

# A Compact X-pinch X-ray Source for Characterization of Inertial Confinement Fusion Capsules

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**Abstract.** We present initial results from experiments performed to characterize plastic capsules using a compact x-pinch pulser with a floor space  $< 1\text{m}^2$ . The pulser produces 80 kA current with a rise time of 40 ns. Various wire materials including tungsten, molybdenum and aluminum were used. X-pinch length was varied to obtain maximum x-ray yield and photon energies. X-rays in 5-9 keV energy range were used for the phase contrast radiography of plastic shells. Results with plastic capsules (1 mm diameter, 20  $\mu\text{m}$  thick wall) show a phase contrast effect at the edges of the wall. The sharpness of the image reveals source size of less than 3  $\mu\text{m}$ .

**Keywords:** Inertial confinement fusion, x-ray source, z-pinch

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## INTRODUCTION

Recently there has been much interest in the development of small, efficient and versatile x-ray sources for a number of applications, which include x-ray backlighting of dense matter [1], x-ray microscopy for biology, and medicine [2]. The main requirements for these applications are: i) short pulse duration (to resolve transient events in high energy density plasmas and “live” biological specimens), ii) reproducibility (position, output energy), iii) brightness, and iv) a small source size (for high-resolution radiography). Radiation in the energy range 1–10 keV is desirable for most applications [3,4]. Jitter free output is required for applications where the x-ray pulse has to be timed relative to an external event. At present, the x-pinch plasma x-ray source has the greatest potential to fulfil all these criteria. These properties also make an x-pinch an ideal source for characterization of inertial confinement fusion beryllium coated, copper doped plastic capsules.

Beryllium coated capsules containing moderate copper doping levels form the baseline NIF ignition target concept due to their favorable hydrodynamic properties during the implosion. In these capsules, DT is introduced into the shell in a gas form and then frozen into an ice layer by cooling the shell to below 20 K. The exact fusion yield achieved is sensitive to the uniformity and morphology of the Beryllium ablator and to the condition of the DT ice layer that is contained within the ablator. Proper characterization of the DT ice layer inside the shell is therefore crucial for high gain.

Since beryllium is opaque to visible light, x-ray radiography techniques need to be used to characterize the DT ice layer. Traditional radiographic techniques in phase contrast mode normally take as long as a few minutes and can be used to measure this layer in off-line experiments. However, various sources of vibration result in movement of the sample during the exposure [5]. This in turn, results in blurring of the image of the ice layer taken just before the laser shot. To avoid this, a bright short burst of x-rays is needed. An x-pinch is a bright source that could provide spatial resolution of 1-2  $\mu\text{m}$  with a single shot (x-ray pulse duration < 1 ns) with photon energies in 1-10 keV range.

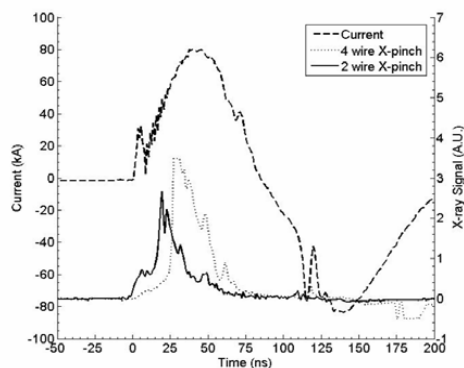
In the X-pinch a large current is pulsed through two wires, which are arranged in the form of an "X". At the point where the two wires touch – the cross point, i.e., at a predetermined position– the currents combine to produce hot dense plasma, which emits energetic x-rays. In this paper, a compact x-pinch with a current of 80 kA and a rise time of  $\sim 40$  ns is used to provide a point x-ray source in the energy range of 1-10 keV to illuminate the ICF capsules. Radiographic images indicate source size better than 3  $\mu\text{m}$  in 5-8 keV energy range.

## EXPERIMENTAL SETUP

A conventional pulsed power generator was used to drive the X-pinch. It consists of a small four capacitor (50 kV, 0.22  $\mu\text{F}$  each) Marx bank, pulse-charging a coaxial water dielectric line (Impedance  $\sim 1.5$  Ohm), which is switched by a self-breaking SF<sub>6</sub> spark gap into an X-pinch load located in an evacuated chamber. The total footprint of the generator and the X-pinch chamber is less than 1m<sup>2</sup> as shown in Fig. 1. The Marx bank was isolated with the pulse forming line with a high voltage cable (UR74), which facilitates use of the pulse forming line on any vacuum chamber for application



**FIGURE 1.** A photograph of an x-pinch pulser. A compact Marx bank may be seen in the background.



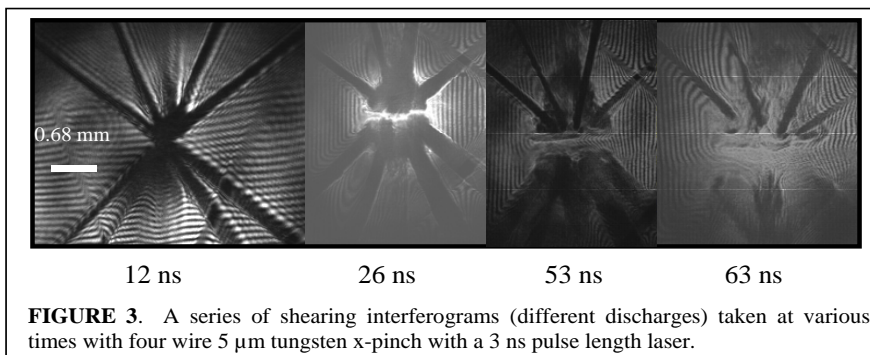
**FIGURE 2.** A typical current waveform showing 80 kA current with a risetime of 40 ns. X-ray signals for 2 wire and 4 wire tungsten x-pinchs are shown. A 4  $\mu\text{m}$  plastic filter ( $h\nu > 100$  eV) was used.

purposes. Another modification in the pulsed forming line is that there is no continuous flow of de-ionized water. Yet, no degradation in the voltage pulse was observed with time. The X-pinch was formed with various wire materials (Al, W, Mo etc.) but typically 5  $\mu\text{m}$  tungsten wires were used. X-pinchs consisting of two and four wires were used. The current pulse peaked at 80 kA with a rise time of 40 ns. The current crowbarred at about 200 discharge chamber (Fig.2).

## EXPERIMENTAL RESULTS

Figure 2 shows typical x-ray pulses recorded with the diamond detectors filtered with 4  $\mu\text{m}$  plastic filter. Soft x-ray emission occurs at about 15 ns for two wire 5  $\mu\text{m}$  tungsten x-pinch whereas x-ray pulse appears at about 25 ns for four 5  $\mu\text{m}$  wire x-pinch. The anode-cathode separation was varied from 2 cm to 1 cm. X-ray emission was a factor of two larger with a 1 cm gap compared to a 2 cm. The aluminum (seven steps, 10  $\mu\text{m}$  thickness), titanium (four, 10  $\mu\text{m}$  each) and copper (three, 10  $\mu\text{m}$  each) wedge filters showed x-ray emission in 1- 10 keV range.

The timing of the x-ray pulse is consistent with the pinch formation at the cross-point as shown in Fig. 3 for a four wire 5  $\mu\text{m}$  tungsten x-pinch. The shearing interferograms (with 3 ns laser pulse) show expansion of wires and jet formation at 12 ns. The gap at the cross-point has been formed at 26 ns just after the pinching at the cross-point. The motion of the plasma away from the cross point may be seen in the interferograms later in time.

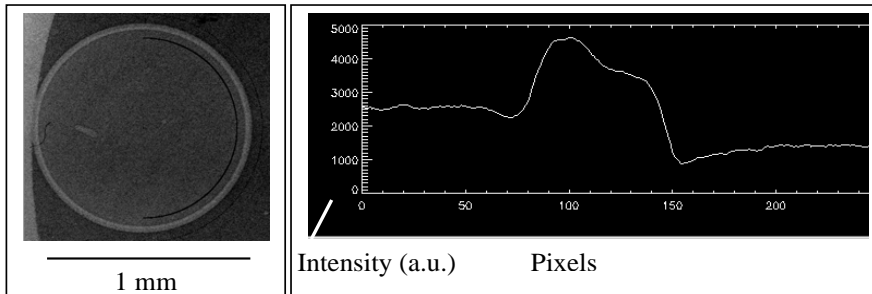


Capsules of various diameters and wall thicknesses were used for radiography in experiments described here. Figure 4 shows an image of a plastic capsule with a diameter of 1 mm and a wall thickness of 20  $\mu\text{m}$ . The image was recorded with a 10  $\mu\text{m}$  copper filter with a magnification of 9. Figure 4 shows the original image and the inside and outside ends of the radial lineouts used to make the radius versus angle plot shown on the right. The profile is averaged over all the lineouts. The sharpness of the image doesn't change with the angle. Intensity oscillations due to phase contrast effect may be seen inside and outside of the edge. The sharpness of the wall edges shows that the source size was less than 3  $\mu\text{m}$ . The attenuation of x-rays through the shell indicates photon energies in 5-8 keV range.

The collapse of tungsten x-pinch to a couple of micron diameter is consistent with initial experiments performed by Beg et al. [6] with a 40 kA current generator.

Recently, Chittenden [7] has shown using a simple scaling model ( $r \sim I^{-\frac{14}{9}} Z^{-\frac{10}{9}}$ ) that the tungsten x-pinch collapses to 1  $\mu\text{m}$  radius spot with a current of 45 kA. The results obtained with the molybdenum and aluminum x-pinches are consistent with this scaling.

To summarize, we have demonstrated that a tungsten wire X-pinch is a practical and viable source for characterization of inertial confinement fusion capsules. More work is presently underway to record spectrum, source size and temporal resolution with the compact x-ray pulser.



**FIGURE 4.** A typical phase contrast image of a 1 mm diameter, 20  $\mu\text{m}$  wall thickness capsule. The dotted line outside and the solid line inside the shell wall show the width of the lineouts. The lineout shows the strong phase contrast effects (image was taken with a 10  $\mu\text{m}$  copper filter with a magnification of 9).

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