INVESTIGATION ON CRYOGENIC LASER FUSION TARGETS - FABRICATION,
CHARACTERIZATION, AND TRANSPORT

MASTER

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by

Kyekyoon Kim

Department of Electrical Engineering
University of Illinois
Urbana, Illinois 61801

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PROSPECTUS

The research progress made under the LLL Subcontract 8320003 is briefly summarized for the period of December 1, 1978 through November 30, 1979. The research has been directed toward fabrication, characterization, and positioning of cryogenic shell laser fusion targets, with particular emphasis on the development of a scheme which would allow for continuous fabrication, inspection, and delivery of the targets. Specifically, progress has been made in the following areas:

1. Fabrication of a uniform spherical shell of DT-condensate using a cold-wall target-freezing-cell.
2. Fabrication of a uniform spherical shell of liquid DT using a room-temperature wall target-freezing-cell.
3. *Support-free cryogenic target fabrication using cold-gas-levitation.*
4. Continuous fabrication of cryogenic targets using free-fall method.
5. Automatic characterization of DT-layer uniformity.
6. Sorting of DT-filled glass microshells using an interference microscope.
7. Development of an a-c interference microscope for accurate characterization of moving targets.
8. Development of a machine which is capable of producing a continuous stream of uniform DT spheres of controllable sizes.
9. Theoretical study on the behavior of liquid hydrogen contained in a spherical shell.

In what follows we present a brief description of the progress in each category.

1. Techniques of Producing a Uniform Layer of DT-Condensate Inside a Glass Microshell

More studies have been made on the techniques of fabricating a uniform spherical shell of DT-condensate using a target fabrication system whose target freezing cell has walls thermally in contact with a liquid helium heat exchanger. A feature unique with this system is that a continuous circulation of fresh cold helium gas is provided for the target freezing cell by a combination of two cold helium gas jets directly wetting a DT-filled glass microshell in the cell and a mechanical pump continuously evacuating the cold gas in the cell. Another unique feature is that there is installed in the freezing cell a heating coil which surrounds the target and which provides the heating pulse to quickly evaporate and refreeze the DT-condensate inside the target once it has been formed. A schematic of this system is shown in Figure 1.

Employing this system, a series of target freezing experiments had earlier been performed using a D_2 -filled glass microsphere mounted on a glass stalk, and resulted in fabrication of a uniform layer of solid D_2 inside the microsphere (See University of California Report UCRL-13904, September 15, 1978). It is, however, important to note that the particular D_2 -filled target used in these experiments was a thin ($\sim 1 \mu m$) glass sphere filled with a low pressure D_2 (~ 50 atm). Consequently, evaporation and refreezing of the once-formed D_2 -condensate could be done rapidly, resulting in a uniform layer of solid D_2 . When a thicker glass sphere is used (of thickness $\geq$ several micrometers), and particularly when the D_2 fill-pressure is high (≥ 100 atmospheres), neither the thermal conduction through the glass shell nor the liquefaction of the D_2 inside the sphere could be done as rapidly as in the case of a thin-walled glass sphere filled with a low pressure D_2 .

Figure 1. Schematic of a target fabrication system whose target freezing cell walls are at cryogenic temperature.

The experiments performed during the current period and to be described in the following were intended to answer two specific questions: first, "Is it at all possible to fabricate a uniform layer of DT-condensate inside a thick glass microsphere filled with high pressure DT gas?"; and second, "If so, is the method compatible and directly adaptable with the existing (and the future) laser-firing target chamber designs?"

A D_2 -filled glass microsphere was again employed for the experiments designed to answer these questions. The glass shell diameter and the D_2 fill-pressure of the target were respectively 200 μm and 200 atm. The freezing cell pressure, which is controlled by the flowrate of the cold helium gas jets, was slowly increased, resulting in a gradual decrease in the temperature of the target. At the cell pressure of 15 mTorr a thin, but uniform, liquid layer of D_2 was first seen to appear. As the cell pressure was further lowered (so was the target temperature) the thickness of the liquid D_2 layer grew, but its uniformity remained intact as far as the visual observation through the Mach-Zehnder interference microscope. This trend continued until the freezing cell pressure reached 1.5 Torr, above which the D_2 -liquid could no longer exist in the form of a uniform layer, but resulted in a droplet formed at the bottom of the target. Pictures representing a typical set of data are shown in Figure 2. Figure 2(a) is a shadow micrograph of the targets used in the experiment which was taken at room temperature. The largest target shown at the top is 200 μm in diameter. The target on the bottom left is empty of D_2 gas. Concentrating on the 200 μm diameter target, one notices that the glass shell is not uniform. Because of this, the reference beam in the Mach-Zehnder interference microscope was adjusted to be at an angle with the object beam to obtain the circular fringe patterns shown in Figure 2(b). The pictures in Figures 2(c) and 2(d) were taken at a cryogenic temperature with the same reference beam adjustment. The flowrate of the cold

2(a)

2(b)

2(c)

2(d)

Figure 2. Pictures of targets mounted on a glass stalk. Fig. 2(a), Shadow micrograph of D_2 -filled targets at room temperature. (The target on the bottom left is empty of D_2 gas.); Fig 2(b), Interference micrograph of the targets in Fig. 2(a).² (Magnification slightly reduced.); Fig 2(c), Shadow micrograph of the same targets at a cryogenic temperature; Fig. 2(d), Interference micrograph of the targets in Fig. 2(c). (Magnification same as Fig. 2(b).)

helium gas jets, as measured at the room temperature end of the helium gas transfer line, was 50 ml/min when the freezing cell pressure was 15 mTorr. In any case, it is important to note that the temperature at the target surface was uniform by design in these experiments.

A dramatic change in the uniformity of the liquid D_2 layer was observed at a particular temperature (to be referred to as the transition temperature), which was consistently repeatable. Namely, as the temperature was lowered to the transition temperature, the D_2 liquid inside the glass microsphere, which had existed as a uniform layer at high temperatures, suddenly moved downward and got collected at the bottom in the form of a droplet. In order to understand the reason for this abrupt change in the behavior of liquid D_2 , one is reminded of the fact that the surface tension force of hydrogen and its isotopes (i.e., H_2 , D_2 , and T_2) vanishes at the critical temperature pertaining to each species. Within this reasoning, it is then not surprising that one should continuously observe the manifestation of the vanishingly small surface tension of liquid D_2 at temperatures not far below the critical point, 38.3 K. The effect of surface tension should then come into being at temperatures far below 38.3 K, resulting in formation of a droplet. In this context, the uniformity of the liquid D_2 layer seen not far below the critical point should depend largely on the extent that the wetting of glass surface by liquid D_2 overpowers the gravitational force effect. Within the limit of the experimental error, it appears that the effect of gravitational force is almost entirely negligible. At and below the transition temperature, however, the combined effect of surface tension and gravitation overpowers the effect of wetting. Unfortunately, because of the difficulties encountered in monitoring the true temperature of the D_2 -filled target using a thermocouple, the transition temperature could not be measured accurately although we believe that it should be a function of the D_2 -fill pressure. In our future work we

will be addressing our attention to clarification of this unresolved problem.

To summarize, a significant implication of the data reported in this section is that one can successfully fabricate a uniform layer of liquid DT inside a DT-filled glass microsphere by simply maintaining the target surface at a uniform temperature below the critical point. This method should prove to be extremely useful when a thick-walled ($\geq$ several μm) glass microsphere filled at high DT pressure (≥ 100 atm) is required as a laser implosion target.

Another significance of the current data is that because of the low pressure of the target freezing cell required for formation of a uniform liquid layer (for example, 15 mTorr which was maintained with a mechanical pump), it opens up the possibility of operating the freezing cell with its walls maintained at room temperature. This possibility is particularly an exciting one because it could lead to a target freezing mechanism which is directly adaptable with the existing room-temperature laser-firing target chamber. Described in the next section is a detailed investigation on the development of this possibility.

2. A Target Freezing Cell With its Walls Maintained at Room Temperature

The research progress reported in this section is concerned with the development of a target fabrication system which can not only operate inside the target chamber, but also retain the integrity of a cryogenic target for as long as required.

A cryogenic target fabrication system has been constructed for a feasibility study. A schematic of the system is shown in Figure 3. Some of the distinct features characteristic of this system are:

- (1) Freezing cell walls are at room temperature.
- (2) Micrometer controls are attached to the target mounting unit such that the target position is variable during the experiment.
- (3) A single jet of cold helium gas is employed for target cooling, which hits the target from one side. This particular feature has been intentionally incorporated in the design to make it more easily adaptable with the target chamber. As a consequence of this single jet configuration, temperature gradient (∇T) exists around the target.
- (4) Injection of the cold helium gas jet into the freezing cell can be pulsed with variable duration. This has been achieved by installing two electronically operated solenoid valves in conjunction with the helium transfer line: one valve directly on the transfer line which is connected to the pressurized helium gas reservoir, and the other on a by-pass from the transfer line which is connected to a vacuum pump. In the usual sequence of operation, the valve on the transfer line (V1), by design, is open whenever the valve on the by-pass (V2) is closed, and vice versa. One then begins

Figure 3. Schematic of a target freezing cell which has room temperature walls.

with V1 closed (namely, V2 open), but 'open and close' V1 with a desired time delay. In this way, an accurately controlled injection of gas jet pulse is achieved with a variable duration.

Using this system, a sequence of target freezing experiments was performed on a glass microsphere, 200 μm in diameter and filled with D_2 gas at 200 atm. Figures 4 and 5 contain pictures illustrating these experiments. Figure 4 shows a picture of the target mounted on a glass stalk and positioned in front of the helium gas jet nozzle unit. Shown below the target is a thermocouple-head installed to sensor the temperatures around the target. Figure 5 contains a series of pictures illustrating the effects of temperature distribution (∇T) around the target. Figures 5.1 and 5.1a are respectively the shadow and interference micrographs of the target at room temperature. As the temperature of the target was lowered below the liquefaction point using the cold helium gas jet, a liquid D_2 droplet was formed inside the target. However, because of the smallness (100 μm D at the nozzle exit) as well as the particular configuration of the jet nozzle, ∇T was created around the target resulting in formation of a liquid droplet at the coldest spot of the target. This ∇T -effect is most vividly illustrated by Figs. 5.2, 5.3, and 5.4, in each of which the target position relative to the nozzle is shown to be different. Figures 5.2, 5.3, and 5.4 are shadow micrographs of the target, and Fig. 5.2a is the interference micrograph of Fig. 5.2. By moving the target to an appropriate position away from the nozzle, not only was the target temperature raised above the transition point but also the temperature distribution around the target became uniform. This (as we have already observed in conjunction with the cold-wall freezing cell technique described in Section 1) resulted in a uniform layer of liquid D_2

Figure 4. Shadow micrograph of a D_2 -filled glass microsphere of 200 μm diameter. Shown to the left of and ²below the target are, respectively, the helium gas jet nozzle and a thermocouple-head.

Figure 5. Pictures of a glass microshell containing liquid D_2 —a sequence of target freezing experiments performed by using the apparatus illustrated by Figure 4; Fig. 5.1. At room temperature (shown on the left is the He gas nozzle); Fig. 5.1a. Interference fringes of Fig. 5.1 indicating the uniformity and the thickness of the glass microshell; Fig. 5.2 through 5.4. At a cryogenic temperature: the target position relative to the nozzle is different in each of these pictures, creating differing VT around the target; Fig. 5.2a. Interference fringes of Fig. 5.2; Fig. 5.4. The target containing a uniform layer of liquid D_2 ; Fig. 5.4a. Interference fringes of Fig. 5.4 indicating the uniformity and the thickness of the liquid D_2 layer.

as shown by Figures 5.5 and 5.5a. In the experiments shown by Figs. 5.2 through 5.5 the pressure inside the freezing cell was measured to be 50 mTorr.

To summarize, a uniform layer of liquid D_2 of variable thicknesses has been successfully fabricated inside a glass microsphere by using a target freezing cell whose walls are exposed to room temperature. Three of the most significant implications of this investigation are:

- (1) The current target freezing technique is directly adaptable inside the existing room temperature target chamber with absolutely no need for adding cryogenic shields.
- (2) Since the uniform liquid D_2 layer inside a target can be retained for as long as desired simply by maintaining the cold helium gas jet, the usual most troublesome constraint concerning the prolonged retention of the integrity of a cryogenic target for laser illumination no longer exists.
- (3) Since the pressure of the target freezing cell as measured during the experiment is in the range of 50 mTorr, the current target fabrication technique appears to be compatible as it is with the target chamber conceived for future laser fusion power plant. Noting that the above pressure was effected by a modest size mechanical pump, it looks very promising that with a more adequate means of vacuum-pumping one can further lower the pressure in the freezing cell to make it more compatible with the existing target chamber. If necessary, one can always shut off the cold helium gas flow before the laser shot by activating the two electronic valves described in the foregoing. In this way one can achieve very low pressure inside the target chamber if it is demanded for more accurate diagnostic measurements of laser target implosion.

3. A System for Fabrication of Cryogenic Targets Using Cold-Gas-Levitation

With the experience gained from the experiments described in Sections 1 and 2 of this report, a target fabrication system, which uses cold helium gas jets to levitate as well as freeze a DT-filled glass microshell, has been re-designed and constructed (see the progress report covering September 1, 1978 through November 30, 1979 for an earlier design of such a system). Figure 6 contains a schematic of this system. Some of the distinct features which characterize this system design are:

- (1) The system can operate with its walls maintained at room temperature.
- (2) The chore of mounting a target on a glass stalk is no longer required with the system.
- (3) The temperature and pressure sensors are movable such that determination of the temperature- and pressure-distributions is possible near the target being levitated.
- (4) Both the target reservoir and the target loading unit are enclosed in the freezing cell such that target re-loading can be conveniently carried out during the experiment without opening the system.
- (5) Provision is made for the partial removal of static electricity from the target by using a commercially available radioactivity source.

Using this system a preliminary test has been performed both at atmospheric pressure and in a vacuum. Two of the major difficulties encountered during this test are: first, that the levitation of a target in a vacuum using a levitation-dimple of plain cylindrical geometry could not raise the

Figure 6. Schematic of a target fabrication system which freezes targets through cold-gas-levitation.

target to a high enough altitude to be observed with an interference microscope; second, that the residual static electricity on the target (even with the radioactive material present in the freezing cell) was at such a sufficiently high level that the target tended to stick to the levitation-dimple bottom and that it was difficult to break it loose.

As an attempt to remedy the first difficulty we are currently in the process of fabricating levitation-dimples of a variety of designs, some of which upon testing will hopefully give rise to a desired target-levitation configuration accessible with the interference microscope. To eliminate the second difficulty we are currently trying to shake the target levitation-head using a variety of piezo-electric transducers of different geometries and vibration characteristics. We expect to find an optimal means of freeing the target from the levitator in the near future.

4. A System for Continuous Fabrication of Cryogenic Targets Using Free-Fall Technique

A target fabrication system which will allow for continuous fabrication, inspection, and transport of cryogenic targets has been designed, and the construction is under way. A schematic of this system is given in Figure 7 (also see the previous progress report covering September 1, 1978 through November 30, 1978). Some of the principal components comprising the design of this system are:

- (1) The target-launching unit for convenient loading and launching of targets.
- (2) The cold helium gas column to freeze the targets in active free-fall.
- (3) The optoelectronic diagnostics for observation of the targets in motion and for characterization of the DT-layer uniformity.
- (4) The sensors to detect the temperature and pressure inside the target freezing cold gas column.

A simple prototype system has been built for room temperature operation, and a preliminary test has been made on the system. The main objective was to assess the feasibility of detecting targets in motion using optoelectronic means. A sample oscilloscope trace obtained during this test is shown in Figure 8. The horizontal and vertical scales of this trace are respectively 20 msec/div-cm and 5 V/div-cm. The pulse on the right corresponds to a target of 300 μ m diameter at the speed of .55 m/sec. The one on the left represents a 1.5 mmD target free-falling at the speed of .5 m/sec. The aperture of the photodetector was 3 mm in diameter. Judging from these data, it appears that our approach of employing optoelectronic means for the detection

Figure 7. Schematic of a target fabrication system designed for continuous production, inspection, and transport of cryogenic targets.

Figure 8. An oscilloscope trace indicating the passage of targets through an optoelectronic detector. The pulse on the right represents a $330\text{ }\mu\text{m}$ diameter target moving at the speed of $.55\text{ m/sec}$. The one on the left is for a target 1.5 mm in diameter, free-falling at the speed of $.5\text{ m/sec}$.

of targets in motion is making headway in the right direction. However, in an actual system designed to fabricate a uniform cryogenic target using free-fall method, one will need more detailed information of the target while it is moving through the target freezing cell than a simple detection of its passage. First of all, one needs to know the speed of the target to determine how long it is exposed to a certain thermodynamic environment, namely, the amount of cooling done on the target. One also needs to observe carefully the behavior of the DT-mixture inside the moving target to ensure that the fusion fuel material condenses into a required uniform layer.

The simple optoelectronic means employed for the prototype system described in this section (namely, a combination of LED and photodiode) obviously cannot produce the desired information sufficient enough to completely characterize the moving target. A solution to this problem could be an rf a-c interference microscope, which will be the subject of Section 7.

5. Microprocessor-Controlled Data Acquisition System as part of the Diagnostics for Characterizing DT-Layer Uniformity

The purpose of the microprocessor-controlled data system is to take a specified length of video information, either full page or single lines, and break it up into a predetermined number of samples. Each sample will be digitally encoded into an eight bit binary code, thus achieving a total signal resolution of $2^8=256$ levels. This series of coded samples will at first be entered into a fast temporary storage in the microprocessor bus system. At the end of the encoding process the microprocessor will then format the data and load them into the main computer (CDC Cyber 175) via a telephone link. Once this is accomplished, the user may program the main computer in a higher level language to do such things as graphic analysis, concentricity mean error calculations, fringe matching to theoretical calculations, density plots, etc.

The system being developed is based on the popular Intel 8080A microprocessor and its family of peripheral chips. The use of this microprocessor system offers great flexibility in the data acquisition task. The system is set up so that the user need only adjust his software programming to control such things as sample rate per line, which lines will be digitized, vertical or horizontal line scan and the number of bits used in quantizing the video signal. Also, through software programming the microprocessor system can format the data, do some simple data manipulation routines and control their transfer to the main computer.

All peripheral interfacing has been designed. The serial I/O port has been constructed and new software is being developed to allow the microsystem to "talk" to the main computer. Construction of the video digitizer section will begin soon. All 8K of Random Access Memory have been installed and are working properly.

A comprehensive overview of the microprocessor-controlled data acquisition system and its operation is contained in Figs. 9 and 10. The heart of this system is the Intel 8080A Central Processing Unit (CPU). The CPU unifies the system as it controls most functions performed by other system components, as well as data and address transfers on the two tri-state bus lines. Basically, it fetches instructions from memory, decodes their binary contents and executes them. In addition, it must be able to reference memory and input/output ports as necessary in the execution of instructions. The CPU also responds to several external signals such as interrupts and direct memory access (DMA) requests. In the latter case the CPU surrenders bus control activities to the DMA controller unit.

Working in conjunction with the CPU is the memory. Two types of memory are used in this system. One type, the Read-Only Memory (ROM) is used primarily for permanent program storage. Specifically, in our system "the ROM" consists of two 2708 chips that contain an SSM8080 Monitor routine that aids the user in system initialization and debugging. This program is maintained even when power is turned off. The other type of memory is volatile and will be erased when power is removed. It is called Random Access Memory (RAM), and unlike ROM, can have information written into it. It is used primarily for temporary program storage and, of course, data storage.

Interface to the outside world is handled through a Programmable Communication Interface (PCI). Once initialized by the CPU via software, this chip acts as a port to the outside peripheral equipment. Basically, it converts parallel data information to serial format and outputs it at a predetermined baud rate. It can also accept incoming serial information and convert it to parallel format for CPU input. In our setup the PCI is connected to a device select circuit. The purpose of this is to allow either the CRT terminal or the main computer via a telephone link and modem to "talk" to the

Figure 9. MICROPROCESSOR - CONTROLLED DATA ACQUISITION SYSTEM

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Figure 10. DATA ACQUISITION PROGRAM OPERATION

microsystem. In addition, it may allow the CRT terminal to "talk" directly with the main computer. The device select is usually programmed by the CPU for a specific task via a Programmable Peripheral Interface (PPI). In some cases, however, the microsystem is off and the manual override must be used to put the terminal on-line to the main computer. Note that, through this interface, software programs may be entered into the microsystem by either the terminal or the main computer. Likewise, data may be transferred to either device or both devices.

The heart of the data acquisition system includes the sync detector and buffer, the timing and converter control unit, the video digitizer, and the DMA controller. Essentially, this section's main task is to take a standard video signal, detect and convert the sync pulses to compatible voltage levels for the timing and converter control units, and digitize the picture information into an eight bit binary number for storage in the RAM.

For proper operation both the DMA and converter control units must be initialized. For the DMA unit the CPU will give it the starting and stopping addresses for the data storage in the RAM. The control unit is preset to the desired operating mode by a latched control word via port A in the PPI. Once initialized and told to run, the video digitizing routine including data storage is totally self-sufficient. This section along with the RAM does all the work, while all other system components, including the CPU, go into a disabled condition. They resume operation once the last address in the RAM has been filled. This is necessary in order to achieve a maximum data transfer rate from digitizer to memory. Once it has regained control, the CPU will output the data in RAM to the main computer where advanced calculations on the data may be made.

6. A Target-Sorting Apparatus Utilizing Mach-Zehnder Interference Microscope

Although it is everyone's desire to employ only the most symmetric and uniform glass microshells for target freezing experiments, the job of selecting one with optimal parameters (diameter, thickness, uniformity, etc.) out of a great number of mixed targets can very easily be a time-consuming and, often times, frustrating adventure. In order to do a more efficient and accurate target-sorting and characterization, we have built a device by utilizing a Mach-Zehnder interference microscope. A schematic of this device is contained in Figure 11. Figure 12 shows a typical group of balls placed on the inspection disk of this device (Note the degree of variations in the target dimension and uniformity). As is clear from the schematic and the picture, the device is capable of inspecting a good number of targets simultaneously, selecting one that meets the desired specifications, picking it up, and mounting on a glass stalk for use in the target freezing experiments.

This device has been fully and successfully utilized to prepare targets used in our recent experiments. For this reason, we expect that from now on all targets used for target freezing experiments will be uniform and symmetric.

Figure 11. Schematic of a device which does target-sorting, characterization, pick-up, and mounting.

Figure 12. Picture of a number of glass microspheres being inspected using the device illustrated by Figure 11.

7. Radio Frequency a-c Interference Microscope

Development of an a-c interference microscope has been under way as a diagnostic tool for inspecting the uniformity of a DT-layer inside a target in motion. In a-c interferometry, one makes an optically phase-modulated scan across a particular slice of the fringe pattern using a vibrating mirror on the reference arm of the interferometer to phase-modulate at a certain frequency. This modulated optical scan of the particular fringe pattern slice is then received at an opto-electronic detector and converted into an electronic signal. In the case of a moving target, the optical scan across the fringe pattern is automatically achieved by aiming the target to go through the object beam of the interferometer. Once this has been done, demodulating the temporal electronic signal and re-constructing the optical phase map of the original fringe pattern slice merely requires a synchronous detection from well-known AM radio operational principles (see Fig. 13 for an illustration of the a-c interferometry). In what follows we present a brief description of each component of the a-c interferometer system under development, and the preliminary data indicating the performance of the system.

Optical System

A schematic of the interferometer system is shown in Fig. 14. The interferometer is of Mach-Zehnder type, in which the mirror on the reference arm is attached to a tubular piezoelectric crystal resonating at a number of frequencies. The higher frequencies are around 2.5 MHz. The mirror was fabricated out of a very thin glass disk (7 mil thick and 1/2" in diameter) to achieve the highest possible resonance frequency. High modulation frequencies are necessary to detect targets moving at higher speeds. For example, with the assumption that the smallest target fringe spacing is 1 μm , the resonance frequency of 10 MHz allows

Figure 13. Operational principle of an a-c interferometer.

Figure 14. Schematic of the a-c interference microscope system.

for the inspection of a target at the maximum speed of 10 cm/s.

Another important point is that the magnified fringe spacing at the detector has to be at least 1.5 times the detector aperture in order for the modulation signal to appear in the detector in any resolvable manner. A fringe pattern smaller than the detector size will be averaged out by the detector resulting in no information pertaining to the original fringe pattern.

Electronics

The electronic system consists of a conventional rf receiver and demodulator. A block diagram is given in Fig. 15. The "antenna" in this case is an avalanche photodiode followed by a pre-amp, filter, and demodulator. This system is simpler to build and operate, and as a result cheaper (at least by an order of magnitude) than the other systems developed thus far by others.* Also, while the other systems can only follow a limited number of fringes, the current system has no limitations to its counting ability.

The final stage of the electronics is the digital interface to a computer. By digitizing the waveform we can use signal processing to clean up the scan inside the computer. This interfacing is nearing its completion.

Results

Preliminary test indicates that the rf interferometer works well at lower scan speeds. However, as the scan speed gets higher, the level of noise in the detection system increases eroding the quality of the results. Since we know that it is mainly due to the poor filtering inside of the system combined with

*See, for example: Glen W. Johnson and Duncan T. Moore, SPIE 103, 76 (1977)

Figure 15. Electronic components of the a-c interferometer system.

a poorly designed pre-amp, this noise problem will be corrected in the near future.

An illustration of the system performance is given in the following pictures. Figure 16 contains the shadow and interference micrographs of a 160 μm -diameter glass microballoon employed for the test. The target was mounted on a glass stalk which in turn was fastened to a rotating motor head, perpendicularly to the axis of rotation, to cause controlled optical scan of the target fringe pattern at different speeds. Figure 17 is a typical scan result showing the *phase map of the interference micrograph of the same target (Fig. 16) moving at the speed of 10 cm/s obtained at a modulation frequency of 150 kHz.*

To summarize, the preliminary results indicate that the a-c interferometer system under development has the potential capability to provide an easy, quick, and accurate look at the phase scan of a target fringe pattern under a high noise environment. With proper care in the design and implementation of the detection electronics the results can only get better. By adding a second interferometer to subtract the common phase events, most of the noise resulting from the physical environment of the interferometer system can also be eliminated. We are currently in the process of pursuing this possibility.

16a. Shadow micrograph

16b. Interference micrograph

Figure 16. Shadow and interference micrographs of a thick $160\text{ }\mu\text{m}$ -diameter glass microshell used in the test of the a-c interferometer.

Figure 17. An optical scan showing the phase map of an interference fringe pattern slice of the target shown in Figure 16.

8. Generation of Monodisperse Hydrogen Pellets

Development of a hydrogen pellet generator has been under way for production of a continuous stream of solid hydrogen microspheres to be used for testing various cryogenic target fabrication schemes. The work so far has concentrated on renovating and modifying a hydrogen pellet generator developed earlier by the University of Illinois.* The system is now at its final stage of renovation, and will be test-run in the near future. Upon the final test this system will be used to study the possibility of filling a glass microballoon with solid hydrogen microspheres of various sizes. This feasibility study will include, among other things, finding the optimal thermodynamic conditions under which the fill process can best be achieved without impairing the integrity of the hydrogen microspheres.

*C.A. Foster, K. Kim, R.J. Turnbull, and C.D. Hendricks, Rev. Sci. Instrum., 48, 625 (1977).

9. Study of Behavior of Liquid Hydrogen Contained in a Spherical Shell

A theoretical effort has been initiated to understand in detail the unusual behaviors of liquid hydrogen in a glass microballoon, which was experimentally observed in Sections 1 and 2 in this report. The principal objective of this study is to formulate a comprehensive theory which can accurately predict the transition temperature above which the liquid hydrogen inside a glass microballoon prefers to exist only in a form of a uniform spherical shell. Below the transition temperature, as was noted in those sections, the liquid hydrogen exists as a droplet located at the bottom of the glass sphere.

Any theory, in order for it to be fundamentally sound, must include from the outset all the elementary forces that exist in the system, namely, the forces that are present in the interface between the target material and the hydrogen (both solid-liquid and solid-vapor surface tensions, γ_{SL} and γ_{SV}), the forces present in the liquid-vapor interface of the hydrogen (the surface tension of hydrogen γ_{LV}), and the gravitational force. The theory we are trying to make mathematically tractable has all these ingredients in its starting equation, which is essentially the total free energy expression of the given target containing liquid hydrogen. A differential equation resulting from this theory, however, is highly non-linear and singular and therefore requires a non-trivial amount of machine computation for its solution. Lack of sufficient information regarding the aforementioned interfacial interaction forces (especially, γ_{SL} and γ_{SV}) as a function of temperature is another deterrent in facilitating the calculations. Nevertheless, a simple minded free energy argument has been employed for preliminary test of the soundness of the theoretical model, which indicates that the transition temperature mentioned earlier can be calculated as a natural outcome of

the theoretical model.

We are currently pursuing this theoretical analysis in more systematic manner, which we hope will enable us to better understand the behavior of liquid hydrogen and guide us in developing new cryogenic target fabrication techniques which otherwise would not perhaps be possible.