GETTING THE MOST OUT OF PV CELLS

As photovoltaics move towards wider market integration in answer to growing needs for energy conservation, more commercially viable manufacturing tools are required. Here **Keith Stay**, Technical Writer, **Synova** discuses the options

Each second the earth receives sufficient sunlight to meet its yearly power requirements many times over. Utilising this free source of energy with photovoltaics is becoming a major industry with long term benefits for our global environment. Once manufactured and installed, photovoltaics will generate electricity from sun light for many years, requiring minimal maintenance, and producing no air pollution nor hazardous waste products. The global production of photovoltaic power has seen a dramatic increase of more than 35% per year, in recent years. With the rising consciousness of global warming affecting our planets biosphere, this demand is going to grow at an ever-increasing rate in the coming years. The worldwide demand for electricity in the developed and even more so in the developing countries will continue to grow and photovoltaics are one of many solutions now being exploited to help satisfy this demand. In order to make the manufacturing processes more viable and increase yield, more efficient and less expensive manufacturing tools are desirable.

An inherent problem with the production of photovoltaic cells (PV) is parasitic shunt resistances that form at the wafer edges between the active layers. These cause significant power losses and are typically due to manufacturing defects, rather than poor solar cell design. Low shunt resistance causes power losses in cells by providing an alternate current path for the light-generated current. Such a current diversion reduces the Fill Factor (FF) and the Open Circuit Voltage (V_{OC}), effectively reducing the efficiency of the cell. This effect becomes more severe at low light levels, since there will be less light-generated current, therefore current lost through the shunt will have a larger impact. In addition, at lower voltages where the effective resistance of the solar cell is higher, the impact of a parallel resistance becomes larger.

Prevention of the shunt resistances (R_{SH}) is therefore a process commonly applied during manufacturing to increase cell yield and is performed by cutting through close to the edges, the N-type emitter on the top surface, to eliminate leakage paths as shown in Figure 1. Edge Isolation (EI) is performed by several conventional technologies today, such as laser cutting, diamond saw or plasma etching. However, these do not always give good results, either because of excessive heat damage as in the case of conventional lasers, reduction in the fracture strength of the wafer from sawing, or the high operating costs of etching.

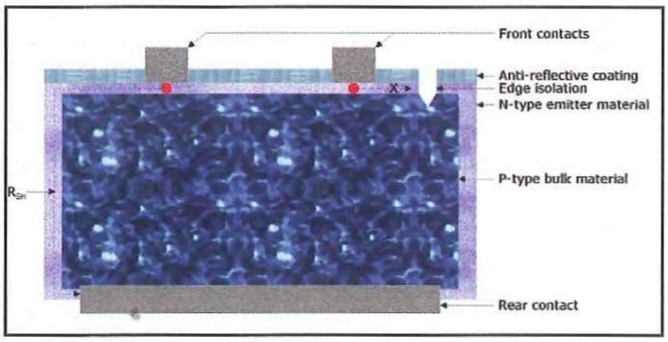


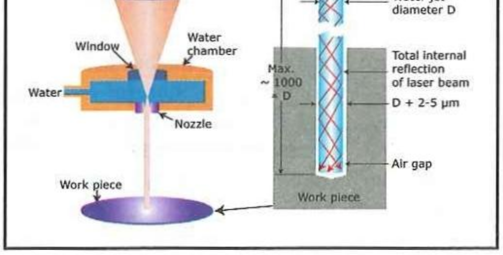
Figure 1 Sketch of solar cell showing shunt path and the influence of EI

The disadvantage of the above method of eliminating the shunt resistances is the loss of current generating surface area at the cell edges. Alternatively, this loss can be mitigated by carrying out the EI on the back surface of the cell, by cutting through the metallised rear contact layer to provide the necessary isolation.

In this article, the use and advantages of the water jet-guided laser, also known as the Laser MicroJet (LMJ), manufactured by Synova, will be described. The main benefits are fast and efficient wafer cutting and EI of PV cells, with no remnant contamination and no thermal or mechanical damage to the cell structure. Both straight and contour shaped cutting and edge isolation grooving can be carried out using this very flexible tool.

The principle of this technology is to couple a high-power, pulsed laser beam into a hair-thin, low-pressure water jet, Fig 2.

Figure 2 Basic principle of the water jet-guided laser



The laser beam is coupled to the optical head, where lenses focus the light through a quartz window into a chamber filled with water under low pressure and into the water jet exiting the nozzle. From this point, the laser beam is guided along 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 beam ablates the material by melting and vaporisation.

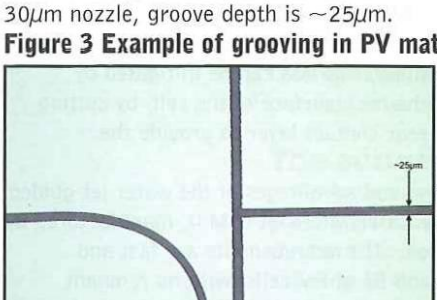
Laser sources ranging from flash-lamp-pumped IR lasers with pulse durations of less than 100ìs to multimode diode-pumped Q-switched diode-pumped lasers operating at 1064nm (infrared), 532nm (green), or 355nm (UV). The only constraint on the laser wavelength is that it must be compatible with the water transmission spectrum.

The diamond or sapphire nozzles have aperture diameters varying between 25 and 100ìm. New, smaller nozzles are under development, allowing kerf widths of only 18ìm. Depending on the nozzle diameter, the pressure of the pure de-ionized water, ranges from 50 to 500bar. However, the mechanical forces applied by the water jet are negligible (less than 0.1N). In comparison, the assist gas jet used in conventional laser cutting applies a force of around 1N. Water consumption is very low, averaging only about 1.5l/hour.

Like the other laser-based technologies, the water jet guided laser features omni-directional cutting. However, the process speed is higher with thin materials. For example, a cutting speed of up to 300mm/s can be achieved on 50ìm thick silicon. Furthermore, using a water jet offers several further benefits compared to conventional, "dry" laser cutting, such as extended working distance and perfectly parallel kerfs walls, as there is no beam divergence. The heat-affected zone (HAZ) problem, which is inherent with conventional lasers, is non-existent thanks to the water jet, which cools the material between laser pulses. Contamination is also eliminated, as the water jet expels the molten material more efficiently from the kerf than the assist gas used in conventional laser cutting. Additionally, a thin water film maintained on the surface of the work piece during cutting, prevents any deposition of particles on the material surfaces.

The following image demonstrates the capabilities and quality of the LMJ when used to carry out grooving for EI of GaAS/InP cell material, in this case with an IR 1064nm fibre laser and a 30μm nozzle, groove depth is ~25μm.

Figure 3 Example of grooving in PV material, showing radial and "T" cuts

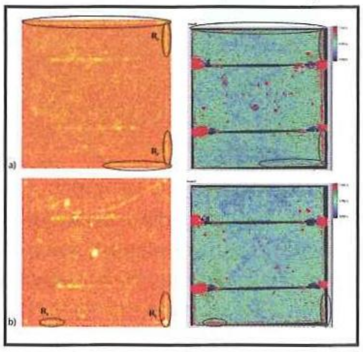


Experimental EI results produced by the Fraunhofer-Institute for Solar Energy Systems ISE, using an IR laser, show that the electrical parameters for LMJ edge isolation are comparable to those produced by commercial lasers. For the dark IV-curves, lower values of the second ideal factor n_2 can be fitted continuously. This indicates reduced damage to the p-n-junction and emitter respectively. Even better results can be expected when a green or UV laser combined with a smaller nozzle would be used.

Successful EI on the back surface of the solar cell was also carried out. In principle, this mode of isolation is preferred to front side EI, due to the reduction in active cell area in the latter case. Similar efficiencies were found as those achieved by front side isolation. The FF was slightly lower, but was compensated by the increase of the short-circuit current (J_{SC}). A 20μm deep laser groove was sufficient for good edge isolation, whereas a 5 μm deep groove seemed too shallow. The isolation process was carried out with a fast scribing speed of 250 mm/sec. Consequently a 156 x 156 mm^2 solar cell could be edge isolated in 4 * 156 mm / 250 mm/s = 2.5 sec. Even higher scribing speeds are possible, if a groove depth of 10μm were chosen. A transfer rate of 1-2 sec per wafer is therefore realistic for the LMJ.

Shunts on solar cells were detected under different operating conditions 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 map because the direct connection of emitter and backside metallisation is not completely separated (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 by increased recombination in the p-n-junction (J_{02}), for example. The front side thermography images in Fig. 4 show that for standard-industry EI a) ohmic shunts still exist, whereas for the LMJ b) they are generally removed.

Figure 4 Thermography measurements (left: Voc; right: reverse bias)



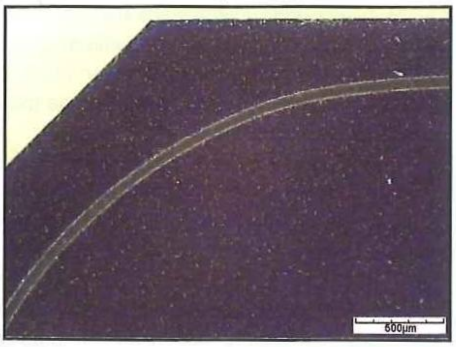
A series of resistance free IV-curves were measured with SunsVoc in order to determine the potential of the solar cell if the series resistance was zero. From this, one can appreciate the limitations of the cell using other parameters (R_P, J_{02}), which are directly influenced by the EI.

The series resistance losses for all cells were approximately equal. This denotes that series resistances of the cells analysed did not have a wide spread and this reduced the maximum achievable FF by approximately $5\%_{rel}$.

The limitation of the FF to approximately 0.80 with the LMJ configuration of IR laser and 20ìm deep groove was caused by the non-optimised p-n-separation on the back surface edge isolation. The limitation however, was compensated by the increase in J_{SC}, so that comparable efficiencies with front side EI cells were achieved. With further optimisation, results could possibly exceed the front side process.

The water jet-guided laser has proved to be highly suitable for cutting and EI of PV cells. The productivity, precision and economic efficiency of the process have been fully demonstrated and is now being used by industry. The advantages of the process are even more evident, when complicated contours have to be cut with simultaneous high demands on accuracy, Figure 5.

Figure 5 Example of rounded EI at PV cell corner



The experimental results obtained with the LMJ could have exceeded the standard-industry-process by using a UV or green laser source and a smaller nozzle. Here edge isolation with lower recombination losses via reduced melt layer thickness, smaller groove widths and isolated cell edges can then be expected.