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Optimization of laser hole drilling process on thick gold spherical hohlraums for intense X-ray generation

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Abstract. Hohlraums of high-Z materials are used as soft X-ray sources to study indirect drive fusion, equation of state of materials etc. Here, we describe a method to develop spherical gold hohlraums of large wall thickness (∼70–80 μm) on which laser entrance and diagnostics holes are drilled using a 10 Hz Nd:YLF laser. Holes of different diameters have been drilled with lenses of different focal lengths. The back wall of the hohlraum is protected from the damage by shutting off the laser at pre-determined hole drilling time.

Keywords. Hohlraum; plasma.

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1. Introduction

The generation of intense blackbody radiation in a hollow microsphere or hollow cylindrical cavity of high-Z material (referred to as hohlraum) [1] using high-power laser beams as drivers is an area of great interest to many scientific investigations and technological applications. Hohlraums are basically used for converting laser light into thermal X-ray radiation and its confinement inside the cavity. The applications include: the laboratory study of radiation hydrodynamics, investigation of equation of state of matter at very high temperatures and pressures, and as a driver for indirect approach to inertial confinement fusion. Hohlraums are typically mm-size cavities made of high-Z material (e.g. gold). They are mostly fabricated by the electroforming technique by depositing high-Z material on a machined mandrel which can be subsequently etched away (dissolved) in suitable solvent, leaving behind gold hohlraum shell [2]. The thickness of the high-Z material is required to be several microns (typically greater than 5 μm) as governed by the parameters of radiation burn-through. If the hohlraum is to be made of high-Z material itself, the minimum wall thickness gets decided by the structural stability. Two or more number of the small holes are drilled in these hohlraums to facilitate entry of the pulsed laser beam and for diagnostics of the X-ray radiation produced inside the cavity. The diameter of these holes is typically in the range of 200–300 μm or greater, as governed by the laser beam focusability and pointing stability, and closure of the entrance hole due to plasma formation on its edge. The total area of these holes should be a small fraction of the inner wall area of the hohlraum to achieve a near blackbody situation inside the cavity. This condition is met for the holes of 200–300 μm diameter on spherical hohlraums of size typically in the range of $\sim$1–1.5 mm diameter (holes cover $\sim$2–3% of the surface area in this case).

The production of spherical hohlraums using the electroforming method is rather difficult. We have explored a much simpler technique to fabricate gold hollow spherical shells, and have produced gold hohlraums of 1.4 mm diameter with entrance and diagnostic holes of $\sim$300 μm diameter. The fabrication procedure makes use of thick foils of gold to make spherical cavities which are subsequently drilled to have laser entrance and diagnostic holes. This method of fabrication using thick foils to pre-form the spherical shell and then further follow up by drilling holes gives good structural stability to the cavity and also offers a possibility to coat the inside of the hohlraum with another material whose thickness is larger than the radiation burn-through. Earlier, we had developed jigs to hold the hohlraums on a drilling machine and used conventional mechanical drilling technique to drill the holes on the spherical hohlraums [3]. But, this technique suffered because of high rejection due to improper holes being drilled, and puncturing of the cavities. In the present work, we have used a sub-ns Nd:YLF laser with a repetition rate of 10 Hz, to drill the holes on the hohlraums. This method ensures that the rejection due to improper drilling is minimal. In addition, the accuracy of drilling the hole and control over achieving the correct hole with the desired diameter is much better in this technique. We present here a brief description of the method for drilling of the hohlraums using the Nd:YLF laser.

2. Experimental set-up

2.1 *Hohlraum fabrication technique*

The material used for making hohlraums was 24 carat gold. Two square pieces (2.3 mm $\times$ 2.3 mm) of a gold foil of $\sim$46 μm thickness were cut out and curved using die and punch, and then placed in contact opposite to each other. They were heated in the interlocked position till the gold material softened and the two hemispherical cavities fused together. The air trapped inside the fused walls expanded the vessel into a spherical cavity. Nearly 50% of the shells thus formed were found to have a diameter of 1.4 $\pm$ 0.05 mm and weighed 9.5 $\pm$ 0.5 mg. If coating of a different material was to be deposited in the inside of the hemispherical shell, then pasting of the hemispheres could be done. The average wall thickness of these shells was calculated to be $\sim$70–80 μm from the measured diameter and weight. This was larger than the initial foil thickness of $\sim$46 μm because during the ballooning of hohlraums, the gold material on the sides (interlocked parts of the two foils) spread uniformly on the surface.

Table 1. The relation between the focal length of the lens, time for drilling and hole diameter.

Focal length (mm)	Time of drilling (s)	Hole diameter (μm)
1250	225	220
950	180	140
570	140	110
454	120	100
335	105	70

2.2 *Hole drilling process*

To optimize the process parameters for the laser drilling, the drilling process parameters were obtained by studying the process on a planar foil of approximately the same thickness as that of the spherical shell. There were two important considerations that needed to be studied: (1) The laser used for the drilling should not damage the back spherical face of the pre-formed spherical hohlraum (i.e., the drilling process should be very slow) and (2) to get the holes of the desired diameters on the hohlraum, the process has to be studied by drilling the holes with different focal length lenses. The holes were drilled with different focal length lenses on the planar gold foil of thickness ~70 μm that was almost of the same thickness as that of the hohlraum. Laser energy was varied and drilling time of the foils was studied for different lenses used. It was found that laser pulse with ~8–10 mJ peak energy (variation of 20% peak to peak and RMS variation of 5%) gave a drilling time of ~2–5 min (at 10 Hz rep-rate) when it was focussed with the lenses of focal lengths varying from ~330 to 1250 mm on the gold foil.

Thus at this energy, the laser drills holes sufficiently slowly so that the damage to the back side of the hohlraum can be easily controlled by switching off the laser at a pre-set time at which the hole is just drilled using the lens of a given focal length. Table 1 shows the drilling time measured for different focal lengths of the lenses and the corresponding diameters (d) of holes obtained with them on the gold foil. Figure 1 shows the variation of the hole diameter that is obtained vs. the focal length of the lens used. As expected, it is a straight line as $d = f\theta$, where θ is the laser beam divergence. Using this information, one can choose the focal length of a lens that will give a hole of the desired diameter. Figure 2 shows the time of drilling for a given lens vs. the focal length of the lens, for a fixed foil thickness. From this data, the time at which laser should be switched off is decided. Using this data, holes were drilled in hohlraums of 1.4 mm diameter and ~70–80 μm wall thickness.

2.3 *Hohlraum mounting and positioning assembly*

The hohlraums were pasted on a pre-fabricated hollow mandrel of 2.2 mm outer diameter, 0.6 mm inside diameter and 4 mm length. A chamfer of 45° was provided

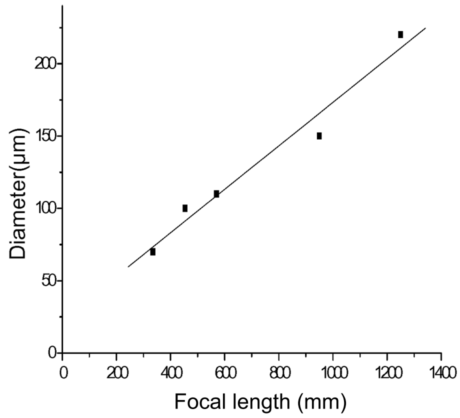

Figure 1. Variation of the hole diameter vs. the focal length of the lens used.

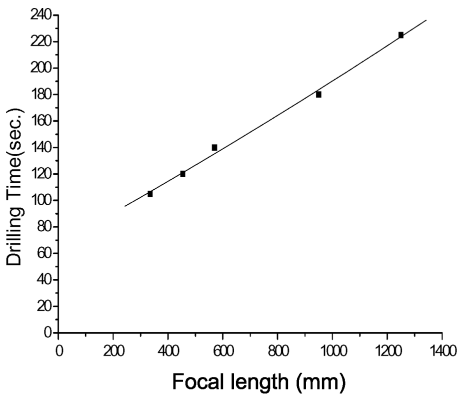

Figure 2. Variation of the time of drilling vs. the focal length of the lens.

on the top to hold the hohlraum. The mandrel was held in a collet chuck to protect hohlraum from getting damaged. A fixture for rotating the spherical hohlraums in two orthogonal planes was fabricated and the collet was mounted on it.

A photograph of the fixture is shown in figure 3. The pointed stag seen in the photograph was a reference mounted on the axis of rotation of the horizontal rotational stage. The point of the stag was brought to the focus of the laser using three X, Y, Z movements. Thus, the drilling laser was focussed on a point that was on the rotational axis of the horizontal rotational stage. A red diode laser collinear with the Nd:YLF laser was used as a visible pointing source. The stag was then removed and the hohlraum mounted on the axis of rotation of the vertical rotational stage (as can be seen in the photograph) and mounted in a collet was brought to the laser focus point with the help of another three X, Y, Z movements on which it was mounted. Thus the point of contact between the hohlraum and the focussed laser beam was the intersection between the axis of rotations of two orthogonal rotation stages. Hence, this simple fixture allowed us to drill diagnostic holes anywhere on

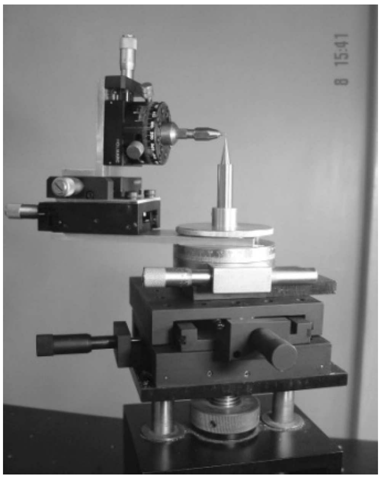

Figure 3. Photograph of the fixture.

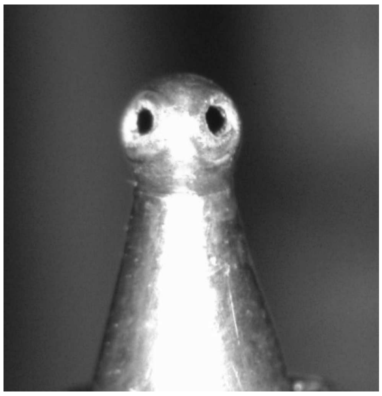

Figure 4. Hohlraum cavity with two holes at 90°.

Figure 5. Hohlraum cavity with three holes.

the surface of a spherical hohlraum. The angular accuracy of both the rotational stages was about half a degree that was sufficient from the point of view of location of the holes with respect to diagnostic ports on the plasma chamber.

3.4 *Hole orientation*

A 1.4 mm diameter hohlraum was mounted on the jig and using a lens of focal length 1.25 m, two holes (one for laser entrance and the other for the X-ray diagnostics) of size $\sim$220 μm, at 90° to each other, were drilled on the hohlraum. Both these holes were in a plane and at right angles to each other as can be seen from figure 4. Care was taken to stop the laser after 225 s, the corresponding drilling time. Figure 5 shows another hohlraum where three holes were drilled such that two were at 90°

to each other in the vertical plane and the third hole was at a rotation angle of 45° from one hole in horizontal plane. All the holes were drilled such that they were in front of the desired diagnostic ports of the plasma chamber.

3. Conclusion

A process for fabricating the hohlraums is discussed. The drilling process was optimized by studying the holes drilled on a foil with different focal length lenses, and the time required to drill the holes. Using the optimized parameters, multiple (two/three) holes were drilled on the fabricated hohlraums, without puncturing them.

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