AN ADVANCED MICROCOMPUTER DESIGN FOR PROCESSING OF SEMICONDUCTOR MATERIALS

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ABSTRACT

In the GAS 330 payload, under development by SSC, two Germanium samples doped with Gallium will be processed. The aim of the experiments is to create a planar solid/liquid interface, and to study the breakdown of this interface as the crystal growth rate increases.

For the experiments a gradient furnace has been designed which is heated by resistive heaters. Cooling is provided by circulating gas from the atmosphere in the cannister through cooling channels in the furnace. The temperatures along the sample are measured by Platinum/Rhodium thermocouples, type S.

The furnace is controlled by a microcomputer system, based upon the processor 80C88. A data acquisition system is integrated into the system.

In order to synchronize the different actions in time a multitask manager is used. Some of the features in the microcomputer system are:

* 16 thermocouple channels
* Digital PID temperature controllers
* Pulse duration modulators for furnace heating/cooling
* 24 analog channels
* Monitor of housekeeping signals
* 1 Mbyte data acquisition system

INTRODUCTION

Since 10 years Sweden has performed materials science experiments in space. The program has involved repeated participation in sounding rocket experiments, aeroplane flights in parabolic trajectory and the preparation of experiments for long duration flights. Within the latter category three reservations for GAS experiments have been made. Of the three payloads associated with these reservations one is ready for flight (G-329) and one is being designed and constructed (G-330). The experiment for the third payload (G-541) is not yet selected.

The G-329 payload contains a 'Space Foundry' for the processing of 8 kg of lead-tin samples of different composition. This payload is described in detail in the Proceedings of the 1985 GAS Experimenter's Symposium and will be omitted in this presentation.

This paper is instead devoted to the G-330 experiments on semiconductor crystal growth.

In the G-330 the breakdown of planar solid/liquid interface will be studied when the growth rate increases from stable to unstable conditions. The samples to be processed are Germanium rods doped with Gallium. The samples have the dimensions Ø 10 x 110 mm.

The breakdown of a planar solid/liquid interface is important to study both from a theoretical and a practical point of view. The conditions for constitutional supercooling to appear are dependent on the convection, and instability occurs theoretically easier in a non-convection case. On the other hand perturbations are less likely to occur during growth from a melt without convection, which would act in a stabilizing way. These phenomena are best studied in a crystal where interface demarcations are used to study the shape of the solid/liquid interface.

GAS 330: AN ADVANCED GAS PAYLOAD FOR PROCESSING OF SEMICONDUCTOR MATERIALS

Two experiments will be run sequentially in separate furnaces. Each furnace will be equipped with a cooler connected to a common paraffin heatsink, capable of storing the energy generated during the processing of one sample. Each experiment will take approximately two hours to process. Before the second experiment can start, an intermediate period of 10 hours is necessary in order to radiate to space the energy, which has been stored in the heatsink during the first experiment.

Electrically controlled gradient furnace

A furnace will be used, in which the gradient can be controlled by resistive heaters and a gas cooling system, see figure 1. The advantage with such a furnace, is that moving parts that may disturb the microgravity condition can be avoided.

The furnace body consists of an Aluminium-Silicate crucible with grooves for the heater wires. The thermocouples are positioned on the inside of the crucible so that a good thermal contact with the sample can be achieved.

For the regulation of the temperature profile in the furnace, it will be possible to use up to

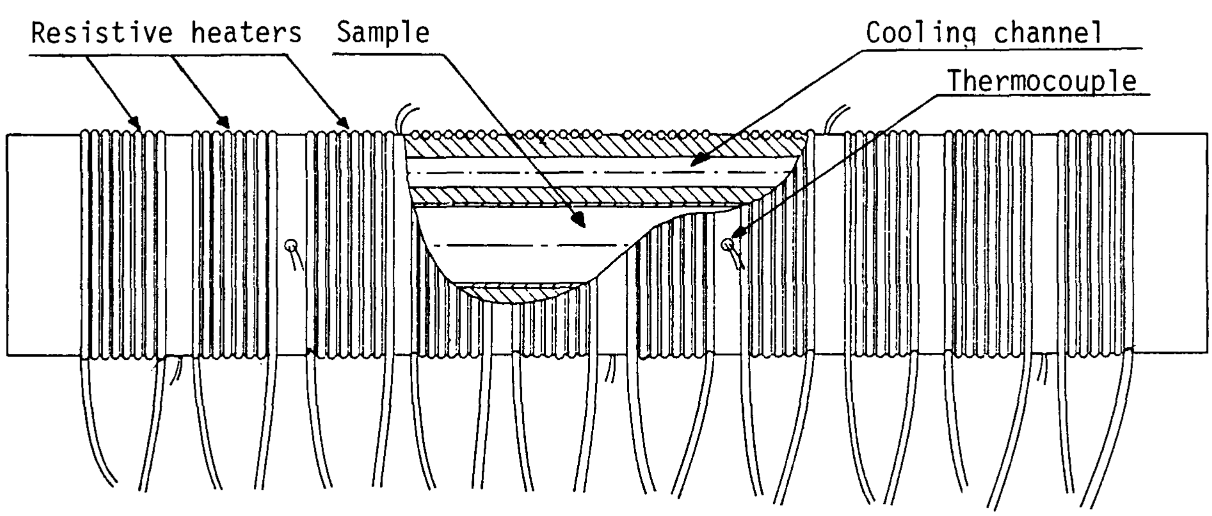

Figure 1. Electrically controlled gradient furnace.

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10 resistive heaters which are individually controlled by digital PID-controllers. The heating elements consist of Kanthal resistance wires.

Cooling gas, taken from the atmosphere inside the GAS cannister, will circulate through cooling channels along the crucible. The cooling channels will be placed between the sample and the heaters. With this arrangement the cooling effect will be distributed along the sample. The cooling gas will be heated on its way along the sample, thereby giving reduced cooling effect towards the hot end of the furnace.

Process sequences

The two experiments will be run through four phases.

In phase one the sample will be heated in an isothermal mode to a temperature approximately 20^{o}C below the melting point. During this phase the heating power will be slowly increased to avoid thermal stress in the crucible.

In phase two the cooling gas will start to flow and the power to the heaters will be regulated to create the predetermined temperature gradient over the sample. During the establishment of the temperature gradient it is important not to melt the whole sample. If the sample should melt, the result would be a polycrystalline Germanium crystal after the solidification.

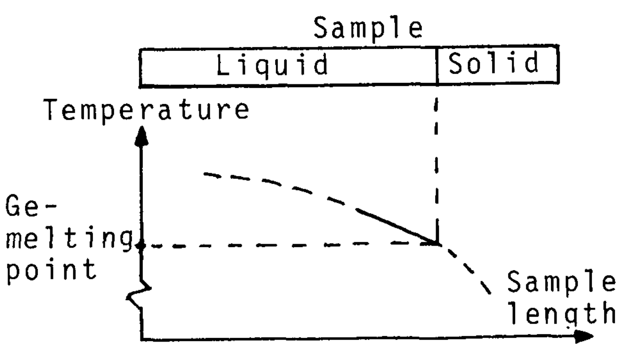

Figure 2. Temperature distribution in the sample.

In phase three the temperature gradient will be stabilized and kept constant in order to homogenize the dopant concentration in the sample, this is illustrated in figure 2.

In phase four the temperature will be lowered and the directional solidification will start. In this type of experiments it is important to have a linear temperature gradient 10-20 mm in front of the solid/liquid interface. The solidification rate for the crystal will be varied in time according to figure 3.

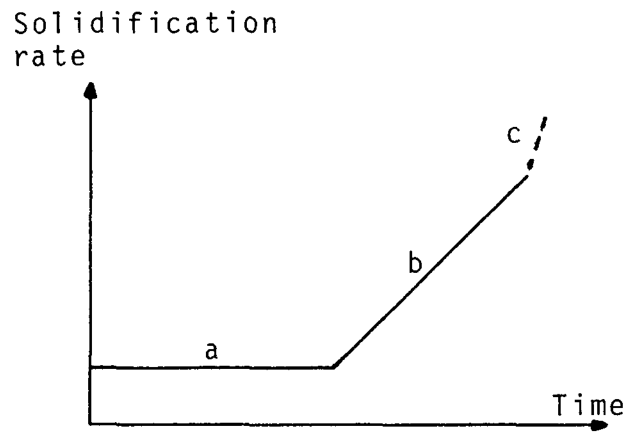

Figure 3. Crystal growth rate.

a. Constant solidification rate.
b. Linear increase of the solidification rate.
c. Maximum solidification rate with all heaters switched off and maximum cooling.

MICROCOMPUTER SYSTEM

The sample processing will be controlled by an 80C88 microprocessor. The same processor will take care of all data acquisition.

The microcomputer system consists of five printed circuit boards: CPU board, analog measurement board, power control board, thermocouple amplifier board and mass storage memory board. (See figure 4).

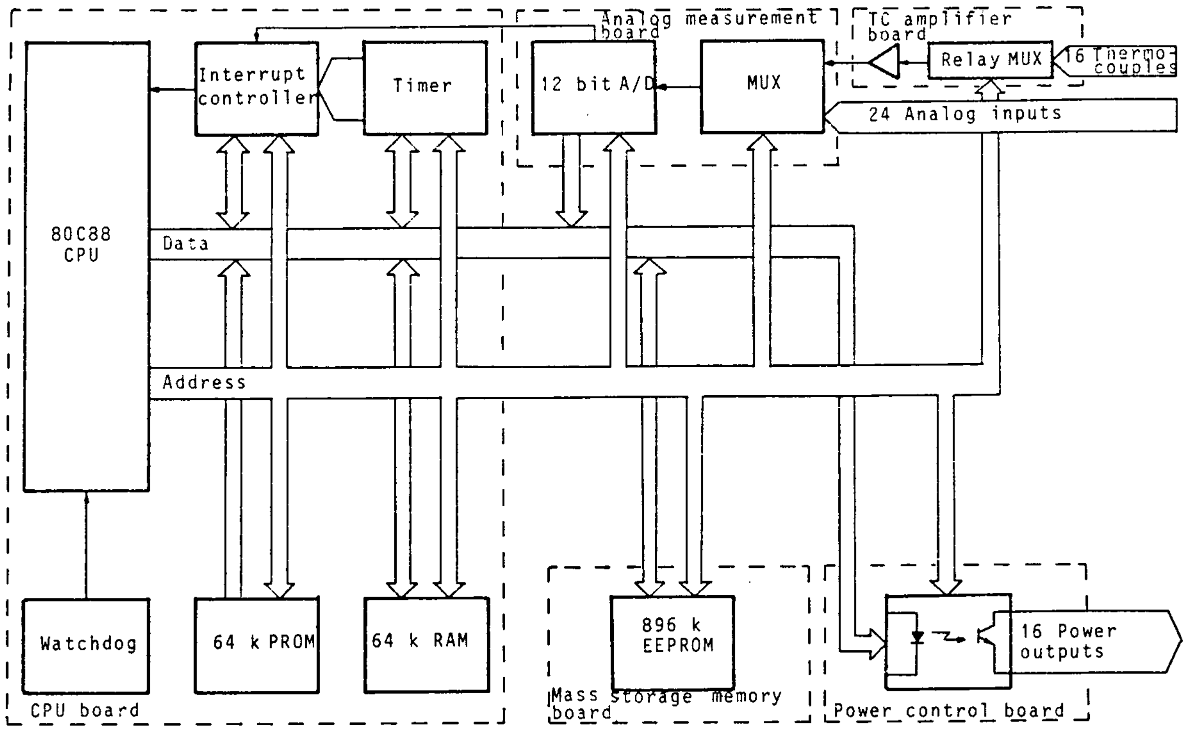

Figure 4. Block diagram.

Processor 80C88

The 80C88 CPU, with 16 bit internal architecture and 8 bit data bus interface, has a direct memory adressing capability of 1 Mbyte. This enables us to integrate the data acquisition system into the control system, since the memory area available for this will be sufficient. A clock frequency of 5 MHz thus gives the system capacity to handle data acqusition, as well as process control.

The CPU board is provided with a 'watchdog' that will reset the system if for some reason the execution is not proceeding as planned. After such a reset or in case of a voltage drop in the power supply, the processor will resume execution from a suitable point in the process. This is achieved by keeping the process status in EEPROMs.

A programmable timer in combination with an interrupt controller makes it possible to create software pulse duration modulators, and a multitask manager that will make the processor switch execution between different tasks at certain intervals. Among the tasks to be implemented is a monitor that will supervise housekeeping signals so that critical conditions in the system can be avoided. Other tasks are thermocouple sampling, A/D conversion, digital PID control, and data storage.

Thermocouple A/D conversion

The most sensitive part of the system is the temperature measurement. Thermocouples, type S, are fixed in the crucible wall of the furnace, giving a voltage level per degree Celsius that is in the µV range. The required relative temperature accuracy (better than ±3^{o}C) corresponds to a voltage accuracy in the order of 10 µV. This forces us to choose highstability low-noise components for the temperature measurements. Furthermore, the design of the printed circuit boards becomes delicate. Four-layer boards are used.

The thermocouple signals are multiplexed by relays that introduce a low thermal emf and low dynamic noise, so that the total error stays well below a few microvolts. Up to 16 thermocouple inputs can be connected. An instrumentation amplifier, with gain setting resistors included in the package to reduce temperature drift, amplifies the signal to a suitable level (0-15 V). This signal is fed from the thermocouple amplifier board to the analog measurement board.

The analog measurement board is featured with 25 channels. One of these channels is used for the multiplexed thermocouple signals and the rest of the channels for housekeeping signals. A CMOS multiplexer distributes the selected signal to a 12 bit A/D converter, which supplies the processor with the required input data.

Digital PID controller

An algorithm for a modified digital PID controller will control the temperature profile along the sample. This means that the formula for the conventional analog PID controller has been adopted and converted by replacing integration with summation, derivation with differentiation and keeping the sampling intervals short. Some of the major shortcomings of the analog PID controller can easily be removed, and motivates the word "modified".

Among the ameliorating features for this application are:

- compensation for nonlinear characteristics of the thermocouples. The registered voltage will be used as an index in a table stored in memory where the corresponding temperature is kept.

- compensation for integral windup, i.e. removing the overshoot that occurs with an analog controller, due to saturation after large changes of the reference value.

- compensation of controller output, due to other conditions than actual control error.

The power to each heater and to the cooling system is pulse duration modulated. Separate controllers determine the pulse durations. A number of control loops will aim to make the temperature profile follow a preprogrammed temperature sequence.

Pulse duration modulation

The pulse duration modulation is interrupt driven. The timer will supply a system clock signal with a period of 10 ms, which will generate the highest priority interrupt. The interrupt service routine will handle the timesharing between tasks and will clear all power outputs. The time between these clock interrupts can be viewed as split up into two parts, see figure 5. All measurements

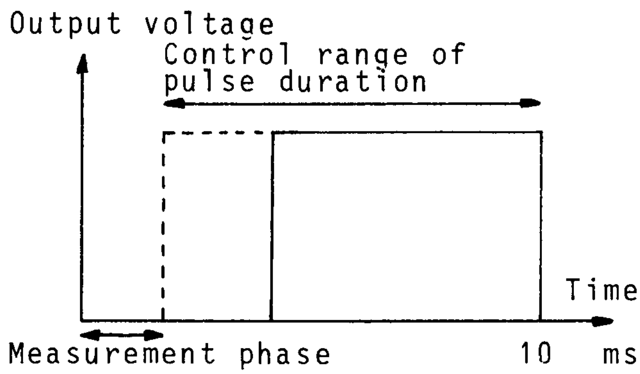

Figure 5. Measurement timing.

take place in the first part, when heater voltage is off. This is necessary to achieve accurate readings. The second part corresponds to the maximum pulse duration allowed.

When the clock interrupt has occurred, the time until the first raising edge of any power output will be set up in the timer. The timer generates another interrupt that will set that specific channel's output high when the specified time has elapsed. The time values will be kept in increasing order in a table stored in memory, so that the output with the longest pulse duration will be switched on first, and the one with the shortest will be switched on last. The next system clock interrupt sets all outputs low and completes one pulse duration modulation period.

The power control board features the output interface to the heaters and cooler. Up to 16 output channels are supplied.

Data storage

The code and data areas for the software take 128 kbytes of the total address space of 1 Mbyte. That leaves 896 kbyte for data storage.

The mass storage memory board is supplied with EEPROM circuits, which enables us to dynamically store various process information supplied by the data storage task. Besides temperatures, the microgravity condition will be registered, as well as a certain amount of housekeeping signals such as cannister temperature and pressure.

SUBSYSTEMS

Many of the design concepts used in the first SSC GAS payload (G-329) will be reused in the G-330, i.e. the structure, the thermal control system using a paraffin heatsink and the Lithium battery system. These systems are described in detail in the proceedings of the 1985 GAS Experimenter's Symposium.

DEVELOPMENT STATUS

The furnace and the microcomputer system have been designed and the software development is going on. The development and construction will continue with the goal to have the G-330 ready for a flight in 1989 if the Space Shuttle flight opportunities permits it.