Lasing in Ne-Like Argon Capillary Discharge at Low Current and the Effect of Current Prepulse

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Lasing in Ne-Like Argon Capillary Discharge at Low Current and the Effect of Current Prepulse

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Abstract. The output characteristics of saturated capillary discharge 46.9 nm Ne-like argon soft x-ray laser obtained with relatively low main discharge current of less than 20 kA, with the lowest being 9 kA. The 3 mm diameter and 200 mm long alumina capillary with Argon filling pressure range between 0.1-0.4 mbar was pumped by a discharge current with a quarter-cycle of about 40 ns. A current pulse with a typical *RC* shape (decay time ~30 μs) was used as a prepulse. Measurements indicate that the laser output is affected by the timing of the application of the prepulse. This effect is most significant when the time delay between the application of the prepulse and the onset of the main current is around 2 to 4 μs, and beyond these times, the effect is less significant.

Keywords: Capillary discharge, soft x-ray lasers
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INTRODUCTION

The first observation of large amplification in the transitions of Ne-like ions in capillary discharge plasma [1], and the subsequent demonstration of saturated operation of the table-top amplifier [2] opened up the possibility compact and high efficiency soft x-ray sources, and has attracted much attention since. Despite the rapid development of that group, it was only lately that other laboratories managed to reproduce those original experiments. The reason is that the requirements for obtaining lasing conditions in the plasma discharge column are very stringent and is very difficult to achieve in practice. An important criterion for soft x-ray amplification in a discharge created plasma is the existence of a stable plasma column with good axial uniformity. Axial inhomogeneities usually accompany high power electrical discharges as a result of non-uniform initial conditions and slow compression. To circumvent this plasma uniformity problem, the capillary channel is filled with a certain amount of preformed plasma just before the injection of the fast main current pulse. This preformed plasma allows the main current pulse to flow homogenously through the plasma column. To date, in successful capillary discharge laser systems this preionization of the argon gas is achieved by the application of a "prepulse" current pulse with peak value of tens of amperes for several microseconds prior to the onset of the main current pulse.

In this work, we report on the demonstration, in our laboratory, of the soft x-ray laser amplification in the Ne-like Ar using a capillary device with excitation current pulse amplitudes of less than 20 kA with the lowest being 9 kA. We also report the experimental results showing the influence of the prepulse current on the operation of a capillary discharge soft x-ray laser.

EXPERIMENTAL SETUP

The schematic diagram of the capillary discharge laser system used in our experiments is shown in Fig. 1. A four-stage double Marx generator which is capable of producing 150 to 300 kV at erection, pulse charges a 5-Ω, 3-nF water filled coaxial pulse-forming-line (PFL). The PFL then discharges via a pressurized, self-breaking spark gap into the capillary load resulting in a main discharge current pulse with a rise-time of about 35 ns and peak values ranging from 9 to 19 kA. This fast excitation current produces z-pinch capillary discharge plasma in the 3 mm diameter and 20 cm long alumina capillary channel. A current pulse with a typical *RC* shape (decay time ~30 μs) was used as a prepulse. Depending on the requirement, the filling argon gas pressure in the capillary was maintained in the region of 0.1–0.4 mbar by continuously injecting the gas through the 3 mm axial hole of ground discharge electrode. The axial soft x-ray emission was monitored using a 1-m grazing incidence spectrograph having a 600-lines/mm gold coated grating placed at 87° with a micro-channel plate intensified charge coupled device array as detector. All the spectra and line intensity collected in this work were time-integrated.

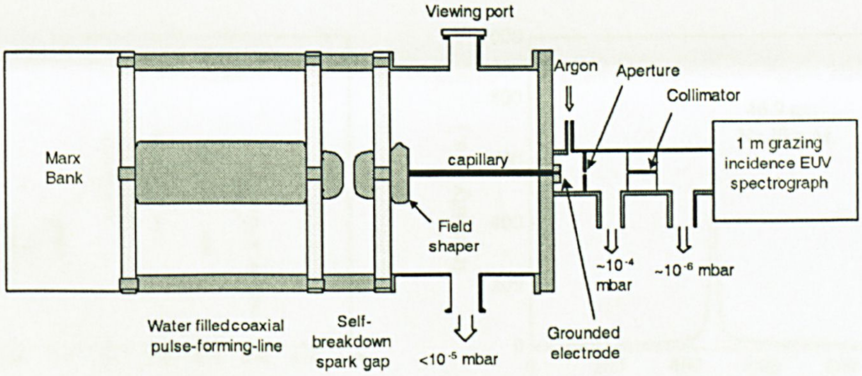

FIGURE 1. Schematic diagram of the experimental apparatus.

RESULTS AND DISCUSSION

Measurements of the integrated laser output as a function of the initial gas filling pressure and the main discharge current were carried out to determine the dependence of the amplification on these discharge parameters. Fig. 2 shows the experimental results for a capillary length of 19 cm. At 19.0 kA, adequate plasma conditions for strong amplification for the 46.9 nm line was obtained over a pressure range from 0.15 to 0.35 mbar with an optimum pressure of about 0.24 mbar. Within the range of 0.1 mbar around the optimum pressure, the fluctuation of the output is smallest. As the amplitude of the discharge current was reduced, this pressure range narrowed down.

At 13.5 kA the optimum pressure was about 0.16 mbar while the pressure range was from 0.10 to 0.22 mbar.

Experimental investigations showed that even for a low main discharge current of 9.0 kA, a clean and dominant lasing 46.9 nm Neon-like Argon line could still be obtained for the laser system, the results of which are shown in Fig. 3. The optimum pressure is about 0.12 mbar while the operating pressure range is considerably narrower at ~0.05 mbar. The shot-to-shot fluctuation of the laser output is also larger compared to that of the higher main current.

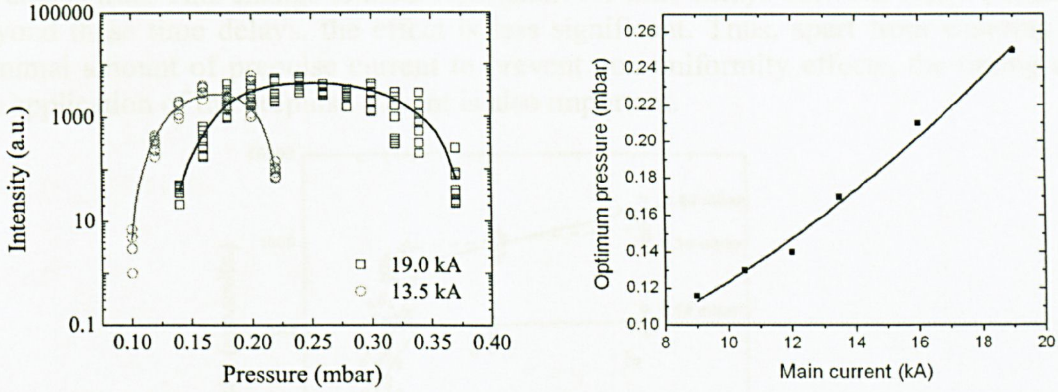

FIGURE 2. (a) Dependence of the integrated intensity on the initial filling pressure. (b) Variation of the optimum pressure with main discharge current.

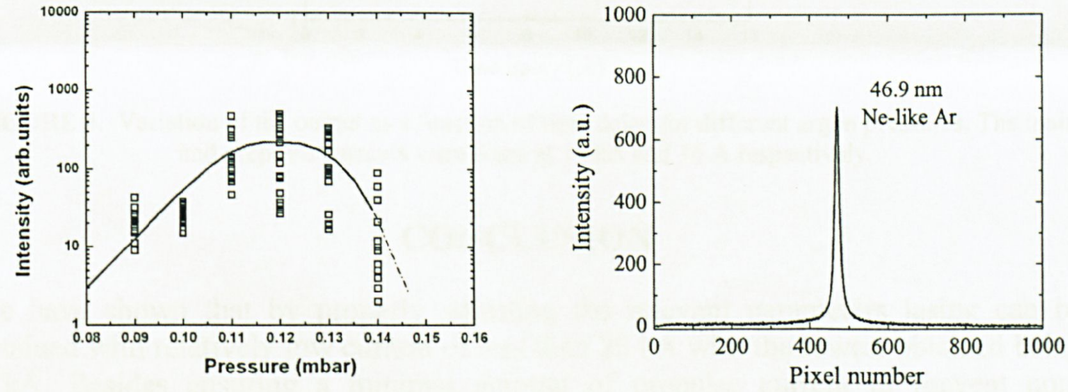

FIGURE 3. Laser output for 9 kA main current. (a) Variation of laser intensity with filling pressure, (b) Spectrum for axial spectra emission showing strong 46.9 nm line.

A series of measurements was conducted changing only the peak prepulse current while the other parameters were kept constant. Strong and reproducible laser emissions were obtained with peak prepulse currents in the range of 10-23 A. For prepulse currents larger than 23 A, the laser emissions were not intense while none was observed below 4 A. In most of the experiments reported here, a peak prepulse current of 16 A was found to be most suitable, giving strong and stable laser output.

Figure 4 shows the dependence of the integrated intensity of the 46.9 nm Ne-like Ar line on time delay for four different filling pressures of 0.12, 0.14, 0.16 and 0.24 mbar. The main and prepulse currents were fixed at 16 kA and 16 A respectively. For all the pressures shown, the output emission exhibit two characteristics as the time delay were reduced: a relatively gradual variation from 12 μs to about 4 μs, and a sharper change for time delays below 4 μs. However, the characteristic for 0.12 mbar filling pressure is different from the rest. For the higher pressures (0.14 to 0.24 mbar), the output emission reduces as the time delay decreases but this trend is reversed for 0.12 mbar. The four intensity curves appear to converge to a common level at a time delay of about 2 μs. These measurements indicate that when the filling pressure is low, the output can be improved by reducing the time delay between the application of the prepulse current and the onset of the main discharge current. For high pressure the reverse is true. This change is most significant for time delays between 2 to 4 μs, and beyond these time delays, the effect is less significant. Thus, apart from ensuring a minimal amount of prepulse current to prevent non-uniformity effects, the timing of the application of the prepulse current is also important.

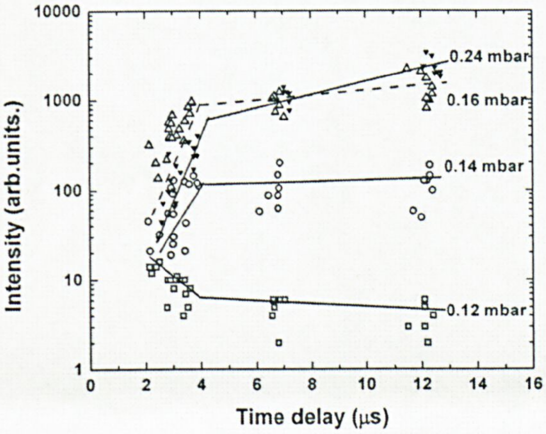

FIGURE 4. Variation of the output as a function of time delay for different argon pressures. The main and prepulse currents were fixed at 16 kA and 16 A respectively.

CONCLUSION

We have shown that by properly adjusting the relevant parameters lasing can be obtained with relatively low current of less than 20 kA with the lowest obtained being 9 kA. Besides ensuring a minimal amount of prepulse current to prevent non-uniformity effects, the timing of the application of the prepulse current is also important.

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