

Wafer Slicing Technology

For Solar Photovoltaic Cells



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INTRODUCTION

Wafer slicing, also called “wafering,” is a key part of the solar photovoltaic (PV) cell manufacturing process. The process begins with solid ingots made of single-crystal or multi-crystalline silicon material. Wire saws are then used to shape the ingots into squared blocks and slice them into thin wafers [figure 1]. These wafers are used as the base for building the active PV cell.

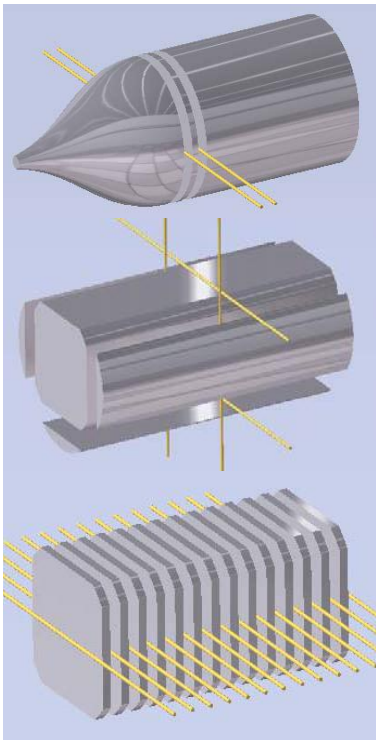


Figure 1: The three stages of wafering: cropping, squaring and slicing

Wire sawing equipment is used by both wafer suppliers and integrated c-Si PV module manufacturers who want to manage their own wafering processes. It is used for both mono-crystalline and poly or multi-crystalline PV technologies.

The industry’s most successful wafering system, the Applied HCT B5, has been the benchmark for PV wafering with an installed base of over 1000 systems and growing.

Since the wafer is the most expensive portion of crystalline silicon-based PV technologies, representing over 50% of c-Si module cost, reducing manufacturing costs is critical to the goal of making solar energy competitive with grid power. This document offers an overview of the wafer slicing process, manufacturing challenges and how next generation wire saw technology can contribute to lowering wafer cost.

WIRE SAW HISTORY

The first practical machines for PV wafering were introduced in the 1980s, based on the pioneering work of Dr. Charles Hauser, founder of HCT Shaping Systems, Switzerland, which is now the HCT Wafering Systems division of Applied Materials. These machines pioneered the principle of using a moving wire coated with an abrasive slurry to create the cutting action. Today, the prevalent type of saw used for shaping and slicing wafers from ingots retains the same basic architecture as Dr. Hauser’s original machine, but with greatly increased load capacity, cutting speed and precision.

THE WAFER SAWING PROCESS

The heart of a modern wire saw is a very thin, high-strength steel wire which carries the slurry that performs the cutting action. The wire is wound on guides that form a horizontal “web” of up to 1,000 parallel wires. Motors rotate the wire guides, causing

the entire wire-web to move at a speed of 5 to 25 meters per second. The wire speed and its linear (back and forth) motion are adjusted throughout the cut. Nozzles continuously spray the moving wires with slurry that typically contains suspended silicon carbide particles. The silicon blocks are mounted to cutting tables. The cutting tables then travel vertically through the moving wire web, cutting the blocks into wafers [figure 2].



Figure 2: Silicon blocks are passed through the web of cutting wires.

While the sawing principle is straightforward, the challenge is in the execution. The wire saw must precisely balance table speed and brick load length to achieve higher productivity while minimizing wafer thickness variations and avoiding wire breakages. It must achieve this with increasingly thinner wire and wafers.

REDUCING COSTS

For crystalline (c-Si) wafer-based PV cells, the crystalline silicon raw material plus the cost of slicing, which make up the total cost of the wafer, represents over 50% of the total module cost. For a given cost of raw silicon, wafer manufacturers can drive down costs with various levers, from material and quality yield to consumables usage and equipment productivity.

Conserving silicon, which can be achieved by reducing the kerf loss (the material lost due to the cutting action itself), and reducing the thickness of the wafers, is at the heart of material yield. Over the past decade,

silicon PV wafer thickness has been reduced from 330 μ m to today's typical 180-220 μ m thickness range. However, cell and module processing limitations need to be addressed before further wafer thickness reduction can be achieved. Kerf loss is a function of the wire diameter, which has been reduced from 180-160 μ m to today's typical range of 140-120 μ m. However, savings through wire diameter reduction are counter balanced by lower productivity and higher wire price. While sawing platforms need to be ready for thinner wire, further wire diameter reduction effectiveness will be dictated by poly pricing trend.

At all wafer thicknesses, crystalline silicon PV cell manufacturers demand extremely high wafer quality yield, with minimum surface damage (micro-cracks, saw marks), topography defects (warp, bow and thickness variation) and no additional downstream processing. Quality yield is a powerful cost reduction lever which cannot be compromised.

Another key driver in wafer manufacturing cost is the consumables costs, driven largely by slurry and wire usage. Manufacturers are adopting recycled slurry in increasing mix percentage as a primary way to reduce consumables costs. Tool productivity, defined as wafer output per year (aka MW/Y), is the last key knob for lowering wafer cost, which can be further enhanced if combined with a smaller tool factory footprint. Higher productivity can not only lower wafer production cost but also improve cash generation per tool per day.

As we have already seen, the challenge for manufacturers is the trade-offs between the various cost reduction levers, which often work against one another. Increasing productivity through increased table speed will challenge quality yield. Decreasing material yield with thinner wire will challenge productivity. The best wire saw designs offer wafer manufacturers the necessary process optimization window to maximize yield and productivity.

PROCESS OPTIMIZATION

The primary process window drivers for minimizing wafer costs are thin wire capability and brick load size flexibility.

As we have seen, the wire saw should be able to accommodate thinner wire diameter depending on the cycles of poly market. The Applied HCT B5 is fully capable of thin wire handling down to 120 μm and below.

Flexible brick load size, defined as the length of silicon bricks charged in the saw, is the other critical knob to enable high productivity while maintaining high yield. Productivity is defined as the number of wafers produced in a given time, and is proportional, for a given wafer and wire size, to the product of brick load and table speed. Brick load size is a powerful lever as one can substantially lower table speed while increasing load length so as to keep yield high while increasing overall tool productivity [figure 3].

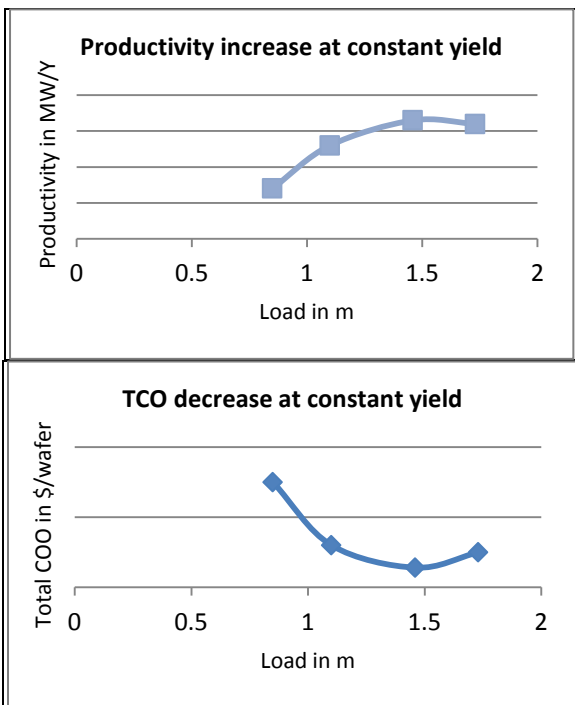


Figure 3: COO and Productivity Graphs

This “return” on increasing load is optimal for brick load size between 1 and 2m and this is why the Applied HCT B5 is uniquely designed with a brick load size window of 2m.

A side effect of increasing load size is increased tool availability as less frequent load swaps are necessary, which further pushes up net productivity [figure 4].

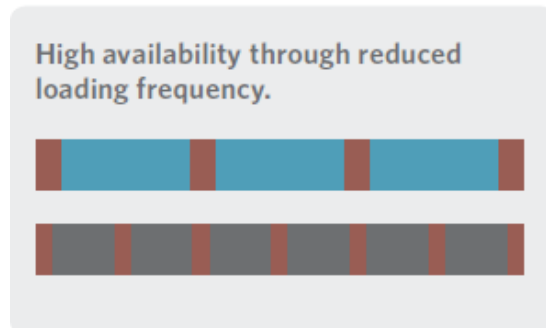


Figure 4: Loading frequency

The Applied HCT B5 is the only system in the market that is uniquely equipped to handle brick load sizes up to 2m, giving manufacturers the necessary process window to optimize productivity and yield. The net result is lower total cost of ownership and improved ROI.

ADVANCED WIRE TECHNOLOGY

The B5 is a proven platform with nearly 1000 systems in high volume manufacturing. It is thin wire capable down to 120 μm and below and easily extendable to advanced structured and diamond wire technologies pursued by Applied HCT.

Structured wire [figure 5] silicon sawing is an evolutionary technology developed by Applied HCT which uses a bi-axially crimped wire and existing slurries to deliver more efficient slurry transport and faster cut rate. The technology was initially developed for HCT squarers, which have quickly become the standard in the industry. Applied HCT is now pushing the technology to deliver even more productivity gains

on squarers and to apply it to wafering for the first time in the industry.



Figure 5: Structured Wire

Moving to thicker structured wire on the Applied HCT squarer is already proven to increase productivity by 70% and reduce COO by 20%. While these gains are impressive, more hardware and process innovation with structured wire promises even higher productivity performance in the near future.

Applying structured wire sawing technology to wafering is a natural evolution which is also expected to deliver significant wafering productivity gains while offering a low risk upgrade path to wafer manufacturers. Initial development at Applied HCT promises 10-20% higher cutting speed with best in class yield.



Figure 6: The Applied HCT B5 Wafering System

Higher productivity saws enable fewer machines to achieve the same wafer output, allowing wafer makers to make significant reductions in fixed costs such as floor space, facilities, operator and maintenance costs. Higher productivity also enables manufacturers to maximize cash generation per year, which improves the tool ROI. The structured wire saw technology is expected to reduce the cost of solar wafers by up to \$0.05 by the end of 2011.

Revolutionary diamond wire sawing technology is designed to further reduce costs through dramatic improvement in cutting speed (2-3X), reduction in wire consumption and elimination of SiC particles in slurries. Diamond wire marks a radical change to the wafering process by changing the physics of the cut. The diamond wire is essentially a wire coated with diamond particles. The diamond particles act as the abrasive elements instead of SiC particles as in conventional wire sawing technology. While diamond wire technology promises to substantially increase throughput and reduce cost, it is still under development. While maturing for squaring, it remains a risky proposition for wafering with significant unknown cell processing impact.

Evolutionary structured wire sawing and revolutionary diamond wire sawing are an effective dual approach to advanced wire technology roadmap uniquely proposed by Applied HCT. Both technologies will be implemented as upgrades, extending the B5 platform capabilities for the foreseeable future. This unique dual approach balances risk and reward and promises a surer path to productivity improvement and manufacturing cost reduction in 2011 and beyond.

CONCLUSION

In the PV industry, advancements in wire sawing technology have enabled a decrease in amount of silicon material required to produce solar electricity (less grams per watt), by enabling the cutting of thinner wafers with less material lost during the sawing operation. As raw material accounts for approximately one third of the cost of c-Si based solar cells today, wire saw technology is critical in reducing the cost per watt and allowing PV to reach price parity with grid electricity. The latest and most advanced wire saws introduce many new innovations to raise productivity and enable the trend for process optimization to drive down cost per watt.

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