Efficiency from the start: innovative value chains in module production

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Over the past few years Europe has made noticeable progress in strengthening local PV production, thereby increasing resilience, sustainability, and independence along the entire value chain. Still, there are many obstacles to overcome, and without any doubt, the most severe threat is the Chinese PV industry and its economies of scale. To stay competitive, it is essential to remain at the technological forefront. This requires not only a keen sense for a unique customer value and an innovative design of the manufacturing process chain, but also a close look at the basics enabling the desired product features.

Specific benefits derive from a thoughtful and automated integration of the production process steps and the close cooperation of the European companies involved along the process chain. This article describes the joint efforts of 3D-Micromac, Singulus Technologies, and M10 Solar Equipment in establishing an innovative module production approach, covering advanced cell cutting and repassivation of the cutting edge as well as a sophisticated solution for solar cell interconnection within the module (see Fig. 1).

Compared to conventional cell separation approaches, 3D-Micromac's patented Thermal Laser Separation (TLS) process grants superior quality of the cutting edge, providing the perfect base for subsequent edge repassivation as Singulus Technologies offers.

The latter method boosts cell efficiency by compensating for losses related to cell cutting. Last but not least, M10 Solar Equipments' Shingle-Matrix module design revolutionizes the connection technology of solar cells, aiming to achieve high panel efficiencies, improved product aesthetics, and outstanding shading resilience, especially in integrated photovoltaic applications (xIPV).

TLS™: the cut makes the difference

While modules based on half- and even third-cut cells have become mainstream throughout the past few years, new designs based on a shingle cell approach enable a wide range of benefits and new applications. Generally speaking, separating solar cells compensates for the increased power loss associated with higher cell currents resulting from today's larger host wafer areas. Simulation results have shown that output power density increases over decreasing shingle cell width.[1]

Based on its market-proven platform for half-cell cutting, 3D-Micromac introduced the microCELL MCS laser tool in 2021. Based on a modular design approach, the microCELL MCS can automatically process over 6,000 wafers per hour for all cutting formats, from half to 1/8 cut cells.

To enable the highest flexibility for new module designs addressing the specific requirements of BIPV and VIPV applications, 3D-Micromac has enhanced the functionality of the microCELL MCS system. In its current design, the tool can separate shingles to a minimum width of about 26 mm, approximating an M12/G12 eighth-cut cell.

Furthermore, 3D-Micromac added the functionality of applying rectangular cuts. Consequently, half-cut shingles, an essential element of M10's Shingle Matrix design, can be processed without needing an additional unloading/loading step or even a second cell cutting tool.

The optimized unloading system automatically loads all shingles and half-cut shingles into special stringer boxes. Alternatively, lower output options are also available, with separated cells being transferred to the matrix stringer directly as part of an inline integration.

As mentioned above, shingling solar cells minimizes power losses at the cell level.

Still, at the same time, a higher number, and consequently lower width, of shingles results in an increase of the cutting-edge-to-surface ratio of each shingle, which has various impacts on the cell performance.

With each cut, the original passivation layer of the host cell is laid bare, resulting in recombination losses. The most effective solution to compensate for these losses is to restore the passivation layer at the cutting edges using the Singulus plasma coating approach, also referred to as PET (passivated edge technology).

Also, the cell separation approach itself plays an important role. The microCELL MCS system takes advantage of 3D-Micromac's patented Thermal Laser Separation (TLS) process, guaranteeing excellent edge quality (see Fig. 2). This cleaving process relies on the application of a defined and controlled stress field imposed by laser-based heating and subsequent cooling. Starting from a laser-induced initial scribe, a crack is guided through the entire cell (see Fig. 3).

Contrary to conventional LSMC (laser scribing mechanical cleaving), TLS reduces recombination losses considerably.[2] Furthermore, TLS creates the perfect base for PET. Compared to LSMC, the regain in pseudo fill factor (pFF) after PET has been proven to be higher by more than 130%.[3] Lastly, TLS reliably prevents micro-cracks originating from the cutting edge, thus not only increasing the mechanical strength of the shingle cell by up to 30% compared to LSMC, but also reducing power degradation over the module's lifetime.

PET: boosting performance on cell and module level

As stated above, the cutting of solar cells is accompanied by cell efficiency losses originating from charge recombination occurring on the newly created unpassivated cut edges. Besides limiting these losses by the choice of cutting technology, another important strategy to further boost the performance on the cell and module level involves compensating losses by repassivating the cut edges. In this regard, Singulus Technologies introduced the vacuum deposition system GENERIS PET, which represents an industrialized solution for the inline deposition of edge passivation layers.

After the TLS process at the microCELL MCS system, several hundred cell cuts including half cuts, multi cuts and shingles are bundled into stacks within special stringer boxes that are subsequently transferred to the GENERIS PET. The optimized, in-house developed handling system unloads stacks from the boxes, aligns stacks, and loads them on the substrate carrier of the deposition tool. After substrate transfer into a vacuum, a plasma-based deposition process repassivates the

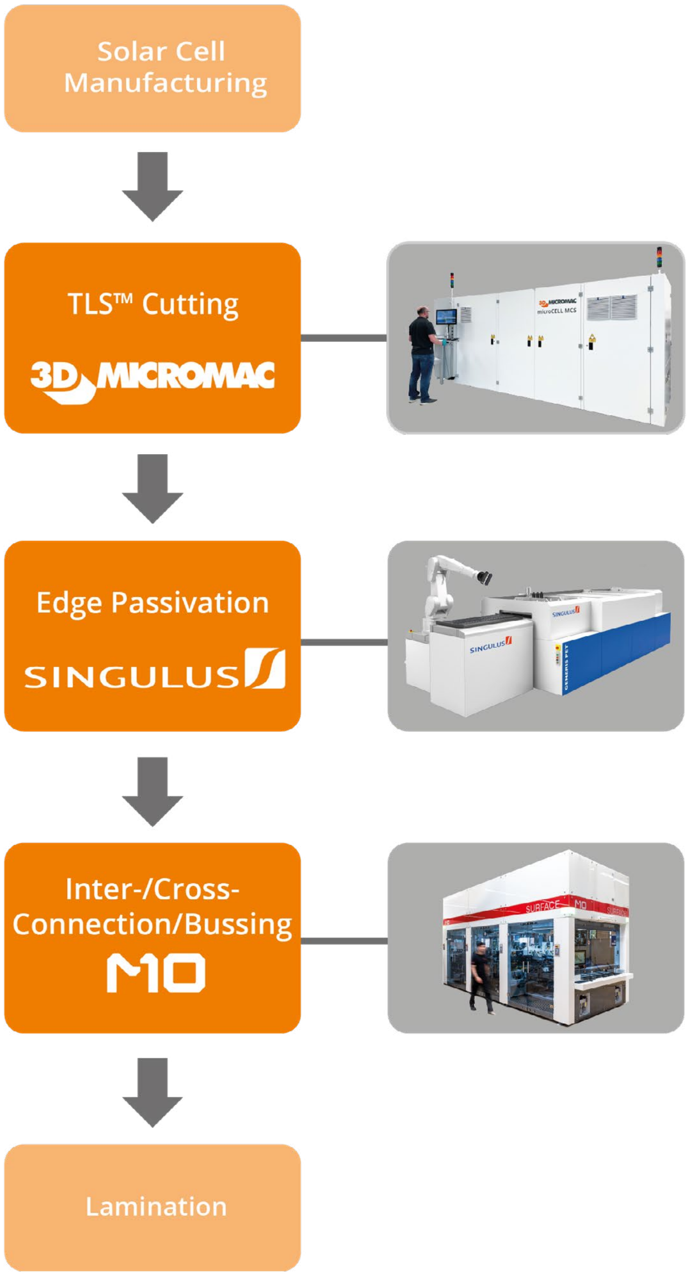

Figure 1: Workflow of module manufacturing for advanced module designs including edge repassivation

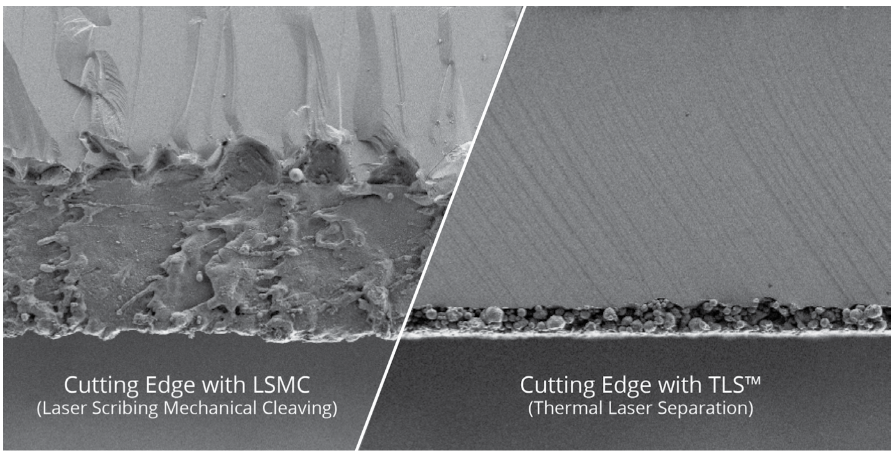

Figure 2: Comparison of edge quality of an LSMC (left) and a TLS separated cell (right)

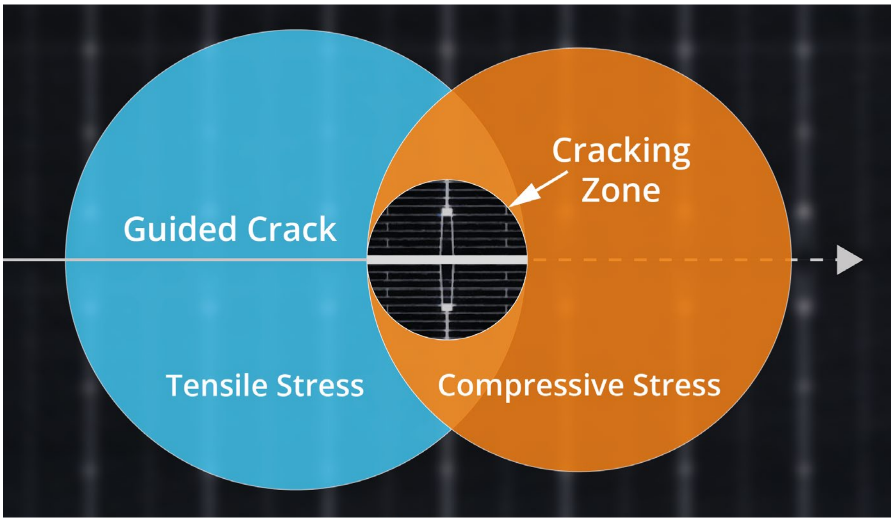

Figure 3: 3D-Micromac's patented TLS™ process relies on the application of a defined and controlled stress field imposed by laser-based heating and subsequent cooling. Starting from a laser-induced initial scribe, a crack is guided through the entire cell

cut edges originating from the TLS process.

The unique carrier design facilitates a high packing density of substrates, thus processing several thousand cell cuts per carrier. In addition, its design confines the deposited layer exclusively to the cut edges, preventing detrimental wraparound deposition of the passivation layer to the cell surfaces. Moreover, utilizing a sophisticated plasma source design, the system ensures the highest flexibility regarding the processability of all wafer and cut formats.

Depending on the equipment configuration and cut format, the GENERIS PET, as an industrialized inline solution for PET, can achieve throughputs of up to 72,000 cell cuts per hour, enabling annual throughputs of several GW. In addition, it is readily suitable for any crystalline solar technology.

In summary, the passivation layer properties achieved by the PET process help recoup up to 80% of the efficiency losses created on cell level by the cutting process compared to its unpassivated counterpart.

Shingle matrix technology: the new benchmark for efficiency

As described above, TLS and edge repassivation considerably increase cell-level efficiency. Regarding the subsequent connection of cell cuts, the shingle technology, named after the overlapping arrangement of solar cells like roof shingles, allows for direct electrical and mechanical connections between the cells, reducing ohmic losses and inactive areas. By placing solar cell-shading electrode busbar and interconnection structures inside the joint, optical losses from electrode shading are reduced to a minimum. These advantages have led to an absolute efficiency increase of up to 1.5%, translating into a relative efficiency gain of 4% to 6% and a direct increase in energy yield.

Conventional solar cells are cut into 5 to 8 stripe-like pieces to manufacture M10 Solar Equipment's shingle-based solar panels using the TLS approach. A pick-and-place process arranges several of these stripes in a row where their currents add up. Many of these rows then form the solar panel, whereby the sum of the row voltage defines the output voltage. By introducing half-cut shingle solar cells at the edges of every other row, the solar cells can be shifted by half their length, hence forming a masonry-like structure (see Fig. 4). This masonry or matrix-like structure is the name-giving and unique feature of these panels.

Aesthetically, M10's shingle matrix technology produces solar panels with a uniform appearance without discernible structures like metal connectors or cell gaps. Thus, they can be integrated into building skins without being recognizable as solar panels while providing higher power output per square meter than alternative solutions hiding solar cells.

Another crucial aspect is shading resilience, which influences the long-term energy yield of solar panels under shading conditions. Scientists from Fraunhofer ISE demonstrated this in several publications in scientific journals using numeric and experimental methods, proving a considerable yield increase.[4]

Conclusion

The joint efforts of 3D-Micromac, Singulus Technologies, and M10 Solar Equipment have led to the development of an innovative module production approach that covers advanced cell cutting and repassivation of the cutting edge. This approach allows for innovative module designs, such as those used in M10's Shingle Matrix modules. Using 3D-Micromac's patented TLS process for separating solar cells and Singulus Technologies' PET for restoring the passivation layer results in superior cutting-edge quality and a high pseudo fill factor (pFF).

Furthermore, M10 Solar Equipment's Shingle-Matrix module design revolutionizes the connection technology of solar cells, aiming to achieve high panel efficiencies, improved product aesthetics, and outstanding shading resilience, especially in integrated photovoltaic applications (xIPV). This innovative approach to module production is a significant step forward for Europe's PV industry, increasing competitiveness, sustainability, and independence along the entire value chain.

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Sources:

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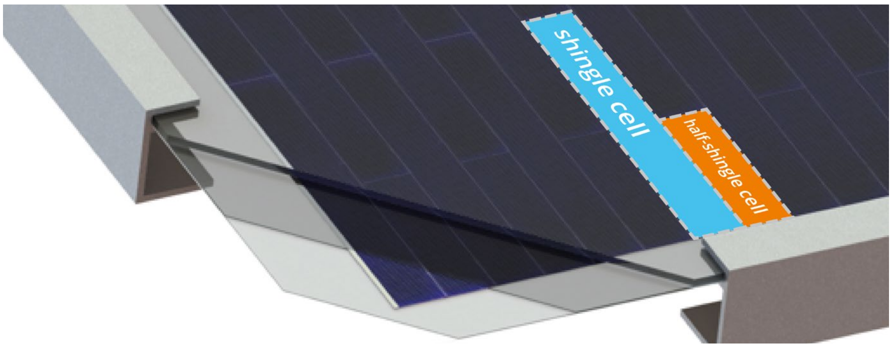

Figure 4: To achieve the masonry like structure of shingle matrix modules, half-cut shingle solar cells are introduced at the edges of every other row (© Fraunhofer ISE, Freiburg)