The importance of laser processes

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In the PV industry the demand for solar modules used to be much higher than the production capacity. Nowadays companies are fighting for every part of the market share and obtainable margins are minuscule. And laser processes play a major role in this competition.

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The end customers have become picky about quality issues to do with PV products and project financiers keep a careful eye on the overall system costs. The constantly growing photovoltaic industry market and the development of new technologies got an additional push, as a lot of money has been put into research and development, especially close to industrial application.

The survival of the fittest is basically fought on two key parameters. The production costs in USD/Wp (costs per watt peak) on the one hand and highest module power values on the other. The former was achieved by heavy reduction of consumable costs. Over the past decade most of the low hanging fruits have been picked. New sawing techniques sped up the wafering process and allowed thinner nominal wafer thicknesses, consuming less Si.

Development of widespread used printing screens, metal pastes and printers reduced the consumption of silver on a cell. Both supported by falling prices for silicon and silver. The high degree of automation, led to minimal human capital costs, and by reaching GW cell capacity, this contributed to the reduction of overhead costs.

The hunt for highest module power has been achieved through material and process improvement all along the value chain, especially silicon wafer quality, lower resistances in cell metallisation and light trapping techniques. The most recent jump in cell power was the implementation of a rear side passivation layer in the so-called PERC (passivated emitter and rear cell) technology.

And this is just the beginning of what put laser processes and laser equipment on the rise once more. In PERC technology this rear side passivation layer is locally opened by laser ablation to allow the back electrode to form electrical contact to the silicon cell through this isolation layer.

This technology concept was known for decades, but it took until a few years ago until its implementation in mass production at a significant share took place. Today most major cell manufacturers converted at least part of their production and new production capacity is rarely planned without it.

The laser equipment market needed to attain a certain size so that machine manufacturers would compete with each other in the quest for the most suitable solar cell concept for the manufacturing industry.

The first machines were designed quickly and with the lack of mass production experience. Due to limited competition, cell manufacturers and research institutes had to buy them. Machine suppliers needed to go through all the learning cycles of what to pay attention to in handling solar wafers, while breakage rates of around 0.5% were not uncommon.

Second generation tool concepts used a rotary table and two lasers to overcome the reduction of throughput caused by transportation dead cycles. With the awareness of quality and reliability a new generation of laser tools became state of the art, which used contactless wafer transportation.

Avoiding wafer damages by the machine concept

Premium manufacturers started to sort out microcracks containing solar cells, to reduce overall breakage loss in the manufacturing line, especially in cell metallisation. It also was found that a significant portion of breakage loss was caused by microcracks, related to upstream equipment. Some worn off rollers, some badly positioned gripers, hard stops on guiding rails and particle contaminated vacuum chucks.

Often such sources of microcracks don't damage subsequent cells, or cells damaged in a row will not break, until the heavy mechanical stress is applied onto the wafer in the printing cycle. By which time they have been mixed up in a different order or with undamaged material.

In the typical PERC-LCO (Laser Contact Opening) process sequence lasers are directly in front of the metallisation lines, the problems related to the rotary tables and vacuum chuck concept was one of the first ones to be discovered.

During mass production at some point, there will be cell breakage. Imagine a small particle is left on one of the vacuum chucks of the rotary table, one cell after the other is transported onto this chuck and once the vacuum applied; the stress at the point of the particle causes a microcrack.

Latest generation laser tool: fed on two lines the throughput achieves values above 8000pcs/h. These unbeaten throughput values allow for minimum costs per wattpeak, as fix costs are divided by a much higher number of cells.

Usually there isn't a microcrack inspection system installed on the laser tool, and these cracks remain unnoticed. Breakage rates for the laser tool remain low and increased breakage rates, on print lines or out of spec cells in the tester and sorter section, are not directly traced back to this specific vacuum chuck. So hundreds and thousands of cells are damaged and production lost at a later stage, before such a particle is removed either by chance or with the next preventive cleaning cycle.

The innovation of contactless wafer transport through the machine did reduce manufacturing costs dramatically. The tools of this latest generation use an air cushion to prevent the cell surface touching the supporting metal plate. The wafer floats at a distance of only 100-300µm above the surface. Lateral movement is achieved by having the supporting plate slightly tilted, so that the wafer is moved gently by gravity force towards a belt. This belt touches the side of the wafer and moves it along with negligible stress.

This means that any particle falling into the wafer transport region, automatically falls downwards, preventing damage to the wafers, which happened in previous generation tools. Costs are also reduced due to less laser machine breakage rates in the printer screen, fewer screens are damaged, less silver paste is wasted and the throughput is improved by increased uptimes.

And throughput really matters. All around the globe teams are working to increase the throughput of existing lines and the throughput value of tools has become a selection criterion for investment decisions.

There are two main reasons for this. There are limited funds available for machine investments and after the production process has been squeezed out for easily achievable cost improvements, the increase of the line throughput is the easiest way to significantly decrease the fixed costs. A throughput increase of ~10% can mean a reduction of USD/Wp by >3%.

Laser equipment doesn't really have piece dependent consumable costs. The concept of the first and second generation tools was limited in throughput to values about 3500-3600 pcs/h, mostly limited by the necessary transportation cycle in the concept. The new design, with contact less motion, not just improves the production mechanically, it also allows for tool capacities well above 4000 pcs/h on a single lane.

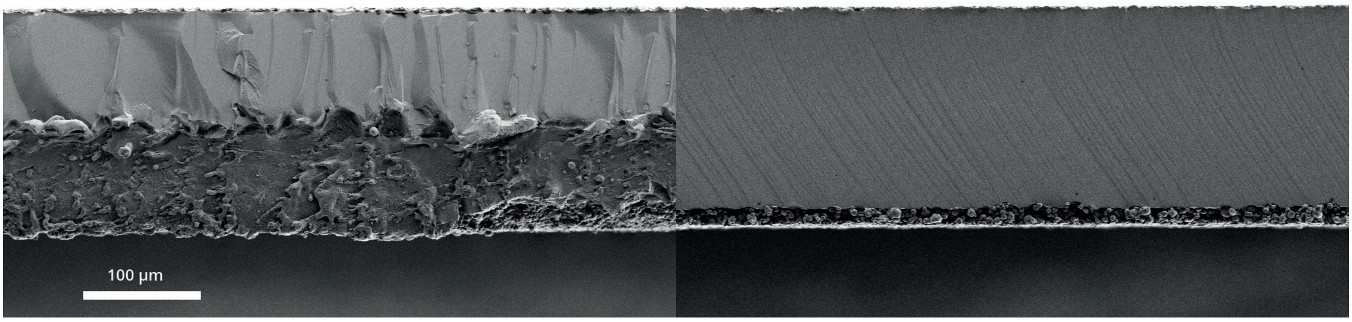
The key for this ~15% throughput increase is found in OnTheFly processing. So the laser process happens while the cell is in motion and it is moving underneath the scanner. The laser beam can jump directly to the next cell after finishing the process for the previous one. With no dead cycle time needed for the stepping cycle the usage rate of the expensive laser source is well above 98%. A single lane tool only needs one laser source.

This year the industry saw the laser equipment manufacturers entering a new round of tool versions again. The new trend is the processing of two lines in parallel. Some use four processing positions and need synchronisation between the lines to boost the throughput values to above 6000 pcs/h, others allow even above 8000 pcs/h with two laser sources only.

This leads to the second key fact on why throughput matters: expansion projects announced are not in the region of just a few tens of megawatt. Factories planned and built come in gigawatt scale nowadays. So for the facility planner and purchaser it definitely matters if you need to buy and operate five laser tools, or whether you can cover the same overall throughput with only four laser tools.

Using lasers to cut cells into pieces

But the trend for lower costs and higher module power is not limited to the solar cell technology only. In module manufacturing engineers can tune up the module power by adapting the latest achievements in know-how as well. One example is the increase of module power by reducing the cells' current and thus lowering electrical losses in the resistance.



Comparison of cross sectional images of half cells cut with former scribe and break ablation technique (left) and by using Thermal Laser Separation (right). Using latest technology not only overcomes the mechanical problems of microcracks and molten silicon, it's also 2-4 times faster than conventional processes.

Instead of connecting 10 or 12 cells in series, 20 or 24 halves of cells are interconnected. This way, with the same original cell power, the module power can be increased by >2%. Adaption in the photovoltaic industry has just started and the potential is huge.

Thinking further ahead, module concepts of even smaller strips than half cells e.g. 1/5 of a cell and glued together in a shingled way are within our sights. The active area of the module is increased, shading losses are reduced, as no busbars block sunlight, copper ribbon can be avoided and electrical losses are minimised by even stronger reducing the overall current in the system.

The key process for manufacturing these strips, from 2 up to 8, out of a full standard solar cell, once again uses a laser process. Early processes used laser ablation to cut the cells. A trench, half the cell thickness deep was made and the remaining part cut by mechanical force. This was relatively slow and left heavy electrical and mechanical damage to the cell in the cut region.

Second the vast production of silicon dust causes significant problems. Tool throughputs are limited, in the region of a few hundred of cells, for slim strips to approximately 1800 pcs/h for half cells.

The latest development in process technology overcomes all these problems. Throughput values above 5000 full cells per hour, no dust production, which leads to health and explosion risks, as well as no downtime for cleaning. No electrical damage with leaving heat affected zones or crystal defects by remolten silicon increased the obtainable module power even more.

There is also better long term stability, with a smooth, undamaged cutting edge. This process is called 'Thermal Laser Separation' (TLS) and was transferred from chip dicing tasks in the semiconductor industry.

Basically it is a combined process of heat expansion and cooling contraction. By overlapping one field of tensile stress, with one field of compressive stress, a crack can be guided through the wafer without being limited by the crystal orientation if the heating point is a laser beam. The crack simply follows this trajectory, splitting the crystal all the way through the wafer thickness causing no electrical or mechanical damage. No dust is created, as temperatures stay well below ablation or even melting temperatures.

All these developments and market conditions demonstrate that laser equipment is an important factor in competitive photovoltaic manufacturing. And it is up to the solar manufacturers to select the most efficient laser equipment in order to secure themselves a prime position in the global PV market. The laser equipment selection is today more than it ever has been, a crucial part of their success story.

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Frederick Bamberg studied MEMS at Albert Ludwigs University Freiburg and obtained his degree in 2004.

From 2000 until 2006 he worked in different research groups at Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg, Germany, BP Solar in Sunbury, U.K. and the University of New South Wales (UNSW) in Sydney, Australia, before working as process engineer at Solarworld in Freiberg, Germany, from 2007 to 2015.

In 2016 he joined 3D-Micromac AG in Chemnitz, Germany, as product manager. He is in charge of PV industry related laser machines and processes.

3D-Micromac AG

3D-Micromac, with headquarters in Chemnitz, Germany, is the leading specialist in precise laser micromachining. Target markets include the photovoltaic, semiconductor, glass and display industries, as well as micro diagnostics and medical technology.

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