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Radiative properties of asymmetric and symmetric X-pinches with two and four wires recently produced on the UNR 1 MA Zebra generator

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Abstract

Experimental results of studies of the 1 MA X-pinch X-ray source in a wide spectral region are overviewed. Implosion dynamics and radiative properties of various X-pinches were studied by spatially and time-resolved X-ray and optical diagnostics. In particular, dynamics of spatial and temporal developments of the structure of X-ray emitting regions (1–5 keV), temporal characteristics of X-ray pulses, X-ray radiation outputs and electron beam characteristics from symmetric and asymmetric Mo, Cu, and combined asymmetric Mo/W X-pinches with two or four wires were studied. The mechanisms of X-ray multiburst generation are discussed. The future applications of the high-current X-pinch as a 5–10 kJ sub-keV–10 keV radiation driver are considered.

Keywords: X-pinch; X-ray; Diagnostics

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1. Introduction

Wire array Z-pinches create substantial soft X-ray powers from hot dense plasmas. X-pinches create plasmas in the same regime employing the process of magnetically driving fine wires [1–5], which is the same process used in Z-pinches, and so X-pinch studies are applicable to wire array physics. Plasmas derived from 1 MA X-pinches can also serve as wideband pulsed X-ray sources of comparable brightness and energy yield to laser produced plasmas [4,6–9]. An X-pinch plasma is formed by touch-crossing two or more wires placed between the electrodes of an 0.1–1.0 MA pulsed power generator [1–5]. A fast rising current (50–100 ns) quickly vaporizes and ionizes the wire material. The X-pinch yields several short (0.1–10 ns [2–5]) thermal X-ray bursts (XRB) in the spectral range from sub-keV to several keV from bright plasma hot spots with dimensions from $\sim$1 to 100 μm surrounded by a cooler plasma seen in the softer wavelengths (with a size of several mm at the cross-wire region [3–8]). The number of hot spots is typically greater than 2. The bright hot spots can be seen even for $\lambda < 2-3$ Å.The size of hot spots has been observed to be smaller when shorter wavelengths are observed. The total number of shorter wavelength sources is usually smaller than the number of sources found for longer wavelengths. Further, the X-ray radiation sources tend to be more isolated as the wavelength of the source becomes smaller. On the other hand, the source becomes larger with increasing wavelength.

Previous studies of magnetically driven 1 MA X-pinches included the study of the X-pinch source structure, the time and energy scaling of X-ray radiation in the energy range from 0.01 up to 500 keV, and investigations of energetic electron beams (>0.01–2 MeV) in the X-pinch plasma [2,4,6–8]. A magnetic field inside an X-pinch may reach >1000 T [9,10]. The hot spots generated during the X-pinch discharge are found to have different electron temperature T_e and density N_e [6]. For example, for Mo and Ti X-pinches the N_e ranged between10^{19} and $2\times10^{22}\,\mathrm{cm}^{-3}$, T_e ranged from 0.85 to 2 keV, and a hot electrons beam fraction is up to 7% [6,11]. The probability of generating a single XRB during the X-pinch shot varied from 10% (for Fe) up to 30% for Ti [3,8]. The total yield of X-ray/EUV radiation reaches >10 kJ for 1 MA Mo X-pinches [3,8]. The μm-scale sources of softer (keV and sub-keV radiation) thermal X-rays are located typically near a cross-wire point. The mm-scale harder X-ray source (more than 10 keV radiation energy) is shifted to the anode side from the cross-wire point and is originated by electron beams of $\sim$2–3 mm in diameter. Three different types of the energetic electron beams, having energies more than or equal to several keV, were observed in X-pinches based on measurement of hard X-ray pulsed emission [12]. The first type of energetic electrons was generated in the vicinity of the original cross-wire point in 70–80% of discharges. They are observed to be temporally well correlated with the initiation of the first XRB and have a similar duration (1–2 ns) [10,12]. The mechanism of generation of this electron beam is connected with a hot spot formation [10]. The second type of electron beams (2.5–10 ns duration) occurs typically after the first XRB and typically is not correlated with the XRB [12]. The location of the region of production of these electron beams was near the cross-wire region in at least 60–70% of the X-pinch discharges. The third type of electron beams (10–30 ns duration) was observed several tens of ns after the current pulse maximum, and had no correlation with the thermal XRB [12]. In more than 60% of experiments these beams were produced in the anode region of the X-pinch. The appearance of this third type of electron beam may correlate with a late-time pinching of a major portion of the X-pinch plasma volume, as was observed in previous Z-pinch plasma experiments [13]. Recent applications