

# LASER MICROJET<sup>®</sup> TECHNOLOGY FOR CUTTING AND EDGE ISOLATION OF SILICON PV CELLS

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## **Biography**

Dr. Tuan Anh Mai received his Dipl.-Ing. (MSc) in mechanical engineering at the University of Ilmenau (Germany) and his Dr.-Ing. (PhD) in materials engineering at the University of Hannover (Germany). Dr. Mai has been working in the field of optics and laser materials processing, especially in developing and customizing laser micromachining processes and systems since 1984. He worked at the Laser Zentrum Hannover and Singapore Institute of Manufacturing Technology as a research scientist and project manager. Before joining Synova as an R&D Manager, he worked in the Netherlands for a laser wafer dicing company as Process Development and Application Manager.

## **Abstract:**

Photovoltaics are a relatively young technology with little or no impact on the environment. As it silently generates electricity from light, PV produces no air pollution or hazardous waste. The global production of photovoltaic power has seen a strong increase of more than 35% per year, in recent years. In order to make the manufacturing processes more viable and increase yield, more efficient and less expensive manufacturing tools are desirable. Preventing short-circuits by isolating the edge of PV cells is a common practise that increases cell yield. Several technologies are available today to prevent these shunts. However, conventional techniques such as laser cutting or plasma etching do not always give good results, because of either excessive heat damage, or high hourly running costs. This paper presents the high quality cutting and

scribing results on silicon PV solar cells using the water jet-guided laser, also known as the Laser MicroJet<sup>®</sup> (LMJ), which results in no thermal or mechanical damage. Both contour cutting and edge isolation show the superiority of the LMJ technology. The study was conducted in cooperation with Solarwatt Solar-System GmbH and the Fraunhofer-Institute for Solar Energy Systems ISE. It includes testing the electrical parameters of the cells after edge isolation, thermography and SunsVoc measurements, SEM and optical microscope images and breakage tests. The water jet-guided laser was also compared to a standard dry laser edge-isolation process. The LMJ technology has recently been integrated into an established solar cell processing system by Manz Automation. A further customer application is with Schott Solar, for the cutting of PV cells, where the superior fracture strength exhibited after processing was decisive in adopting the LMJ technology.

## **Introduction:**

Solar cells facilitate the direct conversion of sunlight into electrical energy. The conversion process is based on the photo effect. The voltage that can be generated per cell depends on the semiconductor material used, and amounts to approx. 0.5V in the case of silicon.

In order to generate higher voltages, individual cells must be connected in series. For low-power solar modules with a limited module surface area, it is almost always necessary for the module voltage to be standardised. However, this cannot be achieved simply by stringing entire cells together. Therefore, fabricating such solar

modules renders it necessary to dice conventional crystalline solar cells with a format of 100 x 100mm, or 150 x 100mm, into individual cells with a smaller surface area and to subsequently connect these in series to form strings.

Besides from wafer cutting, a further step during PV cell production is edge isolation (EI). This operation prevents parasitic shunts between the front and back surfaces which may decrease the cells efficiency. Cell EI requires that the tool cut through any metal layers present as well as the silicon, without having any adverse effects on the material structure.

A common process for edge isolation is plasma etching. Although this technique gives satisfactory isolation results for relatively low-cost equipment, the demand on personnel is very high and the process flow is rather low. Additionally, the process creates some damage to the silicon surface, which may penetrate into the junction, causing a loss in fill factor [1].

Conventional laser cutting may also be used for dicing and edge isolation. The main disadvantage of this technique is heat damage; additionally, re-melting may occur around the cut, resulting in stress-induced cracks in the boundary layer. Drops of molten metallic particles from circuit tracks may also be present on the surface, inducing short-circuits that reduce the PV capability of the cell.

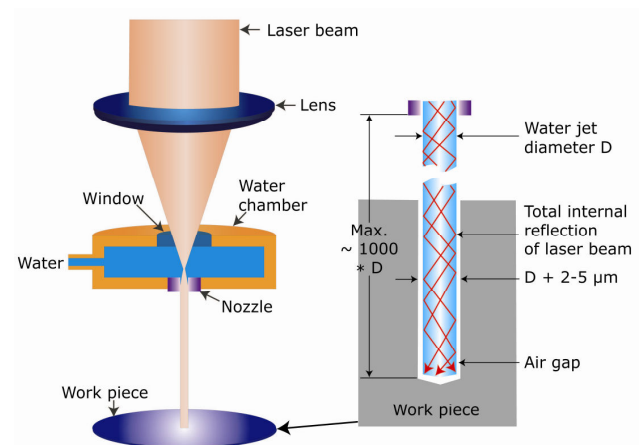
Mechanical methods, such as diamond saws, can generate mechanical damage that is problematic during handling, especially for very thin silicon wafers. The process also reduces the active cell area, thus wasting silicon, and cannot be used on curved contours.

Recently, a new technology – the water jet-guided laser – has been used for contour cutting and edge isolation of PV cells, which is performed, as with conventional lasers, by cutting or grooving the cell close to its edge. However, contrary to conventional laser-based techniques,

the process does not generate heat damage and contamination is negligible.

### Water Jet-Guided Laser:

The principle of this unique technology, also known as the Laser MicroJet<sup>®</sup> (LMJ), is to couple a high-power, pulsed laser beam into a hair-thin, low-pressure water jet as shown in Figure 1.



**Figure 1 Basic principle of the water jet-guided laser**

The laser beam is transmitted by fibre optic cable to the optical head, where a system of lenses focuses the light through a transparent quartz window and into a chamber filled with water under low pressure, where it is focussed into the water jet exiting the chamber. From this point, the laser beam is guided through the cylindrical jet by means of total internal reflection at the air/water interface, due to the differences in refractive index. When it reaches the work piece, the laser ablates the material by melting and vaporisation.

### Technical Specifications:

Different laser sources can be used with the water jet, ranging from flash-lamp-pumped IR lasers with pulse durations of less than  $100\mu\text{s}$  to multimode diode-pumped Q-switched lasers, operating at 1064nm (infrared), 532nm (green), or 355nm (UV). The only constraint on the laser wavelength is that it must be compatible with the water transmission spectrum.

The nozzles are made from sapphire or diamond and have diameters varying between 30 and 120 $\mu\text{m}$ . New, smaller nozzles are currently undergoing laboratory trials, which will allow kerf widths of only 18 $\mu\text{m}$ . Depending on the nozzle diameter, the pressure of the water, normally de-ionized, de-gassed and filtered, ranges from 50 to 500bar. However, the mechanical force applied by the water jet (<0.1N) can be considered as negligible, leaving the material unscathed when exposed to the bare jet. As a comparison, the assist gas jet used in conventional laser cutting applies a force of around 1N – 10 times higher than the water jet-guided laser. Water consumption is very low, averaging only about 1.5l/hour.

#### Comparison with conventional lasers:

Like the other laser-based technologies, the water jet-guided laser can perform omni-directional cutting. However, the process speed is higher on thin materials. For example, a cutting speed of up to 300mm/s can be achieved on silicon that is 50 $\mu\text{m}$  thick. Furthermore, using a water jet offers several benefits, well known to be unobtainable when applying conventional, “dry” laser cutting. These include, extended working distance, heat control and particle removal.

In conventional laser techniques, the conically shaped laser beam is focused directly on the work piece, resulting in a short working distance. When a water jet is used to guide the laser beam, the working distance is much longer (up to several centimetres long, depending on the nozzle diameter) and, as the jet is cylindrical, the kerf walls are parallel.

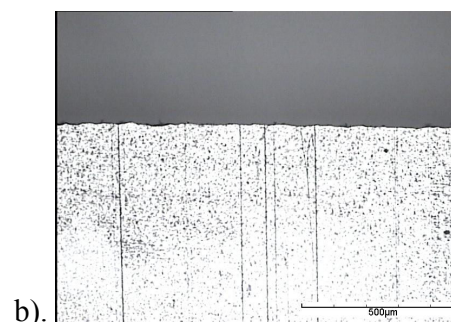
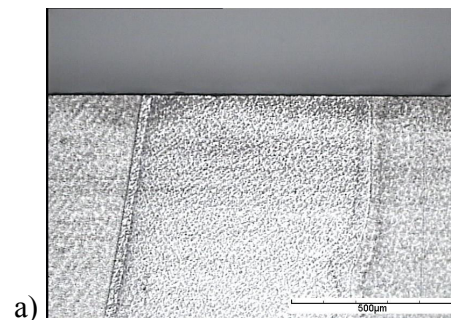
The heat-affected zone, an inherent problem with conventional lasers, is negligible, thanks to the water jet which cools the material between each laser pulse.

And lastly, contamination is considerably reduced compared to conventional lasers, as the water jet expels the molten material more efficiently from the kerf than the assist gas usually applied in laser

cutting. Additionally, a thin water film, maintained on the surface of the work piece during cutting, prevents the remaining particles from adhering to the material surfaces.

#### Contour cutting of solar cells:

In the cutting tests made with the Laser MicroJet<sup>®</sup> with silicon cells, only very slight damage occurred to the layer of the processed edge. The surfaces of the cuts are visually flawless, as illustrated in Figure 2. The measurements of the efficiency gradient across the cell surface area display no process-induced efficiency losses at the cut edges in the short-circuit current and reflection topography. The overall cutting speed is 80mm/s for a wafer thickness of 330 $\mu\text{m}$ . The cutting speed achieved corresponds to that of a conventional laser but, the quality and functionality of the cutting results are greatly improved.



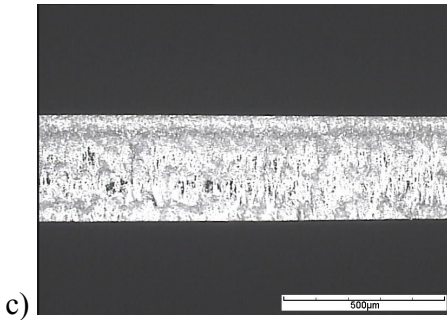


Figure 2 a) Front side of a solar cell cut by LMJ, b) Backside of a solar cell cut by LMJ, c) Kerf wall

With the CNC-controlled Laser MicroJet<sup>®</sup>, any desired 2D contour can be cut in solar cells. Sectional cuts in the material involve no problems whatsoever, as illustrated in Figure 3. Though no post-cleaning process was applied to these samples, the cutting results were superior. For this cutting process a 532 nm Q-switched laser with a 80 µm nozzle was employed.

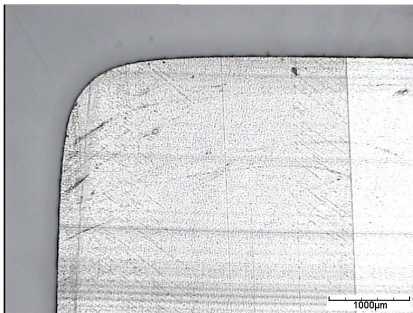


Figure 3 A rounded corner cut by LMJ (top view)

#### Laser MicroJet for edge isolation:

125 commercial solar cells were edge-isolated by a standard EI process and the LMJ process. The LMJ process was equipped with an infrared laser operated at different power and pulse frequencies. After edge isolation, illuminated and dark IV-curves of the cells were measured. Additional SunsVoc and thermograph measurements were also performed. Thereafter, all cells were break tested (4-line-bending apparatus) and both optical microscope and SEM pictures were made of the laser grooves.

The scribing parameters were optimised to produce a minimum amount of debris in the grooves that could possibly lead to shorts over the groove, while keeping a high process rate.

Typical results for the EI grooving process carried out by the LMJ are shown in Figure 4.

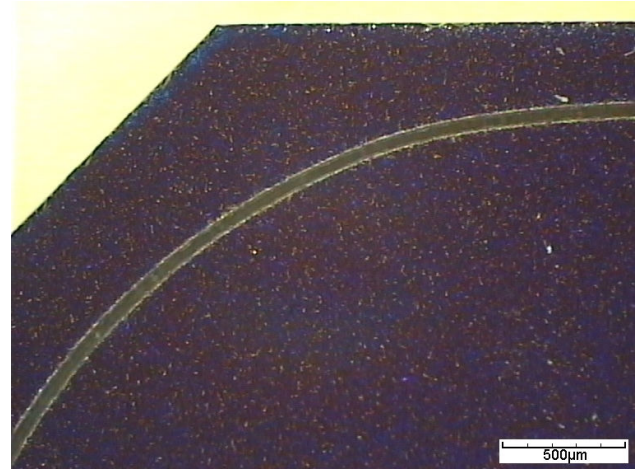


Figure 4 Microscope image of an EI groove at the corner of the cell, scribing speed: 300mm/s

#### Electrical parameters:

The experimental results showed that the electrical parameters of the LMJ edge isolation are comparable to commercial lasers, i.e. the electrical quality of the reference process (standard-industry EI) can be obtained with the LMJ. For the dark IV-curves, lower values of the second ideal factor  $n_2$  (2.0 versus 2.8) can be fitted continuously. This indicates a reduced damage in the p-n-junction and emitter respectively.

The fact that the LMJ process has produced these results is very positive, because the process parameters of LMJ were sub-optimal in some areas due to experimental restrictions:

- An IR-laser was used with LMJ instead of a green or UV-laser. This increases the penetration depth of the laser light.
- The corners of the solar cells were not isolated; only straight lines with a constant scanning speed were processed due to technical restrictions with the lab-type xy-motion system at the Fraunhofer ISE.
- The width of the laser groove was 2-3 times wider than for the commercial laser systems since a 100µm nozzle was used,

which accordingly increased the recombination losses.

For this reason, one can expect to have better results with the LMJ when using a UV or green laser light source and a smaller nozzle.

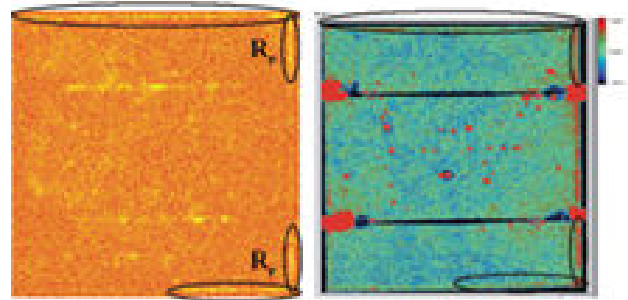
Successful edge isolation on the back surface of the solar cells was also observed. In principle, this kind of isolation is preferred to the front side edge isolation, because the active cell area is reduced in the latter case. Similar efficiencies were found as achieved by the front side isolation. The fill factor was slightly lower, but is compensated for by the increase of the short-circuit current ( $J_{SC}$ ). With regards to the emitter damage,  $J_{02}$  can be optimised.

A 20 $\mu\text{m}$  deep laser groove was sufficient for good edge isolation while a 5 $\mu\text{m}$  deep groove was found to be too shallow. The isolation process was carried out with a fast scanning speed of 250mm/sec. Consequently a 156 x 156mm<sup>2</sup> solar cell could be edge isolated in just 2.5sec. Even higher scanning speeds for the lasers used are possible, because a groove depth of 10 $\mu\text{m}$  (compared to standard lasers) is adequate. A transfer rate of 1-2sec. per wafer would then be realistic for the LMJ.

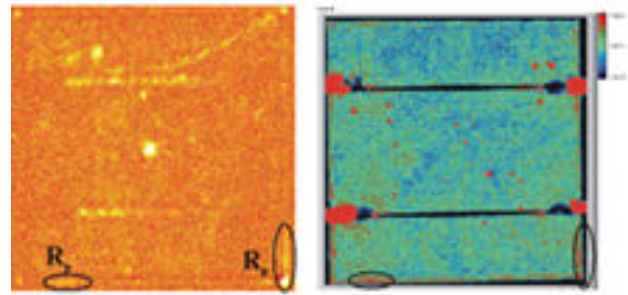
### Thermography measurements:

Shunts of solar cells under different operating conditions have been detected via thermography. In the case of edge isolation ohmic shunts could be distinguished from increased emitter recombination by comparison of thermography maps made in forward bias ( $V_{OC}$ ) and reverse bias. An ohmic shunt exists if the current losses are visible in both kinds of maps because the direct connection of emitter and backside metallization is not isolated completely (this becomes apparent by a reduced parallel resistance  $R_p$ ). A diode shunt is responsible for the current losses if they appear in only one image. This can be explained for example by increased recombination in the p-n-junction ( $J_{02}$ ).

The thermography images in Figure 5 show that for the standard-industry-EI ohmic shunts still exist, whereas with the LMJ they are generally removed. For the edge isolation on the back surface, both kinds of shunts ( $R_p$ ,  $J_{02}$ ) are still present. Here there is a requirement for further process optimisation.



a) Standard-industry process, front side



b) LMJ, front side

**Figure 5** Thermography measurements (left:  $V_{OC}$ ; right: reverse bias)

### Suns $V_{OC}$ measurements:

A series of resistance free IV-curves were measured with Suns $V_{OC}$  in order to find out what the potential of the solar cell would be if the series resistance were zero.

The losses by series resistance were for all cells approximately equal. This denotes that series resistances of the analyzed cells did not spread in a wide range and reduced the maximum achievable fill factors by approximately 5% REL.

The stronger limitation of the fill factor to approximately 0.80 with the configuration of IR laser at 45.2W and 20 $\mu\text{m}$  deep groove for the LMJ was caused by p-n-separation during the as yet non-optimised back surface edge isolation.

The limitation however was compensated by the increase in  $J_{SC}$  so that the efficiencies were comparable with the front side results for the LMJ edge isolated cells. With further optimisation, a process could possibly be achieved which would exceed the front side process.

### Breakage tests:

To analyze the mechanical strength, all cells were break tested with a Zwick BasicLine 4-line-bending apparatus. The maximum breakage force was detected. The required breakage force area depicted in Figure 6 stands for all EI-methods.

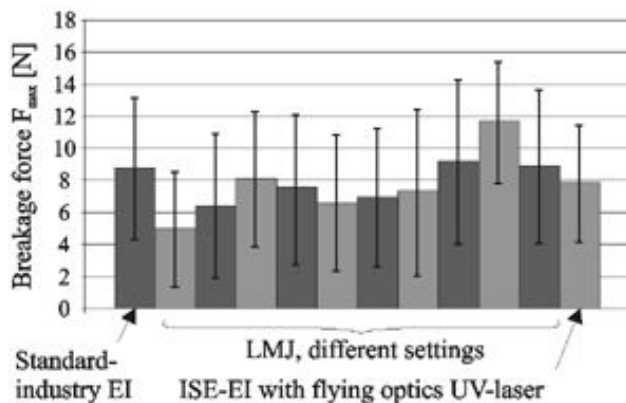


Figure 6 Comparison of the breakage forces of different EI-methods

The broad distribution of the results is due to the small number of tested cells. But it also indicates that only limited large cracks were generated by the edge isolation (with numerous large micro cracks the breakage force would have constant smaller values). This is confirmed by the fact that the cell fragments were large. The cells didn't split as would have been typical for high breakage strengths and a high concentration of small micro cracks. This was visible, especially for the standard-industry isolated cells. 30 cells were break tested and even so the standard deviation was approximately 50 %. An increase in groove depths with LMJ does not necessarily lead to a decrease in breakage force.

### Conclusions:

The water jet guided laser cutting method proved to be the only process suitable for solving the task at hand. The productivity, precision and economic efficiency of the process already justifies the technical effort of combining the beam and jet technologies in a precision machine when it comes to cutting simple shapes in solar cells. However, the advantages of the process become even more evident when more complicated contours have to be cut with simultaneously high demands on accuracy.

On the basis of the results reached, one can ascertain that the water jet-guided laser has also proven suitable for the edge isolation of solar cells. The same electrical parameters are achieved as with the comparative standard laser processes. The highest fill factors for the solar cells tested are obtained with the LMJ, but the number of processed cells per variant was too low to compile sufficient statistical information.

However, it has to be emphasised that the LMJ has reached standard-industry results in spite of sub-optimal testing parameters. The recent results of the LMJ could have even exceeded the standard-industry-process by using a UV or green laser source, a smaller nozzle and a laser-axis coupled CNC controller. With these changes, edge isolation with lower recombination losses via reduced melt layer thickness, smaller groove widths and isolated cell edges can then be expected.

Even with this experimental barrier for the LMJ, indications for an advanced process have been noted:

- Constant lower  $n_2$ -values for LMJ, possibly caused by reduced emitter damage.
- Single process with higher breakage forces.
- Backside edge isolation is possible.
- Better groove quality and homogeneity.

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