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Pulsed Power Driven Hohlraum Research at Sandia National Laboratories

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Abstract. Three pulsed power driven hohlraum concepts are being investigated at Sandia National Laboratories. These hohlraums are driven by intense proton and Li ion beams as well as by two different types of z-pinch x-ray sources. The paper will describe the details of experiments that have been conducted on these hohlraum systems and will discuss several new and novel hohlraum characterization diagnostics that have been developed for this work. These diagnostics include an active shock breakout measurement of hohlraum temperature and a new transmission grating spectrograph for detailed thermal radiation spectral measurements.

Introduction

Indirect drive inertial confinement fusion (ICF) uses high powered laser beams, particle beams, or z-pinches to compress and heat capsules containing fusion fuel with the goal of producing thermonuclear energy. In this scheme, the primary high powered radiation sources are used to heat high-Z radiation cavities, or hohlraums, converting the driver energy to x-rays which implode the capsule.

This paper will describe three pulsed power driven hohlraum designs that are currently being experimentally investigated at Sandia National Laboratories. The first of these hohlraums is proton or lithium ion beam driven and is configured into either conical or cylindrical geometries. The second hohlraum system that is being studied consists of a central cylindrical hohlraum that has two smaller hohlraums attached to its side. The central hohlraum is driven by the implosion of a 40-wire tungsten wire array z-pinch plasma radiation source located on its axis. The third hohlraum concept that is being investigated consists of a low density (2-10 mg/cm^3) foam z-pinch that is imploded. In this design, the energy of the imploding z-pinch is used to directly heat the hohlraum.

A hohlraum can be described by a simple power balance model of the hohlraum cavity. In this model, the peak x-ray source power driving the hohlraum is balanced by power losses into the hohlraum wall and losses due to any holes in the hohlraum wall. This relationship may be written as

$$P_{x-ray} = A_{wall}(1-\alpha)\sigma T^4 + A_{hole}\sigma T^4$$

where $P_{x\text{-}ray}$ is the peak x-ray source power, A_{wall} is the hohlraum wall area, A_{hole} is the area of the hohlraum covered with holes, α is the albedo of the hohlraum wall, σ is Stefan-Boltzmann constant, and T is the hohlraum radiation temperature. A typical value of α for a Au wall hohlraum at a temperature of 75 eV is 0.8. The primary interest in surrounding pulsed power x-ray sources with a hohlraum is due to the ability of the hohlraum to amplify the power of the x-ray source. Neglecting any losses through hohlraum holes, this power amplification for a typical pulsed power driven hohlraum is given by

$$\frac{\sigma T^4}{(P_{wall} / A_{wall})} = \frac{1}{(1-\alpha)} = 5$$

for α=0.8. An additional feature of the hohlraum cavity is that it will also tend to smooth spatial irregularities of the driving pulsed power radiation source.

Ion Heated Hohlraum Experiments

The light ion ICF program is based upon an x-ray driven or indirect drive target concept.[1] Several target experimental series have been carried out on the PBFA II facility to investigate fundamental physics issues associated with this concept.[2] These issues include ion beam spatial parameters (symmetry, position, and vertical beam height), ion beam energy and power deposition, the conversion of ion-beam energy into soft x-ray thermal radiation, and the conversion of ion-beam energy into hydrodynamic motion. Fig. 2 shows the three classes of targets that have been used in our experiments to study the conversion of ion-beam energy into radiation. For all three classes of targets, the radial ion beam passes through the Au walls of the target and due to dE/dx energy losses, is finally stopped in the 3-6 mg/cm^3 CH foam region of the target. The rapid beam heating of the foam causes it to ionize and emit soft x-ray radiation. This soft x-ray emission in turn heats the gold walls of the target which reradiate creating a hohlraum.

The first target experiments on PBFA II employed intense proton beams to study thermal x-ray production in a cylindrical foam target shown in Fig. 1a. Details of these experiments may found in Ref. 2. A peak brightness temperature of 35 eV was measured in these experiments.

In an effort to increase the ion specific power density in our PBFA II experiments, Li beams were employed that increased the specific power density by over an order of magnitude.[2,3] The hohlraum targets used in the Li experiments are shown in Fig. 1b and Fig. 1c. The beam parameters of the PBFA II Li beam had a peak voltage of 10 MeV, a peak power density of 1-1.5 TW/cm^2 averaged over a 6-mm-diameter spherical target, a FWHM of 13-15 ns, and a peak specific power density of 1400 TW/g. The physics issues under study included Li ion coupling into the foam at 1400 TW/g, optical transparency of the CH foam, the tamping of the Au wall by the foam, and the thermal x-ray emission. Evidence of radiation smoothing and the hohlraum nature of this target system was also obtained from data that demonstrated that a 25% asymmetry in the incident Li beam was smoothed to a 6% asymmetry in the thermal x-rays emitted below 280 eV.[3] A brightness temperature of 58 eV was obtained from the XRD diagnostic thermal x-ray flux. The target shown in Fig. 1c was designed to maximize the radiation temperature by maximizing the hohlraum surface to volume ratio. The analysis of this shot series yielded the highest radiation temperature yet achieved in an ion-beam driven hohlraum, 63 eV.

Z-pinch Driven Vacuum Hohlraum System

A z-pinch vacuum hohlraum system that is being studied is shown in Fig. 2. This hohlraum system consists of a central 2 cm diameter by 2 cm tall cylindrical hohlraum that has two 6 mm diameter by 9 mm hohlraums attached to its side. The central hohlraum is

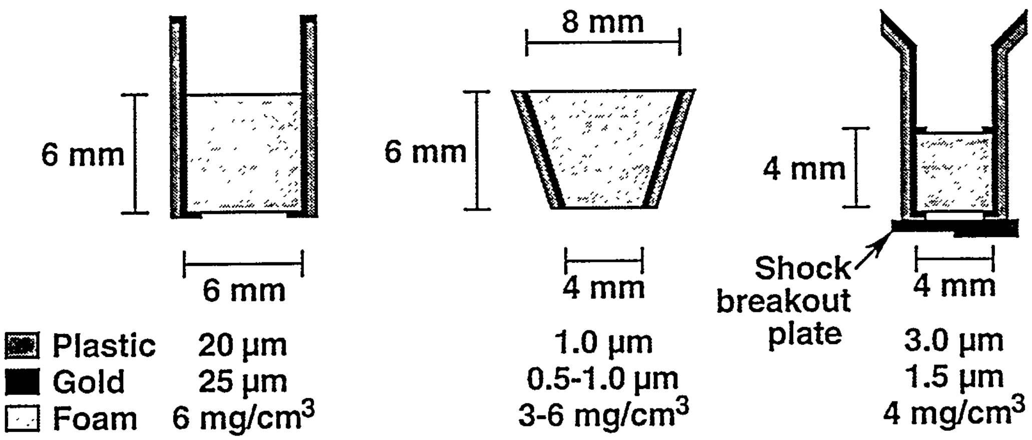

Fig. 1a **Fig. 1b** **Fig. 1c**

Fig. 1. Conical and cylindrical hohlraum targets designed for hohlraum physics studies on PBFA II. a) Proton cylindrical target. b) Lithium beam conical target. c) Lithium beam cylindrical target.

driven by the implosion of a 40-wire tungsten wire array z-pinch plasma radiation source located on its axis. Soft x-ray radiation from the imploded z-pinch heats the walls of the central cavity which reradiate. Holes drilled in the central z-pinch hohlraum allow radiation to flow into the smaller side hohlraums. The geometry of the system is arranged to insure a spatially uniform, near Plankian radiation spectrum in the two side hohlraums.

In recent experiments on the Sandia National Laboratories' Saturn accelerator, the radiation drive in the small hohlraums was monitored with an 11 channel XRD array; a 16 channel transmission grating spectrometer; and a time- and energy-resolved soft x-ray cameras. The shock velocity in polycarbonate step and wedge witness plates was measured by means of a streaked image of laser light reflected from the rear surface of the witness plate. Preshot radiation-hydrodynamic code predictions of shock velocity were within about 10% of the measured values. The degree of uniformity of shock breakout along the ~3-mm-long hohlraum slot (corresponding to a theoretical ~3 eV variation) were consistent with computational predictions. Data from these instruments indicate that radiation temperatures of 80 eV have been reached in the central hohlraum. Measurements of the radiation spectrum and temperature in the side hohlraums show a nearly Planckian spectrum and a shock velocity measured with the active shock breakout technique that is consistent with a prediction of a 65 eV radiation temperature. A key remaining uncertainty is a quantitative understanding of the time-dependent hohlraum radiation drive conditions as measured by the XRD and transmission grating spectrograph. This uncertainty is due to diagnostic hole closure and plasma filling of the hohlraum. Recent experiments utilized CH "tamped" diagnostic apertures, and upcoming experiments will explore the issues further via a direct look at Be-tamped apertures with a higher resolution x-ray imaging diagnostic.

Dynamic Hohlraum System

In an effort to increase the radiation temperature in a pulsed power driven hohlraum, the hohlraum concept shown in Fig. 3 is being investigated.[4] In this design, denoted as a dynamic hohlraum, the energy of the imploding z-pinch is used to directly heat the hohlraum. The hohlraum consists of a 10 mm diameter low density (2-10 mg/cm^3) foam z-pinch that is imploded to a diameter of ~1 mm. The outer region of the foam is

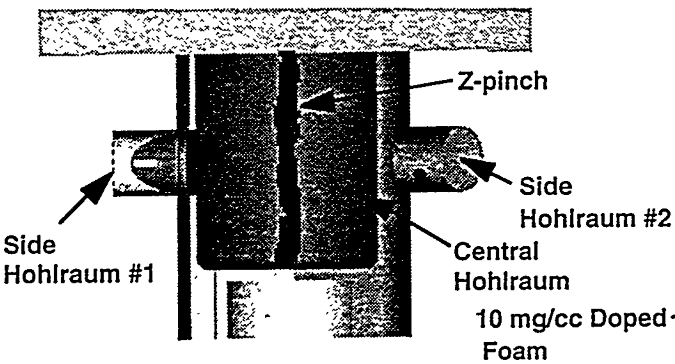

Fig. 2 Schematic of vacuum hohlraum system.

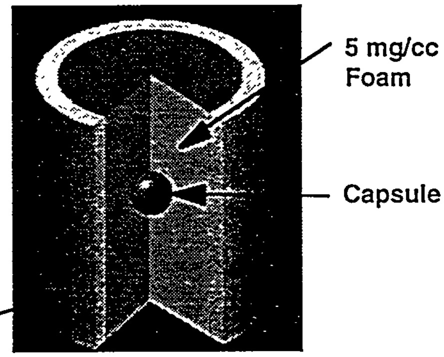

Fig. 3 Imploding hohlraum concept.

doped with gold such that a large fraction of the thermal radiation generated at implosion is contained in the system. The radiation trapped in the final imploded state of this hohlraum enable a high radiation temperature to be reached in this system even when driven by the relatively low power of a pulsed power system. At a future date, an imploding thermonuclear fuel capsule would placed in the center of this system. Calculations predict that a capsule ignition could occur if the system were driven by a current of 60 MA.

A recent experimental series fielded on the Saturn accelerator investigated current initiation in these types of foam systems.[4] This series studied the initiation properties of foam targets at peak currents of 6-7 MA. Optical framing cameras and steak optical fiber arrays were used to observe the early sheath formation in the outer regions of the low density foam. Both prepulse and a gold conducting coating were found to be necessary for good coupling to the accelerator source. Electrode contacts and the anode/current return configuration were determined to be limitations in the experimental series. A variant to these experiments, was to implode a z-pinch tungsten wire array directly onto a low density cylindrical foam. Good results were obtained in heating a foam system by this method. This technique will be explored in future experiments on Sandia's PBFA II-Z facility.

Conclusion

Three pulsed power driven hohlraum concepts are being investigated at Sandia National Laboratories for application to inertial fusion research. These hohlraums are driven by intense proton and Li ion beams as well as by two different types of z-pinch x-ray sources. Research on these hohlraum systems will continue on Sandia's PBFA II-Z facility.

Acknowledgment

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[4] M. S. Derzon et al., Proc. 11th Topical Conference on High Temperature Plasma Diagnostics, Monterey, California, May 12-16, 1996 and the references therein.

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