Front And Back: Incorporating Laser Tech Into A Solar Fab

Laser processing allows precise and repeatable micro-machining of various materials used in solar manufacturing.

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Historically, the profile of laser-based tools within the solar industry has lagged behind that of the etching and screen-printing technologies that dominate the equipment supply chain today. Recently, however, this imbalance has shifted, due to strong demand for turnkey thin-film production lines and new process steps integral to high-efficiency silicon-cell concepts.

Today's laser sources and solar panels have a certain inherent synergy - as efficient energy converters between electricity and light, and as stand-alone products with a near-zero carbon footprint. In addition, lasers are increasingly being integrated into production line equipment used by solar cell and panel manufacturers. Here, laser processing allows precise and repeatable micro-machining of various materials used in producing crystalline silicon (c-Si) cells and thin-film solar panels.

To understand the importance of laser-based tools within the solar industry, we should review the manufacturing stages within c-Si solar fabrication lines. Where are the bottlenecks? How are some cell manufacturers striving to implement advanced cell designs that necessitate the use of new and emerging laser sources?

Within standardized turnkey production lines for c-Si solar cells, a number of key process steps are performed to transform a bare silicon wafer into a photovoltaic solar cell, including saw damage removal, texturing to create a roughened front surface, diffusion to form a phosphorous-doped emitter, phosphorous-silicate glass removal, silicon nitride (SiNx) deposition for light transmission and surface passivation, front-contact and back-contact screen-printing and diffusion furnace firing, electrical isolation of the two surfaces, and cell measurement and sorting.

Typically, c-Si solar cells manufactured in this way have conversion efficiencies in the range of 14% to 16% - well below the percentage possible with high-efficiency methods involving higher-grade silicon or full back-contacted (or interdigitated) designs, which can deliver greater than 20% efficiency.

However, these high-efficiency cells are generally more expensive to produce and can require dedicated production tooling. The alternative route being considered by most cell manufacturers today is to introduce incremental changes to existing production equipment to gradually lower the overall per-watt manufacturing cost of the cells, while - if possible - retaining the same production tools downstream from the cell manufacturing stage.

For increasing the efficiency and yield of c-Si solar cells, the greatest scope for improvement centers on the front and back contacts - how these can be made more conductive and how new manufacturing processes can minimize high-temperature cycling or direct mechanical contact with the surfaces. These themes capture the underlying drivers for lasers as part of new process steps.

Edge isolation

Within today's fabs for c-Si manufacturing, the only process that uses laser-tooling is the electrical isolation process, historically referred to as edge isolation.

These laser tools compete at the edge-isolation stage with both plasma- and wet-etching in removing material from the surfaces of the cell. Lasers perform a routine front-surface perimeter scribe of a few tens of microns width, while plasma etching removes material from the side of the cells, and wet etching performs rear-surface material removal.

However, in next-generation processes for front- and back-contact formation, highly precise materials processing and micro-machining is essential on both the front and back layers of the cells.

This step demands non-contact processing to preserve the structural integrity of cells with decreasing wafer thickness, as thin wafers are key to reducing raw material costs in fabs. The process includes a range of highly selective ultra-fine material removal steps, involving tooling requirements well-suited to laser processing.

Additionally, if we combine laser processing with non-contact metallization schemes, we can potentially remove screen-printing from some manufacturing lines. This omission may be especially important as ultra-thin brittle silicon wafers become a more commonplace offering from upstream wafer suppliers.

The thin-film patterning process is performed after each of the three deposition stages in all thin-film fabs. This process also involves highly sensitive material-removal steps and is often performed with the use of laser patterning tools. Some of the lessons learned from thin-film production can indeed be transferred to next-generation c-Si lines.

Understanding the types of processes that lasers can perform provides some insight into why they are currently adopted within thin-film patterning, and why they are now being considered as essential components for c-Si tooling.

Generally, laser-based tools will be implemented within processes that require selective material removal, high-resolution material scribing, hole-drilling without degrading substrate material properties, or localized material melting or heating.

Through careful choice of laser-beam parameters, the speed and quality of these processes can be optimized. Available laser parameters include the color - or wavelength - of the laser output, the shape and size of the focused beam on the sample, the intensity of the laser pulse, and the speed of the scanned beam or number of pulses per second across the target.

As mentioned earlier, next-generation c-Si cells are likely to involve higher-efficiency designs in styles where the front and back contacts will be deposited in a different manner from that featured on most c-Si cells today.

For the front contacts, several new techniques are currently at the R&D or pilot-line phase. These methods may involve front contacts that are electroless nickel-plated by a non-contact tooling method directly onto the diffused n-type region of the c-Si cell substrate.

This procedure introduces a number of benefits over the existing combination of screen-printing and diffusion furnace firing, including higher conductivity; improved aspect ratios, defined as the ratio of the contact height to width; the removal of direct mechanical contact on ultra-thin, brittle wafers; and the elimination of high-temperature firing, which can cause excessive bowing of thin wafers.

At the back-contact stage, new processes are also emerging. These new techniques include the deposition of rear passivated layers, such as stacks of SiNx to reduce recombination losses and increase light reflectivity, thereby increasing cell efficiencies.

Within these new arrangements, one must often first remove small regions of material from the passivation layers to create openings for the contacts during subsequent metallization stages. In the case of a front-surface SiNx passivation layer, the thickness is typically just 70 nm to 90 nm.

On the front surface, it is common to remove fine lines for fingers with resolution in the 20-micrometer to 30-micrometer range (compare this to screen printing width limits of about 100 micrometers). At the rear side, more flexibility is possible, such as a matrix of spots with ablated diameters of 50 to 100 micrometers.

Next-generation front contacts for c-Si cells may be based on a two-step process. First, a laser selectively removes areas of the SiNx coating, and then, a non-contact metallization scheme deposits the front contacts directly on the n-doped region at the top of the cell.

This application is suitable for laser processing because of its selective material removal, fine features and flexibility in line or spot dimensions. The choice of laser source is as important as the process itself, and fortunately, over the past 18 months, highly specialized laser types have now become available to perform these steps.

To provide the necessary quality, the chosen laser must meet certain requirements. There must be short wavelengths from the laser to maximize absorption within the dielectric layers, as well as an ultrashort pulse duration from the laser - with a single pulse lasting just a few picoseconds.

Short pulses reduce what is known as the thermal diffusion length, or the heat-affected zone. This area is the region of damage around an ablated volume of material. Properly removing thin passivation layers requires this region to be as small as possible.

While we have concentrated on lasers for removing thin layers from the front and back of c-Si cells, almost every thin-film production line today is already using lasers for selective removal - specifically, for the step when a large thin-film substrate is converted to a final thin-film solar panel.

After each of the three deposition stages, in a standard thin-film manufacturing process, laser scribing tools scan highly intense laser beams across the length of the panel to remove one or two material layers at a time. After three such selective material removal processes, a final thin-film solar panel with interconnected cell strips is produced.

Optimization

There remains much uncertainty within the solar industry about how lasers move through the supply-chain, from laser manufacturer to solar cell production line. Lasers are typically integrated within laser (scribing) tools, which have the laser source embedded within a turnkey software-controlled workstation.

Internal to this tool, the beam coming from the laser must be manipulated so that the final beam properties at the target (wafer or panel) are optimized for the specific process required. This step may involve adjusting the size of the beam, or controlling when the beam is on or off, its position at the workplace, the uniformity of the beam, and the depth of focus.

Further, moving the laser beam around often requires the use of galvanometer-controlled scanners to redirect the position of the beam quickly over large processing areas.

Once the laser is integrated into a tool or subsystem, we then have two routes for deployment. The first is integrating the lasers within turnkey production lines - a route common these days within the equipment supply to thin-film panel makers. The second route is potentially of more interest to next-generation processes, particularly for the advanced c-Si cell concepts reviewed earlier.

Here, the pull from cell manufacturers is often to introduce tooling that is differentiated from standardized production line configurations offered from the c-Si turnkey suppliers today. Indeed, customizing c-Si production lines typically involves introducing laser-based tools directly into existing lines or as part of a new capacity expansion.

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