IPG PHOTONICS

APPLICATIONS OF FIBER LASERS FOR SOLAR CELL MANUFACTURING

Applications of fiber lasers for solar cell manufacturing

Introduction

Solar power offers one of the most exciting options for renewable sources of energy. Currently the technology is still evolving with cost-efficiency challenges, and there are increasingly funded efforts to meet these challenges. Due to rapid growth and development, uniform standards for production and deployment of PV products are just beginning to be developed. Currently, many competing technologies such as laser ablation, chemical etching, glass bead blasting and plasma deposition are being used for purposes such as edge isolation, edge deletion, crystal damage removal and thin film ablation by different manufacturers around the globe. However the application of fiber and other lasers offer very significant cost reductions, process simplification and in some cases even the elimination of some process steps when compared to the conventional techniques. Fiber lasers, especially offer cost reduction due to their high wall plug efficiency, reducing the amount of energy required in the PV manufacturing process. Important representative applications examples of fiber lasers in solar cell manufacturing are discussed below.

Types of solar cells

Today, two PV technologies compete for market dominance, crystalline silicon (c-Si) and thin film. Currently about 80 - 85% of all PV modules are manufactured using c-Si technologies.

c-Si technology involves the fabrication of high purity ingots of poly- or single crystal Si material usually from natural quartz. These ingots are doped with boron. The ingots are sliced into wafers and doped on the surface with phosphor using a thermal diffusion process forming a p-n semiconductor junction. Some manufacturers grow thin ribbons of Si directly from molten Si and cut wafers from these ribbons avoiding the requirement of slicing or sawing wafers from ingots, thereby saving significant quantities of costly silicon. Once wafers have been diffused, the front and back metal electrical contacts are added resulting in a finished solar cell. A certain number of these cells are then connected to produce a solar panel. The advantages the c-Si technology are higher cell efficiency (up to 20%), simple and proven technology, while the drawbacks are the amount of costly Si required to produce a given amount of electricity and higher manufacturing costs.

Solar thin film technology is based on semiconductor materials such as amorphous Si, CdTe (Cadmium Telluride), and CIGS (Copper Indium Gallium Di-selenide). The thin film cells are manufactured by depositing multiple layers of these different materials on glass, metal or polymer substrates. The semiconductor junctions are formed in different ways, either as a p-i-n device in amorphous silicon, or as a hetero-junction for CdTe and CIGS. A transparent conducting oxide layer such as Indium tin oxide forms the front electrical contact of the cell, and a metal layer the rear contact. The advantages of this technology include lower cost per peak electrical output Watt due to lower materials and other manufacturing costs and ease of scalability to large panels. The drawbacks are lower efficiency (up to 13%) resulting in larger panel area to produce a given amount of electricity when compared to c-Si based PV modules and complexity of the technology itself.

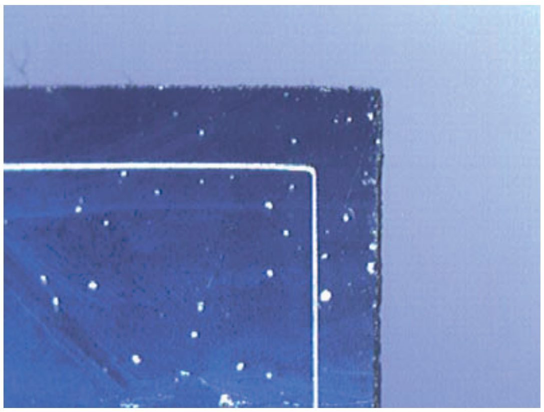
Applications of fiber lasers in c-Si based cell manufacturing

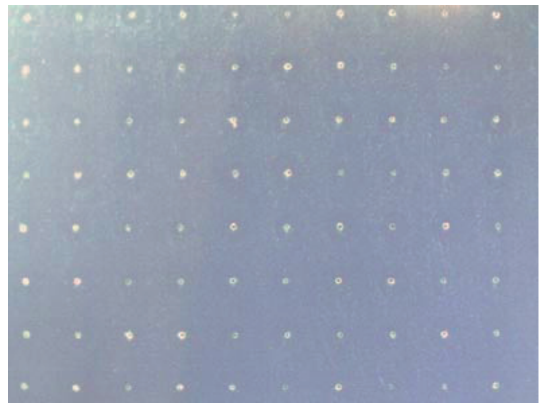
Lasers are positioned to have a very large impact on the manufacturing cost of the c-Si based PV cells since laser based processes can be significantly more efficient than the use of conventional processes due to higher processing speeds, improved process control and reduced electrical power requirements. The most frequently used laser wavelengths are 1064-nm and 532-nm. The selection of the particular wavelength is application dependant and is discussed below.

<u>Edge Isolation:</u> In c-Si cell manufacturing, the p doped silicon wafers are subjected to a thermal diffusion process resulting in a thin n-doped silicon layer forming the p-n Junction. During the diffusion process the edges of the wafer and the back side are also diffused creating an undesired pathway for the photo-current named leakage current resulting in low cell efficiency. To eliminate or isolate this current an isolation groove 40-50 microns wide is laser scribed completely through the n-layer along the edge and circumference on the back of the wafer. Typically the edge isolation can be performed with a Q-switch laser. The choice of wavelength is manufacturer specific as both the 1064-nm and 532-nm are being used by different manufacturers for this application. 20 W (average output power) Q-switch Ytterbium pulsed fiber laser (YLP) laser are being be used for scribing edge isolation grooves at 2m/sec or faster. The advantages of using a 1064-nm fiber laser for this application are high reliability, high scribing speed and low cost. The use of the

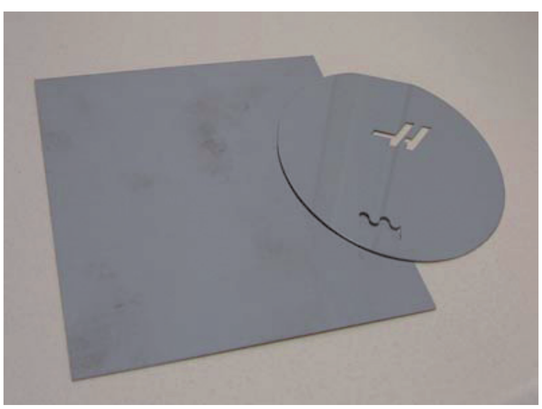
532-nm wavelength (frequency doubled) results in a somewhat reduced scribing speed and increased cost but yields scribes with much reduced crystal damage resulting in potential higher yield.

Drilling Vias: A simple solar cell has front and back contacts for the charge carriers and the front metal contacts cover a significant area of the cell (5-7%) and thereby reducing the cell efficiency by obscuration of the sun light. To increase the efficiency and power from each module, newer technologies such as "Metal Wrap Through" (MWT) and "Emitter Wrap Through" (EWT) are being implemented wherein the front contacts are moved to the back surface, leaving the front surface nearly free of metal obscuration. To connect the front surface of the cell with the back surface, drilling hundreds of small holes or vias in the wafer is part of the solution. A 20 W Q-switch fiber laser is used to drill 50 micro diameter holes in 250 micron thick wafers at a speed of 100-200 holes/sec. For laser drilling of the vias processing throughput can be optimized depending on the wafer thickness and the hole density. To achieve the throughputs required for this application, 1064-nm fiber lasers offer the best combination of peak power, pulse energy and higher pulse repetition rate compared to a 532-nm laser.


Edge isolation groove scribed with a 20W YLP laser


Drilling Vias in 300 micron thick wafer

Cutting Wafers: Due to silicon foundry shortages and associated high material costs, manufacturers are moving towards using thinner wafers (100-200 microns). As the wafers get thinner, it is challenging to cut them with conventional mechanical tools which induce micro cracking and ultimately reducing the strength of the wafers. Fiber lasers, offering a non-contact process, have been successfully implemented in production lines to cut wafers. The Q-Switched YLP fiber lasers, with 50-100 ns pulse and peak power up to 20KW, are used to cut these thin wafers in multiple passes. The YLP Q-switch fiber lasers offer economical and the cleanest process to cut these wafers as secondary process such as chemical etching (often necessary for other competing technologies) are completely eliminated.


Cutting Single crystal and polycrystalline Silicon wafers

Wafer marking

Wafer Marking: Laser marking is the best and easiest way to achieve traceability and product serialization. The wafers can be marked with a barcode or an identification number with a Galvo based system. The process is clean and fast and can be integrated to existing production lines. 10W and 20W YLP Q-switch fiber lasers are being used for marking 2-D barcodes on the silicon wafers.

Other Applications: The efforts to improve the efficiency of the cells and advancement in the technology would also open up doors for future laser applications for manufacturing the c-Si cells. Some of the promising laser applications for the c-Si cells under development include Stringers (Soldering contacts, being developed by Fraunhofer Institute), surface texturing, grooving, fired contacts, laser diffusion and laser buried contacts. Modulated CW Fiber lasers may offer advantages over conventional technologies such as resistive heating that is currently being used for tabbing (Soldering/welding contacts to connect cells in series), because the process is more faster, easier, reliable and controllable. Moreover, fiber lasers are being used in numerous industrial applications for spot welding and soldering applications and similar techniques could be implemented for solar cell manufacturing. Q-switch 1064-nm fiber lasers can be used for processes such as grooving and fired contacts as; they offer numerous advantages over the 532-nm lasers in terms of efficiency, power and cost.

Applications of fiber lasers in thin film based cell manufacturing

Manufacturing technology of thin film based cells is different than the c-Si technology and based on the how the cells are constructed in contrast to c-Si cells. Lasers are currently limited to only two applications such as scribing for individual cells and contacts and edge deletion. The most frequently used substrate is glass although metal or a flexible polymer substrate is also used. Regardless of the substrate, the underlying technology is similar and manufacturing processes such as scribing and edge deletion are common and important processes.

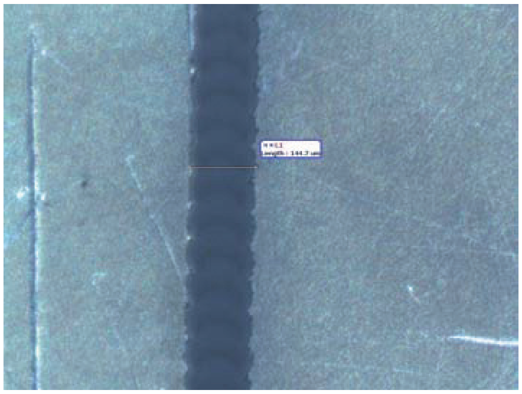
<u>Thin film patterning:</u> The thin film cells are deposited on large substrates (usually 60 cm x 120 cm). Several layers ranging from a few tens to several thousand of Angstroms are deposited usually by sputtering or other thin film deposition processes to form the PV semiconductor structure. The thin films then need to be scribed to form a number of individual cells. These individual cells are created by a combination of laser scribing to remove thin stripes of material and coating thin films, layer by layer. The scribing is performed at precise distances across the whole width of the substrate and along the entire length. The cells are then interconnected in series to achieve the desired output voltage for the module. A typical patterning process has three steps in which the first scribe (P1) is for the front contact; the second scribe is for semiconductor junction (P2) and the last scribe is for the back metal contact (P3).

<u>P1, P2, P3 scribes:</u> P1, P2 and P3 are sequentially performed using either 1064-nm or 532-nm lasers. Typically the P1 is scribed with a 1064-nm Q-switch fiber or a CW fiber laser and the P2; P3 scribes are fabricated with a 532-nm laser. A 20 W Q-switched fiber laser is being used for P1 scribing at approximately a 1 m/sec speed. Laser processing is preferred over other methods such as photolithography due to its simplicity and low cost. Another advantage of a laser based process is the ability to scribe a variety of materials without the need of major process changes in an environmentally clean manner and without the use of chemicals.

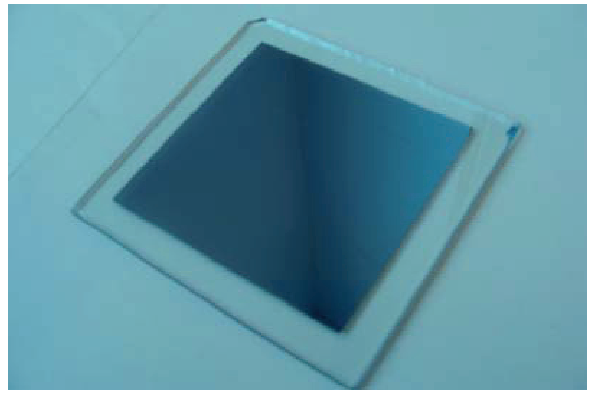
<u>Edge delete:</u> Removal or deletion of all the layers is needed 10-15mm wide around the circumference of the panels. This is required so that the encapsulant is sealing the edges of the thin films completely from the environment to prevent corrosion of the films due to moisture and air. High power Q-switched fiber lasers offer significant advantages over technologies such as glass bead blasting or chemical etching since it is a cleaner process and offers better throughput, avoids the use of acids and has inherently high reliability, all resulting in low cost. A 200 W Q-switched fiber laser (YLP-HP) focused to a large spot or line image achieves removal rates in excess of 20cm2/sec, which meet the production requirements for this process.

<u>Other applications:</u> The other potential laser applications in thin film cells could include ID marking for product serialization, cutting of flexible thin film cells (Flex substrates) for custom shapes and sizes for mobile applications, and also for cutting of the glass substrates. A variety of lasers such fiber, C02, frequency doubled and tripled lasers can be used for these applications.

For most of the processes described, 1064-nm Q-switch fiber lasers are used because they offer the best economical solution in terms of power to cost ratio, reliability and electrical efficiency. The advantages of processing at this wavelength are low cost, high throughputs and low cost of ownership. Where thermal damage is a concern the shorter wavelengths at 532-nm ad 355-nm available can address this issue, but this is partially offset by higher cost, lower throughput and higher cost of ownership. The viability of solar power is highly dependent on keeping the production costs low, so manufacturers have to choose a balance between quality and throughputs in determining a right laser process for each of the various laser based applications.



Patterning thin films (P1)



Edge delete (10mm band)

	YLP Series 1064-nm Q-switch fiber lasers	YLP – HP Series 1064-nm Q- fiber switch lasers	YLR-Series 1064-nm CW fiber lasers	532-nm frequency doubled laser	355-nm frequency tripled laser
c-Si PV Cells					
Edge Isolation	•			•	•
Vias Drilling	•	•		•	•
Wafer Cutting	•		•		
Wafer marking	•			•	
Diffusion*	•		•		
Stringers/soldering			•		
Grooving	•			•	•
Buried contacts	•			•	•
Surface Texturing*	•			•	•
Thin film PV cells					
P1,P2 and P3 contacts	•		•	•	•
Edge Isolation		•			

* Future potential processes currently under development

Benefits of Fiber Lasers

- Maintenance free
- High power
- Wall plug efficiency >30%
- No Optics alignment or replacements (no flash lamps)
- Totally monolithic
- Diode life (MTBF) > 200,000 hrs
- Compact footprint/mobile and low weight
- Long working distance to work surface
- Low cooling requirements
- Optional delivery fiber options; e.g., multiporting
- Suited for many applications such as cutting, welding, drilling, bending, marking etc.
- Same laser can perform multiple functions
- Low cost of ownership

Selecting the best laser for the application

Interactions between laser beam and absorption by materials are quite well understood with the efficiency of absorption relating to the value of laser light power (energy) density and wavelength on the work piece. Because lasers can be managed to offer differing power densities, they are useful in a wide variety of applications covering heating, melting, boiling to vaporization. Selecting the most effective laser candidate is crucial for achieving the desired results. For example, many users observe applications work being done in the 10-micron IR range when the same application can be tackled with a lower cost 1-micron IR or with a green (other visible) wavelength solution.

Working directly with a laser company that has sufficient resources to support a suitably effective applications lab testing for proof-of-concept through manufacturing process development is a good start. Within a short turnaround time and sometimes nominal to no costs, an effective laser manufacturer can easily characterize the optimum laser for the job by working on application-specific sample projects that address performance and throughput specifications; hence, removing the need for other trials (e.g. in-situ or other costly guessing activities). Generally, a fully-equipped laser vendor can support material classification data and has an acquired brain trust of experience, which results from and influenced by tackling many hundreds of applications over many years and various disciplines. When higher level resources are needed, a laser vendor should have access to additional industry professionals that specialize in ablation, welding, cutting, marking and other niche, usually more difficult, problem solving projects. Overall, when today's leading manufacturing challenges require innovative, OEM-based laser suppliers, they should be targeting those laser companies that offer customized business solutions for 1) faster time to market and product development, 2) lower cost of ownership and, most importantly 3) reduced risks.

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