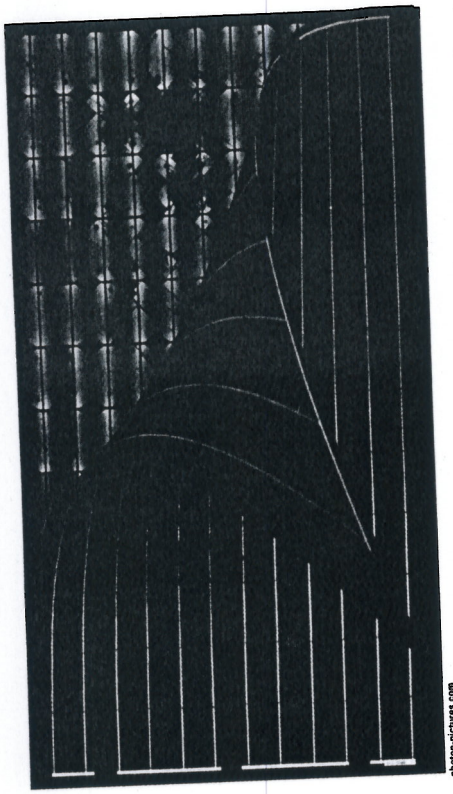
En»light«ening

Market survey on luminescence imaging systems and cameras

Text: Shravan Kumar Chunduri



▲ An x-ray of PV: Luminescence imaging, working like an x-ray for PV silicon substrates, exposes the internal and process-induced defects without damaging the measurement sample.

Highlights

- Luminescence imaging-based inspection is now available for modules installed in field
- Module measurements can be carried out day and night
- Photoluminescence systems are offered that can estimate power potential of as-cut wafers both for standard and quasi-monocrystalline substrates
- Photoluminescence systems can stop defective wafers from entering the expensive screen-printing steps
- Electroluminescence is evolving as a promising inspection process of finished cells and different stages in module making

Pity. The final official quality check that a solar module undergoes is in a factory darkroom.

But what about that newborn module's life in the real world? This infant must survive packing, transport, delivery, installation and more, all of which can conspire to change a well-documented, fully functioning panel into something less that what was expected powerwise. Be it in a solar park or on a residential roof, the underperformance of one module becomes the weakest link among its siblings, leading to a whole string of panels that is less than its parts – and a potential family tragedy for the complete system. While an installer or system owner can complain that something is killing the promised generated power, without a smoking gun, where's the visible proof? The answer may be found in luminescence – and not just in the factory.

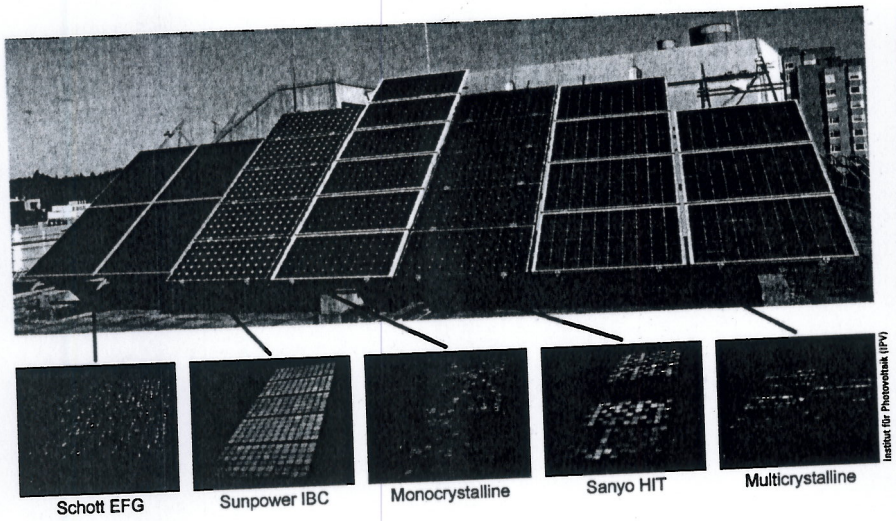
Luminescence is the response of a semiconductor substrate to external excitation. Images of defects, rather than homogeneous distribution of luminous response, caught by cameras in low light, are signs that spell trouble for power performance. Photoluminescence (PL), a non-contact examination of as-cut and semi-processed wafers excited by an external light source, is used to make unwelcome microcracks, as well as, bulk and process induced defects visible at the early production stage. For cells and modules, the detective work is carried out via electroluminescence (EL), where a substrate is electrically biased via contacts to uncover the truth of what lies below the surface. Like X-rays revealing undetectable life-threatening conditions, PL- and EL-based tools, either individually or as part of a hybrid system, can literally bring a concealed ticking time bomb, invisible to the naked eye, to light.

Rise and shine

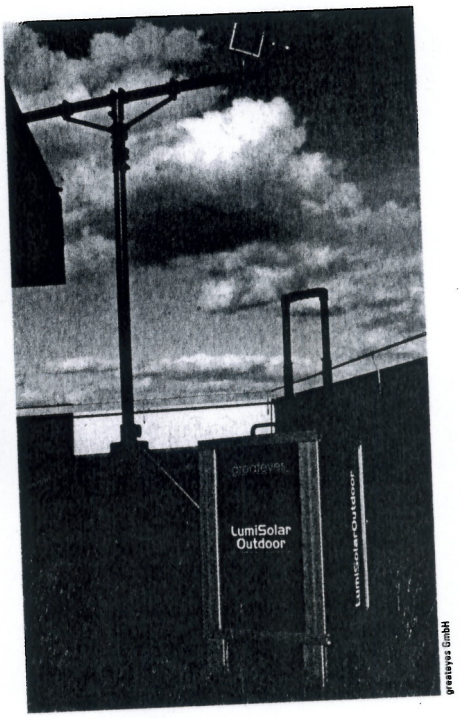
But the enlightening investigation via luminescence of wafers, cells and modules is no longer limited to darkrooms in the factory. Now modules, and the cells that make them up, can also have all of their flaws exposed on site without the need to de- and reinstall the panels, a process that itself could cause further damage to the modules. Thanks to a pair of new tools, root-cause analysis of defective modules can be carried out in the field, especially useful in providing ammunition in insurance and warranty claim disputes. Bombs defused.

And the big news is that the examination can now be done under the light of the sun. This new technique, developed by the Institute of Photovoltaics (IPV) at Germany's University of Stuttgart, can carry out the task of making nearly all of the desired measurements, normally done in darkrooms, in daylight (see PI 11/2012, p. 126). The technology has now been commercialized thorough IPV's spin-off - Steinbeis-Transferzentrum Angewandte Photovoltaik und Dünnschichttechnik - under the brand name DaySy (pronounced »daisy«). The tool is capable of using both EL and PL. While EL is mainly employed to measure the series resistance by regulating the power drawn from the system, the greater part of the testing makes use of PL. While it might sound counterintuitive to employ PL imaging for modules, as a homogeneous light-excitation source for typical module sizes does not make economic sense, IPV innovatively uses sunlight as the light source to trigger the luminescence response. The tool consists of a video camera and a modulation system, such as an inverter, which helps in regulating the power drawn from the modules at a particular frequency. The camera records the response of the system between short circuit and open circuit. The short circuit images are very dark with no luminescence response, while the images taken at open circuit have full-scale PL signals. The only difference between these two images is the PL signal without any background effect. Thus, the parts of the images that have not changed during the modulation are considered noise and filtered out. By analyzing several of these images, IPV's DaySy provides a PL image of the installed system during operation in daylight. Based on such a measuring principle, it can detect common aging defects, such as broken solder bonds, microcracks, interrupted fingers, and inactive cell areas, as well as potential induced degradation (PID).

Then there is a new inspection tool from Germany-headquartered Greateyes GmbH. Unlike the DaySy, Greateyes' EL-based LumiSolarOutdoor, operates almost like a portable darkroom, characterizing installed modules from the twilight of sundown to the diffused light at sunup. With the tool's battery-powered version, the solar module has to be disconnected from the string and attached to the battery, limited to 500 measurements per charge. After the inspection, the module is reconnected to the string. The other LumiSolarOutdoor tool not only avoids the need for disconnecting and reconnecting the module, there is no limit on number of



▲The light of day: A new PL technique developed by IPV in Stuttgart can examine installed PV modules in full daylight, eliminating the need to demount the panels from the racks.



▶ Fresh air: Greateyes has introduced a pair of EL-based product platforms called LumiSolarOutdoor – one powered via battery (shown here) and the other from an external source – that can inspect installed modules from sunset to sunrise wherever they are.

measurements. It simply relies on the power from the grid so that an entire string can be electrically excited at once. Then the operator moves from module to module. According to Greateyes' managing director Martin Regehly, if problems are suspected in only several modules, the battery-powered version is best. But if a large number of modules – or even the whole system – has to be inspected, the line-powered tool would be the right choice. Both systems take one image per module of a maximum size of 2,000 × 1,000 mm at a recommended distance of 3 to 5 m between the camera and panel. While each measurement only requires 1 to 5 seconds, due to the time needed to reposition the equipment and reset the camera, the net throughput is 20 modules per hour.

Though not a new concept, some companies are also offering luminescence imaging systems in a mobile configuration for field-testing of modules. However, these tools still require simulated darkroom conditions, and the solar panels have to be dismantled when testing the already-installed modules. These tools can be employed to inspect the PV panels before mounting them onto the racks. The new MELI from Steinbeis and last year's listed SolarModuleInspect-ELVIS from GPP Chemnitz Gesellschaft für Prozessrechnerprogrammierung mbH from Germany fall into this category.

Except for outdoor testing of modules, this year's survey is only notable for a considerable drop in the number of systems to 93 from the 114 listed last year, but still offered by the same number of suppliers (see table, p. 98). Of the current batch, 12 are purely based on PL, 10 support both EL and PL, while the rest are exclusively designed to accomplish the EL imaging. The overview also covers 23 cameras – the most important integral part of the luminescence tools – from 10 companies (see table, p. 120).

Testing wafer to forecast cell efficiency

As with the luminescence imaging systems for modules in the field, image-capturing is important at the other end of the value-chain spectrum – the wafer. While optically identical to the naked eye, every solar substrate is internally different from the other. The silicon wafer has to go through many thermal and chemical processes before being converted into a fully functional cell and eventually as part of a module. As necessary as these processing steps are, the flip side is the increased danger of damage to the thin substrates. The silicon wafers also come with inherent internal flaws. Defects, either man-made or inborn, can greatly influence the final watt peak. Thus every cell and module leaving its respective manufacturing facility is measured for electrical characteristics. Consequently, the sales metric for cells and modules is simply the watt peaks the solar substrate generates.

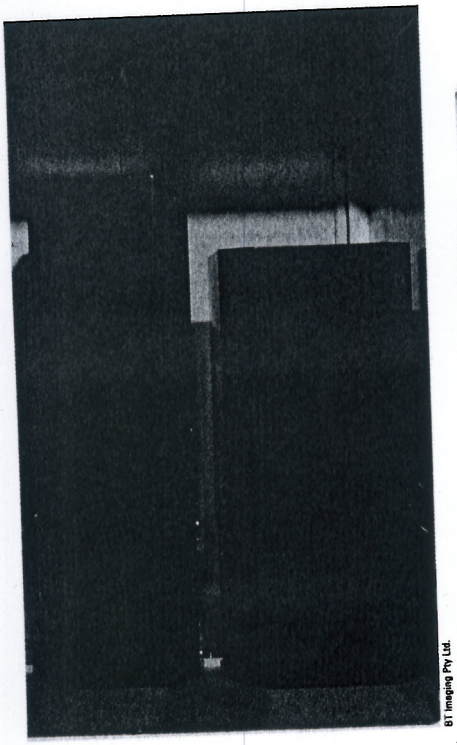
Not so for wafers. Here profit is mainly based on the how many are sold, meaning in a broader sense that producers have had little incentive to investigate wafer quality beyond typical measurements like ingot resistivity, etc. that are printed on the wafer box. To be fair, until recently they have not had the necessary equipment to do so – forecasting cell efficiency from an unpolished as-cut wafer has been next to impossible.

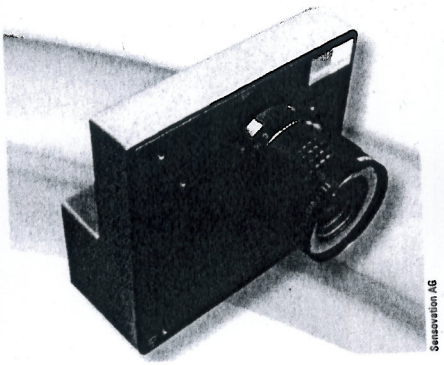
But 2 years ago, BT Imaging Pty Ltd. from Australia developed a technology that approximates the electrical quality of as-cut wafers, determining dislocations and grain boundaries – and their net adverse effect on the final output power at cell level, thus allowing a forecast of the potential efficiency. Since the silicon wafers at this stage do not have any electrical contacts, the choice for carrying out a characterization procedure is PL. US-based 3i Systems Corp has also developed similar tools for as-cut wafers. Three more companies – Germany's Hennecke Systems, Hungary's Semilab Co. Ltd. and McScience Inc. from South Korea – have started offering PL tools that give a prognosis on the performance potential of bare wafers.

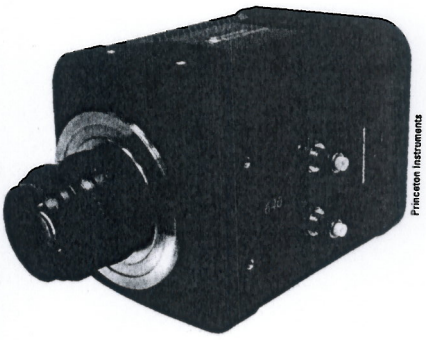
The competitive advantage of Semilab's PLI-101, according to the company, is that the tool is integrated with a µPCD head that allows simultaneous correlation of lifetime results attained based on PL with µPCD measurement. Semilab also claims that the signal-to-noise ratio with its tools is better than any other product on the market, but did not quantify it. The PLI-101 accomplishes the inspection on-the-fly with a throughput of 3,600 substrates per hour. A major upgrade associated with the new PL-B56H from 3i Systems is the throughput. This tool also inspects 3,600 wafers per hour by employing a line-scan camera and on-the-fly transport mechanism. The PL tools from 3i systems, BT Imaging and Hennecke Systems akk achieve the same throughput level, the highest for PL systems reported in the survey.

From quasi-mono to high-quality multi wafers

Last year, one of the major topics in the wafer characterization segment was the inspection of quasi-monocrystalline wafers. While quasi-mono wafers provide the same luminous







◀ Two for one: At BT Imaging, a combination of its iS-G1, an optical grain measurement system, and the PL-based wafer inspection platform iLS-W2, provide comprehensive testing for quasi-monocrystalline wafers.

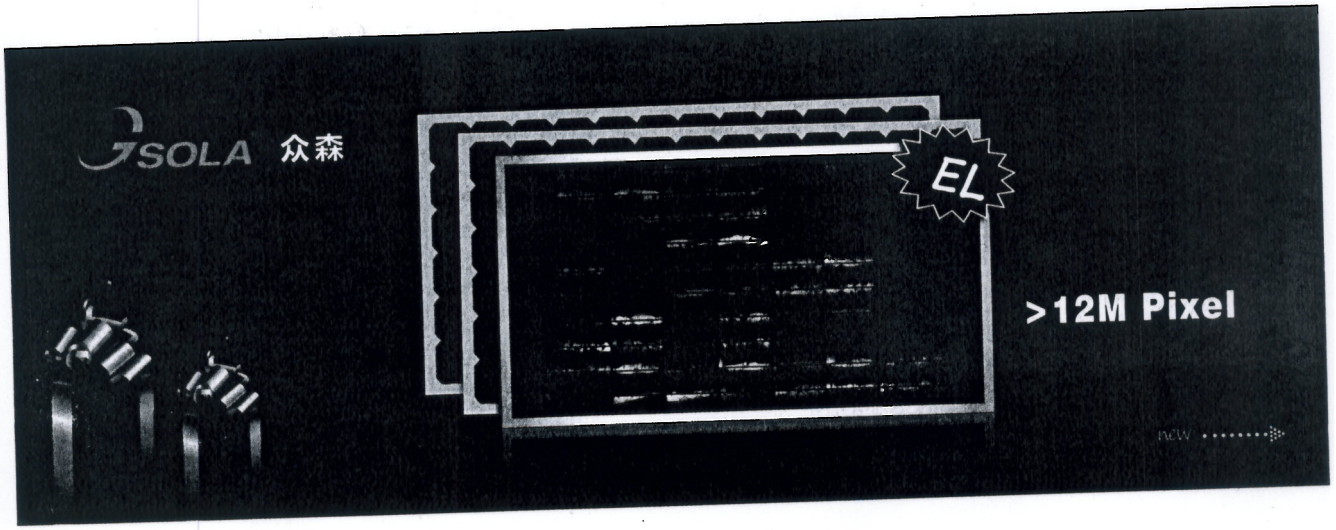
▲ Low cost: Sensovation SamBa Ci, the least expensive camera in the survey, comes without any active cooling mechanism, which, according to the company, makes it suitable for high-speed measurements.

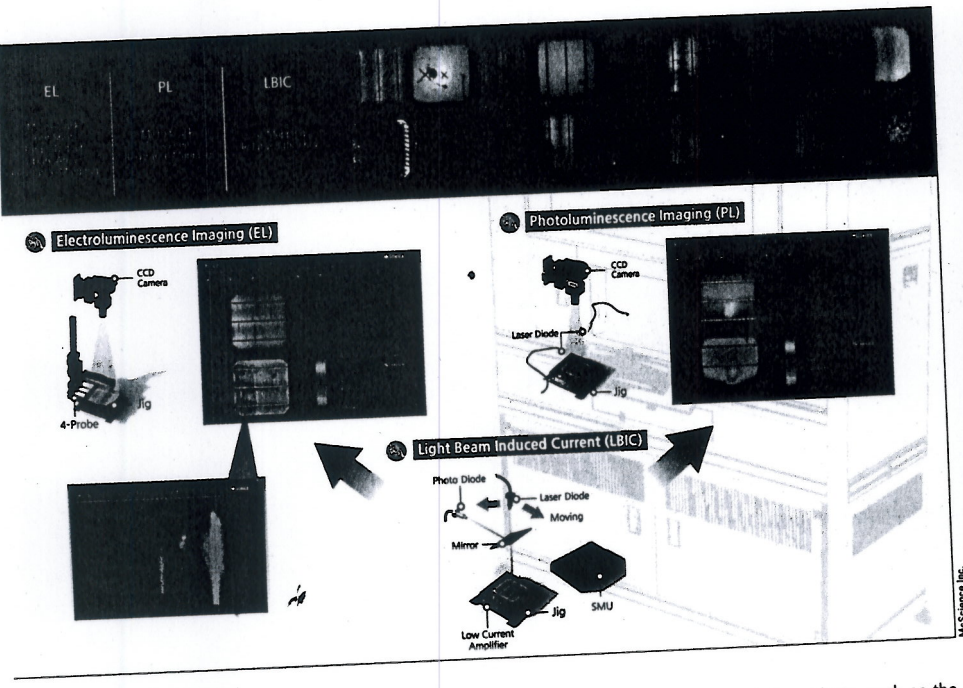
▲▶ Tailored for PL: Priceton's PIoNIR: 640, designed to capture low-level luminescence response, makes it well suited for PL-based inspection of PV wafers and cells.

response as other silicon substrates, the internal flaws are different, mainly in regard to the higher dislocation density. In addition, the ratio of mono versus multi on the wafer is also an important sorting parameter for these wafers,« says BT Imaging's sales and marketing vice president Wayne McMillan. Responding to customer's wishes, the company has developed an optical system called iS-G1 for the inspection of crystal grains unique to quasi-mono wafers. Using a new grain imaging technology the automated algorithms analyze the grains and report metrics such as the percentage of the mono area and, statistics on the number of grains and grain boundary lengths. It supports on-the-fly measurement of up to 3,600 wafers per hour. Together with BT Imaging's iLS-W2, a tool that estimates the efficiency potential of an as-cut wafer, this provides a »comprehensive characterization solution« for quasi-monocrystalline wafers, says McMillan. In addition, 3i Systems' two models, the new PL-B56H and PL-B56, as well as Semilab's PLI-101, can also be used for characterizing quasi-monocrystalline wafers.

But the interest in this wafer class seems to be waning. »Till a few months back,« says McMillan, »all of our customers were pushing us for a solution for quasi-monocrystalline.« However, for the last few months, he says, the latest hot topic has been high performance multicrystalline wafers. The biggest efficiency-limiting factor associated with standard multicrystalline substrates is the higher dislocation density. But for high performance multicrystalline wafers, due to smaller grains and heightened stress release the dislocation density is considerably reduced. However, the reduced grain size is a concern for PL imaging tools. »We have to optimize the tool in order to manage with the small grains and still detect the dislocations,« says McMillan. How is unclear. McMillan only says that »specific product developments« are expected to follow, and that BT Imaging is »co-operating with a customer.«

For now the company is mainly focusing on wafer inspection and offering different configurations. Its new PL-based iQ-W2 measurement tool can be retrofitted into already-installed wafer sorting tools. The QS-W2 is a self-sufficient wafer inspection and sorting system, while the Qa-W2 is the simplest configuration of the QS-W2 with a single loading and unloading station. Thanks to its background in metrology, Semilab also says it can offer its PL system





▲ Comprehensive solutions: Luminescence imaging tool suppliers are adding new features to their products, such as the :3300 EPLB from McScience, which, in addition to EL and PL, can also accomplish LBIC measurement.



▲ »Exciting« option: The LumiSolarCell, which can accomplish both EL and PL, uses LED rather than laser light to excite samples.

vith different platforms and configurations. All of these PL tool makers claim that »several« of he systems have been installed on wafer lines it unidentified manufacturers for forecasting he power potential of the as-cut wafers.

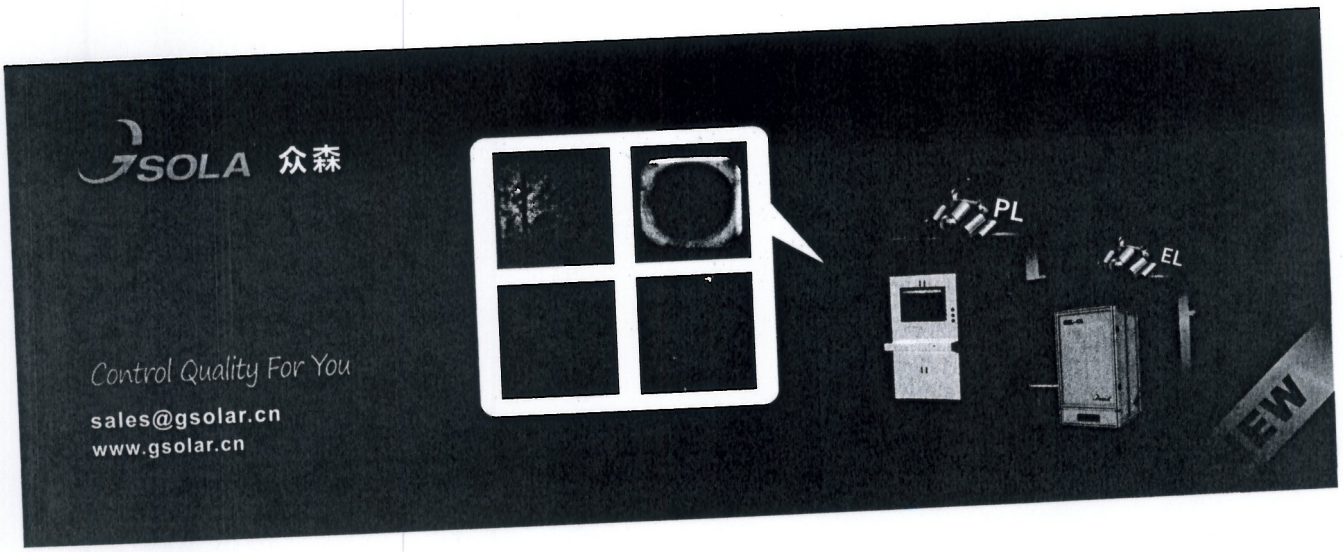
PL for half backed cells

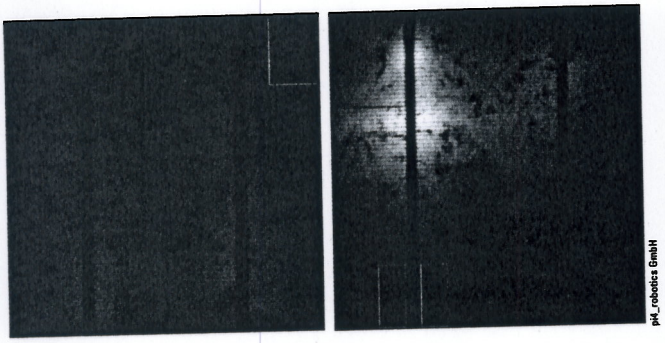
While not so prevalent as in wafer character-ization, PL imaging can also be very useful in inspecting semi-processed wafers in cell lines. An inline version of such a system can be used for checking each wafer, especially after the deposition of the antireflective passivation layers and before screen printing, so that the defective substrates can be stopped from entering the most expensive step in the cell lines – screen printing. 3i Systems' PL-I56 has mainly been designed for this application in cell processing lines. The tool inspects ARC-coated wafers for material defects, such as dislocations, contaminations and low lifetime areas, in addition to cracks and microcracks. The PL systems can be used in standalone configurations for process monitoring by checking the samples from the production line. Germany-based Schmid Group is offering such a PL system for offline applications.

Excited with LEDs

While many of the companies in the survey use laser light to excite the silicon sample for PL measurements, several have started using an LED light source, claiming that this leads to reduced cost, easy scalability, low maintenance, higher safety and compact design. Systems based on LED's, such as the LumiSolarCell from Greateyes, are limited to inspecting wafers only after the passivation coating, meaning they cannot be employed for as-cut wafers. The company says it has been trying, but so far without success. Greateyes' Regehly says that even though the sensitivity of the LumiSolarCell has been increased by a factor of 10 over the last year by optimizing the optical systems LED technology, the system is not yet suitable for characterization of as-cut wafers.

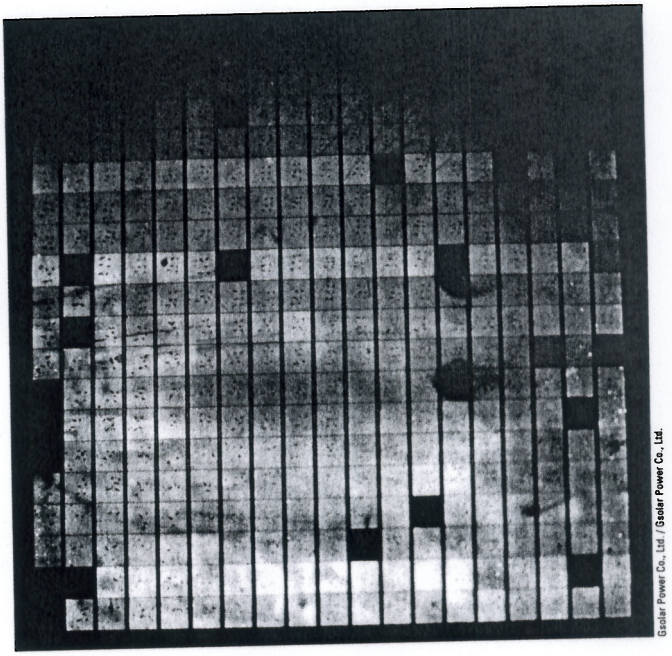
According to a technical paper presented by Greateyes at the 26th European Photovoltaic Solar Energy Conference (EU PVSEC) held in Hamburg, Germany, in September 2011, the selection of the LED wavelength is an important parameter. An LED wavelength





pi4_robotics GmbH

▲ Defect detecting: Pi4_robotics says it can now detect a variety of defects, such as flaws caused by worn solder belts or, as shown, due to malfunction of the fluxing unit.



Gsolar Power Co., Ltd. / Gsolar Power Co., Ltd.

▶ For thin films too: Some companies, like Gsolar, are promoting their EL tools also for the detection of inhomogeneities in deposited layers, pinholes and structuring defects in thin-film modules.

below 800 nm is highly desirable, Greateyes contends, in order to avoid any overlap of the light from the excitation source with that of PL response, but at the same time high enough to ensure sufficient excitation of silicon. Greateyes has opted for LEDs with an approximate wavelength of 650 nm.

The Fast EL Mapper from US-based Reltron, on the other hand, excites the silicon substrate at a higher wavelength of 850 nm, claiming that it has carefully selected filters so that the LED light does not interfere with PL signals. This tool is mainly promoted for R&D and process development. Italy's AEA srl is also offering LED-based excitation as an option, but the company declined to reveal the wavelength.

Two in one – EL and PL

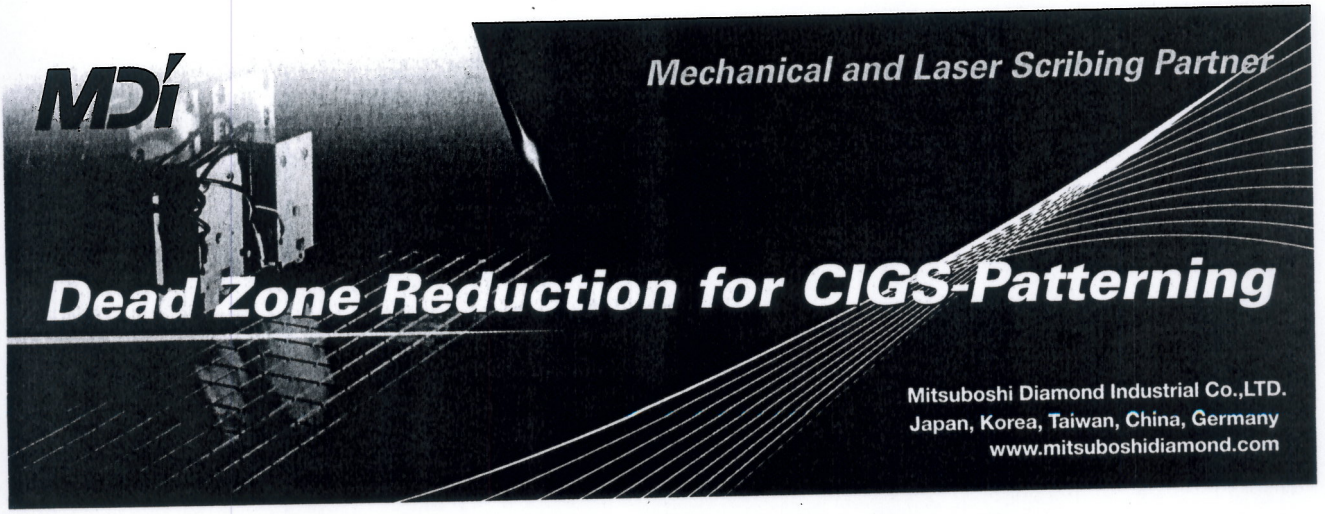
Actually, the tool from Loccioni Group can also accomplish EL-based measurements. Such combined EL/PL systems offer modularity to inspect the PV substrate at different stage, from wafers through modules as is the case with Loccioni Group's EL2912/PL2208. McScience is also offering two modular systems that can characterize wafers, cells and modules. Its K3300 EPLB, in addition to EL and PL, can also accomplish light-beam induced current (LBIC) measurements. According to McScience, when a defect is identified by EL/PL, the operator can set the system to perform LBIC measurements on a specific defect area for local Isc mapping.

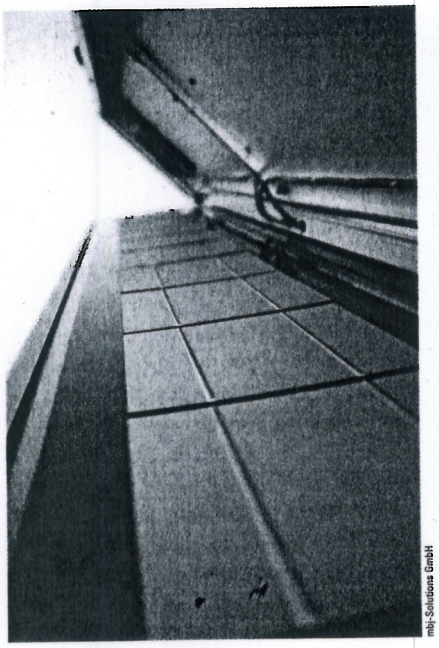
In addition to the modularity, the combination of EL and PL imaging offers flexibility and allows the evaluation of shunt and series resistance, features that are very helpful in R&D-related applications. The result it that companies such as BT Imaging, 3i Systems, Greateyes and Gsolar are all promoting their combined EL/PL tools in offline configurations.

EL for cells, modules and strings

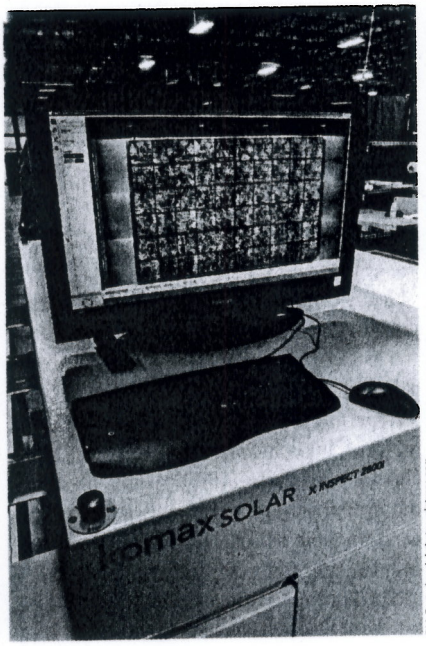
As for pure EL, it is mainly used for the characterization of completely finished cells all the way to framed modules. The majority of products listed in the survey fall into this category. At the cell level, these tools are configured to detect material defects such as dislocations, inclusions and low lifetime areas, in addition to microcracks, metallization anomalies, shunts and series resistance. Depending on the applications, nearly every EL tool supplier is supplying the inspection systems in inline and offline configurations. Most companies are integrating high-resolution cameras, improving and developing the fault detection software, and combining EL with other testing possibilities, such IV measurements.

Companies like Manz are integrating the EL system into the cell tester and sorter and selling the assembly as a package. Berger has also





mbj-Solutions GmbH



Dirk Eusterbrock / photon-pictures.com

◀◀ String inspection: EL inspection of cell strings offered by mbjSolutions not only stops the defective strings from ending up in modules, but also enables damage repair, especially due to soldering abnormalities.

◀ CTS supplier: Taking advantage of the fact that EL inspection can be beneficial in string inspection, CTS tool supplier Komax is offering a wide range of EL tools for different stages in module making.

been doing the same, but the company has not provided the data for its tool.

In fact, EL is the only predominant choice for the inspection of modules and strings. Indeed, EL scanning may be most beneficial when it comes to string inspection. That is because this is the only stage of module making that allows reworking and the elimination of defective substrates before they are sealed in the modules. That is also why production equipment suppliers for module making are also developing an extensive range of EL systems to be integrated into their tools. US-based CTS maker Komax Solar Inc. is a good example. And now its competitor, Germany-based Somont GmbH, has also stepped into the domain of building EL systems specifically designed for its current and previous generation of CTS tools.

While there are no common advancements for the products in this segment, the developments specific to the products of some companies are worth mentioning. Adapting to market conditions, many luminescence imaging tools suppliers have reduced their prices. For example, some systems from 3i Systems are now sold for 30 percent less, and Gsolar has reduced the price for the majority of its products by around 25 percent. MBJ Solutions and Komax have also reduced the prices for some of their offerings.

And now Germany's Pi4_robotics GmbH has introduced a new tester called pi4_el-Tableflasher 40s that combines the AAA-class xenon flasher from H.A.L,M. with a fully automatic EL tester. However, this concept is not new, as the SolarModule EL-flash from MBJ Solutions and the X6000i EL tower flasher from Komax have similar features. In addition, Komax is providing a function to estimate the IV characteristics (not calibrated) of strings to provide an idea of performance for the majority of its product range.

But EL systems are not only suitable for crystalline modules. The technology can be equally effective for inspecting thin-film modules. These tools identify defects such as inhomogeneities in deposited layers, pinholes, and structuring defects. Gsolar, Komax, GPP Chemnitz and MBJ Solutions are offering such systems.

Little news on cameras

Excluding the automatic defect-detection software, EL and PL systems are not worth much without a decent camera. There is no rocket science to building system peripherals, especially when the target is only to generate a luminescence image of the PV device. Still, the news on the camera is now really exciting. The majority of the camera suppliers repeated last year's data with either meager changes or none at all. The current crop of products listed in the survey is suitable for any application and budget. For example, Princeton's PIoNIR: 640, specially made for higher-end PL-related applications, which features an InGaAs sensor with a quantum efficiency of 80 percent and deep cooling down to -80 °C, is still the most expensive in the survey, costing $110,000. Then there are products such as the SamBa Ci from Sensovation with no active cooling mechanisms. According to Sensovation, such a configuration, available for just €5,800 ($7,500), is more suitable for commercial production. There could be some advancements in the near future as many of the camera suppliers are working on improving their products. Sensovation, for example, is working on software to superimpose the images from two cameras to double the effective resolution of the image.

In short, using luminescence systems based on EL to inspect PV substrates at various stages of module manufacturing is also gaining traction at the final testing at the end of cell lines. PL is also making gains, especially in estimating the efficiency potential of as-cut wafers for sorting out defective wafers. It has equally good potential for inspecting semi-processed wafers and preventing defective substrates from entering the screen-printing step, thus saving silver for more appropriate silicon substrates. However, the latest advancement of luminescence imaging, both for EL and PL, is no longer just in the production hall, but out in the real world as well for PV systems – and if the technology works as good as the manufacturers promise, many system developers will undoubtedly want to get their hands on these tools.

But a new innovation may shift the focus back to the gestation stage of the whole process. BT Imaging, already offering a tool to predict the performance of as-cut wafers before they are processed into cells, says it is also developing a system that can evaluate the quality of the silicon bricks before they are sliced into wafers. While BT Imaging's McMillan declined to give any details, if such a tool came on the market, it would be a big game-changer in wafer making, something that could eliminate problems now faced all along the production chain. Stay tuned for more en»light«ening news. ●

Text Shravan Kumar Chunduri

Further information

For specs and product descriptions, see p. 84 - 118

An article explaining and showing EL photos of typical module defects is available exclusively to subscribers in an extended PDF version of this issue (see appendix, p. 150), which can be downloaded at: www.photon.info