Cutting out the kerf

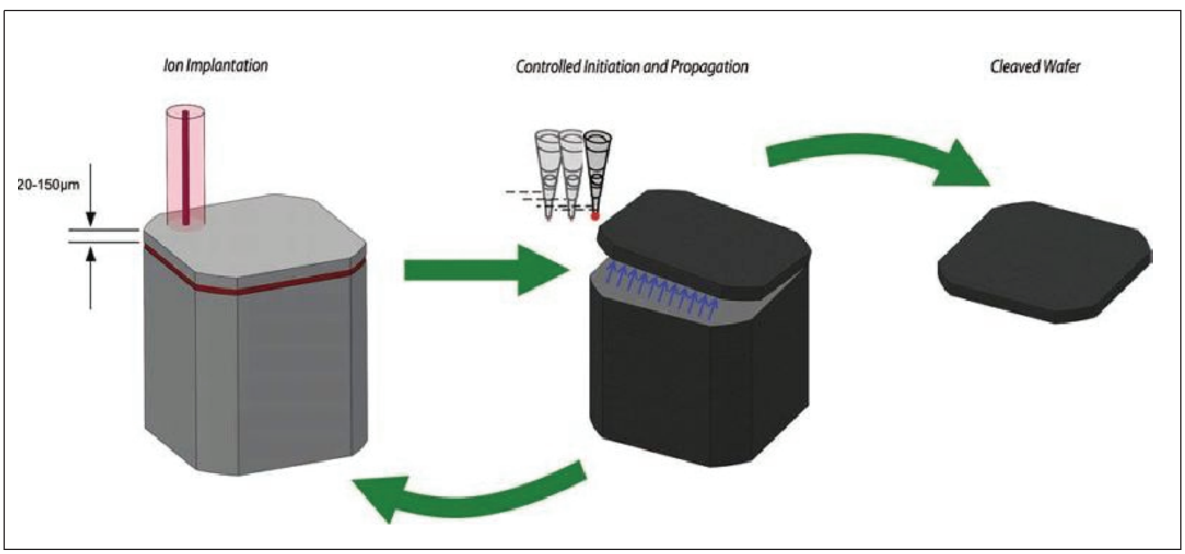
The PV industry continues to search for any incremental cost savings in manufacturing to achieve grid parity and reduce costs to below US$1 per watt generated by solar means. **Alessandro Fujisaka** of the **Silicon Genesis Corporation** discusses how they have a cutting technique that reduces the wastage from cutting wafers by removing the grooves made by the cutting tool, known as the kerf.

The initial cost for a cell manufacturer is the wafer. As a result there are extensive efforts being addressed for wafer manufacturing costs with a focus on the ability to reduce costs by working with thinner wafers and reducing kerf loss (silicon waste) so as to reap the greatest benefit from the initial material costs. A kerf free approach leads the way for reducing crystalline silicon waste in the race towards grid parity and ultimately $1/watt (W) or less. Silicon Genesis (SiGen) has developed a kerf free photovoltaic (PV) wafering approach as opposed to the wire saw process and is improving a technology that can lower costs, improve quality, and allow for thicknesses from 150µm to 20µm.

The SiGen cleaving manufacturing addresses multiple issues of the current wafering technology and market conditions. The major concern is the cost aspects of wafering and the technical barriers to wafer thickness reduction. In crystalline silicon solar cells and modules, the challenge to match the dynamic growth of the thin film sector is unlikely to be realised by developments in the cell technology alone. The cutting of silicon ingots into wafers is a key step in the production of PV cells based on crystalline silicon.

Crystalline silicon holds about 90% of the solar PV market and any opportunity to lower the cost in the wafering process is highly desirable and investigated. The current best practices for the wafering segment are based on wire saw (WS) cutting of silicon ingots. The WS relies on simple cutting of the silicon ingot with a multi-kilometre's long wire and slurry with grit particles and a

Figure 1. Implant and Cleave process



The SiGen process consists of two major steps. The first is an implant step to develop a sub surface cleave plane and then a cleave step to slice PV wafers of various thicknesses at the pre-determined cleave plane

coolant. In either case, inherent kerf loss due to the sawing process results in loss of polySi utilization of up to 50% of the incoming material. This polySi loss represents a significant cost to the industry. The SiGen cleaving approach has been developed to produce wafers with near zero kerf loss, providing significant cost savings.

These savings are realised in a number of ways to create near zero kerf loss resulting in immediate savings of initial material costs. The process allows for the manufacture of wafers at thicknesses from 20μm to 150μm, reducing material demand per cell. The resultant reduction in material demand allows for a proportional reduction on the number of pullers, blockers and cleaners required. The process eliminates slurry and wire contaminants and the subsequent cost to minimise their impact on to the environment.

Kerf free process

The SiGen process consists of two major steps. The first is an implant step to develop a sub surface cleave plane and then a cleave step to slice PV wafers of various thicknesses at the pre-determined cleave plane from mono crystalline

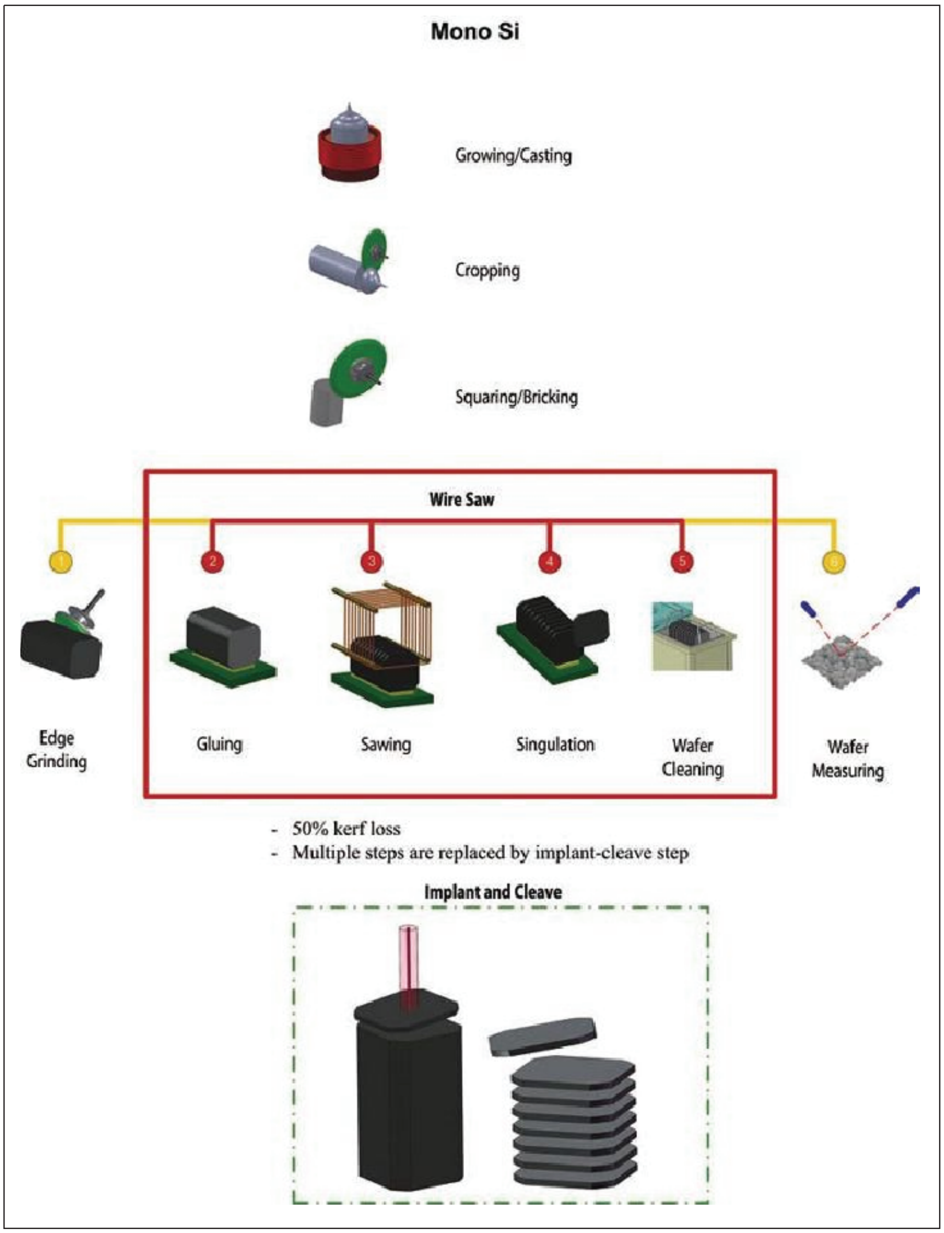


Figure 2. Cleaving vs Sawing Manufacturing

silicon ingots or bricks as shown in figure 1. This process is based on a hydrogen assisted cleaving principle. The first step is to define a cleaving plane at the desired thickness under the brick top surface using high energy hydrogen (proton) beam irradiation. The incident mono energetic protons lose their energy as they traverse a silicon thickness to form a stressed End-Of-Range (EOR) layer. In silicon, ~1-4MeV proton energy is required to form a cleave layer at the desired depth of 20-150mm below the brick surface.

The wafering process is the final step of a wafer formation within a series of steps in the PV value chain, denoted as upstream. The wafering step itself however, is not a single process but again a series of processes after the wire saw cuts the ingot into bricks.

Wire saw and cleaving manufacturing

The upstream steps of wire saw based manufacturing consist of growing the silicon ingots, cropping top and tail, squaring, surface grinding, cropping into bricks, wire sawing, pre-cleaning, separation, final cleaning, sorting and packing. For the wire sawing process itself, the brick is glued and mounted onto a holder and placed into the wire saw. The saw consists of a spool of wire within a suspension of grit particles of SiC in a slurry mixture. The wire is guided onto the brick by a threading unit that spaces the wires at intervals along the brick. The wire spacing and the wire diameter determine the wafer thickness and the kerf loss. It is a complex set of processes that not only adds costs but fundamental limitations in reducing kerf loss and wafer thickness.

The SiGen cleaving manufacturing addresses multiple issues of current wafering technology and market conditions. With a focus on cost savings through reduction of silicon usage, the company has developed an approach to counter the technical barriers to wafer thickness reduction. The wafering production steps are dramatically simplified by the cleaving approach as shown in figure 2.

The additional steps required by the wire saw, as shown in figure 2 involve both equipment usage and material handling that are prime sources for breakage. In addition, all the used slurry and wire have limited recycling options, adding costs and causing potential contamination to the environment.

Figure 3 shows an example of wafer comb from wire saw after pre-cleaning and the 150um as-cleaved wafer that does not require any additional steps.

The cleaving approach represents a clean technology that eliminates the waste in the wafering process. The technology is a non-contact process, it should be emphasized that the wafers exhibit improved characteristics in terms of: reduced/eliminated micro-cracks, improved Total Thickness Variation (TTV), improved strength and improved handling capabilities.

Figure 3. Wafer comb from wire saw and 150um as-cleaved

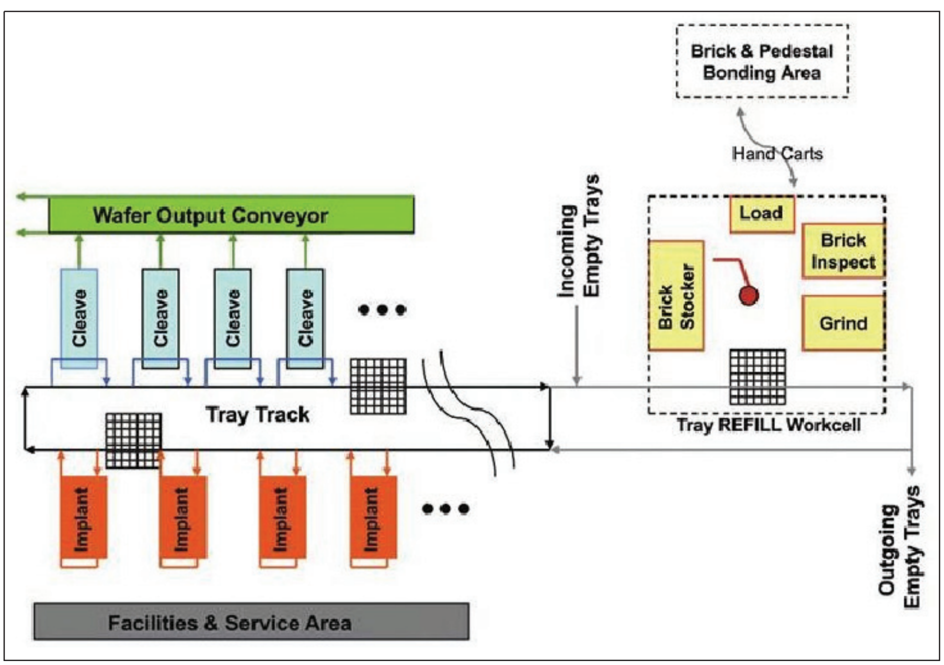


Figure 4. PolyMax Manufacturing Factory Layout

Built in cost savings

Figure 4 shows a factory layout concept with the implant and cleave modules in a more simplified wafering environment. Also shown in the layout is a brick station, with functions to load/unload bricks for inspection, refilling the tray and reconditioning the bricks.

The following methodology was used to compare the cost reduction benefits provided by the SiGen cleaving process: Baseline cost assumptions were used for the fully integrated factory on an annual basis A realistic and validated model has been generated for the cost of wafering for both, the Wire Saw (WS) and the SiGen PolyMax system (PM) for integrated PV manufacturing. On the basis of this model a cost savings is quantified in $/Wp for mono-c-Si wafers by comparing the higher

Wafer	Wafer thickness	180 (WS); 150um and 50um (PM)
	Kerf loss	50.7% (WS); 0% (PM)
	Size	156mm x 156mm
Solar Cell	Efficiency	15.8%

overall cost of WS to PM for wafers 180um, 150um and 50um thick respectively, using validated production assumptions for yield, throughput, fixed and variable costs. This $/Wp cost is combined with the cost assumptions provided by the industry for cell and module manufacturing costs to determine the total module cost in $/Wp.

Note that in all cases, the parameters utilized for the WS case are based on industry benchmarks and inputs from industry representatives.

The numbers include an average value of 3.85 Watts per wafer as a benchmark. The results show that the wafering step is a key cost component in both the upstream and in the downstream of the PV value chain as it determines the amount of feedstock material necessary to meet the projected capacity for the cell and module production. The entire cost analysis will be presented at the 24th European Photovoltaic Solar Energy Conference in Hamburg, September 2009.

Table I: Poly-Si Material Usage per Year

	Wire Saw	Cleaving	
	180um	150um	50um
Poly-Si usage (MT/year)	2,500	924	308
Poly Ratio	1	0.36	0.12

Analysis and Impact

The Cost Reduction Analysis used an assumed cost for poly-silicon at $90/Kg. It is quite evident the cost reduction in the upstream value chain and even at lower prices of poly the cost savings are still indispensable to reach <$1/Wp module cost. The annual estimated silicon feedstock material usage for 373MW wafers for a wire saw factory and cleaving factory is shown in Table I.

For the above metrics, the upstream cost is substantially reduced ranging from 53% to 70% depending upon the wafer thickness considered and the price of poly-Si. Even at lower prices of poly-Si, the savings are extremely important to achieve the module cost target in the market. The downstream processes, cell and module, will benefit with a lower starting cost per wafer and higher quality material from the cleaving process.

At about $2/Wp module prices, solar cells are said to be competitive to grid electricity and for that to happen the referred analysis shows that the cost of poly needs to be reduced to $0.24/Wp level. The Cost Reduction Analysis shows that the cleaving approach would be between $0.22/Wp and $0.07/Wp which in either case is well below the cost target. In general, multi-crystalline wafers offered some advantages over mono-crystalline wafers. The process cost of multi-crystalline wafers was considered lower with the existing manufacturing practices. But the cost reduction analysis showed that the wafering cost reduction achieved with the cleaving process overturns this manufacturing cost difference with the additional benefit of higher conversion efficiency for mono-crystalline wafers.

Knowledgeable choice

The Cost/Watt advantages achieved by the cleaving process is likely to allow companies to better withstand the competitive market dynamics with a higher likelihood to take the leadership position in the PV industry with lower manufacturing costs and improved conversion efficiencies. With the steep price decline, the cleaving approach is not merely a manufacturing tool but a financial tool providing a competitive and sustainable cost-per-watt advantage. The economic impact and applicability of the cleaving process for wafering is substantial. The detailed cost analysis demonstrates that the cleaving process using the SiGen proprietary PolyMax technology is fundamental for the crystalline-silicon based PV solar cells to win the race to <$1/Wp and yet provide substantial gross margin protection to the manufacturers.