Contributed Article
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«Efficient Cutting»
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English Version

Image 1 – Lead photo
Outer diameter (OD) cutting saw
Sawing: a fluid guided cutting disc in thin blade technology

Efficient cutting

Thin blade cutting technology and automation in ingot processing:
Extreme cost pressure in wafer manufacturing is paving the way again for rediscovered thin blade cutting technology. Reliable, low-maintenance solutions for automated processing of multicrystalline silicon bricks open high savings potential.

The international photovoltaic market is located in a huge break. High silicon prices still considered decision criterion in recent years, now the entire manufacturing process is crucial for the price per wafer. To achieve a drastic cost-cutting, all production processes must be put to test. High process stability, reliability, significantly reduced maintenance, low operating costs and a flexible integration in semi and fully automated lines are minimum requirements of leading manufacturers. Regions distinguished itself yet as low-income countries are looking for saving potentials to reduce the high proportion of staff and now, also in Asia, rising personnel costs. More benefits through an automation in the brick production are in the higher utilization, optimal utilization of investment in higher yield by reducing damage to the material and not least in the 100 per cent traceability and quality control.

The efficient wafer starts in the production of silicon bricks. The elaborate stages of wafer manufacturing significantly affect the process steps set up. In particular the quality of the wafers and thus the quality of the photovoltaic modules produced from it. To assess costs and expenditures, a glimpse of the complex production path from the sand to the wafer is worth first.

Before paper-thin wafers arise from silicon bricks, many manufacturing steps apply. These vary depending on the processing technology and are dependent on the selected raw material. Wafers of monocrystalline silicon

(Czochralski-process[(1)]) exhibit the highest level of efficiency. Cylinder-shaped raw columns for further processing are processed first. Then, the end caps (top and tail), and after that the testwafer is separated from about one to two millimeters for material and quality testing, called also "cropping". Finally the drawn raw columns are cut into segments for further processing and are squared in the commercially available wafer format (125 x 125 or 156 x 156 millimeters). Multicrystalline silicon, however, is melted in square quartz crucibles in today standard sizes (length x width x depth, dimensions in millimeters) such as, for example, 878 x 878 x 480 (G5). The raw brick will be trimmed after the "crystallization" on a cutting saw (today mostly a wire saw) to cuboidal raw blocks (bricks) in the wafer format. After grinding the surface areas and the chamfering of edges, the cropping cut is done, referring to the cutting of tops and tails of ingots. These tails are not used for further processing to the wafer due to the impurities, silicon carbide inclusions and reduced conductivity. Manufacturers are therefore dependent on innovative solutions to separate "the wheat from the chaff" in upstream process steps. In other words, during the brick manufacturing damaged parts of silicon are separated out, in order to process only perfect silicon. Already at this time, "later deficient products" are avoided. The previously tested and selected material significantly improves the machine efficiency. Ultimately, the costs of production are substantially reduced. The price per wafer is noticeably cheaper at consistently high quality.

The time of high-priced silicon at a top price of 500 U.S. dollars per kilogram are long gone. Currently, the purchase price of raw material in the spot market is around 20 U.S. dollars per kilogram and varies. Many years the bizarre movements in the price of the raw material influenced significantly the technologies of brick processing. It was long, reducing the average loss of the expensive raw materials, one takes up again today methods well approved over decades. Long unappreciated, now rediscovered, turns out the o.d. saw with the innovative technology of the thin blade technology as a trendsetter. Established methods such as belt -, inner diameter (ID) - and wire saws are replaced by the new version of the proven o.d. saw. To make decisions, which of the possible technologies in the future is used in the silicon brick manufacturing, it is advisable to weigh the common with thin blade cutting technology and critically examine the possibility of integration in the automation process. Because an optimized production with high process and quality stability is not possible without process automation and robotics.

Photo 2 – Internal view wafer
IR-measurement of silicon bricks
X-rays of silicon bricks in the infrared measuring station can detect contaminations, for instance inclusions of silicon carbide.

Insignificant cutting loss

The o.d. saw, the forerunner of the new "thin blade cutting technology" is one of the oldest separation processes. For many decades is the saw, fitted with a 3.5 millimeters strong diamond disc, applied industrially for brittle materials such as glass, ceramic and metal. This technology offers not only maximum process stability, but convinces by the simple and particularly robust application. Especially in the photovoltaics, the workpiece can be fixed without complicated clamping technology in a simple prism rest and guarantees a tension-free and thus chipping-free cut. The German Arnold Group ranks among the pioneers of this processing technology worldwide. In the early 1980s different cutting machines for special requirements of silicon processing companies were manufactured. In 1995, first cutting centres with automated, robot-based operations for loading and unloading were delivered. In times of high silicon price, the almost maintenance-free and extremely robust o.d. saw lost its significance for years because of saw blades-related increased material consumption. Other, more complex technologies that promised a lower consumption of silicon, replaced the proven OD saw.

The traditional technique of the band saw comes from the processing of wood. In addition to Jaespa, a well-known German company, also Asian manufacturers offer band saws. Compared to other techniques of saw the acquisition of a band saw is although favourable, the follow-up costs, however, the higher. So, for example, the band guidance represents a major challenge. The pulleys of the band are running through the aggressive, highabrasive silicon mixture of water. At regular intervals the band guidance must be replaced because of high wear. In addition the welded blade is subject to high tensions, torn belts during production are not uncommon. Although a repair can be done simply and quickly, process reliability and process stability are significantly restricted. The busy diamond band saw belts must be exchanged on average every eight hours. In a continuous, daily production (24/7) this tooling costs at a time of low price per band of 100 euros per piece are amounting to almost 110,000 euros per year; Still not counting standstill, staff, logistics. Although the change and renewed commissioning with relatively little time are performed, the band saw belts noticeably drive operating costs soaring. The qualitative disadvantage is not to be underestimated. At high speed (greater than 40 millimeters per minute), the cutting quality is suffering. The relatively inaccurate cutting often requires another process step. Often, the side faces of the silicon bricks are reground. This means not only the investment in additional grinding machines, but also results in further costs like media, consumables, maintenance and personnel. Band saws can be integrated into automated lines. However, their frequent downtimes require a greater use of staff to reduce accordingly the failures.

In the 1970s was the ID saw for separating wafers in the semiconductor industry, developed by the Swiss company Meyer Burger and used later for the photovoltaic industry. The i.d. saw is a special cutting technique for brittle materials. It allows extremely precise cuts with narrow cutting width of 0.5 millimeters and less, and excelled by minor loss of silicon. Compared with conventional saws, the ID saw differs by the internal cutting surface. In simple words, the ID cutting is a special circular saw technique. The disc is clamped at the periphery like an eardrum in the drums. In the middle of the blade there is a hole, its inner edge is coated with diamond chips and forms the cutting area. Depending on the feed speed and the required quality standards one expects an average time of about seven minutes per cut in a column format of 156 x 156 millimeters. The blade must be replaced manually after about 1,000 cuts. Even for an experienced operator, mounting and dismounting and setting up takes several hours. The material value of the saw blade is approximately 500 euros net, which means around 35,000 euros tooling costs per year; in addition, the stagnation of production must be expected. Years

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ago, extremely high silicon prices controlled the market, despite complex and costly technology, the i.d. saw was benefecial. The maintenance-intensive process of saw is evident just in rising production volumes as unsuitable to the integration in process engineering.

The Swiss specialist HCT, which was taken over a few years ago by Applied Materials, United States, are leaders in wire saws. Unique advantage of wire saw is the low loss of silicon in the cutting process. Just with this saw technology, you can expect with an extremely high manual effort for the incidentals. First place up to 35 bricks under the wire box of the saw. In a single pass, i.e. with 70 cuts, tops and tails are cut of all columns at the same time. The actual separation of the silicon bricks is done by the so-called slurry. An expensive mixture of polyethylene glycol (PEG) and silicon carbide, which sticks to the cutting wire of saw. Tears the wire, the entire wire field of the saw must be rewound to scratch; a long-running machine downtime and expensive loss of production are the consequence.

The set-up time for the manual insertion are enormously high. Also the not necessary cleaning of the cutting table after each round is extremely time-intensive. To replace the expensive slurry in the process of sawing with diamond wire is still under development. Whether with or without slurry this procedure remains very inflexible. The diamond wire costs are also significant. The integration of wire saws in automation processes is logistically very costly and therefore with high investment costs. In the medium term this sawing technology for cost reasons is no longer used for the cropping process.

Thin blade cutting saw sets standard
With the new product generation of "thin blade cutting technology", the renaissance of the oldest cutting process takes place in brick production. This old, but still new technology of OD saw will be provided by Arnold Group for the cropping of multicrystalline silicon bricks.

Machines for the cropping and squaring of monocrystalline bricks are also offered. Manual, semi-automatic and fully automatic processes are possible.

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The thin blade cutting technology with newly designed disc guide is based on the proven and familiar circular cutting blades technology, was fitted but with additional advantages, which allows a cost-conscious brick production. These saws are equipped with slender 1.5 millimeters blades, instead of the commercially available thickness of 3.5 millimeters. This reduces the silicon loss by about 50 percent. The heart of the cutting technology is the disc of a particularly stress-free and treated steel core of just under 1.2 millimeters. On its edge, segments of a metallic-bound diamond concentration are soldered on. The base height of the disc is 6.5 millimeters and is sufficiently dimensioned for up to 15,000 cuts.

The change of the cutting blade requires maximum half an hour. The tight tolerances required by industry with respect to parallelism - disc to the workpiece – less than 0.2 millimeters, adhered angularity is less than 0.3 millimeters and chipping is less than 0.6 millimeters are adhered to even in continuous operation in the common wafer format of 156 x 156 millimeters. Not only low consumption, maintenance and maintenance costs, but above all an extremely high process stability and high machine availability of 97 percent are among the essential advantages of this cutting technology. The reduced consumption costs, lower costs for energy, compressed air and extremely low tooling costs (less than 8,000 euros per year) and not to mention the low use of staff, offer a superior savings potential of up to 80 percent compared to other cutting techniques.

Intelligent automation
A look at other successful industries is worth especially in critical times. The automobile industry, which is under permanent competition and pressure to succeed shows exemplary. Their ingredients are impeccable quality, correct compliance with pre-defined development cycles, optimal and reliable processes and on-time delivery to the "just in-time"-principle. Suppliers are required to provide "Zero-error strategies". This can be achieved only with an extremely high degree of automation.

Back to photovoltaics. Without a similarly high degree of automation, comparable goals are unreachable in the photovoltaic industry. Automation means not only the integration of robots into sub-processes, but far more. Each machine itself must not only provide high process reliability, but sophisticated sensor technology, highly intelligent control technique and interfaces to the periphery such as to the MES (manufacturing execution system).

Photo 3 – Brick production line
Fully automated production line for multicrystalline silicon bricks with grinding, cutting (sawing) and glueing center

The example of a fully automated production line for grinding, cutting with thin blade cutting technology and gluing of multicrystalline bricks shows advantages for manufacturers. Three successively arranged centres are connected to a conveyor belt, one each industrial robot is placed respectively. The communication between the machine controller and robot is done via an overall production and quality control system (PQS).

A manual inspection, together with three screens is foreseen between the manufacturing steps of grinding and separation. The operator can access from here individual process data and machine parameters of each stage of the process, and make changes as needed. Arpat, the process analysis tool of grinding and cutting machines with open interface to the MES, collects, analyses, stores and visualises the processes and settings. On the other two screens the data from the lifetime and resistance measurement are shown, yet described. All machines are equipped with own security restricted areas and additional safety locks. These allow unimpeded maintenance and maintenance work also on the fly.

Grinding, cutting, gluing

At the beginning, each brick, which will run through the fully automated production, is equipped with an identification number. Thus the appropriate process and metrics can be associated with each manufactured brick. Surface and chamfer grinding machines, which are arranged in a semicircle to the conveyor belt, are located in the grinding centre. The robot takes over the complete handling work. The workpieces are clamped and measured by a laser measuring system. The grinding wheels are delivered automatically on the basis of the collected data. Then the robot loads exactly the individual machines according to the specifications. Between the respective grinding processes the second measurement of bricks is carried out, to document all individual operations. A complete documentation of manufacturing quality takes place before and after the treatment by measuring systems inside the machine, also during subsequent chamfer grinding.

After the complete grinding process everything is transported to the infrared (IR)-measuring station with the help of the robot. Each single brick is screened to detect contaminants, for example, inclusions from silicon carbide, already at that time. Then, the integrated lifetime and resistance measurement is performed on the conveyor belt. Here, a comprehensive quality control of the bricks takes place. On the basis of the results of all preliminary carried out measurements and tests, the cut positions are automatically calculated and deposited in the brick identification number.

In the fully automated cutting centre, each individual brick is inserted by the robot directly from the conveyor belt in one of the OD cutting machines in the exact position to the cutting. The sections of the cropping are equipped - regardless how many items of a brick are cut out - with appropriate additional ID on a laser or inkjet printer. A subsequent traceability is therefore fully possible.

Gluing occupies a high priority as a precursor in the wafer production. Still, about 90 percent of this adhesive works in the industry are done manually. This individualized process is therefore dependent on the individual operator. In the automated gluing process – compared with the manual process - requirement of adhesive can be reduced by at least 30 percent. Just in this area it is worked with a high error rate. Any small error can increase dramatically the fracture rate – during wafering or subsequent ungluing.

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Only a standardization of the gluing process through automation can reduce significantly not only the fracture rates of wafers, but also the costs.

Photo 4 – Measuring protocol (without process optimization)
Measuring protocol (grinding) without process optimization

Photo 5 – Measuring protocol (with process optimization)
Measuring protocol (grinding) with process optimization – Zero-fault strategy

Measuring protocol (grinding) withoht process optimazation (left) and with process optimization (right).

Fully automated processes
Heart of the fully automated line is the internally developed process automation of the grinding and cutting machines. With the aim to ensure and increase high process stability, the term "close loop process development" was created. Specifically: current production and process data are collected, visualized, analyzed, using this data to change process parameters in order to perform optimizations.

Equipped with the process analysis tool, it is possible to collect and log data in the ongoing process of individual machines. Among others, geometric workpiece data, general customer-specific workpiece information, process parameters, machine status acc. to SEMI E10 etc. are recorded and evaluated. With the help of the intelligent software the machines are automatically capable of corrections such as adjustments of the grinding wheel. In case of deviations in measure – for instance by external temperature influences - a process error compensation is performed automatically. Using this extensive data collection of grinding process, a very good process capability of less than 1.67 CpK with a tolerance of +/- 0.05 millimeters can be reached and maintained.

Process automation ensures competitiveness

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Automation is a closed system, which serves to optimize the processing and at the same time ensures that only "wafer-compliant" material reaches the process step set up. In the photovoltaic market, the thin blade cutting technology has best chances with small and medium-sized production capacities as well as in the highly competitive market of volume. Beside the already familiar advantages of the product, also the simple and subsequently integrable thin blade cutting machines into automated manufacturing systems speaks for the rediscovered technology.

Investment decisions are forward-looking business decisions. Not the individual price of a machine or even the silicon consumption during machining decides on one investment, but the total investment in cooperation with all costs of production. Ingredients are technically sophisticated machines with fully automated processes in combination with an automatic handling system and a comprehensive data collection.

This creates same reproducible conditions with a continuous repetition accuracy, standardization without manual influences and above all a 100 percent quality control in all production stages. Taking all costs into account, machines with automation prove to be a more profitable investment. Cost reductions with simultaneous continuous quality improvements can only be achieved with a high level of automation along the entire manufacturing process.

Source:
1 – Czochralski-process,
http://en.wikipedia.org/wiki/Czochralski_process

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 com-petencies mechanical cutting, grinding and polishing. Weier has over 20 years of international project experience in the quartz glass and glass fiber

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industry. As of 1995, his focus has been on photovoltaics. He is substantially involved in the conceptual design, development and distribution of machines of glass, quartz glass and silicon processing.
www.arnold-gruppe.de

Photo 6: Peter Weier, Arnold Gruppe

Images:
Motive, 300 dpi

Captions:
Image 1 – lead picture (Outer diameter (OD) cutting saw)
Fluid-beared cutting disc in thin blade technology

Image 2 – internal view brick
IR-measurement for silicon bricks

Image 3 – production line brick
Fully automated production line for multicrystalline silicon bricks-grinding, cutting (sawing) and gluing

Image 4 – measuring protocol (without process optimization)
Measuring protocol (grinding) without process optimization

Image 5 – measuring protocol (with process optimization)
Measuring protocol (grinding) with process optimization – Zero-fault strategy

Image 6 - author
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Sources:
Photos: 1, 3, 4, 5, 6
Arnold Group, Weilburg/Germany

Photo: 2
Intego GmbH, Erlangen/Germany

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