Study of Hybrid X-pinch in the XUV and SXR Spectral Ranges

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Abstract. The first detailed study of hybrid X-pinch radiation in the XUV wavelength range of 10–200 Å on a BIN pulser (discharge current of 270 kA and pulse rise time of 100 ns) with loads of various materials (Al, Mo, Ag and W) is presented. An estimate of the radiation energy output in the investigated spectral range was made. In particular, the Mo hybrid X-pinch emits XUV radiation about one to two orders of magnitude more compared with SXR radiation for a quanta energy of E > 1 keV.

1. Introduction

X-pinches are well-known sources of soft and hard X-ray radiation. Two types of X-pinches exist: a standard one, which is formed on a crosspoint of two or a few wires, and the hybrid X-pinch (HXP) in which the discharge evolves from one short wire stretched between two massive cone-shaped electrodes [1–3]. Studies of the XUV emission from standard X-pinches with pinhole imaging have confirmed the existence of strong XUV emission from the region less than 1 mm to the vicinity of the wire’s crosspoint. Transmission grating spectrometry and the use of differentially filtered diamond detectors with photoconductivity (PCD) have provided information about the spectral and temporal structure, which showed the high spectral brightness of a standard X-pinch in the XUV spectral range. This has enabled to use of X-pinches as a source in diagnostics, such as XUV absorption spectroscopy or radiation scattering. Until recently, however, XUV measurements havenot been carried out for hybrid X-pinches, which are generally much easier to use than standard X-pinches and enable a larger variety of source materials to be used. It is also unknown what parameters of the pulsers that drive HXPs are required for effective generation of XUV radiation (in contrast to soft X-ray radiation (SXR) from a hot spot for which the necessary formation condition dI/dt > 1 kA/ns was found and described in [4]).

2. Experimental Setup

Experiments were performed at the BIN facility with a load discharge current of up to 270 kA and current risetime of approximately 100 ns. Figure 1 shows the diagnostic part of the experimental setup. As a hybrid X-pinch load the wires from various materials (Al, Mo, Ag, W) with 13–30 µm diameter were used. Two-dimensional X-pinch images were obtained by using open pinholes (without filter) with a 100 µm aperture on Kodak DR50 film, which is mostly sensitive in the 1–10 keV range (Figure 1). The temporal parameters of radiation were explored using an AXUVHS5 silicon diode and PCDs with various filters and without them. PCDs have a constant sensitivity over a wide energy
range (10 eV < E < 4 keV) that smoothly falls toward 10–15 keV, and a silicon diode with a 50 µm Al filter which is sensitive to radiation with E > 5 keV.

The X-pinch spectra were studied using a spectrometer with a transmission diffraction grating (TGS) [5, 6], which has a number of advantages compared with reflective grating. The grating used in the experiments had a structure of 50 equidistant free-standing gold bars (N = 50, period d = 1.4 µm) suspended in a rectangular aperture with a width of D = 70 µm and a length of 1.7 mm. The bars of the grating were directed along the long side of the aperture with gaps between them of δ = 0.35 µm so that the aspect ratio of the periodic structure was δ/d = 1/4. The grating efficiency that was calculated using the X-ray database [7] has a near constant value in the spectral region of interest (λ > 10 Å).

The transmission diffraction grating has no astigmatism, and this allows one to realize the spatial resolution on an object in the direction perpendicular to the dispersion in the entire working spectral range. For this purpose, an additional slit (4) with a width of h = 100 µm was placed in front of the grating (5) perpendicular to the bars (Figure 1). For these experimental conditions, the spatial resolution on the object was Δl = h×(a + b)/b ≈ 220 µm. The spectra were recorded either on UV-4 photo film or on the Fuji TR imaging plate (IP) without a protective coating, which are sensitive to XUV radiation.

3. Experimental Results

Figure 2 shows the scope of the discharge current and photodetectors signals for the experiments with Al and Mo hybrid X-pinches. In these experiments, the generation of short pulses (on the order of nanoseconds) in the SXR range was observed, which means that bright spots were formed. The radiation recorded by the open PCD had a duration comparable with the duration of the current pulse risetime. At a late stage in the process, a fast increase in the signal was observed (Figure 2b). The reason for this increase is not yet fully understood. Most likely, this is due to some local breakdown of the detector surface under the action of a pinch radiation.

The estimation of radiation energy according to the open PCD data is 3 J, whereas behind the filter (for E > 1 keV), the energy does not exceed ≈ 25 mJ for all three peaks (Figure 2a). Energy measurements for various X-pinches recorded on the PCD without filter are shown in Table 1.

| material / diameter | Mo 30 µm | W 13 µm | A 25 µm | Ag 25 µm |
|---------------------|----------|---------|---------|----------|
| energy, J           | 6.2 ± 1.5| 4.9 ± 1.5| 3.1 ± 1.3| 3.0 ± 1.3|
Figure 2. Examples of discharge current, SXR and XUV scope signals.

Figure 3 shows an image of the HXP radiating area obtained by the open pinhole and the XUV spectrum obtained by the use of TGS with a spatial resolution and recorded on the photo film. A relatively large (of approximately 1.5 mm) radiating area contains several sources of a much smaller size – the so-called “bright spots”. Determination of the nature of these bright spots requires further analysis, in particular, the detailed study of the emitted spectrum.

![Figure 3](image_url)

Figure 3. Pinhole images of the Mo hybrid X-pinch recorded on the Kodak DR50 film and TGS spectra registered with spatial resolution on an X-ray film that is sensitive to XUV.

Figure 4a shows an example of HXP radiation spectra recorded with spectral and spatial resolution on X-ray film as well as the densitograms for some selected profiles (corresponding to a definite location along the load wire). The characteristic intensity dip within the range of 17 to 44 Å is related to the carbon absorption K-edge of the emulsion layer of the film. In some profiles, we observed shortwave regions (adjacent to the zero order of diffraction) of continuous radiation, which indicates the formation of hot spots in these local parts of the X-pinch. The region of emission with softer radiation (with a maximum of approximately 50–100 Å) has a dimension along the pinch that obviously exceeds the inter-electrode gap width.

Some experiments were performed by recording the radiation on the imaging plate (IP), which has a number of advantages compared with X-ray film. The IP can be used many times, they are practically insensitive to visible light, they do not require any chemical treatment, and therefore, they are easy to use in experiments. Images registered by IPs were recorded by the Durr HD-CR NDT scanner with a 25–50 μm linear resolution. Figure 4b shows the HXP spectrogram of Al recorded using the IP technique. For Ag and Mo loading, the same measurements were made. In contrast to the X-ray films, the images on IP do not have a characteristic dip hole due to the absorption at the carbon
K-edge. However, the Fuji TR IP has less resolution power compared with the X-ray film and requires special calibration in the spectral region of $\lambda > 10$ Å to calculate the absolute radiation energy values in this range.

Figure 4. a). TGS spectrum of HXP with a 30 µm Mo wire recorded on UF-4 film and spectrum outlines. b). TGS spectrum of HXP with a 25 µm Al wire recorded on Fuji TR imaging plates and spectrum outlines.
Experiments using a spectrometer without an additional slit (i.e., without spatial resolution) with registration on the calibrated UF-4 film made it possible to estimate the energy output of HXP in the wavelength range of 10 to 200 Å. The absolute radiation energy was calculated by taking into account the film sensitivity and an experiment geometry to be of 3 to 20 J, which is in good accordance with the current measurements by PCD.

4. Conclusions
The first experiments with hybrid X-pinch using TGS with a spatial resolution and current photo-detectors showed that the total yield of XUV radiation ($10 \, \text{Å} < \lambda < 200 \, \text{Å}$) exceeds the energy of soft X-ray radiation ($\lambda < 10 \, \text{Å}$) by one-two orders of magnitude. Thus, the hybrid X-pinch is an intense source of radiation in the XUV spectral range, which allows it to be considered as an effective XUV source for various applications.

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