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CONTROL SYSTEM FOR GLASSING HOT PRESSES

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Equipment Engineering

June 13, 1984

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ABSTRACT

A software programmable control system has been developed that automates the glass fusing process used in the production of semiconductor thermopile elements. The new control system replaces an older, mostly manual, electro-mechanical design. This report describes the new control design and its functional features.

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INTRODUCTION

Glassing hot presses are used in two different steps in the manufacture of semiconductor thermopiles. The first use is to fuse together stacks of sliced semiconductor material, and the second use is to fuse together sections cut from the stacks (channels) to make thermopiles. [Thermopiles are components of the radioisotopic thermoelectric generator (RTG), as shown in Appendix A.]

Stacks are made up of thin slices of suitably doped silicon-germanium alloy, coated with an insulating glass slurry and stacked alternately N and P doped types. The stacks are placed into the glassing hot press and processed to melt the glass and fuse the assembly into a solid, stable mass. During processing the temperature, atmosphere, and compressive force applied are all controlled by the microprocessor-based controller and are varied simultaneously in a complex manner. The combination of these three parameters must be precisely controlled to obtain glass-semiconductor adherence, to avoid cracking of semiconductor elements, and to obtain proper glass thickness.

The atmosphere within the process chamber changes several times between three different conditions: (1) vacuum, (2) oxygen at 75-mm pressure, and (3) argon at 760-mm pressure. The temperature within the chamber varies, ranging from room temperature to about 890°C for stacks and up to about 770°C for thermopiles. The compressive force applied ranges from about 10 to approximately 750 lbs for stacks and up to 505 lbs for thermopiles. All of the variables (compressive force, atmosphere, and temperature) must be controlled simultaneously with a related time-amplitude profile.

The glass coated semiconductor material to be fused is placed within a ceramic fixture mold (Figures 1 and 2) along with a thermocouple. The loaded fixture is placed between the ram elements (ceramic rods) in the chamber. The fixture thermocouple is connected through a vacuum feedthrough to a datalogger recorder. The last step in loading the system with material to be processed is to lower the cylindrical-shaped vacuum chamber/oven down around the ram and material in the ceramic fixture mold. The process chamber outer walls are raised or lowered by hydraulic means. An interlock system prevents raising the chamber unless the atmosphere pressure within is equal to the outside pressure.

The chamber cylinder contains an electrical heating element with an associated thermocouple sensor. The part to be processed (piece part) is heated primarily by radiant heat transfer. Note that the temperature indicated by the thermocouple located at the piece part lags the temperature indicated by the oven thermocouple by a long time constant.

The total processing time per batch is approximately 5.5 hours for stacks and approximately 5.0 hours for thermopiles, using either the old or the new control design. However, the new control requires no operator attention once the process is started. With the original process control, operator attention was required almost constantly throughout the process. All glassing hot presses at the General Electric Neutron Devices Department (GEND) are rapidly being upgraded to the new control system.

Figure 1. Ceramic Fixture Mold for Stacks

Figure 2. Ceramic Fixture Mold for Thermopiles

SYSTEM DESIGN

A block diagram of the overall glassing hot press is shown in Figure 3. A brief description of the function of each block follows.

Figure 3. Block diagram - Glassing Hot Press

MICRICON* PROGRAMMABLE CONTROLLER

The microprocessor-based controller, as configured, provides two time-amplitude profile outputs. One is used to control chamber temperature and the other controls ram force. The Micricon also provides eight relay contact outputs which are used to control valves or to arm/disarm various functions. Software programs may be loaded into the controller memory from its keyboard or by tape recorder. The controller's clock may be controlled (start/wait) either by internally programmable process variable limits or by external contact closure. By tying external instrumentation (pressure meters, data recorder, etc.) into the controller external clock control jack, very powerful additional decision making capability is implemented into the overall system control.

*Trademark, Research, Inc.

Heat Exchanger

During the cool down portion of the process, gas within the process chamber can be circulated through a water cooled heat exchanger to speed up the rate of cooling. Operation of the heat exchanger is under control of the Micricon controller.

Recorder

A Digistrip* recorder is used to measure and/or record process parameters such as oven and piece part temperature, chamber pressure, compressive force, time, etc. This digital datalogger type instrument also provides eight relays which are associated with programmable amplitude set points. The contacts of several of these relays are connected in series with the contacts of relays in the Micricon controller, and then are connected to the controller external clock control jack. The relays in the Micricon controller can then enable or disable the feedback of set point information and its control upon the Micricon controller clock. This feature can have the effect of dynamically switching control of the process between the driving force (Micricon) and the process monitor (datalogger) to tighten system performance.

Pressure Meters

Two pressure sensors and readout chassis are provided to monitor the process chamber gas pressure. These instruments provide 0 to 1 torr and 0 to 1000 torr full scale sensitivities. The pressure sensors are Baratron** units that provide high accuracy pressure measurement, independent of the type gas being measured.

Oven Heater Drive

The process chamber is heated electrically to melt the glass separating the semiconductor elements. As mentioned previously, the combination of heat, compressive force, and atmosphere must be precisely controlled to obtain glass-semiconductor adherence, avoid cracking of semiconductor elements, and obtain proper glass thickness.

A block diagram of the heat control loop is shown in Figure 4.

*Trademark, Kaye Instruments Co.

**Trademark, MKS Instruments, Inc.

Figure 4. Block Diagram - Heat Control Loop

Argon and Oxygen Supplies

Supplies of high purity argon and oxygen are provided. The introduction of these gases and/or vacuum into the processing chamber is controlled by the Micricon programmable controller.

Vacuum Pump

A mechanical (two stage rotary-oil type) vacuum pump is provided to evacuate the processing chamber.

Hydraulic System

The hydraulic system consists of a servo-controlled ram that is used to provide compressive force (in the range of 0 to 1000 pounds) to the product being processed. Manually controlled provisions are also available to raise or lower the chamber housing so that material to be processed can be loaded into, or taken out of, the chamber.

A block diagram of the force control loop is shown in Figure 5.

Figure 5. Block Diagram - Force Control Loop

In the original control design, copper tubing was used throughout the hydraulic system. This tubing proved to be highly prone to leak oil, causing a cleanliness problem as well as possible product contamination. The new design uses all stainless steel fittings, valves, and tubing. Oil leaks have been eliminated.

An example of a software program for the Micricon controller is shown in Appendix B. The significant factor to be noted is the simplicity of the program. At GEND, software for systems using programmable controllers such as the Micricon are written and maintained by the process engineers rather than the equipment engineers. This powerful tool in the hands of the process engineer allows him to easily study and optimize all process parameters.

Note that the datalogger is also a microprocessor-based instrument and that, in addition to recording parameter amplitude as a function of time, it also contributes significantly to the system control function, as previously explained. This instrument must also be programmed for the specific application. An example of a datalogger program is shown in Appendix C. This software is also written and maintained by the process engineer.

Additional photographs of the glassing hot press are shown in Appendix D.

CONCLUSIONS

The new control system provides the following advantages over the original electromechanical control: (1) fully automatic rather than mostly manual; (2) software programmable; (3) improved repeatability and precision of control; (4) oil leaks eliminated; (5) improved monitoring of process parameters; (6) reduced labor costs; (7) operator independent process control; (8) improved safety features; and (9) improved system reliability.

ACKNOWLEDGMENTS

Two GEND employees were especially helpful in accomplishing the success of this process. They were Scott S. Brown, Manufacturing Operations Engineer, and Edwin A. Sloan, Senior Specialist-Manufacturing Operations Engineering. These individuals provided vital information concerning the parameters to be controlled in this manufacturing operation.

APPENDIX A
RADIOISOTOPIC THERMOELECTRIC GENERATOR

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Figure A-1 is a cutaway view of a radioisotopic thermoelectric generator. The thermal-to-electrical conversion is provided by a thermopile. This thermopile is fabricated from silicon-germanium alloy material which has been fabricated from P-type and N-type semiconductor materials. This raw material is sliced into thin wafers and reassembled in alternate layers to provide 26 thermocouple junctions. These thermocouple junctions are electrically in series and thermally in parallel.

The top end of the thermopile is maintained at an elevated temperature as provided by the heat source. The lower end of the thermopile is kept near ambient temperature by the use of appropriate heat sinking. This heat sink provides the functional characteristic of an RTG, in that a differential temperature must be maintained across the thermopile.

Electrical pick off is provided by gold leads which have been bonded to the thermopile end wafers and to a ceramic feedthrough which is welded in the base plate.

Figure A-1. Radioisotopic Thermoelectric Generator

Silicon-Germanium Alloy Fabrication (Figure A-2).

Four raw materials are required to fabricate the doped silicon-germanium alloy materials. Silicon and germanium are combined with boron as dopant material to fabricate P-type semiconductor material. Phosphorus is used in conjunction with silicon and germanium to fabricate N-type semiconductor material. These raw materials are weighed and mixed in the proper proportions and placed in a crucible within a chill cast system. This material is processed through a temperature profile and is melted by the use of induction heating. After the material has been melted it is immediately poured into a water-cooled, rodium-plated copper mold where the material solidifies. Once the material has been removed from the molds, it is reduced in size by the use of a mortar and pestle made from hardened tool steel. The crushed material is then placed in agate jars containing various sizes of agate balls, and is milled. This milling provides a powdered material which is processed through a series of sieves to obtain the proper particle size distribution. Most of the powder is small enough to pass through a 400-mesh sieve.

Weighed amounts of the powder are then loaded into a die which is subsequently placed in a die train and loaded into a vacuum hot press. The vacuum hot pressing operation provides a sintered compact approaching theoretical density by the application of temperature and pressure profiles. (The temperature reaches approximately 1295°C and the pressure reaches $28,000\text{ lb/in.}^2$.) At the completion of the hot pressing operation, the slug of material is removed from the die and is ground to form a block. These material preparation steps are the same for both P-type and N-type materials.

Figure A-2. Thermoelectric Material Preparation

Thermopile Assembly (Figure A-3)

The semiconductor blocks are sliced into wafers 0.009-in. thick. The wafers are then cleaned and processed through an oxygen atmosphere furnace to oxidize the wafer surfaces. At this point, a slurry of glass frit in an appropriate binder is screen printed on one side of each wafer. The wafers are then fired to remove the binder. Eleven P wafers and 11 N wafers with glass layer applied, are then stacked alternately to provide a 26-wafer composite. This stack is heated under pressure until the glass flows. The resultant stack is sliced into channels, a glass layer applied to each channel using a glass transfer tape, and the binder fired out. Two channels are assembled together and reprocessed through the hot press until the glass flows joining the two channels.

The resultant thermopile consists of 26 bonded wafers in each of the two channels.

Figure A-3. Thermopile Glassing

Thermopile Interconnection (Figure A-4).

After verifying that the elements are electrically isolated and unbroken, semiconductor microcircuit techniques are used to interconnect the 26 elements of each channel electrically in series. The thermopile ends are first polished and cleaned to remove any organics and oxide layers. Each end is then direct current sputtered using tungsten. Photolithographic techniques are used to define the metal areas into interconnecting contacts. After etching, the interconnected piles are cleaned and electrically inspected. The final step in thermopile fabrication is the attachment of output connections. Two gold ribbons are bonded to the cold end of the thermopile using thermocompression bonding.

Figure A-4. Thermopile Element Interconnection

APPENDIX B
SOFTWARE PROGRAM, MICRICON CONTROLLER

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MICRICON PROGRAMMER
BUILD PROGRAM

SEGMENT#	001	002	003	004	005	006	007	008	009	010	011	012	013	014	15	020	
PR1	15	15	600	600	600	880	870	870	870	720	720	720	15	15	15	15	
PR2	1	1	1	1	1	1	1	93	93	93	1	1	1	1	1	2	
TIME	1	5	15	1	48	10	39	15	70	15	1	5	30	60	1	1	
EVENT ON 1		X			X	X	X	X	X								VAC. VALVE
EVENT ON 2			X														OXY. VALVE
EVENT ON 3										X	X	X	X	X			ARGON VALVE
EVENT ON 4												X	X	X			HEAT EXCHANGER
EVENT ON 5			X	X	X	X	X	X	X	X	X	X	X				HEAT ENABLE
EVENT ON 6											X						HOLD-ABOVE 760°C
EVENT ON 7				X													HOLD-BELOW 500°C
EVENT ON 8																	HOLD-ABOVE 660°C
CYCLES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
NEXT	002	003	004	005	006	007	008	009	010	011	012	013	014	015	015	020	
ALARM GROUP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Program for Wafers

MICRICON PROGRAMMER
CONTROL SETTINGS

	LOOP 1	LOOP 2	LOOP 3	LOOP 4	LOOP 5	LOOP 6	LOOP 7	LOOP 8
GAIN 0 TO 64.12	50	1						
RESET 0 TO 60.23	20	0						
RATE 0 TO 8.50	0	0						
HI LMT 100 %	100	100						
LO LMT -100 %	0	0						
FILTER 1 TO 5	0	0						
CONTROL DIR/REV	REV	REV						
CYCLE TIME 4,8,17,34	0	0						
DEADBAND 1 TO 10 %	0	0						

MICRICON CONTROLLER
ALARM SETTINGS

ALARM GROUPS							
ALARM LIMITS	LOOP 1		LOOP 2		ALARM ASSIGNMENTS	LOOP 1	LOOP 2
	1	2	1	2		1.1	1.2
HIDV	15		100		HIDV SSR	NB	N
					HIDV PG-HLD	N	N
					HIDV PG-ABT	N	N
LODV	15		100		LODV SSR	NB	N
					LODV PG-HLD	N	N
					LODV PG-ABT	N	N
HIPV	900		100		HIPV SSR	NB	N
					HIPV PG-HLD	N	N
					HIPV PG-ABT	Y	N
LOPV	0		0		LOPV SSR	NB	N
					LOPV PG-HLD	N	N
					LOPV PG-ABT	Y	N
					BOUT SSR	NB	N
					BOUT PG-HLD	N	N
					BURNOUT	Y	N

APPENDIX C
DATALOGGER PROGRAM

BLANK

1	W.S.421 GLASSING HOT PRESS															
0249	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
100	PART	FURN	FORCE	PRESS	VACUUM			PART								
200	TEMP	TEMP	POUNDS	1k TORR	1 TORR			TEMP								
300																
400																
500																
600																
700																
800																
FUNCTION	08.000	08.000	14.000	15.000	16.000	00.000	00.000	08.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
200	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
300	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
400	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
500	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
600	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
700	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
800	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
INPUT 1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
300	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
500	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
600	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
800	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
INPUT 2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
300	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
500	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
600	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
800	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
CONFIGURATION NUMBER = 400000 600100 001000 420001																

0249	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
LIMIT 1	500.0H	920.0H.	.	.	.	.	.	760.0H.	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
300	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
500	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
600	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
800	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
RELAY 1	1	2	.	.	.	.	.	4	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
300	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
500	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
600	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
800	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
LIMIT 2	.	.	.	.	.	.	.	660.0L.	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
300	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
500	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
600	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
800	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
RELAY 2	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
300	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
400	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
500	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
600	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
700	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
800	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

FNCTN	14 30	15 31	16 32	17 33	18 34	19 35	20 36	21 37	22 38	23 39	24 40	25 41	26 42	27 43	28 44	29 45
INPUT 1	47.0 0	0.0 0	117.0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
OUTPUT 1	3.6 0	0.0 0	22.8 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
INPUT 2	2550.0 0	3080.0 0	3390.0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
OUTPUT 2	509.0 0	619.0 0	778.0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
UNITS																
FNCTN	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
INPUT 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUTPUT 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INPUT 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUTPUT 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UNITS																
INTERVAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D
GLASSING HOT PRESS SYSTEM PHOTOGRAPHS

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Figure D-1. Glassing Hot Press System

Figure D-2. Plenum Chamber

Figure D-3. Servo Control Panel

Figure D-4. Servo Control Plumbing

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