POTENTIAL UTILIZATION OF GLASS EXPERIMENTS IN SPACE

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ABSTRACT

Materials Processing in Space (MPS) is not limited to the development of extraordinary materials requiring microgravity, and fabrication for the needs of space habitats. MPS also provides a unique and lucrative resource for advanced research on novel and improved materials for future Earth development and fabrication. Since about 1978 this has been recognized and implemented at MSCF and other NASA Laboratories. If and when space processing demonstrates unique product or process improvements or innovations unencumbered by gravitation-induced or container-conditioned disturbances, a basis for and encouragement of utilization on Earth may have been established. For instance, the preparation in microgravity and characterization of a composite alloy whose components would on Earth have separated into two liquids, does not just represent a new MPS material, but may stimulate Earth processing of a similar material by other means.

NASA is now making available joint venture formats which can be utilized by industry in the search for novel products and processes on Earth taking advantage of the unique features of microgravity facilities for advanced materials research at low cost to industry.

A review of present and potential microgravity studies in the area of glass science and technology suggests the utilization of NASA's resources in this sector by industry's research and development requirements.

Among these studies are:

Minimum cooling rates for containerless melting of borderline glasses in the absence of segregation and convection.

Conditions of homogeneous nucleation.

Fining mechanisms in the absence of buoyancy.

Containerless production of precursors, including gel synthesis, for wave guide materials.

Fabrication of uniform microspheres and microballoons.

Surface-active glass components.

Diffusion.

High temperature glass ceramic formation free of distribution.

Conditions for bulk metal glass fabrication.

Phase separation and microstructure.

1. LEVELS OF UTILIZATION

The availability of the Space Shuttle, and, eventually, of a Space Station provides a microgravity (10^{-6} to 10^{-2}g) environment for increasing periods of time. There also is an increasing availability and efficiency of astronaut intervention. As a result of this situation materials processing in space (MPS) is fast becoming a resource of potential utility to industrial as well as academic research.

A word like utilization or commercialization, when referring to MPS can easily be misinterpreted. A clear interpretation will help to assess the merit of specific experiments and proposals in this connection.

MPS can advance the state-of-the-art in various levels of achievement. Starting from direct or ultimate towards more subtle achievements these levels might be described as follows:

1. Processing materials in space use. (Example: Building components)

2. Processing materials in space which can not be obtained on Earth. (Example: Electrophoresis) (SNYDER 1983, p. 88) {1a}.

3. Demonstrating a novel or improved material to stimulate Earth development. (Example: Defect-free crystals).

4. Gaining knowledge to stimulate Earth research and development on novel or improved materials. (Example: Transport phenomena).

The most exciting but obviously limited level is level 2. Yet levels 3 and 4 deserve increasing attention by industry, since NASA is now making available joint venture formats for industrial research towards advance materials at very low cost and with proper safeguards for proprietary areas (BROWN and ZOLLER 1981) {2}. Level 1 will fast move from fantasy land to stark reality. When the Princeton "blueprints" (slide) for a space city of 28,000 people by 1990 at a cost of 3G$ were presented to the MPS community around 1970, I countered the skeptical reception by the majority of those present, by saying: "I'm convinced of the reality of a space station though for fewer people, a little later, at much higher cost." NASA's Hans Mark now forsees realization in the very near future.

The Soviet Union has most definitely accepted expanding human habitation outward as a formal long-range goal and considers current endeavors (such as two reusable craft, a light space plane and a heavy lift shuttle etc.) as something like intermediate steps (Office of Technology Assessment 1983) {3a}. Congressman Fuqua, Chairman of the Science and Technology Committee considers this assessment "helpful for our deliberations on Nasa's potential space station initiative."{3b}.[1)]

In reviewing current MPS studies in the areas of glass science and technology at this symposium we are concerned with levels 3 and 4. The scope of these studies should become more familiar to industry for potential utilization; and NASA's selection of future MPS proposals should give a modicum of consideration to this aspect side by side with their scientific quality. Industry involved in producing and using glass as a material per se and in devices has begun to pay attention to this aspect by participating in NASA sponsored conferences covering this sector (e.g., Snowbird, Utah and Bedford Springs, PA. 1983). In what follows a brief description of current projects on glass processing in space is given with this viewpoint in mind.

2. GLASS PROCESSING EXPERIMENTS IN SPACE

Since 1969 the MPS program was, in part, guided by advice from the University Space Research Association (USRA) - an association of now 54 universities - through its topical committees. It is worth noting that virtually all current glass experiments in space correspond with recommendations of USRA between 1970 and 1980. They include:

2.1 Shells

The processing in space of glass shells of exacting dimensions, sphericity and concentricity is of potential value to the production of fusion targets (WANG 1983, p. 129) {1a}. The study of fundamental properties required for this task can proceed unencumbered by the coupling on earth of time, temperature and gravity. WANG works with metal glasses. DUNN (1983 p. 111 {1a}) works with the more conventional glasses now in use, in a preflight gas jet levitation system.

2.2 Critical Cooling Rate and Novel Glasses

From a fundamental as well as a practical viewpoint, one of the most important and essentially unresolved questions regarding the value of glass processing in space is: whether and to which extent nucleation and growth rates, and thus the chance of obtaining novel glass systems, differ in 1G and microgravity environments. Expectations of advantages are based on the absence in microgravity of container walls, contamination, segregation and, consequently, of heterogeneous nucleation. In most cases limitations to the development of new extreme glasses are due to heterogeneous nucleation spawned at surfaces and interfaces, or by gravity-induced segregation. In fact, homogeneous nucleation characteristic of the inherent composition has been demonstrated only in rare cases. Heterogeneous nucleation often occurs at a rate of cooling orders of magnitudes higher than that for homogeneous nucleation. In the case of metal glasses this may make all the difference between obtaining or not obtaining bulk glass form for important new compositions (SPAEPEN 1983, p. 34) {1b}. The program pertaining to this problem includes amorphous silicon and has been extended to 1986. A study with similar objectives using levitation processing developed at JPL includes organic glasses (TRINH 1983, p. 35) {1b}. Ground studies on the fundamental issues governing the possibilities of obtaining bulk metal glasses (TURNBULL 1983, p. 127) {1c} do indeed encourage microgravity experiments examplifying potential technological achievements.

As to oxide glasses the expected suppression of heterogeneous nucleation/crystallization facilitating the expansion of compositional limits for the formation of technologically desirable glasses is the major topic of preflight and flight experiments by DAY 1983 (p. 108) {1a}; experiments in which I have become involved for many years.

If and when a ratio of minimum (critical) cooling rates (Rc) has been established (Rc (Earth)/Rc micro-g), properties of technological interest are to be determined in the microgravity-produced extreme samples. The program also includes fluoride optical glasses recently devised to replace CaF_2 crystals which control the secondary spectrum in optical systems (apochromats). At this point industry has to introduce some P_2O_5 to prevent crystallization.

Similarly, the boundaries of glass formation in the absence of surface (or impurity-, or segregation-) induced crystallization, are of importance for the development of waveguides in the higher (>8μm) wavelength infrared where scattering is minimized permitting longer distances between relays. Promising candidates are heavy cation (e.g. Zr, Hf, Th) fluoride glasses which are now studied in a microgravity program by DOREMUS 1983, p. 31 {1b}, (see also BANSAL et al. 1983 { 4 }.

At Marshall Space Flight Center a ground facility using new laser heating and cooling techniques has been set up to evaluate critical cooling rates of borderline glass formers in containerless production of bulk glass samples as potential flight candidates (ETHRIDGE 1983, p. 115) {1a}, ETHRIDGE and CURRERI 1983 { 5 }.

Fundamental understanding of homogeneous and heterogeneous nucleation and crystallization as well as practical information pertaining to glass processing in space is the objective of a broad-based investigation at JPL (WEINBERG 1983, p. 38) {-1b}.

2.3 Gel Synthesis of Glasses

Both for MPS and for precursors of flight experiments the recently expanding field of low temperature glass synthesis from gels is of significant interest.

Gel synthesis avoids mechanical mixing and yields compositionally homogeneous samples which are promising candidates for flight precursors (DOWNS 1983, p. 109) {1a}. An extensive evaluation of monoliths obtained in this way for flight selection has been carried out at BATELLE in the systems SiO_2-GeO_2 (and TiO_2), and GeO_2-PbO (and Bi_2O_3) (MUKHERJEE 1983, p. 119) {1a}.

The utilization of properly selected microgravity experiments based on gel synthesis of glasses should aid the development of advanced materials and processes in industry.

2.4 Immiscibility

In many metallic as well as non-metallic binary (and polynary) systems the phase diagram shows an above-liquidus immiscibility region. Usually two liquids one above the other are obtained in a melt. Even after stirring and fast casting an ingot contains two separate regions. In the absence of gravity two liquid phases will not so separate and a novel micro-phase-separated material may be obtained.

Such experiments are contained in the flight and pre-flight program of DAY (1983) e.g. in systems CaO-SiO_2 (B_2O_3, GeO_2).

In the field of crystalline metal alloys new materials have, indeed, been obtained from liquids separating in 1G in a recent flight experiment. (GELLES et al. 1983) (9)

2.5 Surface Tension

Surface tension is an important factor in the behavior of bubbles. The behavior of gas bubbles in glasses is of interest for several reasons. One is the necessary development of mixing and fining techniques for glasses melted in a microgravity environment where convection - mobilized for this purpose under 1G - is absent. Another one is the separation of convection (buoyancy) and solution mechanisms for better understanding of the technologically important fining process in the glass industry on earth. Bubble behavior also affects microballoon formation. A very large program is under way since 1977 in this area (SUBRAMANIAN and collaborators at Clarkson. References can be found on pages 92 and 93 of Reference 1a). A fascinating aspect of these investigations is the migration of bubbles in containerless melts on the surface of which a hot spot creates a gradient in surface tension. WEINBERG in the referenced study, p. 38 {1b} also addresses bubble behavior. He, and many associates, have pioneered the problem in many earlier studies reference to which is found on pages 38 and 39 of Reference 1b.

Components decreasing the surface tension of a glass tend to enrich in the surface. This change in composition is of importance whenever the glass surface plays a decisive role (substrate, amplifier, source of reduction or crystallization). UHLMANN and TULLER 1983, p. 37 {2b} determine the compositional gradients near and at the surface under conditions undisturbed by gravity-induced convection and segregation. I am now associated with this study of a problem with which I have been involved in for some time.

2.6 Composites

The precise arrangement of a second phase in a composite could be obtained without interference of gravity by space processing. I am not aware at this time of any experiment underway. I understand that ZARZYCKI 1983 { 6 } has submitted a proposal involving metal spheres in a glass matrix with an eye on some electrotechnical application.

Similarly, glass ceramic specimens whose matrices tend to sag in 1G might be obtained in an microgravity environment.

3. Soviet glass experiments in space are listed in App. 1.

SUMMARY

Glass processing experiments in space underway or proposed may well suggest utilization in research and/or development aiming at new or improved materials of industrial interest. Joint venture formats have been made available by NASA recently which seem advantageous for industrial participation at low cost and

with proper safeguards of proprietary rights. It is hoped that interaction of industry, academy and NASA in this sector will be encouraged and broadened as a result of the evaluation of current and proposed glass experiments and the incentives offered. Eventually, industry might initiate their own microgravity experiments using NASA facilities (RINDONE 1983) {7}.

REFERENCES

1. NASA Technical Memorandum [a]TM 82525, April 1983
   Materials Processing in Space, Program Tasks

   [b]TM 82548, October 1983
   Materials Processing in Space, Program Tasks, Supplement

   (Additional references are listed in these two memoranda.)

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3. Office of Technology Assessment [a]"Salyut: Soviet Steps Toward Permanent Human Presence in Space"

   Technical Memorandum 003-00937-4, 1983-12-22

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7. RINDONE G. Statement before Congress Subcommittee on Space Science 14 Sept. 1983.

8. PETROVSKII G., RYUMIN V., SEMESHKIN I. Steklo i Keramika 1983 (1) 5.

9. GELLES S., MARKWORTH A., MOBLEY C. Low-Gravity Experiments on Liquid Phase Miscibility Gap (LPMG) Alloys - Materials Experiments Assembly (MEA) Proceedings of the 4th European Symposium on Materials Sciences under Microgravity. ESA SP-191, June 1983.

FOOTNOTES

1. Since completion of this paper the President has endorsed a USA commitment to a space station.

APPENDIX 1

Some Soviet Glass Experiments in Space[8]

1. Surface Tension. Bubble Behavior.

Surface tension was reported to assert its influence more in microgravity than at 1 G. A glass sample was degassed reasonably (almost all bubbles brought to the surface) when an angular momentum of the "space station" was specified for 20 minutes. Bubbles in the case of a stationary condition of the sample were found migrating towards the hotter zone.

2. Absence of Convection.

A zone colored blue by cobalt doping was maintained in microgravity.

3. Immiscibility.

In a laser glass immiscibility was suppressed enough to allow to increase from a maximum not much above 2% to a level of 10% the amount of Nd_2O_3 accepted, thus increasing efficiency. A phosphate-based optical glass (OPS 3215) was increased in radiation resistance, a result attributed to suppressed immiscibility.

4. Composites.

The efficiency of a magneto-optic borate glass was reported improved by the more even distribution of the active iron oxide crystals in the matrix.