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Effect of ion density acoustic on THZ generation in laser-dense plasma interaction

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ABSTRACT

Terahertz applications such as biological sensing, imaging, surface chemistry and high field condensed matter studies cause to propose the source of this radiation over the last decade. Various schemes based on optical rectification, Quantum cascade intersubband, photoconductive antenna, Varactor Frequency Doublers, synchrotron radiation and est. are used to generate terahertz radiation. Electromagnetically Induced Transparency in an Ideal Plasma was demonstrated by Harris. Recently, the terahertz radiation via an electromagnetically induced transparency at ion acoustic frequency region with laser-produced dense plasmas is reported by Nakagawa. In this work, we consider the interaction of a high intensity laser pulse with dense plasma. By using the ion hydrodynamic equations and The Maxwell's equations, ion density variation is obtained that could be demonstrated terahertz power. This new achievement can optimized the power of generated THz in ion acoustic frequency region.

INTRODUCTION

EIT or electromagnetically induced transparency is a new technique which can control the refractive index of the electromagnetic waves in the medium. Harris for the first time found the electromagnetic wave with the frequency lower than plasma frequency could be propagated in plasma [1, 2]. Generation of terahertz radiation at the ion acoustic frequency region by the EIT technique is reported [3, 4]. More applications as imaging, surface investigation, studies in condensed-matter, biological sensing for terahertz radiation is reported. It cause for finding the high power sources. THz radiation is interested over the last decade. Various schemes are presented to generate THz radiation such as optical rectification, photoconductive antenna, Quantum cascade intersubband, Varactor Frequency Doublers and est. using the femtosecond laser pulses with electro-optic crystals and semiconductors through optical rectification is a direct way to make THz by [5-8]. The powers of these sources are ranged in $\mu W - mW$ level. In this work we have investigated the effective parameters on ion acoustic frequency region by consideration EIT technique. The continuity and force equations of ions particles are considered. Thz power is demonstrated by developing the acoustic ion oscillation.

OUR WORK

Hydrodynamic and Maxwell's Equations

We used the continuity and force equations of ions particles our work:

$$\frac{\delta n_i}{\delta t} + \frac{\delta}{\delta x}(n_i u_i) = 0 \qquad (1)$$

$$\frac{\delta}{\delta t}(n_i u_i) + \frac{\delta}{\delta x}(n_i u_i^2) = \frac{Ze}{m} n_i E_l - \frac{1}{m}\frac{\delta p_i}{\delta_x} - \frac{e^2 n_i}{4m\omega^2}\frac{\delta}{\delta x}E_l^2 \qquad (2)$$

that n_i, u_i, m and p_i are density, velocity, mass and pressure of the ion particles, respectively. We have obtained the Eq. (3) from Eqs. (1) and (2) as:

$$\frac{\delta^2 n_i}{\delta t^2} - \frac{\delta^2}{\delta x^2}(n_i u_i^2) = \frac{Ze}{m}\frac{\delta}{\delta x}(n_i E_l) - \frac{1}{m}\frac{\delta^2 Pi}{\delta x^2} - \frac{e^2}{4m\omega^2}\frac{\delta}{\delta x}(n_i \frac{\delta}{\delta x}E_l^2) \qquad (3)$$

Passband frequency (ω_s) is the same ion frequency and we can consider: $V_i = V_s = V_s e^{i(K_s x - \omega_s t)}$, $P_i = 3\theta_i n_i$ and . We obtain:

$$\frac{\delta^2 n_i}{\delta t^2} - \{u_s^2 \frac{\delta^2 n_i}{\delta x^2} + 2(\frac{\delta u_s}{\delta x})^2 n_i + 2u_s \frac{\delta^2 u_s}{\delta x^2} + 2u_s \frac{\delta u_s}{\delta x}\frac{\delta n_i}{\delta x}\} =$$
$$\frac{Ze}{M}E_l \frac{\delta n_i}{\delta x} + \frac{Zen_i}{M}\frac{\delta}{\delta x}E_l - \frac{3\theta_i}{M}\frac{\delta^2 n_i}{\delta x^2} - \frac{e^2}{4M\omega^2}\frac{\delta n_i}{\delta x}(\frac{\delta}{\delta x}E_l^2) - \frac{e^2 n_i}{4M\omega^2}\frac{\delta^2}{\delta x^2}E_l^2 \qquad (4)$$

If we have $E_l = E_l e^{i(k_l x - \omega_l t)}$ then Eq. (4) change to:

$$\frac{\delta^2 n_i}{\delta t^2}+\frac{\delta^2 n_i}{\delta x^2}\{-u_s^2-\frac{3\theta_i}{M}\}+\frac{\delta n_i}{\delta x}\{i2u_s^2 ks\frac{ZeE_l}{M}-\frac{i2e^2K_lE_l^2}{4M\omega^2}\}$$
$$+n_i\{-k_s^2u_s^2+i\frac{Zek_l}{M}E_l+\frac{e^2K_l^2E_l^2}{4M\omega^2}\}=0$$

(5)

E_l could be calculated as bellow [8]:

$$\frac{\delta V_l}{\delta t}+j\omega_l V_l=-\frac{qE_l}{m}-\frac{q}{2m}(B_aV_s+V_aB_s) \qquad (6)$$

In Eq. (6) the first term is smaller than the others and it could be omitted, and we know:

$B_a=\frac{K_aE_a}{\omega_a}$, $B_s=\frac{K_sE_s}{\omega_s}$ and $V_s=\frac{+jqE_s}{\omega_a m}$

Then we obtain

$$E_l=-\frac{i\omega_e m}{q}V_l\exp(k_lx-\omega_lt)-\frac{iq}{2m\omega_a\omega_s}(E_aE_s)\exp_i(K_lx-w_lt)$$

(7)

By substituting Eq. (7) into Eq. (5), we obtain:

$$\frac{\delta^2 n_i}{\delta t^2}+\frac{\delta^2 n_i}{\delta x^2}\{-u_s^2e^{2i(k_sx-\omega_st)}-\frac{3\theta i}{M}\}$$
$$+\frac{\delta n_i}{\delta x}\{2iK_su_s^2e^{2i(k_sx-\omega_st)}+\frac{Ze}{M}E_le^{i(k_lx-\omega_lt)}$$
$$-\frac{i2e^2k_l}{4M\omega^2}E_l^2e^{2i(k_ex-\omega_lt)}\}+n_i\{-k_s^2u_s^2e^{2i(k_sx-\omega_st)}$$
$$+\frac{iz_lk_l}{M}E_ll^{i(K_lx-\omega_lt)}+\frac{e^2k^2_l}{4M\omega^2}E_l^2e^{2i(k_ex-\omega_lt)}\}=0$$

(8)

With considering $\xi=x-\frac{\omega}{k}t$, the equation is changed to:

$$\frac{d^2n_i}{d\xi^2}\left\{\frac{1}{v}-u_s^2e^{2ik_s\xi}-\frac{3\theta_i}{\mu}\right\}+$$
$$\frac{dn_i}{d\xi}\left\{2ik_su_s^2e^{2ik_s\xi}+\frac{ze}{m}E_ee^{ik_e\xi}-\frac{i2e^2k_e}{4mw_a^2}E_e^2e^{2_ik_e\xi}\right\}+$$
$$n_i\left\{-k_s^2u_s^2e^{2i_gk_s\xi}+\frac{izek_e}{m}E_ee^{ik_e\xi}+\frac{e^2k_e^2}{4mw_a^2}E_e^2e^{2_iik_e\xi}\right\}=o$$

(9)

Without consideration of Thermal effect

We have used equation of motion for the electron oscillation [8]

$$\frac{\delta\rho}{\delta t}-2i(\omega_p-(\omega_a-\omega_s))\rho=i\frac{nq^2(k_a-k_s)^2}{2m^2\omega_a\omega_s\omega_p}E_aE_s \qquad (10)$$

and we know $\rho=en$, so we obtain

$$\frac{\delta n}{\delta t}-i2en.(\omega_p-(\omega_a-\omega_s))=i\frac{n_0q^2(k_a-k_s)^2}{2m^2\omega_a\omega_s\omega_p}E_aE_s \qquad (11)$$

$$\frac{1}{n}\frac{\delta n}{\delta t}=i(2e\delta\omega_s+\frac{q^2(k_a-k_s)^2}{2m^2\omega_a\omega_s\omega_p}E_aE_s) \qquad (12)$$

$$n=ne^{i(2e\delta\omega_s+\frac{q^2(k_a-k_s)^2}{2m^2\omega_p\omega_a\omega_s}E_aE_s)t} \qquad (13)$$

By using the Poisson Eq. we know

$$\frac{\delta V_l}{\delta t}=j\omega_lV_l=-\frac{qE_l}{m}-\frac{q}{2m}(B_aV_s^*+V_aB_s^*) \qquad (14)$$

We can substite

$B_a=K_aE_a/\omega_a, V_a=iqE_a/\omega_am, B_s=k_sE_s/\omega_s$ and $V_s=iqE_s/\omega_sm$ in Eq.(14). We calculated E_l as

$$E_l=-i\{(\omega_a-\omega_s)V_l+\frac{q^2}{2m^2\omega_a\omega_s}(K_a+K_s)E_aE_s\} \qquad (15)$$

Using the Maxwell equation, we obtain:

$$n_i=\frac{q^2}{8\pi em^2\omega_a\omega_s}(K_a+K_s)E_aE_se^{-i\omega_lt}$$
$$+n_0e^{i(2e\delta\omega_s+\frac{q^2}{2m^2\omega_a\omega_s}(K_a+K_s)E_aE_s)} \qquad (16)$$

CONCLUSION

Electromagnetic radiation at THz region with the ELT technique is feasible. Ion plasma frequency at the dense plasma is corresponded. Our calculation shows the average power of the Thz radiation will be increased by controlling the density variation. This may related to the thermal or non thermal plasma model. In this work we have solved the ion motion in the both model.

REFERENCES

1 K. J. Boller, A. Imamoglu, and S. E. Harris, Phys. Rev. Lett.**66**, 2593 (1991).
2 D. F. Phillips, A. Fleischhauer, A. Mair, R. L. Walsworth, and M. D. Lukin, Phys. Rev. Lett. **86**, 783 (2001).
3 K. Morawetz and D. Kremp, Phys. Plasmas, **1**, 225 (1994).
4 M.Nakagawa and *et al.*, PHYSICAL REVIEW E 80, 025402R (2009).
5 Melo, A.M. , Lima, J.L.S., Oliveira, R.S. , Sombra, A.S.B., "Photonic time division multiplexing using ultrashort picoseconds pulses in terahertz optical asymmetric demultiplexer," optical communications, 205,299-312(2002).
6 Saeedikia, D., Mansour, R.R., "A Submiliwatt Terahertz High-Temperature Superconductive Photomixer Array Source: Analysis and Design," IEEE T. Appl. Supercon., 15, no.3, 3868-3873(2005).
7 P.Zobdeh and et al., Progress In Electromagnetics Research Symposium Proceedings, Moscow, Russia, August 18-21, 1623(2009).
8 S. E. Harris., Phys. Rev. Lett. VOL. 77, No. 27,5357-5360,(1996).