X-RAY AND OPTICAL OBSERVATIONS OF THE DYNAMICS OF A COMPACT FAST CAPILLARY DISCHARGE WITH POTENTIAL AS A SOFT X-RAY SOURCE

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A series of observations using soft X-rays and optical techniques diagnose key plasma parameters in a low inductance large aspect ratio fast capillary discharge. The capillary discharge is operated with less than 1 Joule of stored electrical energy and is designed for fast repetition rate operation. Peak current is between 5 and 8 kA with a quarter period between 8 and 11 ns. The energy storage capacitor is directly charged during 1 μs. Gas is fed into the hollow cathode volume and extracted at the anode, establishing a pressure gradient, which is found to be essential. The pre-breakdown phase is characterized by transient hollow cathode physics, where optical emission from the hollow cathode and measurements of the electron beams that propagate through the cathode orifice and are collimated along the capillary axis to emerge at the anode. The discharges are performed in Xe, Ar, N with admixtures of He. The capillary is of 1.6 mm diameter, either a smooth bore or is segmented with a length of 21 or 16 mm respectively.

The breakdown is associated with a fast propagating axial ionization wave. Soft X-ray emission occurs, depending on capillary diameter and length, after the first quarter cycle of current and can extend well into the current reversal. Soft X-ray spectroscopy reveals He-like ionization in nitrogen and intense Ar IX lines. However this emission occurs only from a small sub-millimetre volume on axis close to the anode. Optical emission spectroscopy from a larger volume shows a lower temperature surrounding plasma with very similar characteristics when viewed from both ends of the discharge. Strong axial electron beams are associated with the X-ray spectrum seen from a small volume of on-axis plasma, but the optical spectrum from the surrounding plasma requires their absence. The temporal evolution of the Ar and Xe soft X-ray emission is notably different for the segmented and smooth bore capillaries, whereas the time integrated spectrum is similar. Wall components are important in the spectrum for N discharges but not for Ar and Xe. The pressure and the imposed filling pressure gradient are important for both the X-ray output power and for wall erosion. In Xe a 2 % conversion efficiency in the 13.5 nm pass band is achieved under the correct pressure conditions. A scheme using longitudinal moiré-schlieren refraction at 532 nm reveals the evolution of the radial line density profile and we find an important degree of compression on-axis. We are also able to measure the incoming radial compression velocity.

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