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Role of Initial Condition in Lasing of Fast Capillary Discharge Plasmas

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The dependence of the lasing condition of fast capillary discharge plasmas on the initial plasma parameters has been experimentally investigated. The results show that there is an optimum initial condition for lasings. The experimental results also indicate that the variation of lasing power can be correlated with the electron density of the initial plasmas and that the initial condition is an important factor for obtaining larger laser energy using capillary discharges.

Keywords:

capillary discharge, soft x-ray laser, pre-ionization, Ne-like Ar, Z-pinch

Fast capillary Z-discharges have attracted attention as promising laser sources at soft x-ray region since 1994 [1,2]. For the realization of larger energy and shorter wavelength lasers with capillary discharges, understanding the pinching dynamics of plasmas is crucially important [3,4]. The lasings from capillary discharges can be obtained with a pre-ionization current consisting of tens of A which is applied prior to the main discharge current of tens of kA. This pre-ionization current has been recognized to be effective only for forming a homogeneous pinch at the main discharge phase. Therefore, little attention has been paid to the parameters of initial plasmas produced by the pre-ionization discharge, which have the possibility of affecting the conditions of pinch plasmas, that is, the output power of the lasers. To investigate the relationship between initial plasma parameters and the lasings, we examined the lasing signals of Ne-like Ar at 3p-3s transition (λ ~ 469Å) changing the timings of the main discharges and the peak values of the pre-ionization current. In the experiment, lasing signals were measured by a vacuum X-ray diode (XRD), and the rising rate of the main discharge current, *dI dt*, and initial enclosed medium gas pressure, P_0, were fixed. These two values have been considered dominant factors to determine the compression process of pinch plasmas.

The evolution of the average resitance of the capillary plasmas during the pre-ionization discharge is shown in Fig. 1. The resistance was derived from the current and voltage values applied to the capillary. Each of the lines in Fig. 1 corresponds to the different peak value of the pre-ionization current. The pre-ionization current is produced with an inductively isolated RC discharge circuit. The values of R and C are 200 Ω and 0.4 μF, respectively. Therefore, the time constant of this pre-ionization circuit is 80 μs.

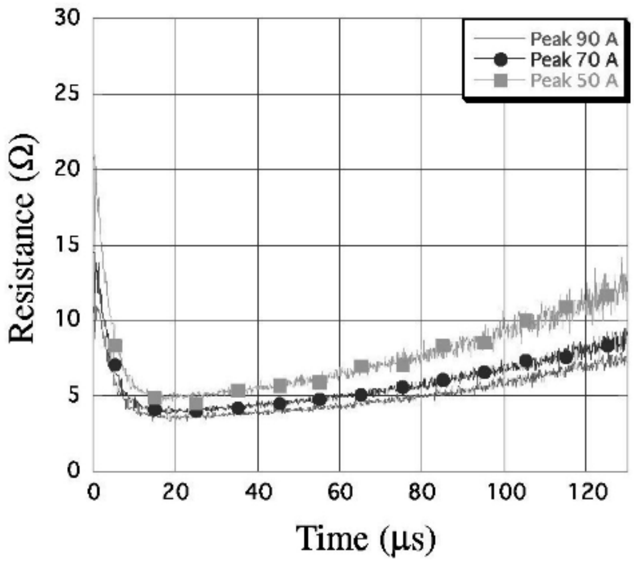

Fig. 1 Evolution of average resistance of capillary plasmas during pre-ionization.

The main discharges were driven by the pulse power generator LIMAY-1 with time delay after the onset of the pre-ionization current [5]. Fig. 2 shows the peak output power of the lasers versus the time delay t_d of main discharges from the onset of the pre-ionization current. Here, the values of dI/dt and P_0 were fixed at 7×10^{11} A/s and 200 mTorr (Ar), respectively. As shown, an optimum region for lasings exists approximately in t_d = 20 ~ 40 μs and the output power diminishes before and after this region. A comparison of Fig. 1 and Fig. 2 indicates that the behavior of the lasing power can be correlated with the resistance of the initial plasmas. The resistance profile also can be correlated with the electron density of preionized (weakly-ionized) plasmas. In fact, the

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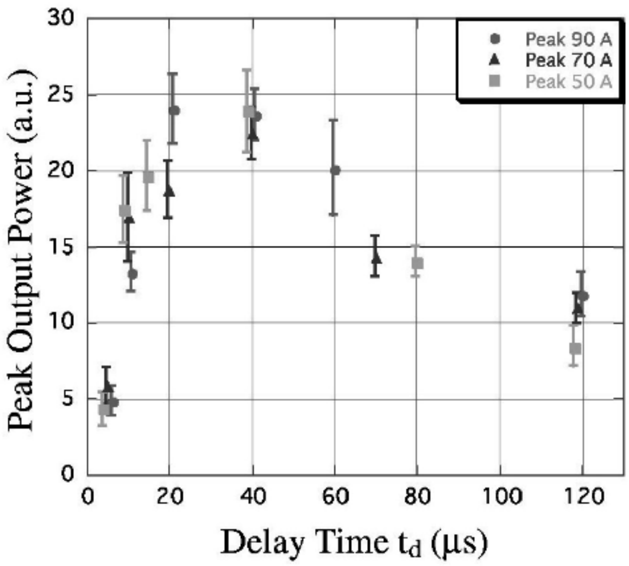

Fig. 2 Variation of peak output power of soft x-ray lasers.

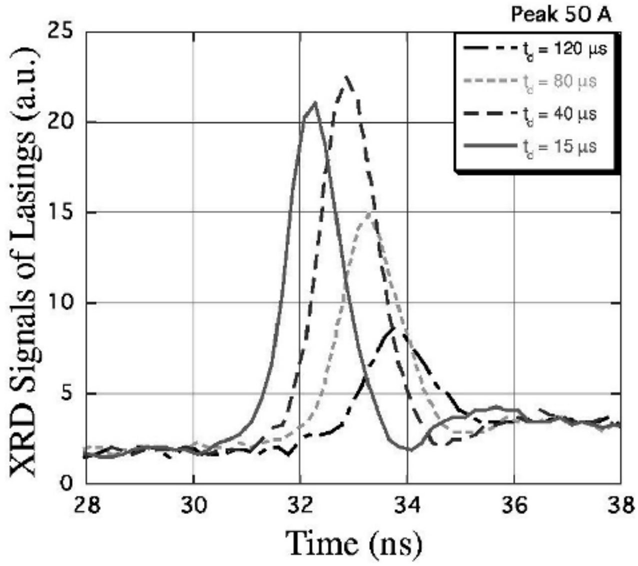

Fig. 3 XRD signals of lasings coresponding to different conditions of pre-ionized plasmas.

qualitative similarity of the electron density with the resistance was confirmed by spectroscopic (Stark broadening) measurements. Consequently, the shifts of the lasing power can be attributed to the evolution of electron density in the pre-ionized plasmas.

Fig. 3 shows the lasing signals under different conditions of pre-ionized plasmas corresponding to various timings of the main discharges for a pre-ionization current with a peak of 50 A. The transverse axis indicates the time from the 10% maximum position of the main discharges. The figure shows the changes of both the lasing timing and the lasing power profile clearly depend on the time delay of the main discharges from the onset of pre-ionization. This result also indicates that the conditions of the initial plasmas can affect the dynamics of pinch plasmas.

Based on the experimental results, we can conclude that the conditions of initial plasmas, especially the electron density produced by pre-ionization current, can affect the dynamics of compression processes and hence the parameters of the pinched plasmas. The difference of electron density of pre-ionized plasmas is considered to modify the output power of the lasers, because the initial electron density can affect the current distribution of the main discharges by the skin effect, which is estimated to provide various internal structures in the pinching plasmas [6].

These results indicate that not only dI/dt and P_0 values, but also the condition of pre-ionized plasmas are important factors for the lasing condition. Thus we can conclude that the pre-ionized plasma condition plays an essential role in obtaining the scaling formula for larger energy and shorter wavelength lasers using the capillary discharge scheme.

[1] J.J. Rocca, V. Shlyaptsev, F.G. Tomasel, O.D. Cortazar, D. Hartshorn, and J.L.A. Chilla, Phys. Rev. Lett. **73**, 2192 (1994).

[2] G. Niimi, Y. Hayashi, N. Sakamoto, M. Nakajima, A. Okino, M. Watanabe, K. Horioka and E. Hotta, IEEE Trans. Plasma Sci. **30**, 616 (2002).

[3] N. Sakamoto, G. Niimi, Y. Hayashi, M. Masnavi, M. Nakajima, E. Hotta and K. Horioka, Dense Z-pinches, Proc. High Power Particle Beams, AIP Proc. **651**, 169 (2002).

[4] M. Masnavi, M. Nakajima and K. Horioka, J. Appl. Phys. **95**, 434 (2004).

[5] N. Sakamoto, G. Niimi, M. Nakajima, E. Hotta and K. Horioka, Res. Rep. Natl. Inst. Fusion Sci. NIFSPROC-**51**, 45 (2002).

[6] T. Hosokai, M. Nakajima, T. Aoki, M. Ogawa and K. Horioka, Jap. J. Appl. Phys. **36**, 2327 (1997).