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F. Elsner
Inertial Fusion Division
General Atomics
PO Box 85608
San Diego, CA 92186-5608
(619) 455-3967

ABSTRACT

Some preliminary experiments have been performed to determine the effect of mandrel geometry and plating bath composition on the thickness uniformity of gold and copper electroformed hohlraums. It was observed that for gold plating, the edge radius has a dramatic influence on uniformity in a direction opposite that expected (i.e. uniformity worsened with larger radius) and that extension of the front small-diameter cylinder gave a slight improvement in hohlraum symmetry. In the case of copper plating it was found that, as expected, reduced metal concentration improved uniformity, however, it was also found that the selection of additives has an even more pronounced effect.

I. INTRODUCTION

Electroforming is currently used to fabricate the metal containers that are used for indirect-drive inertial confinement fusion. These containers are known as hohlraums. In this fabrication method, substrate mandrels are finely machined to very precise specifications and are subsequently electroplated with the desired metal (typically gold or copper). The coated mandrels are then removed by dissolution in acid or an appropriate solvent, to produce the hohlraums. An example of a mandrel used to produce a hohlraum for experiments on NOVA is shown in Fig. 1. The coating on the small diameter front and rear cylinders is removed before dissolution to produce the laser entrance holes of the hohlraum.

Until recently little attention had been paid to the thickness uniformity of the gold and copper electroforms mainly because minor variation in the wall uniformity was not an important issue for the hohlraums used for experiments in the NOVA laser. However, for thick-walled (~25 μm) hohlraums used in cryogenic experiments and for the central cans used in the Z-pinch facility the wall thickness uniformity is more important. Upon inspection of the metal distribution it was observed that large thickness variations (as much as 25% for copper

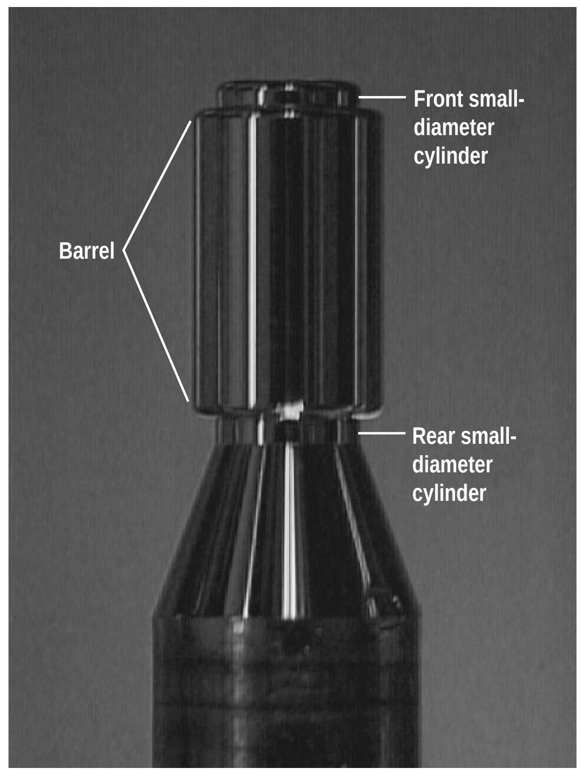

Fig. 1. Machined copper mandrel for fabricating a NOVA gold hohlraum. The barrel is typically 1.6 mm long.

and 10% for gold) existed along the length of the cylindrical hohlraum. These variations are significant.

The following sections will describe some of our initial attempts to influence the electroplated metal distribution for both gold and copper hohlraums. It should be emphasized here that these results are preliminary and are based on a small number of simple experiments. The experimental observations will be discussed briefly as well as suggestions for further work.

II. EXPERIMENTAL

A. Gold Hohlraum Production

Copper mandrels were fabricated from OFHC (oxygen free high conductivity) copper rods which were micromachined on a Precitech Optimum 2000 lathe by single-point diamond turning. The parts were cleaned prior to plating by ultrasonicating the mandrels in hexane and then ethanol, followed by removal of surface oxides (using a 2% solution of Metex L-5-B copper cleaner in water), again rinsing with ethanol, and blowing dry with filtered nitrogen. Diameters of the parts were measured on a laser micrometer (LaserMike 183) to within 0.3 µm. The copper mandrels were then electroplated with gold from a commercially available plating bath (BDT 510 from Enthone-OMI). The parts were held vertically in a rotating chuck and were immersed in the plating bath which consisted of a solution of Au(I)sulfite, proprietary additives and 50–200 ppm of sodium arsenite brightener. The parts were plated at a constant current density of 4 mA/sq. cm using a gold wire anode while the solution was continuously stirred, filtered to 0.8 µm, and maintained at 38–42°C. After ~1.5 hr plating the gold thickness was ~22 µm. The parts were removed from the bath, rinsed and measured with a laser micrometer to determine the thickness distribution.

B. Copper Hohlraum Production

Acrylic mandrels were machined from cast acrylic (polymethyl methacrylate) rod, cleaned with detergent in water, rinsed and dried. The surfaces of the mandrels were then made conductive by sputter coating ~0.2 µm of copper. The sputtered copper degraded relatively quickly in air which required that the electroplating be performed shortly after sputtering. The sputtered mandrels were held in a rotating chuck and electroplated with copper from either a "high concentration" (Technic's Copper U) copper plating solution or a "low concentration" (Technic's Copper FB) copper plating solution (Fig. 2). The plating was performed in a 400 mL beaker with rapid stirring, a bagged phosphorized copper anode and a constant current density of 20 mA/sq. cm. A coating thickness of ~5 µm was obtained after ~25 min. The parts were then rinsed with water, ethanol and then blown dry with filtered nitrogen.

	Copper U	Copper FB
Copper Sulfate	28–32 oz/gal	8.5–9.5 oz/gal
Sulfuric Acid	110–140 ml/gal	460–500 ml/gal
HCl	50–60 ppm	50–60 ppm
Proprietary Additives:		
U Brightener	7–20 ml/gal	
FB MUC		0.4% by volume
Component A		1.0 ml/gal
Primary		0.1 ml/gal

Fig. 2. Composition of copper plating baths examined.

III. RESULTS AND DISCUSSION

A. Gold Hohlraum Production

1. Effect of edge radius. It is often suggested[1,2] that reducing sharp corners and edges (i.e. designing substrates with large radii at the corners) will improve the uniformity of metal distribution during electroplating. To examine the effect of edge radius on gold plating uniformity, copper mandrels with different edge radii (Fig. 3) were concurrently electroplated with 22 µm of

Fig. 3. Mandrels of edge radius: (1) 0.15 mm, (2) 0.40 mm, (3) 0.60 mm, (4) 0.80 mm.

gold. The thickness variation (measured thickness minus minimum thickness) along the barrel length is depicted graphically in Fig. 4. As the graph indicates, the observed trend is for the plating uniformity to actually *worsen* as the radius of curvature increases. No explanation is offered for this surprising result, but it seems to indicate that for this plating system, minimizing the edge radius improves gold plating uniformity.

2. Extension of front small-diameter cylinder. In an attempt to reduce some of the edge effects we examined the possibility of extending the front small-diameter cylinder of a mandrel in the hope that the excess material being deposited on the hohlraum edge would instead be deposited on the end of the front small-diameter cylinder which could be subsequently removed. The effect of extending the front small-diameter cylinder is shown in Fig. 5. For this particular mandrel geometry it can be seen that the thickness distribution becomes more symmetric about the midpoint of the hohlraum as the front small-diameter cylinder length is increased, but that there still remains a rather steep increase in thickness at the edges of the hohlraum.

C. Copper Hohlraum Production

1. Effect of plating bath composition on uniformity. In order to fabricate copper hohlraums, we examined two copper sulfate plating solutions (Technics Copper U bath and Copper FB bath). Reducing the metal concentration of a plating solution is suggested[3] for improving the uniformity of the deposit. In support of this practice, the data shown in Fig. 6 demonstrate that the Copper FB bath yields a much more uniform deposit than the Copper U bath. However, there is also a more subtle difference between the two solutions regarding the different additives used. To determine the influence of the additives, a solution of Copper FB containing the three

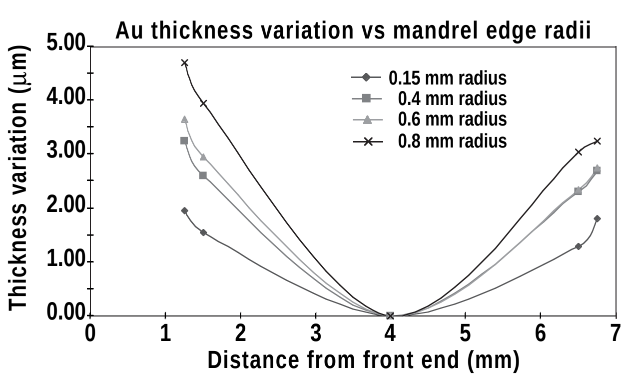

Fig. 4. Conventional wisdom is that increasing the radii of sharp edges will improve the metal distribution. Our results demonstrated the opposite effect.

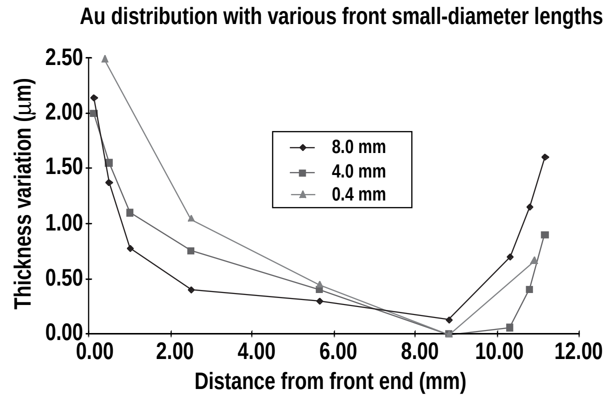

Fig. 5. Extending the front small-diameter cylinder gave a slight improvement in uniformity.

recommended additives was compared to a Copper FB bath containing the single U additive. Parts plated under identical conditions for these two solutions gave shiny copper electroplates at a comparable current and voltage. The thickness distribution from the two solutions was however, quite different. The FB bath with the U additive had a thickness distribution similar to that observed for the Copper U solution indicating that reducing the metal concentration alone is insufficient for improving uniformity, and that the use of trace amounts of additives will have a profound effect on plating properties.

IV. SUGGESTIONS FOR FUTURE WORK

One obvious solution to the uniformity problem would be to remachine the hohlraums after electroplating. However, the process of realigning the parts is a significant challenge and remachining the work would add considerably to the time and cost of hohlraum fabrication. Thus, a process for producing uniform hohlraums directly from the plating solution would be considerably more appealing.

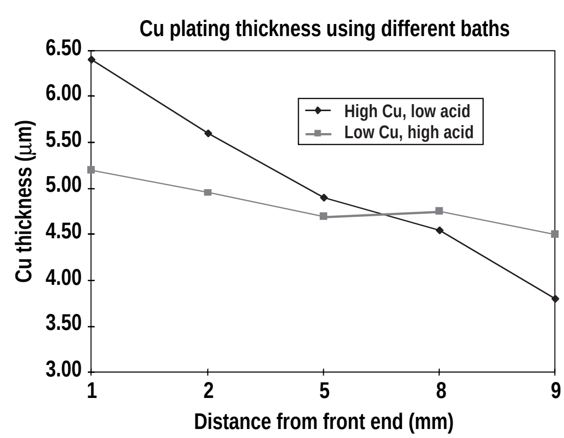

Fig. 6. Bath composition affects plating uniformity.

A partial review of electroplating literature[4–7] has revealed a number of techniques which can be used to influence the uniformity of the metal distribution. Some commonly referred methods include the following:

1. Selection and control of plating bath composition
2. Modification of current density
3. Pulse or periodic reverse current
4. Rapid and uniform agitation
5. Careful control of anode properties
   A. Relative anode:cathode surface area
   B. Position relative to cathode
   C. Plating cell geometry*
6. Shields*
7. Robbers*
8. Auxiliary anodes*
9. Modification of mandrel geometry*

These methods are for guidance only and do not guarantee a positive result. The optimum process conditions must be verified empirically and for those methods labeled with an asterisk any changes in mandrel geometry will require reoptimization of the plating procedure. Therefore methods labeled with an asterisk are least attractive from the standpoint of their limited range of use. From our previously discussed experience with copper plating it is clear that bath composition plays a major role in plating distribution. Of the remaining methods listed, most can be readily examined in just a few experiments with the exception of pulse or periodic reverse plating (PPR) which requires optimizing a waveform and therefore would require more experimentation. Literature reports[5,7] of improved plating distribution via PPR suggests that it is worth examining.

V. CONCLUSION

Gold and copper electroformed hohlraums have a nonuniform wall thickness along the cylinder length. Experimentalists and designers should be conscious of this when planning and interpreting experiments. If more uniform distributions are required, some significant developmental efforts will be necessary to optimize the plating operation.

We have examined several geometric and chemical variations and obtained results which are both interesting and useful. However, there are a number of other techniques for influencing metal distribution during electroplating, and the optimum process conditions will have to be determined experimentally.

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