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Lower cost of ownership with diamond-wire -sawn multicrystalline silicon wafers

In order to achieve a cost-efficient, competitive, high-quality production process for mc-Si wafers, a number of components are important. It calls for a wire-friendly, technologically sophisticated and specific saw, a suitable and optimized cutting tool, a compatible cooling lubricant and a high degree of process know-how extending to the cell and module process.

In photo voltaics, monocrystalline (Cz-Si) and multicrystalline (mc-Si)materials are processed to produce wafers. Up to now, use of the low-cost diamond wire saw process was reserved for monocrystalline wafers. Due to the particular material properties of mc-Si, special developments are needed in both systems engineering and the process in order to saw this material as economically as possible. In addition to the requisite developments relating solely to wafer production, it was necessary to develop new texturing methods in the solar process on account of the fact that existing, established methods, such as the HF:HNO3:H2O Iso texture, no longer achieve the desired texturizing results.

Using the modified process, the Meyer Burger wire saws achieve a performance on a par with that achieved when sawing Cz-Si. Likewise, the plasma texturin-genables lower reflectivity values to be achieved, similar to the level of the monocrystalline texture. The reflectivity values of 10-12% are well below those of wet texturing (Iso texture) of typically 22%.With plasma texturing, the module power rises (typ. +0.4% abs) with simultaneous cost reduction of ca. 0.1 USD per wafer.

Meyer Burger plasma texturing may be used to texture all Si wafers highly effectively, in particular mc-DW wafers.The process offers many benefits, among them very low water consumption.The greatest benefits are the easy integration into the production process, the marked increase in efficiency thanks to significantly reduced reflectivity in the solar module, and a totally even, black module finish.

From silicon brick to silicon wafer

In the case of a multi-wire saw, a wire is winded several thousand times around at least two wire guide rollers and tensioned. The wire guide rollers have fine grooves that keep the wire in predetermined positions to form the wire field. The silicon brick is fixed above the wire field and pressed into it. If the saw wire is now moved, it cuts into the silicon brick. The wafer thickness is essentially defined by the distance between the above-mentioned fine grooves and the wire diameter.

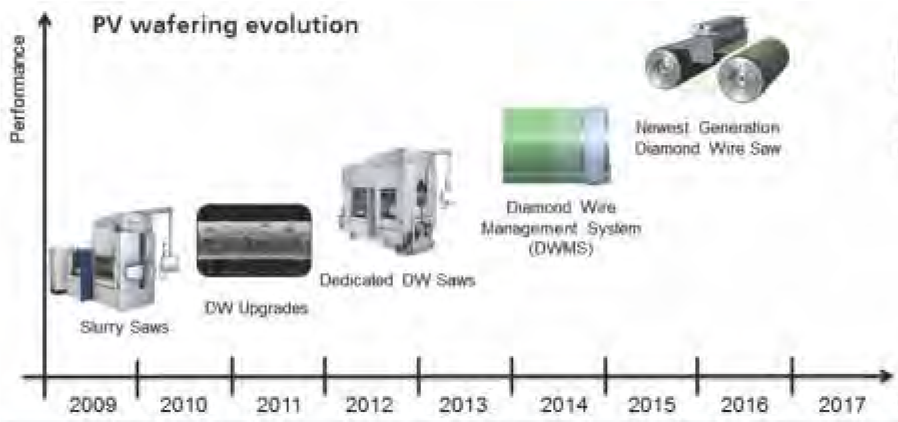
In the past, the use of a suspension consisting of a loose abrasive [generally silicon carbide (SiC)] and a carrier liquid [generally polyethylene glycol (PEG)] initially became established. This suspension is known as 'slurry' and the sawing process as 'slurry sawing technology'.The increased international price pressure also brought about a demand for an improved, more cost-effective and faster sawing process. Diamond wire sawing technology is extremely well suited to meet these high expectations. This technology essentially differs from slurry sawing technology in that the abrasive particles are fixed to the saw wire and the expensive carrier fluid is eliminated. The latter was replaced by an inexpensive coolant additive diluted with 98% or even as much as 99.5% deionized water.

The switch to the diamond wire sawing technology proved to be difficult because the material process changed from a lapping process to an abrasive process. Because the available saws were only able to achieve a high wafer quality with an uncompetitive sawing process, rapid development of the multi-wire saws was necessary. A good example is the development from the DS271 (slurry) to the state-of-the-art diamond wire saw DW288 Series 3 (see Fig.1).

This brought about a dramatic reduction in wafer production costs. It was achieved first and foremost through the use of ever-thinner saw wires and the associated better ratio between kerf loss and number of wafers. The introduction of a cheap and effective cooling lubricant and the drastically shortened cutting time accounted for further cost reductions. For example, it has been possible to decrease the core diameter of the saw wire from 140 µm to 70 and then to 60 µm. In this way, kerf loss is halved, saving valuable natural resources with every cut. For comparison, it should be pointed out that the thickness of a human hair is around 50-80 µm. The control system for the latest generation of Meyer Burger saws is already designed for 50 µm wire thickness.

The diamond particles are generally between 5 and 20 µm in size and are fixed to the core wire by means of metal or synthetic resin deposition. Fig.2 shows an REM photo of a galvanically coated, diamond-studded saw wire (electroplated wire [EPW]).

The use of diamond-studded wire also enabled the cutting time to be greatly shortened. As can be seen from Fig. 1, Cz-Si is cut in around 2 hours with a DW288 Series 3 and state-of-the-art diamond wire.6 to 8 hours are required when using slurry technology. Great potential for cost savings can be found in wire consumption. It is stated in meters of wire consumed per wafer ([m/Wf] or [m/pcs]).For Cz-Si, 1 m/pcs was documented on an industrial scale; this is the lowest possible wire consumption to date. The wire accounts for the highest proportion of the process costs, but wire saw technology, in this case with DWMS (explained in the following text), is decisive for the wire performance.



Kerf	µm	150	150	120	<100	<90
Time	hrs	4	3	3	2(Cz-Si) 3(mc-Si)	2(Cz-Si) 2,5(mc-Si)
DW Use	m/Wf	2	1.2	1	1,2(Cz-Si) 2(mc-Si)	1(Cz-Si) 1,25-1,8(mc-Si)

Fig. 1: Changes in kerf, cutting time and wire consumption resulting from the changeover from slurry process to a dedicated diamond wire saw, taking the example of the DS271 and the DW288 Series 3 (source: Meyer Burger(Switzerland) AG).

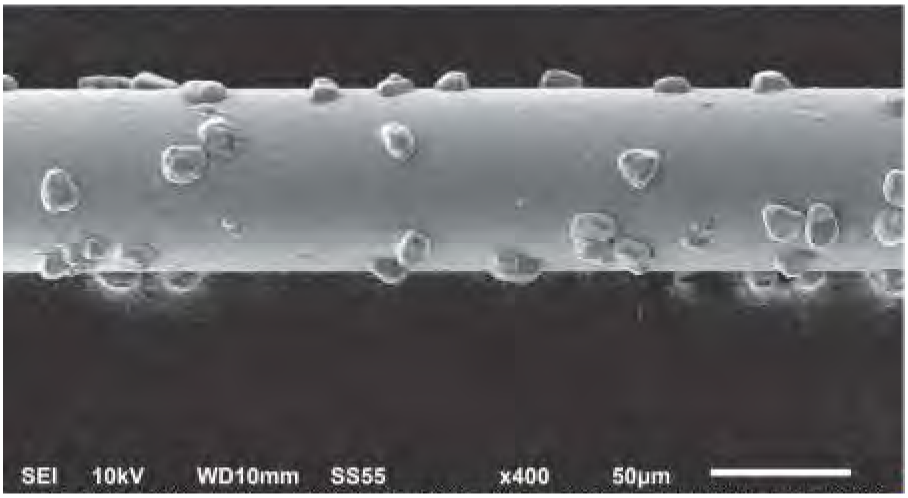


Fig. 2: REM photo of an unused diamond wire (electroplated wire [EPW]) - galvanically coated wire with a core diameter of 60 µm.

Efficient wafering of multicrystalline silicon with diamond wire

It was also possible to reduce cutting times dramatically for mc-Si, almost to those for Cz-Si. The figure in this case is currently less than 2.5 hours. Wire consumption is also slightly higher and varies considerably from 1.8 m/pcs to 1.25 m/pcs.This is understandable because mc-Si material varies considerably, too: crystallites of different sizes, variable proportions of the hard orientation, varying proportions of undesirable foreign matter, etc. Meyer Burger has developed dedicated saws capable of sawing mc-Si wafers with the low wire consumption of 1.25 m/pcs. In order to ensure the achievement of this target, a material quality classification for mc-Si was developed in-house.Various material properties were measured, evaluated and weighted for this purpose. Based on this material classification, a suitably adapted sawing process can be precisely developed for and in conjunction with the customer. This know-how is being employed at Meyer Burger to cut the cost of the diamond wire sawing process.

This is only one side of the coin, however. The product - a high-quality wafer-is as important as cost-effectiveness.The quality of a silicon wafer is quantified by a variety of factors. They include in particular the wafer thickness [Total Thickness Variation (TTV)] and the saw mark depth [SawMark (SM)].The biggest challenge for mc-Si wafer production at present is compliance with the specific customer limits for the saw mark parameter. Based on the internal mc-Si material quality classification, we were able to ascertain that this is primarily due to the different silicon material qualities currently available on the market. Each mc-Si producer uses its own crystallization process and has its own suppliers for auxiliary materials and consumables, while some also use modified or self-developed crystallization ovens, resulting in different distributions and concentrations of dissolved and solid impurities in the mc-Si block (or mc-Si ingot). In addition to multi crystallinity, the concentration and distribution of these very impurities determine the characteristics of the particular mc-Si and in turn the differences to Cz-Si, as well as between mc-Si from different producers. We also ascertained that an excessively cost-optimizedcrystallization process presents a greater challenge for the subsequent sawing process than a quality-oriented crystallization process. Consequently, the wire consumptions achieved varied between the mc-Si producers from 1.8 m/pcs to the current world record of 1.25 m/pcs (these results obtained by measuring, for comparison purposes, at the same cutting time of around 135 minutes).

Optimization of the overall system

Reducing wire consumption enables the cost of wafer production to be lowered

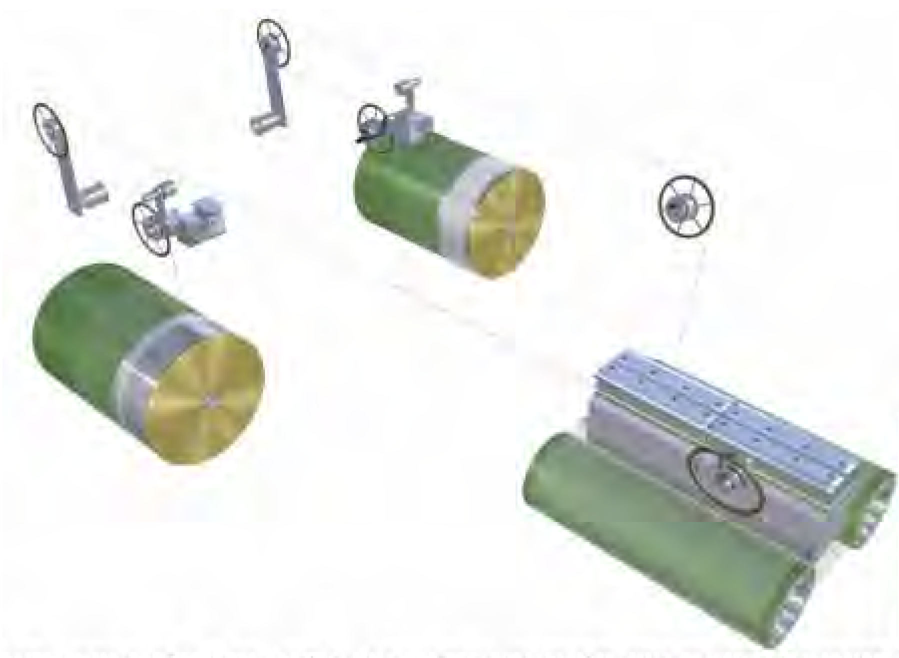


Fig. 3: Depiction of the patented Diamond Wire Management System (DWMS) for reducing wire wear.(Patented by Meyer Burger (Switzerland) AG)

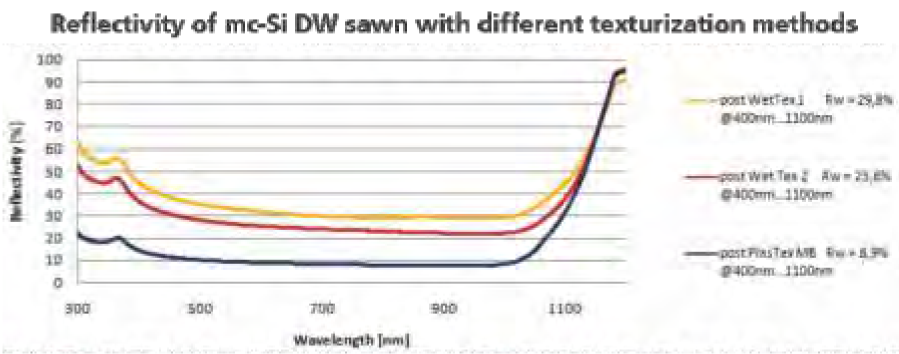


Fig. 4: Reflectivity curves over the relevant spectral range from 300nm to 1200nm of differently textured mc-Siwafers. The plasma-textured wafers (black) exhibit the lowest overall reflectivity. This value is typically only around 10%.More light thus enters the wafer and the solar cell can generate more electricity. This is clearly apparent as an increase in the performance of the solar module.

effectively. The initial goal is to determine the causes of wire wear. The next stage is to improve wire production, taking the process knowledge into account. It was possible, for example, to reduce wire wear within the sawing process by refining the electroplating processes. Another important and necessary step was the development of the Diamond Wire Management System (DWMS). This system devised and patented by Meyer Burger (Switzerland) AG reduces the wire wear arising from the winding and unwinding of the wire on the storage spool. This is made possible by high-precisionwindingof the required quantity of wire onto a storage spool before cutting. This prevents axial chafing of the wire and resultant damage before it even begins to saw the silicon. Thanks to this innovative development dedicated to diamond wire use, the full capacity of the wire can be used for cutting, thereby reducing wire consumption, cutting time and ultimately the wafer production costs (see Fig. 3).

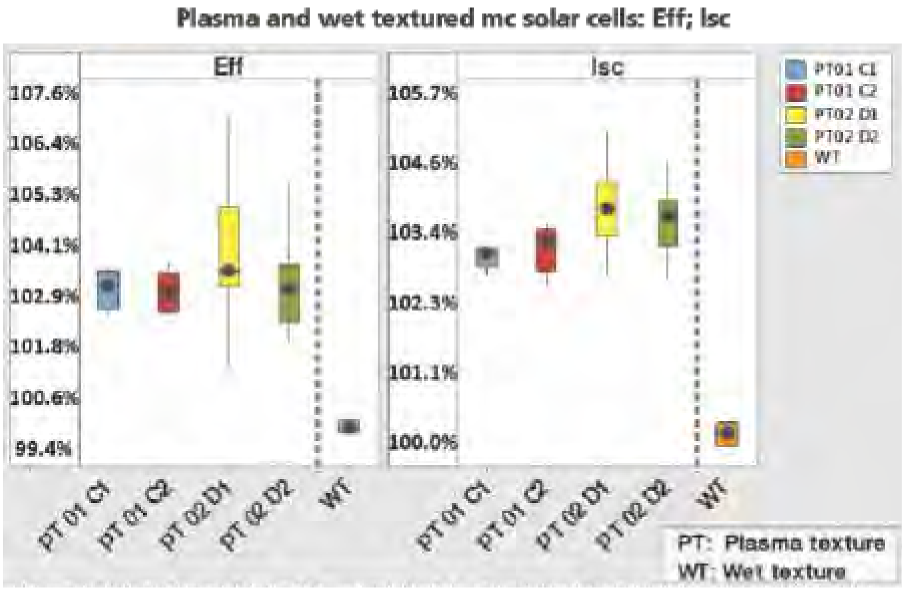


Fig. 5: Measuring the effects of plasma texturing in comparison to a very efficient wet texturing process:as expected, the lower reflectivity increases the short circuit current by ca. 3.5%.Moreover, the passivation is retained, which is shown by the increase in efficiency, also of 3.5%.

	Water	Cell	Module	
Technology	DW plus wire mgt II	PERC multi	Standard process	For 72 cell module
Costs	-13 ct / wafer	+3ct / wafer	+/- 0	-7.2 USD / module
Efficiency	-	+0.5% abs.	+ 6 Wp plasma-texture	+6 Wp per module
COO (ct/kWh)				91% compared to standard

Fig. 6 shows the overall calculation (conservative):13 ct/Wf savings from the diamond wire process are offset by a maximum cost increase of 2-3ct/Wfdue to plasma texturing. However, the cost savings from the diamond wire process can only be used efficiently in conjunction with plasma texturing. In return, the overall efficiency of the solar module is increased. The total module cost of ownership (COO) is 5% lower.

Use of diamond-wire-sawn multicrystalline silicon (mc-DW) wafers in the cell process

When sawing with diamond wire, a very thin layer of amorphous silicon is formed on the wafer surface. This can be easily etched away in the alkaline texturing process.

Mc-Si wafers, however, are acid textured and this texture has virtually no points of attack on the Si surface sawn using diamond wire. At the present time, therefore, a standard cellline is unable to directly process multicrystalline waferssawn using diamond wire (mc-DW wafers).

Many manufacturers of wet chemical systems are working on solutions. Meyer Burger offers a further method that even greatly increases the efficiency of the solar cells and, in turn, of the solar modules: plasma texturing. This option is described below because plasma texturing is especially suited to thinner wafers and is thus a safe investment for the future.

Meyer Burger plasma texturing may be used to texture all Si wafers highly effectively, in particular mc-DW wafers. The process offers many benefits, among them very low water consumption. The greatest benefits are the easy integration into the production process, the marked increase in efficiency thanks to significantly reduced reflectivity in the solar module, and a totally even, black module finish (comparable with modules produced from monocrystalline wafer material).

In addition to surface reflectivity, which must be minimized in conjunction with the anti-reflectivity coating (ARC), electrical passivation of the wafer surface is also very important in cell production. In experiments, we were able to ascertain that the benefits of the sawing process, the plasma texturing process and the cell process can easily be combined.

Plasma texturing increases the efficiency of mc-Si material because this is a surface effect. Module measurements confirm that with correct process management, almost the entire benefit of the cell performance increase remains in the module.

The costs of plasma texturing vary according to region: Where process water is not a problem, costs of around 2-3 ct/Wf incl. depreciation are to be expected. If process water is very expensive, plasma texturing enables a considerable saving in water and the costs are under 2ct/Wf.This has to be seen against the efficiency increase in the cell and in the module:

Two advantageous process steps can now be used for mc-Si materials: sawing using the diamond wire process and performance-enhancing plasma texturing. The processes must, of course, be individually optimized and coordinated. With its systems, Meyer Burger provides the necessary support to minimize risk for its customers. What has not yet been taken into account in this calculation is that moving the solar module into a higher performance class can yield additional marketing benefits. Work is currently under way to use diamond-wire-sawn wafers with an enhanced wet texturing process as well. Results to date show no reduction in reflectivity, however, and the additional process costs are as yet unknown. In addition, there is a possibility of significantly greater mechanical stress on the wafers that might lead to a reduced yield with thinner wafers in future. However, cell lines that use mc-Si material will have the option to use mc-DW materials very soon. This will enable a marked cost reduction, putting cost pressure on modules with Cz-Si material. The cost savings spiral continues turning.

Summary

In order to achieve a cost-efficient, competitive, high-quality production process for mc-Siwafers, a number of components are important. It calls for a wire-friendly, technologically sophisticated and specific saw, a suitable and optimized cutting tool, a compatible cooling lubricant and a high degree of process know-how extending to the cell and module process. The provision of these components from a single supplier enables the challenges arising from the current and future requirements of the PV market to be mastered successfully and to the benefit of the customer.