L.3 Intense soft x-ray generation from capillary discharge plasma

The capillary discharge program had been initiated in the Laser Plasma Division, RRCAT to study the generation of coherent x-ray radiation in the soft x-ray region. In order to realize this task, a 400 kV, 40 kA capillary discharge plasma system has been designed. The x-ray emission from the capillary discharge plasma of argon has been measured and the results are presented here.

The system consists of a 400 kV, 750 J, 10 stage Marx generator, Pulse Forming Line (PFL) in the form of a waterline capacitor (with parameters C = 6 nF, L = 70 nH and Z = 3.3 Ω), a spark gap filled with SF_6 gas, and a ceramic (alumina) capillary (2.8 mm dia) followed by a x-ray diagnostic line, as shown schematically in the Fig.L.3.1.

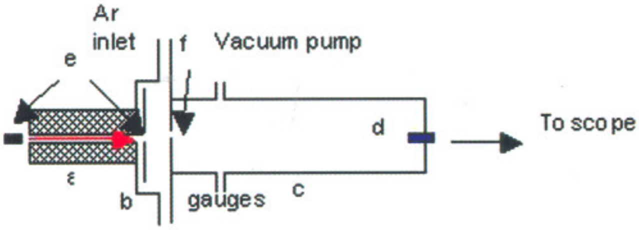

Fig. L.3.1: Schematic showing a)capillary with Ar plasma(red) b)Ar chamber c)diagnostic line under vacuum d) x-ray diode e)electrodes f)orifice. Arrow(red) indicates current flow.

In a capillary discharge plasma in argon gas, the population inversion and consequent lasing action in the Ar^{8+} species, are generated through collisional excitation mechanism. The density and temperature of the argon plasma are rapidly varied by applying a fast varying current pulse (dI/dt > 1011 A/s). The magnetic field associated with this current, compresses the plasma forming a 100 - 200μm thin filament-like channel which acts as the lasing medium. In order to obtain reliable and uniform compression, a long pre pulse is used to generate the plasma and the main pulse is used for compression.

To detect the soft x-ray radiation and to ascertain lasing action (at 46.9 nm, in the case of Ar gas), both, spectroscopic and time resolved studies are needed. As part of these x-ray laser studies, the x-ray radiation generated in the capillary channel was measured using p-i-n diodes (IRD-AXUV 20HS1) which are sensitive for the wavelength of our interest. For preliminary experiments, the Marx generator was charged for 18 kV/stage to get peak erected voltage ~180 kV corresponding to a currnent of ~20 kA.

A thin aluminum foil (0.75 μm) was used to cover the diodes in order to block the visible radiation from the plasma. The diagnostic line was evacuated (10^{-3} - 10^{-4} mbar) to reduce the absorption of soft x-rays generated in the capillary plasma. The emission from the capillary is observed to consist of an x-ray peak after a delay of ~ 30 ns from the starting of current pulse. This pulse overrides a broad x-ray pulse which starts after 10 ns, as shown in the Fig.L.3.2.

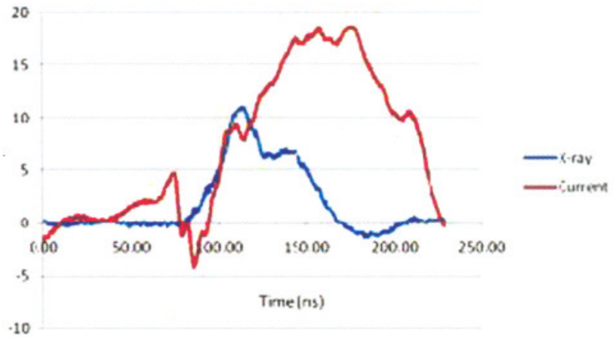

Fig. L.3.2 : A typical x-ray pulse showing a fast rising signal riding on a broad x-ray signal (volts) along with the current (kA) through the capillary.

The sharp pulse is absent when the same measurements are repeated with different x-ray diodes (Quantrad) which are not sensitive for soft x-ray radiation due to the thicker dead layer of these detectors. The measurements were repeated at different argon gas pressures in the range : 0.1 - 0.4 mbar.

The main hurdle in these measurements is the presence of large electro-magnetic interference (EMI) due to the presence of discharges as well as fast rising high voltages and large currents. This resulted in appearance of voltages of few kV on metallic parts in the diagnostic line. Only after overcoming the EMI problem, the x-ray emission measurements could be completed. In order to perform detailed parametric study of x-ray generation the control system is fully automated. A controller has been developed in-house, which can control the main system and the pre pulse generator. In addition, the voltages and the delay between the pre-pulse and the main pulse, can be varied from this controller to study the dependence of the x-ray emission on these parameters.

The present measurements have shown production of a sharp x-ray spike in the argon filled capillary discharge. However measurements of other parameters like monochromacity, divergence etc. of the x-ray beam are required to know about occurrence and x-ray lasing. Future measurements will include the spectroscopic study, and x-ray emission measurements at longer distances. Efforts will also be made to increase the current flowing through the capillary channel beyond 20 kA, and study its effect on the x-ray generation.

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