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I.D. SLICING AND THE AUTOMATED FACTORY

T. LEWANDOWSKI

SILICON TECHNOLOGY CORPORATION

OAKLAND, NEW JERSEY 07436

Silicon wafering in the semiconductor industry today is done almost exclusively on I.D. saws operating semiautomatically. One machine operator is required for support of every four to ten saws. The exacting cost goal of the Low-Cost Solar Array Project demands a much higher level of automation. The I.D. saw of today must be enhanced to operate with less human intervention. This improved saw must be integrated into a slicing system which makes maximum use of each individual saw. The slicing system, in turn, must be controlled by some central intelligence so it can meet the demands of the overall manufacturing process.

The objective of automation is, of course, increased productivity. The ratio of process output to resource input must be increased while the desired production rates are maintained. The output of a solar array factory is measured as peak output power of the finished product. The measure of resources used is the cost of materials, capital equipment, labor, and consumables.

The saw productivity can be increased by reducing silicon waste, decreasing usage of consumables, keeping the saw slicing, and increasing the cutting speed. These variables are strongly interrelated. An improvement in one may adversely affect others. Since the saw improvements which follow are evaluated qualitatively only, a net productivity gain is possible only if no negative effects are likely.

The I.D. saw as it exists today is capable of cutting a number of wafers automatically. The desired number is entered manually from the machine control panel, and operation is initiated. When the correct number of wafers is completed, operation stops. The machine now sits idle until the operator removes the wafers and restarts the slicing operation. An automatic wafer removal system would eliminate the need for manual intervention. The unpredictable human response is eliminated enabling the saw to spend more time slicing and thereby reducing idle time.

Another area which requires action by the operator is blade dressing. Blade deflection monitors are widely used to determine when a blade needs service. If axial blade deflection exceeds a preset limit during a slice, the slice is completed and the saw is stopped before a new slice is started. An alarm light alerts the operator who must manually dress the blade. A strip chart recorder maintains a record of deflection versus time which can be used to determine what part of the blade needs dressing.

Blade dressing affects blade life, wafer quality, kerf loss, and slicing speed. Proper blade dressing is a necessity for high productivity. An automatic system which can interpret blade deflection data and can respond with the correct dressing action is an important machine enhancement. Excess blade deflection can also be caused by loss of blade tension. When dressing does not restore correct cutting action, retensioning is usually necessary. Early detection of tension loss would permit corrective action before blade damage occurs and would eliminate unnecessary blade dressing.

Occasionally, a wafer will stick to the back of the blade and, if not removed, will break subsequent wafers. Corrective action is to shut down the saw and to flush out the wafer or the pieces with a water stream. Detection of this condition is important because saw operation will be largely unattended and loss of a considerable number of wafers could result.

A portion of potential productivity is lost because of the compromise necessary in cutting speed. High cutting speed will cause edge chipping on entry and exit. A fixed speed system must be operated at a speed slow enough to limit edge chipping. This speed is lower than is possible in the bulk of the material; therefore, total cycle time is increased. Programmed feed enters the ingot slowly to prevent edge chipping and then increases speed in the center to the highest value consistent with acceptable wafer quality. The cutting speed is decreased again at the end of the cut. The net result is a higher average cutting speed. Programmed feed rate increases saw productivity by increasing average slicing speed.

After a slice has been completed, the blade must be withdrawn before another slice can be started. Withdrawal time can be reduced considerably with simple saw modifications. Decreasing the blade withdrawal time reduces the time the saw is not cutting.

The goal of most of the aforementioned machine enhancements has been to reduce the necessity for human intervention with machine operation. A large slicing operation may involve dozens or possibly hundreds of saws. Because human presence on the production floor is limited, alarm conditions indicated on the individual machines can be overlooked, thus reducing productivity.

There is also a need for record keeping to anticipate reloading of silicon, blade changes, and other maintenance operations. Since the controls on newly designed saws are microprocessor based, a digital serial communication interface can easily be added with the necessary firmware to send needed information to a central point.

This central monitoring point would have to receive data from a large number of saws, store the data, and display the information to the operator. The basic data received from the machines would be their state (i.e. cutting, idle, or alarmed) and an indication of a wafer being completed. The central monitoring system must have enough intelligence to act as a controller on a communication link with many stations and to operate on the data provided so that it can be presented in a usable manner to the operator.

The most likely configuration for interface with an operator is a CRT and a keyboard. Alarm data would be displayed automatically. Display of other data could be requested using the keyboard.

Distributed control is a concept that has been used for several years now and is becoming more popular in the process control industry. The system intelligence is distributed as is the system hardware. Intelligence is placed close to the source of data or point of control. Various intelligent components communicate over a "data highway." They can pass data among themselves and pool their computational power to control the system.

The data highway is the key element of the system. It permits high speed communication among system elements. In situations where there are many system components which do not need to send or to receive large volumes of data, the components are connected via a low speed bus to a data concentrator. This concentrator assembles and disassembles the message to be sent or to be received on the data highway.

Careful examination of the slicing system with central monitoring reveals many of the features of distributed control. Each saw is a data source and control point which communicates with a central monitoring point over a low speed serial data bus. If the central monitoring point is used as a data concentrator and connected to a data highway, a distributed control system is created.

The primary function of this control system is to coordinate the activities of the entire system and to insure that each element is operating near its maximum capacity. Many elements in solar array processing are similar to the slicing element in that they are made up of many components (saws) operating in parallel. If the control system can keep each component operating near capacity, the total number of components can be reduced from the number required for an uncontrolled system. Efficient control should reduce capital equipment requirements.

A secondary function of the control system is exchange of information among system elements. This can be used by the destination element to improve its operation; for example, the results of product inspection can be fed back to the slicing element for possible corrective action.

Data fed back to the slicing process would be useless unless the identity of the saw which produced the off-specification product is known. This could be accomplished by adding a wafer marking operation after slicing. A less expensive alternative would be to add intelligence to the wafer transport element and to use the data highway to pass the desired source and destination information. This is another area where equipment cost may be reduced.

Another important feature of a distributed control system is its ability to log data on its own operation. This data base can be used for off-line analyses to test schemes for improving process performance.

Distributed control simplifies interfacing equipment built by different manufacturers because standardization is required only at the data highway level. Equipment can be built with hardware and software designed to interface with the data highway. System design would then require system software only.

Application of distributed control will improve productivity by reducing material waste and lowering capital expenditures. Successful integration of an I.D. saw into an automated factory requires the enhancements described in order to improve productivity and to minimize the amount of human intervention necessary to operate the entire system. The human element is not removed; its focus is merely shifted from dull, repetitive jobs to the more demanding tasks of system optimization.

DISCUSSION:

YOO: For real success in automation, I think that one of the most important factors is ho'' accurately you monitor the blade condition. You mentioned checking the blade condition by blade deflection only. Maybe there are some other factors that influence the real quality of the blade other than blade deflection. In other words, possibly, monitoring the center of the ID blade, etc.

LEWANDOWSKI: Centering of the ID blade is usually a setup procedure. I imagine there is a possibility that it would shift in operation, but I have never heard anyone complain about that happening. As for monitoring other variables to determine the condition of the blade, yes, there are other variables that are important. One that we worked with to some extent is blade torque. We find a clear correlation between slice quality and the amount of torque required by the slicing process. We have done some work on measuring the force required at the cutting blade. The paper that was presented on Monday, the source of data was STC and it goes back a number of years where we had originally done work in this area. We are active in this area now and we are aware of other parameters that may be useful in determining blade condition, and we intend to make use of them.

DAUD: Could you give us a price estimate as to how much it will increase the saw price?

LEWANDOWSKI: No. As you get to a higher level of automation there has been less work done. Many of the machine improvements that I talk about do exist or are in the design stages and we can give you a price on them if you are interested. The real gains that you are going to see from automation are not at the machine level. They are going to be at the system level and they are going to make use of the ability to communicate from subsystem. When you put a sensor on the saw it only benefits you if it is on every saw. If you put it in another subsystem it can be used to a greater extent, more efficiently, and it would result in less overall capital expenditure. The system level is where automation is really going to pay off. It has benefits on the saw level, the enhancements I talked about to increase productivity for example, but the big gains will be seen at the system level and there really hasn't been all that much work done on that yet.

LIU: You mentioned that one of the items that you will be monitoring on your automated system would be the tensioning of the blade. I assume what you meant by that you would be able to monitor the actual tension of the blade _in situ_ while it's wafering. Is that what you meant?

LEWANDOWSKI: When you start losing hydraulic pressure the force you are applying to the blade is reduced, therefore the blade becomes more flexible.

KACHAJIAN: In further response to that question, we will also in time be monitoring the cutting force at the point of contact with the workpiece. Together with the actual blade deflection and the measuring of the cutting force we can determine if the cutting force increases or decreases and that could be a function of the loss of tension in the blade. If the blade is not tensioned properiy it will not be cutting properly, and that will show up as an increased force.

LIU· Are you saying that we are losing tensioning on the blade because we are losing the hydraulic pressure itself, or is it just an indication of the blade being stretched during the wafering?

LEWANDOWSKI: Both. You can be losing hydraulic pressure; you do lose some tension because of blade yielding. You can retension, up to a point of course, and still cut effectively even though you have less tension due to yielding.

KACHAJIAN: The only time you can not recover really is when the core has been rubbed, and the steel has yielded dramatically in one direction. Then there is hardly anything you can do.

MORRISON: I suggest that you might monitor concentricity o, .ically; a continuous monitoring might indicate whether you are getting a slip of tension or distortion of the blade.

I understand you people are building a multi-saw laboratory in-house and I am wondering how much of the type of systems you describeu i- your presentation we can expect to see there and on what kind of a schedule.

LEWANDOWSKI: Saws that go into that laboratory will be equipped with just about all of the enhancements that are available today. We hope to have requirements for the centralized monitoring system defined by the end of the year and would be going into design at the beginning of next year. Again, this device is kind of a tricky one because we are selling to two different markets with widely varying requirements. Semiconductor is more of a batch-type process. They are cutting many different specifications on a slicing operation and they may have more of a need for this thing initially as strictly a monitoring type of device. In solar, I believe its real use will come when we are talking about integrating into a completely automated factory.

KACHAJIAN: The saws, unautomated, but ready for automation and design, will be in place by the third quarter of this year (and that is more than 10).

ILES: There is an old-fashioned way of dressing which I think involves mounting the ingots on a surface--a sort of a poor man's dressing--and as the blade came through each time, it at least cleaned the debris. ıs that idea completely slipped away now or is it still an option?

LEWANDOWSKI: I would say that it is not an option simply because one of the things you want to avoid is excessive dressing. This is detrimental to bladelife. That is why it is important to develop a sensor or sensors that can tell you when the blade needs to be dressed, and dress it only when it needs to be dressed. The manner in which you dress it makes a big difference. If the blr ıe is deflecting during a slice one way or another it indicates that it should be dressed on the opposite side and not on both sides. What you are suggesting would dress it both sides every time through.