View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by NASA Technical Reports Server

N88-17702

A PAYLOAD FOR INVESTIGATING THE INFLUENCE OF CONVECTION ON GaAs CRYSTAL GROWTH*

Alfred H. Bellows and Glenn A. Duchene

GTE Laboratories Incorporated
Waltham, Massachusetts 02254

ABSTRACT

A comparative study of the influence of buoyancy driven fluid flow on gallium arsenide (GaAs) crystal growth has been undertaken. Crystals will be grown from melts with different degrees of convective flow including growth in the microgravity environment of space. The space growth of GaAs will be performed in a GAS payload. A well-insulated growth furnace has been designed for both earth-based and space-based experiments. The self-contained payload will carry two such furnaces in addition to a large battery power source and a microprocessor-based control and data acquisition system for regulating the growth process with high precision. The microcomputer will also monitor the growth conditions and measure and record the acceleration in 3 axes.

INTRODUCTION

The influence of convection on the growth of GaAs crystals is being studied through a series of carefully designed comparative experiments. Gallium arsenide is an important electronic substrate material. It exhibits an intrinsically high electron mobility making it a desirable material for very high-speed signal processing devices, and its direct energy gap makes it a useful material for light emitting devices. Nonetheless, the current GaAs IC yields remain low, the cause being, in part, the presence of inhomogeneities caused by the significant degree of temperature fluctuation at the growth interface. In a gravitational field, density gradients in the melt caused by temperature gradients induce appreciable convection currents which produce pronounced turbulence at the growth interface.

---

* This work is being supported in part by NASA-Lewis Research Center and Wright-Patterson Air Force Base Research Center, under Contract No. NAS3-24644.

The comparative studies which GTE is performing are being undertaken in an attempt to determine the significance of convection in the generation of these inhomogeneities. To this end, the studies will include growth orientation with respect to gravity, the effect of magnetic fields to restrict convection by increasing the kinematic viscosity of the melt by resisting fluid motion through Lenz's law, and the effect of nearly eliminating the gravity vector altogether. The last set of experiments will, of course, be performed in a GAS experiment aboard Shuttle.

The payload has been designed to carry two identical but isolated growth experiments. The GaAs crystals are one inch in diameter and four inches long and are contained in well-insulated sealed chambers. The experiment cycle begins at launch when the NASA-installed altitude switch activates the power pack and the first of the two completely isolated control systems. Thus, the first crystal growth will take place early in the mission before the battery pack has cooled significantly. Heat dissipated during the experiment will elevate the payload temperature somewhat so the second experiment is planned to be performed about two days later after some cooling has occurred. The second experiment will be activated by an astronaut.

THE PAYLOAD

The payload is illustrated in Figure 1. It is composed of three major elements: the growth furnaces, the electronic control system, and the battery packs.

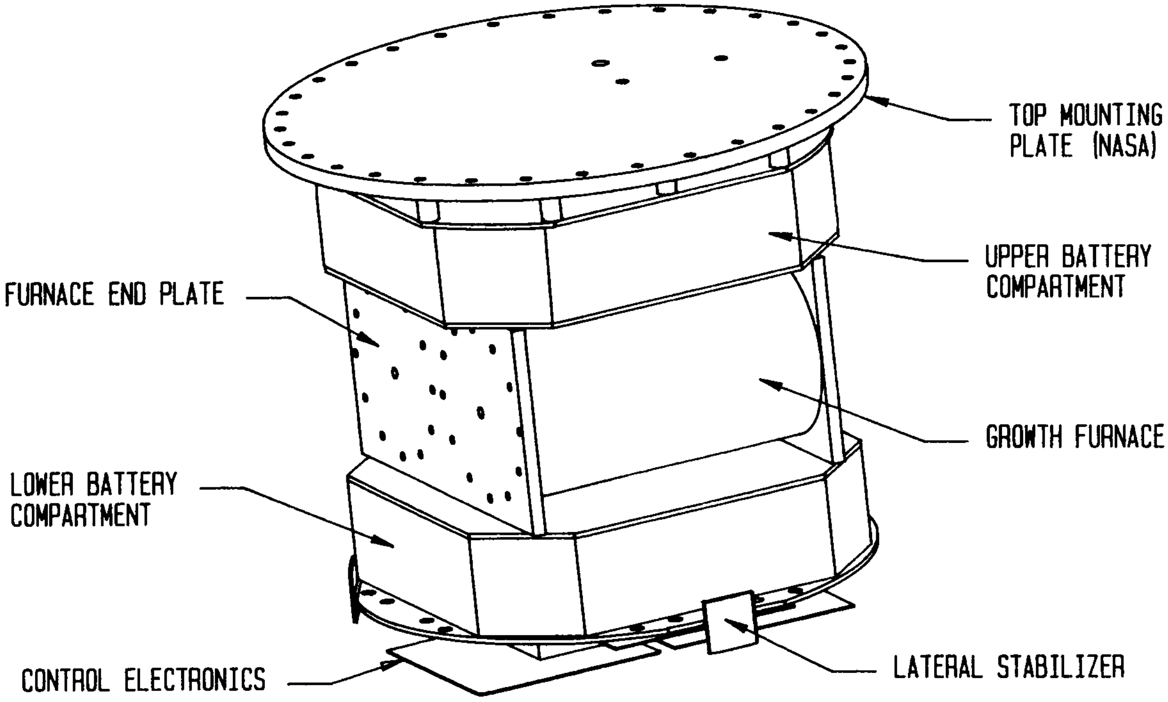

Figure 1. The GaAs Crystal Growth Payload.

The structure is basically that of a stack of inherently rigid boxes, and as such has a moderately high natural frequency. The major weight of the payload is found in the batteries which are enclosed in two separate enclosures, one of which is attached directly to the top plate. The two growth furnaces are side by side and are installed between the two battery packs primarily for thermal symmetry between the furnaces and the batteries. Since heat is dissipated into the battery packs the batteries should still be warm enough to exhibit good performance during the second experimental cycle which occurs about 2 days after the first. Also for thermal reasons, the electronic controls are located at the bottom of the payload to minimize the effect of furnace heat on the electronic components.

Because the furnaces are sealed to maintain a dry, inert atmosphere, they must be vented overboard. Therefore, the top mounting plate will be provided with NASA's standard "battery box" vents, which explains the spacers from which the upper battery compartment is suspended. The vent lines are provided with additional relief valves to maintain a slightly elevated pressure around the experiment. The lower end plate of the lower battery compartment is circular and nearly fills the diameter of the GAS container to restrict air circulation between the heated growth furnace portion of the payload and the electronic portion. It also provides additional mounting area for the control electronics. Lateral stabilizers are also attached to this plate.

The battery compartments are made of linen-based phenolic sides and type 5052 aluminum end plates. Stainless steel tie rods clamp the end plates together, placing the phenolic side panels in compression.

The two furnaces are enclosed in type 6061 aluminum cylinders which are sealed with type 5083 aluminum heads screwed to the cylinders. O-rings in this joint provide hermetic sealing. Each head is shared by both furnaces resulting in a very rigid but compact assembly.

THE FURNACE

The GaAs boule is at the center of each furnace. Because of the high temperature (1238°C) required for melting and the presence of highly reactive arsenic vapor at that temperature, the boule is sealed within a quartz ampoule. In order to avoid freely floating melt and the accompanying effects of Marangoni convection, a spring loaded piston is also enclosed within the ampoule. The piston is made of graphite and the springs are leaf springs made of boron nitride. These materials were selected because of their high temperature durability and their resistance to the effects of As vapor. These components can be seen in Figure 2, a cross section view of the furnace.

The quartz ampoule is instrumented with several thermocouples sheathed in Inconel and placed within an alumina tube wrapped with platinum heater windings. The windings are graduated in a configuration that produces a nearly linear temperature profile along the GaAs boule so that the melted end is about 60°C hotter than the solid, seed end.

The heater/ampoule assembly is enclosed in rigid fibrous ceramic insulating cylinders. Because of variations in conductivity over temperature, the inner, hence hotter, insulation is yttria-stabilized zirconia optimized for ultra-high temperature applications, while the outer, cooler, insulators are of bonded fibrous alumina. This combination has been found to minimize heat loss. To survive the vibration tests, as well as launch, these rigid but frangible components must be tightly nested within the aluminum enclosure. Zirconia felt is used in the joints to provide a cushion for this purpose as well as to reduce open passageways for additional heat loss.

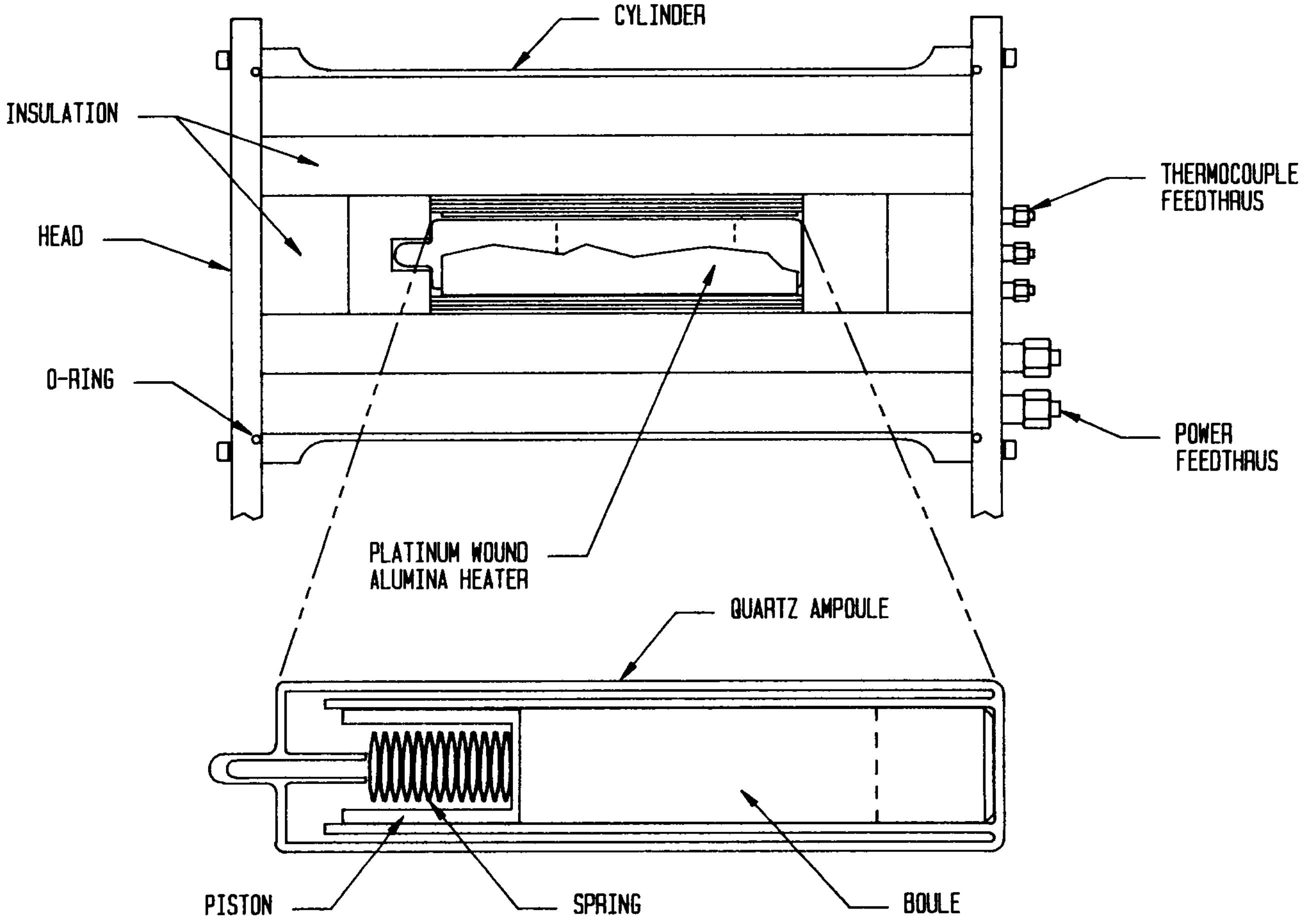

Figure 2. Section View of the GaAs Crystal Growth Furnace.

ELECTRICAL SYSTEM

The electrical system is composed of four major components: The battery power source, the furnace control system, the data acquisition system, and the microacceleration measurement system.

Prime power is derived from an array of 256 alkaline-manganese dioxide cells arranged in a parallel/series configuration to provide 48 volts when fresh. The cell is a size F (MN2300) which we purchase as an assembly of eight cells in a 12-volt lantern battery. After removing the battery case, the semipotted assembly of cells is installed into the urethane foam lined battery compartment. Wires are soldered to the nickel straps already welded to the cells to complete the series connection necessary to develop 48 volts. Each of the eight series strings is wired to a fuse block in one corner of the battery compartment. Thus, each string can be independently checked for continuity and state of charge after the battery compartment is completely closed and secured. Diodes protect a defective string from discharging the good strings. The fuses are installed after all connections are made, verified, and insulated.

Furnace control is accomplished with a microcomputer programmed for the warmup, equilibration, recrystallization and annealing cycles required for good crystal growth. The microcomputer used is a Tattletale IV® which uses a CMOS 6303 microcomputer chip which utilizes an enhanced version of the Motorola 6801 instruction set. It has 11 A/D inputs, 16 digital I/O, and is programmed in BASIC. Custom signal conditioning circuitry designed at GTE provides thermocouple amplification and ice point compensation using AD595 ICs. The amplified outputs are fed to A/D inputs of the Tattletale. The control thermocouple signal passes through a custom circuit which also expands the 1100°C to 1300°C range for high resolution of the crystal-growing temperature range. Voltage and current through the furnace are similarly monitored using AD202 isolation amplifiers.

The program monitors furnace temperature and battery power every 15 seconds, recalculates a new power level, converts that to a duty factor for the power switching transistor (MOSFET) and outputs this duty factor as a 12-bit serial number. Another custom circuit holds the 12-bit number, converts it to a duty cycle operating at 22 Hz which drives the power MOSFETs through an optical isolator followed by a Schmitt trigger to recover switching speed. The efficiency of this system results in very little power loss, about 1%, and the thermal stability of the furnace is a fraction of a degree. A typical plot of power and temperature is shown in Figure 3.

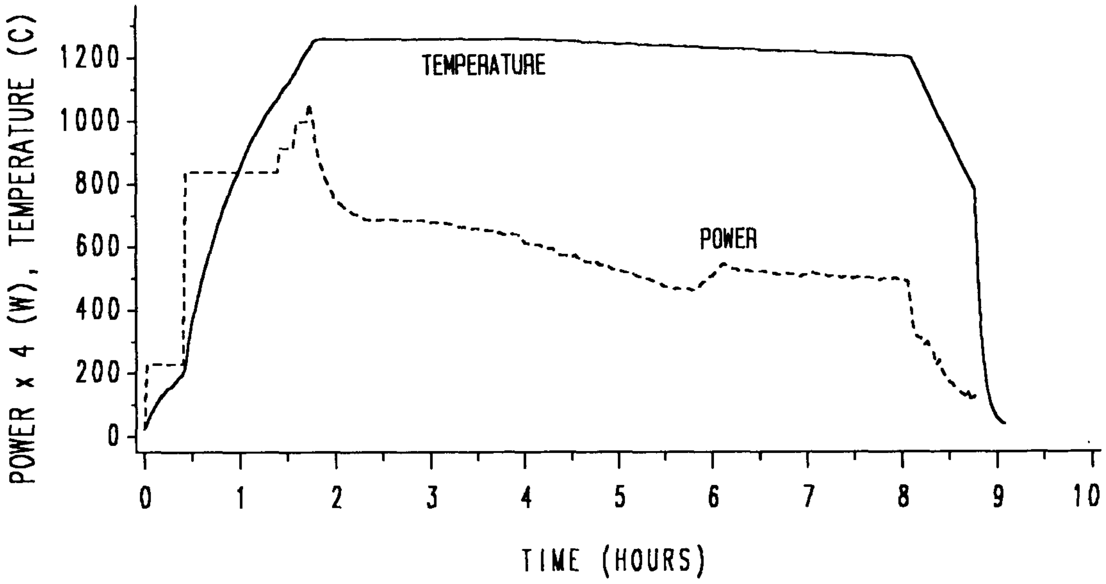

Figure 3. A Typical Experiment Cycle.

The program has been written to include a waiting period at start-up so that the experiment can be scheduled to take place during the astronaut's sleep period when vibration is at a minimum. The time delay will be based on the mission schedule published prior to flight which may, of course, change at the last minute, precluding the most optimal conditions for crystal growth. The program also prevents a subsequent restart in the event of a false trigger pulse.

Data acquisition is largely accomplished by the same microcomputer that is controlling the furnace, and it takes place concurrently with the control program. At each update of the furnace both the control temperature and power level are stored in RAM. Every two minutes a full complement of data including voltage, current, six furnace thermocouple temperatures and one on-board thermistor temperature are stored. At completion of the experiment, data continue to be collected at a slower rate for about two days. Additional data including two more furnace temperatures and several temperature points distributed throughout the payload are recorded by a second Tattletale. Some of the recorded data are extraneous to the crystal growth experiment, *per se*, but it is stored for future reference and for diagnostic purposes in the event of experiment failure.

Acceleration measurements in three axes will be made throughout the recrystallization period. Three Sundstrand QA2000 accelerometers are mounted orthogonally in a block. These accelerometers have a threshold signal near 10^{-5}g, and our recording range is set to cover from this point to about 10^{-2}g. Each accelerometer is attached to a small circuit card with signal conditioning circuitry and a Tattletale IV mounted in tandem with a 4MAT® memory expansion board. Since the Tattletale cannot measure negative signals, the signal conditioning consists of precision half-wave rectification and inversion of the negative signal so that 2 positive signals can be sent to 2 separate A/D channels. The memory expansion board in combination with the Tattletale provides over 150K bytes of memory for each axis of acceleration. A system malfunction in one axis will not affect data collected from the other two accelerometers.

Altogether, there are 7 Tattletale microcomputers on board: 2 for the 2 separate furnace controls, 2 for supplementary data collection, and 3 for the 3 axes of acceleration.

MODELING

Extensive thermal modeling using NOTHAN, a GTE-written program particularly efficient for nonlinear axisymmetric studies such as this one, was performed for the design of both the payload and the furnace. The furnace was modeled in detail to design the heater winding configuration to establish a nearly linear thermal gradient over the length of the boule. A linear gradient is desirable so that a steadily dropping temperature results in a uniform growth rate of the crystal. This model also was useful in the determination of optimal insulation configuration, selection of temperature monitoring points, and other design details of the ampoule and furnace.

The model was also used to predict overall heating of the payload during an experimental run and the cooling rate of the battery packs subsequent to the run. These data were used to suggest that the second experiment should be performed about 48 hours after the first one begins.

CURRENT STATUS

Presently the payload is nearly complete and could be readied for flight on short notice. Ground-based crystal growth is continuing, and experimental improvements may be incorporated into the payload in the future. Processing through Goddard is in its final stages. It is hoped that a flight opportunity will be available soon after flights are resumed.

ACKNOWLEDGEMENTS

Thanks are due to Dr. Joseph Proud and Dr. John Gustafson for initiation, guidance, and support of this program. Members of the research team, James Kafalas, Dr. Brian Ditchek, Kirk Beatty, and others have been of invaluable assistance. The support of Dr. Richard Lauver and others at NASA is also gratefully acknowledged.