy of the reflected photon is corresponding to the energy of gamma- ray.

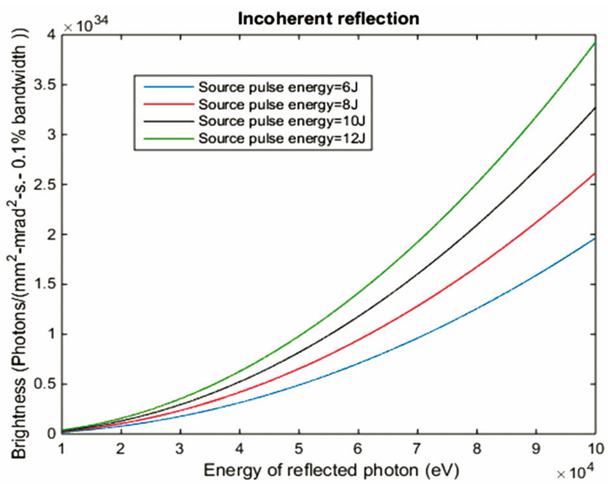

Fig. 8 — Variation of brightness of the reflected radiation versus energy of the reflected photon in the case $2\gamma \rangle (n_e \lambda_s^3)^{1/6}$ when mirror is moving uniformly for different values of source pulse energy ε_s =6 J, 8 J, 10 J, 12 J

In Fig. 9 we show the trajectory of the uniformly accelerated mirror. Figure 10 shows the variation of the normalized frequency of the reflected wave versus dimensionless acceleration parameter wt/c for the uniformly accelerator mirror. From this figure we see that as we increase the value of wt/c the frequency of the reflected wave increases with factor of $\approx 4\gamma^2$.

Figure 11 shows the trajectory of an electron in the field of linearly polarized electromagnetic wave. We see that in this field the path of the motion of electron is described by Fig. 8 curve. Figure 12 shows the variation of electric field of the wave reflected from oscillating mirror with $\Omega/\omega_0 = 1$. Figure 13 shows the variation of the intensity of the reflected source pulse I_r from oscillating mirror as a function of relativistic Lorentz factor γ. From this figure we see that as we increase the value of relativistic factor γ corresponding intensity of

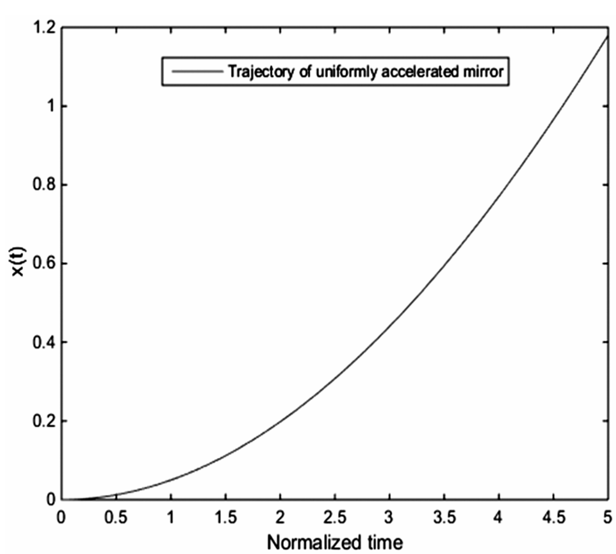

Fig. 9 — Trajectory of the uniformly accelerated mirror

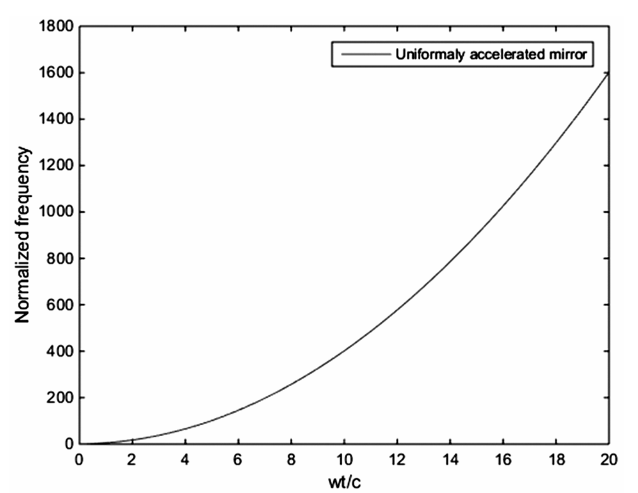

Fig. 10 — Variation of the normalized frequency of the reflected wave versus dimensionless acceleration parameter wt/c for the uniformly accelerated mirror

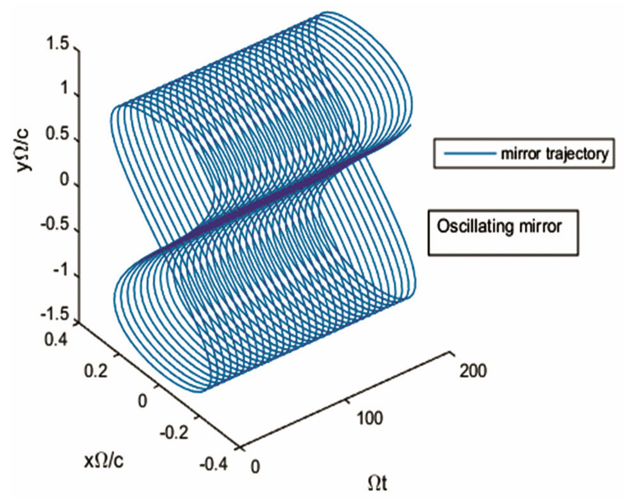

Fig. 11 — Trajectory of the oscillating mirror for $a_0 = 10$

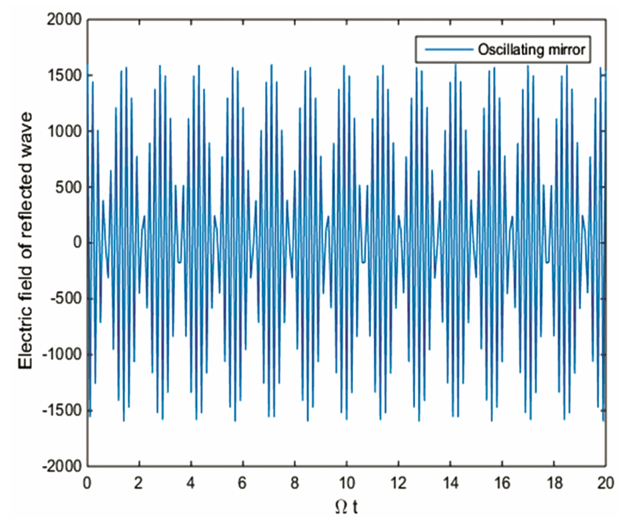

Fig. 12 — Variation of electric field of the wave reflected from oscillating mirror with $\Omega / \omega_0 = 1$

the reflected wave also increases and at the value $\gamma \approx 80$, it is able to create electron-positron pair from the vacuum[3,4,21], vacuum polarization[3,4] and the laser field approaches to the Schwinger field[3,4].

5 Conclusions

A solid dense plasma slab, accelerated in the RPD regime, can efficiently reflect a counter-propagating relativistically strong source pulse consisting of up-shifted frequency and high harmonics. This reflected source pulse is chirped due to mirror acceleration. Numerical results for brightness show that when the plasma mirror velocities are greater than some threshold then the distance between electrons in the slab becomes longer than the incident wavelength so the reflection from plasma slab is not coherent. In effect, one can develop a compact source of high-brightness X-rays and short gamma rays. These sources will possibly open-up a wealth of applications in biology and medicine[10], laboratory astrophysics[22] and material science.

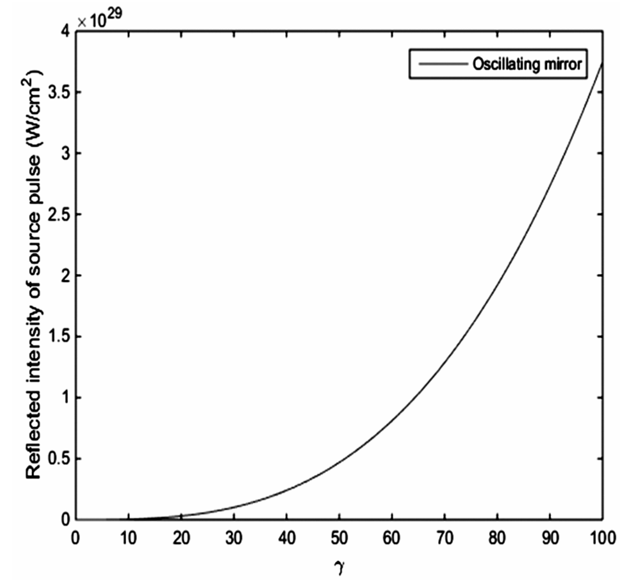

Fig. 13 — Variation of the intensity of the reflected source pulse $I\gamma$ from oscillating mirror as a function of relativistic Lorentz factor γ

Acknowledgement

Financial support from the Department of Science & Technology, New Delhi, (Government of India) is thankfully acknowledged.

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