Theoretical limit of hole boring and transition to plasma blowout in multi-picosecond laser-plasma interactions

Natsumi IWATA [1], Sadaoki KOJIMA [2], Masayasu HATA [1] and Yasuhiko SENTOKU [1]

1) Institute of Laser Engineering, Osaka University, Japan

E-mail: iwata-n@ile.osaka-u.ac.jp

2) Institute for Chemical Research, Kyoto University, Japan

With the advent of kJ class high intensity lasers, multi-picosecond (ps) laser pulses with relativistic intensities become available such as LFEX, NIF-ARC, LMJ-PETAL and OMEGA-EP. In a recent LFEX laser experiment, it is demonstrated that the hot electron temperature increases drastically when the laser pulse duration is extended to multi-ps [1]. Moreover, the corresponding PIC simulation shows that the laser hole boring where the photon pressure must surpass the plasma pressure [2] is stopped at several picoseconds even though the laser is still irradiated, and the surface plasma starts to blowout to the front side. The blowout triggers the production of superthermal electrons [3]. Thus, the limitation of the hole boring in the multi-ps time scale is a key to understand the electron heating, however, such a phenomenon has not been discussed so far.

In this study, we develop a theoretical model that explains the transition from the hole boring to blowout. Based on the momentum and heat flux balance relations for electrons irradiated by linearly polarized laser with considering a skin depth effect and electron pressure, we found that the hole boring limit density n_s, above which the laser is incapable of sustaining the charge separation, is given by

$$\frac{n_s}{n_c} = 8a_0^2 \frac{1 + R - (1 - R)\,\beta_h^{-1}}{2} \qquad (1)$$

where n_c is the non-relativistic cutoff density, a_0 is the normalized laser amplitude, $\beta_h \equiv v_h/c$ is the electron heat flux velocity divided by the light speed, and R is the reflection rate. From Eq. (1), the maximum density for the hole boring is found to be $n_{s\max}/n_c = 8a_0^2$ with $R = 1$ and $\beta_h = 1$. We demonstrated that the hole boring distance becomes zero around the derived limit density n_s as shown in Fig. 1, by using the PIC simulation. We further calculate the time scale for the front density to reach n_s, based on the pressure balance equation for ions in a preformed plasma [4]. The time scale is found to be the range of multi-ps in the LFEX laser experiment condition.

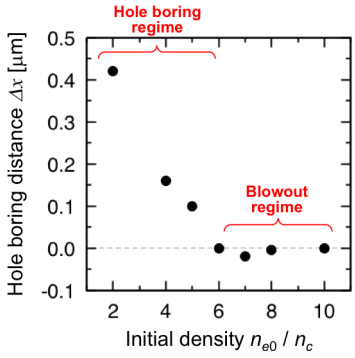

Figure 1: Dependence of the hole boring distance on the initial plasma density obtained in the PIC simulation for a fixed laser amplitude $a_0 = 1$ and a slab plasma.

References

[1] S. Kojima *et al.*, J. Phys. Conf. Ser. **717**, 012102 (2016)

[2] S. C. Wilks, W. L. Kruer, M. Tabak and A. B. Langdon, Phys. Rev. Lett. **69**, 1383 (1992) ; Y. Sentoku, W. Kruer, M. Matsuoka and A. Pukhov, Fusion Sci. Technol. **49**, 278 (2006)

[3] A. J. Kemp and L. Divol, Phys. Rev. Lett. **109**, 195005 (2012) ; A. Sorokovikova *et al.*, Phys. Rev. Lett. **116**, 155001 (2016)

[4] A. J. Kemp, Y. Sentoku and M. Tabak, Phys. Rev. Lett. **101**, 075004 (2008)