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**COPPER-COATED LASER-FUSION TARGETS
USING MOLECULAR-BEAM LEVITATION**

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A series of diagnostic experiments at the Shiva laser fusion facility required targets of glass microspheres coated with 1.5-3.0 μm of copper. Previous batch coating efforts using vibration techniques gave poor results due to microsphere sticking and vacuum welding. Molecular Beam Levitation (MBL) represented a noncontact method to produce a sputtered copper coating on a single glass microsphere. The coating specifications that were achieved resulted in a copper layer up to 3 μm thick with the allowance of a maximum variation of 10 nm in surface finish and thickness. These techniques developed with the MBL may be applied to sputter coat many soft metals for fusion target applications.

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I. INTRODUCTION

A series of ICF diagnostic experiments this year required targets of glass microspheres with a double coating; fluorocarbon and copper. Both electroplating and sputtering methods were pursued as fabrication methods for the copper layer. Previous sputter coating efforts using vibration techniques gave poor results with soft metals due to microsphere sticking and vacuum welding.¹ Molecular Beam Levitation (MBL) represents a noncontact way to produce the soft metal coating.

In this process a glass collimated hole structure (CHS) is utilized to direct streams of argon molecules that levitate a hollow glass microsphere (HGM) with a mass of less than a microgram to a height of 50-150 micrometers. The levitator operates in the molecular flow regime as discussed in prior literature.²

This paper will deal with the various aspects of sputtering copper using a MBL. The MBL design is discussed and the coating parameters defined that are necessary to produce coatings 1.5-3.0 μm thick with thickness and surface variations $\leq 1\%$ of coating thickness on HGM that are 100-200 μm in diameter.

II. EXPERIMENTAL

These experiments were carried out in a 45 cm diameter stainless steel chamber pumped by a liquid nitrogen trapped 15 cm diffusion pump. The sputter source is a Sloan S-310 magnetron gun with DC and RF capabilities.

Previous MBL work by J. Bunch, A. Lowe of LANL and J. Crane, R. Smith of LLNL showed problems in levitation after a continuous metal film was deposited.³ The MBL fixture designed as shown in Figure 1 will allow operation in either a DC or RF argon sputtering discharge. The modifications from the prior configuration as used in plasma polymerization⁴ involve electrical isolation and water cooling of the CHS. These modifications result in stable levitation of the microsphere during coating.

The electrical isolation of the CHS allows the microsphere and the CHS (which are both immersed in the sputtering plasma) to float together at nearly the same potential, thus reducing the image force attraction of the microsphere and the ground plane.⁵ The potential difference is not exactly zero due to geometrical effects, and there is still some attraction of the microsphere to the CHS surface.

The microsphere attraction comes from a combination of electrostatic charge and dipole polarization force.⁶ The electrostatic charge occurs as the levitating gas flows through the glass CHS (which is surface metallized as it becomes coated). This effect is noticeable when there is no plasma present and it is not clear what happens when the CHS is immersed in the sputtering discharge. The dipole polarization force is produced by the nonuniform field that occurs around all conducting surfaces in contact with the sputtering plasma.

The CHS is water cooled to reduce radiant heating of the microsphere from the plasma. This cooling feature is also a control variable in order to grow a sputtered film of zone T classification in the Structure Zone Model of Thornton.⁷

There is no centering ring used on this MBL as at sputtering pressures of 0.3-1.6 Pa the HGM will levitate at the location it is placed when loaded on the CHS. The higher pressures (> 3 Pa) used in plasma polymerization seem to have a noticeable damping effect on a levitated sphere.

Initial attempts at coating with RF sputtering were unsuccessful due to excessive instability of the levitated microsphere when the plasma was ignited. However, DC sputtering successfully produced the first target quality

coatings of copper on microspheres. The microspheres are currently levitated 50-150 μm off the CHS surface and coated at a distance of 4.5 cm from the throat of the Sloan S-310 sputtergun, which is operating at a DC power level of 200 W. The initial lift-off of the microsphere from the CHS surface is extremely delicate. The lift-off is greatly facilitated by a metalization layer on the sphere and on the CHS to minimize triboelectric charging from the argon gas flow. The microsphere metalization can be supplied by either a batch strike with a hard metal or by a metal flash with the sphere stationary on the CHS. The levitation is accomplished with an argon gas flow of 0.2-0.3 sccm through a CHS with capillary openings of 25 μm . Total sputtering pressure is between 0.3-1.5 Pa with the target coatings being achieved at a pressure of 0.85 Pa. The microsphere must be levitated in the absence of plasma; a shutter must be over the CHS or the sputter gun off. Polarization forces prevent the initial separation of the microsphere from the CHS when a plasma is present. A slight mechanical shock from the piezo-electric crystal is needed for initial lift-off and as the shutter is opened exposing the microsphere to the coating flux the levitating gas flow must be increased as the ball is forced down toward the CHS surface. Levitation height is adjusted to 75-100 micrometers by microscope observation. Microsphere stability should be noted while the height is adjusted, any

dynamic instability where lateral oscillation is greater than 10-20 micrometers will indicate a defective sphere. These instabilities can occur from surface contamination, or from non-concentric spheres which produce nonuniform coatings.⁸

The microspheres while coating are very susceptible to any fluctuations in plasma density. This was noted on occasion when sputtergun arcing would extinguish the plasma and eject the HGM from the levitator. Gun current changes, even minor transients, while not causing ejection will tend to disrupt the microsphere motion. As the coating run progresses the levitation gas flow must be increased to compensate for the increasing mass of the sphere. The flow rates and increases are proportional to S-gun power levels which were empirically derived and allow levitator flow to be automatically incremented by a clock controlled feed back servo loop.⁹

III. RESULTS

Figure 2 shows SEM micrographs representing the surface finish and a cross section revealing microstructure of sample HGM coatings. These coatings illustrate that on a clean, particulate free HGM a peak-to-peak finish of 10 nm is possible. The coating on the target sphere (Fig. 2b) replicates the ripple finish of the substrate glass. These

coatings were produced with a sputter rate of $1.1 \mu\text{m/hr}$ at a power level of 220 watts. The cross section SEM picture Fig. 2c reveals a typical dense columnar microstructure showing *fine grain growth*.

Figure 3 is a 430X microradiograph of a dual coating on a sphere. This sphere has undergone interferometric selection for concentricity and surface contamination. A $2.3 \mu\text{m}$ layer of copper was sputtered using MBL and $15 \mu\text{m}$ of CF was coated as a final layer. A densitometer trace of the radiograph has shown both coatings to be uniform.

IV. SUMMARY

One of the advantages realized with the MBL procedure has been the ability to coat copper on spheres with a surface finish not yet obtainable through other techniques. The MBL procedure inherently produces a uniform coating by its dynamic balancing process. Soft metals can be coated without contact and without transfer of debris. Problems to be resolved include electrostatic effects that limit control of levitation, cooling of the microsphere to preclude excessive grain growth, and low rate long duration coating run time.

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FIGURE CAPTIONS

- FIG. 1. Levitator design for microsphere coating.
- FIG. 2. SEM photographs of sputtered copper on hollow glass microspheres showing surface finish and structure.
- FIG. 3. Actual microradiograph of dual coated sphere and schematic illustration.

Fig. 1

SPUTTERED COPPER ON GAS LEVITATED MICROSPHERE

A.

2 μm

- 1.5 μm thick coating
- 140 μm X 5 μm sphere
- 10 nm surface

B.

2 μm

- 1.3 μm thick coating
- Surface finish replicates glass sphere finish

C.

1 μm

- 1.5 μm thick coating
- Cross section
- Columnar structure

Fig. 2

MICRORADIOGRAPH OF TWO COATINGS ON GLASS MICROSPHERE

Outer coating: 15 μm thick CF_{1.3}

Inner coating: 2.3 μm thick Copper

Fig. 3