9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Study on propagation characteristics of relativistic laser light in overcritical density plasma

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The propagation characteristics of intense laser lights in inhomogeneous plasmas, of which density changes from low to overcritical density, are important for various laser-plasma applications, e.g., ion acceleration and fast ignition in laser fusion. Especially in fast ignition, the heating laser light has to propagate the coronal plasma to deliver the energy to the imploded core. Therefore, understanding the propagation characteristics of the intense laser light is necessary to realize efficient heating.

Two characteristics related to the propagation of high-intensity lasers in dense plasma have been discussed. One of these is called “relativistic transparency” [1,2]. Electrons in plasma are oscillating by the electric field of the laser light. As the laser intensity increases, the oscillation energy of the electrons reaches relativistic energy, and the effective electron mass increases by a factor of γ (Lorentz factor). This lowers the plasma frequency and enables propagation at higher densities. Another property is hole-boring [3]. At the front of the laser, electrons are pushed by the ponderomotive forces. This causes charge separation, generating an electric field along the direction of laser propagation. The ions then move in the same direction, resulting in a decrease in plasma density, which enables laser propagation. It is known that the relativistic transparency mode transits to the hole boring mode as the plasma density increases. However, the physical mechanism behind this transition is unclear.

We had performed plasma particle simulations using the PICLS code [4] to understand the characteristics of intense laser light propagation in inhomogeneous plasmas. First, 1D PIC simulations are performed to clarify the mechanism of the transition from the relativistic transparency mode to the hole-boring mode. We found that the transition from the relativistic transparency to the hole-boring occurs at the point where the pulse front velocity and the ion velocity are equal. We had derived the theoretical equation of the transition velocity as $\sqrt{2a_o/\overline{M_\iota}}$, here a_0 is normalized amplitude, $\overline{M_\iota}$ is ion mass normalized by electron mass. The velocity predicted by our theoretical model was in good agreement with the laser propagation velocity at the transition in the 1D-PIC simulations. 2D PIC simulations had been performed to investigate the multidimensionality. The results showed that the hole-boring started from a lower plasma density than in 1D when the laser intensity was somewhat higher. This may be due to the strong magnetic field generated at the laser front causes the ions at the front location to be rotated and excluded in the direction perpendicular to the laser propagation direction. This magnetic channel structure assists the energy transport of the laser pulse.

References

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