Manufacturing c-Si Solar Cells with Lasers

Choosing the right tool for the job

Solutions to **Make, Manage and Measure Light**℠

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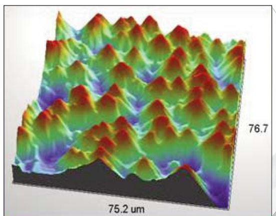
The Potential for c-Si Solar Cells

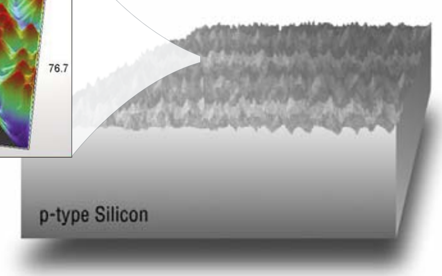
The benefits and promise of clean, renewable solar energy are apparent to all. On a clear day, the sun provides nearly 1 kilowatt of energy per square meter on the earth's surface. The earth's surface absorbs more energy in an hour that the world uses in a year. Each step towards less expensive, more efficient ways of harnessing this energy using readily available materials represents exciting progress.

This document covers a few of the applications where lasers can be used during the fabrication of crystalline silicon (c-Si) solar cells.

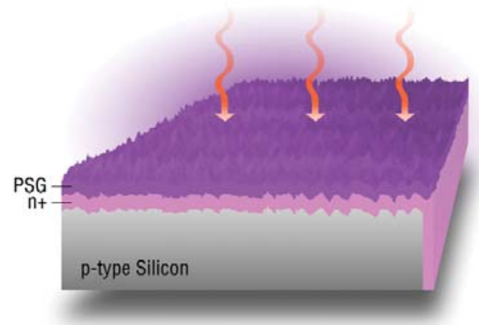
Overview of Traditional c-Si Solar Cell Manufacturing Processes without Lasers



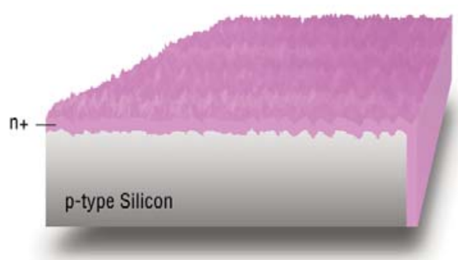
Typical surface finish of c-Si wafer after acid texturing step. Image courtesy of Veeco Instruments.



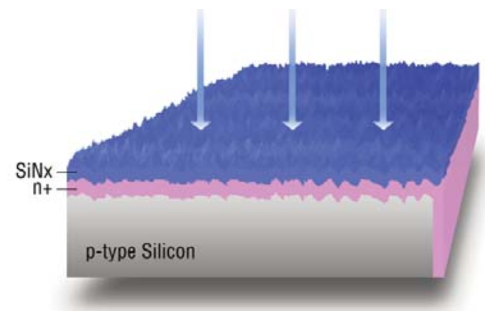
Step 1: Acid etch to remove saw marks and texture to improve absorption.



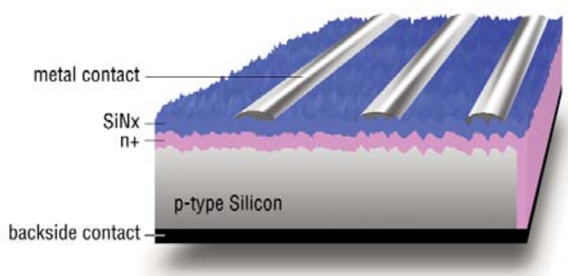
Step 2: Thermal diffusion of phosphorus doping – wafers are heated in a furnace with $POCl_3$ gas to create the n+ emitter via diffusion.



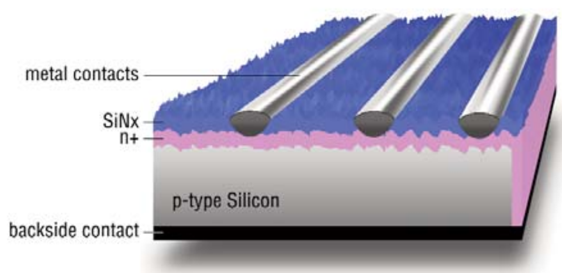
Step 3: The hydrofluoric (HF) acid etch process removes the unwanted layer of phosphor silicate glass (PSG) produced during the diffusion step.



Step 4: PECVD of an anti-reflection (AR) thin film dielectric coating of Silicon Nitride (SiNx) or alternatively oxidation to form a SiO_2 AR layer on the front surface to further improve light absorption.



Step 5: This step shows the addition of screen printed metal paste that, once fired, forms the busbars and finger gridlines of the front surface contacts.



Step 6: Heating or "firing" of screen printed metal paste gridlines results in the lines melting through the thin insulating layer of SiNx, to effectively make electrical contact with the underlying silicon layer, in this case the n+ emitter.

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Laser-Based Manufacturing Processes on c-Si Solar Cells

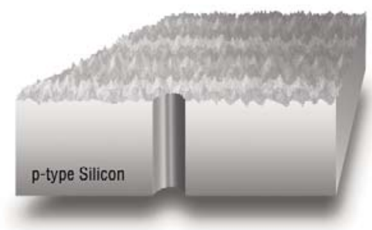
The use of lasers in making photovoltaic devices can both improve cell efficiencies and reduce overall manufacturing costs through faster processing time and improved yields. Below is a discussion of several key laser applications in c-Si solar cell manufacturing.

Metal Wrap Through (MWT) Laser Drilling

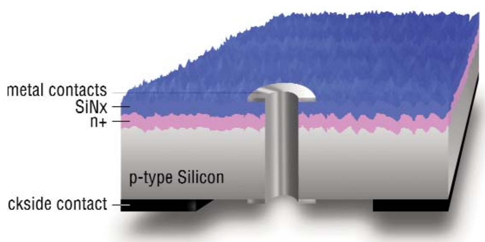
MWT laser drilling technology is a process developed to replace the busbars on the front side of the solar cell with via holes that connect the fingers on the front side to contacts on the back side of the cell. This allows both positive and negative polarity contacts on the back side of the solar cell. Advantages of MWT laser drilling include:

- Eliminates a front-to-backside interconnection
- Boosts cell efficiency by eliminating the shading losses associated with front side busbars
- Allows for higher fill factors
- Improves cell interconnection within modules
- Improves aesthetics of cell

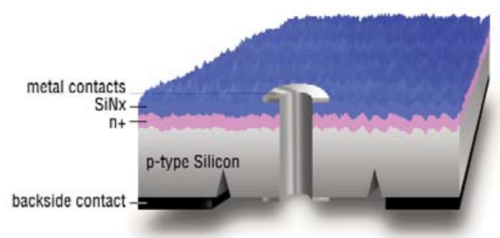
In addition to drilling the silicon wafer, lasers are also used for rear contact isolation where a thin gap is scribed between the N and P contacts at the base of the MWT via connection.



Step 1: Via holes are drilled through the silicon wafer prior to thermal diffusion of the phosphorus doping.

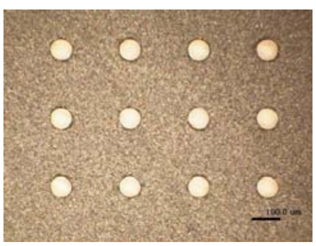


Step 2: During the "firing" step, metal paste is melted to plate the inner sleeve of the via holes. Hence the name metal wrap through (MWT).



Step 3: The wafer is laser scribed in order to electrically isolate the solar cell.

Emitter Wrap Through (EWT) Laser Drilling



200 µm thick c-Si wafer drilled with 50-60 µm diameter.

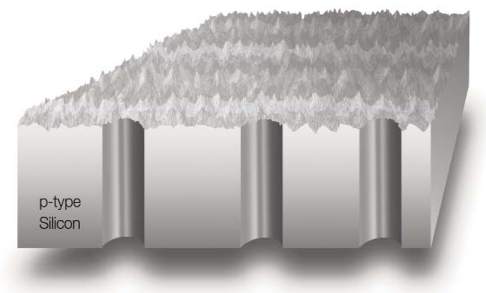
Similar to Metal Wrap Through, with an Emitter Wrap Through (EWT) solar cell, the laser is used to drill via holes to conduct electricity from the front to the back sides of the wafer. Rather than metal plating the via holes, these laser drilled holes are then diffused with phosphorus during the gas phase thermal diffusion process. The inner surface of the via holes are then treated to create a higher concentration of dopant in order to improve conductivity.

The EWT solar cell is a back-contact cell, meaning that both the positive and negative contacts are located on the back side of the cell, as opposed to opposite sides of the cell with a traditional solar cell.

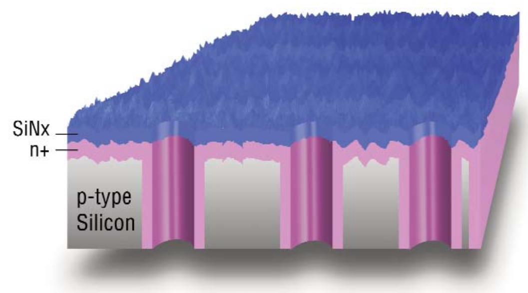
The EWT process allows the elimination of the entire front side metal grid, while keeping the front of the wafer as an emitter to maintain the high efficiency collection and conversion of solar energy. The laser-drilled and doped vias then "wrap" the emitter on the front surface through to the back side contacts.

The advantages of EWT laser drilling are:

- Eliminates a front-to-backside interconnection
- Boosts cell efficiency by eliminating the shading losses and series resistance associated with front side grid
- Back-contact cells are easier to interconnect within the module
- Improved aesthetics of solar cell by the removal of the front side fingers and busbars



Step 1: Via holes are drilled through the silicon wafer prior to thermal diffusion of the phosphorus doping.

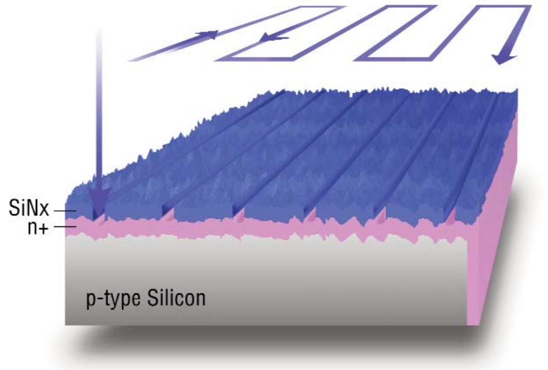


Step 2: The wafer goes through a gas phase diffusion step to create the n+ emitter. The via holes function to "wrap" the emitter through (EWT) to the rear surface so that both the front side grid and front-to-back interconnections can be eliminated.

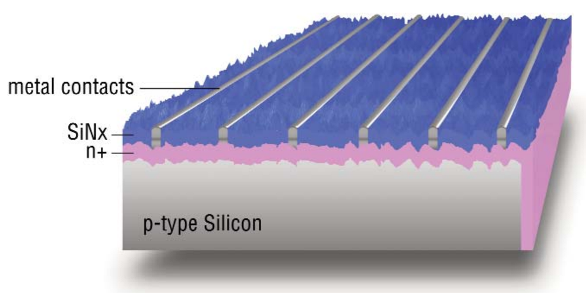
Laser Ablation of ARC Layer

A simple but effective variation on traditional contact screen printing of the fingers and busbars is to first scribe the grid pattern in order to selectively remove the silicon nitride anti-reflective coating (ARC) layer prior to adding paste and furnace firing. Advantages of this step include:

- Simple and fast, non-contact process that can be easily incorporated into existing production lines
- Removes the "dead" ARC layer to allow a direct metal-silicon junction
- Further lowers contact resistance and reduces emitter resistive losses, to improve overall cell efficiency



Step 1: After deposition of the ARC layer, the laser is scanned over the front surface and selectively ablates the ARC layer in the pattern of the front side grid.



Step 2: The cells are screen printed and furnace fired to complete the fingers and busbars, which bond directly with the n+ layer for better electrical contact.

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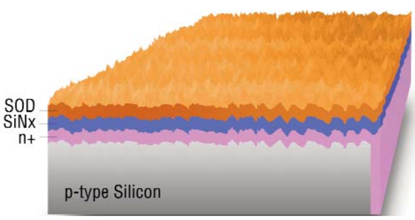
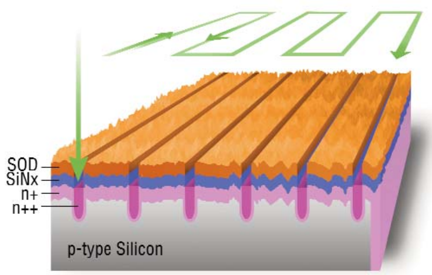
Laser Doping of Selective Emitter (LDSE)

The LDSE process was developed by the University of New South Wales to improve the front side contact formation. This involves adding an n-type dopant to the wafer and then using a laser to both ablate the ARC layer and drive the dopant into the underlying silicon to create a shallow, highly doped n++ emitter region. Advantages include:

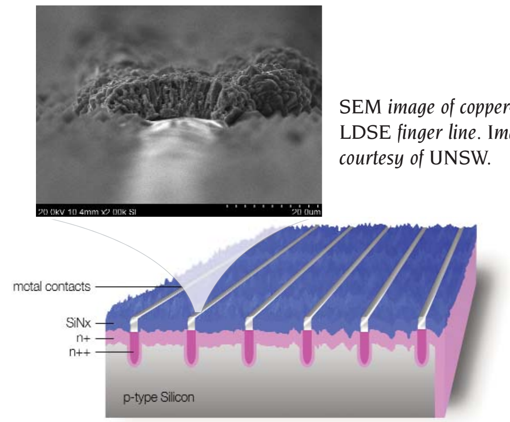
- Significantly improved overall cell efficiency versus standard screen-printed solar cells
- Narrower scribe lines and fingers mean less shading loss and higher fill factor
- More closely spaced lines reduces power loss in the emitter
- Shallow, localized n++ junction results in higher short circuit current density (Jsc) for the cell
- Reduced heavily doped emitter volume reduces the power loss in the emitter
- Improved metal-silicon contact translates to improved efficiency through reduced contact resistance
- Localized heating with the laser means fewer furnace steps required, and lower grade wafers can be used



Step 1: After ARC deposition, a thin phosphorous coating is applied to the wafer front side.



Step 2: The laser is scanned over the wafer and simultaneously ablates the ARC and melts the silicon to allow phosphorous diffusion.



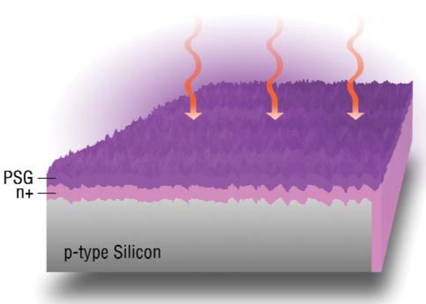
SEM *image of copper-plated* LDSE *finger line. Image courtesy of* UNSW.

Step 3: The dopant is removed and the cell is electroplated to create self-aligned fingers and busbars.

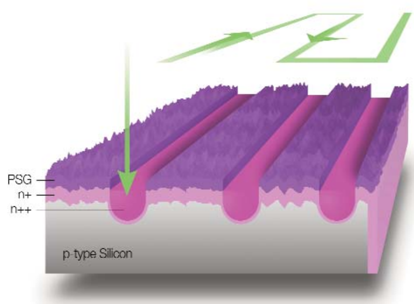
Laser Doping of Emitter Using PSG as Doping Precursor

The University of Stuttgart IPE process was developed to form highly doped regions under the fingers and busbars to create selective emitters. This process uses a laser to melt the phosphor silicate glass (PSG) layer which is formed during the furnace diffusion process. Phosphorus then diffuses into the silicon below to form the n++ emitter. Advantages of this approach are:

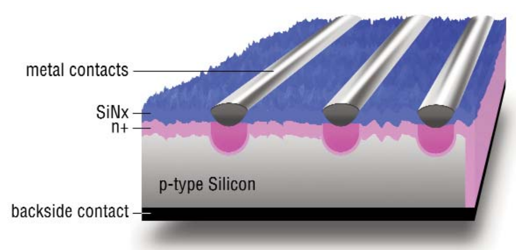
- Simple process for boosting cell efficiency through the local formation of selective emitters
- By using the existing PSG layer as a doping precursor, this process eliminates an additional step of adding dopant to the wafer



Step 1: During the thermal diffusion process, a layer of phosphor silicate glass (PSG) is formed.



Step 2: The laser is scanned over and melts the PSG. The phosphorous combines with the melted silicon, increasing the doping concentration.

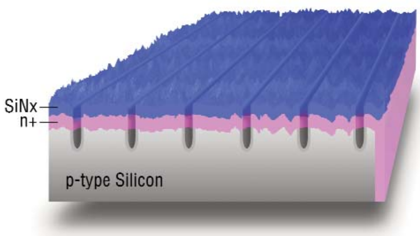


Step 3: The cells are screen printed and furnace fired to complete the fingers and busbars.

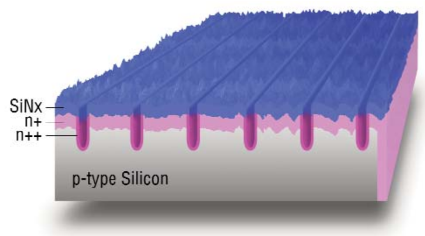
Laser Grooved Buried Contacts (LGBC)

The process of Laser Grooved Buried Contacts was developed to reduce shadowing effects and increase the active surface area of a c-Si solar cell by effectively turning the busbars on their side. Advantages of the LGBC process include:

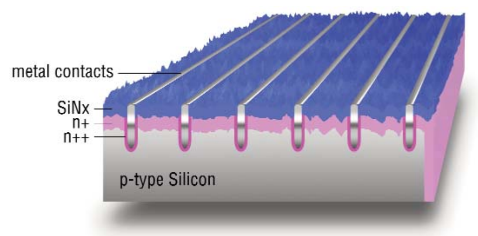
- The relatively deep and narrow trench gives a good contact area while only occupying a small surface area on the face of the cell, thus reducing shadowing effects and increasing the active surface area of the cell.
- With LGBC, the formation of a nickel silicide at the semiconductor-metal interface and the large metal-silicon contact area lowers the overall grid resistance which contributes to higher cell efficiency. Typically copper is used for LGBC, which further lowers grid resistance as copper is a better conductor than many of the metal pastes used in traditional screen printing.
- As with the selective emitter doping process, by removing the “dead” ARC layer at the surface of the solar cell, and by doping the contact surface between the metal-silicon junction, the conductivity of the LGBCs is improved and finger spacing can be reduced without a large effect on shading. This further lowers contact resistance and reduces emitter resistive losses.



Step 1: After the deposition of the ARC layer, a deep groove is laser scribed into the silicon.



Step 2: After scribing, the walls of these grooves are heavily doped, forming n++ type groove walls.

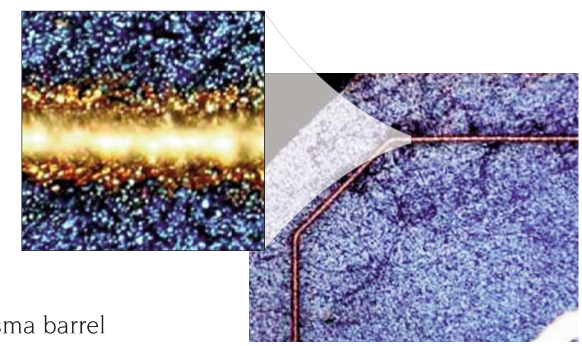


Step 3: The grooves are filled with plated metal contacts (vertical busbars) then screen printed (fingers) and furnace fired to complete the front side grid.

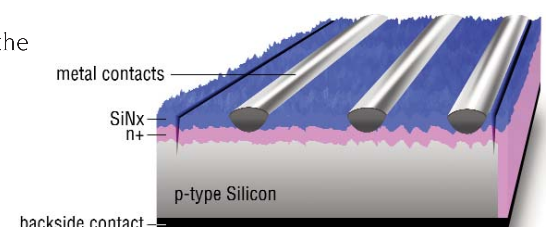
Laser Edge Isolation

During the gas phase thermal diffusion of phosphorus dopant, the p-doped wafers are coated with an outer layer of n-doped silicon to form the P-N junction which generates the flow of electrons. The challenge is that this thin layer of dopant coats the entire wafer and can bridge the front and rear surfaces of the cell. Thus the cell edges need to be trimmed to conductively isolate the back of the cell from the front. While there are a number of technologies to accomplish this task such as mechanical scribing, water jet, chemical etching, and plasma barrel etching, Laser Edge Isolation has the advantages of:

- High speed processing speeds which translates to faster throughput
- Non-contact process which means increased yield through reduced panel breakage
- Narrow scribe grooves as close to the edge as possible maximizes the cell active area and thus efficiency
- Low cost of operation
- High repeatability
- Low environmental impact, no disposal of silicon waste
- In-line process (versus batch)
- No post-process rinsing/drying



Crystalline silicon solar cell edge isolation (with close up view) using a Pulseo 355 nm DPSS Q-switched laser. 20 µm scribe width and 10 µm scribe depth.



After the screen printing and furnace firing steps, cell edges are laser scribed to electrically isolate the back of the cell from the front.

Key Photovoltaic Market Laser Requirements

- Reliability and system uptime
- Turnkey laser sources optimized for c-Si solar cell manufacturing
- Global service and support network
- Short pulse width and high peak power for cleaner processing and minimal damage to solar cells
- High beam quality for smaller diameter holes and narrower scribe lines
- Variety of wavelengths to choose the best tool for the job
- Short trigger delay to maximize throughput in multi-positioning drilling applications
- Laser supplier with experience and strong applications development and support capabilities

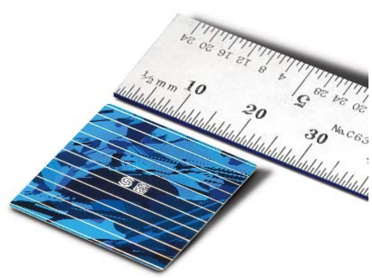
Laser Fired Contacts

Thinner wafers often have a thin nitride or oxide passivation layer coating the silicon on the rear side of the wafer. The problem is that this layer is non-conductive.

Laser Fired Contacts refers to a process developed by Fraunhofer ISE of irradiating the rear side aluminum electrode, such that it heats up and melts through this passivation layer to bond with the silicon layer below, creating a localized Al/Si alloy.

Laser Marking

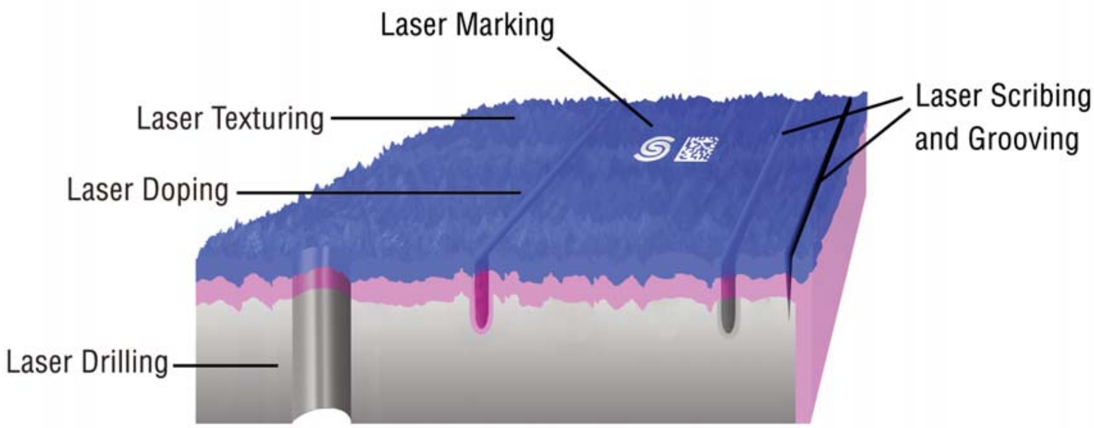
Human readable characters can be made less than 75 μm in size with line widths of 10 μm. Using a machine readable data matrix, large amounts of wafer-specific or test data can be coded into a very small space on the wafer for unique identification and cradle-to-grave product traceability over the life of the solar cell. Semi-transparent manufacturer's logos and logo outlines are also popular for product branding.



Laser marking wafers is popular for product traceability and product branding.

Choosing the Right Tool

The laser processes described on the previous pages are just a few examples of the many ways lasers can be used in the fabrication of c-Si solar cells, both for more consistent processing and for improved cell efficiency. Most applications can be categorized into just a few basic micromachining processes; drilling, texturing, doping, scribing, and marking. Spectra-Physics has a strong history of leadership and innovation in tools for micromachining silicon, both in the semiconductor and photovoltaic industries. Whatever your application, chances are we've got the perfect tool.



Laser Drilling

The Pulseo® short-pulsed, 532 nm and 355 nm DPSS Q-switched lasers are the perfect choice for laser drilling applications. The Pulseo lasers' high peak power and excellent absorption of these wavelengths by silicon means:

- Smaller hole diameters, which translate to a higher active cell area
- Higher yield through less collateral damage to the surrounding wafer, including less micro-cracking, little to no silicon melt (shunt risk), and a smaller heat affected zone

Laser Doping

For laser doping applications using an added dopant (LDSE), the Millennia® Prime™ family of lasers is the ideal choice, offering high throughput and high uptime at an excellent cost per watt.

For laser doping applications using PSG as a doping precursor (IPE), the Pulseo family of lasers offers the highest peak power available. This ensures high throughput and low thermal damage to the surrounding cell.

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The Spectra-Physics Laser Advantage

- **High Uptime** – through superior product reliability, design, and support.
- **Diode Life** – double the industry average.
- **Support** – Global service and support network servicing large installed base.
- **Proven** – for 24/7 industrial use with an installed base of thousands of lasers.
- **Short Pulse Width** – means higher peak energy, and less heat affected zone.
- **Excellent Beam Quality** – for narrow scribe lines.
- **Better Pulse-to-Pulse Energy Stability** – translates to more precise scribe depth control.
- **Experience** – state-of-the-art industrial laser applications lab and our ability to accelerate the learning curve for laser scribing with your existing materials and processes.

Wafer Scribing

For the wide variety of crystalline silicon manufacturing processes that require scribing the front or back side of the cell (LGBC, ablating the ARC layer, edge isolation, and wafer scribing and break), the HIPPO™ and Pulseo laser families are ideal. Short wavelengths mean smaller feature sizes and better absorption of the laser energy within the dielectric layers for maximum efficacy. This translates to:

- Thinner scribe lines
- Less shadowing losses
- Higher active cell area
- Higher cell efficiency

The short pulse widths of the HIPPO and Pulseo lasers mean high peak power and better vaporization of ablated material, which translates to:

- Cleaner scribe lines
- Less material displacement and lower kerf height
- Less micro-cracking and lower thermal damage for improved cell integrity
- Scribe lines that are closer to the edge of the cell, to further maximize the cell active area

Wafer Marking

Compact, rugged, and cost effective, the Explorer® laser series is ideal for wafer marking. The Explorer laser has excellent pulse-to-pulse stability for consistent, high quality “soft” marking of silicon wafers, without inadvertently ablating excess material and damaging the cell.

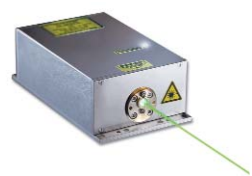
Laser Selection Guide

The table below summarizes key laser applications for c-Si solar cell manufacturing and the correct laser to use for each.

	Pulseo	HIPPO	Explorer	Millennia
	Q-switched 10–34 W, 100–120 kHz 532 nm, 355 nm	Q-switched 5–27 W, 50–100 kHz 1064 nm, 532 nm, 355 nm	Q-switched 2 W, 50 kHz 532 nm	CW 6–15 W 532 nm
Metal Wrap Through (MWT) Laser Drilling	✔			
Laser Doping of Emitter Using PSG as Doping Precursor	✔			
Laser Groove Buried Contacts (LGBC)	✔	✔		
Laser Doping of Selective Emitter (LDSE)	✔			✔
Laser Scribing of Silicon Nitride	✔	✔		
Emitter Wrap Through (EWT) Laser Drilling	✔			
Laser Fired Contacts		✔		
Laser Edge Isolation	✔	✔		
Laser Defect/Shunt Repair	✔	✔		
Laser Marking			✔	

Pulseo® High Power Q-Switched Lasers

HIPPO™ Mid Power Q-Switched Lasers



Explorer® Compact Q-Switched Lasers

Millennia® Prime™ High Power CW Lasers

An Overview of Spectra-Physics

Spectra-Physics has long been recognized as the laser technology leader – serving customers in over 70 countries around the world. Founded in 1961 and headquartered in Santa Clara, CA, Spectra-Physics designs, develops and manufactures premier lasers and laser systems for a variety of commercial and industrial markets, including photovoltaic solar cell manufacturing.

Overall, the advantages of using lasers for manufacturing crystalline silicon solar cells are clear, but the challenge comes in the variety of materials, thicknesses, speeds of each application. Spectra-Physics offers a wide range of tools for laser drilling, doping, scribing, dicing and marking of crystalline silicon solar cells and has long been an industry leader for innovative lasers such as the Pulseo®, Explorer®, HIPPO™ and Millennia® lasers. These families of industrial lasers have a proven track record and installed base around the world. In addition to being able to offer the right tool for the right job, Spectra-Physics also has the depth of applications knowledge and experience to help maximize the efficiency of your process.

Experience and innovation allow Newport's Spectra-Physics lasers to stand out from the competition. Our diode pump modules are the industry leaders, allowing for twice the lifespan of diodes used in competitive lasers. Another key differentiator is the laser solid base and EternAlign™ optical mounting technology. This proprietary technology ensures stable optical alignment over the life of the laser. Setting our industrial lasers apart is our unique approach to harmonic conversion. Other key laser components such as diodes, fibers, shutter and output window are all easy to replace in the field, thus lowering inventory, shortening mean time to repair and increasing uptime. And, each of our lasers comes with the confidence to know you have Newport's proven global service and support team, if and when you need them.

At Newport we are dedicated to providing the solutions that help our customers change the world. For more information on Newport products and solutions, please call us or visit www.newport.com/qsl.

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