A call for quality

Power loss from crystalline module degradation causes a big headache for the industry

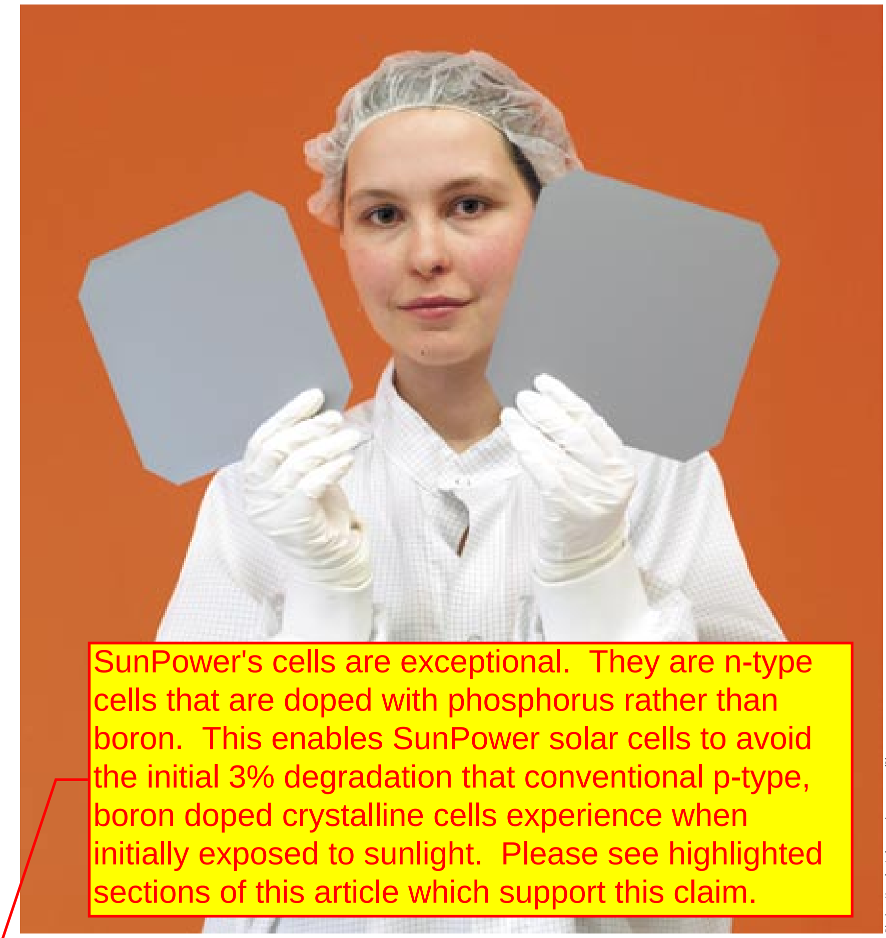
It's not just thin-film modules – crystalline solar cells are also subject to degradation. That's already well-known. But the magnitude of this unpleasant effect on monocrystalline products depends primarily on the composition of the silicon being used. Still, few manufacturers dare to say what has long been common knowledge: a lot of low quality silicon is being sold, and it's slipping through the quality control system used by cell and module manufacturers.

It's a commonly used sales argument: although monocrystalline modules are expensive, they're efficient. And unlike much less expensive thin-film modules, they maintain their efficiency over many years – you know what you're getting. Unfortunately, this is only half the truth. Most crystalline modules also undergo a certain amount of degradation, in other words, a reduction in efficiency.

The material of the silicon ingots, from which the wafers for cell production are cut, are usually produced using the so-called Czochralski process, which usually employs doped boron as an acceptor. The boron enables the production of boron-oxygen complexes in the silicon lattice (see box, p. 108). The phenomenon is well-known, the resulting effect is ubiquitous. The question is how strong the effect is – especially with monocrystalline cells in which the effect is more strongly tied to the quality of the base material than with multicrystalline silicon.

In the last 5 years, Roland Burkhardt, CEO of Sunways AG, has observed a deterioration in quality on the ingot and wafer market. Sunways produces cells and processes them into modules. It relies heavily on its upstream suppliers, namely ingot and wafer manufacturers. There's only one place in the production chain where the degree of degradation can be influenced – that is when the ingots are pulled. And this seems to be the weak link. Burkhardt would like to return to »where we were in 2003, when we could purchase high-quality wafers, and as a customer on the free market I didn't have to chose between two evils.« In the path of the PV boom, only a few manufacturers adhered to their own quality standards. »Mainly those that also deliver to the semiconductor industry,« he adds. The semiconductor industry has strict regulations, every parameter is defined. The PV industry, on the other hand, is more lax.

Before being processed into cells, Sunways is forced to test all wafers and sort them accordingly. It can happen that in each delivery every tenth wafer is sorted out, explains Burkhardt. And before the modules are shipped, their efficiencies are also tested. The efficiency is then listed as a few percentage points



Birgitta Kowsky / photo-pictures.com (3)

One wafer is like the other – at least on the outside. But qualitatively, there could be a big difference between two different products.

Quality check: Sunways first checks its wafers for quality. Good products pass directly for processing, less good wafers are improved, and poor products are sorted out.

lower than the actual value. »We correct the performance data downward, because it definitely doesn't reflect the efficiency we could list if we didn't take into account the degradation effect,« explains Burkhardt. Up to now, the greatest degradation measured by Sunways was around 7 percent.

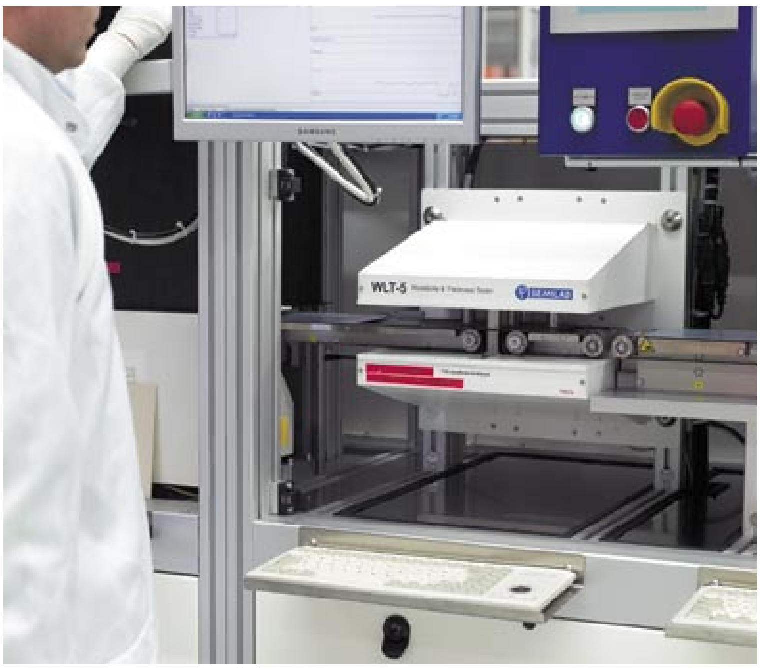
Degradation is being ignored, or remains unknown

The Institute for Solar Energy Research GmbH Hameln (ISFH), which has been working with this subject since the mid-1990s, estimates degradation as high as 7 percent in cells with low-quality silicon. Higher quality product can have an efficiency loss of less than 2 percent. If manufacturers don't take into consideration variation in quality prior to delivery, logically, after some time the system's yield will be lower than what would be expected from the module power specifications.

The affected customers will inevitably lose faith – in the module's manufacturer, and perhaps the industry as a whole. This is Roland Burkhardt's concern: »Quality cannot suffer,« he says, »that comes back to haunt us all.« An elevated quality awareness has to take root at all levels of the PV industry – from silicon production to cell and module manufacturing.

Until now, only one method has been found for keeping degradation at a minimum: use silicon with lower boron concentrations. The increase in efficiency losses is directly proportionate to the increase in the number of boron atoms. Material with lower boron concentrations is characterized by higher resistivity. Above 3 ohm cm a wafer is considered »high-ohmic.« The industry doesn't exclusively use this material on account of two disadvantages associated with it: first, ingot manufacturers are more limited when selecting the base material. Whereas silicon of varying quality can be mixed when producing low-ohmic wafers, a high-ohmic product requires exclusively high-quality raw material. Second, solar cells made from high-ohmic material have slightly lower efficiencies. »Less boron means less power,« says Franz Ziering, responsible for »strategic purchases« at Ersol Solar Energy AG. »But the power you gain by using cells with low-ohmic silicon is lost when degradation sets in later.«

Since the takeover of ASi-Industries (today Ersol Wafers), Ersol is one of those companies lucky enough to own its own ingot and wafer production facility. »It's our



declared goal to control both production levels,« says Ziering, »the selection of base material is absolutely critical.« But if you can't produce the desired premium silicon yourself, you have to look for it on the market – and that can be difficult, since the supply of low-ohmic products is significantly greater than the supply of high-ohmic silicon. If the former is the only thing available, there's no other choice but to adjust the efficiency downward – like Sunways does. But it would be naïve to assume that the entire industry follows Sunways' example: »We keep precise track of what the customers report,« says Ziering, since »this subject affects German manufacturers, too.«

The established industry leaders in Europe, Japan, and the USA are at least familiar with the degradation effect – which makes their disregard for it that much more objectionable. Newcomers, on the other hand, particularly in China, seem to be generally unaware of this danger. »The PV industry doesn't know a lot about the degradation of monocrystalline cells,« says Bond Wang, manager at Xi'an Longi Silicon Technologies Co. Ltd., a Chinese ingot producer from the semiconductor industry. He's been active on the PV market since 2003. In China, many PV companies aren't even two years old, and the employees come from other industries. Thus products are delivered without undergoing sufficient testing, because they simply don't know about the problem of degradation. The result: datasheets contain performance data that cannot be achieved. »We see three reasons for this situation,« says Wang, »a knowledge gap, strong demand, which doesn't allow for a quality control offensive, and the problem that


Norbert Michalke / photon-pictures.com

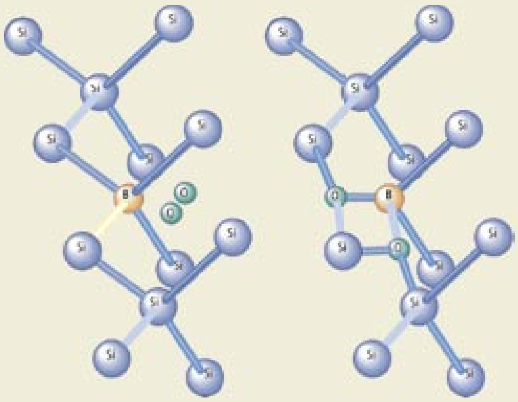
Hard and harder: During the sawing process you can tell the difference between high- and low-ohmic silicon ingots at this point – high-ohmic silicon is harder.

The boron-oxygen complex and the degradation it causes

First and foremost, the element oxygen is responsible for degradation in monocrystalline modules. When growing ingots using the Czochralski process, the liquid silicon comes into contact with the gas, small amounts of which are then lodged in the semiconductor element's lattice structure. It's always two oxygen atoms that diffuse through the silicon lattice in the form of dimers, but they don't cause any damage. The degradation only occurs when oxygen builds a complex with the doped boron acceptor in the semiconductor structure.

The catalyst for the entire process is light, which starts the photoelectric effect. As soon as a boron atom loses its electron hole, energy is released. That attracts the oxygen dimer until it binds with the boron, which is present in the lattice as a single negatively charged ion following the photoreaction, while the dimer is double positive charged. The boron-oxygen complex builds its own energy level in the silicon lattice and can capture electrons and holes, which are then lost to the electricity production process. This in turn decreases efficiency and therefore the power of the module in question. The Institute for Solar Energy Research Hameln (ISFH), which has been working with this subject matter for more than 10 years, speaks of an efficiency loss of about 3 percent.

The magnitude of the degradation is linearly dependent on the boron concentration in the silicon lattice, and grows quadratically with the concentration of oxygen. Depending on silicon quality, the degradation halts at a certain point after a particular amount of time. After an exponential increase, low-ohmic materials reach their saturation after 10 hours, and high-ohm materials take one to two days. *iru*



As long as the boron atom has its electron hole, the oxygen dimer ignores it (left). A photoreaction causes the boron to lose its hole, turning itself into a negatively charged ion, which attracts oxygen – a boron-oxygen complex is formed (right) that's responsible for module degradation.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there doesn't seem to be an alternative.«

Concrete questions – diffuse answers

Xi'an Longi is working on a solution. Oxygen can be kept away from the silicon during crystal pulling by using for example the Magnetic Czochralski process (MCz). The company, based in Xi'an in Shaanxi province, claims it's the only company in China working with this process. Wang says they received »convincing results in testing reduction of degradation effects.« MCz is »a good guarantee for long-term cell and module performance.« Admittedly, the production equipment is more complex and the energy demand higher, which naturally increases the cost of the end product when compared with its oxygen-rich competitor.

Xi'an Longi Silicon Technologies Co., Ltd.

The production halls at Xi'an Longi in the Chinese province of Shandong: The company obtains wafers with very low oxygen content using the Magnetic Czochralski process.

All the same, a number of well-known cell producers have inquired into wafers from Xi'an Longi – among them Suntech Power, as well as Q-Cells and Motech. Hence the leading Chinese manufacturer is apparently one of the companies to recognize the problem. At the PV conference in Fukuoka, Japan last December, Suntech CEO Shi Zhengrong warned of spreading shortages: »Recycled silicon causes quality problems in wafers, cells, and modules, including efficiency degradation on account of the lamination process, breakage, and delamination.« But Suntech wouldn't provide details on PHOTON's inquiry about how it was handling the degradation effect. The only answer was that Suntech was dedicating itself, together with industrial and university partners, to the production of high-quality modules, and of course the base material and technology have a significant role to play in this context. A very similar answer was provided to the same question then posed to Trina Solar Energy Co. Ltd. »We don't see an alternative to using high-quality materials,« explained the company, which exclusively produces polycrystalline cells.

There's good reason that Suntech's Shi claimed in his speech in Japan that recycling wafers, cells, and modules is the main cause of quality loss. In Asia, companies have decided to purchase the tops and tails, or remainders in the crucible from ingot production, as well as broken wafers, to partially process this material themselves – with or without doping, high- or low-ohmic. Recycling in and of itself is a good thing, since »high-quality cells can be recycled so that more high-quality cells can be produced,« says Karsten Wambach, director of the Solar Materials business area that deals with this subject at SolarWorld AG subsidiary

Deutsche Solar AG. It's important to conduct a precise examination of the incoming goods, a clean quality control, and have a reliable mastery of the production processes, he adds. »Recycling is justified,« Franz Ziering agrees, »you can glean acceptable raw materials with it.« But sometime, every conceivable method is being employed at once. »Necessity is the mother of invention,« he says.

Phosphorous rather than boron – and vice versa

Uniform standards would make it much easier to control the results of recycled material as well as products manufactured in conventional processes. A beginning could be the standard called Data Sheet and Product Information for Crystalline Silicon Solar Wafers for Solar Cell Manufacturers, which was prepared by experts on behalf of the German Association for Electrical, Electronic & Information Technologies (VDE). This standard, which also includes information on the purity of the silicon used in the wafer, is currently being voted on by the European standards organization CENELEC. Daniel Fraile from the European PV Industry Association (EPIA) expects the document to be published by the end of the summer. However, no one can say how long it will take to pass these guidelines on a global level, and whether the worldwide industry will really accept and implement it also remains to be seen.

All the parties involved need to rethink things, whether ingot manufacturers or module producers. The latter need to back up their credibility among end customers, while the first could dedicate itself to the reduction of the degradation effect – because this is possible: »We know how to avoid it,« says Jan Schmidt, researcher at the ISFH in Hameln, but that has »just a limited influence on the industry.« Schmidt says the lack of interest is a result of a sellers market. »The manufacturers can sell their silicon without even having to make an effort. There's no need to change their processes. And they couldn't if they wanted, since the machines run non-stop,« he says.

There are two possibilities for ingot manufacturers: they can keep oxygen from accumulating in the silicon during the pulling process. Or, instead of using boron as an acceptor, another element could be used, for instance gallium or indium. The first possibility is the use of the MCz process, although a large investment is required to use this method. The second possibility wouldn't cost a lot, and would completely eliminate the effect, but is complicated to institute: the specific resistivities of gallium and indium vary strongly inside the crystal, so the use of these elements is much more complicated than using boron.

Schmidt feels substituting the two-doped elements for boron is a promising solution. During ingot production, phosphorous is used rather than boron, the result is negative not positive doped wafers. In cell production, boron has to be used rather than phosphorous, as usual. That would completely eliminate the degradation effect. »In terms of technical costs, it would be identical to conventional processes, but cell manufacturers have to completely alter their cell structures and production cycle,« says Schmidt.

These efforts would have benefits beyond taming degradation. Tests at ISFH show that these methods could allow for the production of high-power cells with an efficiency of 19 percent or perhaps even more. And Roland Burkhardt from Sunways isn't the only one to welcome an initiative that will help raise quality levels. Above all, he puts his faith in the ever-present principle of competition. As soon as more silicon is available on the market, »quality criteria will have value again.« But, it'll be a few years until that time comes.

Ines Rutschmann

SunPower's revolutionary all-back contact n-type cell is already reaching efficiencies of up to 23%. Because it is based on negatively doped silicon (using phosphorus) it will not experience light induced degradation like conventional p-type boron doped solar cells.