The eyes have it

Visual inspection tooling: Automated optical imaging is becoming a more common feature in PV cell production today. From the color sorting, right through to detailed process control, a range of optical imaging approaches and technologies are shedding the light required to deliver quality, increase average efficiencies, and enhance yield.

PV cell producers are taking a second look at visual inspection equipment. According to some key suppliers, an uptick in the application of automated optical inspection (AOI) equipment in cell production is underway. These suppliers, including Germany's Vitronic, ISRA Vision/GP Solar, and greateyes all report surging orders for AOI tooling for cell production in 2016. "The market situation is that we are really overwhelmed with the interest and orders from the Chinese companies," says Eric Rüland Managing Director ISRA Vision/GP Solar, "particularly during the last 10 – 12 months." Rüland is certainly not alone.

"We have high demand and can almost not produce enough to supply it," reports Richard Moreth, head of PV sales at Vitronic. While Moreth acknowledges that Vitronic was one of the later companies to arrive in the supply of AOI to the PV sector, he describes a transformation currently underway. Moreth says the application of AOI is increasing in terms of the number of AOI units installed on a single line, and the number of manufacturers turning to the solution to ensure quality and facilitate greater process control.

About AOI

Automated optical inspection (AOI), sometimes referred to as machine vision, involves the deployment of advanced camera equipment and an illumination source, and then associated imaging processing software and data handling hardware to carry out detailed inspection of PV products. In cell production, AOI systems are most commonly deployed at the end of the line, for color sorting as a final quality inspection point. AOI can also be deployed to monitor various cell coatings, and front and rear side metallization. With such a wide range of process steps, it should come as no surprise that the extent to which AOI is deployed varies greatly between manufacturers.

"With some major customers of mine, within one line they have one AOI system," explains Vitronic's Moreth. "While other customers, have around 14 systems per line."

Based on these two examples, a wider trend of AOI deployment is apparent. A number of equipment suppliers report that a dichotomy exists between Chinese and non-Chinese cell producers. While producers located outside of China, such as in Malaysia or Korea for Hanwha Q Cells and the Philippines for SunPower, are more likely to deploy AOI systems across a range of cell production process steps, many Chinese producers have only the single AOI inspection point at the final production stage. But here too things have changed in recent times, with AOI rapidly replacing manual end-of-line cell inspection.

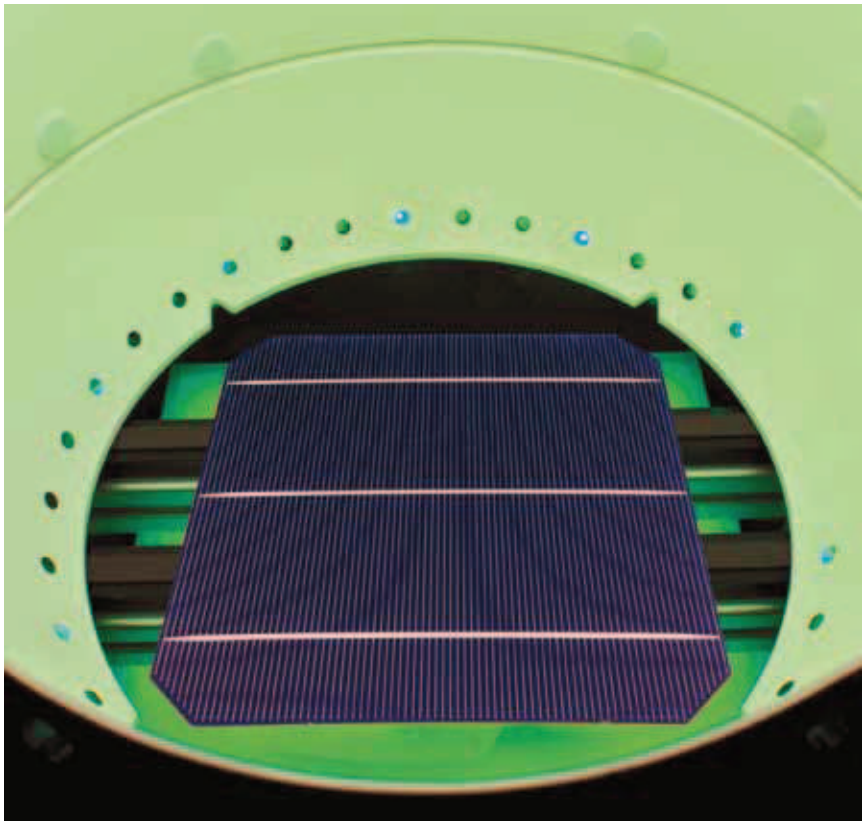
"Stability is not given if on one line there are 30 people sorting cells," says Rüland. "Everybody has a different opinion of what is a light blue, what is a problem, or if a stain is a critical problem or not. There could be variation between night and day shift, or a mainland Chinese operation and a Southeast Asian operation."

Besides quality, there is also a powerful economic driver of AOI deployment for end-of-line cell inspection. As wages grow in China and Southeast Asia, having 30 staff members across three or four shifts per line becomes expensive and a straightforward target to deliver savings through the deployment of automation.

EL and PL

Electroluminescence (EL) and photoluminescence (PL) testing are also becoming more common in cell production, although to varying degrees. Both processes can be considered a form of AOI, with the cell lighting up in EL as current and voltage are pushed through the cell and carrier recombination takes place, with PL deploying light to excite the cell for the same purpose.

Photo: Isra Vision/GP Solar



High contrast imaging can ensure cell quality, Isra Vision/GP Solar reports, while achieving a throughput of up to 4,000 cells/hour.

Photo: BT Imaging



BT Imaging's ILS C3 was released in beta in 2016. Two tools have already been shipped.

EL and PL can reveal a number of cell defects, including faults that result in recombination and resistance effects within the cell, although in varying detail. As EL testing requires a contacting of the cell, it is most commonly deployed as an additional step after IV testing.

"I think already a majority of manufacturers have an EL test in the line," says Roman Kemmler – Director Marketing and Sales at greateyes. The Berlin-based company supplies both EL and PL inspection systems and Kemmler reports that pressure on manufacturers to implement EL or PL testing has mounted as a quality assurance step. "I also think that one possibility is that demand comes from the customer to integrate cell inspection systems," says Kemmler. "The other is that the request comes from the manufacturer if they face problems with a production process or want to increase quality or make the process more stable."

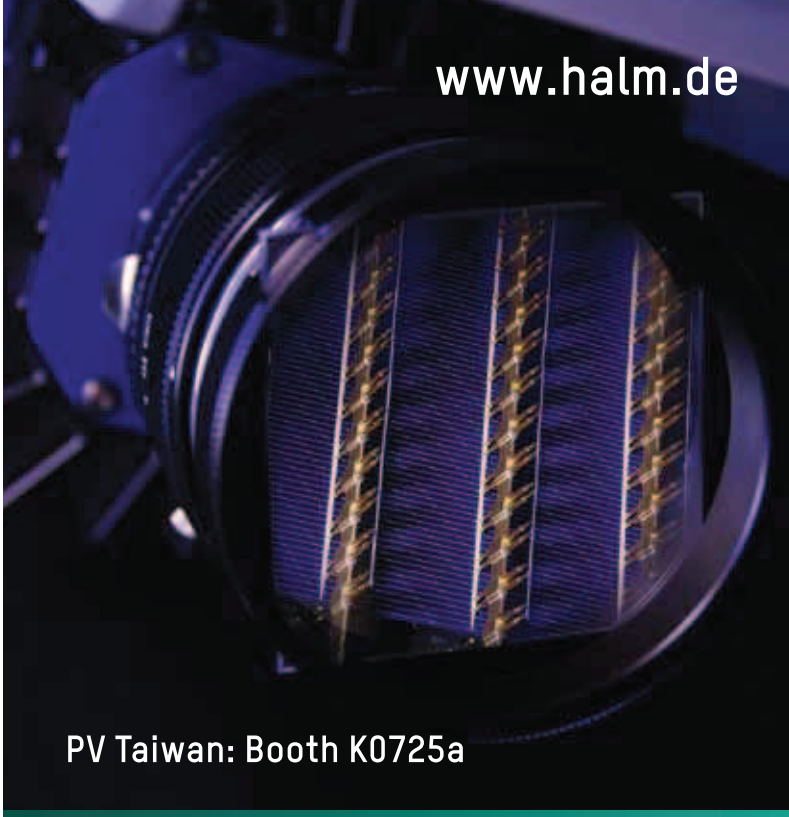
Process control

AOI without illumination can primarily be deployed in process control for incoming wafer inspection, after PECVD coating to check for deposition thickness and metallization, with the possibility of tailoring visual inspection processes to a range of manufacturer processes. By deploying AOI at these steps, manufacturers can track various production parameters and make adjustments to process controls, materials or equipment.

"When print inspection is carried out directly after printing, or if there is inspection directly after coating, then there can be warning deviation levels," explains Moreth. "But operators need to know when to exchange the screen, or change the viscosity of the paste, the pressure of the paste, or the fill of the printing. From the optical systems warning, advice is generated and then things such as temperature can be adjusted."

This, he argues, is one key to the effective deployment of AOI systems in cell production. Moreth notes that he has seen turnkey cell lines provided by suppliers, in which AOI systems were equipped as standard. However, the process feedback was either not appropriately monitored nor acted on. Moreth describes his advocacy of the importance of acting on AOI feedback as "AOI missionary work." Moreth continues that providing high reso-

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Photo: Greateyes



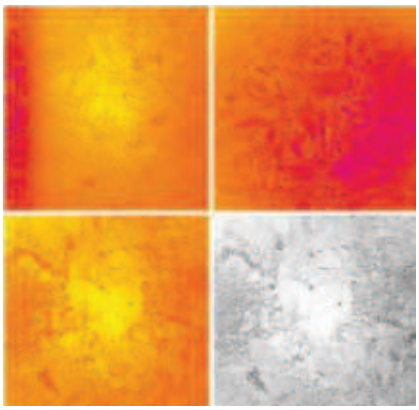
Greateyes deploys high powered LED light sources in some of its imaging tooling.

lution images and analysis software is key in delivering process information. Rüland concurs that it is not only the measurements themselves that are important, but the way that information is relayed to process operators. "What I see is that everyone wants to go to the highest level of resolution, so the customers are able to catch even the smallest defects," he says.

"We call this the Zero Defect Tolerance. A future-oriented tool developed together with equipment supplier ASYS makes it possible to monitor a complete screen printing and inspection line by wireless connection from smartphones or watches. So if there is a reading outside of process windows on the optical inspection, then the line doesn't stop but the operator can receive a message to, for example, check the screen on line three."

This kind of continuous process feedback via a streamlined messaging process can assist in eliminating errors before they occur, increasing yield. And it is yield improvement that is one of the key drivers for AOI deployment in cell production, Rüland remarked. Along with an increase in average efficiency, and an improvement in overall quality, the three factors can drive uptake of AOI.

Photo: Isra Vision/GP Solar



PL testing can result in the detection of a range of faults that do not show up in standard AOI, including EL, testing.

Higher resolution

While acknowledging that EL imaging, incorporated in the IV stage, can allow for the detection of faults not picked up by optical inspection, Rüland reports that ISRA has moved away from supplying EL testers at the cell stage. With increasing efficiencies, the addition of EL can increase the time taken to flash and test a cell, impacting throughput.

Kemmler suggests that in some instances two IV/EL testing units can be installed on one cell line to get around this, but others are more skeptical of the efficacy of the solution. Ian Maxwell, the CEO of BT Imaging from Sydney, Australia, is also skeptical.

"One of the reasons that EL imaging is deployed is that it can be incorporated into the IV tester with simply the addition of a camera," Maxwell sets out. "This provides some insights into the electrical defects within the cell. At BT Imaging, we do the same thing except that there is no contacting of the cell. One of the benefits is that the process is not slowed down."

BT deploys scanning PL testing, where an infrared LED light source scans the surface of the cell, exciting it to produce an image that reveals much greater detail than both EL and standard visual inspection. Besides the increased throughput, Maxwell suggests that this additional detail matters.

"The other reason BT Imaging moved to scanning PL testing is that with an EL image, all the defects that appear are dark compared to the background luminescence of the sample. Multi is the worst case scenario, where the recombination defects like dislocations, grain boundaries, and impure regions all show as being dark, because there is higher recombination within those zones." By contrast, with BT's scanning PL Maxwell says that print, contact or firing issues all appear as bright zones, while areas where there is recombination appear darker. "It results in a wonderful reverse contrast, which enables us to fully automate all of the defects that manufacturers worry about on the cell level."

Greateyes' Kemmler echoes the advantages of this approach, pointing to the distinct advantage that PL has in its ability to be installed, like standard AOI, at various cell production stages, because contacting is not required. Despite these advantages, it is still far from standard to see PL testing integrated into production lines, and offline PL testing is more common when faults are detected at the IV stage.

New cell concepts

The ongoing move towards various recipes for high-efficiency cells may help push the deployment of more advanced testing concepts such as PL. The production of PERC, HJT and IBC technologies can all be supported and aided with various AOI processes, including PL, and with a higher efficiency and therefore more valuable cell, the opportunity for inspection equipment providers has not gone unnoticed.

Rüland also notes that process pathways for high-efficiency concepts are narrower. "For one [high-efficiency] line we sold nine systems, and in the standard line it is sometimes just one or two systems," says Rüland. "Even if HJT or IBC is only a small share of the total market, if it is multiplied by seven or even nine, then it can be an interesting future market." Maxwell says that for PL testing, high-efficiency cells respond even more strongly, making the resulting images more detailed. "It gets easier to test higher efficiency cells because they are more efficient LEDs themselves. With new cell designs, we tweak our algorithms for that customer to account for the different types of defects that may be detected."

BT Imaging reports that it has built up an "almost complete" library of automated assessment algorithms for cell testing, based on the different cell architectures. Rüland says this sophisticated approach to software not only increases the efficacy of the testing, but also facilitates higher throughput. ISRA and Vitronic report that they have achieved throughput of 4,000 cells/hour with its AOI systems. "Our goal is never to be the bottleneck." ◆

Jonathan Gifford