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Industrial PERC Solar Cell Processing with a High Power Nanosecond Pulsed Laser

Crystalline-silicon (c-Si) solar cells continue to be a leader amongst the various competing solar cell technologies. The reasons for this include a stable supply of silicon, well-developed manufacturing processes, and, of course, the high and increasing conversion efficiencies that can be achieved. Here, we report on a relatively straightforward, laser-based manufacturing process for Passivated Emitter Rear Cell or Contact (PERC) technology that has been shown to generate absolute cell efficiency gains of a percentage point or more over conventional cells.

In a conventional solar cell, there is an aluminum metallization layer that makes contact across the full area of the back of the cell. PERC technology involves creating a dielectric passivation layer on the rear side of the cell with openings to allow electrical contact to the metallization layer. PERC cells have higher efficiency over conventional cells for a few reasons:

1. The passivation layer significantly reduces electron recombination near the back of the cell, where the electrons would otherwise experience a strong attraction to the aluminum metallization layer. Hence more electrons reach the front-surface emitter and current density is increased.
2. The passivation layer enhances the cell's ability to capture light—particularly at longer wavelengths—by reflecting back through the cell for a second pass any light that has reached the rear without being absorbed and generating electrons. In this way, the absorbing length of the cell is effectively doubled and current density is further improved.
3. The passivation layer reduces heating of the backside metallization layer by reflecting out of the cell infrared light that is not absorbed by the silicon ($\lambda > 1{,}180$ nm) and would otherwise be absorbed by the aluminum. Cells are more efficient when operating at a lower temperature.

Figure 1 illustrates the key steps for fabrication PERC solar cells. First, the back side of the cell is coated with a special dielectric layer, typically SiO_2, Al_2O_3, SiN_x, or some combination thereof. The dielectric coating as applied is continuous, and it is therefore necessary to create openings in a subsequent process step for ohmic contact. The best way of doing this is to use a laser to ablate the dielectric film and expose the underlying silicon in the desired pattern—typically narrow linear stripes. The aluminum metallization is then applied on top of the dielectric layer. Aluminum paste is screen printed to this surface and a subsequent thermal annealing process alloys the aluminum with the laser-exposed silicon to form a good ohmic contact.

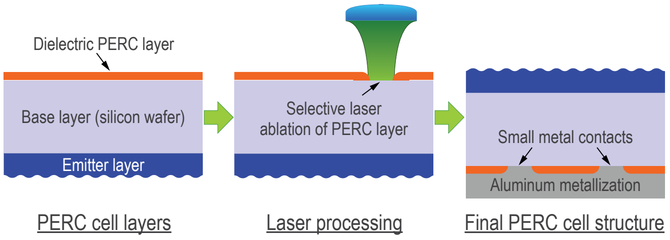

Figure 1: Illustration of manufacturing process flow for PERC cell fabrication

While PERC scribe geometries are somewhat varied, a 6" cell will typically have between 75 and 300 laser-scribed lines which are ~155 mm long, 30-80 µm wide, and evenly spaced by 0.5-2 mm. For the case of 1-mm line separation, the aggregate length of the PERC scribes on a single wafer is approximately 25 meters. Target processing rates demanded by industry can be as high as 3,600 WPH (wafers per hour), equating to a required scribing speed of 25 m/s. Fast 2-axis galvo scanners as well as spinning polygon scanners can achieve such speeds.

Industrial PERC processing also requires a laser that can keep up with such high scan speeds. For this, we have tested the Spectra-Physics Quasar® 532-75 high-power hybrid-fiber laser with TimeShift™ programmable pulse technology. The laser offers both high power and high pulse repetition frequencies (PRF) along with short pulse widths below 5 nanoseconds. For thin film removal, shorter pulse durations have been shown to be more energy efficient compared to longer pulse widths. With Quasar, the shortest pulse durations are generated at the highest operating frequencies, which is ideally suited for PERC processing. Additional benefits of short-pulse processing include less heating and reduced risk of thermal damage to the underlying silicon crystalline lattice.

When scribing materials with pulsed laser sources, an important process parameter is the spot overlap, O_p. This parameter is typically expressed as a percentage and is indicative of the relative amount by which a subsequent pulse irradiates the same material as the previous pulse. For an ablated diameter D_{abl}, a scanning speed V_s, and a laser pulse repetition frequency *PRF*, overlap O_p is calculated as:

$$O_p = 1 - \frac{V_s}{D_{abl} \times PRF}$$

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To create a sufficiently uniform edge in the dielectric opening, an overlap value of ~25% is typically chosen. With this value, and the known V_s (25 m/s) and D_{abl} (nominally 45 µm), the above equation can be rearranged to calculate the minimum *PRF* requirement for PERC processing, which comes out to be ~850 kHz.

At such high PRFs, not many lasers are capable of generating high energy pulses, but Quasar is certainly one of them. The high energy at high pulse frequencies available from Quasar is graphically illustrated in Figure 2 below. Figure 3 shows a Quasar generated PERC scribe with a slightly higher overlap condition, executed at a scribe speed of 25 m/s and a PRF of 1 MHz.

Figure 3 demonstrates clean film removal with no visual damage to the silicon, as indicated by the preservation of the fine texture in the scribed region.

In subsequent tests, we found that the Quasar laser delivers sufficient pulse energy at its maximum PRF of 1.7 MHz, which is approximately 2× the minimum requirement (850 kHz). Hence, 0.5 second per wafer throughput is possible with a single Quasar laser beam at a scribing speed of ~50 m/s .

Further throughput improvement is also possible via beam-splitting. When Quasar is operated at 850 kHz PRF corresponding to 1 wafer per second (WPS) throughput, the actual available energy is approximately 3 times the requirement. Therefore a 3-beam split can effectively triple the throughput to 3 WPS. Irrespective of the final system configuration, the Quasar laser platform and its unique TimeShift pulse-tailoring technology has the power, speed, and flexibility to meet the demands of industrial PERC solar cell manufacturing.

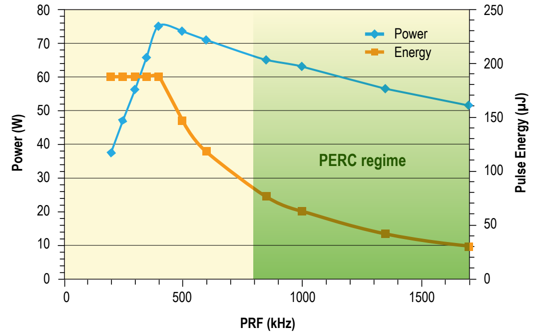

Figure 2: Pulse energy and power vs. pulse frequency for Quasar 532-75

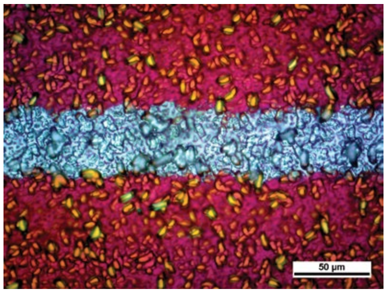

Figure 3: Quasar-ablated PERC scribe at 25 m/s speed (1 wafer per second); image courtesy of LasFocus

PRODUCTS: ***QUASAR 355-60, QUASAR 355-45, QUASAR 532-75***

The breakthrough performance of the Quasar series leads the industry with unprecedented highest UV average power and energy at high rep rate for fast micromachining. Quasar features novel TimeShift technology for programmable pulse profiles for the ultimate in process speed, flexibility, and control. The newest Quasar laser, Quasar 355-60, produces >60 W of UV output power at 200 kHz and 300 kHz, and >300 µJ pulse energy, complementing Spectra-Physics' breakthrough Quasar 355-45 laser. Quasar 355-60 operates over a wide repetition rate range from single-shot to 3.5 MHz, with pulse widths from <2 ns to >100 ns. Quasar 532-75 rounds out the Quasar series with >75 W of green output power. The Quasar family of lasers has excellent beam characteristics and very low noise.

	Quasar 355-60	Quasar 355-45	Quasar 532-75
Wavelength	355 nm	355 nm	532 nm
Power	>60 W @ 200 kHz, 10 ns >60W @ 300 kHz, 10 ns	>45 W @ 200kHz, 10 ns >45 W @ 250kHz, 10 ns >41 W @ 300kHz, 10 ns	>75 W @ 200kHz, 10 ns
Repetition Rate	0 to >3.5 MHz	0 to >1.7 MHz	
Pulse Width	<2 to >100 ns	<5 to >100 ns	

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