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ELECTROSTATIC LEVITATION, CONTROL AND TRANSPORT IN HIGH RATE, LOW COST PRODUCTION OF INERTIAL CONFINEMENT FUSION TARGETS*

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Summary

Inertial confinement fusion requires production of power plant grade targets at high rates and process yield. A review of present project specifications and techniques to produce targets is discussed in this paper with special emphasis on automating the processes and combining them with an electrostatic transport and suspension system through the power plant target factory.

Inertial confinement fusion is a process by which low atomic number isotopes (e.g. deuterium and tritium) are compressed, heated and induced to fuse into higher atomic number products, releasing energy and energetic particles. The process may be accomplished by confining a hot plasma for a long time by means of a magnetic field (tokamaks, stellrators, etc.) or by accelerating a mass of material radially inwardly in a spherical geometry allowing inertial forces to confine the heated material until it fuses. In magnetic confinement systems, the holding time is 0.1 to 1 second and the number density of

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the plasma is 10^{14} to 10^{15} per cc. Inertial confinement systems compress matter to number densities of 10^{26} per cc and hold it for 10^{-9} second. The temperatures in both systems must be 10^{8} K or greater for thermonuclear ignition to occur.

One of the major problems of inertial confinement fusion (ICF) is the fabrication of targets. The targets (often referred to as pellets) are generally multilayer spherical shells containing a fuel which is usually a mixture of deuterium and tritium (DT). The fuel may be a gas, liquid or solid, depending on the particular target and the experiment to be done.

Currently we begin the fabrication of some targets by making a very high quality hollow glass sphere.[1] Diameters are from 70 to about 1000 micrometers, wall thicknesses are from 0.5 to more than 20 micrometers, and glass compositions include borosilicate, lead, tungsten-phosphorous, soda-lime and other compositions. The wall thickness must not vary more than 1% (of thickness) over the entire sphere, the shell must be spherical to better than 1% (of radius), and the peak-to-valley roughness of the surface should not be more than 100-200 Å (with a few--four or five--peaks to 1000 Å permitted on the entire sphere). In some of our current sphere production systems, we achieve runs in which 90% of the spheres meet the very stringent requirements for target quality shells. Figure 1 shows the quality of the glass shells as seen from a scanning electron microscope (SEM) image. The comparison is with a commercially available glass shell commonly used as plastic filler, etc.

Each sphere used as a target must be carefully studied and its entire surface and wall characterized to ensure that the sphere meets the quality requirements.[2] The characterization process includes studies by radiography, interference microscopy, and optical microscopy. Figure 2 shows typical interference microscope photographs of transparent spheres. A radiograph of an opaque target is shown in Fig. 3. The resolution obtainable in the radiography studies is not as good as can be obtained from interference microscopy.[3] However, opaque targets force the use of radiography at the present time.

Some targets may have an innermost sphere of high atomic number, high density material such as gold or uranium. The subsequent layers and coatings are required to achieve quality specifications at least as stringent as those on the inner sphere; that is, surface finish of 100-200 Å peak-to-valley and thickness variations less than 1%. To obtain coatings of such high quality with high yields (yield will be defined here as the number of spheres coated satisfactorily divided by the number put into the coater), we must utilize systems in which the spheres do not touch each other or any surfaces during the coating process.

An example of a coating presently being deposited on glass shells is a $CF_{1.3}$ (polymerized fluorocarbon) material which is glassy in nature and somewhat brown due to open carbon bonds.

This material is produced by passing the monomer through an RF discharge.[4] As shown in Fig. 4, the discharge is produced in a helical resonator structure which couples inductively and without electrodes to the plasma contained in the quartz reactor vessel. The shells are presented to the coating plasma on a vibrating stainless steel dish which is pulse biased to extract high energy ions ($E \sim 400$ V).

These ions aid in periodically changing the charge on the shells, allowing their free motion and aiding in the polymerization process. Similar coatings have been produced on flat substrates with organic beams containing only ions.

The plasma coating process presently being used is basically a batch process and gives a yield of about 10^{-3}. Because of the time necessary to characterize every input sphere, such a yield is only acceptable in a research mode. To improve the yield and permit better control of parameters in the coating process, we have elected to develop various single sphere handling and levitation techniques. Using these techniques, individual spheres which have been through the full 4π characterization process (complete study of the entire 4π solid angle of the sphere) will be individually put in the coating system, coated, and recovered individually. Several of our levitation systems utilize electrodynamic fields produced by an ac driven quadrupole to suspend charged spheres. The control and transport of the levitated spheres during the coating process is also controlled electrically.

A three-dimensional quadrupole of revolution to be used in a coating system utilizing atomic, molecular or ion beams is shown in Fig. 5. In this configuration, a charged sphere is injected into the quadrupole where the sphere is trapped and held for coating. A combination of ion and electron beams allows the coatings to be applied while the charge on the sphere is maintained sufficiently high to keep the sphere levitated.

If we make the presumption that ICF becomes a viable means of producing energy, "factories" for high rate, low cost production of targets must be developed. ICF reactors will fire at rates of one to ten per second, and to be economically feasible costs per target must be kept under about $1.00 per target. To produce multilayered targets at such low costs, automated systems must be developed. We have developed a circular quadrupole levitator, control and transport system which can be a major component of an automated target production system.

Linear rail quadrupole levitator with minor modifications can be used to transport shells through the processing steps of a target factory. Segmenting the rail electrodes and superimposing a three phase transport field the shells can be sequentially positioned, accelerated, decelerated and maintained at a given velocity in a variety of environmental conditions.

While the linear rail quadrupole systems are interesting and useful, a slightly modified geometry may prove to be more worthwhile as a "factory component." We have experimented with a circular rail quadrupole with which targets can be levitated, coated, transported and injected into a fusion reactor. Figure 6 is a photograph of an operating quadrupole in the circular configuration. An associated particle charging injector makes it possible to inject and trap relatively large spheres in the levitator. We have suspended 600-micrometer nickel spheres in the circular structure in preparation for coating them.

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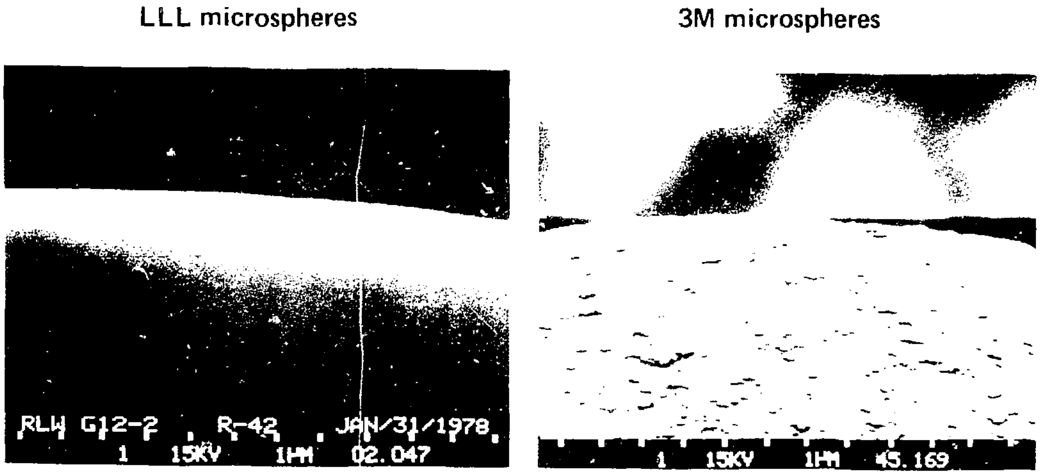


Surface finish, 100–200 Å

Surface finish, 0.5–2μ

FIGURE 1. SEM micrograph surface comparison of the improved LLL shells with the best commercially available 3M shells.

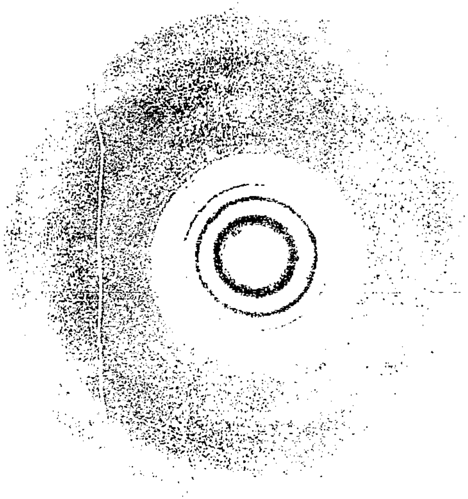
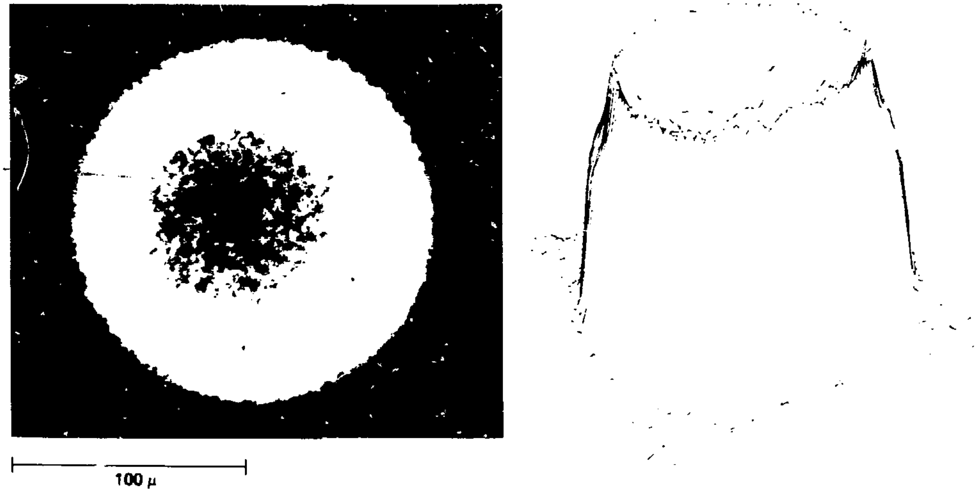


FIGURE 2. Interference photograph of a microsphere in the interferometric inspection system.



Mean x-ray energy: 5 keV

FIGURE 3. Microradiograph of a glass microsphere and its computer representation.

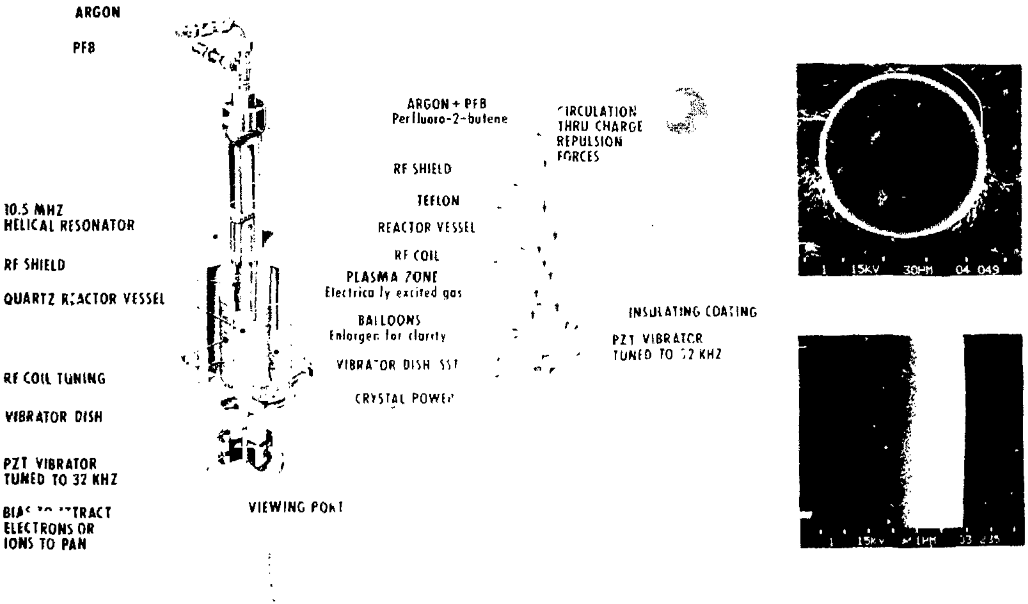


FIGURE 4. The helical resonator plasma coater, an advanced coating system, which provides a reproducible controllable discharge with which to activate the monomer.

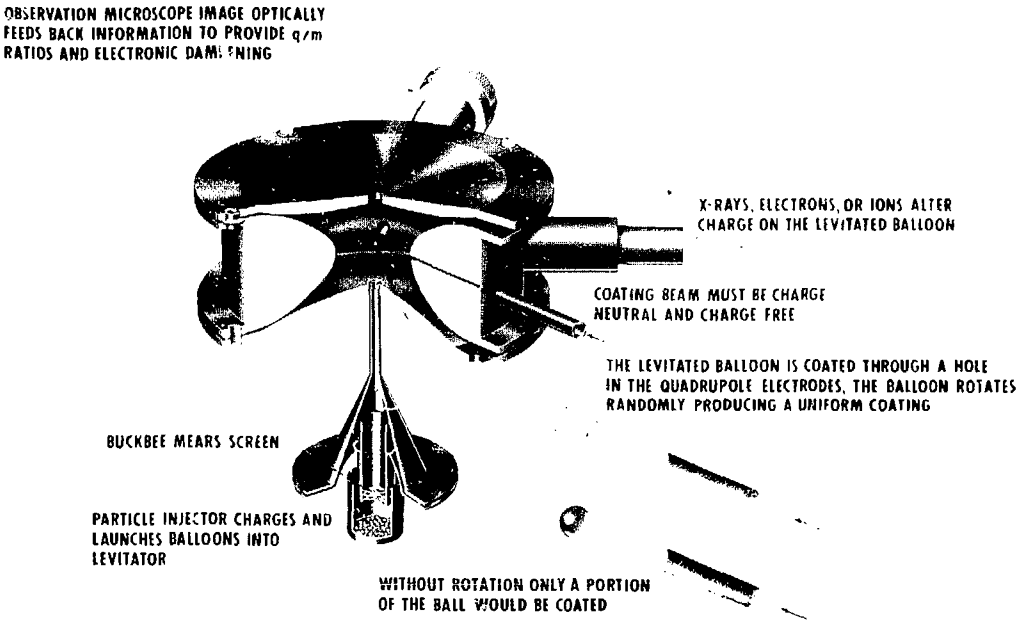


FIGURE 5. This three dimension quadrupole allows operations on single shells to be performed while maintaining their position in space and providing stable noncontact support.

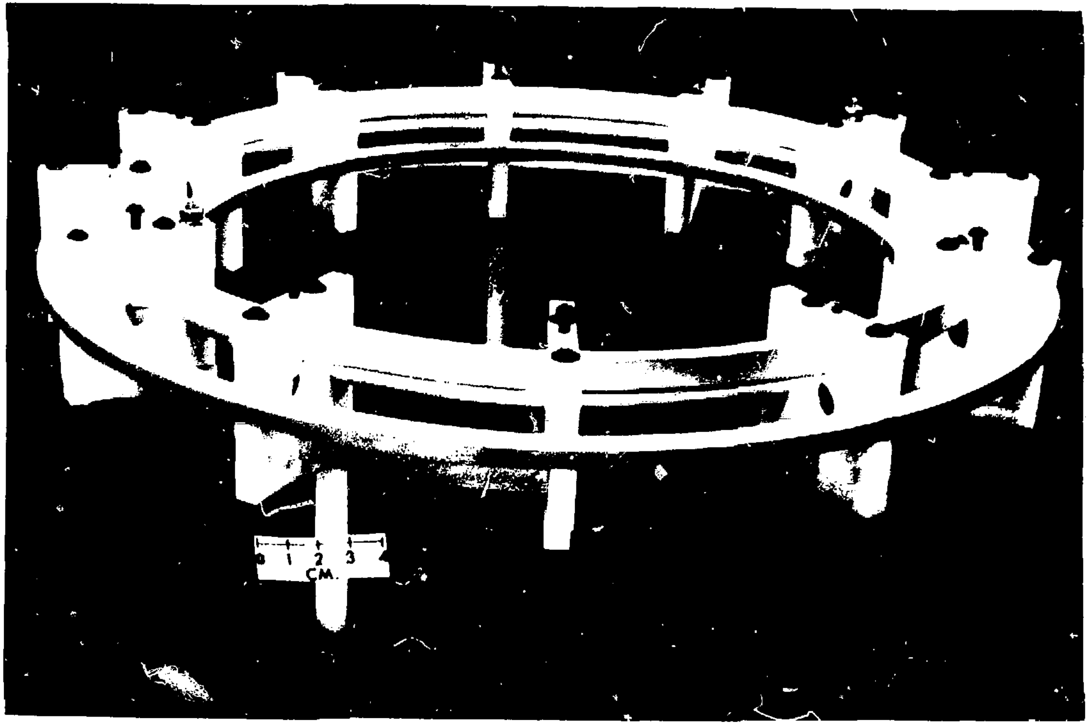


FIGURE 6. Experimental circular quadrupole rail levitator that has demonstrated multiple target support.