Sawing, peeling and blasting

Today's wafer manufacturing processes are too expensive. But cheaper processes are being developed.

Wafer production is a dirty business: for hours on end, wire saws slice wafers from ingots, thereby wasting almost as much silicon as they use to produce wafers – although silicon prices are outrageously high. Currently, there are few alternatives to sawing, but that is likely to change in the near future.

Francois Henley, director of production equipment manufacturer Silicon Genesis, with one of its ultra-thin wafers. The company bombards ingots with hydrogen ions to produce a silicon foil.

Wire saws that cut wafers from massive silicon blocks are frequently compared to egg slicers: several thin wires placed in rows dig deep lines into ingots for hours on end. But the comparison isn't as fitting as you'd think when you take a closer look: after all, an egg slicer doesn't smash half of the egg it's cutting into some inedible egg puree – if it did, every housewife would toss the thing in the garbage.

But this is exactly the problem with which the wafer industry has had to live: manufacturers using wire saws waste almost the same amount of silicon as they cut into individual wafers. For instance, a standard wafer with 156 mm edge lengths – later a 3.65 W cell – weighs about 11 g. Using a saw produces an additional 9 g of silicon waste material (kerf), which is mixed with silicon carbide, water and glycol. This slurry is used to cut silicon slices from the ingot. This kerf loss costs manufacturers around 30 euro cents (47¢) per W in standard wafer production. That's almost one-fourth of a wafer's production and material costs.

If you want to produce cheaper solar cells, it pays to use silicon as sparingly as possible: on the one hand, by making the wafer as thin as possible, and on the other, by producing as little waste as possible. The very nature of wire saws makes this quite difficult: the thinnest wires used thus far have 100 µm diameters. The particles of silicon carbide, used as an abrasive, also measure a few micrometers. Thus, in the end, kerf loss is still about 120 µm – and that's per wafer. But that's the optimum, many wafer manufacturers still use 160 µm thick wires. Obviously, it would make sense to try to recover the fine ground silicon particles from the slurry. Unfortunately, any silicon that can be recovered no longer has the proper purity level. Developing wire saws that are able to produce thinner wafers would also be tricky – though certainly there would be demand for such saws. Thinner cells require comparatively less silicon, and they are flexible, like a piece of plastic foil, which opens entirely new areas of application for PV. For instance, imagine modules on arched surfaces, like cars or buildings.

SiGen: Blasting with hydrogen ions

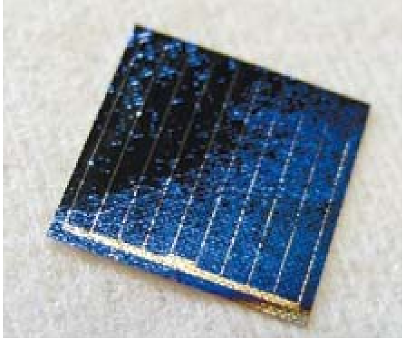
Francois Henley will definitely point out the various disadvantages of wire saws when he makes his wafer production presentation on the second day of the 23rd European PV Conference in Valencia, Spain. The CEO of California-based Silicon Genesis Corp. (SiGen) is traveling to Valencia with a presentation about his company's process for manufacturing very thin wafers without the expensive waste. »Our estimates of wafer manufacturing cost points to the PolyMax system being about $1 per W lower compared to sawing,« Henley explained to PHOTON International. That would reduce production costs today by about half – and would be a true sensation, if it actually works. Norwegian PV company REC seems to have faith in the process. It announced a development partnership with SiGen in mid-August, which is worth an initial $4 million. At the same time, REC underscored that the technology was still in the early stages of development – perhaps, this was just a tactic to confuse the competition, since SiGen's CEO Henley feels the process is as good as ready for practical application. The company plans to release the first production machine as early as next year. This could prove interesting for other companies, since REC doesn't formally hold exclusive rights to the technology.

REC and SiGen both reported that they presently have a machine – tucked away in a secret laboratory – that can produce 50 µm wafers. The Georgia Institute of Technology in Atlanta has used wafers produced with this machine to manufacture cells with rather respectable efficiency levels, reports Henley, who intends to reveal more details in Valencia. The SiGen process only uses a trusty wire saw to cut silicon slices from the ingot that are several centimeters thick. Otherwise, the system is an adaptation of the semiconductor industry's Simox process (separation by implanted oxygen). This process uses an ion accelerator to fire oxygen ions at a silicon slice under high vacuum conditions. The ions penetrate the silicon crystal and form a layer, at different depths depending on the accelerator's energy. Finally, the silicon with the buried oxygen layer is heated for 8 hours at 1,350 °C. This causes the oxygen to bind with the silicon to form a silicon oxide layer in the silicon substrate. The semiconductor industry uses these layers as electrical isolators. But, it can also be used as a predetermined breaking point to pull an extremely thin wafer from the substrate. This, of course, requires several process steps – for instance, in addition to ion implantation, the silicon surface also has to be polished. »Using the original layer-transfer technology was too expensive,« says Henley, since it requires a rather high dose of implanted oxygen ions. To do this you'd need very heavy, complicated machinery. Furthermore, the process simply takes too long.

Silicon Genesis Corporation (SiGen)

»We use a two-step-process instead,« says Henley. First, an ion implanter is used to fire hydrogen ions 10 to 120 µm deep into the substrate, obviously, at a dose significantly lower than the dose used in the Simox process. The result is a predetermined breaking point. And the second step? Well, Henley is keeping that under wraps for now but the Polymax process' patent provides some hints. Apparently, the hydrogen gas around the predetermined breaking point produces micro-bubbles. These spread out as the silicon slice is heated at temperatures above 500 °C and separate the layer from the silicon crystal along the predetermined breaking point. To ensure that the silicon doesn't crumble, a support is pressed against the slice – the patent doesn't specify whether it's adhered, pressed or applied with electrostatic force. Yet, the rumor is the process uses a cylinder that gently removes the silicon foil (see graphic, p. 102). At the same time, the heating stage heals any crystal defects caused when the ions were fired at the silicon. »That was one of the key technology risks,« says SiGen's CEO. »The amazing thing is, if you do the process correctly, you can recover the lattice and bulk carrier lifetime.« And there aren't any microcracks either, which frequently lead to annoying and expensive breakage during cell production – this also saves on silicon costs.

When the machine hits the market next year, it will be able to produce enough wafers for about 6 MW of cells annually. The system should cost about $4 to $5 million per unit, says Henley. Our calculations show that the machine will need about 15 seconds to produce a single wafer. Henley says the system can process 36 silicon slices



IMEC (2)

Ultra-thin wafers and the cells in which they're used: At 50 µm, these wafers are three-times thinner than standard wafers. The wafers are literally ripped from the silicon on a layer of silver.

simultaneously, but batch processing like this would result in cycle times of as long as 9 minutes. In other words, several Polymax machines would be needed to keep up with the throughput of some cell production lines that can already produce a wafer per second.


Wilhelm Breuer / photon-pictures.com

A few years ago, silicon researcher Gerhard Willeke presented his ultra-thin wafers. His process etched a thin wafer from a thicker, conventional wafer. In the meantime, Willeke is working on thinner wafers that are etched from ingots using lasers and KOH.

IMEC: Screen-printed silver paste

With that in mind, there's another, very promising process currently being developed by Belgian research institute IMEC in Leuven. It too will be presented in Valencia. »Our cycle times are very industry-compatible. Most steps take just a few seconds,« says Frédéric Dross, who developed the so-called Slim-Cut process, which produces 50 µm wafers. Dross estimates that his production system uses three times less silicon than processes that use saws.

The Slim-Cut process doesn't use an expensive ion accelerator, but rather standard cell manufacturing equipment and a physical trick: the differences in thermal expansion behavior between silicon and silver. If you heat a wafer with 125 mm edge lengths to 500 °C, the wafer's sides expand by about 0.1 mm. The same sized silver foil expands by nearly 1 mm. Conversely, the materials shrink to the same extent if you cool them down by 500 °C.

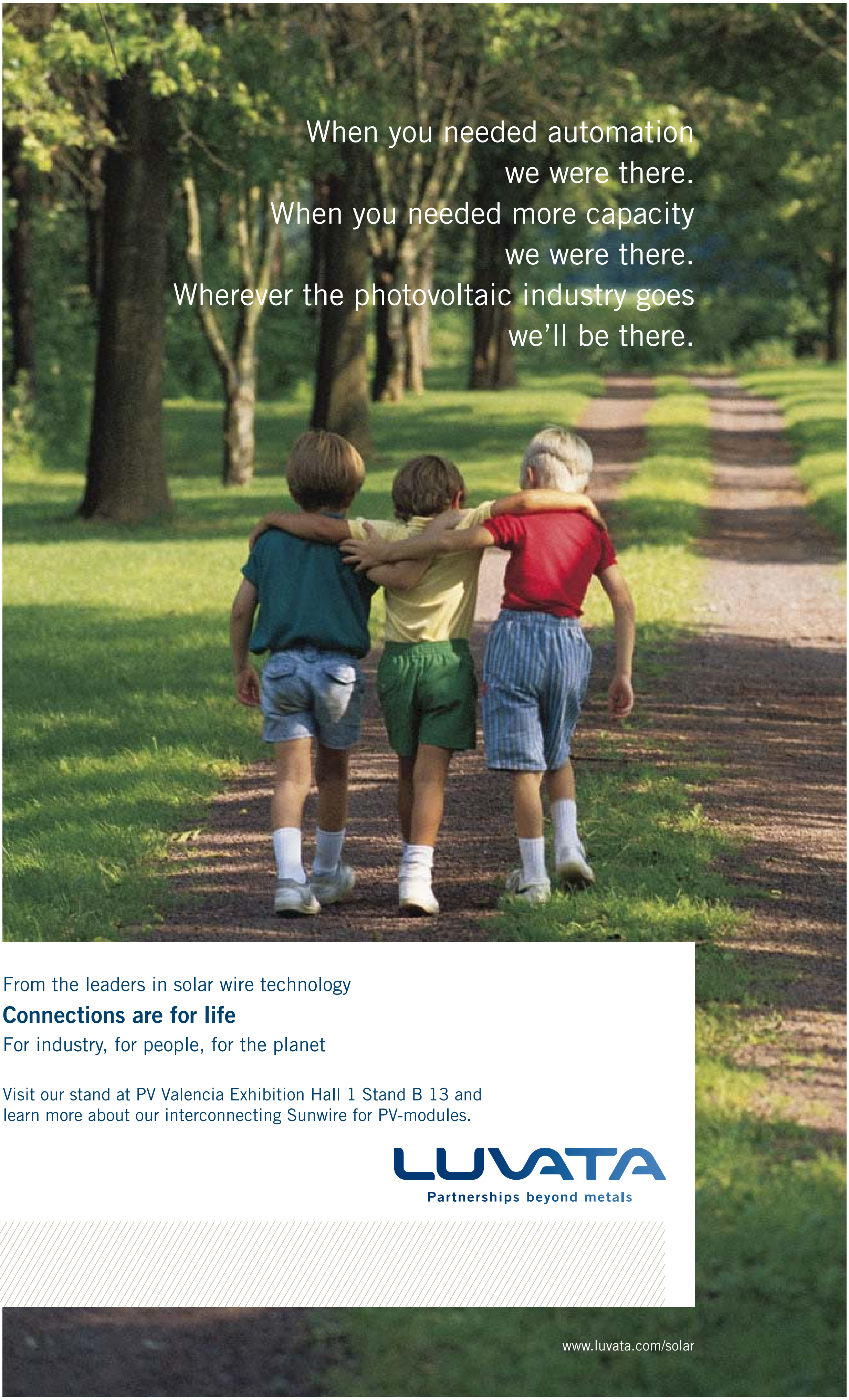
Dross and his colleagues at IMEC are now applying these principles to wafer production: using screen printing machines, like the models used to apply front contacts, they've managed to produce a 300 µm wafer with 125 mm edge lengths, with a layer of silver and other metals. Subsequently, the researchers dry the metal layer at 200 °C and then burn the silver into the silicon with a normal inline furnace at 500 °C. When cooled, the bimetallic effect occurs. Since the metal is burned into the silicon, the upper, approximately 50 µm-thick layer of the wafer rips off – the result is an arched silver-silicon foil. Finally, the researchers etch away the metallization in a cleansing bath, after which the silicon foil relaxes (see graphic, p. 102).

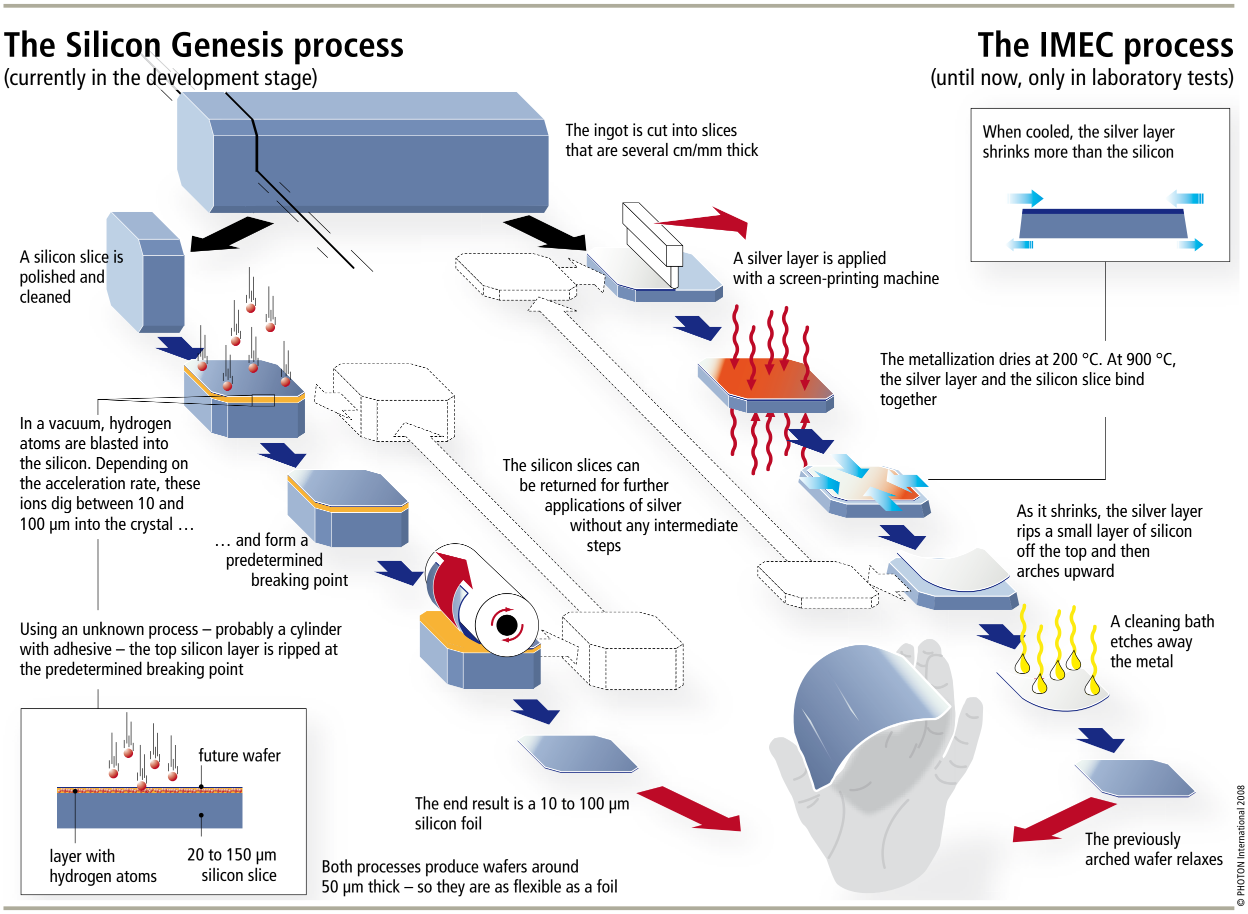
The mini-cells produced with these 50 µm wafers have an efficiency of 10 percent. »We did that using a simple cell process, without optimizing anything, which means efficiencies of 19 to 20 percent are absolutely feasible,« believes Dross. It's still unclear how often wafer foils like this can be pulled from a slice of silicon. In the laboratory, researchers have done it twice, successfully. But it's hard to imagine running an initially 300 µm substrate through this process more than twice. »In principle, we're thinking about using a silicon slice that's several centimeters thick,« says Dross. Nonetheless, this process still results in a certain amount of material loss: after every foil is peeled back, the surface of the initial substrate has to be etched to ensure the next wafer is symmetrical – currently, that wastes about 40 µm of silicon, although Dross hopes to reduce that to around 15 µm.

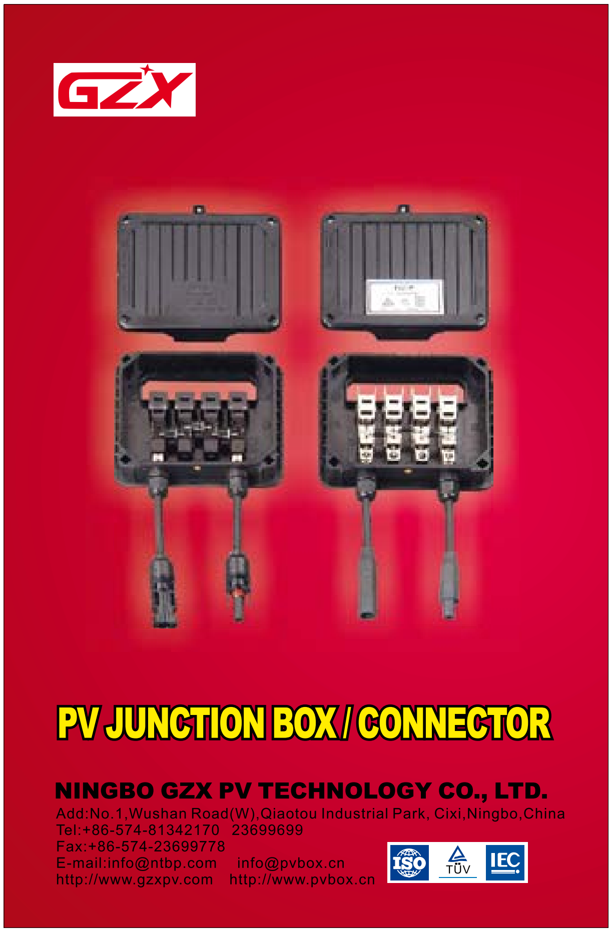
Still, the idea isn't ready for prime time, yet. »We've proved that it works, in principle. But we still need to answer a lot of questions« says Dross. For instance, how to handle the silicon foils. Apparently, they break

Applied Materials Switzerland SA (HCT)

Still using the good old-fashioned method of wafer production: A wire saw using slurry cuts through the silicon block.


When you needed automation
we were there.
When you needed more capacity
we were there.
Wherever the photovoltaic industry goes
we'll be there.





as soon as you take them into your hands. It's possible that heavy strain on the materials during separation produces microcracks in the silicon. The SiGen process, by contrast, hasn't had this problem. Moreover, the Slim-Cut process doesn't allow for production of certain wafer sizes: both silver and silicon expand in all directions, so the process results in intended and unintended stress between the materials. One day, Dross hopes to solve this problem by replacing silver with a polymer foil that only expands in one direction. That would also solve another problem facing this process: it would no longer require expensive silver. Right now, the process still recycles the silver left in the cleaning liquid.

ISE: laser beams and water-jet saws

Perhaps in the future, wafer manufacturing will look entirely different: the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg, Germany is currently working on a saw that cuts without wires or fixed parts. Rather, researchers are cutting silicon into loaves with laser beams and water-jet saws. In this process, a stream of fluid containing potassium hydroxide (KOH) is used to direct a laser beam, in other words, it acts as a liquid light conductor. The liquid lands on the ingot waiting to be sawed, and then the laser heats the line of KOH, causing it to etch the silicon. The process has already produced cuts as deep as 7 cm, reports Gerhard Willeke from the Fraunhofer Center for Silicon PV in Halle. »This process produces surfaces free of damage. And ideally, the silicon that is left over can be recycled.« Hence, the laser process combines the best of both worlds. It's still unclear what kind of potential wafer thicknesses the process can produce or how long it takes to cut a single wafer. But, more information about the process is to follow in Valencia. *Christoph Podewils*