The computer in manufacturing—Reduction of scrap by computer monitoring

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ABSTRACT

A computer furnace monitoring system was implemented as the first stage of a computer process monitoring system designed to provide better control of the process used to manufacture high power semiconductor devices. The purpose of the furnace monitoring system is to reduce scrap resulting from furnace malfunctions that are otherwise not detected in time to salvage the product. The system also improves reproducibility by maintaining a tight control of the elevated furnace temperatures (±2°C at 1250°C). Additional results of the system are greatly improved operation visibility during the run, increased furnace utilization as a result of computer assisted scheduling, and improved correlation of results among different furnaces.

The @ 2500 computer provides the process I/O necessary to monitor furnace temperatures as measured by thermocouples, sound alarms when deviations from the spec occur, store information for later analysis, plot furnace behavior, and assist in scheduling by calculating cycle times. It also provides the furnace operators with the ability to quickly and accurately determine furnace temperature at any time during the cycle. The real time foreground/background operating system of computer, based on a strict priority system, allows data analysis programs to run without disturbing the real time monitoring of physical parameters such as temperature.

The furnace operator's interface with the computer, a set of related programs accessed from a teletype by a single command, is also described. The system is user-oriented, and employs a conversational question and answer format that guides the operator through the various procedures. The system also incorporates error detection and correction methods to prevent mistakes from improperly entered data.

The computer is an effective tool for the reduction of cost resulting from scrap. It also provides the basis for an integrated monitoring system encompassing the entire manufacturing process.

INTRODUCTION

The computer has long been used by industry to handle payrolls, accounting, and various records, and by scientists for mathematical analysis, modeling, and simulation. A less explored area, however, is that of the computer as a manufacturing tool: the computer can play an important role in day-to-day operations in a manufacturing environment, where features such as memory technology, innovative architecture, and language syntax must pale in significance when compared to the manufacturing user's concern with the computer's effect on his product quality, amount and cost of defective material produced, and consequences of missing a production schedule.

The Westinghouse Semiconductor Division in Youngwood, Pennsylvania, is such a manufacturing facility. The production of high power semiconductor devices involves processing raw silicon in rod form through several diffusion, alloy, metallization, and passivation operations before the fabrication is complete, and the device is tested, packaged, and ready for use in its final form. The most advanced technology, however, cannot make a good product unless the many parameters which define the process recipe are accurately measured and controlled. Parameters such as furnace temperatures, gas flows, belt speeds, and humidity are critical to the manufacturing process, and even the most sophisticated gauges are useless unless someone can continuously observe them.

After investigating several alternatives, we decided to purchase a minicomputer to help reduce D.A. (defective apparatus) by monitoring some of these vital parameters. The monitoring of diffusion furnace temperatures was selected as the initial application because of relative ease of implementation (reading voltages generated by thermocouples) and the large potential return on investment. The furnace monitoring system would be the first step in establishing a real-time and historical data base of product characteristics and performance. Other important parameters, such as gas flows, could be added to the system, and the multi-tasking capability of the computer chosen would permit the execution of data analysis and design programs in a background model while real-time monitoring continued in the foreground.

The computer selected was a Westinghouse @ 2500. Important features include well-developed process-oriented hardware that can be fully controlled under a high level language (FORTRAN IV), and a multitasking operating system.
system which provides the foreground/background capability mentioned above. The computer was installed in October, 1974, and has been expanded to its present configuration of 64K core, 3.75 million (16-bit) words disk storage, incremental plotter, line printer, card reader, CRT computer console, TTY furnace system console, and process hardware consisting of a 40-point-per-second analog input system, external interrupt system, contact closure input system, and contact closure output system. Approximately 16K of core is reserved for the furnace monitoring software, and the computer operating system occupies another 12K. The rest of core is available for other real-time and batch programs. The computer is capable of running 1,024 tasks on a priority basis.

The name chosen for the computer, "DARIN," stands for "Defective Apparatus Reduction and Information," and reflects the computer's purpose: D.A. reduction and an improved product by providing information that was otherwise either unavailable or difficult to obtain.

THE DIFFUSION PROCESS

The first step of the manufacturing process is the diffusion of dopants into the sliced silicon to impart the desired electrical characteristics. From three to six separate diffusion operations are required for each device, and errors in this step of the process are usually irreversible.

Diffusion operations are carried out in large furnaces at elevated temperatures (1100 to 1250°C). The temperature must be maintained within a tolerance of ±2.5°C for extended periods (two to 40 hours). This soak cycle is followed by a six hour slow cool to quench the diffusion. Each furnace is equipped with a timer set to maintain the peak temperature for the prescribed time and then switch over to a programmed slow cool. If the timer or furnace controller malfunctions, the junction may be driven too deep. A run that is damaged in this manner cannot be salvaged. Since a run contains from 200 to 1000 slices, such furnace malfunctions are very costly, not only in terms of scrap generated, but also in production time lost when a replacement run must be started from the beginning of the four to six week process.

A closely related problem is that of scheduling the furnaces. It is very difficult for the foreman to keep track of the conditions of 51 furnaces, used for 11 processes, each with different behavior characteristics, and very few set for the same time cycles.

COMPUTER IMPLEMENTATION

Computer monitoring was instituted for half the furnaces in June, 1975. It has since been expanded to include all the furnaces. The system was designed not only to flag furnace malfunctions, but also to be a useful tool for the furnace operators.

As an example, one of the simplest features of the system, that of temperature reading, has proven extremely valuable. Before the computer was installed, furnace temperatures were checked by a slow and often inaccurate procedure: a thermocouple, attached to a chart recorder, was inserted into the center zone of the furnace, and allowed to stabilize for approximately 15 minutes, before the temperature was read as a voltage, which was then converted to degrees by a table. This method could only be used with empty furnaces; there was no way to read the furnace temperature while a run was loaded in the furnace.

In addition, the chart recorders, although calibrated weekly, were prone to drift, and could drift as much as 15°C without detection. Such errors were unknowingly passed on to the furnaces profiled with those recorders, and were an additional source of D.A.

SYSTEM DESCRIPTION

The furnace monitoring system is centered around a set of tables occupying approximately one-fifth of the core reserved for the system. The tables describe the real-time state of each furnace, as well as define temperature specifications and furnace characteristics. Each time a furnace is loaded, the tables are updated to reflect cycle information such as the times the run should enter cool down, be unloaded, and a projection of the time the furnace will be re-heated and ready for a new run.

The system is controlled by a master scheduling routine, MAST, which references the computer's internal 60 Hz clock and issues calls to tasks performing the following functions:

1. Calibrate analog-to-digital conversion system every 15 seconds.
2. Read and store furnace temperatures every 15 seconds.
3. Compare temperatures to specs every 60 seconds.
4. Record out-of-spec data on disk every 60 seconds.
5. Sound alarms as they occur.

TEMPERATURE MEASUREMENT

Furnace temperatures are measured with a type S (Platinum/Platinum-10% Rhodium) thermocouple located on the outside of the liner of each furnace. This configuration provides accurate detection of temperature behavior (±0.5°C), minimizes thermocouple exposure to corrosive elements in the furnace, and does not interfere with furnace loading or unloading.

The thermocouples are connected to the computer by screw terminals in a thermally insulated compartment used as a cold junction box (CJB). A resistance temperature detector (RTD) mounted within the CJB measures room temperature. This temperature is converted to millivolts and is added to the millivolt measurement of the type S thermocouple before the thermocouple measurement is converted to degrees centigrade.

The relationship between temperature and voltage for a
type S thermocouple is linear in the ranges 0°-30°C and
1000°C to 1300°C. The diffusion furnaces have soak tempera­
tures between 1135°C and 1250°C. Therefore, an equation
of the form \( Y = mX + b \) can be used to convert room
temperature, as measured by the RTD, to millivolts on a
type S thermocouple scale. A second equation of the same
form is used to convert millivolts, as measured by the
thermocouple with reference to the 0° established by the
RTD, to degrees centigrade. The equations are detailed
below.

\[
RT_dC = (RT_dM/V/0.7114) + 25 \quad (1)
\]

\[
RT_mV = (RT_dC*0.0061) - 0.01 \quad (2)
\]

\[
FT_dC = (FT_mV + RT_mV)*83.25 + 205.2 \quad (3)
\]

RT\textsubscript{dC} = Room temperature in °C
RT\textsubscript{dM}V = (milli-) Voltage detected by RTD
RT\textsubscript{mV} = Room temperature in millivolts (for type S
thermocouple)
FT\textsubscript{dC} = Furnace temperature in °C
FT\textsubscript{mV} = Furnace temperature measured in millivolts
(type S thermocouple)

The constants in equation (1) are specific to the Model S4
RTD used. The constants in equations (2) and (3) are
derived from a least squares fit of temperature versus
voltage, using tables from the National Bureau of Standards
(1971).

Although temperature readings are constantly updated,
they are only compared to spec temperatures while the
furnace is loaded. A set of flags informs the comparison
program, CHEK, of the status of each furnace and, there­
fore, of the action to be taken. The possible furnace states
are:

1. Empty
2. Shut down (for maintenance or cleaning)
3. Loaded, in soak cycle, and in spec
4. Loaded, in cool down cycle, and in spec
5. Ready to be unloaded
6. Loaded and out of spec

CHEK examines the status flag of each furnace and then
performs the appropriate check. No check is made for
conditions 1 and 2. Furnaces in soak (3) are checked for
temperature within ±2.5°C of spec, for time to turn off gas
flows, and for the beginning of cool down. Furnaces in cool
(4) are monitored to maintain a cooling rate of at least one
degree C per minute until 800° is reached.

When a furnace goes out of spec (6), a timer is started. If
it returns to spec within five minutes, normal monitoring
continues; if it remains out of spec for five minutes, an
alarm is sounded and a message is printed on the TTY,
notifying the furnace operators of the furnace, its tempera­
ture, and the spec. If corrective action does not bring the
furnace back in spec within ten minutes, the alarm is rung
again. The alarm is also sounded if a furnace does not enter
the cool down cycle within ten minutes of the prescribed
time.

While a furnace is out of spec, the data is logged on a
disk file once a minute. This provides a record of furnace
behavior that can be used to determine corrective action,
interpret results, or study furnace characteristics. Any
furnace, regardless of condition, can be flagged to log data
in this manner, providing a means of studying reheat cycles
and recovery times. This data is summarized once a day in
a table showing furnace number, the time it went out of
spec, how long it remained out, the spec temperature, and
the minimum, maximum, and average temperature during
that period. If more detail is needed, the data can be printed
as a simple chronological list or displayed on the x-y plotter
as a graph of temperature versus time.

**FURNACE OPERATOR'S INTERFACE**

The furnace operators interact with the computer through
a conversational task, CON1, which runs on the TTY at the
operator's loading station. The operator specifies the des­
ired action, such as loading a run, and the task calls in
the appropriate program or subroutine. All interaction is in
the form of questions from the computer and answers from the
operator. Error detection and correction methods are in­
cluded in the programs. The programs were designed to be
user-oriented, and to make the computer a useful tool for
the furnace operators, requiring a minimum of operator
response.

The operators use the computer to load and unload runs,
to read furnace temperatures, and to check furnace availa­
bility. The alarms and printed messages alert them to
problems and help them determine the necessary corrective
action. Sample interactions are shown in Figures 1 and 2.
TIME TO TURN OFF WATER IN FURNACE 34  CLOCK = 8:44

RUN IN FURNACE 34 IS DONE—CLOCK = 9:05

TYPE OPTION NO.
04
FURNACE? 34

RUN ENDED IN FURNACE 34 AT 9:5
FURNACE?
00
BYE

TYPE OPTION NO.
06
FURNACE?
26
FURNACE 26 READS 1249.5
FURNACE?
27
FURNACE 27 READS 1251.0
FURNACE?
24
FURNACE 24 READS 1135.5
FURNACE?
34
FURNACE 34 READS 1150.1
FURNACE?
47
FURNACE 47 READS 1100.0
FURNACE?
48
FURNACE 48 READS 1104.6
FURNACE?
00
BYE

RESULTS

The results of the furnace monitoring system have exceeded the initial goal of reducing D.A. by catching furnaces that fail to go into cool. It was projected that, to be cost-effective, the computer should catch at least one furnace malfunction of this type a month. The actual savings have been 3 to 4 furnace loads a month, a considerable amount of product. The computer also provides instantaneous and accurate temperature readings, which not only saves time over the previous manual method, but also enables the operators to determine temperatures at any stage in the furnace cycle instead of only while the furnace is empty. The operators and foreman are able to obtain up-to-date information on furnace status, including projections of next available furnace for a given process. Sample displays of this information are shown in Figures 3 and 4.

The computer's ability to track furnace behavior has been used to study the reheat time of furnaces, which resulted in increasing throughput by 3-5 hours in some cases, and also provides data used to determine which furnaces should be replaced.

Potential benefits are even greater. The computer provides more extensive and current information on the furnace system than was available before. We are currently expanding the system to include formation of a data base that will be used to correlate furnace behavior, device characteristics determined by the diffusion operations, and performance at final test. Data is also being collected on the frequency and type of maintenance required by each furnace, with the goal of scheduling regular preventive maintenance. Work-in-process inventory in the diffusion area is also being tracked by the computer, and provides the foreman with more current information than was obtainable with the previous cumbersome handcount method.

CONCLUSIONS

The small computer has become a valuable production tool in the manufacturing environment of Youngwood. The improved process control, combined with the computer's versatility in the areas of data gathering and analysis, offer almost unlimited potential. In order to be effective, however, such a system must be designed to fit the manufacturing process. It must be specific enough to meet the peculiar needs of each application, yet the programs must be structured to allow for changes in the environment; in our system, a furnace may be converted from one process to another, experimental runs may require a non-standard temperature, etc.
Most important, the system must be oriented toward the user—in this case, hourly employees, supervisors, and engineers who are not computer operators or programmers. The conversational question-and-answer method has been very successful at Youngwood, allowing the user to "converse" with the computer in familiar terms. The user's feedback should also be used to improve the system. For example, initially the computer only alerted operators to problems, such as a temperature out of spec. After becoming familiar with the computer and with entering data on the TTY, the operators asked if the computer would be able to somehow print a message when it was time for them to turn off gas flows. Such a modification of the original system was well worth the program changes because it contributed not only to the objective of reducing D.A. in an area that had not been originally considered, but also made the...
computer a more useful tool, not just a 'glorified thermometer' or an expensive new gadget that is more trouble than it is worth. To be truly effective, as a manufacturing tool, the computer system must be carefully designed, and simplicity of interface with the end user, regardless of his background, must not be dismissed as an unnecessary frill. The furnace monitoring system was a test case for the computer at the Semiconductor Division. It has been successful, and the experience gained in solving the problems of implementation is being applied to the expansion of the system to include monitoring of other processes. The computer is becoming even more important as a manufacturing tool in areas not originally considered, such as work-in-process inventory and device design, and we are looking forward to continued expansion into other areas that affect the daily dollars and cents concerns of the manufacturing plant.