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PARTICULATE MATERIALS

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LEVITATION, COATING, AND TRANSPORT OF PARTICULATE MATERIALS*

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ABSTRACT

Several processes in various fields require uniformly thick coatings and layers on small particles. The particles may be used as carriers of catalytic materials (platinum or other coatings), as laser fusion targets (various polymer or metallic coatings), or for biological or other tracer or interactive processes. We have devised both molecular beam and electro-dynamic techniques for levitation of the particles during coating and electrodynamic methods of controlling and transporting the particles between coating steps and to final use locations. Both molecular beam and electrodynamic techniques are described and several advantages and limitations of each will be discussed. A short movie of an operating electrodynamic levitation and transport apparatus will be shown.

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Many scientific, industrial and consumer oriented uses for particulate materials benefit from the application of uniform coatings and layers of various types and compositions. Powders are given protective coatings against moisture incursion, candies and decorative particles are provided with various layers for color and taste properties. Medications are multiple layer for time release characteristics. Particles used for catalysis must be coated with the finely divided catalyst. The cascade developer process used in many xerographic reproduction systems utilizes carrier beads which are coated to provide charging and carrier functions for the toner material. Some inertial confinement fusion targets require coatings and layers of various materials. These are only a few examples of a very large number of processes, applications and uses in which uniform coatings and layers are either desirable or necessary.

For several years in our work on laser fusion targets we have been developing techniques for coating spheres used for ICF targets. The spheres have been metal, glass and polymer materials. In order to have a perspective on the problems faced in our coating development, consider the quality parameters of the spheres and the coatings to be deposited. The finished product must have a very smooth surface -- peak to valley roughness of a few hundred Angstroms with not more than half a dozen peaks of a thousand Angstroms altitude. Because a coating generally will, at best, replicate the substrate surface, the spheres which are to be coated must meet the same quality criteria as the coatings. If we examine the

reasoning behind the surface smoothness criteria, we find that the real concern is that

$$\int_0^{\text{outer surface}} \rho dr = \text{constant for all } \theta, \phi \quad (1)$$

to ensure symmetry of the implosions. It is obvious that the condition stated in Equation (1) is impossible to fulfill and the real question becomes -- how bad can the surface be and still be good enough? Based on experience and calculations in which all the appropriate physics is used, we come up with a set of quality criteria for permissible irregularities in terms of altitude and lateral dimensions. For an irregularity (bump) on the surface which is about as wide as the shell is thick, the altitude should be less than 1% of the shell thickness. For a 1.0 micrometer thick shell, the worst case bump should be less than 100 Angstroms high.

Any variations in density of the shell material or voids within the shell thickness translate into variations in the integral in Equation (1) and must be very small -- equivalent to a variation of less than 1% of the shell thickness.

This short consideration of the surface and material quality criteria provides a background for a discussion of some of our experimental techniques and results. Many of the techniques we have developed are applicable to solutions of problems in related areas.

The materials of concern in the field of particulate coating have a wide range of physical and chemical properties. Methacrylates are commonly used as coatings on xerographic carrier heads. Silver is coated on small sugar spheres for producing decorative particles for cakes and pastries. Various other coatings of fluorocarbons, hydrocarbons, glasses, metals and alloys and other inorganic materials are of interest in many fields including laser fusion target fabrication. In many applications, but particularly in production of laser fusion targets, the coatings should be as uniform as is physically possible.

Techniques for the deposition of materials in relatively uniform, smooth layers on planar substrates have been developed for many years. However, the application of high quality coatings to surfaces with very small radii of curvature presents new problems. Let us consider, for example, coating a 150 μm diameter hollow glass sphere with a layer of platinum a few micrometers thick. Application of the platinum by sputtering, CVD, or evaporation with the sphere stationary would lead to unacceptable variations in the thickness of the layer. Rolling or bouncing of the sphere on a plate or in a shallow dish provides enough motion to avoid coating entirely on one side of the sphere but increases the probability of picking up contamination (dust, shards, etc.) on the surface. Particulate contamination on the sphere will give rise to defects which grow more severe as the coating thickness grows. A solution to many of our problems appears to be levitation of the sphere during the desposition of the layers.

Several levitation techniques have been suggested and some have been studied in detail. Those which have been tried experimentally include optical beam levitation, gas jet or molecular beam levitation, electrostatic support with feedback control, and electrodynamic levitation. Our primary efforts have been directed toward electrodynamic (quadrupole) and molecular beam levitation.

An experiment which is often done in elementary physics classes is that of supporting a ping-pong ball in the stream of air from a vacuum cleaner outlet hose. The experiment is easily done and usually very successful. This suggests that we may be able to support very small glass spheres in a gas stream while they are being coated. In principle, this is a correct assumption. However, the actual method used is only conceptually related (very slightly) to the ping-pong ball experiment.

Figure 1 is a schematic diagram of a molecular beam levitator (MBL). Gas at a very low pressure is allowed to expand vertically into a vacuum through a collimated hole structure as shown in the figure. If no other modification is made, the streaming molecules can transfer sufficient momentum to a ball sitting on or above the hole structure to lift the ball. However, the ball will be unstable in the flow and will tend to slide off the column of molecules. Pressures are low enough that aerodynamic effects such as those keeping the ping-pong ball in the air-stream do not occur. To provide a stabilizing influence, part of the hole structure is covered with a chamfered ring which directs an outer

ring of molecules toward the center of the flow region and provides a "well" in which the ball sits. Pressures in the downstream region (the support area) are low enough that ion or molecular beam coating processes or sputtering processes can be used to apply material to the sphere. Spheres with masses from less than 100 nanograms to over three grams have been levitated by this technique in an environment in which sputter coating can be accomplished.

Figure 2 is a photograph of a 100 micrometer radius sphere which is levitated above a collimated hole structure ready for coating. The levitated spheres rotate during the coating process and very uniform layer thicknesses and smooth surfaces can be achieved. Spheres as massive as a 3/8" diameter steel ball bearing have been levitated and coated in a MBL system.

A long term disadvantage of the present MBL coating systems may be the lack of automation possibilities. We have not yet worked out the details of levitation-coating-transport for high rate production of ICF targets. In future ICF systems several targets per second may be required for each reactor. Target costs of not more than a few cents each may also be necessary.

Looking forward to low cost, automated production has led us to consider electrostatic and electrodynamic systems for levitation and transport of targets.

The control of charged particles (ions and electrons, for example) by quadrupolar fields has been known and well studied for many years. Quadrupole levitation and control of macroscopic particles has also been used for several years. We have added some features which make it possible to levitate, control and transport macroscopic particles.

Figure 3 is a schematic diagram of a quadrupole structure driven by an AC voltage source. The equation of motion of a charged particle in the dynamic field of the quadrupole indicate a dynamically stable position along the z-axis of the quadrupole or, at least, a non-growing motion about the z-axis. If the system pressure is less than about 10^{-4} Torr the particle motion is undamped and motion about the z-axis continues indefinitely with an amplitude which depends on the initial conditions of the motion. However, if the pressure is greater than about 10^{-4} Torr, the motion is damped and the amplitude of the particle motion about the z-axis decreases with time. A particle injected into the quadrupole in the z direction but off-axis or with non-zero components of velocity in the x and y directions will move toward the z-axis and continue its motion only in the z direction.

Control of the motion of particles in the z direction, along the axis of the quadrupole can be accomplished by providing a traveling wave or moving potential well in which the particles are held. Figure 4 shows the configuration used to accomplish both the levitation and transport in the quadrupole structure. The rails of the quadrupole are segmented

longitudinally with every third segment of each rail connected to the same terminal of a low frequency (variable frequency) three phase AC supply. The four rails are also driven as is normally the case by single phase AC. Figure 5 is a photograph of a 80 μ m long segmented quadrupole system with a particle injector at the input end.

By varying the frequency of the three phase voltage, the velocity of a traveling wave along the rails can be varied. If any two of the three phases are interchanged, the direction of the wave can be reversed. With a single phase voltage of 3600 volts_{rms} and a frequency of 60 Hz on the rails as a levitating signal and a three phase voltage of 2200 volts_{rms}, hollow 600 micrometer nickel spheres, glass spheres and various other materials have been levitated and moved under control through the quadrupole. The dynamic potential well in which the particles are contained is sufficiently deep that moderate mechanical shocks (a few g's) do not dislodge the particles. The quadrupole structure can be rotated so its axis is vertical and particles in the system remain trapped and can be moved vertically up and down the system.

Typical dimensions and electrical parameters of the quadrupole system are:

rail diameter - 6 mm

segment length - 1.5 cm

segment spacing (insulating wafer) - 1.0 mm

rail spacing (rail-to-rail on a square array) - 2.5 cm

rail length - 80 cm

rail-to-rail voltage - 3600 volts_{rms}, 60 Hz

segment-to-segment voltage - 2200 volts_{rms}

Figure 6 is a photograph of a circular (racetrack) rail apparatus which has been used to levitate and transport particles. Electric field traps and transport potential wells are also used in this arrangement to move and control particles.

Ion and molecular beam coating can be done on particles which are held in these quadrupole levitators. We have operated the levitators in atmosphere and in vacuum. Particles have been levitated and coated and their charge controlled by means of electron and ion beams.

In environments of 1 g or less, the quadrupole levitators and transporters offer excellent means of manipulating particles and holding them "untouched" during coating or other processes. The molecular beam levitator as it is presently structured provides another satisfactory means of levitating particles in a normal gravity environment for ultra-smooth surface coating.

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MOLECULAR BEAM LEVITATION

A laterally stabilizing force can be created to keep the levitated microsphere centered during the plasma coating process.

10-05-1079-4476

Fig. 1

Fig. 2

ELECTROSTATIC TARGET TRANSPORT SYSTEM

10-01-0978-3370

Fig. 3

ELECTRODE STRUCTURE FOR TRANSPORT LEVITATOR

10-05-0380-1130

Fig. 4

PROTOTYPE RING LEVITATOR SYSTEM

Fig. 5