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Fast Electron Beam Guiding for Efficient Core Heating
高効率加熱のための高速電子ビームガイディング

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In cone-guiding fast ignition, the guiding of fast electron beam with significantly large beam divergence is one of the most important issues for achieving efficient core heating. We proposed two guiding schemes, one is the “Tongari” tip guiding by resistive magnetic field and the other is the guiding by externally applying axial magnetic field. The guiding performances for these two schemes are demonstrated by Particle-In-Cell and Fokker-Planck simulations.

1. Introduction

In cone-guiding fast ignition [1], fast electrons generated inside the cone propagate the distance of 50μm ~ 100μm to the imploded dense core, and then heat the core up to ignition temperature. Thus, the fast electron beam control (*e.g.*, enhancement of energy coupling of heating laser to fast electrons, optimization of fast electron energy spectrum, reduction of beam divergence and beam guiding to core) is one of the most crucial issues to achieve the ignition and high gain in fast ignition.

According to the previous work [2], the fast electron beam has large beam divergence (full angle of ~100 degree), which could be one of the main factors for lowering the core heating efficiency. To improve the heating efficiency, there are some ideas on beam guiding using self-generated magnetic fields [2, 3]. The other one is the guiding by external magnetic field along to the beam propagation direction [4].

In the present paper, we propose the beam guiding schemes by the self-generated resistive magnetic fields and external magnetic fields, and evaluate the fundamental performances.

2. Resistive Guiding

The magnetic field growth in collisional plasmas is derived from Faraday’s law and Ohm’s law, together with the assumption of quasi neutrality for beam and return currents ($\vec{j}_{fe} = -\vec{j}_{be}$);

$$\frac{\partial \vec{B}}{\partial t} = \eta(\nabla \times \vec{j}_{fe}) + \nabla\eta \times \vec{j}_{fe},$$

where η is the resistivity. The first and second terms are the sources by the radial gradient of fast electron current and by the gradient of resistivity. Here, we use the magnetic field caused by the second term, which works to confine the fast electrons in the higher-resistivity region [5]. To guide the fast electron beam, we propose “Tongari” cone tip (“Tongari” is Japanese word, means “pointed”). If we use higher-Z material for the tip compared with the surrounding imploded plasma,

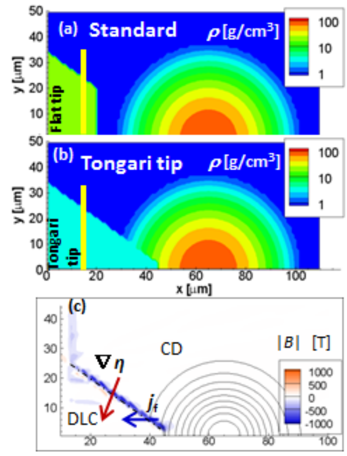

Fig. 1 Spatial profiles of (a) inital density of standard Au flat top tip and (b) DLC Tongari tip and (c) resistive magnetic field at 500fs. The yellow lines in (a) and (b) show the beam injection points.

the confinement field will be generated at the material contact surface. Though ahigh-Z material, such as Au, is preferable for generating the strong magnetic field, the energy loss and scattering of fast electrons become large in the high-Z material. So, we estimate the guiding performance for different cone materials (Au, Cu, Al, DLC) by Fokker-Planck simulations where we used the fast electron beam profiles obtained from a 2D PIC simulation [2] for a 30-degree cone with 10^{19}W/cm^2 heating pulse, and a spherically compressed CD core (Gaussian density profile with peak density of 200g/cm^2, ρR = 0.12g/cm^2 and uniform temperature of 300eV) was assumed (Fig. 1 (a)-(b)). The spatial profile of magnetic field for the case of DLC Tongari tip at t = 500fs is shown in Fig. 1 (c). It is found that the strength of magnetic field is ~ 0.7kT at this moment. The simulation results are summarized in **Table I**. The strength of confinement magnetic fields generated at the cone-plasma interface is about 1kT and it increases with material-Z. The collisional effects are also large in the high-Z material. As the results, the core heating rate for the Au and Cu Tongari tip cases is smaller than that for the standard Au cone. The core heating rate is enhanced for the Al and DLC tip cases, which means the low-Z material such as Al and DLC is preferable.

Table I summary of guiding performance of Tongari tip.

Tip material	B_{max} [T]	E_{cone}*	E_{core}*	ΔT_{e0}*
Au	1250	1.9	0.8	1.0
Cu	1020	1.8	1.0	1.4
Al	977	1.3	1.3	1.8
DLC	723	1.4	1.3	1.9

*The values of deposited energies in cone tip E_{cone} and in core E_{core}, and electron temperature enhancement at core center ΔT_{e0} due to heating are normalized by the values for the standard Au flat cone tip (5μm thickness) case.

3. External Field Guiding

Under the sufficiently-strong axial magnetic fields, the generated fast electrons twist around the magnetic field lines and are expected to be guided into the core. In addition to the guiding effects, the fast electron stopping rage becomes effectively shorter due to the gyro-motion. The preliminary evaluation of guiding performance was done by 2D PIC simulations (collisionless), where we assumed that an Au plane target ($50n_{cr}$, Z=40) with 1μm scale pre-plasma is irradiated by an intense laser pulse with 1μm wavelength, 10^{19}W/cm^2 intensity, 200fs flat top (30fs rising) duration and 5μm spot diameter. The external magnetic fields with strength of $B_{x,ext}$ = 0 ~ 10kT are uniformly applied along to the beam propagation direction. In **Fig.4**, the beam

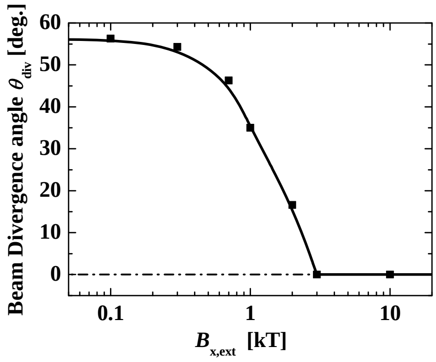

Fig. 2 Beam divergence angle θ_{div} as a function of external magnetic field strength $B_{x,ext}$.

divergence θ_{div} is plotted as a function of $B_{x,ext}$. It is found that t θ_{div} starts to decrease at $B_{x,ext}$ = 0.1kT and reaches θ_{div} = 0^o at $B_{x,ext}$ = 3kT. These results indicate that the effective guiding can be achieved with $B_{x,ext}$ > a few kT. Such a high field could be achieved by implosion [6] of spherical shell target with external magnetic field [7].

4. Concluding Remarks

On the basis of PIC and Fokker-Planck simulations, we showed the guiding performances for two types of guiding concepts, *i.e.*, one is the resistive guiding by Tongari tip and the other is the guiding by externally applied axial magnetic fields. We propose the guiding scheme by combination of two guiding concepts and plan to introduce it into FIREX-I integrated experiments.

Acknowledgments

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References

[1] R. Kodama, et al., Nature **418**, 933 (2002).
[2] T. Johzaki, et al., Nucl. Fusion **51**, 073022 (2011).
[3] P A Norreys, "Recent Energy Transport Experiments on the Valcan Petawatt Laser Facility", presented at 37th EPS conf. on Plasma Phys., June 2010, Dublin, Ireland.
[4] D. J. Strozzi, et al., Bull. APS **55**, 68 (2010).
[5] B. Ramakrsishna, et al., Phys. Rev. Lett. **105**, 135001 (2010).
[6] P. Y. Chan, et al., Phys. Rev. Lett. **107**, 035006 (2011).
[7] C. Courtois, et al., J. App. Phys. **98**, 054913 (2005).