# Magnetic Field Generation in Ultraintense-Laser-Plasma Interactions

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The mechanism of intense magnetic field generation in ultraintense-laser-plasma interactions is studied by theory and particle-in-cell (PIC) simulations. Recently, it is reported that the anisotropy has been experimentally demonstrated in laser-produced plasmas. It is also pointed out that giga-gauss magnetic fields is generated by ultraintense laser pulses. We have already published that the Weibel-type electromagnetic instabilities can be theoretically excited by electrons in a velocity distribution with anisotropic temperature. If these electromagnetic waves excited, the target may have a possibility not only to give rise to a new type of energy loss mechanism but also to influence the implosion characteristics. In this work, we present PIC simulation of the interaction of ultraintense laser pulses with plasmas. Intense self-generated magnetic fields is produced by the mechanism of Weibel instability in underdense plasmas.

## 1   Introduction

Recently, ultraintense ultrashort-pulse lasers have been developed, and the Fast Ignitor becomes an alternate approach to inertial confinement fusion [1]. The interaction of such intense lasers and plasmas has been studied. In laser-produced plasmas, self-induced magnetic fields have been demonstrated both experimentally [2,3] and theoretically. It is sure that these fields play an important role, for example, in the anomalous reduction [4,5] of thermal flux and in dynamic behaviors of spherical compression of pellets. It is pointed out that giga-gauss magnetic fields may be generated by ultraintense laser beam. Recently, it is reported that electron distribution anisotropy [6] has been experimentally demonstrated in laser-produced plasmas. We have already published that the Weibel-type electromagnetic instabilities [7,8] can be theoretically excited by electrons in a velocity distribution with anisotropic temperature. If these electromagnetic waves excited, the target may have a possibility not only to give rise to a new type of energy loss mechanism but also to influence the implosion characteristics. In this work, 2-D particle-in-cell simulation results are presented for laser-produced plasmas with nonvanishing thermal flux, vanishing current and nonvanishing temperature anisotropy. These results agree well with typical experimental values.

## 2   Simulation of magnetic field generation

We simulated the Weibel-type instability using two-dimensional (2-D), relativistic, electromagnetic, particle simulation code with following parameters; time step $0.1\omega_{pe}^{-1}$,

spatial step $0.2c\omega_{\mathrm{pe}}^{-1}$, cells $64 \times 64$, electrons 40000, ions 40000, initial temperature $(T_y)$ 1 keV, $(T_z)$ 1 keV, where $c$ is the speed of light and $\omega_{\mathrm{pe}}$ the electron plasma frequency, y and z are perpendicular to the laser-incident axis, respectively.

Maximum growth rate of the fields in the collisionless linear stage is given [9]

$$\gamma^{\mathrm{max}} = \sqrt{\frac{8}{27\pi}}\omega_{\mathrm{pe}}\sqrt{\frac{k_{\mathrm{B}}T_{\parallel}}{mc^2}}\frac{A^{3/2}}{A+1}, \tag{1}$$

where $k_{\mathrm{B}}$ is the Boltzmann constant and $m$ the electron mass, and $A$ is the anisotropic factor and defined by

$$A \equiv \frac{T_y}{T_z} - 1, \qquad (\text{for} \quad T_z < T_y). \tag{2}$$

# 3   Results and Discussion

We took '$x$-axis' for the laser-incident axis, The laser electric field and induced longitudinal field are shown in figure 1. Electron phase space profile ($v_x$-$x$) is shown in figure 2. A plot of $v_y$-$v_z$ (figure 3) shows the velocity-space anisotropy at early and later times. Figure 4 shows a temporal profile of the magnetic energies induced by Weibel-type instability. While magnetic fields present exponential growth, transverse electric fields are relatively very small. We estimate the maximum growth rate of resultant magnetic fields to be $0.643\omega_{\mathrm{pe}}$ from our simulation and to be $0.719\omega_{\mathrm{pe}}$ from equation (1).

The fields present an exponential growth versus the time, and reached its maximum at $38\omega_{\mathrm{pe}}t$. If electron number density is of the order of $9.96 \times 10^{20}\mathrm{cm}^{-3}$ on our simulations, the most unstable magnetic fields reached 6.84MG at maximum.

We have clarified that the self-excited large magnetic fields can be generated by Weibel-type instability in intense laser irradiated plasmas.

We are investigating the saturation process of the magnetic fields, relaxation process of anisotropic electron distribution, propagating of Weibel-types and the relation between the fields and the thermal flux.

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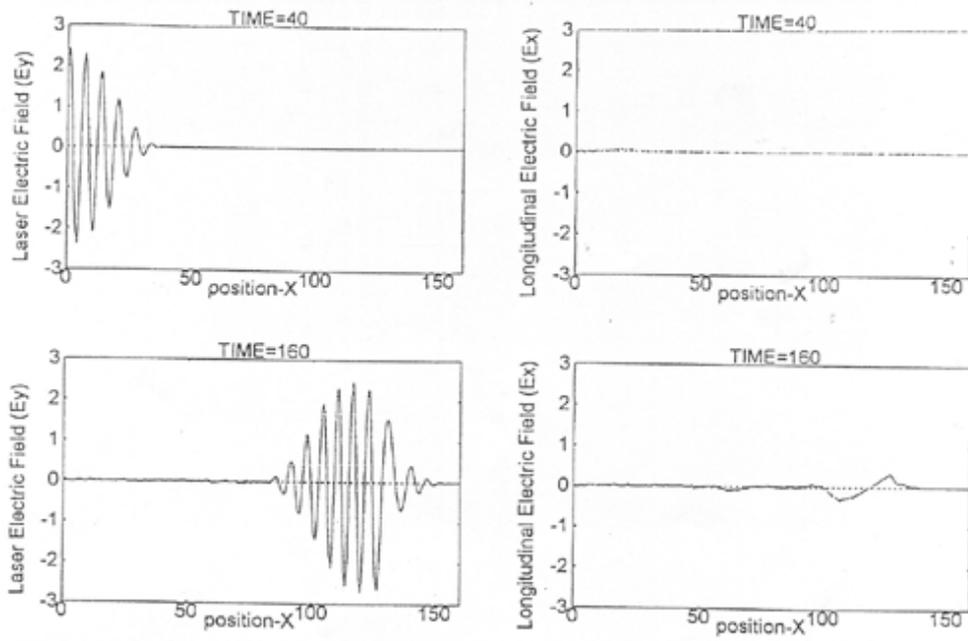[9] N.A.Krall and A.W.Trivelpiece, *Principles of plasma physics* (McGraw-Hill), p.490 (1973).

FIGURE 1. Profiles of laser electric field and induced longitudinal electric field.
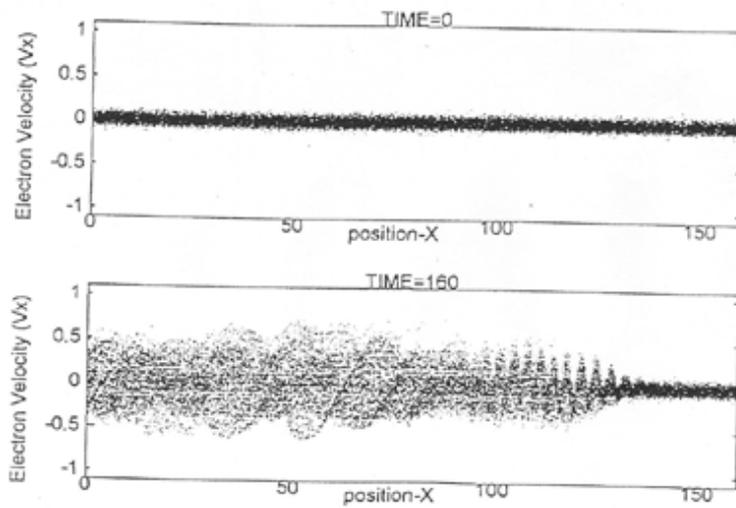


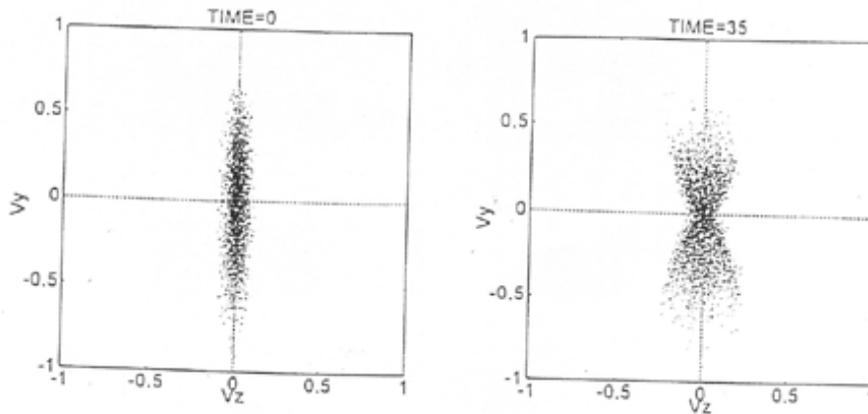FIGURE 2. Electron phase space profile ($v_x$-$x$).

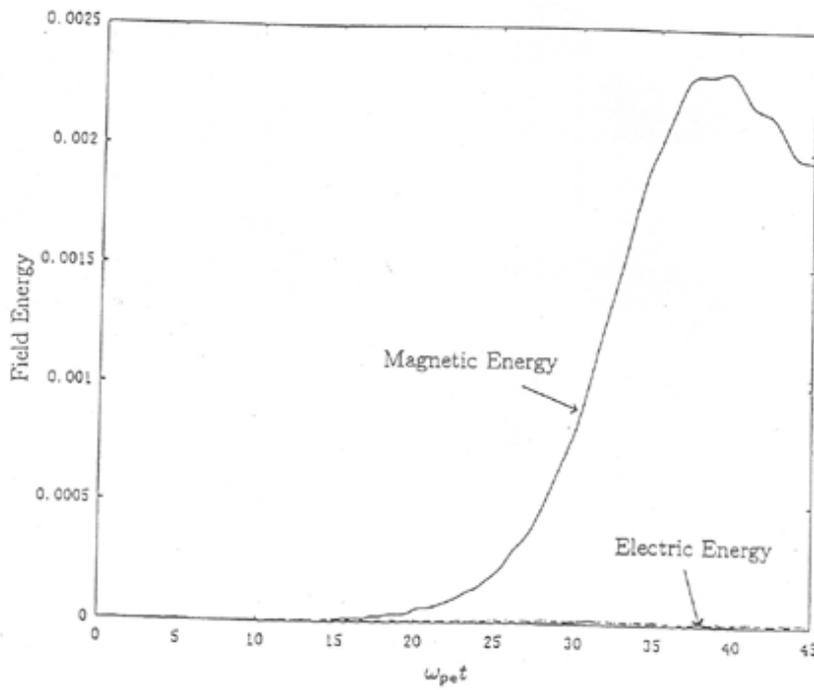FIGURE 3. Velocity distribution function of electrons.



FIGURE 4. Temporal profiles of magnetic energies. Electric fields are relatively small.