# Swiss Wafer Slicing Technology for the Global PV Market from Meyer Burger AG – Novel Trends for the Future in Photovoltaic Wafer Manufacturing

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## Abstract

Since more than 50 years Meyer Burger builds equipment to machine hard and brittle materials, with many of the over 3'500 machines installed worldwide having performed reliably for decades. Our customers slice and process materials for the semiconductor, photovoltaic, optical and ceramic industries.

Since almost the entire pv-industry (and semiconductor industry) is situated outside of Switzerland, namely the united states, Germany, Eastern Europe and Asia, it might seem astonishing that the majority of solar wafer saws installed throughout the world are manufactured by two competing Swiss companies. Meyer Burger builds the entire range of saws required to manufacture a wafer, starting with the cropping followed by the squaring or bricking and subsequently the wafering using wire saws. With the strong incentive for cost reduction, in order to reduce the price of the final solar panel, an increasing emphasis is placed in process development. In house jointly with universities and research institutes, the fundamental mechanisms of the complex slurry-sowing processes are researched. The current hot-topics are the increase of wafer output per kg of silicon by reducing the kerfloss, while increasing the cutting speeds and maintaining the high quality requirements. Because no further machining step follows the slicing of the wafers, any saw mark or large surface damage would be visible on the final solar cell.

Improving these processes and working on the basic understanding of the cutting mechanisms are not only very challenging but also exceptionally exciting, due to the unusual numerous physical processes involved such as Non-Newtonian hydraulics, Thermodynamics, Solid State Physics along with new measurement principles which have to be employed or even developed. This new knowledge is subsequently implemented into very interesting engineering tasks demanding all of the registers of the mechanical engineers responsible for calculating the statics, lifetime and wear of components as well as dimensioning the hydraulic systems such as pumps and gauges for the slurry supply system. However, also the electrical / electronics and software engineers find a demanding playground in binding in all the control circuits of the machines and supply systems. These are entirely controlled via in-house developed and programmed computer numeric controls (CNC) which have full internet capability, making it possible to support a customer by long distance diagnostics on any continent of the world.

## 1 Introduction

Over 80 % of the global solar cell production requires the cutting of multi- or monocrystalline silicon blocks into wafers, whereby multi-wire sawing is the main slicing technique of the photovoltaic and microelectronics industry. It is this technology, which allows for a high throughput, a small kerfloss and an excellent surface quality, enabling the wafers to be used without any further machining. The current state of the art is to produce solar cell wafers of 156 x 156 mm as thin as 250 μm. However, the roadmap of the pv-industry points towards the next generation of 210 x 210 mm and larger, while reducing the thickness even further down to a 100 μm. At the same time the goal is to reduce the kerfloss even more in order to economise on the precious silicon, as well as increasing the cutting rate while maintaining and even improving the high surface quality. In order to master these new challenges, the basic knowledge about the microscopic details of the sawing process is required and is subject to ongoing research.

The numerous steps required for the manufacturing of a wafer, which will eventually be integrated into a solar panel are illustrated in (Fig. 1.1). Starting with the purified silicon, either poly-silicon ingots are cast in a furnace

by heating up nuggets of silicon in a mould or, a single crystal is grown e.g. by pulling using the Czochralski method. From these raw shapes, rectangular ingots, already with the square or semi square profile of the solar cell are sawn, using ID-hole and band saws. Finally these Ingots are sliced on multi wire slurry saws into wafers. After these wafers have been separated, they are washed and the dimensions are measured, as part of quality control. Some of our customers continue in-house with the next photolithographic, doping and contacting processing of their wafers and in some cases the manufacturer even proceeds by integrating the wafers into the solar modules. However, traditionally most wafering plants sell their as cut wafers to the lithography companies, who sell their wafers to the module makers.

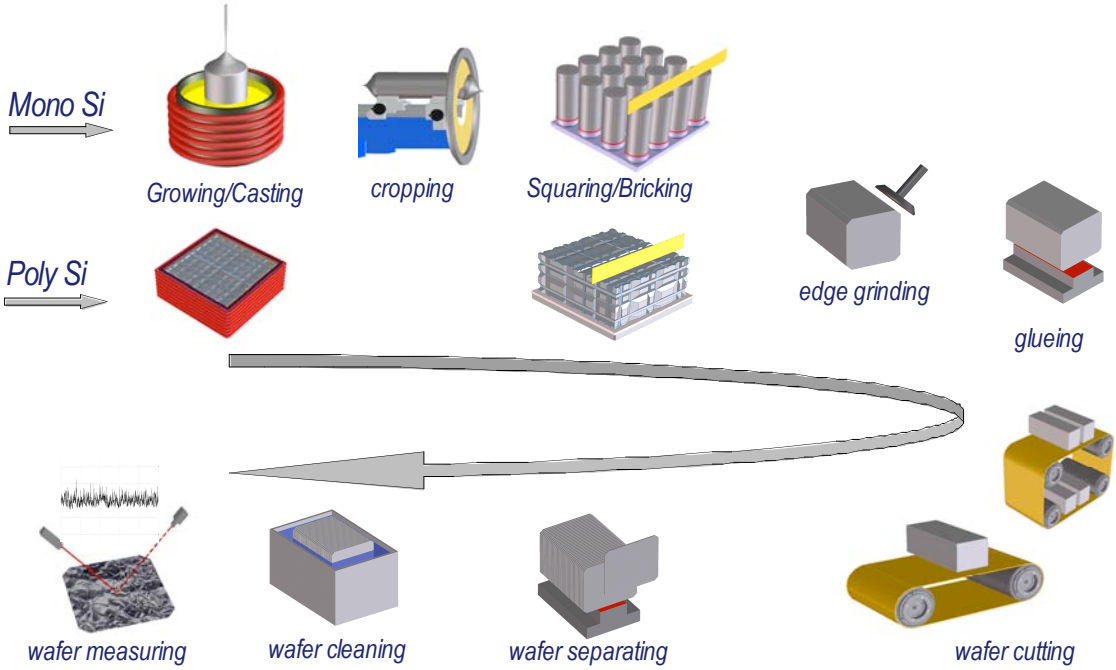


**Fig. 1.1** The standard crystalline PV wafer manufacturing chain.

# 2 The Slicing Technology

## 2.1 Cropping – The ID-Hole Saw

The left hand picture in Fig. 2.1 illustrates the cropping process of cutting the conical caps off the raw single crystal on an inner diameter hole saw (ID saw) TS207, after which the outer diameter is ground.

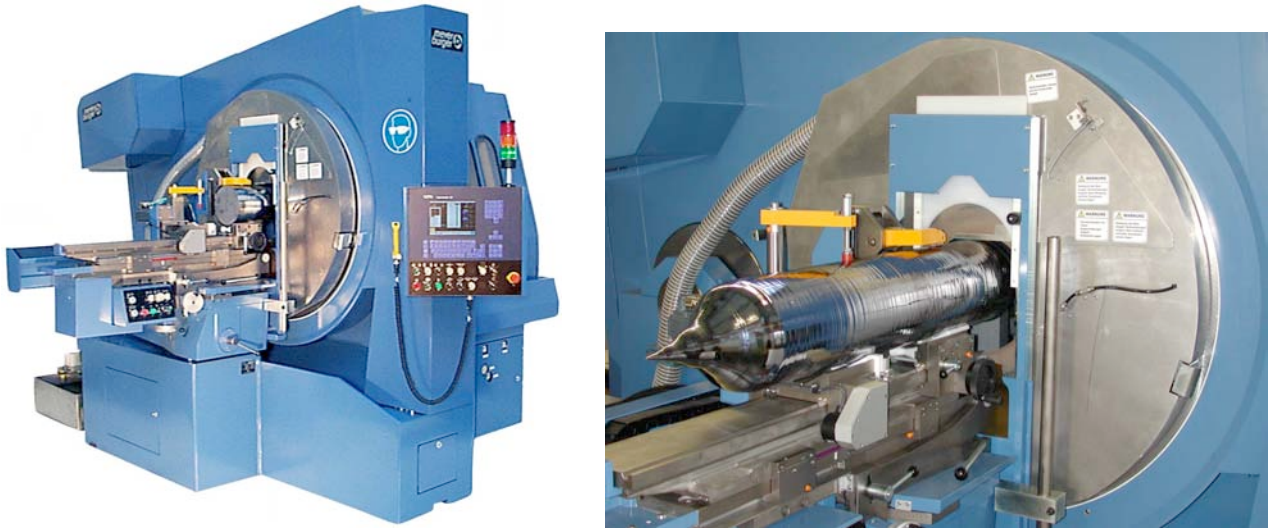

**Fig. 2.1** An 8“ single crystal ingot being cropped on an ID-hole saw (ID: Inner Diameter) TS207.

Unlike with single crystals determined for the semiconductor industry, no flats or notches are ground into the ingot to indicate the orientation of the crystal axis. This ID saw is basically a very large version of the TS23, which is still in use as a wafering machine in the semiconductor industry, and is much liked in the optical, ceramics and, boutique crystal“ industry for its extraordinary flexibility and precise crystal orientation capabilities. The ID-hole saw makes use of the advantage of tensioning a very thin disk with an inner hole, resulting in a disk with a very much higher stability than the equivalent outer diameter saw would have, thus reducing the saw dust of the kerf. Any larger pieces, such as the caps and the sides from squaring, are easily recycled. However, the recycling of the silicon saw dust is hitherto uncommon.

## 2.2 The Band Saw

To increase the fill factor of a solar panel, the single crystal ingots have to be squared (see Fig. 1.1 – 3rd picture, top row). Equally the very hard crust must be sawn of the polysilicon ingots and the bricks, with the format of the future wafers, cut out of the polysilicon casting. This is commonly done using band saws, using saw bands plated with diamonds allowing for very high cutting and feed rates. Combined with fast table transfers, these machines are the workhorses in the foundries, guaranteeing high throughputs at short downtimes.

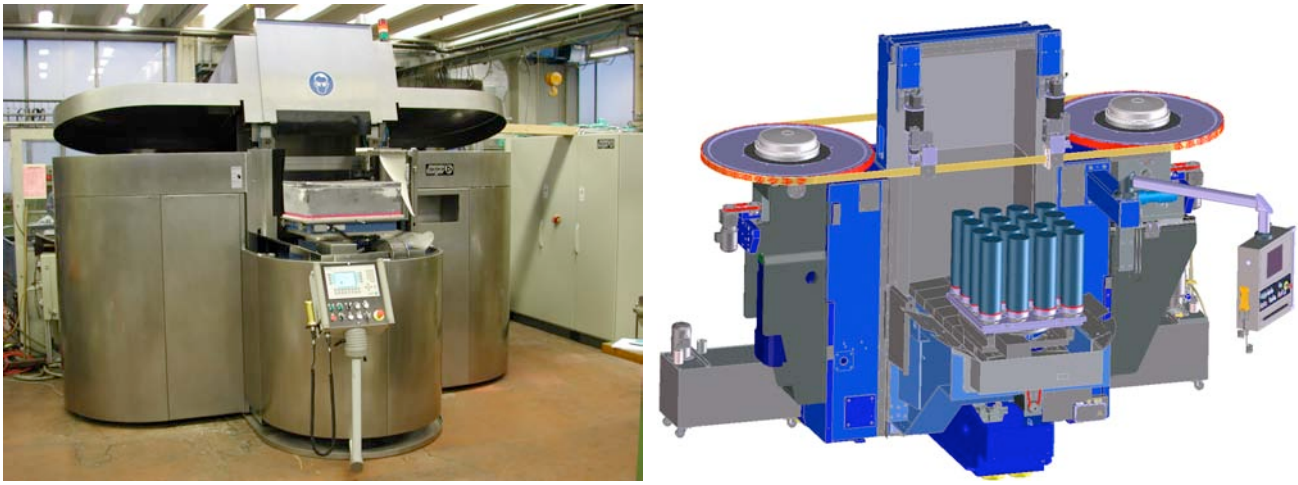

**Fig. 2.2** Photo of the BS800 with a poly silicon ingot to be cut into bricks (left). Skeleton view of the BS 805, loaded with single crystals for squaring (right).

## 2.3 The Multi-Wire Saw

Silicon pillars up to a length of almost one meter, coming from the band saw, are sliced into wafers of a thickness

**Fig. 2.3** Left: The principle of multi-wire sawing - the workpiece is pushed into the wire web, which is wound from one side to the other and transports the cutting medium into the saw-gaps. Right: The DS 262, capable of slicing 2 m of accumulated length in one single run, producing over 4’500 wafers / run.

somewhere between 180 and 280 μm on a wire saw. The multi-wire saw schematics are depicted in Fig. 2.3. A single wire, with a typical diameter of 140 to 160 μm and a spool length of 600 – 800 km, is fed from the supply spool through a wire tensioning system to the four wire guide rollers, which are grooved with a constant pitch. By winding the wire over these wire guide rollers a wire web is formed. On the output end, a take-up spool collects the used wire. An abrasive slurry, supplied through a system of nozzles onto the wire web, is carried with the moving wire into the sawing channel where it performs its cut-grinding process. This slurry consists of hard grinding particles, generally SiC with a diameter in the range of 10 to 15 μm which are suspended in glycol or oil. By pushing the silicon work pieces against the wire web they are sliced into thousands of wafers in one single run.

## 2.4 Silicon Carbide Grit for Slurry Sawing

By developing a recycling process for exhausted SiC slurry, a significant step forward in cost reduction has been achieved. The slurry exhausts by an excessive accumulation of silicon dust, removed in the cutting process and not due to the grains loosing their cutting ability. This silicon dust causes a saturation of the volume load of the solid fraction in the slurry, which either needs to be diluted with fresh slurry or completely replaced.

Several recycling systems are available on the market. One of these is a centrifuge system, where the solids are partially separated from the liquid phase. However, the fraction of very fine silicon particles and broken SiC remain in the liquid. It is these fines, which have to be removed for a good cutting ability of the slurry.

A very much better solution than the in-line centrifuge, is a system allowing for a complete recycling of the slurry by entirely separating the liquid from the solid phase. This method removes the complete fraction of solids including the fines, form the PEG. Further, the recycled liquid is of the same transparency as the new one. Such a system is offered as a worldwide service cutting the cost for slurry in half, compared with a process using exclusively new material.

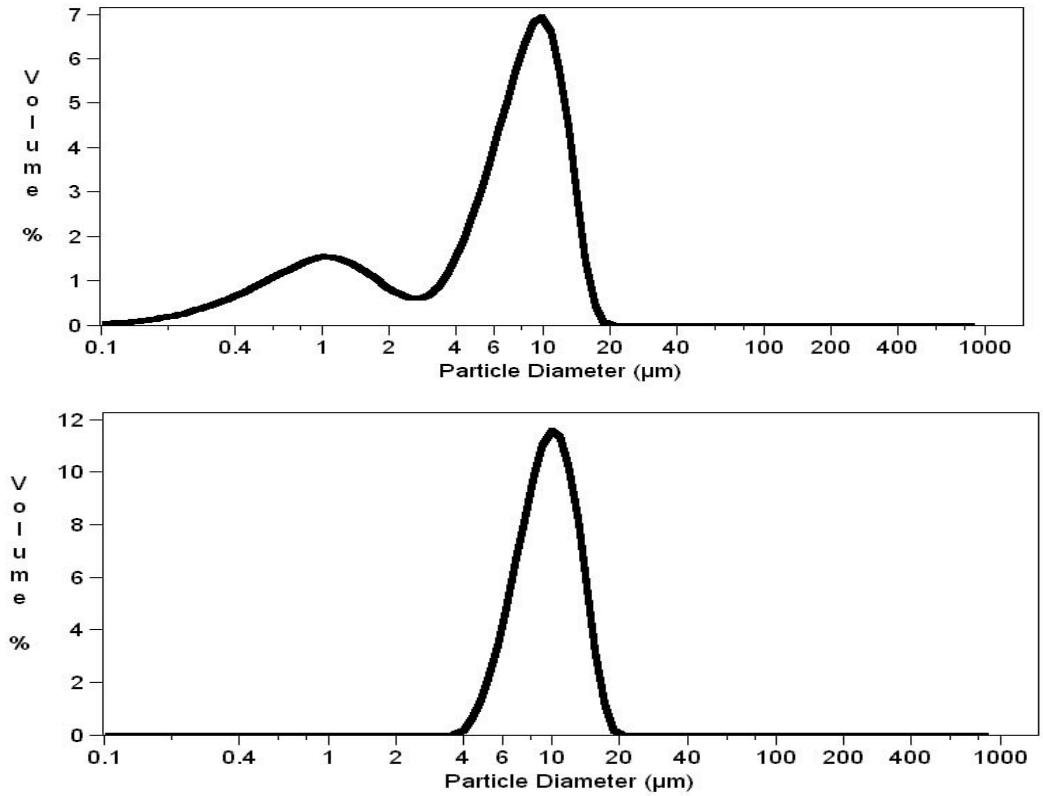


**Fig. 2.4** The SiC grain size distribution before (top) and after the recycling operation (bottom).

# 3 The Economical Aspects

The present concerns of the photovoltaic (PV) industry are dominated by the issue of the raw silicon shortage for wafer production. In the wafer manufacturing process, illustrated in Fig. 1.1, more than 50% of the raw silicon has to be discarded as saw dust, which at present cannot be recycled economically. Such a material balance puts the cutting process under pressure to become even more cost effective than it already is.

## 3.1 Material Usage in Wire Sawing

In order to satisfy the growing wafer demand while the same amount of silicon is being produced, sets the targets of improvement in economising on silicon as well as in reducing the cost for the consumables, such as the silicon carbide grit. Reducing the wafer thickness and decreasing the kerfloss, increases the yield in wafers per kg of silicon.

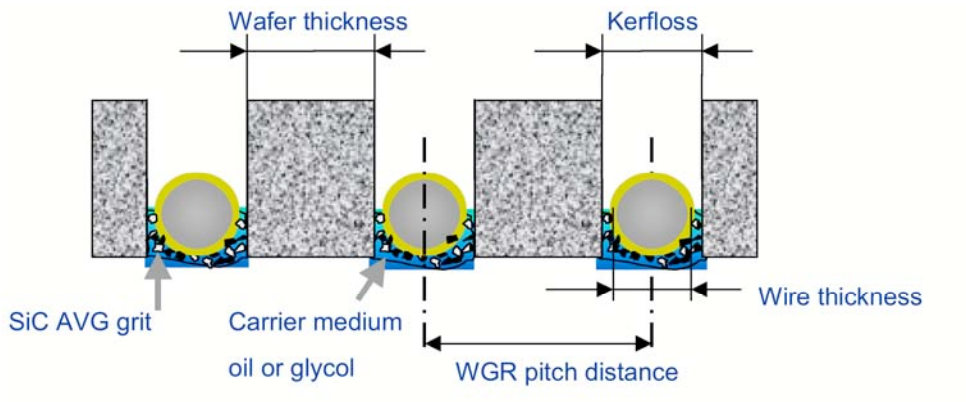


**Fig. 3.1** The geometrical parameters of the cutting zone.

| Year | Wafer Thickness [µm] | Kerfloss [µm] |
|---|---|---|
| 2005 | 230-270 | 200-220 |
| 2010 | 180 | 160 |
| 2020 | 100 | 100 |

**Tab. 3.1** Roadmap for the development in wafer thickness and kerfloss [EPIA].

International committees such as EPIA predict the wafer thickness to be reduced down to less than half of today's average production thickness, within the next 15 years (Table 1). However, the present market situation points towards trend of producing thinner wafers, in combination with thinner wires, even earlier.

## 3.2 Consumables

A further advantage will be the reduction in slurry consumption, which is the dominant cost factor due to the high cost of the abrasive grit (see Fig. 3.2). With thinner wafers and decreasing pitch distance, the overall slurry consumption rises. However, normalised to one single wafer, the reduction in slurry consumption could yield up to 30%. The reduction of the cost per wafer (due to reduced kerfloss and slurry reduction) is visualized in Fig. 4.1: The yield in wafers per kg silicon (dashed line) and cost per wafer (dash-dotted line: wire diameter is kept constant at 0.120 mm) versus the wafer thickness. All these advantages pose a significant challenge to reach this goal. Not only do wafers as thin as 120 µm or even 100 µm have to sliced, but they must be handled after the sawing process, where it is possible that usual artefacts like, lattice tensions or crystal defects cause wafers to break in the handling processes following the slicing.

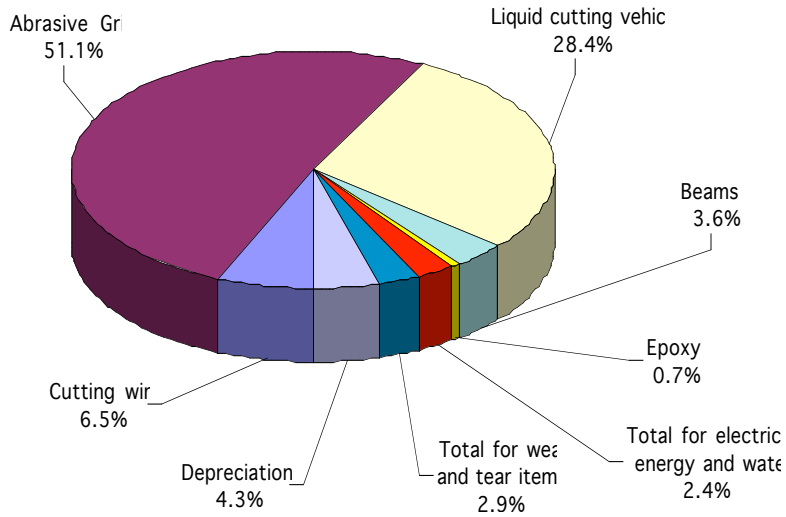


**Fig. 3.2** Cost of ownership for a wire saw: As wafers get thinner, the operational costs for the abrasive and the liquid carrier increase.

# 4 Future Developments - New Technologies

## 4.1 Machines

In retrospect, the last ten or twenty years have mainly dealt with the scaling up of the wire saw technology. At the onset of this technology, only relatively small amounts of material were cut in one run. Currently there is equipment on the market capable of slicing over 2 m of accumulated length of silicon in to wafers (Fig. 2.3). However, we now face a new philosophy in the industry: For the first time a manufacturer introduced a new wire saw with a reduced cutting capacity in terms of the length of silicon to be sliced in one run, enabling to increase the wafer surface quality at an increased yield while reducing the service costs and down times. By optimising the geometry of the cutting region of the new DS-264 (Fig. 4.1) the saw yield could be boosted to almost 100 %. At the same time the table feed speed and therefore throughput has been doubled without any drawback on the quality. Process developments are under way, targeting on thinner wafers and reducing the kerfloss by using thinner wires in order to economise on the expensive raw material. Currently the pv-industry requires wafers with a thickness of down to about 200 μm. The goal is to reduce the standard thickness down to 100 μm, as this increases the yield in number of wafers / kg of silicon and reduces the cost per wafer, increasing the return on investment of the pv-manufacturer.

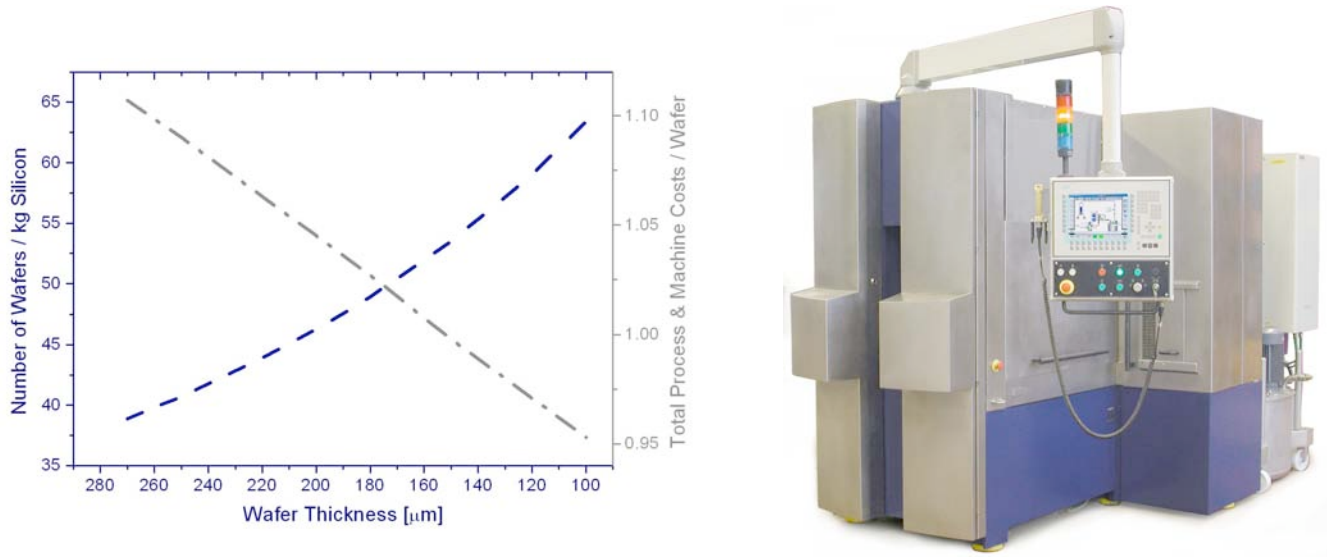


**Fig. 4.1** The benefits of the new DS-264 wire saw technology (left): The gain in wafers per volume of raw material increases while the process costs decrease (Wafer size = 156 x 156). The new generation wire saw DS-264 (right).

Originally intended for emerging markets in the Far East and the fast growing demand from sapphire wafer manufacturers, the DS-265 (Fig. 4.2) has become very popular with research institutes of the pv-domain. It's compact design allows for a high operational flexibility enabling rapid changes between different cutting media. Current hot topics in the pv research community are comparisons of, SiC based slurry with diamond slurry and diamond wire. For basic research, the diamond wire saws are still an interesting alternative (Fig. 4.2 -right) and a full slurry compatible version is under development.


**Fig. 4.2** Concept of the two-roller technology (left). The easy accessibility of the DS 265 is clearly visible (centre). This enables a rapid conversion from SiC to diamond slurry or diamond wire. The DWT multi-wire saw is ideally suited for pure diamond wire pv slicing experiments.

## 4.2 Suspension Agent for Slurry

The currently employed slurry systems based on PEG, oil, or other glycol-based substances are well suited for today's applications. However, with the growing demand for thinner wafers and increasing ingot lengths to be cut on wire saws, the need for a slurry system with a lower viscosity is rising with the following requirements:

- Reducing the energy consumption
- Equal or better suspendability of the particles compared with PEG
- Reduction of the SiC fraction required for cutting
- Recyclable
- Higher cutting speeds on the wire saw

Such suspension agents are currently under development. Their feasibility and capability have been proven and the products are now at a stage where they can enter first pilot production tests.

## 4.3 Fixed Abrasive Wire

Diamond coated wire has been used for several years to cut very hard and brittle materials such as sapphire, SiC single crystals, or various compound semiconductors. The main advantage of diamond wire over slurry, is the possibility to significantly increase feed speeds. It is possible to cut down the processing time to one quarter of the time required for slurry sawing. However, the very long cutting wire lengths required for solar wafering, are still a demanding challenge for the diamond wire manufacturers. Therefore, first large-scale feasibility studies are run for the semiconductor industry, as the sawing process employed for semiconductor silicon requires shorter lengths of wire. The results are promising and will be transferred to solar wafers, as soon as the length of wire required can be manufactured. The wire also needs to be uniform in diameter over its entire length, which is very much more difficult to achieve in an electroplating process than the simple drawing of the standard steel wire.

Several kinds of diamond wire are on the market. All products have in common that an abrasive, predominantly consisting of diamonds, is bound onto a wire core.

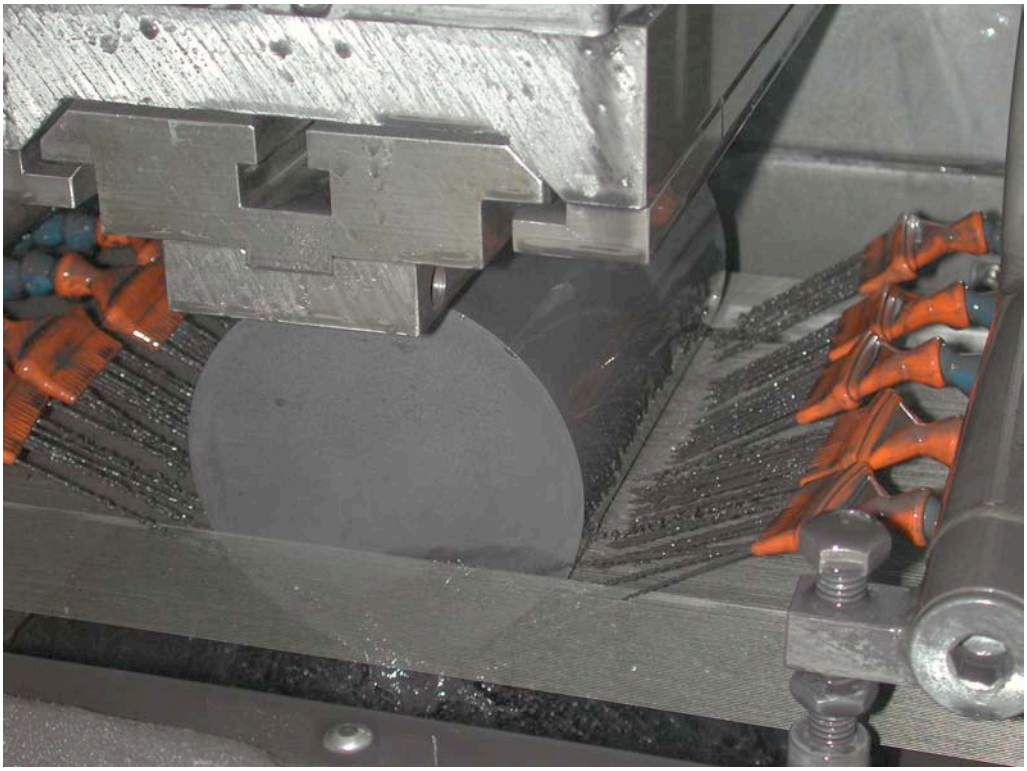

**Fig. 4.3** Slicing semiconductor grade silicon with diamond wire on a DS 265.

However, there is a wide range of substrate wires employed for the diamond wire production. Most widely available is diamond wire, consisting of a steel core onto which a layer of diamonds is applied and bound with an electrolytically deposited layer of nickel. Another method uses the same steel wire and binds the powder in an epoxy matrix, as used in sand paper manufacturing. The use of high-strength polymer fibre as core material is presently under research. However, no such product has been introduced into the market yet.

# 5 References


- C. Funke et al. “Microscopic Mechanisms of Multi-Wire Sawing”; Freiberger Forschungshefte B327 Werkstofftechnologie; ISBN 3-86012-218-5 (2004) 206.
- H. J. Möller; “Basic Mechanisms and Models of Multi-Wire Sawing”; Adv. Eng. Mat. 6 7 (2004) 501
- M. Chandra et al. “Challenges in Slicing Large Diameter Silicon Wafers Using Slurry Wiresaw”; MED-Vol 8; Proceedings of the ASME (1998) 807.