Enhancement In Tera Hertz Radiations Produced By Short Pulse Laser

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Abstract: In this work, there is a comprehensive Theoretical formalism for the generation of THz radiation with the use of two femtosecond laser pulses on applying the d.c. electric field in a magnetized collisional plasma. Due to filamentation action of femtosecond pulses in magnetized collisional plasma, there occurs non Linear coupling in transverse d.c. electric field. In this mechanism, non-linear electromagnetic force leads to non Linear transverse oscillatory current that excites at resonance to generate THz radiation. The amplitude of THz radiation can be increased by increasing magnitude of magnetic field.

Key words: femtosecond Laser pulses, filamentation, THz radiation.

I. Introduction

In Today's Modern technical world, THz radiation has become a very important research tool due to its many scientific, technical, industrial and commercial applications such as THz spectroscopy, THz sensors, THz scanners, THz explosive detectors. Out of numerous mechanisms provided by the researchers in the literature, THz pulse energy generation is maximum in case of filamentation because of its special ability of filaments to produce weak plasmas in the presence of propagating filament pulse, which can rectify narrow band pulse in to a broad band pulse [1,2], it results in efficient THz radiation production [3]. Consider two femtosecond laser pulses with electric field acting along Z-axis, magnetic field is acting along Y-axis and d.c. electric field is applied along X-axis to provide movement to electrons in plasma. Plasma is a very suitable non-linear medium for THz production with short pulse lasers [4-6]. With an advantage that it can sustain very high powers and shows stronger non Linear effects [7-10]. The laser exerts a nonlinear electromagnetic force F_{qw} and Ponderomotive static force F_{pq} on electrons [11]. The static Ponderomotive force and pressure gradient force oppose each other 's effect and forms density ripple with zero frequency. The non-linear electromagnetic force at beat frequency is responsible for electron velocity and density oscillations, which further results in d.c. drift of electrons so that transverse electronic current $J_{w,k}$ can be produced and it further generates THz radiation [12-14].

In this paper's section II we obtain the expressions for non-linear velocity perturbation and non-linear density perturbation at THz frequency. In section III we discuss enhancement in production of THz radiation by using standard wave propagation equation after satisfying the phase matching conditions. Discussion and conclusion is given in section IV of the paper.

II. Derivation of non-linear velocity and density perturbation

When d.c electric field is applied along X-axis on magnetized collisional plasma [11-16], then electrons will move with drift velocity

$$\vec{V}_{d.c} = \frac{-e\,\vec{E}_{st.}}{m_e\,\upsilon_e} \qquad (1)$$

where e is the charge of single electron, m_e is the mass of single electron and υ_e is the collisional frequency of electrons. We incident two filamented lasers in to magnetized collisional plasma, The electric field of lasers are,

$$\vec{E}_j = \hat{y}\, B_{j0}\,[\,1+ \mu_j \cos qx]\, e^{-i(\omega_j t - k_j z)} \quad \text{where } j=1\text{and}2$$

Here μj denotes modulation depth and the difference in frequencies of two lasers, $\omega = \omega_1 - \omega_2$ lies in THz frequency range. These filamented lasers are also responsible in providing oscillatory velocities to plasma electrons.

$$\vec{V}_j = \frac{e\,\vec{E}_j}{m_e\,(i\omega_j - \upsilon)} \qquad (2)$$

They are also responsible to exert static Electromagnetic force $F_{pq} = e\,\vec{V}\,\varphi_{pq}$ and beat frequency non-linear electromagnetic force $F_{p\omega} = e\,\vec{V}_{p\omega}$

$$\Phi p\omega = \frac{e}{4\, m_e T_e}\left[\frac{B_{10}^2\,\mu_1}{(i\omega_1 - \upsilon_e)^2} \quad \frac{B_{20}^2\,\mu_2}{(i\omega_2 + \upsilon_e)^2}\right] + \quad e^{iqx} \qquad (3)$$

Where, T_e is the equilibrium temperature of electrons. By using standard equations of motion, we will calculate the velocity components along X and Z axis

$$\vec{V}_x^{NL} = \frac{(\upsilon - i\omega)\, F_x}{m_e\,\omega_\alpha^2} + \frac{\omega_c}{m_e\,\omega_\alpha^2} F_z \qquad (4)$$

$$\vec{V}_Z^{NL} = \frac{(\upsilon - i\omega)\, F_z}{m_e\,\omega_\alpha^2} - \frac{\omega_c}{m_e\,\omega_\alpha^2} F_x \qquad (5)$$

Here, $[(\upsilon - i\omega)^2 + \omega_c^2] = \omega_\alpha^2$ and ω_c represent cyclotron frequency
Density perturbation along X and Z axis is given by

Density perturbation along X-axis

$$\vec{n}^{NL}_{w,k} = \frac{n_0^0 \; e^2 B_{10}B_{20}[ik^2]\omega_c}{2m_e^2 \omega \, \omega_\alpha^2 (i\omega_1 - \upsilon_e)(i\omega_2 + \upsilon_e)} e^{-i(\omega t - kz)} \quad (6)$$

Density perturbation along Z-axis

$$\vec{n}^{NL}_{w,k} = \frac{n_0^0 \; e^2 B_{10}B_{20}[ik^2](\upsilon - i\omega)}{2m_e^2 \omega \, \omega_\alpha^2 (i\omega_1 - \upsilon)(i\omega_2 + \upsilon)} e^{-i(\omega t - kz)} \quad (7)$$

With the help of density perturbation, the non-linear current density along X and Z axis is given by

$$\vec{J}^{NL}_{X\,\omega,k} = \frac{-n_0^0 \, e^4 \, B_{10} B_{20}[i]}{2\, m_e^3 \, \omega_\alpha^2 (i\omega_1 - \upsilon_e)(i\omega_2 + \upsilon_e)} [(\upsilon - i\omega) + \omega_c)] \left[\frac{K^2 \vec{E}_{st.}}{\omega \, \upsilon_e} - \frac{eq(\mu_1+\mu_2)}{8\,T_e} \left(\frac{A_{10}^2 \; \mu_1}{(i\omega_1 - \upsilon_e)^2} + \frac{A_{20}^2 \; \mu_2}{(i\omega_2 + \upsilon_e)^2} \right) (\upsilon - i\omega - \omega_c) \right] .\left(e^{-i(\omega t - kx)}\right) \quad (8)$$

$$\vec{J}^{NL}_{Z\,\omega,k} = \frac{-n_0^0 \, e^4 \, B_{10} B_{20}[i]}{2\, m_e^3 \, \omega_\alpha^2 (i\omega_1 - \upsilon_e)(i\omega_2 + \upsilon_e)} \left[\frac{e\,k\,(\mu_1+\mu_2)}{8\,T_e} \left(\frac{A_{10}^2 \; \mu_1}{(i\omega_1 - \upsilon_e)^2} + \frac{A_{20}^2 \; \mu_2}{(i\omega_2 + \upsilon_e)^2} \right) \frac{mk[(\upsilon - i\omega) + \omega_c]}{e} \right]$$

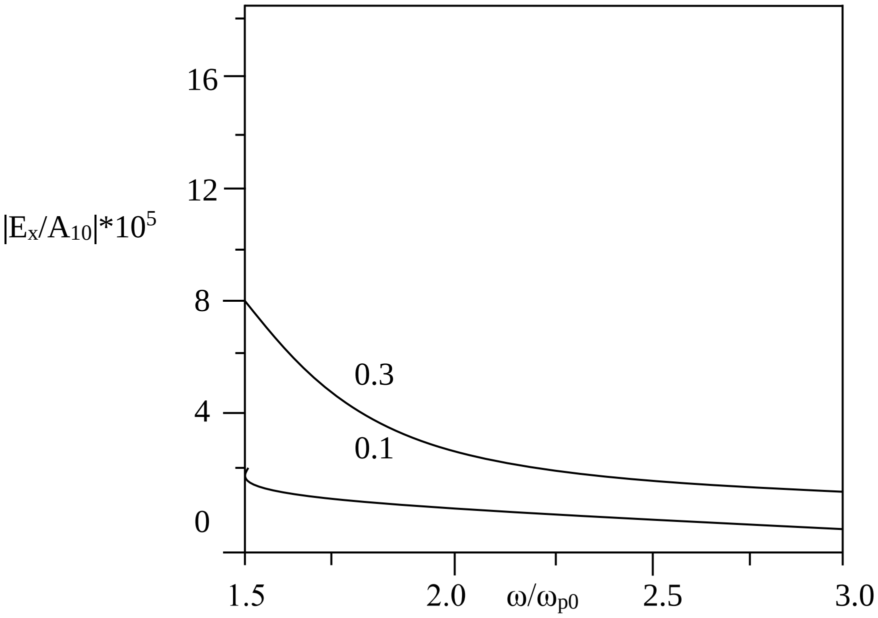
$.(e^{-i(\omega t - kz)})$
(9)

III. Enhancement in the Production of THz radiations

By using standard equation of wave propagation and by using Phase Matching Condition we get

$$E_x = \frac{-2\pi\omega}{K'C^2}\left[\frac{\epsilon_{ZX}}{\epsilon_{ZZ}}\right]\vec{J}^{NL}_{X\,\omega,k} + \vec{J}^{NL}_{Z\,\omega,k} \quad Z$$
(10)

And by using the particular values of ω_c/ω_p = 0.1 and 0.3, The plot between ($|E_x/A_{10}|*10^5$) and (ω/ω_{p0}) shows enhancement in the amplitude of normalized THz radiation
$\omega_1 = 2.4 \times 10^{14}$ rad/s,$\omega_2 = 2.1 \times 10^{14}$ rad/s, $E'_{st.} = 0.053$, $\omega_p = 2.0 \times 10^{13}$ rad/s,$\mu_1 = \mu_2 = 0.3$,q'= 0.3
and ω'= 2.0 to 5.0.



IV. Discussion and Conclusion

The non Linear interaction of femtosecond laser pulses with magnetized plasma on applying the d.c. electric field produces perturbation in the velocity of electrons which is responsible for perturbation in the density of electrons. Due to both, non Linear current is produced and this non-linear current at beat frequency results in the generation of THz radiations and phase matching conditions are satisfied. The normalized amplitude of THz radiation can be enhanced by various parameters on applying electric field and magnetic field.

References

1. Tzortzakis.S, Franco.M, Andre.Y.B, Chiron.A, Infrared femtosecond light filaments in air. Journal of optical society of America B. 2002;19:1117-1131.

2. Couairon.A. Dynamics of femtosecond and filamentation from saturation of self focusing laser pulses. Phys. Rev. A. 2003.

3. D.Amico et al. Conical forward terahertz emission from femtosecond laser beam filamentation. Phys. Rev. Lett. 2007.

4. Niti kant and Manzoor Ahmad Wani. Density transition based self focusing of cosh-Gaussian laser beam in plasma with linear absorption. Communication in theoretical physics. 2015;64.

5. N.Kant, V.Thakur. Second harmonic generation by chirped laser pulse in magnetized plasma. Optik. 2016;127:4167-4172.

6. Kant N, Saralch S, Singh H. Ponderomotive self-focusing of a short laser pulse under a plasma density ramp. Nukleonika. 2011;56:149-153.

7. W.P. Leemans et al. High quality electron beams from a laser wake field accelerator using plasma channel guide. Phys. Plasmas. 2004;11:2899.
8. A. Pukhov. Strong field interactions of laser beam. Rep. Prog. Phys. 2003;66:47.
9. Kant, N., Wani, M. A., & Kumar, A. (2012). Self-focusing of Hermite–Gaussian laser beams in plasma under plasma density ramp. *Optics Communications*, *285*(21-22), 4483-4487.
10. Mukherjee, R. (2020). Electrical, thermal and elastic properties of methylammonium lead bromide single crystal. Bulletin of Materials Science, *43*(1), 1-5.
11. N. Kant, V. Thakur. Enhanced resonant second harmonic generation in plasma based on density transition. Nukleonika. 2015;60.
12. Gupta, V. K., Sethi, B., Upadhyay, N., Kumar, S., Singh, R., & Singh, L. P. (2011). Iron (III) selective electrode based on S-methyl N-(methylcarbamoyloxy) thioacetimidate as a sensing material. *Int. J. Electrochem. Sci*, *6*, 650-663.
13. A.Mehta, Jyoti Rajput, K. Kang and Nitikant. THz generation by beating of two chirped pulse lasers in spatially periodic plasma. Laser Physics. 2020;30:4.
14. Mukherjee, R., Huang, Z. F., & Nadgorny, B. (2014). Multiple percolation tunneling staircase in metal-semiconductor nanoparticle composites. Applied Physics Letters, *105*(17), 173104.
15. Mukherjee, R., Lawes, G., & Nadgorny, B. (2014). Enhancement of high dielectric permittivity in CaCu3Ti4O12/RuO2 composites in the vicinity of the percolation threshold. Applied Physics Letters, *105*(7), 072901.
16. V.Thakur, N.Kant , S.Vij, V.Sharma. Influence of exponential density ramp on second harmonic generation by short pulse laser in magnetized plasma. Elsevier. 2018;171:523-528.