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Spectroscopic Investigation of Radiation from a Low Current X-Pinch

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Abstract

We present the results from low current X-pinch machine capable to produce the current around 50 kA with a rise time (10%- 90%) of 34 ns. The X-pinches were made from two 7.5-10 μm diameter wires. Time-integrated x-ray spectroscopic measurements of the radiation produced by X-pinch have been made using a defocusing spectrograph based on a cylindrically bent mica crystal. The small size of the spectrometer made it possible to place it near to the X pinch wires without damaging the filters. In these experiments, the x-ray film was placed near to the crystal to get high intensity of lines, without significantly decrease of the spectral resolution. Intense soft x-ray radiation spectrum was determined by fast filtered PIN diodes.

Introduction

An X-pinch plasma is produced by exploding two or more fine metal wires that cross and touch at a single point in the shape of an X, which forms the load in the anode-cathode gap of a pulsed power generator. The characteristics of electromagnetic radiation emitting from X-pinch machine are dependent on the material and diameter of the wires as well as the electrical characteristics of the generator. Typically, the wires are metallic (10 ˚ 50 μm diameter) and the current characteristics vary from 80 kA to 1 MA with the rise time of 50 ns to few microseconds [1-5]. The major application of the X-pinch as a bright-point source of x-ray radiation is a point˚ projection radiography of plasmas, biological samples [1], and other objects [2]. However, the small size and predictable location of the radiation source(s) within the X-pinch make it attractive for the applications such as x-ray backlighting [3] and microlithography [4]. It may also possible to use the X-pinch for the EUV lithography due to the point source of radiation. Recently, experiments have been performed on table-top X-pinches with low currents in the range of 40-80 kA [5]. In this paper, we describe the method to obtain the spectroscopic information about the radiation emission from relatively low current (<50 kA) table-top X-pinches.

Experimental Arrangement

The X-pinch device has been developed for the purpose of studying high density plasma generated by the low current driver. It is operated by a Marx bank which is a pulsed power generator containing four capacitors (0.2 μF, 50 kV each) which then couples the electrical energy into a water dielectric, pulse-forming coaxial line (impedance ~ 2 ohms). The line is switched by a self-breaking sulphur hexafluoride (SF_6) spark gap which has internal electrode separation of 6 mm to the x-pinch load located in an evacuated chamber. A schematic of the X-pinch device is shown in Fig. 1(a). The current is monitored by a Rogowski Groove which is placed around at one of the current return post attached to the anode plate. The main diagnostic for detecting time-resolved x-ray and EUV emission from the X-pinch were BPX65 and SXUV HS5 diodes, respectively. These have smaller sensitive area (1mm × 1mm) and can be easily mounted on the SMA female connectors. Therefore, these low cost BPX65-PIN diodes with a fast response around nanosecond are ideally suited for x-ray measurements from pulsed power machines. A set of six filtered BPX65-PIN diodes is designed to measure the x-ray fluence in the range of 1 keV to 10 keV. Each diode is filtered so that the x-ray transmission convolved with the detector response forms a Ross filter pair with another diode. The BPX65-PIN diode detector response convolved with various filters is shown in Fig. 1(b).

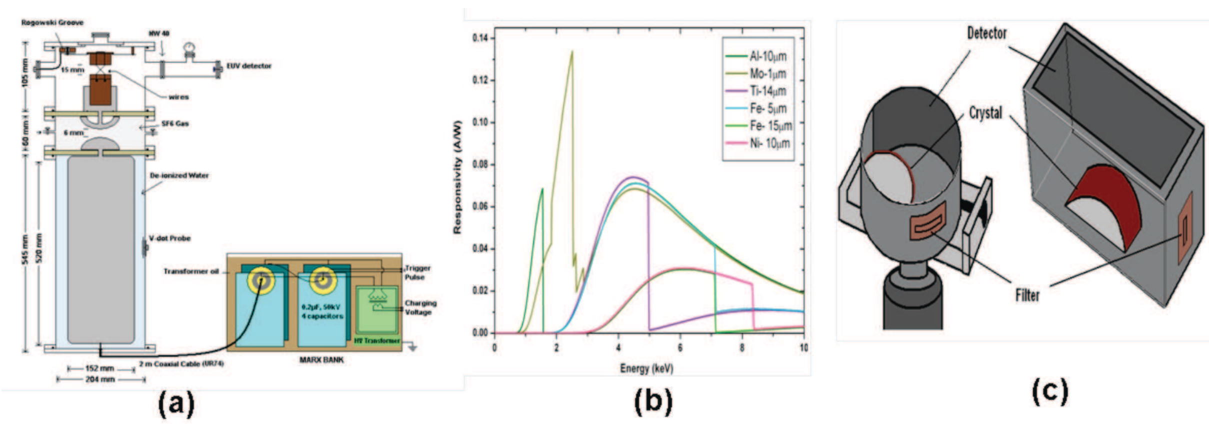

Fig. 1: (a) Schematic of the X-pinch device, (b) BPX65-PIN diode response convolved with various filters, and (c) schematic of crystal spectrometers.

Two small size defocusing convex crystal x-ray spectrometers (fig.1(c)) were designed and manufactured with the special goal ˚ to get space & time resolved spectra in a single shot, while placing it very close to the plasma. The basic elements of spectrometers are cylindrical convex mica crystals ($2d$ = 19.8Å) with radii 10 and 20 mm, respectively. Both spectrometers have slits with sizes 1mm × 5mm, covered by Be 15 μm or Al 3 μm filters. The time integrated spectra are recorded on Kodak BioMax MS high sensitive photographic film.

Results and Discussion

The parameters of rectangular spectrometer are calculated by using the optical scheme of the spectrometer as explained by E. Baronova *et al.* [5]. These parameters are compared with the experimental data and then the circular spectrometer is calibrated. The mica crystal, used in both spectrometers, has good reflection coefficients. Therefore, the spectrometer wavelength range up to fifth reflection order is given in Fig. 2(a). The best reflection order for measuring a particular wavelength depends on the reflection coefficient of that order, the resolution, number of emitted photons, etc. It is seen that 10 Å can be measured on the film (X_D =23 mm) only in the first order of reflection, while 5 Å can be measured for three orders.

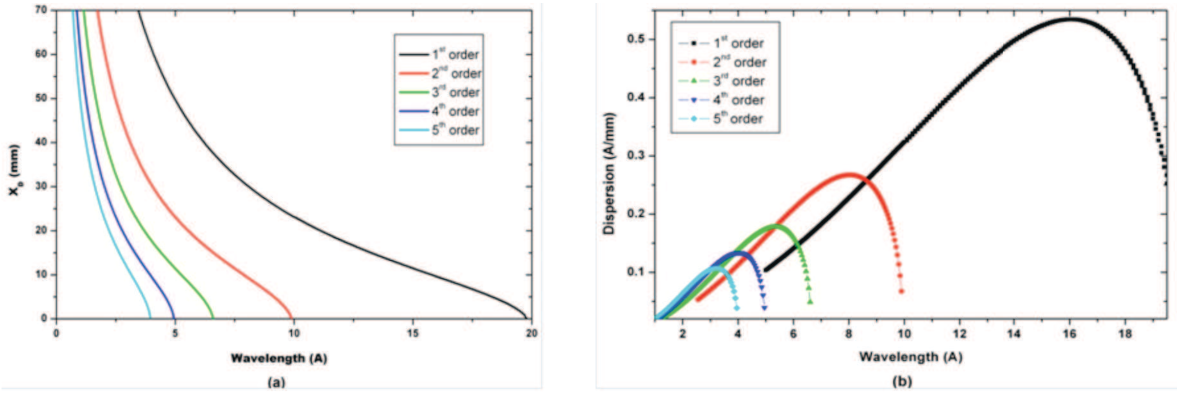

Figure 2: (a) Wavelength positions on the detector (film), (b) Spectrometer dispersion.

The value of the dispersion is calculated by using the expression $d\lambda/dX_D=(\lambda_1-\lambda_2)/(X_{D1}-X_{D2})$ as shown in Fig. 2(b). It is noted that, for some wavelengths, the dispersion is better in higher orders of reflection. For the wavelength of less than 10 Å, the dispersion is also less than 0.3 Å/mm and becomes lesser in higher orders of reflection. For any given order of reflection, the dispersion is about twice as good at both ends of the detector as it is at the center. Thus, in the first order, the dispersion at 8.5 Å is almost the same (0.26 Å/mm) as in the second order.

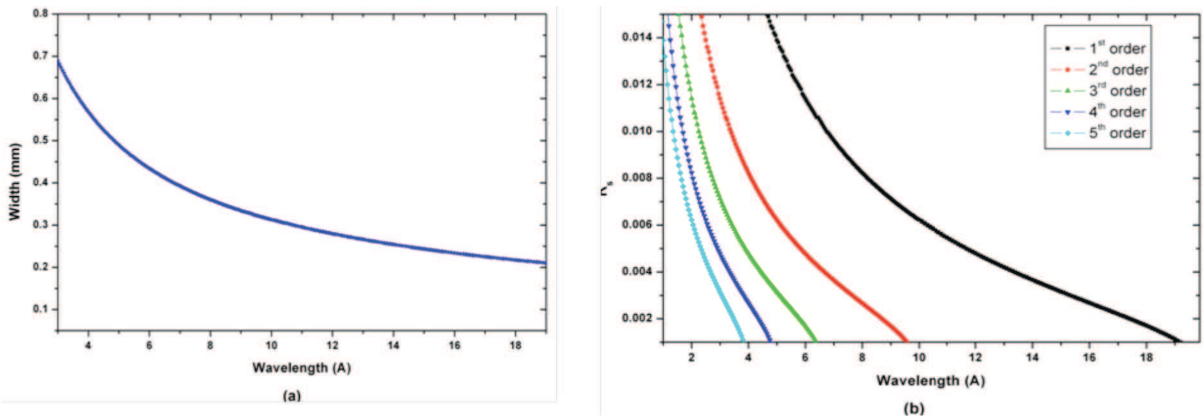

Figure 3: (a) Linewidth calculation for spectrometer, (b) Spectral resolution for first through fifth reflection orders of mica.

From geometric considerations, that is, disregarding line broadening introduced by the finite rocking curve of the mica crystal, it can be shown that the line width is related to the size of the source by the expression given by Swartz *et al.* [6]. For the source size of 1 mm, the linewidth and spectral resolution R_s are shown in Fig. 3(a) and 3(b), respectively.

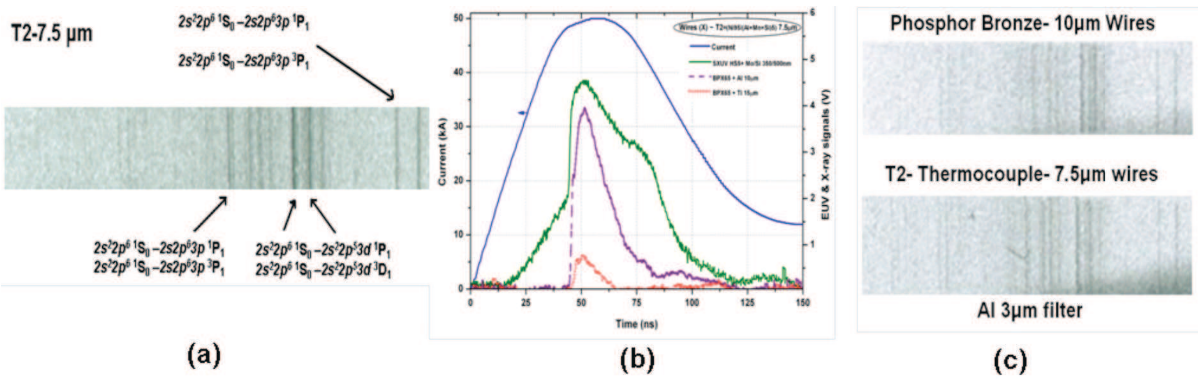

Figure 4: (a) Ni L-shell spectra and (b) time-resolved x-ray signals. (c) Cu and Ni L-shell spectra.

A typical spectrum of Ni L-shell, taken with a circular x-ray crystal spectrometer is shown in Fig. 4(a). The time-resolved signals of the current, EUV and the x-ray are shown in Fig. 4(b). The bulk of x-rays are emitted in the low energy range below 5 keV. The x-ray yield is about 50 mJ for 2 × 7.5 μm T2-thermocouple (Ni/(Al+Mn+Si), 95/5) wires, and 60 mJ for 2 × 10 μm phosphor bronze (Cu/Sn, 96/4) wires.

Conclusion

From spectra taken with the two spectrometers, it is concluded that for a given element (wire material) the intensity is isotropic, its distribution is same, and the resolution for both spectrometers is almost similar. The Cu and Ni L-shell spectra obtained in the experiments with phosphor bronze and thermocouple X-pinch wires are most pronounced (lines), indicate an electron temperature from 200 to 500 eV. The $2s^2 2p^6\ {}^1S_0 \circ 2s^2 2p^5 3s\ {}^1P_1$ and $2s^2 2p^6\ {}^1S_0 \circ 2s^2 2p^5 3s\ {}^3P_1$ lines for Cu have Bragg angles around 38-39°, close to the Brewster angle (45°), suitable to study the polarization of those lines in various experimental geometries.

References

[1] S. V. Lebedev *et al.*, Rev. Sci. Instrum. 72, 671 (2001)

[2] B. M. Song *et al.*, IEEE Trans. Nuclear Sci. 51, 2514 (2004)

[3] L. E. Aranchuk, J. Larour, and A. S. Chuvatin, IEEE Trans. Plasma Sci. 33, 990 (2005)

[4] D. H. Kalantar *et al.*, J. Vac. Sci. Technol. B9, 3245 (1991)

[5] E. Baronova et *al.,* Rev. Sci. Instrum. 77, 103104 (2006)

[6] W. Swartz, S. Kastner, E. Rothe, and W. Neupert, J. Phys. B 4, 1747 (1971)