A proton axe for thin silicon

Silicon Genesis gradually reveals how its new kerf-less wafer production method works. At PHOTON's Munich event, the Californian company presented a 20 µm thin wafer

▲ Inconspicuous HQ: Silicon Genesis' base of operations in San Jose, California.

Text: Christoph Podewils

o Highlights

- Silicon Genesis has developed a new process for slicing ultra-thin wafers that dramatically reduces silicon waste produced using today's wire saws
- The company's machine uses protons and lasers to cleave thin silicon sheets
- After a 50 µm wafer was presented last year, the company presented its first 20 µm thin wafer at PHOTON's Production Equipment Conference
- A commercial machine with a throughput of 200 156 × 156 wafers per hour is scheduled to undergo its first pilot tests in the second and third quarters of 2009

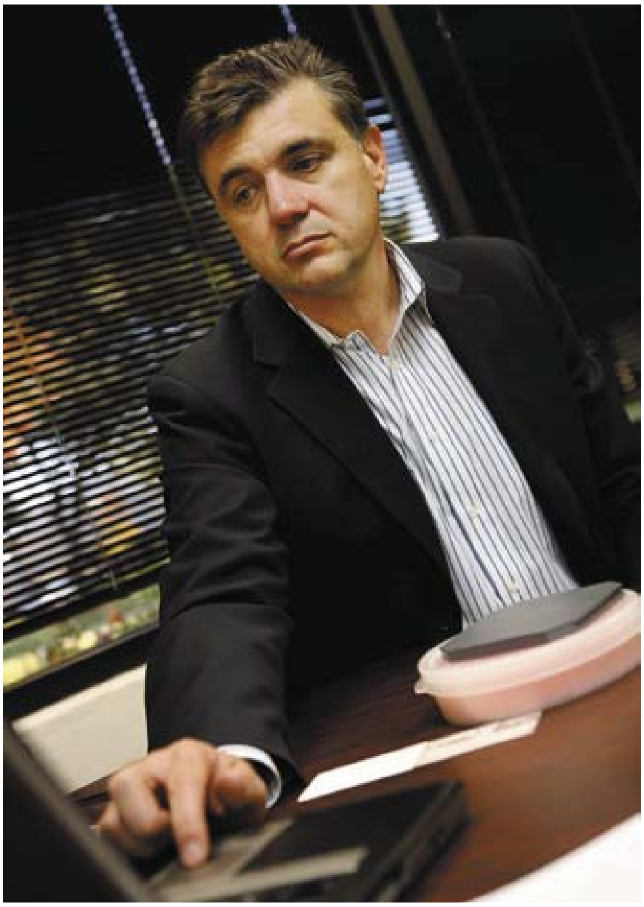
Daggett Drive in San Jose, California, winds through an industrial zone, but it looks more like a park path: there is plenty of greenery on both sides of the street and tall trees arching over the asphalt. To the left and to the right, buildings, resting on manicured lawns under trees, peek through the greenery. It's unclear whether those responsible for building this industrial park had the intention of creating as inspiring a work atmosphere as possible or if they just wanted to conceal the companies located here as best they could. The mirrored windows in several buildings do give the impression that the residents of Daggett Drive don't appreciate too much curiosity.

Behind one of those mirrored windows sits Francois Henley, in his office, where he has agreed to provide us with some insight into a process that someday could revolutionize wafer production – even if it will take a few years until the machine is ready for production. This new process could supersede high-loss sawing of silicon blocks into thin wafers and thus save huge amounts of raw material losses: Henley, president of Silicon Genesis Corp. (SiGen), grabs a small plastic box, opens it, removes a black, shiny silicon sheet, and bends it between his thumb and index finger. The wafer has a completely normal format for a monocrystalline wafer: 125 mm edge lengths. But it's only 50 µm thick – just a quarter the thickness of state-of-the art wafers used in current cell production. The surface of this silicon foil is many times smoother than a conventional wafer. Moreover, these wafers have fewer microcracks, underscores Henley. All of this is a result of the technology used to produce this wafer – a machine about which PHOTON International reported last September (see PI 9/2008, p. 98). Henley is this machine's inventor and he is currently developing it for production purposes, with the help of his colleagues.

A prototype on the path to series production

The device is located deep inside the building complex, in a windowless room. Photography is forbidden. During our visit about three months ago, the nearly 10 m long apparatus certainly still looked like a prototype: tubes and cables protruded from its stainless steel housing, and there was a sign warning about radioactive gamma rays. These rays are produced by an ion accelerator, which blasts charged hydrogen atoms at an up to 10 cm thick silicon block. These protons penetrate the silicon at variable depths – depending on the voltage used to accelerate the protons. At a depth of between 50 and 150 µm, they form a thin layer of hydrogen atoms. If this layer is then heated at about 500 °C, the hydrogen atoms expand so much that they split the silicon, separating off the silicon foil.

The proton beam is steered with electromagnets and can be aimed at any part of the future wafer – it's similar to an electron beam in a cathode ray tube. The same steering method is applied to the machine's powerful laser, which is used in an additional production step to scan the silicon. Working together, the ion accelerator and the laser have an effect much like an axe when chopping a block of wood: they attack a corner of the silicon block with massive energy – in other words, protons and heat (see diagram, p. 120) – causing a breaking point to form at one corner and spread through the silicon. The path the crack takes is controlled by the machine, which shoots a much lower dose of protons at the remaining portion of the silicon sheet's surface area. »The only thing to do is guide the crack,« says Henley humbly. The machine is an example of linear-elastic fracture mechanics (LEFM). To put it simply, LEFM says that the voltages occurring at a crack's peak can be endlessly large, theoretically. In



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▲ Revolutionary potential: Is Silicon Genesis' new wafer process about to stand the PV industry on its head? Francois J. Henley, the company's CEO, with a silicon slice that can be used to produce ultra-thin wafers.

practice, that's not necessarily the case, because it if were, any material with a crack would simply explode. Still, it has enough power to cleave the silicon on a predetermined path.

Henley's machine is based on technology developed by Russian inventors Reutow and Ibragimow in 1983, when the two patented the use of a proton beam to produce wafers in the Soviet Union. Their process was not pursued further, on account of its complexity. Engineers from SunPower Corp., which currently manufactures the world's highest efficiency, conventional silicon solar cells, apparently felt the same way: in 1998, they tested a similar process, says Henley. This process also proved too expensive – above all, due to the amount of energy required. Henley, an electrical engineer, claims the Russians' process consumed about 50 times more electricity than SiGen's method. That's because they treated the entire surface of the silicon block uniformly with protons. Still, SiGen's development doesn't exactly fall in the best energy efficiency category: for a wafer thickness of 150 µm, the machine requires about 0.6 kWh of electricity per W of future solar power – that is many times the amount of electricity consumed for wafer manufacturing with saws and ancillary systems. However, using the machine to produce thinner wafers would require less energy, since the protons don't need to be accelerated to the same degree. And, of course, the proton axe also saves more energy, since unlike saw-based production pro-


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▲ World premiere: At PHOTON's Production Equipment Conference, SiGen presented 20 µm thin wafers sliced using its proprietary technology.

cesses, more than half of the silicon doesn't end up on the floor as kerf loss.

It's already been proven that SiGen's wafers function as cells: in a lab experiment, one of the company's solar cells, using just 40 µm thick wafers, achieved an efficiency of 13.2 percent. A 275 µm thick reference wafer made of conventional material with the same cell processing achieved 14.6 percent, reported Henley at the European Photovoltaic Solar Energy Conference (EU PVSEC) in Valencia, Spain, last fall. But a great deal could be achieved if manufacturers would optimize their cell processes to accommodate SiGen wafers. That's an important point, since existing wafer saw processes and their ancillary systems cannot simply be replaced with SiGen's machines, emphasizes Henley. Indeed, more effort is required. The protons penetrate the silicon sheet most effectively if the silicon's crystal lattice has a 1-1-1 orientation. But manufacturers of cell production equipment in their specifications generally require wafers made of silicon monocrystals with an orientation of 1-0-0. This allows cell producers to etch a high-quality pyramid structure in the silicon surface. Surface texturing is an obligatory step in today's cell production as it improves the light absorption and therefore increases cell efficiency. To achieve a texture using a silicon wafer with 1-1-1 crystal orientation, the wafer has to be etched differently. But this requires manufacturers to make changes to their cell lines. The same holds true for ultrathin wafers, which can't be dealt with in today's cell production lines.

While most cell and module companies would have problems in processing 150 µm thin wafers, at PHOTON's PV Production Equipment Conference on March 4 in Munich,

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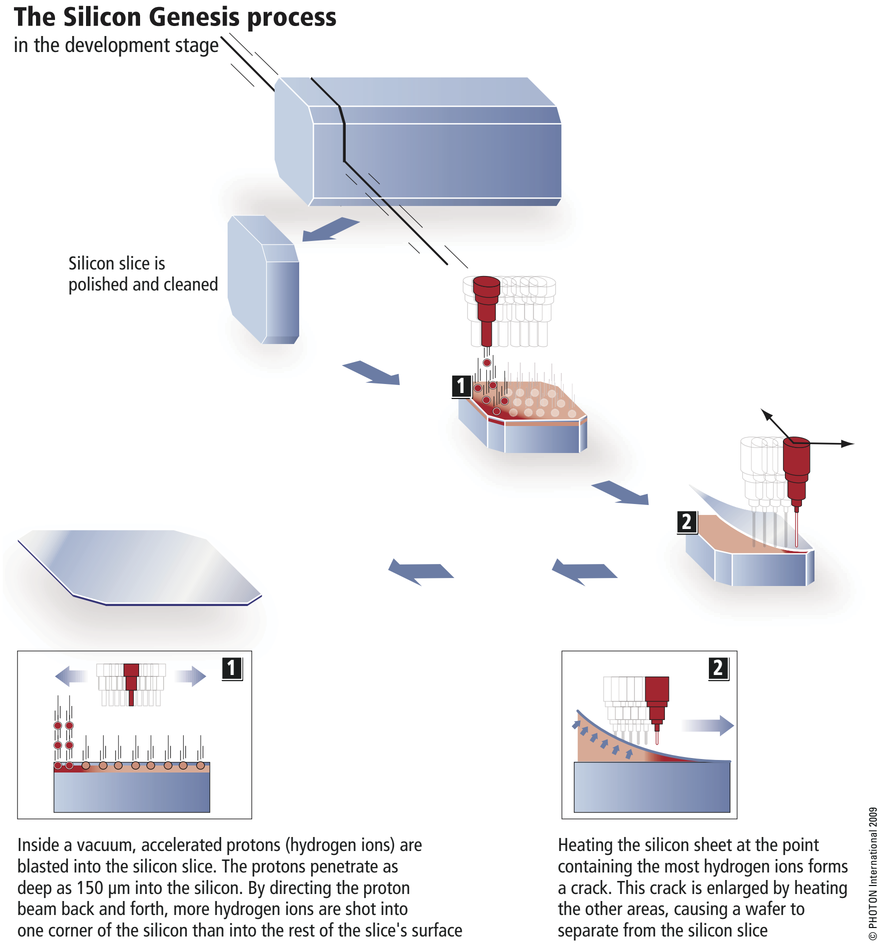
▲ Silicon can be flexible, too – it just has to be thin enough.



SiGen even presented its first 20 µm thin silicon slice. »It is a foil, because it is not quite a thin film and not quite a wafer,« explained Henley. Though this announcement caused a lot of commotion in the room, this wafer thickness is nothing that can be expected in production any time soon.

That's not the case for the equipment. One company allowed to test the machine is NorSun AS. »What we have seen is promising. We have many reasons to think that it will work well,« says Jon Hindar, CEO of the Norwegian wafer manufacturer. Presumably, in a few months, the company will have access to a prototype of the system, which it will examine extensively. It will take a few more years for the technology to be ready for mass production, believes Hindar. »It is difficult to state today exactly when this can take place, because NorSun as a wafer manufacturer will need customers that are willing to make the modifications necessary in their cell lines to adopt ultra-thin wafers.»

But, of course, companies could also use the system for cutting much thicker wafers – just to save on kerf loss. Henley, at least, plans to have a fully commercial system up and running next year, he said at PHOTON's conference. While an initial R&D system for 50 µm wafers was finished in mid-2007, an R&D device for 150 µm wafers was completed in late 2008 and a machine capable of cutting 20 µm thin slices in early 2009. The commercial machine, the so-called Alpha system, which will have a throughput of 200 156 x 156 wafers per hour, is scheduled for integration in the second quarter of 2009 with pilot tests planned in the second and third quarters. And to shorten the path toward commercialization, SiGen is looking for more cooperation partners than NorSun and REC, the first wafer manufacturer the Californians had signed a commercial agreement with. SiGen also allocated some future manufacturing capacity for REC. »There are aspects of exclusivity, but it doesn't stop us being able to sell equipment into certain thickness ranges where we could start working with third parties,« Henley said in Munich.

Unlike in the semiconductor sector, where SiGen licensed its cleavage technology for silicon-on-insulator processing to MEMC, Shinetsu and Applied Materials, for example, according to Henley the company has changed its business model to selling equipment in the solar area. Nevertheless, he's looking for contract manufacturing partners. »We would not try to grow our manufacturing organically in terms of capacity – that would be much too slow, we are interested in partnerships that could give us some good leverage,« says Henley.

Although he wouldn't reveal exact price and operating costs of this proton axe, if the process really works in mass production then cost of ownership should be dramatically lower than for today's wire saws: Daggett Drive could be ground zero for a new phase in the battle to achieve lower production costs. NorSun's Hindar believes, »It is potentially a game-changing technology.« ●