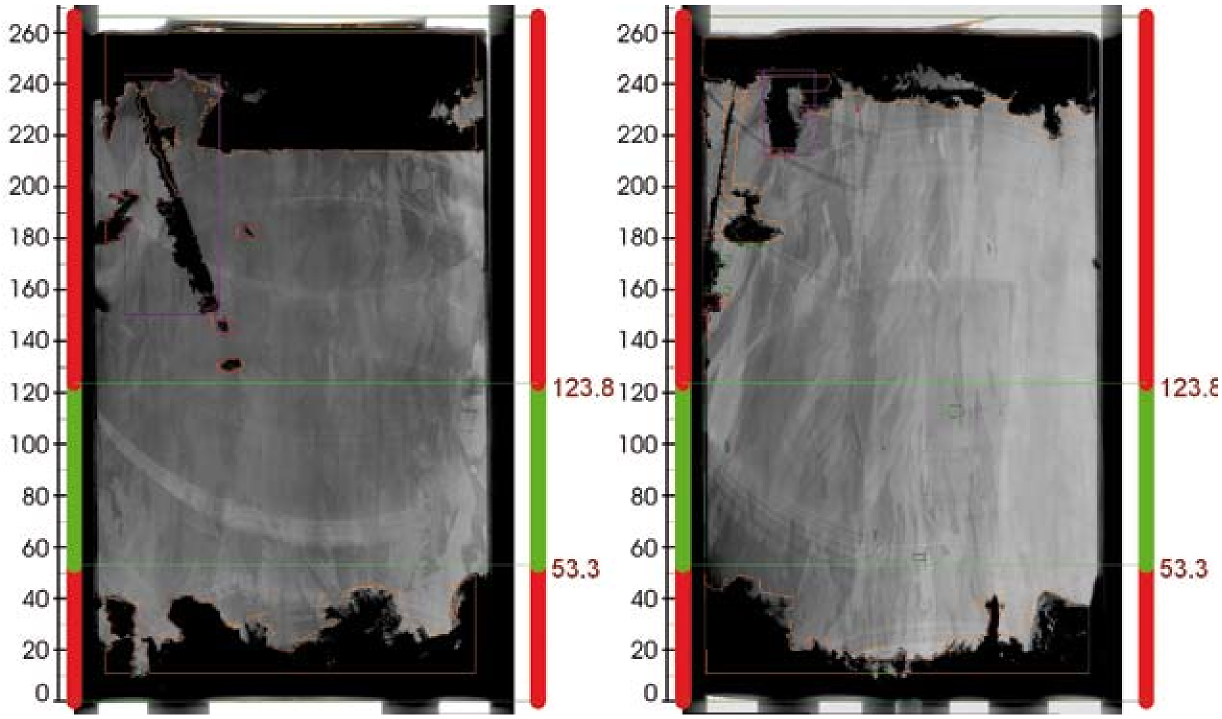

X-rays of silicon bricks in the infrared measuring station can detect contaminations, for instance inclusions of silicon carbide.

Perfect wafers

Automation in ingot processing: Efficient wafer production starts with the production of silicon bricks. Optimized production with highly stable quality cannot be realized without process automation and robotics, explains Peter Weier of Arnold Group.

Enormous investments in new machines and facilities are pending worldwide. With regard to the grid parity demanded, a change towards process-optimized production is clearly perceivable. Integrated and partially or fully automated production with high process reliability is becoming the strategic goal of market-leading manufacturers in order to counteract cost pressure.

Different production steps are required before ultrathin wafers can be manufactured from silicon bricks. These vary depending on the processing technique and also depend on the basic material selected. Monocrystalline silicon obtained using the Czochralski method is the most productive. The raw, cylinder-shaped ingots are prepared for further processing. In the first step, the tops and tails are cut off, then test wafers with a thickness of roughly one to two millimeters are sliced off for material and quality testing. Then the ingots are cut into segments for further processing and squared into the standard wafer format (125 x 125 or 156 x 156 millimeters). Multicrystalline silicon ingots are manufactured by directional solidification, which resembles a casting process. The silicon is melted in square quartz pots in today's standard sizes (length x width x depth, in millimeters), for example 878 x 878 x 480 (G5). After "crystallization," the ingot is cut to cuboid blocks in wafer format using a ribbon or wire saw.

The elaborate pre-stages of wafer production already influence the subsequent process steps, but above all the quality of the wafer and thus also the quality of the photovoltaic modules produced from these. This is why wafer manufacturers need innovative solutions in order to separate the "wheat from the chaff" in upstream process steps. That means that defect spots in the silicon are already cut out during brick production in order to then continue processing tested silicon only afterwards. Subsequent "scrap" is already avoided from the beginning. Thus the capacity utilization of the machinery can be optimized significantly due to the pre-tested and pre-selected material. In the end, the production costs can be substantially reduced. This way, wafers can be produced more economically while retaining a constantly good quality.

Intelligent automation

It's worth taking a look at other industries, especially in critical times. The automotive industry, which is under constant competitive pressure to succeed, is a role model here. Impeccable quality, correct adherence to development cycles, optimum and fail safe processes as well as punctual delivery in accordance with the "just in time" principles guarantee the success. Suppliers are demanded to offer "zero error" strategies.

Back to photovoltaics. Without a similar high degree of automation, comparable goals cannot be achieved in this industry. However, automation not only means including robots in partial processes, but much more. Each machine must not only provide high process reliability, but also a sophisticated sensor technology, highly intelligent control technology and interfaces to the periphery, as for example to the manufacturing execution system (MES).

The substantial advantages for brick manufacturers become apparent when we take the example of a fully automated production line involving cutting (sawing) and gluing multi-crystalline bricks. Three centers aligned in series are connected with a conveyor belt. An industrial robot is placed centrally in each center. The communication between the machine control and the robot takes place via a superordinate production and quality control system (PQS).

Before a brick is processed through the fully automated production line, it receives an identification number. This makes it possible to allocate each produced brick the corresponding process and measuring data.

Efficient grinding

The grinding center features surface grinding and chamfering machines aligned in a semicircle towards the conveyor. The robot takes the brick off the conveyor belt and places it into an available surface grinding machine. The centering device integrated in the machine centers the workpiece axis automatically to the machine axis. The workpiece is clamped and measured by a laser system. The grinding disks are paced automatically on the basis of the recorded measuring data. After simultaneous course grinding of two facing sides of the brick, the same sides pass through fine grinding. Then the bricks are measured for a second time for immediate inspection and documentation of the production quality. Turned by the robot, the workpiece is also course and fine ground on the other two sides using the previously described work steps. After the grinding work on the parallel surfaces is finished, the robot picks up the brick and inserts it in the chamfering machine. With a 45 degree turn, it puts the brick into the right position for chamfering. First, two 45 degree edges are chamfered, and after a 90 degree angle turn by the robot the other two edges. The production quality prior and after processing is completely documented by measuring systems located inside the machine.

Constant tracing

Once the grinding process is completed, the robot transports the brick to the infrared (IR) measuring station. Every single brick is x-rayed in order to detect contamination like inclusions of silicon carbide, for example, at this time already.

Directly after IR measuring, integrated service life and resistance measurement takes place on the conveyor belt. The quality of the bricks is checked extensively at this point. Any contamination reduces the service life of the semicon-

Photo: Arnold Group

A fully automated production line for multicrystalline silicon bricks, with grinding, cutting (sawing) and gluing center.

ductor material silicon. The applied microwave PCD technology (µ-PCD measuring technique) operates at very high injections with a very short light pulse of approximately 200 nanoseconds. The photoconductivity is detected with the reflection of a microwave. Bricks in which, for example, no inclusions were detected in infrared measuring may still contain contamination in the form of heavy metals, crystallization effects and/or concentrations of iron. The quality of the affected brick is only partially impeccable in case of detected damage.

Based on the results of all previous geometry and quality tests, the system automatically calculates which parts are flawless and which will have to be cut out in the downstream cropping center. This way, only the "good parts" of the brick are processed further.

That leads to a substantial improvement of the material balance due to savings in silicon consumption. If such extensive measuring operations are not performed, possible wire cracks and substantial quality problems with a high scrap rate are inevitable.

Precise cut

Back to the production line. Before the brick enters the cutting center via the conveyor, the identification number is scanned again in order to record the subsequent steps comprehensively. The automatically generated calculations of the previous geometry, infrared and µ-PCD technique measurements are also used for cutting via the identification number.

In the fully automatic cutting center, the brick is cut using the single-cut method based on the previous calculations. This gives the robot the chance to position each brick exactly as specified for the individual cutting steps. The cutting saws are aligned longitudinal to a linear traverse axis in the cutting center. The robot takes the individually transported bricks off the conveyor belt and places them directly in one of the outer diameter (OD) saws for cutting (also called cropping or cap cut). This denotes the cutting off of the top and bottom layer and/or the cutting of SIC (silicon carbide) inclusions in the silicon material of the bricks. The robot takes the sections out of the saw and gives them a consecutive identification number. While each part has its own identification number in the automotive industry, for example, the identification number of a brick remains with the corresponding additional characters in brick production, independent of how many individual parts are produced from a brick. This allows later continuous tracing of which part belongs to what brick. The brick is taken out of the saw and the "good parts" placed on the conveyor belt. End pieces or sections are placed separately on a lateral conveyor belt system. Due to contamination or reduced conductivity, the end pieces are not directly suited for further processing into wafers, but may partially be added to the crystallization process again after a recycling process. This efficient use of the material leads to substantial savings in the overall material balance.

The applied thin blade cutting technique is based on the traditional circular OD sawing blade technology. In contrast to the standard blade strengths of 3.5 millimeters, however, these saws are equipped with slim 1.5 millimeter saw blades for approximately 10,000 to 15,000

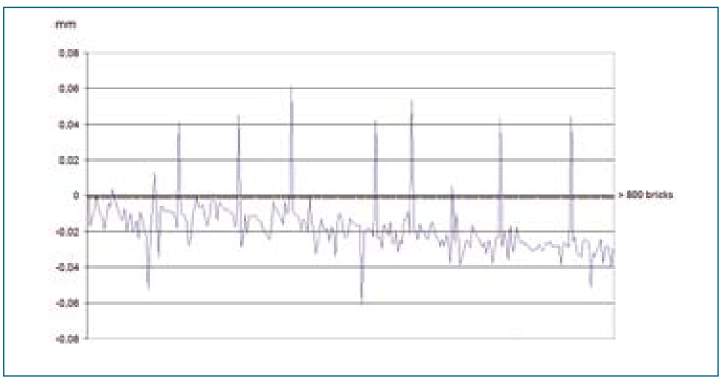

Photo: Arnold Group

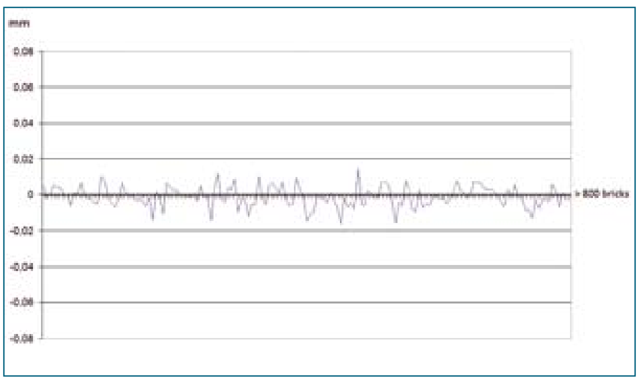

Photo: Arnold Group

Measuring protocol (grinding) without process optimization (left) and with process optimization (right).

Sawing: a fluid-borne cutting disk in thin sheet technology.

cuts. The silicon loss is thus reduced by around 50 percent. Among the advantages of this sawing technique are not only low consumption, maintenance and repair costs, but also an extremely high process stability and a just as high machine availability. The savings potential compared to other sawing techniques is around 80 percent.

Exact gluing

In the gluing center, the robot picks the silicon bricks off the conveyor belt and places them in the storing shelf. For optimized wire field utilization, the PQS system has already automatically calculated the individual brick lengths to a gluing batch. In the next step, the robot prepares the gluing process. First, the workpiece carriers are placed on a work slab; then glue is applied to the glass plates by the dosage system and these are then placed on the metal workpiece carriers. Now the robot gets the brick off the shelf and cleans it in the cleaning facility. Then the brick receives a strand of glue and placed on the glass plate.

Gluing as a preliminary stage in wafer production is highly important. Around 90 percent of this gluing work is still performed manually in the industry. This individualized process thus greatly depends on the individual worker. The glue demand in the automated gluing process can be reduced by at least 30 percent compared to the manual one. When using larger containers instead of smaller cartridges, further substantial savings are possible in the fully automated gluing section. Many manufacturers are still far from standardization. This is why there is still a very high error quota, especially in this sector. Every small error can drastically increase the break rate, whether during wafering or subsequent degluing. Some manufacturers try to achieve a certain uniformity in the gluing process by limiting the staff to just a few. But only the standardization of the gluing process through automation can perceivably lower the break rate of wafers and the associated costs.

High availability

All the cells of the production line each have their own safety zone. In the grinding and cutting center, only the work radius of the robot is surrounded by a safety fence. This way, all grinding, chamfering and cutting machines are located outside of the safety fence and are equipped with an additional safety gate. Maintenance and repair work like tool exchanges can therefore be performed at any time after closing the respective safety gate and access to the facility is unrestricted. All other machines are still in fully automatic operation in the entire process chain. This ensures the high availability of the production line.

Continuous optimization

There is a manual inspection place between the grinding/polishing center and the cropping center of the line. This is equipped with three monitors. From there, operators can access the individual process data and machine parameters of the entire line and make changes in line with quality demands. Arpat, a process analysis tool of the grinding and cutting machines with open interface to the superordinate MES, provides all machine

THE AUTHOR

Peter Weier heads the Business Unit Silicon of Arnold Group, Weilburg, Germany. Arnold Group offers process and automation technology for the broad spectrum of silicon brick processing by one source with the core competencies mechanical cutting, grinding and polishing. Weier has over 20 years of international project experience in the quartz glass and glass fiber industry. As of 1995, his focus has been on photovoltaics. He is substantially involved in the conceptual design, development and distribution of machines for glass, quartz glass and silicon processing.

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data. The tool records, analyses, saves and visualizes the individual processes and settings. Data from the service life and resistance measurements can be viewed on the second and third monitor.

Fully automatic process cycles

The core of the fully automated line is the internally developed process automation system of the grinding and cutting machines. The term "close loop process development" was created with the aim of securing and raising the high process stability. It means that current production and process data is collected, visualized and analyzed. Process parameters are changed with the help of this data in order to perform optimizations.

Equipped with the process analysis tool, it is possible to collect and log data in the current process of the individual machines. Amongst other things, geometrical workpiece data, general customer-related workpiece information, process parameters, machine status according to SEMI E10, and so on, is recorded and analyzed. With the help of intelligent software, the machines are capable of making automatic corrections like adjusting the grinding wheel. In case of deviations from measurements, e.g. due to external temperature influences, the process error compensation is performed automatically.

With this extensive data recording, it is possible to achieve and maintain a very good process capability in the grinding process of less than 1.67 CpK with a tolerance of +/- 0.05 milimeters. The "zero error" strategy, meaning "almost zero scrap" can already be accommodated with these values.

For the user, this systematic data analysis option is an excellent tool in order to continuously optimize and improve the process to increase his advantages over the competitor. Stable processes are also a requirement for a high degree of automation, but also for reproducible production quality.

Securing competitiveness

A manufacturer with a 250-megawatt capacity produces around 67,570,000 wafers annually in a 24-hour operation. If for example the break rate is reduced from five to four percent through process automation and automatic handling, the scrap rate of around 3,380,000 wafers reduces by 680,000 to approximately 2,700,000 wafers – an enormous saving every year, taking a unit price of roughly 2.00 U.S. dollars per multi-crystalline wafer: around 1,360,000 U.S. dollars.

Decisions for investment are foresighted corporate decisions. Not the individual investment price of a machine is decisive here, but the cost package of the entire investment and, above all, the total cost of ownership (TCO). Criteria of a well-adjusted overall package are technically well-engineered machines with fully automated processes, an automatic handling system and a quality data recording system. This creates equal, reproducible prerequisites with continuous repeat accuracy, standardization without manual influences and one hundred percent quality control in all production steps. The advantages of automation are only achieved with the decision for the right concept with the right manufacturing equipment that enables stable processing. ◆