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PULSED CAPILLARY DISCHARGE OPERATED AS A COMPACT SOFT X-RAY SOURCE

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Abstract. We analyze experimental results of radiation emission from a compact pulsed capillary ns discharge source, designed for soft x-ray applications, operated in Nitrogen and N/He mixtures at voltages in the range of 18-24kV. The discharge operates in an alumina capillary of length 21mm and 1.6mm inner diameter. The electrical energy stored is ~0.5 J with peak current of ~5kA. Fast charging from an IGBT based pulsed power circuit allows operation at 35-150 Hz. Characteristic time-integrated Nitrogen spectra were recorded from 10-220 Å with clear evidence of He-like Nitrogen line at 28.9 Å, which represents a possible source for a water window soft x-ray microscope. Time-evolution measurements show the influence of axial electron beams, generated by hollow cathode dynamics, on the x-ray emission. We discuss optimal frequency of operation, voltage applied, geometrical and pressure conditions for cathode and anode, for soft x-ray generation. Time-integrated MCP images of a filtered slit-wire system delivered an estimate of the maximum emission energy of our source, as well as clear evidence of full wall detachment, of ~100μm in radial size for the entire emission range.

1. INTRODUCTION

Over the last decade capillary discharges have been studied as bright soft x-ray sources; see e.g. Vrba et al. (2004), Tamas et al. (2007), Wyndham et al. (2009). This type of plasma discharge, emitting in the water window range (280 – 540 eV) as a source of He-like nitrogen emission at 2.89 nm, is a candidate for “table-top” soft x-ray microscopy. In the present work, x-ray emission spectra from the plasma are analyzed to find the optimal conditions for Nitrogen He-like emission. In order to optimize the discharge, parameters such as voltage, frequency, and pressure are varied. The axial production of intense electron beams, generated prior to breakdown by the hollow cathode effect, has been discussed by Avaria et al. (2009). The soft x-ray output is analyzed considering different electrode configurations, which strongly influence the parameters of the x-ray emitting plasma. To distinguish between electron beams, produced by hollow cathode effect and fluorescence, and x-ray emission, we use a set of magnets and collimators, which avoids confusion in some of the diagnostics techniques employed, as it has been discussed by Wyndham et al. (2010). Here the use of filtered MCP slit-wire imagery allows an approximation of the maximum energy of our source, as well as an estimate in size for different radiation ranges.

2. EXPERIMENTAL DETAILS

The Pulsed Capillary Discharge uses as energy storage a capacitor of approximatelly 1.6nF, filled with flowing water, which serves both as coolant and dielectric. The discharge takes place inside an alumina capillary, 2.1mm long with outter diameter of 6.3mm and inner diameter of 1.6mm. The charging circuit delivers approximately 0.5J directly to the capacitor plates in less than 1μs. The circuit has been discussed in a previous work by Wyndham et al. (2009). A schematic of one half of the capacitor system and capillary is shown in Fig. 1.

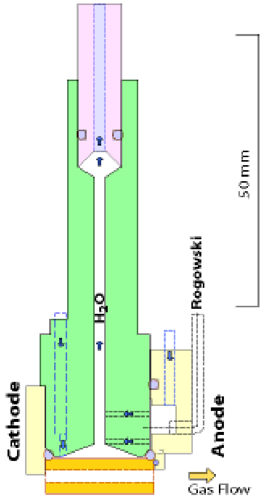

Figure 1: Capillary system.

The gas mixture is fed continually through the cathode to the anode maintaining a constant flow of gas. Pressure is measured both at the anode (ground) and cathode side. The system is mounted on NW50 fittings to allow mounting of a set of diagnotics. Voltage is measured by an external resistive compensated monitor and current is measured by a single groove Rogowski coil. Diagnostics are placed on the anode side and consist of a negatively biased Faraday cup, which doubles as a bare XRD detecting electrons and x-rays, filtered wideband planar diodes, and an EUV Rowland circle spectrometer with CCD interface which records spectra in the range of 20-400 Å.

3. EXPERIMENTAL RESULTS AND DISCUSSION

We present comparative spectra for the N/He mixture. The total intensity of emission increases with the voltage applied, as shown in Fig. 2, but as the voltage increases, so do the impurity lines from wall ablation. Oxygen lines begin rising and Nitrogen lines decrease in amplitude as voltage reaches 24kV, this limits the maximum voltage to be used if impurities are to be avoided, as is the case of soft x-ray microscopy applications. Fig. 3 shows discharges at 24kV for different pressure values at the anode. A ratio of cathode/anode pressure of about 20:1 is optimal on using cathode and anode apertures of 0.7mm and 1.5mm respectively, which are found to be the optimal values for our current configuration. The value for cathode pressure is optimized at the value obtained when breakdown coincides with the capacitor plate voltage maximum, which in our case corresponds to 600mTorr.

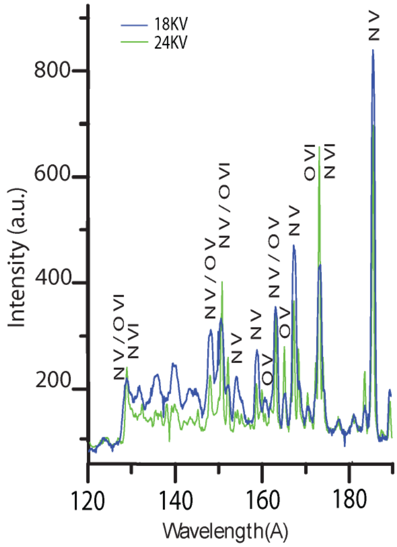

Figure 2: Spectra for N/He discharge at two different values of voltage.

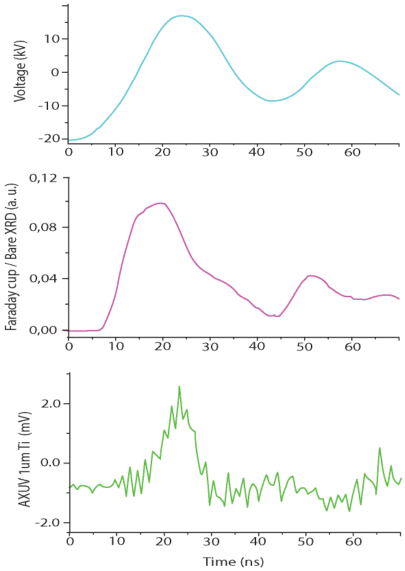

Figure 4: Voltage, Faraday cup/ Bare XRD and AXUV 1µm Ti filtered diode.

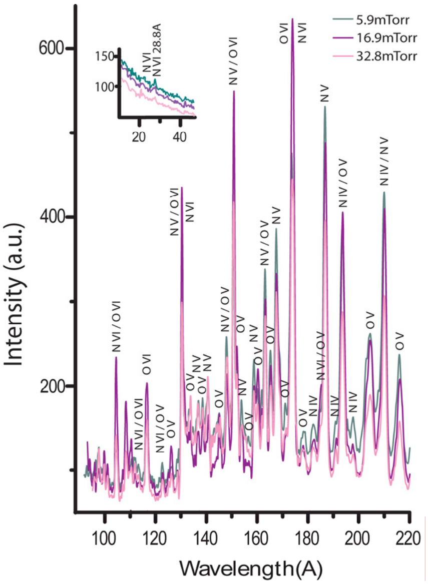

Figure 3: Spectra for N/He discharge at 24 kV.

The variation in frequency does give a proportional improvement in intensity for this range of operating parameters. Additionally, attention must be made when operating the discharge above 150Hz or higher, as the heat load on the alumina capillary causes damage on the alumina tube, greatly reducing reliability.

Fig. 4 shows the Faraday cup/ Bare XRD signal. It shows a slight negative peak less than 3ns after voltage breakdown, which we attribute to electron beams originated at the hollow cathode region. The positive signal indicates x-ray emission, which spikes about 8ns after breakdown and extends well after 40ns. The signal from the AXUV 1µm Ti filtered diode starts 10ns after voltage breakdown and extends for about 15ns, it indicates emission in the range of 300-450 eV. Therefore, the emission line at 28.9Å shown in Fig. 3, can be attributed to emission taking place during this time range, whereas total x-ray emission continues well after this time at lower energies.

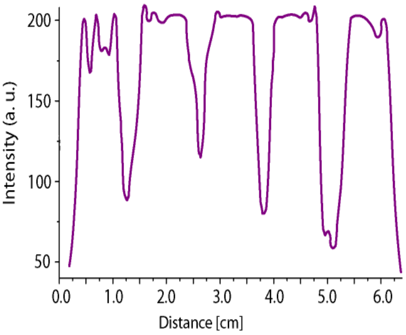

Figure 5: Intensity profile for MCP unfiltered slit-wire image.

Using the plot obtained from MCP slit-wire images and following Choi et al. (2002), we obtain a value of ~200μm in diameter size for the case of an unfiltered image. This clearly shows full wall detachment. When filtering the system with 1 μm of Ti, we obtain a value of ~100μm. We conclude the hotter plasma emitting in the desired energy range is located on axis, as well as the cooler plasma. The cooler plasma may surround the hotter plasma or take place at different time ranges, either before and/or after the more energetic emissions.

4. SUMMARY

We have presented a possible source for soft x-ray microscopy. We have discussed the optimal parameters for soft x-ray production and found the time range at which the He-like Nitrogen emission at 28.9Å takes place. We also report the source size indicating full wall detachment and found that the desired emission comes from a much smaller plasma volume, on axis, radiating at 300-450eV.

Acknowledgements

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