PHOTOVOLTAIC

Lasers for **Best** Growth Market

Solid-State Lasers Enable Yield & Throughput Increases in Solar Manufacturing

Applications for lasers within the manufacturing of solar cells and panels has grown considerably within the past decade, as the solar industry has matured into a multi-billion dollar market segment with forecasted compound annual growth rates in excess of 40 %. However, laser solutions do not represent an exclusive technology type for cell manufacturers who can choose between laser and non-laser based equipment for their production lines. Therefore, laser adoption within the solar industry must provide specific benefits for certain manufacturing processes. This article reviews the key advantages of lasers within existing production line equipment used, and outlines important trends seen throughout the industry as a whole.

Solar panels are comprised of either silicon wafer based cells (referred to as crystalline-silicon, or c-Si) or thin-films deposited typically on large glass panels. Both work on the same principle. Sunlight is captured within an absorber material and electrical current is produced via the photovoltaic (or PV) effect. Depending on the material used for the cells, different levels of sunlight-to-electric power conversion efficiency are obtained, from around 6–10 % for thin-films to 14–20 % for c-Si types. Other differences between c-Si and thin-film relate to the raw material costs (significantly higher for silicon based cells) and manufacturing processes (c-Si panel production has a discrete 'back end' for cells and 'front end' for modules).

Today, c-Si cell production accounts for around 90 % of worldwide installations. It is widely expected that this number will drop to around 70–80 % over the next decade as emerging thin-film technologies move from pilot- to production-phase. Production expansion plans within the c-Si value-chain over the past 12 months have nonetheless been incredible; silicon foundry expansions are now factored in to satisfy industry-standard 10-year raw material contracts for almost all leading c-Si cell suppliers worldwide. As a result, c-Si should remain by far the dominant technology type over the next decade.

Within thin-film production, the main application for lasers is the so-called 'patterning' process, in which large panels are isolated and interconnected to form thin cell strips whose voltage output is subsequently added in series across the panel[1]. However, it is within c-Si cell manufacturing that the most diverse range of laser applications can be found[2]. This article focuses on one specific place within c-Si production lines where lasers are currently utilized in high-volume, namely edge isolation. An overview here of laser versus non-laser technologies reveals metrics which can be applied to other laser applications within the solar industry. Further, laser edge isolation is sufficiently mature within the solar industry that the evolution of laser types used here serves to highlight the technical challenges that underpin solar industry roadmap objectives.

Edge isolation is a process whereby the front and rear surfaces of a thin silicon wafer are electrically isolated, following a phosphorous diffusion process that dopes the p-type silicon with an n-type top layer. Technology used for this diffusion step today also covers the edges and rear surface of the cells, creating an undesirable shunt pathway which lowers the overall efficiency of the cell. Therefore, the edges need to be isolated electrically to eliminate this. Currently, edge isolation is performed either by etching (either plasma or wet-edge) or by using laser scribing. When using lasers,

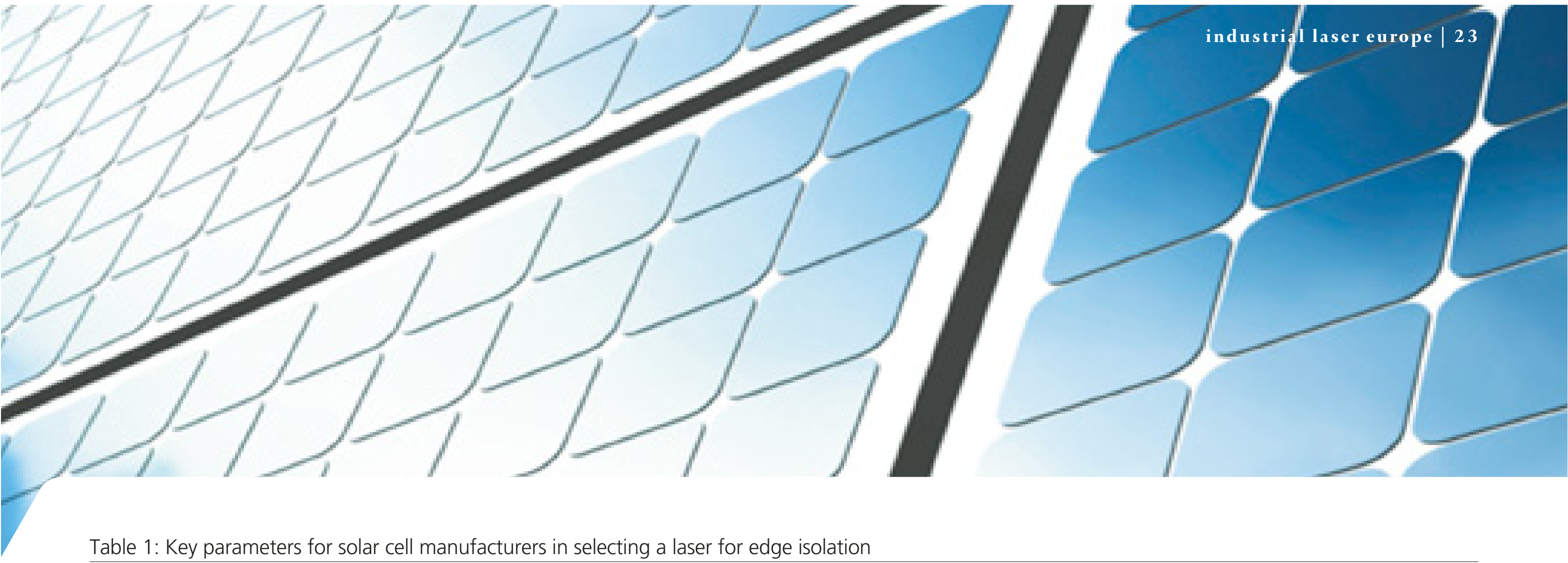


Table 1: Key parameters for solar cell manufacturers in selecting a laser for edge isolation

Laser Parameter	Benefit for Solar Cell Production	Market Trend
Dioded-Pumped Solid State	Environmentally benign 'green' manufacturing tool	Maintain the use of Q-Sw DPSS lasers
Low cost of ownership	Minimize production costs	Maintain & improve performance levels
Global service and support	Minimize downtime	Same-day response
Short pulse-width	High peak-power enables efficient material removal	Maintain performance levels
High repetition rate	Meet cycle time requirements	Maintain performance levels
Short wavelengths	Strong absorption in silicon & reduction in microcracks	Towards 355 nm
High average power	Increased throughput rates / productivity	Average powers of 30 - 40 W at 532 or 355 nm

a narrow groove is scribed around the edges of the front surface through to the lower p-type layer, isolating the front surface within the enclosed active area (*see figure 1*).

Preferred technologies used for edge isolation vary somewhat from region to region worldwide, and are also a by-product of so-called 'turn-key' production line equipment used by end-users[3]. Often, turn-key production line suppliers have a preference for one of the technologies (etching or laser), and provide an efficiency and yield specification which simply covers the entire production line, not the individual components comprising the completed line. For c-Si manufacturers who retain more flexibility through customized module build within their own production lines, the choice tends to be more open, and here, we typically see an increase in lasers chosen at this stage and, moreover, increased knowledge of the relative merits of different laser sources.

One of the key advantages of lasers versus dry or wet etching relates to an important driver today within the solar industry; installation of 'green' production line equipment at solar manufacturing sites. Bearing in mind that widespread solar adoption globally remains highly dependent on consumer acceptance and government subsidies, any suppliers using production line equipment with an 'environmentally benign' footprint stand to increase market share within a highly competitive global landscape. Lasers – and in particular diode-pumped solid-state (DPSS) lasers – represent a near-ideal production line equipment type, since they run off standard single-phase electricity, require no external plant water supply, nor do they produce any hazardous waste, the latter often a by-product of plasma and wet etch technologies.

As a newly established market segment, solar has benefited overnight from the immediate availability of DPSS lasers previously developed for applications within more mature markets such as microelectronics. Therefore, DPSS lasers have become the laser type by default straight away, and comparisons of DPSS lasers with older laser types (e.g. gas or flash-lamp-pumped solid-state lasers) are not even considered by cell manufacturers. In principle, edge isolation can be performed with many different pulsed DPSS laser types, a fact which drove many early adopters of lasers for this application to start with low-cost and low-power Nd-based systems operating at their fundamental wavelength of 1064 nm. Early tools also suffered from the teething problems typical of new capital equipment and processes, when first introduced to a high-volume manufacturing environment.

Recently though, there has been a tendency to retrofit existing production equipment using DPSS lasers operating at 1064 nm with shorter wavelength second and third harmonic variants. This is neither completely unexpected nor surprising. Crystalline-silicon is known to have significantly stronger absorption characteristics at both 532 and 355 nm, when compared to 1064 nm. Stronger absorption results

in shorter penetration depths on the surface of the wafers, and more precise and localized material removal. Consequently, many new edge isolation tools using lasers offered by suppliers are now based upon DPSS lasers operating at either 532 or 355 nm.

The push to move wavelength selection from the infra-red to the green and ultra-violet regions has come directly from solar cell manufacturers. Their motives to implement new production lines with higher-cost, short-wavelength DPSS lasers do not derive from any aesthetic benefits of 'cleaner' looking front-surface scribing. Their reasons stem from concern regarding the risk of 'microcracks'; one of the most problematic defects known within solar cell manufacturing. Any microcrack within the bulk silicon material can render the cell inoperative, if, subsequently, any stress is applied to the cell. Stress on cells can come at several different points; wafer handling during the remaining back-end production line stages, during the front-end module assembly, during final panel installation, or even due to adverse weather conditions such as high winds or heavy rainfall. Now, remember that the industry-standard warranty-period for solar panels is no less than 25 years! Put simply, short wavelength lasers used for edge isolation provide decreased risk of microcracks and therefore allow higher yield rates to be obtained. As a result, the higher capital cost compared to long-wavelength lasers is justified many times over.

Another productivity-driven trend within laser edge isolation is the average power level used. Power means scribing speed, which in turn drives wafer throughput rates. The main concern here is that the laser tool should not be a limiting factor in the overall throughput of the production line, nor should it be equipped with over-specified equipment optimized for faster process speeds than can be used! As the typical capacity of a c-Si production line has grown in recent years from ~15–20 MW to ~25–40 MW, the laser average powers have similarly increased from around 10 W to 40 W also.

The remaining specifications for DPSS lasers used in edge isolation are operational features: TEM$_{00}$ output profile with typical M^2 values of around 1.1 and fast repetition rates up to 100 kHz. Short-pulse operation from optimized nanosecond Q-Switched lasers is ideal for the scribing process. Sub-ns pulse-width lasers have not been considered to date for laser edge isolation; any possible benefits from machining with sub-ns pulse-widths are outweighed considerably when comparing to a Q-Switched DPSS laser system's price, cost-of-ownership, and industry-proven heritage. Indeed, since solar production operates 24/7, it is obligatory that only industry-qualified DPSS lasers are used for edge isolation, and that a global service and support network is available to allow routine service checks, thereby ensuring scheduled downtime for no more than a few hours at any time. An overview of laser parameters of most value to solar cell manufacturers is given in *Table 1*.

Industrial-qualified AVIA™ lasers from Coherent have been at the forefront of this recent shift in laser optimization for edge isolation. Market demands, driven by rapid capacity expansions, have been met by high power levels (38 W at 532 nm; 23 W at 355 nm). With an established track-record supporting microelectronics manufacturing and a large installed base globally, the requisite field service and support network for such industrial laser is already in place. This explains in part the popularity of AVIA™ lasers for laser edge isolation with solar manufacturers, and the rate at which so many end-users have moved from design phase to full production. *Figure 3* shows the AVIA™ laser.

As the solar industry matures and adopts other laser processes in different production process steps, it is expected that solar – not microelectronics – will drive the development of new turn-key industrial lasers specific to these requirements. This will, in turn, enable traditional market segments to exploit new laser products not currently available to them. At that time, the solar industry will no longer be using lasers developed to meet application requirements in other industries, but will have become the dominant force driving strategy for R&D expenditure within some of the leading worldwide laser manufacturers.

Fig. 1: Schematic illustration of laser edge isolation on a c-Si solar cell

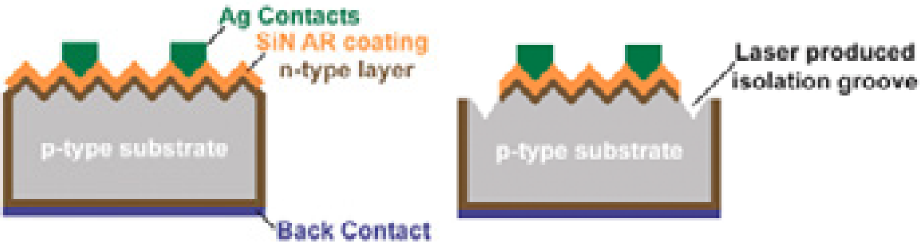


Fig. 2: Laser scribed isolation groove on the front surface of a solar cell

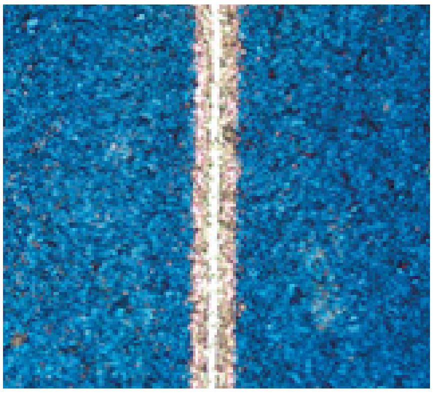
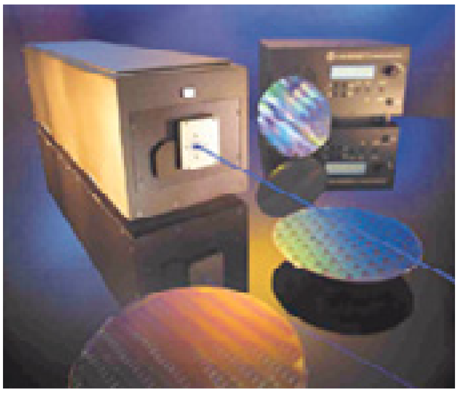


Fig. 3: AVIA™ Q-Switched DPSS lasers are driving edge isolation productivity enhancements



Sources

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[2] C. Dunsky, "Lasers in the solar energy revolution," Industrial Laser Solutions, Vol. 22, No. 8, August 2007, pp 24–27

[3] O. Papathanasiou, "Wafer etching facts and trends," Photon International, December 2007, pp 128–139

Finlay Colville & Corey Dunsky • Coherent Inc.

Interview with Finlay Colville

Good Reason for Optimism

Coherent has a policy of specifically targeting lucrative market niches – something that in itself is not new. Impressive, however, is the sense of purpose that the company demonstrates when they set their sights on specific global opportunities: for the past few years, one of the areas of primary focus has been photovoltaics. A market-focused team was set up at the US headquarters and Dr. Finlay Colville (Coherent Inc.) has been appointed as Director of Marketing to exclusively concentrate on this area. During a short stop in Munich we had the chance to talk to him about the potential of this market .

Mr. Colville, solar cell production has been inspiring the laser industry to make very optimistic growth forecasts. Is this optimism founded?

Most certainly! This is an industry that has been outperforming its own predictions for a number of years now, as well as being an industry that relies on the laser for various production processes. On top of this, there are a number of other laser processes that will likely find their way into solar cell factories in the near future – thereby promising us even more potential.

But present there are only two laser processes that are actually being used?

When we talk about markets and growth rates in the photovoltaic industry, it is important to differentiate between two technologies that, in turn, come up with different growth rates, technological approaches and laser applications: on one hand, crystalline-silicon (c-Si) cells and on the other hand, thin-film panels. In both cases, lasers are currently being used during one step of each production process.

Which technology is the most interesting from a laser manufacturer's viewpoint?

90 % of the solar panels being produced today are c-Si cells. This means that the priorities speak for themselves. Both technologies are growing, both offer interesting laser applications – but the biggest potential is obviously with the crystalline cells. And this is where you will find one of the largest applications for lasers today – edge isolation.

But isn't this is an application where a laser is frequently not used?

That's partly correct: when the first people started production they didn't use a laser by default for this step. They carried out the isolation mainly with plasma-etching or sometimes with wet-chemical processes. But even these cell manufacturers are more and more asking themselves which direction their production should take in the future, which process is more efficient and which best meets the demands of solar cell production – the arguments are very quickly on the side of the laser.

You mentioned that edge isolation is at present the one really big application. How big is the market – what numbers are we talking about?

There are no market reports specific to laser use within the solar industry, but at the moment we are talking about several 10's to around a hundred lasers per year – so it's not yet an industry that's demanding thousands of lasers. In fact, often only one laser is utilised for each production line. A high-volume c-Si cell manufacturer operating a 300-MW fab, has to have about 10 or 12 production lines – in other words, 10 or 12 lasers.

Nevertheless, it is expected that a few hundred lasers per year are going to be needed ...

This would be the case if only half of the production lines that are working with conventional methods re-tool with lasers. But the biggest push is sure to come from the enormous growth potential of the solar cell industry – we're talking here about a growth of 30–40 % per year. This means that we are dealing with an extremely dynamic market that only has one constant – that it is considerably surpassing its own growth forecasts during the past few years. On top of this, there are other steps in the production line that are going to start using the laser. I can foresee at least eight to ten other potential laser applications at pilot or research phase, some of which will mature into the production lines for crystalline solar cells in the next 5 years.

How far advanced are these processes? Can you already find them in production lines?

At present, only in isolated cases. As I've already said: the one big market is edge isolation for c-Si cell production. All the other things are more or less at the R&D stage. Even so – very soon two or three lasers per production line are going to be the norm. There is, however, one big technologically justified reason for the growth potential of lasers in the production of crystalline cells:

There is a significant trend in the industry towards thinner Si wafers. The raw material is at present one of the largest cost factors in the production of crystalline cells. At the moment we are talking about 200 µm and in five years the industry hopes to be down to 100 µm, this means halving the silicon cost and reducing considerably the total raw material costs. Dollars per Watt – this is the dominant force behind innovation in this industry, too. Thinner wafers, nevertheless, also mean more difficult handling and higher breakage rates. This is where contact-free laser processes have an inherent advantage, particularly when shorter wavelengths in the UV with shorter penetration depths in silicon can be used to produce better-defined edges with fewer microcracks.

Mr. Colville, we have already talked about the number of laser units that are needed. Would you risk a prognosis for the next five years? And will crystalline cells continue to dominate?

Combining c-Si and Thin-Film, it is sure to grow to a few thousand. The markets continue to grow and we will see a number of new processes in the production of solar cells – for crystalline cells as well as for thin-film cells. Crystalline cells will continue to represent the major part, even if the thin-film proportion will probably grow to about 15 %.