L.6: Energy enhancement of 46.9 nm soft x-ray laser from fast capillary discharge

Z-pinch plasma produced from fast capillary discharge at high voltage and high current provides a very promising technique to generate table top soft x-ray laser at 46.9 nm wavelength. This soft x-ray laser has several potential applications like nano-imaging, interferometric lithography, dense plasma diagnostics, etc. These applications require good laser energy in the soft x-ray laser pulse. Significant enhancement (~35 times) in the energy of this laser from existing ~ 2 µJ to ~ 70 µJ per pulse is reported here.

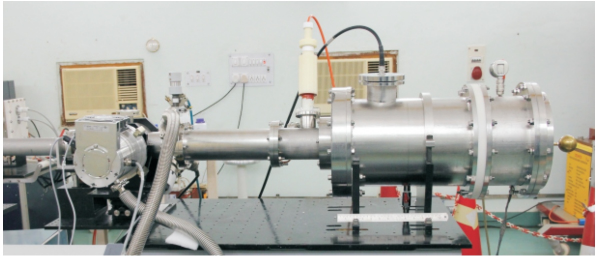

Fig. L.6.1: Capillary discharge x-ray laser system.

In order to generate this enhancement, discharge current as high as few tens of kilo-ampere was passed in a very short time (few tens of nanoseconds) through pre-ionized argon gas inside an alumina capillary. The high magnetic field associated with the discharge current created Z-pinch compression of the discharge plasma. This led to formation of hot and dense plasma column having Ne-like Ar ions in abundant. Under suitable discharge conditions, population inversion builds up between 3s and 3p energy levels of Ar^{8+} ion leading to soft x-ray amplification of associated emission at 46.9 nm from 3p - 3s transition. Figure L.6.1 shows the capillary discharge soft x-ray laser system in the laboratory. The required discharge conditions for the lasing were achieved through indigenously designed pulse power system. In this system, a tesla-transformer based charging unit charges a water-capacitor to voltages of the order of few hundreds of kV in nearly ~ 3 µs time. A fast spark gap switch allows the capacitor to discharge its energy rapidly (few tens of ns) through argon filled capillary and drive the required current. A pre-pulse current (few tens of ampere) is used for pre-ionization of argon gas a few microsecond before the main discharge current. This helped in achieving uniform as well as efficient compression of plasma and also inhibited plasma instabilities to a large extent. The suitable plasma conditions i.e., density and temperature must be achieved to get soft x-ray lasing at 46.9 nm. This depends on optimization of several parameters like main discharge current, its duration, pre-pulse current and its time difference with respect to main current, argon gas pressure, capillary length and its inner diameter (ID). The temporal, spatial and spectral studies were carried out to well characterize the various properties of this soft x-ray laser, e.g. laser pulse duration, wavelength, divergence, spatial coherence, energy, etc.

The energy of the laser pulse was measured after heavy attenuation by 2.4 µm thick Al filter using calibrated vacuum diode detector. With capillary of length 15 cm and 2.8 mm ID, we had earlier achieved energy in the laser pulse to be ~ 2 µJ at discharge current of ~26 kA. This was attained after optimizing the argon pressure and the pre-pulse conditions. Now, in order to get further increase in the laser energy, the length of the gain medium, i.e. plasma column length, was increased. Accordingly, the capillary length was first increased to 20 cm. Capillaries of inner diameters of 2.8 mm and 3.2 mm were tried with this length. Capillary ID of 3.2 mm was found to be more favourable than that of 2.8 mm for higher laser output. Discharge current was varied in the range from 25 kA to 40 kA with quarter period ($T_{1/4}$) of current of ~ 45 ns for capillary of 20 cm length and 3.2 mm ID. After optimization of gas pressures and pre-pulse conditions, laser energy of ~10 µJ could be obtained at discharge current of ~ 40 kA. Capillary length was then substantially increased to 45 cm with 3.2 mm ID. Such a long plasma column led to a significant increase in the inductance of the discharge path leading to an increase in the quarter period of current to ~90 ns. The discharge current was applied here in the range from 25 to 35 kA. As a result of optimization of other parameters like gas pressures and pre-pulse conditions, the laser energy was increased significantly to ~50 µJ per pulse. Some of the laser shots (Figure L.6.2) have also shown ~70 µJ of energy recorded in the single laser pulse, which is ~35 times more than the earlier recorded laser energy of ~2 µJ. Experiments with capillaries of higher inner diameters (> 3.2 mm) need to be explored and expected to increase the laser energy further up to few hundreds of micro-joules in near future.

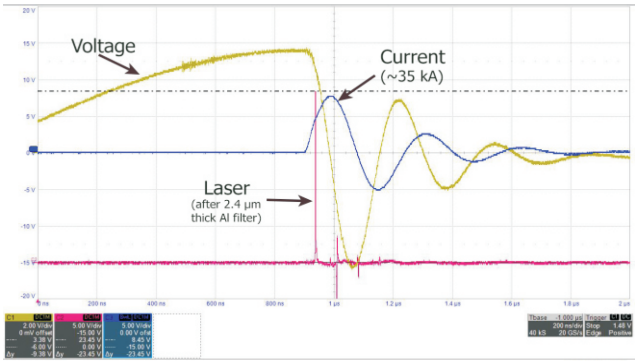

Fig. L.6.2: Temporal profile of voltage, current and recorded laser pulse.

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