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SOME CONSIDERATIONS FOR VARIOUS POSITIONING SYSTEMS AND THEIR SCIENCE CAPABILITIES

C. A. Rey, D. R. Merkley and T. J. Danley
Intersonics, Inc.
Northbrook, Illinois

Abstract

Containerless processing of materials at elevated temperatures is discussed with emphasis on 1) high temperature chemistry and thermophysical properties and 2) materials science and materials processing. Acoustic and electromagnetic positioning of high temperature melts are discussed. Results from recent ground-based experiments, including KC-135 testing of an acoustic levitator, are presented. Some current positioning technologies and the potential for enhancing them are considered. Further, a summary of these technologies and their science capabilities for the development of future experiments is given in this paper.

Need for Containerless Processing

The capability of conducting materials research in a containerless state at high temperatures is of significant interest to the scientific community. In a typical materials process, contaminants from the crucible can alter or even invalidate results of the investigation. As the processing temperature increases, there is an increase in the probability and the rate of unwanted reactions occurring between the crucible and its contents. Containerless processing eliminates the crucible, thus eliminating the dominant source of contamination. In acoustic levitation, the materials being investigated come in contact only with the medium in which the acoustic waves propagate. This medium typically may be dry air or an inert gas, such as argon, or even a special gas for specific reactions. In electromagnetic levitation the specimen investigated can be processed in either vacuum or some suitable gas, but the specimen must have sufficient electrical conductivity.

Nonresonant Acoustic Levitator Systems

Fig. 1A illustrates the basic concept central to a single-axis resonant system.[1] The nonresonant system shown in Fig. 1B uses an acoustic transducer at the bottom, which produces a primary, nearly plane wave, which impinges on a small reflector.[2] The approximately spherical reflected wave interferes with the primary wave and the resulting acoustic field produces continuous restoring forces on a specimen. The magnitude of these forces is quite small. While sufficient to levitate small objects at ambient temperatures, it is not strong enough when the supporting gas is at a high temperature. However, in the microgravity of space these restoring forces are more than adequate to position a research specimen.[3]

One configuration of the Single Axis Acoustic Levitator, called SAAL, is shown in cross section in Fig. 1B. Three levitation experiments using the SAAL on an October, 1985 Space Shuttle flight successfully demonstrated for the first time containerless processing of glass specimens at high temperatures and attained some scientific and engineering objectives.[4] Positioning of both solids and liquids without a container at temperatures from 800 to 1500°C was achieved.

In each case a specimen was injected and captured in the acoustic potential energy well. Specimens were positioned in the containerless state while being heated, melted, cooled, and solidified.

Acoustic Levitation Furnace (ALF)

The acoustic levitation furnace (ALF) facility under development will use a hotwall furnace and acoustic positioning for containerless processing of materials up to 1750°C. The facility is capable of processing a substantial number of experimental specimens under a variety of conditions thus enabling multiple research efforts. The ALF is designed with six opposed acoustic sources in three orthogonal axes to provide acoustic control of both solid and liquid specimens.[5] Fig. 1C shows the schematic arrangement of these acoustic transducers. The resulting acoustic field produces an energy well that is symmetric and stable, providing excellent translational stability for the specimen. These features can ensure that the containerless state is maintained throughout processing and that the specimen remains both centered and spherical when melted.

High Temperature Acoustic Levitator (HAL)

The high temperature acoustic levitator (HAL) is a facility designed for containerless processing of materials at temperatures up to 2000°C or above. The facility employs an array of six high power acoustic transducers which produce a very symmetric acoustic field promoting a stable levitating environment. A beam heating technique is used to obtain temperatures in excess of 2000°C. In one version of this approach radiation emitted from compact xenon arc lamps are focused onto a levitated sample using ellipsoidal reflectors. Fig. 2 shows a brassboard version of HAL which has been designed to be flown aboard the KC-135 microgravity test facility.

Fig. 3A shows sound positioning versus time data for a density 2.2 gm/cm_3 sample. Good damping of residual motion is apparent within a time constant of about 2 seconds. Figure 3B shows a similar plot for a specimen density of 8.9 heated to over 1400K.

Stabilized Electromagnetic Levitator (SEL)

The Stabilized Electromagnetic Levitator is a highly stable multi-coil levitator for melting and undercooling studies in a microgravity environment. The module design is shown in Fig. 2. SEL is characterized by independent control of heating and positioning. Both highly or poorly conductive materials, metallic or non-metallic, may be levitated. High frequency induction heating of samples to 2700°C or greater will be possible. Heating and cooling rates of at least 200°C/sec. would be available. By varying the signals between coils, sample stability and oscillation can be controlled. Independent heating will allow undercooling studies without sample instability.

The basic design and development work for a SEL test module has been completed at Intersonics under a SBIR grant from NASA. The test module is a single-axis system powered by modified, commercially available, high efficiency, solid-state, radio frequency amplifiers. Techniques for coil construction, transmission line fabrication and insulation are under development at Intersonics.

Summary and Conclusion

Acoustic levitation in space is providing the experimenter and eventually the manufacturer with new techniques for high-temperature containerless materials processing. In acoustic levitation the technology has evolved from a single-axis resonance tube levitator in 1971 to the nonresonant, three-axis, opposed source system now under development in ALF and HAL. An electromagnetic system is being developed which may have greater flexibility than previous designs. A summary of the science capabilities for these systems is given in Table 1.

With the availability of these new techniques for high-temperature containerless materials processing, a vastly expanded range of materials from processing up to (and perhaps beyond) 2700°C are envisioned. It is reasonable to anticipate that significant advances in the production of new materials, new ceramics, alloys, and optical and electronic materials will result.

Acknowledgment

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References

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INTERSONICS
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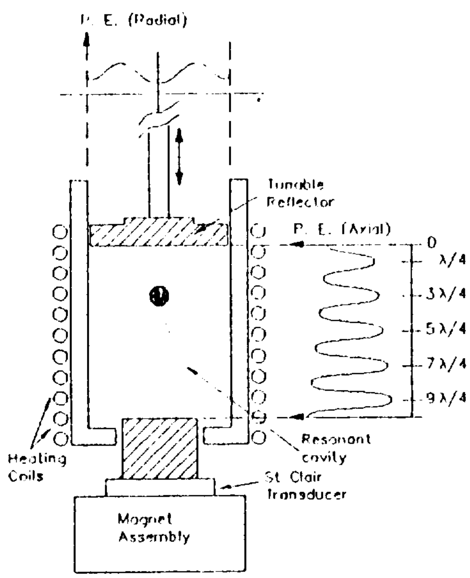
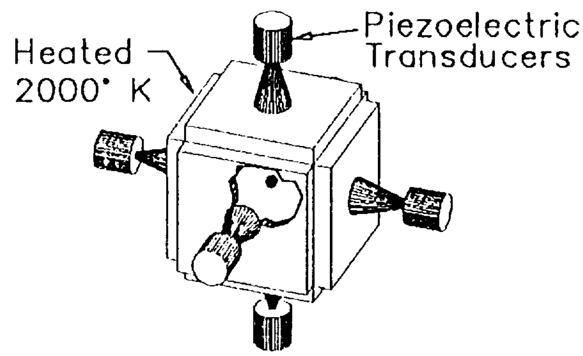
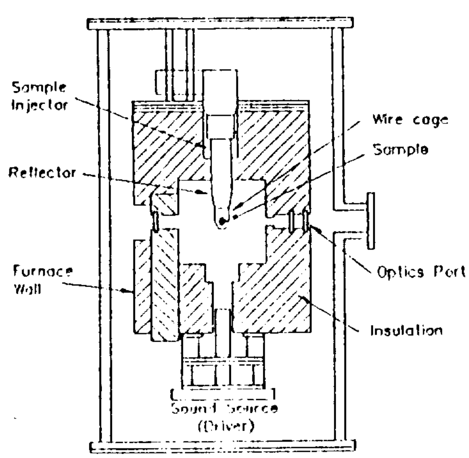
ACOUSTIC LEVITATORS



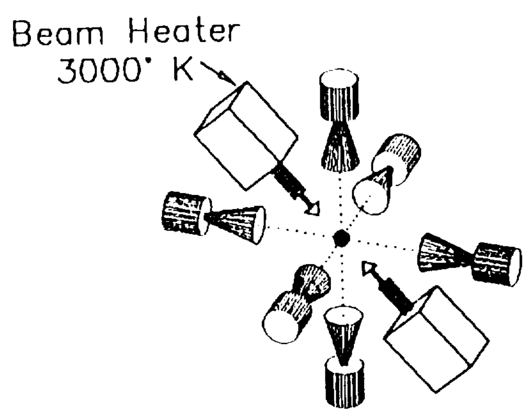
SINGLE AXIS RESONANT LEVITATOR
Figure A



ACOUSTIC LEVITATION FURNACE (ALF)
Figure C



SINGLE AXIS ACOUSTIC LEVITATOR (SAAL)
Figure B



HIGH TEMPERATURE ACOUSTIC LEVITATOR (HAL)
Figure D

FIGURE 1

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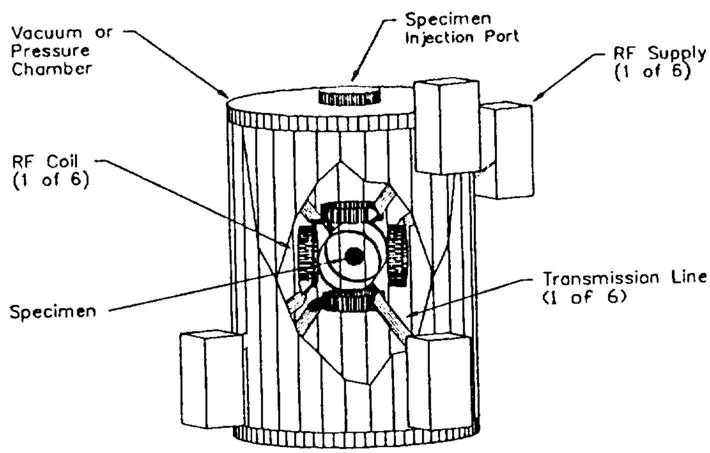
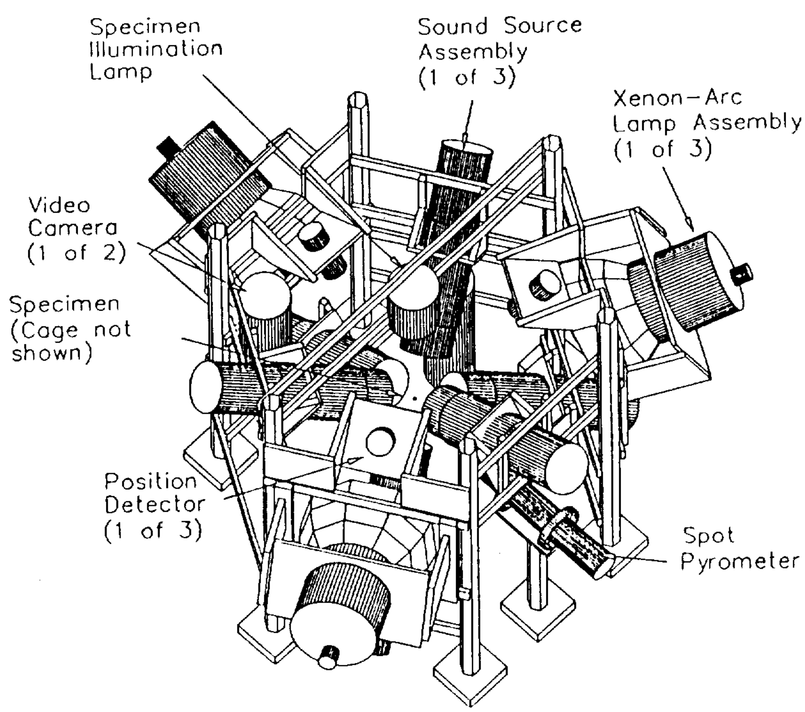


STABILIZED ELECTROMAGNETIC LEVITATOR (SEL)



HIGH TEMPERATURE ACOUSTIC LEVITATOR GENERAL ASSEMBLY

FIGURE 2

HAL KC135 TESTS JAN 12, 1990

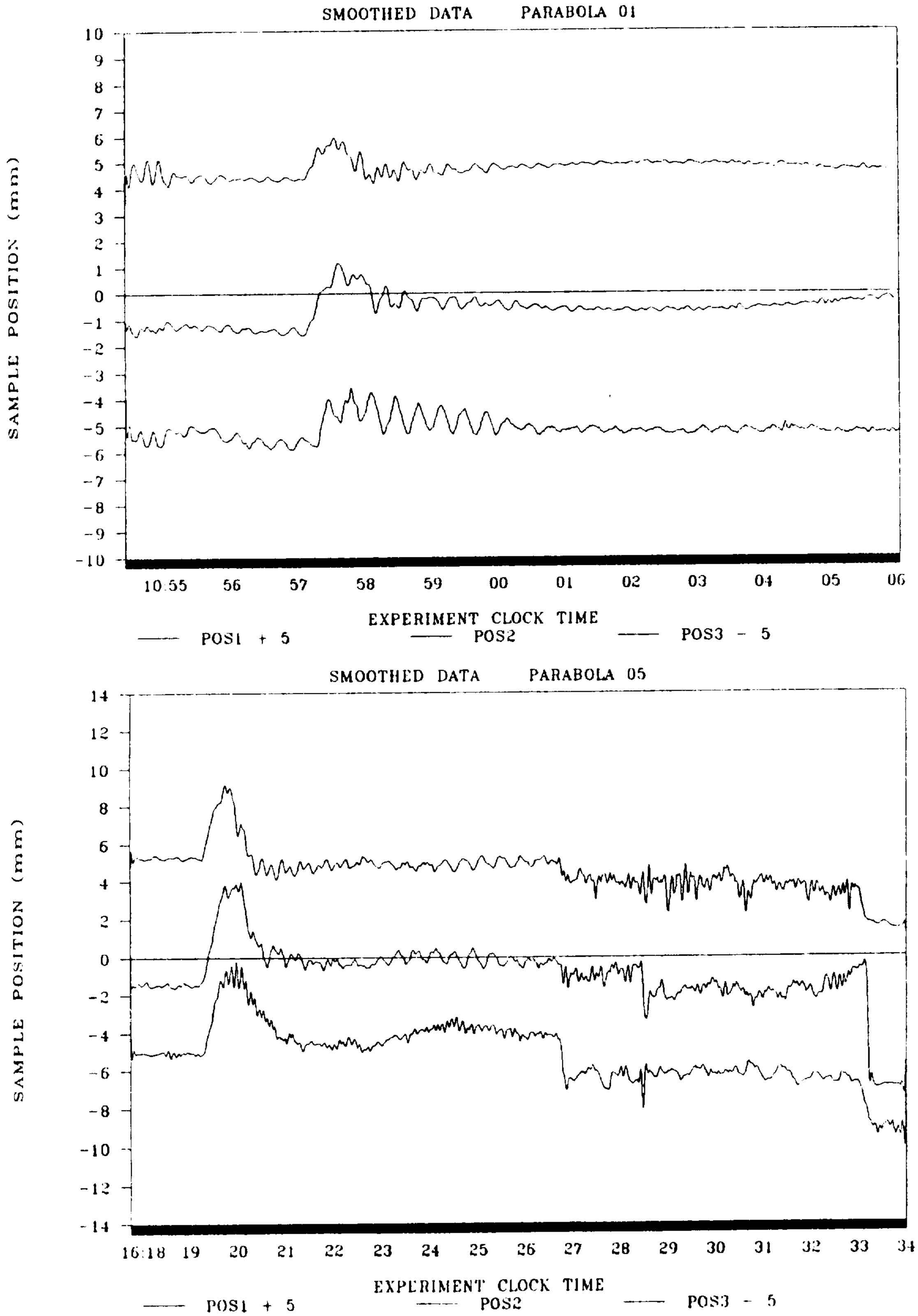


FIGURE 3

MICROGRAVITY SCIENCE CAPABILITIES SUMMARY FOR

HIGH TEMPERATURE CONTAINERLESS PROCESSING MODULE (HTCPM)

A High Temperature Containerless Processing Module (HTCPM) could be one of the modules supported by the DPM package for Spacelab, and could be a precursor module for the Modular Containerless Processing Facility (MCPF) for the space station. Depending on the science requirements, it may utilize one or more of the following technologies:

PARAMETER	ACOUSTIC (HOT WALL) (ALF)	ACOUSTIC (BEAM HEATED) (HAL)	STABILIZED ELECTRO-MAGNETIC (SEL)
Temperatures	800–1750 °C	30–2000 °C or higher	30 to 2700 °C or higher
Specimen Isothermality	Very Good (± 2 °C/cm)	Good	Good
Processing Gas	Inert, Reducing, Oxidizing	Inert, Reducing, Oxidizing	Inert, Reducing, Oxidizing, Vacuum
Gas Purity Particulate Contamination	Good Class 1000 or Better	Excellent	Excellent
Heating and Cooling Rates	Slow to Moderate (< 2 °C/sec.)	Very Fast (~200 °C/sec.)	Very Fast (~200 °C/sec.)
Conductive Specimen Required	No	No	Yes
Liquid or Solid Processed	Yes	Yes	Yes
Specimen Size	2 - 10mm	2 - 6mm	2 - 6mm

SOME POSSIBLE APPLICATIONS FOR CONTAINERLESS PROCESSING AT HIGH TEMPERATURES IN MICROGRAVITY

HIGH TEMPERATURE CHEMISTRY

- Cp VS TEMPERATURE, UNDERCOOLED LIQUIDS
- OPTICAL PROPERTY MEASUREMENT - n, k, e, ETC
- SURFACE FILM BEHAVIOR, GROWTH RATES, ETC
- THERMODYNAMICS AND KINETICS (OF OXIDE AND NITRIDES)
- VAPOR PRESSURES BY LIF, ETC
- PASSIVATION/CORROSION EFFECTS

MATERIALS PROCESSING

- PURIFY, REMOVE OXIDES, IN METALS/ALLOYS
- HIGH PURITY SEMICONDUCTORS
- MICRO ALLOYING, SUPER ALLOYS
- CONTROLLED MICRO STRUCTURES
- HIGH Tc SUPERCONDUCTORS
- DEEP UNDERCOOLING, AMORPHOUS MATERIALS
- NON-EQUILIBRIUM STUDIES
- OXIDE DISPERSION STRENGTHENING
- OPTICAL MATERIALS, BENCHMARK MATERIALS

TABLE 1