The picture of quality

Market survey on luminescence imaging reveals rival inspection technologies are really well-matched pals

Text: Shravan Kumar Chunduri

Highlights

- This year's survey includes 114 imaging systems and 32 cameras
- Electroluminescence is becoming a standard inspection procedure at various stages of module production
- At cell-level characterization, electroluminescence imaging is often used as a subsystem of IV testers
- With its non-contact process for inspecting cells, photoluminescence is emerging as a credible option
- Photoluminescence tools to forecast electrical performance of as-cut wafers before processing are already on the market

Next to IV testing, a compulsory quality check that every PV device produced has to undergo, electroluminescence (EL) imaging is emerging as the most important characterizing technique to rate the quality of PV substrates. With its ability to peek into the silicon bulk and map a wide range of inherent and process-induced defects in silicon substrates, EL imaging has already become a standard measurement practice at major module factories.

But EL is not the only imaging system on the market. Another process for putting cells to the inherent-flaw test – photoluminescence (PL) – continues to make headway. Unlike EL, where handling the cells is essential for inspection tests, PL is a non-contact process. And PL is not only proving extremely attractive for cells, but also in characterizing semi-processed and as-cut wafers to extrapolate potential efficiencies – it can even peer into silicon bricks to detect flaws.

And that is why EL and PL, while perhaps rivals at the cell level, are actually complimentary technologies that provide quality control along the value chain of production from silicon bricks to finished modules. As a result, an increasing number of imaging suppliers are coming out with both EL and PL systems.

And the desire for PL is set to grow. That is because this year's hottest news is about quasi-monocrystalline silicon wafers. This new class of silicon material, undoubtedly on the radar screen of nearly every wafer manufacturer, is claiming it can marry the higher-efficiency performance of monocrystalline with the manufacturing process and cost of multicrystalline silicon (see PI 6/2011, p. 260). While quasi-mono wafers provide the same luminous response as other silicon substrates, the internal flaws are different, mainly in regard to the higher dislocation density (see box, p. 138).

PL involves the response of excitation of the sample by means of an external light source, while EL is obtained by biasing the substrate. In both cases, these systems are configured to capture the luminous response of PV substrates via a charge-coupled device (CCD) camera, the most important component of the systems. The electrons injected into the semiconductor material recombine radiatively with the available holes by transferring their excess energy to an emitted photon. For silicon, this emitted light is in the range of 950 to 1,250 nm with its peak at nearly 1,150 nm. The CCD cameras integrated into these systems record this low-level light. Ideally, homogeneous luminescence-intensity distribution is expected, but the defects present in the substrates cause disruption, enabling the offending flaws to be mapped. PL also allows these wafers to be sorted at an earlier stage according to potential output.

In a gambit to be ready for the day when quasi-monocrystalline blocks hit the big time, several luminescence imaging suppliers are already working on developing algorithms



▲ Clear future: Luminescence imaging is evolving as a reliable characterizing technique in PV processing. While EL is earning faith in module manufacturing, PL is adding a new feather to its cap by forecasting the electrical quality of as-cut wafers.

that can estimate the electrical performance of this new class of substrates at the as-cut wafer stage.

In fact, PL imaging has already made remarkable progress in characterizing as-cut wafers currently on the market. Last year, Australia-based BT Imaging Pty Ltd. introduced an innovative PL imaging tool that approximates the electrical quality of as-cut wafers at an inline speed (see PI 1/2011, p. 158). The system is configured to spot only those wafer defects that would reduce the solar cell's output power. Following this lead, three more companies – Germany-based Op-tection GmbH, and US-based companies 3i Systems Corp. and Intevac Inc. – have also developed similar systems to characterize the electrical quality of as-cut wafers.

The continuing development of PL and the increasing credibility of EL is reflected in this year's examination of luminescence products on the market. This year's survey includes 32 cameras (see table, p. 166), compared to 25 models last year, and 114 complete systems (see table, p. 142), up from 92. The number of suppliers increased by three to 28 compared to our 2011 survey. The reason for the trend is simple: on the supply side, traditional camera makers are expanding into the quickly growing solar space; on the demand side, wafer, cell and module makers are using the handy luminescence technology to improve quality control and increase yield.

EL and PL systems

In the past, many system suppliers only provided users with the ability to generate an image of the PV substrate, leaving the decision on how to classify it up to the operator. But now, system suppliers are increasingly developing proprietary algorithms to detect faults automatically. In addition to the traditional list of defects such as microcracks, shunts, metallization flaws and soldering-induced damage, some luminescence imaging systems are offered with higher-end applications such as series resistance lifetime mapping. The current market also offers systems with variable throughputs, camera resolutions and configurations that are suitable for production-scale operations as well as R&D-related applications.

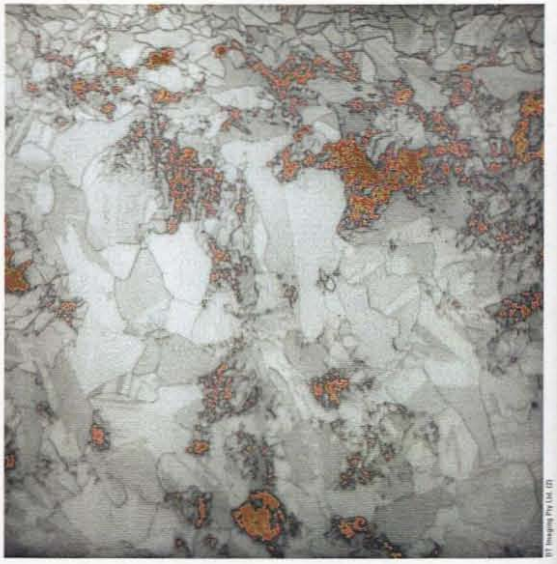
As noted, the applications for PL start high up in the value chain, first examining silicon bricks, then as-cut and semi-processed wafers, and finally finished cells. While EL covers the characterization of cells as well, it can also inspect strings and modules. With the option of combining the technologies to cover the whole sequence of production, some companies have decided to integrate both EL and PL tools into their product portfolios.

BT Imaging – measuring on the fly: Australian equipment manufacturer BT Imaging is offering such dual systems – but mainly for laboratory applications. The production-scale solutions are largely based purely on PL. Its **iLS-W1**, with a throughput of 2,400 wafers per hour, not only maps, analyzes and quantifies the efficiency-limiting defects in as-cut wafers, but by using a specifically developed image-processing algorithm, it also estimates the net adverse effect on the final output power of the wafers, even before they are processed into cells. According to Wayne McMillan, the sales and marketing vice president, between 5 and 10 of these systems were shipped in 2011, but McMillan would not provide the exact number.

Based on this success, in June, BT Imaging is planning to come out with the **iLS-W2**, a third generation PL system upgrade, currently in beta testing. McMillan says the new version will have an increased throughput, raising the hourly wafer rate to 3,600 by requiring only 1 second per wafer to accomplish all of the necessary inspection procedures. It will achieve this by taking full megapixel-scale images »on-the-fly,« a process in which the conveyor belt never takes a break. According to BT Imaging's CTO, Thorsten Trupke, basically it is not the actual image acquisition that limits throughput, but mainly the traditional stop-and-go automation mechanism. Trupke would not give any specifics on the new optics, characterizing it as proprietary information. But if the process proves reliable, the iLS-W2 could be a game changer for luminescence imaging. The price for the iLS-W2 will be between $200,000 and $250,000. The iLS-W1 is priced from $250,000 to $300,000.



▲ Flying fast: BT Imaging, the first to introduce a wafer sorter at the as-cut stage to predict the electrical yield of solar cells based on PL imaging, has now added »on the fly« measurement capabilities to its new iLS-W2, which tests and sorts at a rate of 3,600 wafers per hour.



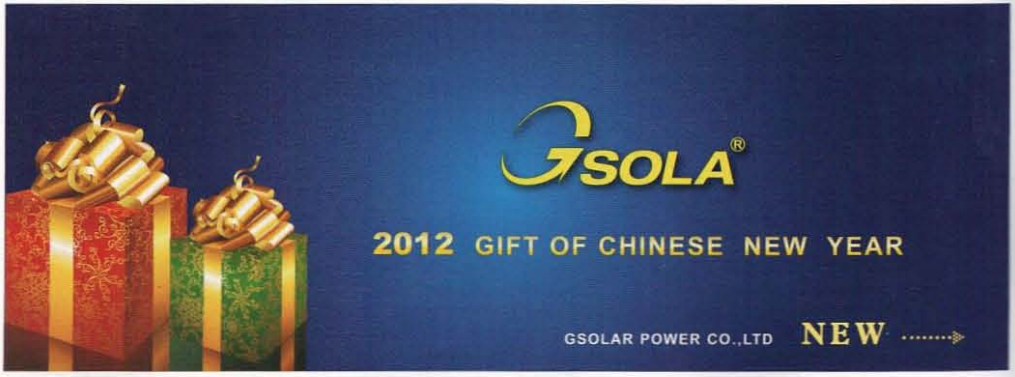
▲ Pretty but poor: With a startling resemblance to an exotic Google Maps image, this wafer was processed with BT Imaging's PL device and analyzed by its new software. This allows a numeric grade to be assigned for dislocations and alphabetic classification of impurity content. In this case, it reveals an unwanted high dislocation density and a lack of impurity content. Its score? An A4 rating.

BT Imaging also has a new product tool for R&D applications covering both EL and PL. The **LIS-R2** is set to hit the market at the beginning of this year. This multi-functional tool, integrated with the same optics used in the iLS-W1, replaces the previously listed **LIS-R1** and **LIS-P2w**. According to BT Imaging, the LIS-R2 enhances the image acquisition speed by ten times, requiring only 2 seconds to generate a PL image for an as-cut wafer.

The tool can be used at several process stations in the PV value chain, including the option of acquiring PL images for silicon bricks, providing information about the lifetime variation and crystallographic structures such as dislocations. After the brick has been sliced, the LIS-R2 can provide uncalibrated PL images showing lifetime variations of as-cut wafers. This feature is also applicable to semi-processed and completely processed cells.

But the most important feature of the LIS-R2 at this stage of PV processing is its ability to make a quasi-steady-state photoconductance measurement, which allows a calibrated lifetime measurement as a function of the injection level. This data can be used in an automatic station to calibrate the PL intensity so that specially resolved lifetime mapping can be obtained. »The logic,« says Trupke, »is that it converts the measured PL intensity into an absolute quantity – a minority carrier lifetime.« This is the most important material parameter for processing a silicon wafer into a solar cell.

Another key offline characterization method offered by the LIS-R2 series is resistance imaging at the cell level. It is based on a combination of PL images that are taken at different illumination intensities and various current levels. BT Imaging has developed a proprietary algorithm that gives the absolute series resistance value in ohm cm^2. According to Trupke, this feature is very useful in process



development, especially when evaluating new device structures such as selective emitters and experimenting with new metallization pastes. Accordingly, BT Imaging is also offering EL with this tool for a contacting setup. When compared to the LIS-R1, the new LIS-R2 has around a 50-percent smaller footprint and a lower price tag of $200,000 to $350,000.

In addition to making advancements to its lab- and production-scale characterization tools, BT Imaging is also developing grading procedures for the tested multicrystalline silicon wafers – the necessary software has already been integrated into the iLS-W1 and iLS-W2. The company is also working on adapting the same grading algorithm for quasi-mono wafers.

Op-tection – a cluster of new products: Germany-based Op-tection GmbH is offering 19 tools, including several new and upgraded products. The most interesting among them is the **OSIS Wafer Sorter PL**, which is currently capable of handling mono- and multicrystalline wafers based on PL imaging. In cooperation with Schott Solar AG, Op-tection has developed an algorithm for integration into the tool that can forecast the energy yield of as-cut wafers. A similar software suite for quasi-mono wafers is also under development. In the case of standard silicon substrates, the OSIS Wafer Sorter PL uses a proprietary algorithm for sorting as-cut wafers based on the forecasted cell efficiency by examining edge contamination fractions, dislocation clusters and PL intensity, as well as its distribution. The tool is fully automatic and designed for box-to-box wafer sorting into user-defined categories. Op-tection says the OSIS Wafer Sorter PL can support a characterizing speed of up to 3,600 wafers per hour, depending on the configuration. It is sold at a price range of €200,000 to €450,000 ($267,200 to $601,200).

As for purely PL-based inspection of cells, the company is offering the **OSIS cell PL inline**. It can check cells for common defects such as microcracks, contaminations and dislocations at an inline speed of up to 3,600 cells per hour. The price ranges from €89,000 to €102,000 ($118,900 to $136,300).

Another new product for cell level characterization based on PL is the **OSIS Cell mc (EL/PL)**. As the name indicates, it can do EL as well. This tool is mainly promoted for laboratory applications, process development and random sampling. The system is configured to detect microcracks, shunts, printing defects and dislocations.

PL is an option for four other cell-level characterization systems – the **OSIS Sorter Cell-1800, OSIS Sorter Cell-3000, OSIS Sorter Cell-2400, OSIS Sorter Cell-600**. These systems are designed to be optionally integrated with other tools for carrying out IV testing, automated optical inspection (AOI) and color measurement. The major difference between these similar-looking products is the throughput they can support, as indicated by the suffixes.

The remaining three new products are mainly aimed at module manufacturing. The **OSIS String 12K** is an automated string inspection system that characterizes 120 strings measuring 2,000 × 160 mm per hour, based on an automatic defect-detection algorithm. The **OSIS Module F** is a similar system, but scans panels sized up to 2,000 × 1,000 mm in size. Op-tection has also introduced a new model for thin-film module characterization called the **OSIS Module I (inline) Thin Film**. The tool takes an EL image of the module so that the software can scan for flaws such as laser-scribing defects, dark areas and shunts. The tool is priced at €90,000 ($120,200).

For its previously featured models, Op-tection is offering software upgrades, especially with improved algorithms. In some cases, the tools can also be retrofitted with additional inspection possibilities such as IV, AOI and color measurement.

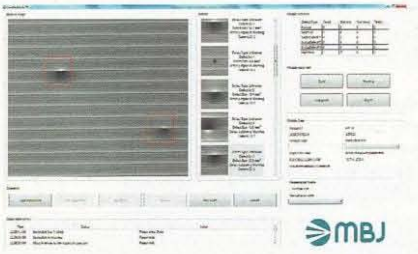
3i Systems – also for as-cut wafers: 3i Systems Corp. is moving toward characterization of quasi-mono wafers. According to the US-headquartered company's Wayne Chen, a commercial-scale system should be available during the first quarter of 2012.

For now, 3i Systems, has introduced two PL-based systems for multi- and monocrystalline wafers. The new **PL-B56** is an automatic as-cut wafer inspection and sorting tool. Like the tools from Op-tection and BT Imaging, this system is designed to test and sort wafers according to their anticipated performance, enabling a cell manufacturer to select the correct process recipe. The PL-B56 comes with automatic wafer loading and unloading subsystems. This tool is integrated with infrared (IR) inspection in its standard configuration. It checks the as-cut wafers for defects such as black cones in monocrystalline substrates, as well as black edges and microcracks in both type of wafers, and the grain size in multicrystalline and quasi-monocrystalline wafers. The PL-B56 can also predict the potential watt peaks that can be squeezed out of each wafer. The entire task is accomplished at the rate of 1,400 to 1,500 wafers per hour. Optionally, the PL-B56 can be integrated with an AOI and a lifetime measurement. 3i Systems ships the PL-B56 for a price range of $300,000 to $450,000.

The other new model, the **FL-B01**, is a desktop tool that is mainly for offline applications such as R&D. The system has a combined capability to accomplish both EL and PL imaging at one loading stage and can be used to inspect both cells and wafers. In as-cut wafers, it is configured to spot black cones, black edges, microcracks, scratches, dislocations and impurities, while in cells it can additionally inspect the metallization patterns. The company is selling this R&D tool at a price range of $200,000 to $300,000. 3i's other systems promoted last year have not undergone any major changes.

Schmid – expanding from EL to PL: The Schmid Group has decided to take part in the survey for the first time. In addition to three models – one production scale and two offline products – already in its portfolio, the Germany-headquartered equipment supplier has recently developed a new PL system. The





▲ Thin films, too: MBJ Solutions has come out with its first two tools dedicated solely to the characterization of thin-film modules for detecting defects such as flaws in laser scribing, as shown here in the screenshot.



▲ Unchanged: Seven out of 11 MBJ Solutions products, including the Solar Module EL basic for module analysis, have not undergone any major changes since the last survey.

A24 off-line is a tabletop device mainly suited for lab-scale applications. Based on the PL imaging principle, it can inspect substrates from the stage of as-cut wafers to finished cells. According to Ruben Wössner, the technical head of Schmid's engineering department, the first A24, priced at $168,000, will be shipped in the first quarter of 2012. Wössner says work is still in progress to develop a fully automated version of this system. He gave no information on when it would be available.

Schmid has two other offline lab tools in its **A-series**: the **A20** and **A18**, both based on the EL-imaging principle. The latter, designed for offline inspection of cells based on the EL principle with a listed price $50,000, has been shipped four times. The company has registered eight sales for its A20 off-line Module EL for testing modules. The device is priced at $68,000.

In addition to these lab-scale systems, Schmid offers an inline production-scale tool. The **Smart EL: Cell**, which has already been sold to three customers, automatically detects cracks, dark areas and finger defects. It can also identify microcracks, but only in monocrystalline substrates. The Smart EL: Cell supports a throughput of 1,200 cells per hour. The basic configuration is priced at €20,000 ($26,700).

Gsolar – reverse bias: Gsolar Power Co. Ltd. is offering a new system that features PL imaging. The Chinese company's **GEL-PL**, also capable of handling EL, can be used to characterize cells as well as wafers. But the tool, mainly promoted for R&D needs, will not be able to handle quasi-monocrystalline material, says Ran Xu, the company's deputy general manager. The GEL-PL, offered with an automatic defect-detection algorithm to map the typical list of defects, is priced at $150,000.

Gsolar has three additional new tools, all based on EL. The **GEL-C4** is a multifunctional tool, which not only takes EL and IR measurements, but can also accomplish reverse-bias EL. While EL is carried out by exciting the sample with forward biasing, Xu says that reverse-bias EL, for example at -10 V, helps in mapping additional material defects related to grain boundaries. The GEL-C4 is priced at $60,000.

The other two new systems are for module characterization. The **GEL-M8**, according to Xu, is suitable for high-volume production lines with a throughput of 120 modules per hour. It has two cameras, each with resolutions of 3,328 × 2,030 pixels, integrated into the system, making it »very good« for screening the cell matrix before lamination, says Xu. The **GEL-M4-900** has a 9 megapixel resolution, an upgrade of the 6.5 megapixel resolution with its **GEL-M4**. This improvement reduces the measurement time to less than 5 seconds for a 2,000 × 1,200 mm module. Gsolar has not made any significant upgrades to the remainder of its systems.

Greateyes – exciting with LEDs: While all of the other PL systems featured in the survey use a laser light source to excite the silicon substrate, Germany-based Greateyes GmbH is the only other company, apart from US-based Reltron LLC, to employ an array of light-emitting diodes (LEDs) for its **LumiSolarCell** system. LEDs have many advantages compared to laser-based systems, says managing director Martin Regehly, such as reduced cost, easy scalability, low maintenance, higher safety and compact design. 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 below 800 nm is highly desirable in order to avoid

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▲ Traffic light bingo: The LumiSolarProfessional series (shown on the right is the HighRes version) of EL systems from Greateyes is now offered with a fault-detection algorithm, which is pictured in the screenshot (on the left). The image displays the relative percentage of deviation from a »good« reference cell – green means good to go, yellow means watch out, and red means trouble.

any overlap of the light from the excitation source with that of PL, 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.

While this sounds exciting, the flip side of the technology is that LED-based excitation is currently limited to use on wafers after passivation. That means the as-cut wafers cannot be inspected with such a system setup. However, Greateyes is working on this limitation, says Regehly.

The LumiSolarCell system mainly consists of a cooled back-illuminated CCD camera with a 1,024 × 1,024 pixel resolution and four LED arrays and related filters. On request, the system is supplied with vacuum contact adapters for inspecting back-contact cells. The LumiSolarCell is also capable of accomplishing EL.

The company's other two systems – the **LumiSolarProfessional** and **LumiSolarProfessional High Res** – are configured to test modules. According to Regehly, the system software has been upgraded for an »optimized« process of stitching several images together when scanning a module. In addition, the tools are now integrated with defect detection algorithms. The design of the dark chamber has been improved by using smaller doors that are more stable »in order to allow frequent and reliable use of the system,« says Regehly. Greateyes, which also produces cameras, says it has been able to reduce the signal-to-noise ratio by 20 percent during module image acquisition for EL measurements.

Intevac – sensor tailor-made for PL: US-based Intevac Inc. says it has made several changes to its only PL system, the **NanoVista**, mainly in regard to the algorithms to estimate the energy yield of as-cut wafers. According to Ian Latchford from Intevac's marketing department, the tool analyzes around 15 image features and metrics to forecast the final cell efficiency, while edge impurities, grain boundaries and dislocations are the key defects checked. A mean absolute error of just 1 percent is routinely obtained between the predicted and measured final efficiency, meaning a 99-percent accuracy. All of this is done at a pace of up to 1 second per wafer, for an hourly throughput of up to 3,000 wafers.

According to Latchford, Intevac's tool has also been improved in the areas of repeatability and reproducibility of the measurements since last year. The other major change is a reduction in NanoVista's listed price. While the system was previously priced at a wide range of $300,000 to $500,000, the shipment price is now given as $250,000.

The NanoVista uses Intevac's own electron-bombarded active pixel sensor (EBAPS) technology. The sensor consists of an indium-gallium-arsenide (InGaAs) photocathode combined with a complementary metal-oxide semiconductor (CMOS) imaging anode. The photocathode spectral response is tailored to capture almost the entire emission spectrum of silicon photoluminescence and is responsive to an emission band of 950 to 1,320 nm. The CMOS anode has a 1,280 × 1,024 pixel resolution. It is capable of capturing up to 30 frames per second at full resolution. The camera is rated with a 25-percent quantum efficiency at 1,000 nm. However, for unknown reasons, Intevac has not listed its camera separately in our survey.

Hamamatsu – optional camera: The Japanese supplier Hamamatsu KK has upgraded its **EL/PL Analyzer**. The system, which as the name indicates can characterize using both EL and PL-based imaging, is offered with an option to select the camera either with or without a cooling mechanism. While the EL/PL Analyzer relies on EL to identify process-induced defects, such as discrepancies in metallization patterns and cracks, its PL imaging is mainly employed to investigate the flaws in the material and crystallographic structure of silicon substrates.

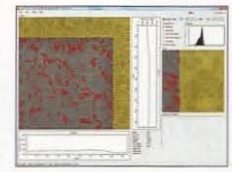
The system's fault-classification function provides a contrast between intrinsic and induced defects, with the former shown as white spots in the displayed image. According to a technical paper provided by Hamamatsu, the intrinsic defects leave clear imprints in the EL emission at 1,500 nm, while the induced defects do not. However, both defects are clearly visible in the range of 950 to 1,150 nm. In addition to this, the company says the system is capable of measuring minority-carrier lifetime and series resistance. Hamamatsu is selling the tool for a price range of €72,000 to €340,000 ($96,200 to $454,300).

Reltron – new LED excitation: The most interesting news about the **Fast EL Mapper** from US-based Reltron is that it is now promoted as being able to carry out PL-based imaging via LED excitation. Unlike Greateyes, which also uses LEDs, Reltron excites the sample at a higher wavelength of 850 nm. Still, according to Roberto Collins, Reltron's president, the company has carefully selected filters so that the LED light does not interfere with PL signals.

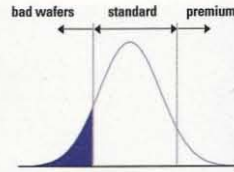
The Fast EL Mapper is also capable of accomplishing EL imaging. The reason for having both measurement options, according to Collins, is to provide the opportunity to inspect wafers as well as cells in R&D and process development, which is the targeted segment for the system. While PL is mainly



The future is now: Op-tection is one of four companies that has developed PL systems that can forecast the electrical quality of as-cut wafers. Its OSIS Wafer Sorter PL (above) is advertised as being able to predict a substrate's future cell efficiency (above).



Key metrics analyzed by software



achievable cell efficiency



Corner brick wafer



Dislocation clusters



Good wafer

Op-tection GmbH (2)

▲ The ugly, the bad and the good: Op-tection's OSIS Wafer Sorter PL analyzes edge contamination fractions (left) and dislocation clusters (middle) using PL imaging to predict performance. A »good« wafer (right) is shown as a reference.

used to identify cracks and areas with reduced carrier lifetime, EL is mostly employed for tasks such as resistance mapping. In addition, Reltron can configure the same system for production-scale applications. However, Collins notes that the system is limited to the EL measurement principle in such cases. The flexible platform of the Fast EL Mapper can handle measurements for cells, strings and production-size modules. Depending on the application, Reltron configures the system's peripherals. Collins says that most of its buyers use the production-scale systems for module manufacturing. Reltron claims that the Fast EL Mapper only requires between 4 and 6 seconds to scan a module or string. It is priced at $65,000.

McScience – new entrant: Although McScience Inc. is new to the survey, its luminescence imaging product – the **K3300** – is not new to the market. The South Korean company, a producer of inspection tools to the LED industry, has been making its K3300 since 2008. The tool is configured to detect defects such as microcracks and abnormalities in metallization patterns, while mapping shunts and the lifetime of cells in development using either EL- or PL-based characterization. But it is not clear how the K3300 employs PL and what defects the tool maps with the help of EL, as McScience has not responded to our inquiry seeking additional information. According to the company's specifications, the tool has an hourly inspection rate of 60 to 70 modules and 1,200 cells. It costs $90,000.

Strictly electroluminescence

While PL is attractive for inspection of solar substrates at the wafer and cell stages, it becomes more difficult to use the technology farther down the value chain as the substrate size grows. For modules, EL is the preferred imaging process. Unlike in cell processing, in which EL is only applicable for completely processed cells, in module manufacturing the measurement principle can be applied at every stage of module manufacturing. In fact, EL suppliers have specifically developed tools for different applications. The EL systems listed in the survey support different setups – from offline to fully inline, with variable image resolutions of up to 72 megapixels, and suitable for various budgets, with prices ranging between $21,400 and $850,000.

Pi4_ robotics – portable onsite systems: Germany's Pi4_robotics GmbH increased its range of EL-based products by a third to 18, mainly catering to the needs of various stages in module manufacturing. While many may appear to be new, that is only because most of the systems introduced in previous years have been renamed.

Pi4_robotics is offering module inspection tools for onsite use before installation with its new **Portable Module Inspection** series, with one providing an 8 megapixel image resolution and the other 1.4. Both models are able to inspect module sizes of up to 2,000 × 1,100 mm but are not integrated with an automatic defect-detection algorithm. The image resolution also differs between the two systems for flasher integration. While the 2010 version of the Module Automatic for Flasher Integration offered an 8 megapixel image resolution with a 10-second inspection time, the updated model has increased the resolution nine-fold to 72 megapixels, albeit requiring a longer inspection time of 25 seconds.

For the inline module characterization, Pi4_robotics is again offering five different models. All are capable of accepting a substrate size of up to 1,970 × 1,040 mm with an image resolution of 72 megapixels. Each model is integrated with an automated defect detection algorithm for shunts, spots of excess current density, dead cells, luminescence distribution and dark spots. The major differentiating factor among the tools is the cycle time. Of the two **Module High Speed Automatic Inline** tools, one has a 10-second cycle time and the other 28 seconds. The other three, prefixed as the Module Automatic Inline models, either take 45, 70 or 90 seconds to inspect a module in an inline configuration.

While the two models in the **Module Basic Inline/Offline** series can either be used as inline or manual tools, they are mainly designed for manual operation in module factories. The major difference between them is the image resolution, with either 8.6 megapixels or 4.3. Both have the same maximum throughput of 120 modules per hour. They are not offered with defect-detection software, thus leaving the job of analyzing the produced images to the operator.

Pi4_robotics has also developed two stand-alone systems, designated as **Module Economic Offline**, purely for offline applications. The company says these are the most cost-effective solutions it offers as they can provide high-resolution images with up to 72 megapixels and can be integrated with an automatic defect-detection algorithm. One has a 30-second cycle time and the other a 60-second cycle time. Both are capable of characterizing thin-film modules as well.

For string inspections, Pi4_robotics is offering three tools – the **string inspection, string inspection & alignment** and **String Inspection High Speed**. The first two have the same throughput of 360 strings per hour but with differing resolutions of 1.44 megapixels or 8. The high-speed version is rated with a lower cycle time of 3 seconds, which accounts for a nominal throughput of 1,200 strings per hour at a 1.44 megapixel resolution.

text continues on p. 165 ▶▶

Luminescence imaging systems

Company	3i Systems	3i Systems	3i Systems	3i Systems
model	PL-A56	EL-A56	PL-I56	SE-A56
market introduction	2009	2009	2010	2010
Type of measurement				
electro- or photoluminescence	photoluminescence	electroluminescence	photoluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	156 × 156 mm / 160 - 220 µm	156 × 156 mm / 160 - 220 µm	156 × 156 mm / 160 - 220 µm	156 × 156 mm / 160 - 220 µm
cell type	multi, mono	multi, mono	multi, mono	multi, mono
max. module dimensions	–	–	–	–
Cell parameters				
microcrack / false detection rate	yes / < 2%	yes / < 2%	yes / < 2%	yes / < 2% (with EL option)
shunts / shunts & series resistance auto. distinction	– / –	yes / –	– / –	yes / –
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	no	no	no	no
other possible measurements	black cone, black edge	black cone, black edge	black cone, black edge	black cone, black edge
String & module parameters				
microcrack / false detection rate	– / –	– / –	– / –	– / –
other possible measurements	–	–	–	–
Input for photoluminescence				
type of light / wavelength	laser, monochromatic / 808 nm	– / –	laser, monochromatic / 808 nm	– / –
max. area of homogeneous illumination	170 × 170 mm*1	–	170 × 170 mm*1	–
Input for electroluminescence				
max. voltage / current	– / –	-18 - 18 V / -10 - 10 A	– / –	-18 - 18 V / -10 - 10 A
Imaging system				
camera manufacturer	–	–	–	–
type of camera	cooled CCD	cooled CCD	cooled CCD	cooled CCD
type of sensor	–	–	–	–
resolution	1,024 × 1,024 pixels	1,024 × 1,024 pixels	1,024 × 1,024 pixels	1,024 × 1,024 pixels
pixel size	8 µm	8 µm	8 µm	8 µm
quantum efficiency at 1,000 nm	–	–	–	–
full well capacity	30,000 e-	30,000 e-	30,000 e-	30,000 e-
dark current	–	–	–	–
readout noise	< 1 e- (rms)	< 1 e- (rms)	< 1 e- (rms)	< 1 e- (rms)
cooling method / attainable temperature	Peltier / -20 °C	Peltier / -20 °C	Peltier / -20 °C	Peltier / -20 °C
readout rate	–	–	–	–
dynamic range (A/D converter)	14 bit	14 bit	14 bit	14 bit
min. & max. field view of camera in standard config.	170 × 170 mm*1	170 × 170 mm*1	170 × 170 mm*1	170 × 170 mm*1
possibility to enhance the field view / range	yes / –	yes / –	yes / –	yes / –
typical exposure time	–	–	–	–
System				
automation	manual, inline*2	manual, inline*2	inline*2	manual, inline*2
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
max. / nominal throughput	1,600 / 1,400 cells/h	1,600 / 1,400 cells/h	1,600 / 1,400 cells/h	1,600 / 1,400 cells/h
nominal throughput for strings / modules	– / –	– / –	– / –	– / –
max. throughput for strings / modules	– / –	– / –	– / –	– / –
weight	800 kg	750 kg	400 kg	3,000 kg
dimensions (length × width × height)	1,700 × 1,000 × 1,900 mm	1,700 × 1,000 × 1,900 mm	1,700 × 1,000 × 1,900 mm	5,300 × 1,280 × 1,830 mm*3
certification	CE	CE	CE	CE
Utilities				
power supply (phase / voltage / frequency)	1 Ph, 220 ± 20 V, 50 Hz*3	1 Ph, 220 ± 20 V, 50 Hz*3	1 Ph, 220 ± 20 V, 50 Hz*3	1 Ph, 220 ± 20 V, 50 Hz*4
max. power	1,600 W	1,600 W	1,600 W	4,300 W
ambience (humidity / temperature)	< 75% / 0 - 40 °C	< 75% / 0 - 40 °C	< 75% / 0 - 40 °C	< 75% / 0 - 40 °C
System control & software				
computer hardware	PC	PC	PC	PC
PC interface	USB, RS232	USB, RS232	USB, RS232	USB, RS232
compatible data formats	jpg	jpg	jpg	jpg
software allows remote machine operation	yes	yes	yes	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	3 months	3 months	3 months	3.5 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	$300,000 - $550,000	$250,000 - $500,000	$200,000 - $300,000	$450,000 - $650,000

Notes

*1 wider field of view opt.
*2 auto. load, unload, inspect, sort
*3 other power supply opt.

*1 wider field of view opt.
*2 auto. load, unload, inspect, sort
*3 other power supply opt.

*1 wider field of view opt.
*2 auto. load, unload, inspect, sort
*3 other power supply opt.

*1 wider field of view opt.
*2 auto. load, unload, inspect, sort
*3 depend. on no. of bins
*4 other power supply opt.

i Systems	3i Systems	3i Systems	Berger	Berger	BT Imaging
DCF-A56	PL-B56	FL-B01	PSL EL 2	PSL MEL	iLS-W1
010	2011	2011	2009	2010	2011
ectroluminescence	photoluminescence	electro-, photoluminescence	electroluminescence	electroluminescence	photoluminescence
56 × 156 mm / 160 - 220 µm	156 × 156 mm / 160 - 220 µm	156 × 156 mm / 160 - 220 µm	210 × 210 mm / –	210 × 210 mm / –	156 × 156 mm / no limit
ulti, mono	multi, mono	multi, mono	multi, mono, multi-junction	multi, mono, multi-junction	multi, mono, UMG, cast mono
–	–	–	–	1,800 × 1,200 mm	–
es / < 2% (with EL option)	yes / < 2%	yes / < 2%	yes / –	yes / –	– / –
es / –	– / –	yes / yes	yes*1 / yes*1	yes*1 / yes*1	– / –
es	yes	yes	yes*1	yes*1	–
o	no	no	yes*1	yes*1	no
lack cone, black edge, color	black cone, black edge, disloc.	black cone, black edge, disloc.	yes*1	yes*1	electrical wafer quality grade*1
– / –	– / –	– / –	– / –	yes / yes	– / –
	–	–	crack detection*2	yes	–
– / –	laser, monochromatic / 808 nm	laser, monochromatic / 808 nm	– / –	NIR / 900 - 1,700 nm	laser, monochromatic / –*2
–	170 × 170 mm*1	170 × 170 mm*1	–	1,800 × 1,200 mm	165 × 165 mm
8 - 18 V / -10 - 10 A	– / –	-18 - 18 V / -10 - 10 A	0 - 5 V / 0 - 10 A (for cells)*3	0 - 150 V / 0 - 40 A	– / –
–	–	–	–	–	–
ooled CCD	cooled CCD	cooled CCD	–	–	–
–	–	–	–	InGaAs	–
024 × 1,024 pixels	1,024 × 1,024 pixels	1,024 × 1,024 pixels	320 × 256, 640 × 512 pixels	640 × 512 pixels	1,024 × 1,024 pixels
8 µm	8 µm	8 µm	30, 25 µm	25 µm	160 µm
–	–	–	~ 70%	~ 70%	–
0,000 e-	30,000 e-	30,000 e-	–	–	–
–	–	–	–	–	–
1 e- (rms)	< 1 e- (rms)	< 1 e- (rms)	–	–	–
eltier / -20 °C	Peltier / -20 °C	Peltier / -20 °C	no cooling / –	internal cooling / –	– / –
–	–	–	–	–*2	–
4 bit	14 bit	14 bit	14 bit	14 bit	16 bit
70 × 170 mm*1	170 × 170 mm*1	170 × 170 mm*1	210 × 210 mm	1,800 × 1,200 mm	165 × 165 mm
es / –	yes / –	yes / –	yes / –	yes / –	no / –
–	–	–	0.03 s	0.03 s	0.5 - 1 s*3
anual, inline*2	manual, inline*2	manual, inline*2	auto. integrated	auto. integrated	auto.
C-mount	C-mount	C-mount	C-mount	C-mount	C-mount
500 / 1,400 cells/h	1,500 / 1,400 cells/h	1,500 / 1,400 cells/h	2,400 / 1,800 cells/h*4	– / –	2,400 / 1,800 - 2,400 wafers/h
– / –	– / –	– / –	– / 50 modules/h*2	– / 50 modules/h*3	– / –
– / –	– / –	– / –	– / 80 modules/h*2	– / 80 modules/h*3	– / –
3,000 kg	3,000 kg	500 kg	< 1 kg	< 1 kg	< 150 kg
3,500 × 1,280 × 1,830 mm*3	3,200 × 1,280 × 1,830 mm*3	600 × 600 × 1,000 mm*3	–	–*4	700 × 350 × 800 mm
E	CE	CE	CE	CE	CE
Ph, 220 ± 20 V, 50 Hz*4	1 Ph, 220 ± 20 V, 50 Hz*4	1 Ph, 220 ± 20 V, 50 Hz*4	1 Ph, 110-220 V, 50-60 Hz	1 Ph, 110-220 V, 50-60 Hz	3 Ph, 380 V, 60 Hz
3,000 W	2,000 W	1,000 W	< 100 W	< 100 W	< 2,000 W
< 75% / 0 - 40 °C	< 75% / 0 - 40 °C	< 75% / 0 - 40 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C
C	PC	PC	PC with RAID drive	PC with RAID drive	PC with RAID drive
SB, RS232	USB, RS232	USB, RS232	Ethernet	Ethernet	Ethernet, USB
g	jpg	jpg	bmp	bmp	jpg, bmp
es	yes	yes	yes	yes	yes
es	yes	yes	yes	yes	yes
year	1 year	1 year	1 year	1 year	1 year
5 months	3.5 months	3 months	1 - 1.5 months	1 - 1.5 months	3 - 4 months
orldwide	worldwide	worldwide	–	–	worldwide
450,000 - $850,000	$300,000 - $450,000	$200,000 - $300,000	≥ €66,000 ($88,200)	≥ €45,000 ($60,100)	~ $250,000 - $300,000

wider field of view opt.	*1 wider field of view opt.	*1 wider field of view opt.	*1 with IV/IR imaging	*1 with IV/IR imaging	*1 using BTI Universal Grading System™
auto. load, unload, inspect, sort	*2 auto. load, unload, inspect, sort	*2 auto. load, unload, inspect, sort	*2 with IV/HV-ISO test	*2 30 Hz	*2 near IR
depend. on no. of bins	*3 depend. on no. of bins	*3 depend. on no. of bins	*3 modules: 0 - 150 V / 0 - 40 A	*3 with IV/HV-ISO test	*3 for wafers
other power supply opt.	*4 other power supply opt.	*4 other power supply opt.	*4 subsystem of IV testing	*4 subsystem of IV testing	

Luminescence imaging systems

Company	Buchanan Systems	Chroma ATE	GPP Chemnitz	GPP Chemnitz
model	EL-MES Cell Tester	7218-M	SolarModuleInspect-EL	SolarCellInspect-EL
market introduction	2010	2009	2009	2008
Type of measurement				
electro- or photoluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	160 × 160 mm / no limit	– / –	– / –	156 × 156 mm / –
cell type	multi, mono	multi, mono	multi, mono	multi, mono
max. module dimensions	–	2,200 × 1,400 mm	1,000 × 2,000 mm*1	–
Cell parameters				
microcrack / false detection rate	yes / 0.1 - 0.5%	– / –	yes / –	yes / –
shunts / shunts & series resistance auto. distinction	yes / –	– / –	yes / –	yes / –
printing defect detection	yes	–	yes	yes
effective lifetime of cells	–	–	–	–
other possible measurements	–	–	opt.	thin-film process steps
String & module parameters				
microcrack / false detection rate	– / –	yes / –	yes / –	yes / –
other possible measurements	–	dark area, cracks, broken fingers	–	film inhomogenities, impurities*1
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	– / –
max. area of homogeneous illumination	–	–	–	–
Input for electroluminescence				
max. voltage / current	32 V / 15 A	100 V / 25 A	12 - 60 V / 15 A	40 V / 19 A
Imaging system				
camera manufacturer	Vision Components	Sensovation	–	–
type of camera	–	CCD	cooled CCD, Peltier	cooled CCD
type of sensor	Sony Exview HAD CCD	–	interline trans., prog. scan CCD	–
resolution	1,280 × 1,024 pixels	3,326 × 2,504 pixels	12,000 × 6,000 pixels	2,000 × 2,000 pixels
pixel size	6.5 µm	5.4 µm	7.4 µm	–
quantum efficiency at 1,000 nm	~ 6%	–	–	–
full well capacity	16,000 e-	25,000 e-	40,000 e-	–
dark current	–	–	–	–
readout noise	–	–	–	–
cooling method / attainable temperature	no cooling / –	passive cooling / –	– / –	– / –
readout rate	max. 14 fps	–*2	14 fps	–
dynamic range (A/D converter)	10 bit	–	14 bit	–
min. & max. field view of camera in standard config.	160 × 160 mm	2,200 × 1,400 mm	–	–
possibility to enhance the field view / range	yes / –	yes*1 / –	– / –	– / –
typical exposure time	5 µs - 17.59 s	2 s	5 µs - 60 s	–
System				
automation	manual	auto.	manual, auto.	manual, auto.
optical interface for lenses	C-mount	C-mount	F-mount, C-mount	F-mount, C-mount
max. / nominal throughput	10 cells/h / –	– / –	– / –	– / –
nominal throughput for strings / modules	– / –	– / 180 modules/h	– / –	– / –
max. throughput for strings / modules	– / –	– / 360 modules/h	– / –	– / –
weight	60 kg	–	150 kg	≤ 35 kg
dimensions (length × width × height)	455 × 520 × 800 mm	117 × 117 × 64 mm	2,000 × 1,500 × 1,500 mm	500 × 500 × 1,100 mm
certification	CE, BGV A3	–	CE	CE
Utilities				
power supply (phase / voltage / frequency)	–, 110-230 V, 50-60 Hz	–, 220 V, –	–, –, –	–, –, –
max. power	400 W	–	–	1,500 W
ambience (humidity / temperature)	< 80% / < 40 °C	– / –	– / –	– / –
System control & software				
computer hardware	PC	industrial PC	PC, industrial PC	PC, industrial PC
PC interface	Ethernet	GigE	USB, Ethernet, RS232	USB, Ethernet, RS232
compatible data formats	csv, txt, bmp, jpg, png	jpg, bmp	bmp, jpg, png	bmp, jpg, png
software allows remote machine operation	yes	yes	yes	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	2 years	1 year	1 year	1 year
time of delivery	3 months	2 - 3 months	2 - 3 months	2 - 3 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€19,000 ($25,400)	$40,000 - $50,000	€50,000 - €120,000 ($66,800 - $160,300)	€60,000 - €80,000 ($80,200 - $106,900)

Notes

*1 depend. on automation
*2 24 MHz

*1 opt. 3,000 × 4,000 mm

*1 doping, structuring problems

GPP Chemnitz	GPP Chemnitz	GPP Chemnitz	Greateyes	Greateyes	Greateyes
SolarModuleInspect-EL	SolarModuleInspect-EL	SolarModuleInspect-ELVIS	LumiSolarProfessional System	LumiSolarProfessional HighRes	LumiSolarCell
2009	2009	2011	2008	2009	2010
electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence	electro-, photoluminescence
– / –	– / –	– / –	> 50 × 50 mm / no limit	> 50 × 50 mm / no limit	200 × 200 mm / no limit
multi, mono	multi, mono	multi, mono	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films
1,300 × 2,000 mm	1,000 × 2,000 mm	1,000 × 2,000 mm	1,000 × 2,000 mm*1	1,000 × 2,000 mm*1	–
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
yes / –	yes / –	yes / –	yes / no	yes / no	yes / no
yes	yes	yes	yes	yes	yes
–	–	–	no	no	no
opt. add.	–	–	thin-film process steps	thin-film process steps	EL: series, shunt resistance
yes / –	yes / –	yes / –	yes / –	yes / –	– / –
–	–	–	film inhomogenities, impurities	film inhomogenities, impurities	–
– / –	– / –	– / –	– / –	– / –	high power LED / 627 nm
–	–	–	–	–	200 × 200 mm
12 - 60 V / 15 A	12 - 60 V / 15 A	-10 - 10 V / -15 - 15 A	0 - 300 V / 0 - 15 A	0 - 300 V / 0 - 15 A	0 - 100 V / 0 - 7.5 A
–	–	–	Greateyes	Greateyes	Greateyes
cooled CCD, Peltier	–	cooled CCD	cooled CCD	cooled CCD	cooled CCD
–	xview HADCCD	–	back-illuminated silicon	back-illuminated silicon	back-illuminated silicon
24,000 × 12,000 pixels	1,388 × 1,038 pixels	–	1,024 × 2,048 pixels	2,048 × 4,096 pixels	1,024 × 1,024 pixels
7.4 µm	6.45 µm	–	25 µm	13.5 µm	13.5 µm
–	–	–	25%	15%	15%
40,000 e-	–	–	700,000 e-	100,000 e-	100,000 e-
–	–	–	0.001 e-/pix.s at -20 °C	1 e-/pix.s at -20 °C	1 e-/pix.s at -20 °C
–	–	–	4 e- (rms)	2 e- (rms)	2 e- (rms)
– / –	– / –	– / –	Peltier / -20 °C	Peltier / -20 °C	Peltier / -20 °C
14 fps	14 fps	14 fps	2 fps	2 fps	2 fps
14 bit	14 bit	14 bit	16 bit	16 bit	16 bit
2,000 × 1,100 mm	–	–	200 × 50, 1,000 × 250 mm	200 × 50, 1,000 × 250 mm	160 × 160 mm
– / –	– / –	– / –	yes / –	yes / –	yes / –
5 µs - 60 s	4 µs - 60 s	–	0.3 s	1 s	5 s
manual	manual, auto.	manual*1	manual loading*2	manual loading*2	manual loading*1
F-mount, C-mount	C-mount	F-mount	M42, Minolta-MD, F-mount	M42, Minolta-MD, F-mount	M42, Minolta-MD, F-mount
– / –	– / –	– / –	– / –	– / –	~ 180 cells/h / –
– / –	– / –	– / –	30 strings/h / 30 modules/h*3	30 strings/h / 30 modules/h*3	– / –
– / –	– / –	– / –	60 strings/h / 60 modules/h*3	60 strings/h / 60 modules/h*3	– / –
280 kg	150 kg	≤ 25 kg	~ 100 kg	~ 100 kg	25 kg
2,400 × 1,800 × 1,500 mm	2,000 × 1,500 × 1,500 mm	2,200 × 950 × 1,100 mm	2,000 × 1,500 × 1,500 mm	2,000 × 1,500 × 1,500 mm	450 × 450 × 1,100 mm
CE	CE	CE	CE	CE	CE
–, –, –	–, –, –	–, –, –	1 Ph, 115-250 V, 60 Hz	1 Ph, 250 V, 60 Hz	1 Ph, 250 V, 60 Hz
–	–	–	1,500 W	1,500 W	1,500 W
– / –	– / –	– / –	< 85% / 10 - 30 °C	< 85% / 10 - 30 °C	< 85% / 10 - 30 °C
PC, industrial PC	PC, industrial PC	PC, industrial PC	PC, industrial PC	PC, industrial PC	PC, industrial PC
USB, Ethernet, RS232	USB, Ethernet, RS232	USB, Ethernet, RS232	USB, RS232	USB, RS232	USB, RS232
bmp, jpg, png	bmp, jpg, png	bmp, jpg, png	bmp, jpg	bmp, jpg	bmp, jpg
yes	yes	yes	yes	yes	yes
yes	yes	yes	yes	yes	yes
1 year	1 year	1 year	1 year	1 year	1 year
2 - 3 months	2 - 3 months	2 - 3 months	2 - 3 months	2 - 3 months	2 - 3 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
≥ €150,000 ($200,400)	≥ €50,000 ($66,800)	≤ €30,000 ($40,100)	€56,000 ($74,800)	€62,000 ($82,800)	€69,000 ($92,200)

*1 mobile

*1 larger opt.
*2 for research and offline inspection
*3 1.65 × 0.8 m

*1 larger opt.
*2 for research and offline inspection
*3 1.7 × 0.8 m

*1 for research and offline inspection

Luminescence imaging systems

Company	Gsolar	Gsolar	Gsolar	Gsolar
model	GEL-C3	GEL-C4	GEL-M2*1	GEL-M4
market introduction	2008	2011	2008	2008
Type of measurement				
electro- or photoluminescence	electroluminescence*1	electroluminescence*1, *2	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	156 × 156 mm / –	156 × 156 mm / –	– / –	– / –
cell type	multi, mono	multi, mono	multi, mono, thin films	multi, mono, thin films
max. module dimensions	–	–	2,000 × 1,000 mm	2,000 × 1,000 mm
Cell parameters				
microcrack / false detection rate	yes / –	yes / –	yes / –	yes / –
shunts / shunts & series resistance auto. distinction	no / no	no / no	no / no	no / no
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	no	no	no	no
other possible measurements	contamination, wafer defects*2	contamination, wafer defects*3	contamination, wafer defects*2	contamination, wafer defects*1
String & module parameters				
microcrack / false detection rate	– / –	– / –	yes / –	yes / –
other possible measurements	–	–	broken fingers, contamination*2	broken fingers, contamination*1
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	– / –
max. area of homogeneous illumination	–	–	–	–
Input for electroluminescence				
max. voltage / current	10 V / 10 A	30 V / 10 A	60 V / 10 A	60 V / 10 A
Imaging system				
camera manufacturer	Gsolar	Gsolar	Gsolar	Gsolar
type of camera	cooled CCD	cooled CCD	cooled CCD	cooled CCD
type of sensor	silicon	silicon	silicon	silicon
resolution	3,328 × 2,030 pixels	3,328 × 2,030 pixels	3,328 × 2,030 pixels	3,328 × 2,030 pixels
pixel size	7.2 µm	7.2 µm	7.2 µm	7.2 µm
quantum efficiency at 1,000 nm	5%	5%	5%	5%
full well capacity	–	–	–	–
dark current	–	–	–	–
readout noise	–	–	–	–
cooling method / attainable temperature	Peltier / -10 °C	Peltier / -10 °C	Peltier / -10 °C	Peltier / -10 °C
readout rate	–	–	–	–
dynamic range (A/D converter)	14 bit	14 bit	14 bit	14 bit
min. & max. field view of camera in standard config.	156 × 156, opt. 210 × 210 mm	156 × 156, opt. 210 × 210 mm	–	–
possibility to enhance the field view / range	yes / –	yes / –	yes / –	yes / –
typical exposure time	< 3 s	< 3 s	< 10 s	< 10 s
System				
automation	manual	manual	manual	manual
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
max. / nominal throughput	720 cells/h / –	720 cells/h / –	– / –	– / –
nominal throughput for strings / modules	– / –	– / –	– / –	– / –
max. throughput for strings / modules	– / –	– / –	– / 120 modules/h	– / 180 modules/h
weight	60 kg	60 kg	700 kg	700 kg
dimensions (length × width × height)	550 × 650 × 1,075 mm	550 × 650 × 1,075 mm	1,650 × 2,200 × 2,750 mm	2,200 × 2,300 × 900 mm
certification	–	–	–	TÜV
Utilities				
power supply (phase / voltage / frequency)	1 Ph, 220 V, –	1 Ph, 220 V, –	1 Ph, 220 V, –	1 Ph, 220 V, –
max. power	–	–	–	–
ambience (humidity / temperature)	> 40% / 10 - 40 °C	> 40% / 10 - 40 °C	> 40% / 10 - 40 °C	> 40% / 10 - 40 °C
System control & software				
computer hardware	PC	PC	PC	PC
PC interface	USB	USB	USB	USB
compatible data formats	bmp, jpg, DEM	bmp, jpg, DEM	bmp, jpg, DEM*2	bmp, jpg, DEM
software allows remote machine operation	opt.	opt.	opt.	opt.
software allows remote machine fault diagnosis	opt.	opt.	opt.	opt.
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	1 month	1 month	1 month	1 month
distribution area	worldwide	worldwide	worldwide	worldwide
price	$35,000	$60,000	$40,000	$40,000

Notes

*1 forward and reverse bias
*2 and sintering defect

*1 forward and reverse bias
*2 + IR imaging
*3 and sintering defect

*1 module face up
*2 proprietary software to mark defect

*1 wafer defect, sintering defect

Gsolar	Gsolar	Gsolar	Gsolar	Gsolar	Gsolar
GEL-M4-900	GEL-M5*1	GEL-M7*1	GEL-M8	GIVE 2214*1, *2	GEL-PL
2011	2010	2010	2012	2010	2012
electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence*3	electro-, photoluminescence
– / –	– / –	– / –	– / –	– / –	160 × 160 mm / –
multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono	multi, mono, thin films	multi, mono
2,000 × 1,200 mm	2,000 × 1,000 mm	2,000 × 1,000 mm	2,000 × 1,200 mm	2,200 × 1,400 mm	–
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
no / no	no / no	no / no	no / no	yes / yes	no / no
yes	yes	yes	yes	yes	yes
no	no	no	no	no	no
contamination, wafer defects*1	contamination, wafer defects*2	contamination, wafer defects*2	contamination, wafer defects*1	contamination, wafer defects*4	contamination, wafer defects*1
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
broken fingers, contamination*1	broken fingers, contamination*2	broken fingers, contamination*2	broken fingers, contamination	–	broken fingers, contamination*1
– / –	– / –	– / –	– / –	– / –	– / –
–	–	–	–	–	200 × 200 mm
60 V / 10 A	60 V / 10 A	60 V / 10 A	60V / 10 A	60 V / 10 A	10 V / 10 A
Gsolar	Gsolar	Gsolar	Gsolar	Gsolar	Gsolar
cooled CCD	cooled CCD	cooled CCD	cooled CCD	cooled CCD	cooled CCD
silicon	silicon	silicon	silicon	silicon	silicon
3,386 × 3,108 pixels	3,328 × 2,030 pixels	3,000 × 4,000, 6,000 pixels	2 × (3,328 × 2,030 pixels)*2	3,000 × 4,000, 6,000 pixels	3,103 × 3,086 pixels
7.2 µm	7.2 µm	7.2 µm	7.2 µm	7.2 µm	7.2 µm
5%	5%	5%	5%	5%	5%
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
Peltier / -10 °C	Peltier / -10 °C	Peltier / -10 °C	Peltier / -10 °C	Peltier / -10 °C	Peltier / -10 °C
–	–	–	–	–	–
14 bit	14 bit	14 bit	14 bit	14 bit	14 bit
–	–	156 × 156, opt. 210 × 210 mm	–	–	156 × 156, opt. 210 × 210 mm
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
< 5 s	< 10 s	< 5 s	< 10 s	< 10 s	< 2 s
manual	auto.	manual, auto.	manual	manual, auto.	manual
C-mount	C-mount	C-mount	C-mount	C-mount	C-mount
– / –	– / –	– / –	– / –	– / –	360 substrates/h / –
– / –	– / –	– / –	– / –	– / –	– / –
– / 240 modules/h	– / 120 modules/h	– / 120 modules/h	– / 120 modules/h	– / 120 modules/h	– / –
700 kg	750 kg	750 kg	1,000 kg	1,200 kg	350 kg
2,000 × 1,850 × 1,050 mm	2,200 × 2,300 × 1,200 mm	2,200 × 2,300 × 900 mm	2,500 × 1,500 × 1,500 mm	2,300 × 2,600 × 4,000 mm	1,300 × 700 × 1,660 mm
TÜV	–	–	TÜV	–	TÜV
1 Ph, 220 V, –	1 Ph, 220 V, –	1 Ph, 220 V, –	1 Ph, 220 V, –	1 Ph, 220 V, –	1 Ph, 220 V, –
–	–	–	3,000 W	–	2,000 W
> 40% / 10 - 40 °C	> 40% / 10 - 40 °C	> 40% / 10 - 40 °C	> 40% / 10 - 40 °C	> 40% / 10 - 40 °C	> 40% / 10 - 40 °C
PC	PC	PC	PC	PC	PC
USB	USB	USB	USB	USB	USB
bmp, jpg, DEM	bmp, jpg, DEM	bmp, jpg, DEM	bmp, jpg, DEM	bmp, jpg, DEM	bmp, jpg, DEM*1
opt.	opt.	opt.	opt.	opt.	opt.
opt.	opt.	opt.	opt.	opt.	opt.
1 year	1 year	1 year	1 year	1 year	1 year
1 month	1 month	1 month	1 month	1 month	1 month
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
$53,000	$60,000	$65,000	$160,000	$150,000	

wafer defect, sintering defect	*1 conveyor inside *2 wafer defect, sintering defect	*1 has two cameras *2 wafer defect, sintering defect	*1 and sintering defect *2 two cameras	*1 has two functions: flash test and EL test *2 GIVE means IV+EL *3 + IV measurement *4 wafer defect, sintering defect	*1 proprietary software to mark defect

Luminescence imaging systems

Company	Hamamatsu Photonics	Intevac	Komax Solar	Komax Solar
model	EPLI (EL/PL Analyzer)	NanoVista™	X1000s EL string tester	X3000s EL string tester
market introduction	2009	2011	2010	2008
Type of measurement				
electro- or photoluminescence	electro-, photoluminescence*1	photoluminescence	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	200 × 200 mm / –	156 × 156 mm / –	156 × 156 mm / no limit	156 × 156 mm / no limit
cell type	multi, mono, thin films	multi, mono, cast mono	mono, multi, UMG	mono, multi, UMG
max. module dimensions	–	–	156 × 2,025 mm (strings)	156 × 2,065 mm (strings)
Cell parameters				
microcrack / false detection rate	yes / –	– / –	yes / –	yes / –
shunts / shunts & series resistance auto. distinction	yes / –	– / –	no / no	no / no
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	–	yes	no	no
other possible measurements	carrier lifetime, series resist.*2	dislocations, grain boundaries*1	inactive areas	inactive areas
String & module parameters				
microcrack / false detection rate	– / –	– / –	yes / –	yes / –
other possible measurements	–	–	–	IV curve
Input for photoluminescence				
type of light / wavelength	laser, monochromatic / 810 nm	– / 808 nm	– / –	– / –
max. area of homogeneous illumination	200 × 200 mm	210 × 210 mm	–	–
Input for electroluminescence				
max. voltage / current	60 V / 12 A	– / –	24 V / 25 A	60 V / 10 A
Imaging system				
camera manufacturer	Hamamatsu Photonics	Intevac	–	–
type of camera	InGaAs*4	depend on cust.	passive-cooled CCD	NIR-sensitive cooled CCD
type of sensor	InGaAs focal plane array	EBAPS	–	–
resolution	320 × 256, 640 × 512 pixels	1,280 × 1,024 pixels	1.3 megapixels*1	1.4 megapixels*1
pixel size	30, 20 µm	–	3.75 µm	6.45 µm
quantum efficiency at 1,000 nm	–*3	25%	–	–
full well capacity	–	–	7,000 e-	18,000 e-
dark current	–*3	–	–	–
readout noise	–	–	–	4.5 e- (rms)
cooling method / attainable temperature	Peltier / -70 °C	– / –	Peltier / –	Peltier / -12 °C
readout rate	60, 1.6 fps	–	–	–*4
dynamic range (A/D converter)	14, 12 bit	–	12 bit	12 bit
min. & max. field view of camera in standard config.	depend. on lens	170 × 170 mm	500 × 370 mm	170 × 170 mm
possibility to enhance the field view / range	– / –	– / –	– / –	yes / –
typical exposure time	depend. on applic.	1 ms - 1 s	2 - 5 s	0.5 s
System				
automation	manual	manual, inline	manual	–*2
optical interface for lenses	C-mount	–	C-mount	C-mount
max. / nominal throughput	– / –	3,000 wafers/h / –	– / –	– / –
nominal throughput for strings / modules	– / –	– / –	– / –	– / –
max. throughput for strings / modules	– / –	– / –	– / –*2	– / –*3
weight	~ 250 kg	70 kg	200 kg	500 kg
dimensions (length × width × height)	780 × 980 × 1,900 mm	1,100 × 1,000 × 1,800 mm	2,120 × 500 × 1,010 mm	2,500 × 915 × 1,150 mm
certification	CE	FDA, CE (in progress)	CE	CE
Utilities				
power supply (phase / voltage / frequency)	–, 230 V, 50-60 Hz	1-2 Ph, 200-240 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz
max. power	< 3,000 W	< 2,000 W	3,000 W	3,000 W
ambience (humidity / temperature)	30 - 70% / 10 - 30 °C	< 80% / < 30 °C	10 - 90% / 10 - 30 °C	10 - 90% / 15 - 35 °C
System control & software				
computer hardware	PC, industrial PC	industrial PC	PC	industrial PC
PC interface	USB, RS232, Ethernet	Ethernet, USB	Ethernet, USB	Ethernet, USB
compatible data formats	bmp, jpg, tiff, csv ,png	txt, jpg, png, tiff	png, xml	png, xml, csv
software allows remote machine operation	yes	–	no	yes
software allows remote machine fault diagnosis	yes	–	no	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	3 months	3 months	2 months	2 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€72,000 - €340,000 ($96,200 - $454,300)	$250,000	€30,000 ($40,100)	€45,000 - €105,000 ($60,100 - $140,300)

Notes

*1 with & without IV
*2 and spectroscopic EL/PL imaging
*3 unique InGaAs sensor optimized for low noise
*4 opt. cooling and non-cooling

*1 edge impurities

*1 per two solar cells
*2 stand-alone

*1 per solar cell
*2 opt. auto. defect detection
*3 stand-alone
*4 16 MHz

Komax Solar	Komax Solar	Komax Solar	Komax Solar	Komax Solar	Komax Solar
X3500i EL string tester	X2000s EL module tester	X2000i EL module tester	X4000s EL module tester	X4000i EL module tester	X4200i EL module tester
2009	2010	2010	2009	2009	2010
electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit
mono, multi, UMG	mono, multi, UMG	mono, multi, UMG	mono, multi, UMG	mono, multi, UMG	mono, multi, UMG
156 × 2,164 mm (strings)	1,050 × 2,000 mm	1,050 × 2,000 mm	1,050 × 2,000 mm	1,050 × 2,000 mm	1,300 × 2,000 mm
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
no / no	no / no	no / no	no / no	no / no	no / no
yes	yes	yes	yes	yes	yes
no	no	no	no	no	no
inactive areas	inactive areas	inactive areas	inactive areas	inactive areas	inactive areas
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
IV curve, backlight	–	–	IV curve, backlight	IV curve, backlight	–
– / –	– / –	– / –	– / –	– / –	– / –
–	–	–	–	–	–
60 V / 10 A	60 V / 25 A	60 V / 25 A	60 V / 10 A	60 V / 10 A	75 V / 10 A
–	–	–	–	–	–
NIR-sensitive cooled CCD	active-cooled CCD	active-cooled CCD	NIR-sensitive	NIR-sensitive	NIR-sensitive
–	–	–	–	–	–
8 megapixels*1	1.4 megapixels*1	1.4 megapixels*1	1.4 megapixels*1	1.4 megapixels*1	1.4 megapixels*1
10 µm	6.45 µm	6.45 µm	6.45 µm	6.45 µm	6.45 µm
–	–	–	–	–	–
–	18,000 e-	18,000 e-	18,000 e-	18,000 e-	18,000 e-
–	–	–	–	–	–
–	–	–	5 e- (rms)	5 e- (rms)	5 e- (rms)
– / –	Peltier / –	Peltier / –	– / –	– / –	– / –
–*2	–	–	–	–	–
12 bit	12 bit	12 bit	12 bit	12 bit	12 bit
360 × 230 mm	1,300 × 1,000 mm	1,300 × 1,000 mm	550 × 410 mm	550 × 410 mm	550 × 410, 180 × 180 mm
yes / –	– / –	– / –	yes / –	yes / –	yes / –
0.8 s	5 - 10 s	5 - 10 s	2 - 5 s	2 - 5 s	2 - 5 s
inline*4	manual	inline*3	–*2	inline*3	inline*3
C-mount	C-mount	C-mount	C-mount	C-mount	C-mount
– / –*2	– / –	– / –*2	– / –	– / –*2	– / –*2
– / –	– / –	– / –	– / –	– / –	– / –
120, 240 strings/h / –	– / –*2	– / 80 modules/h	– / –	– / 80 modules/h	– / 80 modules/h
350 kg	400 kg	400 kg	650 kg	850 kg	850 kg
2,500 × 470 × 1,150 mm	2,100 × 1,200 × 1,070 mm	2,100 × 1,200 × 1,070 mm	2,990 × 1,570 × 1,212 mm	2,570 × 1,570 × 1,247 mm	2,570 × 1,570 × 1,247 mm
CE	CE	CE	CE	CE	CE
1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz
3,000 W	3,000 W	3,000 W	3,000 W	3,000 W	3,000 W
10 - 90% / 15 - 35 °C	10 - 90% / 10 - 30 °C	10 - 90% / 10 - 30 °C	10 - 90% / 15 - 35 °C	10 - 90% / 15 - 35 °C	10 - 90% / 15 - 35 °C
industrial PC	PC	PC	industrial PC	industrial PC	industrial PC
Ethernet, USB	Ethernet, USB	Ethernet, USB	Ethernet, USB	Ethernet, USB	Ethernet, USB
png, xml, csv	png, xml	png, xml	png, xml, csv	png, xml, csv	png, xml, csv
yes	no	no	yes	yes	yes
yes	no	no	yes	yes	yes
1 year	1 year	1 year	1 year	1 year	1 year
2 months	2 months	2 months	2 months	2 months	2 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€90,000 - €120,000 ($106,900 - $160,300)	€30,000 ($40,100)	€30,000 - €45,000 ($40,100 - $60,100)	€50,000 - €110,000 ($66,800 - $147,000)	€65,000 - €165,000 ($86,800 - $220,400)	€80,000 - €180,000 ($106,900 - $240,500)

*1 per two solar cells
*2 25 to 50 MW
*3 25 MHz
*4 software detection

*1 per 36 solar cells
*2 stand-alone

*1 per 36 solar cells
*2 50 MW
*3 opt. software detection

*1 per solar cell or six cells
*2 opt. software detection

*1 per solar cell or six cells
*2 50 to 100 MW
*3 opt. software detection

*1 per solar cell or six cells
*2 75 to 150 MW
*3 opt. software detection

Luminescence imaging systems

Company	Komax Solar	Komax Solar	Komax Solar	Manz Automation
model	X4800i EL thermo module tester	X5000i thinfilm module tester	X6000i EL tower flasher	Manz EL 2400*1
market introduction	2012	2011	2012	2008
Type of measurement				
electro- or photoluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	156 × 156 mm / no limit	– / –	156 × 156 mm / no limit	156 × 156 mm*2 / no limit
cell type	mono, multi, UMG	thin films	mono, multi, UMG	multi, mono
max. module dimensions	1,300 × 2,000 mm	1,000 × 1,600 mm	1,300 × 2,000 mm	–
Cell parameters				
microcrack / false detection rate	yes / –	– / –	yes / –	yes / < 0.2%
shunts / shunts & series resistance auto. distinction	yes / –	yes / –	no / no	yes*3 / yes*3
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	no	no	no	no
other possible measurements	inactive areas	inactive areas	inactive areas	dark areas, firing defects, disloc.
String & module parameters				
microcrack / false detection rate	yes / –	– / –	yes / –	– / –
other possible measurements	thermography	–	AAA sun simulation	–
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	– / –
max. area of homogeneous illumination	–	–	–	–
Input for electroluminescence				
max. voltage / current	75 V / 10 A	80, 150 V / 9.5, 5 A	75 V / 10 A	max. 16 V / 20 A
Imaging system				
camera manufacturer	–	–	–	–
type of camera	NIR-sensitive	active-cooled CCD	NIR-sensitive	cooled CCD
type of sensor	–	–	–	silicon area scan
resolution	1.4 megapixels*1	1.4 megapixels	1.4 megapixels	1,024 × 1,024 pixels
pixel size	6.45 µm	6.45 µm	6.45 µm	–
quantum efficiency at 1,000 nm	–	–	–	> 30%
full well capacity	18,000 e-	18,000 e-	18,000 e-	–
dark current	–	–	–	–
readout noise	5 e- (rms)	2.4 e- (rms)	5 e- (rms)	–
cooling method / attainable temperature	– / –	Peltier / -20 °C	– / –	– / –
readout rate	–	–	–	–
dynamic range (A/D converter)	12 bit	12 bit	12 bit	–
min. & max. field view of camera in standard config.	550 × 410 mm	540 × 410 mm	1,270 × 1,970 mm	130 × 130 - 160 × 160 mm
possibility to enhance the field view / range	yes / –	yes / –	yes / –	yes / –
typical exposure time	2 - 5 s	2 - 20 s	2 - 5 s	0.3 s
System				
automation	inline	inline	inline	inline
optical interface for lenses	C-mount	C-mount	C-mount	–
max. / nominal throughput	– / –*2	– / –	– / –*1	– / 2,400 cells/h
nominal throughput for strings / modules	– / –	– / –	– / –	– / –
max. throughput for strings / modules	– / 80 modules/h	– / 80 modules/h	– / 40 modules/h	– / –
weight	850 kg	850 kg	850 kg	2,500 kg*4
dimensions (length × width × height)	2,570 × 1,570 × 2,900 mm	2,570 × 1,570 × 1,247 mm	2,570 × 1,570 × 5,160 mm	> 4,200 × 2,000 × 2,800 mm*4
certification	CE	CE	CE	CE
Utilities				
power supply (phase / voltage / frequency)	1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz	1 Ph, 230 V, 50/60 Hz	–, 400 V, 50 Hz
max. power	3,000 W	3,000 W	1,000 W	2,500 W
ambience (humidity / temperature)	10 - 90% / 15 - 35 °C	10 - 90% / 15 - 35 °C	10 - 90% / 15 - 35 °C	0 - 90% / –
System control & software				
computer hardware	industrial PC	industrial PC	industrial PC	industrial PC
PC interface	Ethernet, USB	Ethernet, USB	Ethernet, USB	Ethernet
compatible data formats	png, xml, csv	png, xml, csv	png, xml, csv	tiff, bmp, png
software allows remote machine operation	yes	yes	yes	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	2 months	2 months	2 months	3 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€90,000 - €140,000 ($120,200 - $187,000)	€70,000 - €170,000 ($93,500 - $227,100)	€65,000 - €115,000*2 ($86,800 - $153,600)	€103,000 ($137,600)

Notes

*1 per solar cell or six cells
*2 50 to 100 MW

*1 50 MW
*2 not incl. flasher price

*1 only with Manz's ICT 2400 cell tester
*2 or 125 × 125 mm
*3 multi-sensor data fusion
*4 total cell tester

MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions
SolarModule EL-Basic*1	SolarModule EL-Lab*1	SolarModule EL-Inline*1	SolarModule EL-quickcheck*1	SolarModule EL-flash	SolarString EL-Basic
2010	2010	2010	2010	2010	2010
electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
no limit / no limit	no limit / no limit	no limit / no limit	no limit / no limit	no limit / no limit	– / –
multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films
1,000 × 2,000 mm	1,000 × 2,000 mm	1,000 × 2,000 mm	1,000 × 2,000 mm	1,300 × 2,000 mm	–*1
yes / –	yes / –	yes / –	– / –	– / –	yes / –
yes / no	yes / no	yes / no	yes / no	– / –	yes / no
yes	yes	yes	–	–	yes
no	no	no	–	–	no
–	–	–	–	–	–
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
geometry	geometry	geometry	–	–	geometry
– / –	– / –	– / –	– / –	– / –	– / –
–	–	–	–	–	–
0 - 70 V / 0 - 20 A	0 - 70 V / 0 - 20 A	0 - 70 V / 0 - 20 A	0 - 70 V / 0 - 20 A	0 - 70 V / 0 - 20 A*1	0 - 10 V / 0 - 20 A
MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions
cooled CCD	cooled CCD	cooled CCD	cooled CCD	cooled CCD	CCD
silicon	silicon	silicon	silicon	silicon	silicon
6,000 × 12,000 pixels*2, *3	6,000 × 12,000 pixels*2, *3	6,000 × 12,000 pixels*2, *3	1,900 × 3,800 pixels*3	2,400 × 4,000 pixels*2, *3	960 × 12,000 pixels*2, *3
6.45 µm	3.75 µm	6.45 µm	3.75 µm	3.45 µm	3.75 µm
10%*4	8%*4	10%*4	8%*3	8%*4	8%*4
19,000 e-	7,000 e-	19,000 e-	7,000 e-	7,000 e-	7,000 e-
–	–	–	–	–	–
6 e- (rms)	–	6 e- (rms)	–	–	–
Peltier / 10 - 30 °C < ambient	Peltier / 10 - 30 °C < ambient	Peltier / 10 - 30 °C < ambient	Peltier / 10 - 30 °C < ambient	Peltier / 10 - 30 °C < ambient	passive / –
–	–	–	–	–	–
12 bit	12 bit	12 bit	12 bit	12 bit	12 bit
–	–	–	–	–	–
no / –	no / –	no / –	no / –	no / –	yes / –
–	–	–	4 s	4 s	2 - 4 s
manual	manual	manual, auto.	manual	manual	manual, auto.
C-mount	C-mount	C-mount	C-mount	C-mount	C-mount
– / –	– / –	– / –	– / –	– / –	– / –
– / 60 modules/h	– / 30 modules/h	– / 60 modules/h	– / 60 modules/h	– / 60 modules/h	180 strings/h / –
– / 60 modules/h	– / 30 modules/h	– / 72 modules/h	– / 120 modules/h	– / 120 modules/h	180 strings/h / –
550 kg	550 kg	550 kg	400 kg	–	200 kg
2,415 × 1,200 × 1,245 mm	2,415 × 1,200 × 1,245 mm	2,415 × 1,200 × 1,245 mm	2,100 × 1,200 × 1,070 mm	–	2,120 × 500 × 1,245 mm
CE	CE	CE	CE	CE	CE
3 Ph, 400 V, 50-60 Hz	3 Ph, 400 V, 50-60 Hz	3 Ph, 400 V, 50-60 Hz	1 Ph, 230 V, 50-60 Hz	1 Ph, 230 V, 50-60 Hz	1 Ph, 110-230 V, 50-60 Hz
2,000 W	2,000 W	2,000 W	900 W	900 W	700 W
20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C
PC	PC	PC	PC	PC	PC
USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet
xml, jpg	xml, jpg	xml, jpg	xml, jpg	xml, jpg	xml, jpg
yes	yes	yes	no	no	no
yes	yes	yes	yes	yes	yes
1 year	1 year	1 year	1 year	1 year	1 year
2 - 3 months	2 - 3 months	2 - 3 months	2 - 3 months	2 - 3 months	2 - 3 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€50,300 ($80,600)	€48,500 ($64,800)	€54,400 - €78,000 ($86,000 - $104,200)	€29,800 ($39,800)	€27,000 - €48,000 ($36,100 - $64,100)	€36,400 ($48,600)
*1 before and after lamination *2 multi-camera system *3 cameras moving *4 at 900 nm	*1 before and after lamination *2 multi-camera system *3 cameras moving *4 at 900 nm	*1 before and after lamination *2 multi-camera system *3 cameras moving *4 at 900 nm	*1 before and after lamination *2 multi-camera system *3 at 900 nm	*1 opt. 0 - 200 V / 0 - 20 A *2 multi-camera system *3 cameras fixed *4 at 900 nm	*1 length 2,000 mm *2 multi-camera system *3 cameras fixed *4 at 900 nm

Luminescence imaging systems

Company	MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions
model	SolarCell EL-Basic	SolarModule EL-Inline25*1	SolarModule EL-quickline*1	SolarModule TF-inline*1
market introduction	2009	2011	2011	2011
Type of measurement				
electro- or photoluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	156 × 156 mm / –	no limit / no limit	no limit / no limit	no limit / no limit
cell type	multi, mono	multi, mono, thin films	multi, mono, thin films	thin films
max. module dimensions	–	1,000 × 2,000 mm	1,000 × 2,000 mm	1,100 × 1,300 mm
Cell parameters				
microcrack / false detection rate	– / –	yes / –	– / –	– / –
shunts / shunts & series resistance auto. distinction	– / –	yes / no	yes / no	yes / no
printing defect detection	–	yes	–	–
effective lifetime of cells	–	no	–	no
other possible measurements	–	–	–	scribe defects
String & module parameters				
microcrack / false detection rate	yes / –	yes / –	yes / –	– / –
other possible measurements	–	geometry	–	–
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	– / –
max. area of homogeneous illumination	–	–	–	–
Input for electroluminescence				
max. voltage / current	0 - 10 V / 0 - 20 A	0 - 70 V / 0 - 20 A	0 - 70 V / 0 - 20 A	0 - 220 V / 0 - 14 A
Imaging system				
camera manufacturer	MBJ Solutions	MBJ Solutions	MBJ Solutions	MBJ Solutions
type of camera	cooled CCD	cooled CCD	cooled CCD	cooled CCD
type of sensor	silicon	silicon	silicon	silicon
resolution	1,392 × 1,040 pixels	6,000 × 12,000 pixels*2, *3	1,900 × 3,800 pixels*2	5,100 × 6,000 pixels*2, *3
pixel size	6.45 µm	3.75 µm	3.75 µm	6.45 µm
quantum efficiency at 1,000 nm	10%*1	8%*4	8%*3	10%*4
full well capacity	19,000 e-	7,000 e-	7,000 e-	19,000 e-
dark current	–	–	–	–
readout noise	–	–	–	6 e- (rms)
cooling method / attainable temperature	Peltier / 10 °C < ambient	Peltier / 10 - 30 °C < ambient	Peltier / 10 - 30 °C < ambient	Peltier / 10 - 30 °C < ambient
readout rate	–	–	–	–
dynamic range (A/D converter)	12 bit	12 bit	12 bit	12 bit
min. & max. field view of camera in standard config.	–	–	–	–
possibility to enhance the field view / range	yes / –	no / –	no / –	no / –
typical exposure time	0.5 - 4 s	–	4 s	–
System				
automation	manual	manual, auto.	manual	manual, auto.
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
max. / nominal throughput	600 cells/h / –	– / –	– / –	– / –
nominal throughput for strings / modules	– / –	– / 60 modules/h	– / 60 modules/h	– / 60 modules/h
max. throughput for strings / modules	– / –	– / 72 modules/h	– / 120 modules/h	– / 72 modules/h
weight	30 kg	550 kg	400 kg	350 kg
dimensions (length × width × height)	360 × 675 × 515 mm	2,415 × 1,200 × 1,245 mm	2,100 × 1,200 × 1,070 mm	1,500 × 1,020 × 1,140 mm
certification	CE	CE	CE	CE
Utilities				
power supply (phase / voltage / frequency)	1 Ph, 110-230 V, 50-60 Hz	3 Ph, 400 V, 50-60 Hz	1 Ph, 230 V, 50-60 Hz	1 Ph, 230 V, 50-60 Hz
max. power	400 W	2,000 W	900 W	2,000 W
ambience (humidity / temperature)	20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C	20 - 70% / 10 - 30 °C
System control & software				
computer hardware	PC	PC	PC	PC
PC interface	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet
compatible data formats	jpg, bmp	xml, jpg	xml, jpg	xml, jpg
software allows remote machine operation	no	yes	no	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	2 - 3 months	2 - 3 months	2 - 3 months	2 - 3 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€18,900 ($25,300)	€52,600 - €58,000 ($70,300 - $77,500)	€41,200 - €47,000 ($55,000 - $62,800)	€62,500 - €72,500 ($83,500 - $96,900)
Notes	*1 at 900 nm	*1 before and after lamination *2 multi-camera system *3 cameras moving *4 at 900 nm	*1 before and after lamination *2 multi-camera system *3 at 900 nm	*1 before and after lamination *2 multi-camera system *3 cameras moving *4 at 900 nm

MBJ Solutions	McScience	Nisshinbo Mechatronics	Nisshinbo Mechatronics	Nisshinbo Mechatronics	Nisshinbo Mechatronics
Module TF-Lab*1	K3300	PVE1116i-S	PVE1116i-M	PVE1120i-T	PVE1020i-MTW
	2008*1	2008	2008	2009	2011
electroluminescence	electro-, photoluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
limit / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit
films	multi, mono	multi, mono	multi, mono	multi, mono	multi, mono
100 × 1,300 mm	1,000 × 2,000 mm	1,100 × 1,600 mm	1,100 × 1,600 mm	1,100 × 2,000 mm	1,000 × 2,000 mm
– / –	yes / –	– / –	– / –	– / –	– / –
yes / no	– / –	no / no	no / no	no / no	no / no
	yes	yes	yes	yes	yes
no	–	no	no	no	no
cribe defects	forward, reverse IV	yes	yes	yes	yes
– / –	yes / –	yes / –	yes / –	yes / –	yes / –
	–	yes	yes	yes	yes
– / –	laser / –	– / –	– / –	– / –	– / –
	200 × 200 mm	–	–	–	–
0 - 220 V / 0 - 14 A	-10 - 10 V / -15 - 15 A	150 V / 10 A	150 V / 10 A	150 V / 10 A	80 V / 10 A
MBJ Solutions	–	–	–	–	–
ooled CCD	Si CCD	cooled CCD	cooled CCD	CCD	CCD
icon	high sensitivity type	–	–	–	–
100 × 6,000 pixels*2, *3	1.4 megapixels	1,000 × 1,000 pixels	1,000 × 1,000 pixels	1,040 × 1,392*1 pixels	2,672 × 4,000*1 pixels
45 µm	< 10 µm	–*1	–*1	–*2	–*2
80% *4	–	–	–	–	–
3,000 e-	–	–	–	–	–
	–	–	–	–	–
e- (rms)	–	–	–	–	–
eltier / 10 - 30 °C < ambient	– / –	– / –	– / –	– / –	– / –
	20 fps	–	–	–	–
12 bit	12 bit	–	–	–	–
	–	1,100 × 1,600 mm	400 × 400 mm	600 × 800 mm	800 × 1,000 mm
no / –	yes / –	yes / –	yes / –	yes / –	yes / –
	0.5 s	5 s	1.5 s	3 s	5 s
manual, auto.	manual, auto.	auto.	auto.	auto.	auto.
C-mount	C-mount	C-mount	C-mount	C-mount	F-mount
– / –	1,200 cells/h / –	– / –	– / –	– / –	– / –
– / 40 modules/h	– / 60 modules/h	– / 90 modules/h	– / 45 modules/h	– / 80 modules/h	– / 60 modules/h
– / 40 modules/h	– / 70 modules/h	– / –	– / –	– / –	– / –
350 kg	< 100 kg	850 kg	1,600 kg	1,400 kg	1,200 kg
1,500 × 1,020 × 1,140 mm	2,000 × 1,500 × 1,500 mm	3,100 × 1,900 × 980 mm	3,302 × 1,750 × 950 mm	3,450 × 1,605 × 1,370 mm	3,010 × 1,810 × 1,310 mm
CE	CE	–	–	CE	–
1 Ph, 230 V, 50-60 Hz	–, 220 V, –	3 Ph, 200 V, 50/60 Hz	3 Ph, 200 V, 50/60 Hz	3 Ph, 200 V, 50/60 Hz	3 Ph, 200 V, 50/60 Hz
2,000 W	< 2,000 W	–	–	–	–
20 - 70% / 10 - 30 °C	< 80% / < 30 °C	20 - 80% / 15 - 35 °C	20 - 80% / 15 - 35 °C	20 - 80% / 15 - 35 °C	20 - 80% / 15 - 35 °C
PC	PC, industrial PC	PC with RAID drive + PLC	PC with RAID drive + PLC	PC with RAID drive + PLC	PC with RAID drive + PLC
USB, Ethernet	Ethernet, RS232	USB, Ethernet, RS232C	USB, Ethernet, RS232C	USB, Ethernet, RS232C	USB, Ethernet, RS232C
xml, jpg	bmp, jpg	bmp, jpg	bmp, jpg	bmp, jpg	bmp, jpg
yes	yes	no	no	no	no
yes	yes	no	no	no	no
1 year	1 year	1 year	1 year	1 year	1 year
2 - 3 months	< 3 months	3 - 4 months	3 - 4 months	3 - 4 months	3 - 4 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€54,500 ($72,800)	$90,000	¥30 mn ($385,500)	¥32 mn ($411,200)	¥28 mn ($359,800)	¥8 mn ($102,800)

*1 before and after lamination
*2 multi-camera system
*3 cameras moving
*4 at 900 nm

*1 1.7 mm/pixel

*1 0.4 mm/pixel

*1 using movable mechanism, three cameras
*2 0.6 mm/pixel

*1 using movable mechanism
*2 0.3 mm/pixel

Luminescence imaging systems

Company	Op-tection	Op-tection	Op-tection	Op-tection
model	OSIS Cell (mc)	OSIS Cell automatic contacting	OSIS Cell EL-inline	OSIS Sorter Cell-1800
market introduction	2009	2009	2009	2009
Type of measurement				
electro- or photoluminescence	electroluminescence	electroluminescence	electroluminescence	electro-, photoluminescence
Substrate				
max. cell dimensions / thickness	156 × 156 mm / 300 µm	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit
cell type	multi, mono, quasimono	multi, mono, quasimono	multi, mono, quasimono	multi, mono, quasimono
max. module dimensions	–	–	–	–
Cell parameters				
microcrack / false detection rate	yes / –	yes / –	yes / –	yes / –
shunts / shunts & series resistance auto. distinction	yes / –	yes / –	yes / –	yes / –
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	no	no	no	no
other possible measurements	integral intensity, dislocations*1	integral intensity, dislocations*1	integral intensity, dislocations	PL, IV test, AOI, Isc, Voc*1
String & module parameters				
microcrack / false detection rate	– / –	– / –	– / –	– / –
other possible measurements	–	–	–	–
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	laser / –
max. area of homogeneous illumination	–	–	–	210 × 210 mm
Input for electroluminescence				
max. voltage / current	-16 - 16 V / -20 - 20 A	-16 - 16 V / -20 - 20 A	0 - 16 V / 0 - 20 A	0 - 16 V / 0 - 20 A
Imaging system				
camera manufacturer	Op-tection	Op-tection	Op-tection	Op-tection
type of camera	CCD, cooled CCD	CCD, cooled CCD	CCD	depend. on application*2
type of sensor	silicon, silicon deep depletion	silicon, silicon deep depletion	silicon	–
resolution	1, 1.4 megapixels	1, 1.4 megapixels	1.4 megapixels	–
pixel size	6.5, 13 µm	6.5, 13 µm	6.5 µm	–
quantum efficiency at 1,000 nm	46%	46%	–	–
full well capacity	100,000 e-	100,000 e-	–	–
dark current	0.01 e-/pix.s at -80 °C	0.01 e-/pix.s at -80 °C	–	–
readout noise	–	–	–	–
cooling method / attainable temperature	– / -70 °C	– / -70 °C	– / –	– / –
readout rate	16, 4.1 fps	16, 4.1 fps	16 fps	–
dynamic range (A/D converter)	14, 16 bit	14, 16 bit	14 bit	–
min. & max. field view of camera in standard config.	160 × 160 mm	160 × 160 mm	160 × 160 mm	–
possibility to enhance the field view / range	no / –	no / –	no / –	no / –
typical exposure time	1 s	1 s	1 s	–
System				
automation	manual	auto. contacting	auto. contacting	auto. sorting
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
max. / nominal throughput	60 cells/h / –	300 cells/h / –	2,400 cells/h / –	1,800 cells/h / –
nominal throughput for strings / modules	– / –	– / –	– / –	– / –
max. throughput for strings / modules	– / –	– / –	– / –	– / –
weight	40 kg	60 kg	60 kg	650 kg*3
dimensions (length × width × height)	400 × 500 × 800 mm	758 × 282 × 874 mm	758 × 282 × 874 mm	3,580 × 900 × 1,800 mm*3
certification	CE	CE	CE	CE
Utilities				
power supply (phase / voltage / frequency)	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz
max. power	< 500 W	< 500 W	< 500 W	< 2,000 W*3
ambience (humidity / temperature)	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C
System control & software				
computer hardware	PC	PC	industrial PC	industrial PC
PC interface	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet
compatible data formats	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff
software allows remote machine operation	yes	yes	yes	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	1 month	1 month	1 month	2 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€26,000 - €30,000*2 ($34,700 - $40,100)	€32,000 - €36,000*2 ($42,800 - $48,100)	€42,000 - €54,000*1 ($56,100 - $72,100)	€184,000 - €290,000*4 ($245,800 - 387,500)

Notes

*1 and reverse bias
*2 price depending on configuration and options

*1 and reverse bias
*2 price depend. on config. and options

*1 price depend. on config. and options

*1 and color, integral intensity
*2 EL, PL, AOI
*3 depend. on module options
*4 price depend. on config. and options

Op-tection	Op-tection	Op-tection	Op-tection	Op-tection	Op-tection
OSIS Module A	OSIS Module C	OSIS Module D	OSIS Module I (inline)	OSIS String 1K	OSIS String 6K
2009	2009	2010	2010	2010	2010
electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
– / no limit	– / no limit	– / no limit	– / no limit	– / no limit	– / no limit
multi, mono, quasimono, thin films	multi, mono, quasimono, thin films	multi, mono, quasimono, thin films	multi, mono, quasimono	multi, mono, quasimono	multi, mono, quasimono
2,000 × 1,000 mm*1, *2	2,000 × 1,000 mm*1, *2	2,000 × 1,000 mm*1, *2	2,000 × 1,000 mm*1	2,000 × 160 mm*1	2,000 × 160 mm*1
yes*3 / –	yes*3 / –	yes*3 / –	yes / –	– / –	– / –
yes*3 / –	yes*3 / –	yes*3 / –	yes / –	– / –	– / –
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
–	–	–	AOI (geometry)	AOI (geometry)	AOI (geometry)
– / –	– / –	– / –	– / –	– / –	– / –
–	–	–	–	–	–
0 - 360 V / 0 - 15 A	0 - 360 V / 0 - 15 A	0 - 360 V / 0 - 15 A	0 - 360 V / 0 - 15 A	0 - 32 V / 0 - 10 A	0 - 32 V / 0 - 10 A
Op-tection	Op-tection	Op-tection	Op-tection	Op-tection	Op-tection
CCD	CCD	CCD	CCD	CCD	CCD
silicon	silicon	silicon	silicon	silicon	silicon
1.4, opt. 8.3 megapixels	1.4, 8.3, 72 megapixels	72 megapixels	16 megapixels	1 × (1.4 megapixels)*2	6 × (1.4 megapixels)
3.5, 5.4 µm	6.5 µm	6.5 µm	6.5 µm	6.5 µm	6.5 µm
–	–	–	–	–	–
25,000 e-	–	–	–	–	–
< 0.03 e-/pix.s at -20 °C	–	–	–	–	–
10 e- (rms)	–	–	–	–	–
Peltier / -25 °C	– / –	– / –	– / –	– / –	– / –
16, 1.5 fps	16 fps	16 fps	16 fps	16 fps	16 fps
14, 16 bit	14 bit	14 bit	14 bit	14 bit	14 bit
–	–	–	–	–	–
– / –	– / –	– / –	– / –	– / –	– / –
2.5 s	2 s	2 s	2 s	2 s	2 s
manual	manual	manual	auto. defect detection*2	auto. defect detection*3	auto. defect detection*2
C-mount	C-mount	C-mount	C-mount	C-mount	C-mount
– / –	– / –	– / –	– / –	– / –	– / –
– / 60 modules/h	– / 60 modules/h	– / 60 modules/h	– / 80 modules/h	60 strings/h / –	120 strings/h / –
– / –	– / –	– / –	– / 80 modules/h	60 strings/h / –	120 strings/h / –
500 kg	500 kg	500 kg	500 kg	250 kg	250 kg
1,800 × 1,800 × 2,600 mm	1,600 × 1,800 × 2,600 mm	1,600 × 1,800 × 2,600 mm	3,040 × 1,750 × 1,550 mm*3	2,290 × 484 × 925 mm	2,290 × 484 × 925 mm
CE	CE	CE	CE	CE	CE
1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz
< 500 W	< 5,000 W	< 5,000 W	< 500 W	< 500 W	< 500 W
< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C
industrial PC	industrial PC	industrial PC	industrial PC	industrial PC	industrial PC
USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet
bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff
yes	yes	yes	yes	yes	yes
yes	yes	yes	yes	yes	yes
1 year	1 year	1 year	1 year	1 year	1 year
15 months	2 months	2 months	2 months	2 months	2 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€58,000 - €68,000*4 ($77,500 - $90,900)	€78,000 - €88,000*4 ($104,200 - $117,600)	€68,000 - €78,000*4 ($90,900 - $104,200)	€70,000 - €90,000*4 ($93,500 - $120,200)	€35,000 - €42,000*4 ($46,800 - $56,100)	€60,000 - €68,000*3 ($80,200 - $90,900)
*1 larger opt. *2 for strings as well *3 manual, opt. auto. *4 price depend. on config. and options	*1 larger opt. *2 for strings as well *3 manual, opt. auto. *4 price depend. on config. and options	*1 larger opt. *2 for strings as well *3 manual, opt. auto. *4 price depend. on config. and options	*1 larger opt. *2 inline, manual *3 long edge and short edge leading option *4 price depend. on config. and options	*1 larger opt. *2 camera traversing *3 inline, manual *4 price depend. on config. and options	*1 larger opt. *2 inline, manual *3 price depend. on config. and options

Luminescence imaging systems

Company	Op-tection	Op-tection	Op-tection	Op-tection
model	OSIS String 12K	OSIS Module I (inline) Thin Film	OSIS Cell mc (EL/PL)	OSIS cell PL inline
market introduction	2011	2011	2011	2011
Type of measurement				
electro- or photoluminescence	electroluminescence	electroluminescence	electro-, photoluminescence	photoluminescence
Substrate				
max. cell dimensions / thickness	– / no limit	– / no limit	156 × 156 mm / 300 µm	156 × 156 mm / no limit
cell type	multi, mono, quasimono	thin films	multi, mono, quasimono	multi, mono, quasimono
max. module dimensions	2,000 × 160 mm*1	1,190 × 790 mm*1	–	–
Cell parameters				
microcrack / false detection rate	– / –	– / –	yes / –	yes / –
shunts / shunts & series resistance auto. distinction	– / –	– / –	yes / –	no / –
printing defect detection	–	–	yes	no
effective lifetime of cells	–	–	no	no
other possible measurements	–	–	integral intensity, dislocations*1	contaminations, dislocations
String & module parameters				
microcrack / false detection rate	yes / –	– / –	– / –	– / –
other possible measurements	AOI (geometry)	scribing defects, shunts	–	–
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	laser / –
max. area of homogeneous illumination	–	–	–	210 × 210 mm
Input for electroluminescence				
max. voltage / current	0 - 32 V / 0 - 10 A	0 - 360 V / 0 - 15 A	-16 - 16 V / -20 - 20 A	– / –
Imaging system				
camera manufacturer	Op-tection	Op-tection	Op-tection	Op-tection
type of camera	CCD	CCD	CCD, cooled CCD	CCD
type of sensor	silicon	silicon deep depletion	silicon, silicon deep depletion	silicon deep depletion
resolution	12 × (1.2 megapixels)	1 megapixel	1, 1.4 megapixels	1 megapixel
pixel size	3.75 µm	13 µm	6.5, 13 µm	13 µm
quantum efficiency at 1,000 nm	–	–	46%	46%
full well capacity	–	–	100,000 e-	100,000 e-
dark current	–	–	0.01 e-/pix.s at -80 °C	0.01 e-/pix.s at -80 °C
readout noise	–	–	–	–
cooling method / attainable temperature	– / –	– / –	– / -70 °C	– / -70 °C
readout rate	16 fps	4 fps	16, 4.1 fps	4.1 fps
dynamic range (A/D converter)	8 bit	16 bit	14, 16 bit	16 bit
min. & max. field view of camera in standard config.	–	–	160 × 160 mm	160 × 160 mm
possibility to enhance the field view / range	– / –	– / –	no / –	no / –
typical exposure time	2 s	2 s	1 s	15 s
System				
automation	auto. defect detection*2	auto. defect detection*2	manual	auto. sorting
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
max. / nominal throughput	– / –	– / –	60 cells/h / –	200 - 3,600 wafers/h*1 / –
nominal throughput for strings / modules	120 strings/h / –	– / 60 modules/h	– / –	– / –
max. throughput for strings / modules	120 strings/h / –	– / 60 modules/h	– / –	– / –
weight	250 kg	500 kg	40 kg	1,000 kg
dimensions (length × width × height)	2,100 × 410 × 795 mm	3,040 × 1,750 × 1,550 mm*3	400 × 500 × 800 mm	2,410 × 1,100 × 2,000 mm
certification	CE	CE	CE	CE
Utilities				
power supply (phase / voltage / frequency)	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz
max. power	< 500 W	< 500 W	< 500 W	< 4,000 W
ambience (humidity / temperature)	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C
System control & software				
computer hardware	industrial PC	industrial PC	PC	industrial PC
PC interface	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet
compatible data formats	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff
software allows remote machine operation	yes	yes	yes	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	2 months	2 months	1 month	2 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€39,000 - €47,000*2 ($52,100 - $62,800)	€90,000*4 ($120,200)	€64,000 - €83,000*2 ($85,500 - $110,900)	€89,000 - €102,000 ($118,900 - $136,300)

Notes

*1 larger opt.
*2 inline, manual
*3 price depend. on config. and options

*1 larger opt.
*2 inline, manual
*3 long edge and short edge leading option
*4 depend. on line, config.

*1 and reverse bias
*2 price depend. on config. and options

*1 based on config.
*2 price depend. on config. and options

Op-tection	Op-tection	Op-tection	Op-tection	Op-tection	Pi4_robotics
OSIS Sorter Cell-600	OSIS Sorter Cell-2400	OSIS Sorter Cell-3000	OSIS Wafer Sorter PL	OSIS Module F	pi4_alporti 8 Megapix*1
2011	2010	2011	2011	2010	2011
electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	photoluminescence	electroluminescence	electroluminescence
156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	156 × 156 mm / no limit	no limit / no limit	no limit / no limit
multi, mono, quasimono	multi, mono, quasimono	multi, mono, quasimono	multi, mono, quasimono	multi, mono, quasimono	multi, mono, thin films
–	–	–	–	2,000 × 1,000 mm	2,000 × 1,100 mm
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
yes	yes	yes	yes	no	yes
no	no	no	no	no	no
PL, IV test, AOI, Isc, Voc*1	PL, IV test, AOI, Isc, Voc*1	PL, IV test, AOI, Isc, Voc*1	prediction of cell efficiency	–	yes
– / –	– / –	– / –	– / –	yes / –	yes / –
–	–	–	–	inefficient areas	yes
laser / –	laser / –	laser / –	laser / –	– / –	– / –
210 × 210 mm	210 × 210 mm	210 × 210 mm	210 × 210 mm	–	–
0 - 16 V / 0 - 20 A	0 - 16 V / 0 - 20 A	0 - 16 V / 0 - 20 A	– / –	360 V / 15 A	60 V / 10 A*2
Op-tection	Op-tection	Op-tection	Op-tection	Op-tection	Pi4_robotics
depend. on application*2	depend. on application*2	depend. on application*2	CCD	CCD	1× NIR area
–	–	–	silicon deep depletion	silicon	–
–	–	–	1 megapixel	1.4, 8.3 megapixels	8 megapixels
–	–	–	13 µm	6.5, 10 µm	–
–	–	–	46%	–	–
–	–	–	100,000 e-	–	–
–	–	–	0.01 e-/pix.s at -80 °C	–	–
–	–	–	–	–	–
– / –	– / –	– / –	– / -70 °C	– / –	– / –
–	–	–	4.1 fps	16, 4.1 fps	–
–	–	–	16 bit	14, 16 bit	16 bit
–	–	–	160 × 160 mm	2,000 × 1,000 mm	–
no / –	no / –	no / –	no / –	yes / opt.	yes / –
–	–	–	15 s	2 s	0.5 s
auto. sorting	auto. sorting	auto. sorting	auto. sorting	auto. defect detection	manual, portable
C-mount	C-mount	C-mount	C-mount	C-mount	C-mount
900 cells/h / –	2,400 cells/h / –	3,000 cells/h / –	200 - 3,600 wafers/h*1 / –	– / –	– / –
– / –	– / –	– / –	– / –	– / 60 modules/h	– / 15 modules/h
– / –	– / –	– / –	– / –	– / 720 modules/h	– / 25 modules/h
650 kg*3	650 kg*3	650 kg*3	1,000 kg	40 kg	– 40 kg
3,580 × 900 × 1,800 mm*3	3,580 × 900 × 1,800 mm*3	3,580 × 900 × 1,800 mm*3	2,410 × 1,100 × 2,000 mm	–	1,360 × 620 × 510 mm*3
CE	CE	CE	CE	CE	CE
1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	3 Ph, 400 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1 Ph, 115-230 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz
< 2,000 W*2	< 2,000 W*3	< 2,000 W*3	< 4,000 W	< 500 W	< 700 W
< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 30 °C	< 80% / < 40 °C
industrial PC	industrial PC	industrial PC	industrial PC	industrial PC	PC
USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet	USB, Ethernet	Ethernet, USB
bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff
yes	yes	yes	yes	yes	no
yes	yes	yes	yes	yes	no
1 year	1 year	1 year	1 year	1 year	1 year
2 months	2 months	2 months	2 months	1 month	1 - 3 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€83,000 - €250,000*4 ($110,900 - $334,000)	€196,000 - €330,000*4 ($261,900 - $440,900)	€216,000 - €350,000*4 ($288,600 - $467,600)	€200,000 - €450,000*2 ($267,200 - $601,200)	€30,000 - €40,000*1 ($40,100 - $53,400)	€19,900 ($26,600)

*1 and cell color, integral intensity
*2 EL, PL, AOI
*3 depend. on module options
*4 price depend. on config. and options

*1 and cell color, integral intensity
*2 EL, PL, AOI
*3 depend. on module options
*4 price depend. on config. and options

*1 and cell color, integral intensity
*2 EL, PL, AOI
*3 depend. on module options
*4 price depend. on config. and options

*1 based on config.
*2 price depend. on config. and options

*1 price depend. on config. and options

*1 portable module inspection series
*2 opt. higher voltage
*3 case dimensions

Luminescence imaging systems

Company	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics
model	pi4_elporti 1.4 Megapix*1	string inspection & alignment	string inspection	cell inspection & alignment
market introduction	2011	2007	2009	2007
Type of measurement				
electro- or photoluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	no limit / no limit	no limit / no limit	no limit / no limit	no limit / no limit
cell type	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films
max. module dimensions	2,000 × 1,100 mm	–	–	–
Cell parameters				
microcrack / false detection rate	yes / –	yes / –	yes / –	yes / –
shunts / shunts & series resistance auto. distinction	yes / –	yes / yes	yes / yes	yes / yes
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	no	no	no	no
other possible measurements	yes	yes	yes	yes
String & module parameters				
microcrack / false detection rate	yes / –	yes / –	yes / –	yes / –
other possible measurements	yes	yes	yes	yes
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	– / –
max. area of homogeneous illumination	–	–	–	–
Input for electroluminescence				
max. voltage / current	60 V / 10 A*2	60 V / 12.5 A*1	60 V / 12.5 A*1	60 V / 12.5 A*1
Imaging system				
camera manufacturer	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics
type of camera	1× NIR area	–	–	–
type of sensor	–	–	–	–
resolution	1.44 megapixels	8 megapixels	1.44 megapixels	4 megapixels
pixel size	–	–	–	–
quantum efficiency at 1,000 nm	–	–	–	–
full well capacity	–	–	–	–
dark current	–	–	–	–
readout noise	–	–	–	–
cooling method / attainable temperature	– / –	– / –	– / –	– / –
readout rate	–	–	–	–
dynamic range (A/D converter)	16 bit	16 bit	16 bit	16 bit
min. & max. field view of camera in standard config.	–	–	–	–
possibility to enhance the field view / range	yes / –	yes / –	yes / –	yes / –
typical exposure time	0.4 s	0.5 s	0.3 s	0.5 s
System				
automation	manual, portable	auto.	auto.	auto.
optical interface for lenses	C-mount	F-mount	C-mount	C-mount
max. / nominal throughput	– / –	– / –	– / –	1,440 / 1,200 cells/h
nominal throughput for strings / modules	– / 15 modules/h	360 strings/h / –	360 strings/h / –	– / –
max. throughput for strings / modules	– / 25 modules/h	360 strings/h / –	360 strings/h / –	– / –
weight	~ 40 kg	< 50 kg	< 50 kg	< 50 kg
dimensions (length × width × height)	1,360 × 620 × 510 mm*3	500 × 500 × 950 mm	500 × 500 × 950 mm	400 × 500 × 800 mm
certification	CE	CE	CE	CE
Utilities				
power supply (phase / voltage / frequency)	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz
max. power	< 700 W	< 1,000 W	< 1,000 W	< 1,000 W
ambience (humidity / temperature)	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C
System control & software				
computer hardware	PC	PC, industrial PC	PC, industrial PC	PC, industrial PC
PC interface	Ethernet, USB	Ethernet, USB, RS232, others	Ethernet, USB, RS232, others	Ethernet, USB, RS232
compatible data formats	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff
software allows remote machine operation	no	yes	yes	yes
software allows remote machine fault diagnosis	no	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	1 - 3 months	1 - 3 months	1 - 3 months	1 - 3 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€9,890 ($13,200)	€89,840 ($120,000)	€68,900 ($92,100)	€89,840 ($120,000)
Notes	*1 portable module inspection series *2 opt. higher voltage *3 case dimensions	*1 opt. 40 V / 19 A	*1 opt. 40 V / 19 A	*1 opt. 40 V / 19 A

Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics
cell inspection	Inline/Offline 4.3 Megapix*3	Inline/Offline 8.6 Megapix*3	Offline 72 Megapix, 60s*3	Offline 72 Megapix, 30s*4	Inline 72 Megapix, 90s*1, *2
2009	2009	2007	2009	2010	2009
electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
156 × 156 mm / –	no limit / no limit	no limit / no limit	no limit / no limit	no limit / no limit	no limit / no limit
multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films
–	1,970 × 1,040 mm*1	1,970 × 1,040 mm*1	1,970 × 1,040 mm*1	1,970 × 1,040 mm*1	1,970 × 1,040 mm*3
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
yes / yes	yes / –	yes / –	yes / yes	yes / yes	yes / yes
yes	yes	yes	yes	yes	yes
no	no	no	no	no	no
yes	yes	yes	yes	yes	yes
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
yes	yes	yes	yes	yes	yes
– / –	– / –	– / –	– / –	– / –	– / –
–	–	–	–	–	–
50 V / 12.5 A*1	60 V / 10 A*2	60 V / 10 A*2	60 V / 12.5 A*2	60 V / 12.5 A*2	60 V / 12.5 A
Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics
–	3 × NIR area	6 × NIR area	1 × NIR area	6 × NIR area	1 × NIR area
–	–	–	–	–	–
1.44 megapixels	4.3 megapixels	8.6 megapixels	72 megapixels	72 megapixels	72 megapixels
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
– / –	– / –	– / –	cooled interior / –	cooled interior / –	cooled interior / –
–	–	–	–	–	–
16 bit	16 bit	16 bit	16 bit	16 bit	16 bit
–	–	–	–	–	–
yes / –	yes / –	yes / –	yes / –	yes / –	yes / –
0.3 s	0.4 s	0.4 s	0.4 s	0.4 s	0.4 s
auto.	manual, offline, inline	manual, offline, inline	manual, auto., offline	manual, auto., offline	auto., inline
C-mount	C-mount	C-mount	C-mount	C-mount	C-mount
1,440 / 1,200 cells/h	– / –	– / –	– / –	– / –	– / –
– / –	60 strings/h / 60 modules/h	60 strings/h / 60 modules/h	50 strings/h / 30 modules/h	80 strings/h / 60 modules/h	60 strings/h / 40 modules/h
– / –	120 strings/h / 120 modules/h	120 strings/h / 120 modules/h	60 strings/h / 40 modules/h	100 strings/h*3/ 80 modules/h	60 strings/h*4/ 40 modules/h
< 50 kg	~ 320 kg	~ 320 kg	~ 800 kg	~ 800 kg	~ 800 kg
400 × 500 × 800 mm	2,450 × 1,350 × 1,200 mm	2,450 × 1,350 × 1,200 mm	2,600 × 1,700 × 1,400 mm	2,600 × 1,700 × 1,400 mm	2,600 × 1,700 × 1,400 mm
CE	CE, UL	CE, UL	CE, UL	CE, UL	CE, UL
1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz
< 1,000 W	< 700 W	< 700 W	< 2,000 W	< 2,000 W	< 2,000 W
< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C
PC, industrial PC	PC, industrial PC	PC, industrial PC	PC, industrial PC	PC, industrial PC	PC, industrial PC
Ethernet, USB, RS232	Ethernet, USB, RS232	Ethernet, USB, RS232	Ethernet, USB, RS232	Ethernet, USB, RS232	Ethernet, USB, RS232
bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff
yes	yes	yes	yes	yes	yes
yes	no	no	yes	yes	yes
1 year	1 year	1 year	1 year	1 year	1 year
1 - 3 months	1 - 3 months	1 - 3 months	1 - 3 months	1 - 3 months	1 - 3 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€68,900 ($92,100)	€28,900 ($38,600)	€39,800 ($53,200)	€59,800 ($79,900)	€98,600 ($131,700)	€89,000 ($118,900)

*1 opt. 40 V / 19 A

*1 larger opt.
*2 opt. higher voltage
*3 Module Basic series

*1 larger opt.
*2 opt. higher voltage
*3 Module Basic series

*1 larger opt.
*2 opt. higher voltage
*3 Module Economic series

*1 larger opt.
*2 opt. higher voltage
*3 string inspection opt.
*4 Module Economic series

*1 incl. loading/unloading for 60 × 10 cells/modules
*2 Module Automatic series
*3 larger opt.
*4 string inspection opt.

Luminescence imaging systems

Company	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics
model	Inline 72 Megapix, 70s*1, *2	Inline 72 Megapix, 45s*1, *2	Inline 72 Megapix, 28s*1, *2	Inline 72 Megapix, 10s*1, *2
market introduction	2010	2009	2010	2010
Type of measurement				
electro- or photoluminescence	electroluminescence	electroluminescence	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	no limit / no limit	no limit / no limit	no limit / no limit	no limit / no limit
cell type	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films
max. module dimensions	1,970 × 1,040 mm*3	1,970 × 1,040 mm*3	1,970 × 1,040 mm*3	1,970 × 1,040 mm*3
Cell parameters				
microcrack / false detection rate	yes / –	yes / –	yes / –	yes / –
shunts / shunts & series resistance auto. distinction	yes / yes	yes / yes	yes / yes	yes / yes
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	no	no	no	no
other possible measurements	yes	yes	yes	yes
String & module parameters				
microcrack / false detection rate	yes / –	yes / –	yes / –	yes / –
other possible measurements	yes	yes	yes	yes
Input for photoluminescence				
type of light / wavelength	– / –	– / –	– / –	– / –
max. area of homogeneous illumination	–	–	–	–
Input for electroluminescence				
max. voltage / current	60 V / 12.5 A	60 V / 12.5 A	60 V / 12.5 A	60 V / 12.5 A
Imaging system				
camera manufacturer	Pi4_robotics	Pi4_robotics	Pi4_robotics	Pi4_robotics
type of camera	2 × NIR area	6 × NIR area	12 × NIR area	24 × NIR area
type of sensor	–	–	–	–
resolution	72 megapixels	72 megapixels	72 megapixels	72 megapixels
pixel size	–	–	–	–
quantum efficiency at 1,000 nm	–	–	–	–
full well capacity	–	–	–	–
dark current	–	–	–	–
readout noise	–	–	–	–
cooling method / attainable temperature	cooled interior / –	cooled interior / –	cooled interior / –	cooled interior / –
readout rate	–	–	–	–
dynamic range (A/D converter)	16 bit	16 bit	16 bit	16 bit
min. & max. field view of camera in standard config.	–	–	–	–
possibility to enhance the field view / range	yes / –	yes / –	yes / –	yes / –
typical exposure time	0.4 s	0.4 s	0.4 s	0.4 s
System				
automation	auto., inline	auto., inline	auto., inline	auto., inline
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
max. / nominal throughput	– / –	– / –	– / –	– / –
nominal throughput for strings / modules	60 strings/h / 50 modules/h	80 strings/h / 80 modules/h	128 strings/h / 128 modules/h	360 strings/h / 360 modules/h
max. throughput for strings / modules	60 strings/h*4 / 50 modules/h	80 strings/h*4 / 80 modules/h	128 strings/h*4 / 128 modules/h	360 strings/h*4 / 360 modules/h
weight	~ 800 kg	~ 800 kg	~ 800 kg	~ 800 kg
dimensions (length × width × height)	2,600 × 1,700 × 1,400 mm	2,600 × 1,700 × 1,400 mm	2,600 × 1,700 × 1,400 mm	2,600 × 1,700 × 1,400 mm
certification	CE, UL	CE, UL	CE, UL	CE, UL
Utilities				
power supply (phase / voltage / frequency)	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz
max. power	< 2,000 W	< 2,000 W	< 2,000 W	< 2,000 W
ambience (humidity / temperature)	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C
System control & software				
computer hardware	PC, industrial PC	PC, industrial PC	PC, industrial PC	PC, industrial PC
PC interface	Ethernet, USB, RS232	Ethernet, USB, RS232	Ethernet, USB, RS232	Ethernet, USB, RS232
compatible data formats	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff
software allows remote machine operation	yes	yes	yes	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year
time of delivery	1 - 3 months	1 - 3 months	1 - 3 months	1 - 3 months
distribution area	worldwide	worldwide	worldwide	worldwide
price	€108,600 ($145,100)	€128,600 ($171,800)	€164,800 ($220,200)	€398,000 ($531,700)
Notes	*1 incl. loading/unloading for 60 × 10 cells/modules *2 Module Automatic series *3 larger opt. *4 string inspection opt.	*1 incl. loading/unloading for 60 × 10 cells/modules *2 Module Automatic series *3 larger opt. *4 string inspection opt.	*1 incl. loading/unloading for 60 × 10 cells/modules *2 Module High Speed Automatic *3 larger opt. *4 string inspection opt.	*1 incl. loading/unloading for 60 × 10 cells/modules *2 Module High Speed Automatic *3 larger opt. *4 string inspection opt.

Pi4_robotics	Pi4_robotics	Pi4_robotics	Reltron	Schmid	Schmid
Flasher Integration 8 Megapix*2	Flasher Integration, 72 Megapix*1	String Inspection High Speed*2	Fast EL Mapper	A18 off-line Cell EL	A20 off-line Module EL
2010	2011	2010	2008	2010	2010
electroluminescence	electroluminescence	electroluminescence	electro-, photoluminescence	electroluminescence	electroluminescence
no limit / no limit	no limit / no limit	no limit / no limit	no limit / no limit	156 × 156 mm / 160 - 260 µm	156 × 156 mm / no limit
multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono, thin films	multi, mono	multi, mono
1,000 × 2,100 mm*1	1,000 × 2,100 mm*1	–	no limit	–	1,000 × 1,665 mm
yes / –	yes / –	yes / –	yes / < 1%	– / –	– / –
yes / yes	yes / yes	yes / yes	yes / yes	– / –	– / –
yes	yes	yes	yes	no	no
no	no	no	yes	no	no
yes	yes	yes	dark, light IV	hot-spot detection*1	–
yes / –	yes / –	yes / –	yes / depend. on size of crack	– / –	– / –
yes	yes	yes	defects, mismatching, cell volt.	–	–
– / –	– / –	– / –	LED / 850 nm	– / –	– / –
–	–	–	203 × 203 mm	–	–
60 V / 12.5 A*2	60 V / 12.5 A*2	60 V / 12.5 A*1	-75 - 75 V / -14 - 14 A	-10 - 10 V / 10 A	100 V / 15 A
Pi4_robotics	Pi4_robotics	Pi4_robotics	Reltron	Apogee	PCO
1 × NIR area	6 × NIR area	6 × NIR area	cooled CCD	cooled CCD	CCD
–	–	–	CCD	–	–
8 megapixels	72 megapixels	1.44 megapixels	≤ 4,096 × 4,096 pixels	2,048 × 2,048 pixels	1,392 × 1,024 pixels
–	–	–	9 µm	7.4 µm	6.5 µm
–	–	–	6%	1%	2%
–	–	–	≥ 100,000 e-	40,000 e-	16,000 e-
–	–	–	–	0.01 e-/pix.s at -30 °C	0.05 e-/pix.s at 10 °C
–	–	–	< 6 e- (rms)	7 e- (rms)	6 e- (rms)
– / –	– / –	– / –	Peltier / -30 °C	– / –	– / –
–	–	–	3 - 30 fps	–	max. 11.7 fps
16 bit	16 bit	16 bit	16 bit	16 bit	12 bit
–	–	–	1,100 × 2,200 mm	–	–
yes / –	yes / –	yes / –	yes / 1,500 × 2,200 m	yes / –	– / –
0.5 s	0.5 s	0.3 s	1 s*1	3 s	2 s
auto., inline	auto., inline	auto.	manual, auto.	manual	manual
C-mount	C-mount	C-mount	F-mount	F-mount	C-mount
– / –	– / –	– / –	1,200 / 700 cells/h	– / –	– / –
– / 80 modules/h	– / 60 modules/h	1,200 strings/h / –	600 strings/h / 600 modules/h	– / –	– / –
– / 100 modules/h	– / 80 modules/h	1,200 strings/h / –	900 strings/h / 900 modules/h	– / –	– / –
– 250 kg	– 450 kg	< 50 kg	< 500 kg	40 kg	400 kg
–	–	500 × 500 × 950 mm	2,400 × 2,400 × 2,400 mm	460 × 460 × 800 mm	2,160 × 1,110 × 1,700 mm
CE, UL	CE, UL	CE	CE	CE	CE
1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1/3 Ph, 100-250 V, 50-60 Hz	1 Ph, 85-265 V, 47-63 Hz	1 Ph, max. 220 V, 50-60 Hz	1 Ph, max. 220 V, 50-60 Hz
< 700 W	< 2,000 W	< 1,000 W	2,000 W	750 W	1,500 W
< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 40 °C	< 80% / < 30 °C	30 - 90% / < 40 °C	30 - 90% / < 40 °C
PC, industrial PC	PC, industrial PC	PC, industrial PC	rack-mounted industrial PC	PC with RAID drive	PC with RAID drive
Ethernet, USB, RS232	Ethernet, USB, RS232	Ethernet, USB, RS232, others	USB, RS232, PCI, Ethernet	Ethernet, USB	Ethernet, USB
bmp, jpg, tiff	bmp, jpg, tiff	bmp, jpg, tiff	bmp, tiff, jpg, txt	bmp, jpg	bmp, jpg
yes	yes	yes	yes	yes	yes
yes	yes	yes	yes	yes	yes
1 year	1 year	1 year	1 year	1 year	1 year
1 - 3 months	1 - 3 months	1 - 3 months	3 months	2 - 3 months	2 - 3 months
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€39,800 ($53,200)	€128,800 ($172,100)	€89,840 ($120,000)	$65,000*1	$50,000	$68,000

*1 larger opt.
*2 opt. higher voltage
*3 Module Automatic series

*1 larger opt.
*2 opt. higher voltage
*3 Module Automatic series

*1 opt. 40 V / 19 A
*2 3s cycle time

*1 for multi, mono
*2 depend. on options

*1 for cells with two and three bus bars

Luminescence imaging systems

Company	Schmid	Schmid	Vitronic	Zenith Solar
model	A24 off-line PL	Smart EL Cell	VINSPECsolar	EL-4P
market introduction	2011	2010	2009	2007
Type of measurement				
electro- or photoluminescence	photoluminescence	electroluminescence	electroluminescence	electroluminescence
Substrate				
max. cell dimensions / thickness	156 × 156 mm / no limit	156 × 156 mm / no limit	210 × 210 mm / no limit	125 × 125, 156 × 156 mm / –
cell type	multi, mono	multi, mono	multi, mono, thin films	multi, mono
max. module dimensions	–*1	–*1	no limit	1,200 × 2,000 mm
Cell parameters				
microcrack / false detection rate	– / –	mono / < 10%*2	yes / –	– / 1 - 0.5%
shunts / shunts & series resistance auto. distinction	– / –	no / –	yes / no	– / –
printing defect detection	yes	yes	yes	yes
effective lifetime of cells	yes	no	–	yes
other possible measurements	–	dark areas, pinch roll scratches	contour defects, grid line def.*1	thin-film process steps
String & module parameters				
microcrack / false detection rate	– / –	– / –	yes / –	yes / 0.5%
other possible measurements	–	–	shunts, contour defects*2	thin films
Input for photoluminescence				
type of light / wavelength	laser, monochromatic / 808 nm	– / –	– / –	– / –
max. area of homogeneous illumination	180 × 180 mm	–	–	208 × 208 mm
Input for electroluminescence				
max. voltage / current	– / –	30 V / 30 A	– / –	5 - 100 V / 5 - 20 A
Imaging system				
camera manufacturer	Sensovation	Vision Components	Vitronic	–
type of camera	CCD	CCD, Smart Camera System	digital	cooled CCD
type of sensor	–	Sony ICX285AL	CMOS	back-illuminated silicon
resolution	3,326 × 2,504 pixels	1,280 × 1,024 pixels	4 megapixels	1,360 × 1,024 - 3,326 × 2,504 pixels
pixel size	5.4 µm	6.5 µm	–	10 µm
quantum efficiency at 1,000 nm	5%	3%	–	25%
full well capacity	25,000 e-	17,500 e-	–	700,000 e-
dark current	25 e-/pix.s at 45 °C	3 e-/pix.s at 20 °C	–	103 e-/pix.s at -20 °C
readout noise	20 e- (rms)	–	–	4 e- (rms)
cooling method / attainable temperature	– / –	– / –	no cooling / –	Peltier / -30, -50 °C
readout rate	2.5 fps	14 fps	3 fps	–*1
dynamic range (A/D converter)	–	8 bit	12 bit	16 bit
min. & max. field view of camera in standard config.	–	170 × 170 mm	170 × 170, 1,300 × 2,000 mm	170 × 170, opt. 210 × 210 mm
possibility to enhance the field view / range	yes / –	yes / –	yes / –	yes / 20 × 20 mm
typical exposure time	1 s	1 s	1.2 s	0 - 9 s
System				
automation	manual	inline, manual	inline, stand-alone	manual, auto.
optical interface for lenses	C-mount	C-mount	–	C-mount
max. / nominal throughput	360 cells/h / –	1,200 cells/h / –	3,600 cells/h / –	150 / 120 cells/h
nominal throughput for strings / modules	– / –	– / –	360 strings/h / 360 modules/h	15 strings/h / 15 modules/h
max. throughput for strings / modules	– / –	– / –	900 strings/h / 900 modules/h	120 strings/h / 120 modules/h
weight	< 100 kg	< 100 kg*3	< 20 kg	320 kg
dimensions (length × width × height)	560 × 580 × 1,000 mm	1,600 × 600 × 700 mm*3	1,000 × 600 × 1,500 mm	2,500 × 2,200 × 1,000 mm
certification	CE	CE	CE	CE
Utilities				
power supply (phase / voltage / frequency)	1 Ph, max. 220 V, 50-60 Hz	–, 230 V, 50Hz	2 Ph, 110-230 V, 50-60 Hz	–, 220 V, 50 Hz
max. power	1,500 W	< 1,000 W	< 500 W	1,500 W
ambience (humidity / temperature)	< 60% / < 30 °C	< 80% / < 0 - 40 °C	< 80% / < 35 °C	< 80% / < 30 °C
System control & software				
computer hardware	PC with RAID drive	PC, smart camera	industrial PC	PC, industrial PC
PC interface	Ethernet, USB	Ethernet	Ethernet	USB, RS232
compatible data formats	tiff	bmp	txt, jpg, tiff	bmp, jpg, tiff
software allows remote machine operation	yes	yes (webbrowser, PLC)	yes	yes
software allows remote machine fault diagnosis	yes	yes	yes	yes
Warranty, delivery, distribution, price				
warranty	1 year	1 year	2 years	1 year
time of delivery	6 months	3 months	4 months	~ 1 month
distribution area	worldwide	worldwide	worldwide	worldwide
price	$168,000	€20,000 *4 ($26,700)	~ €40,000 ($53,400)	$35,000 - $60,000

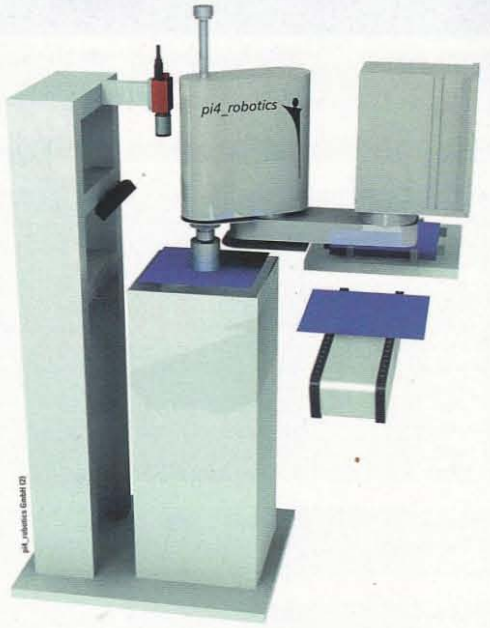
Notes

*1 for cells with two and three bus bars or wafers

*1 only for cells, software supp. up to seven bus bars
*2 bad cells
*3 offline system.
*4 basic version

*1 and cracks with electrical effects, minor active cells
*2 grid line defects, cracks, minor active cells

*1 7 Hz at full frames/s





▲ From cells to modules: Germany's Pi4_robotics increased its range of EL-based products by a third to 18, mainly catering to the needs of various stages in module manufacturing. However, the company also offers a product series for testing solar cells (shown on the left) for mapping a typical list of defects such as microcracks (shown on the right).

For cell inspection, Pi4_robotics is again promoting two inline-capable models. Its **Cell Inspection** has a picture resolution of 1.44 megapixels and an hourly production flow of 1,200 in the maximum and nominal mode of operation, while the **cell inspection & alignment** is a 4 megapixel version with a 1,440-cell throughput per hour.

In addition to developing products suitable for various applications and configurations, Pi4_robotics is again offering an innovative platform called PV-Ident for its products. PV-Ident records the unique crystal patterns in the silicon substrates. The stored data functions like a fingerprint for solar cells to trace their history, including native defects and process quality at important process stations such as metallization and soldering. The PV-Ident can be used as an alternative to physical marking methods.

MBJ Solutions – going inline: Germany-headquartered MBJ Solutions GmbH has provided the data for 11 systems. Among the four new tools is the **SolarModule EL-Inline25**, a multi-camera, high-resolution EL tester with a resolution of 6,000 × 12,000 pixels and a maximum throughput of 72 modules per hour. Compared to the SolarModule EL-Inline launched last year, the new version costs up to 26 percent less with a price range of €52,600 to €58,000 ($70,300 to $77,500). According to MBJ's Dieter Lorenz, the system is ideally suited for small factories. However, the company is also offering the possibility to upgrade the system to a higher speed by replacing the cameras.

The **SolarModule EL-quickline** comes with an increased medium-scale resolution inline system of 7.8 megapixels due to an updated multi-camera design that enables what Lorenz describes as »good image quality.« The new model, an inline version of the previously listed SolarModule EL-quickcheck system, is now offered with automatic-loading and unloading, and an automated contact unit for bus ribbons.

MBJ Solutions has come out with its first two tools dedicated solely to the characterization of thin-film modules – the **SolarModule TF-Lab** for offline R&D and the **SolarModule TF-inline** for inline applications. Both have a measurement time below 60 seconds per module. MBJ Solutions has not made any changes to its other tools.

Buchanan Systems – upgrades unknown: As Buchanan Systems GmbH has not responded to our request for additional information on its latest specifications, it is hard to judge what has changed. But by comparing this to the German company's specifications in the last survey, it appears that most of its tools have not been altered. Buchanan appears to have dropped its **EL-MES String Inline** tool for determining soldering-induced problems

Although its **Inline Laminate Tester SEMI** was introduced in 2010, Buchanan has only now included information on the inline system, most likely designed to test the laminates before framing. The company has also presented first-time specifications for another tool introduced in 2010, its **EL-MES Cell Tester**. But now the company seems to have updated it with a new version, the **EL-MES Cell Tester 12**. The tools are completely identical, except that the newer version replaces an outsourced camera from Vision Components GmbH with Buchanan's own camera. With its much higher resolution, the latest model costs €22,000 ($29,400).

Nisshinbo – low cost, high performance: Japan's Nisshinbo Industries Inc. has come out with its first new product since 2009, the **PVE1020i-MTW**. According to Miho Makino from the sales department, the system combines the advantage of high resolution and lower prices. The PVE1020i-MTW employs a camera with a resolution of 2,672 × 4,000 pixels, far higher than the original three models. While the PVE1020i-MTW requires 5 seconds to scan a module, a similar product, the **PVE1120i-T**, needs 3 seconds. But the new PVE1020i-MTW is priced at ¥8 million ($102,800), a little more than a quarter of the much more expensive PVE1120i-T.

GPP Chemnitz – updates unknown: GPP Chemnitz Gesellschaft für Prozessrechnerprogrammierung mbH is offering its first new product in 2 years, the **SolarModuleInspect-ELVIS**. The German company entered our survey with two products last year, both still on offer, and added three more models for its current listing. Oddly, GPP Chemnitz has now submitted details for another model called **SolarModuleInspect-EL** with exactly the same name and nearly identical specifications as its other model. The only obvious difference is the camera resolution, which is either 24,000 × 12,000 pixels or 1,388 × 1,038

Cameras for luminescence imaging

Company	Andor Technology	Andor Technology	Andor Technology	Andor Technology
model	iKon-M DU934 Deep-Depletion	Luca R DL-604M-OEM	Clara	iKon_M PV inspector
market introduction	2007	2007	2009	2010
Application				
electro- or photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electroluminescence	electro-, photoluminescence
Camera				
type of camera	low-noise NIR Si CCD	electron multiplier CCD	interline CCD	low-noise NIR CCD
type of sensor	deep-depletion CCD*1	electron multiplier CCD	Sony ICX285 sensor	deep-depletion CCD*1
resolution	1,024 × 1,024 pixels	1,002 × 1,004 pixels	1,392 × 1,040 pixels	1,024 × 1,024 pixels
pixel size	13 × 13 µm	8 × 8 µm	6.5 × 6.5 µm	13 × 13 µm
quantum efficiency at 1,000 nm	46%	8%	2%	46%
full well capacity	100,000 e-	30,000 e-	18,000, 30,000 e-*1	100,000 e-
dark current	0.01 e-/pix.s at -80 °C	0.17 e-/pix.s at -20 °C	0.0015 e-/pix.s at -20 °C	0.14 e-/pix.s at -70 °C
readout noise	2.5*2, 10.3*3 e- (rms)	< 1 - 18 e-*1 (rms)	3*2, 6.5*3 e- (rms)	9 e-*2 (rms)
cooling method / attainable temperature	deep thermoelectric / -100 °C	air cooled / -20 °C	deep thermoelectric / -20 °C	deep thermoelectric / -70 °C
readout rate	2.5 fps	12.4 fps	11.6 fps	4.4 fps*3
dynamic range (A/D converter)	16 bit	14 bit	16, 14 bit	16 bit
min. & max. field view of camera in standard config.	13.3 × 13.3 mm*4	8 × 8 mm*2	9 × 6.7 mm*4	13.3 × 13.3 mm*4
possibility to enhance field view / range	yes / –	yes / –	yes / –	yes / –
typical exposure time	100 ms	700 ms	1,000 ms	100 ms
System				
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
dimensions (length × width × height)	204.2 × 105 × 107 mm	54.8 × 96 × 86 mm	98 × 112 × 127 mm	105 × 107 × 204.2 mm
certification	–	–	–	–
Utilities				
power supply	5, 7.5, ± 15 V	5, ± 9 V	5, ± 15 V	5, ± 15 V
max. power	48 W	14 W	36 W	30 W
ambience (humidity / temperature)	< 70% / 0 - 30 °C	< 70% / 0 - 30 °C	< 70% / 0 - 30 °C	< 70% / 0 - 30 °C
System control & software				
computer hardware	PC	PC	PC	PC
PC interface	USB2.0	USB2.0	USB2.0	USB2.0
compatible data formats	fits, tiff, bmp, avi	fits, tiff, bmp, avi	fits, tiff, bmp, avi	fits, tiff, bmp, avi
software compatibility	Windows, Linux, Halcon, Solis	Windows, Linux, Halcon, Solis	Windows, Linux, Halcon, Solis	Windows, Linux, Halcon, Solis
Warranty, delivery, distribution, price				
warranty	1 year	1 year	1 year	1 year*5
time of delivery	4 - 6 weeks	3 - 4 weeks	3 - 4 weeks	4 - 6 weeks
distribution area	worldwide	worldwide	worldwide	worldwide
price	€25,950 ($34,700)	€12,950 ($17,300)	€9,450 ($12,600)	€24,950 ($33,300)
Notes	*1 back-illuminated *2 at 50 kHz *3 at 3 MHz *4 image area	*1 at 13.5 MHz *2 image area	*1 2 × 2 binned *2 at 1 MHz *3 at 20 MHz *4 image area	*1 back-illuminated *2 at 3 MHz, *3 at 5 MHz *4 image area *5 5-year vacuum warranty



pi4_robotics GmbH

◀ Outdoors? No problem: The elporti series of EL testers from Pi4_robotics is offered in a compact design that enables onsite module testing before installation.

pixels. Undoubtedly due to the higher resolution of the first tool – though it is hard to imagine that any PV-related application would require such a high resolution – GPP Chemnitz is promoting the system for higher-end applications with a selling price of €150,000 ($200,400), three times the listed price of the other model. The company has not provided any information regarding advancements associated with its older systems.

Chroma – new to survey: Chroma ATE Inc. is a new name in the list of EL suppliers. However, the Taiwanese company has been selling its **7218-M** model since 2009. According to Grayson Cheng, the EL product manager, Chroma's tool detects typical defects in modules, such as dark areas, cracks and finger interruption. However, he notes, »It's still the operator's call to pass or fail the module.« Cheng adds that the company is in the process of integrating its knowledge base in building cell inspection AOI systems into the 7218-M's software. Cheng is optimistic that Chroma will be ready with the automatic detection function in the first quarter of 2012. The system is currently capable of generating an EL image of a solar module with a resolution of 3,326 × 2,504 pixels at a maximum characterization pace of 360 modules per hour. The 7218-M is sold for a price range of $40,000 to $50,000.

Komax – new product for thin-film modules: While most EL system suppliers come from the field of inspection tools, the simple

Andor Technology	BoostSolar	Greateyes	Greateyes	Hamamatsu	Hamamatsu
Andor Neo sCMOS	LMEL01	GE 1024 1024 BI	GE 2048 512 BI	ORCA-05G	ORCA-R2
2010	2010	2009	2010	2007	2008
electroluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electroluminescence	electro-, photoluminescence
scientific CMOS	–	cooled scientific CCD	cooled scientific CCD	CCD	cooled CCD
scientific CMOS*1	Sony interline transfer CCD	back-illuminated full frame	back-illuminated full frame	interline transfer CCD	interline transfer CCD
2,560 × 2,160 pixels	1,392 × 1,040 pixels	1,024 × 1,024 pixels	2,048 × 512 pixels	1,344 × 1,024 pixels	1,344 × 1,024 pixels
6.5 × 6.5 µm	6.5 × 6.5 µm	13 × 13 µm	13 × 13 µm	6.5 × 6.5 µm	6.5 × 6.5 µm
6%	–	10%	10%	~ 4%	~ 4%
36,000 e-	–	100,000 e-	100,000 e-	15,000 e-	18,000 e-
0.03 e-/pix.s at -40 °C	–	1 e-/pix.s at -20 °C	1 e-/pix.s at -20 °C	–	0.0005 e-/pix.s at -40 °C
1 e- (rms)	–	< 10 e- (rms)	< 10 e- (rms)	10 e- (rms)	6 e- (rms)
– / -40 °C	– / –	two-stage Peltier / -20 °C	two-stage Peltier / -20 °C	– / –	Peltier / -40 °C
100 fps*2	–	2 fps*1	2 fps*1	9 fps	16 fps
16 bit	16 bit	16 bit	16 bit	12 bit	16 bit
16.6 × 14 mm	–	depend. on lens	depend. on lens	depend. on lens	depend. on lens
yes / –	yes / yes	yes / –	yes / –	– / –	– / –
30ms	100 - 3.6 × 10⁶ ms	depend. on applic.	depend. on applic.	depend. on applic.	depend. on applic.
C-mount, F-mount	C-mount	C-mount, M42, Minolta-MD	C-mount, M42, Minolta-MD	C-mount	C-mount
159.5 × 120 × 143.5 mm	–	45 × 87 × 123 mm	45 × 87 × 123 mm	–	–
–	ISO9001,CE	CE	CE	CE	CE
12 V	–	100 - 240 V	100 - 240 V	100 - 240 V	100 - 240 V
60 W	–	15 W	15 W	–	–
< 70% / -25 - 55 °C	80% / 10 - 45 °C	< 70% / 0 - 30 °C	< 70% / 0 - 30 °C	– / –	– / –
PC	PC	PC	PC	PC	PC
CameraLink, USB2.0*3	FireWire	USB	USB	IEEE1394	IEEE1394
fits, tiff, bmp, avi	16 bit tiff	jpg, bmp, tiff	jpg, bmp, tiff	–	–
Windows, Solis, iQ, SDK	Windows XP	SDK for Windows XP, Vista	SDK for Windows XP, Vista	Hamamatsu DCAM driver*1	Hamamatsu DCAM driver*1
1 year*4	1 year	1 year	1 year	2 years	2 years
4 - 6 weeks	3 weeks	4 - 6 weeks	4 - 6 weeks	~ 2 weeks	~ 2 weeks
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
€16,450 ($22,000)	180,000 CNY ($28,300)	~ €17,000 ($22,700)	~ €17,000 ($22,700)	~ €4,000 ($5,300)	~ €13,000 ($17,400)

*1 front-illuminated
*2 at 280 MHz
*3 configuration purposes only
*4 5-year vacuum warranty

*1 at full resolution

*1 at full resolution

*1 SDK available

*1 SDK available

operating principle of luminescence imaging technology is also attracting equipment makers to develop their own tools to be integrated into manufacturing equipment. US-based Komax Solar Inc. is a typical example. The company, with its leading position in making of combined tabber and stringer (CTS) and lay-up systems, has developed an extensive range of EL systems mainly for stations in module manufacturing.

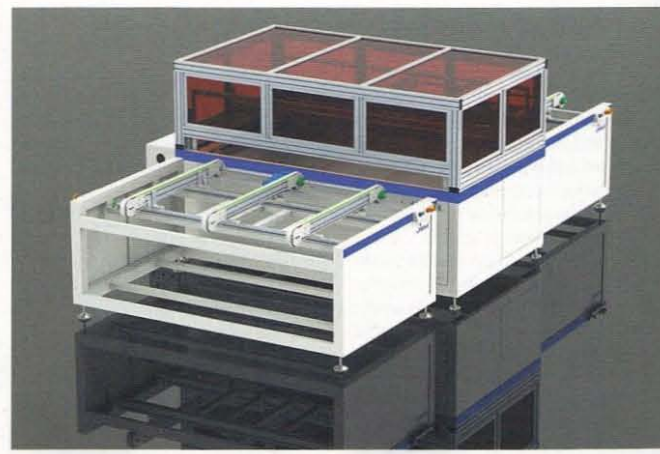
For the current survey, while appearing to have cut its overall portfolio from 13 to 11, Komax has just »simplified its catalog« by grouping several models into series, says Philippe Genin, the general manager for test equipment. In fact, it has actually come out with one new product – the **X5000i series**, focused on thin-film technology. As with the other module characterizing tools from the company,



◀ High prediction accuracy: Intevac claims its NanoVista PL system can calculate an as-cut wafer's eventual cell performance with a 99-percent accuracy. The tool is said to analyze around 15 image features and metrics to forecast the final cell efficiency, while edge impurities, grain boundaries and dislocations are the key defects checked.

Cameras for luminescence imaging

Company	Hamamatsu	Hamamatsu	Hamamatsu	Hamamatsu
model	ORCA-II BT 1024G	C9100-14	C10633-13	C10633-34
market introduction	2006	2008	2008	2010
Application				
electro- or photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence
Camera				
type of camera	cooled CCD	electron multiplier CCD	InGaAs	InGaAs
type of sensor	back-illuminated CCD	electron multiplier CCD	InGaAs focal plane array	InGaAs focal plane array
resolution	1,024 × 1,024 pixels	1,024 × 1,024 pixels	320 × 256 pixels	640 × 512 pixels
pixel size	13 × 13 µm	13 × 13 µm	30 × 30 µm	20 × 20 µm
quantum efficiency at 1,000 nm	~ 10%	~ 18%	–*1	–
full well capacity	80,000 e-	400,000 e-*1	–	–
dark current	0.0012 e-/pix.s at -75 °C	–	–	–*1
readout noise	6 e- (rms)	< 1 e- (rms)	–	–
cooling method / attainable temperature	Peltier / -75 °C	Peltier / -80 °C	– / –	Peltier / -70 °C
readout rate	3 fps	9 fps	60 fps	1.6 fps
dynamic range (A/D converter)	16 bit	16 bit	14 bit	12 bit
min. & max. field view of camera in standard config.	depend. on lens	depend. on lens	depend. on lens	depend. on lens
possibility to enhance field view / range	– / –	– / –	– / –	– / –
typical exposure time	depend. on applic.	depend. on applic.	depend. on applic.	depend. on applic.
System				
optical interface for lenses	C-mount	C-mount	C-mount	C-mount
dimensions (length × width × height)	–	–	–	–
certification	CE	CE	CE	CE
Utilities				
power supply	100 - 240 V	100 - 240 V	100 - 240 V	100 - 240 V
max. power	–	–	–	–
ambience (humidity / temperature)	– / –	– / –	– / –	– / –
System control & software				
computer hardware	PC	PC	PC	PC
PC interface	IEEE1394	CameraLink	USB2.0	RS422
compatible data formats	–	–	–	–
software compatibility	Hamamatsu DCAM driver*1	Hamamatsu DCAM driver*2	Hamamatsu DCAM driver*2	Hamamatsu DCAM driver*2
Warranty, delivery, distribution, price				
warranty	2 years	2 years	2 years	2 years
time of delivery	~ 2 weeks	~ 2 weeks	~ 2 weeks	~ 8 weeks
distribution area	worldwide	worldwide	worldwide	worldwide
price	~ €26,000 ($34,700)	~ €39,000 ($52,100)	~ €17,000 ($22,700)	~ €160,000 ($213,800)
Notes	*1 SDK available	*1 max. 730,000 e- *2 SDK available	*1 photo-response 0.65 (A/W) *2 SDK available	*1 unique InGaAs sensor optimized for low noise *2 SDK available



▶ Hands-on: Gsolar says its new GEL-M8 EL system is ideally suited for testing a cell matrix before lamination, claiming the tool's two high-resolution cameras can handle up to 120 modules per hour in manual operation.

Hamamatsu	Hamamatsu	PCO	PCO	PCO	PCO
C10000-401	C10000-701	pco.1300solar	pco.1400	pco.4000	pco.edge sCMOS
2007	2009	2008	2009	2007	2010
electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence
TDI CCD	TDI CCD	CCD	CCD	CCD	scientific CMOS
back-illuminated TDI sensor	back-illuminated TDI sensor	Sony interline transfer CCD	Sony interline transfer CCD	Kodak interline transfer CCD	scientific CMOS
2,048 × 128 pixels	4,096 × 128 pixels	1,392 × 1,024 pixels*1	1,392 × 1,024 pixels*1	4,006 × 2,672 pixels*1	2,560 × 2,160 pixels*1
12 × 12 µm	12 × 12 µm	6.5 × 6.5 µm	6.5 × 6.5 µm	9 × 9 µm	6.5 × 6.5 µm
~ 20%	~ 20%	2%	2%	1%	~ 5%
80,000 e-	80,000 e-	16,000 e-	24,000 e-	60,000 e-	30,000 e-
–	–	0.05 e-/pix.s at 10 °C	0.05 e-/pix.s at 10 °C	0.3 e-/pix.s at 10 °C	2 e-/pix.s at 5 °C
100 e- (rms)	100 e- (rms)	6 e- (rms)	7 e- (rms)	12 e- (rms)	< 1.4 e- (rms)
– / –	– / –	forced air*2 / -25 °C*3	housing / –	forced air*2 / -40 °C	forced air*2 / -20 °C
–*1	–*1	max. 11.7 fps*4	max. 13.5 fps*2	max. 5 fps*3	max. 100 fps*3
12, 8 bit	12, 8 bit	12 bit	14 bit	14 bit	16 bit
depend. on lens	depend. on lens	depend. on lens	depend. on lens	depend. on lens	depend. on lens
– / –	– / –	– / –	– / –	– / –	– / –
depend. on applic.	depend. on applic.	500 ms	500 ms	5,000 - 30,000 ms	< 200 ms
F-mount	–*1	C-mount	C-mount	F-mount	F-mount, C-mount
–	–	113 × 104 × 110 mm	100 × 100 × 50 mm	84 × 66 × 175 mm	130 × 70 × 80 mm
CE	CE	CE	CE	CE	CE
12 V	12 V	24 V	12 V	90 - 260 V	12 - 24 V
–	–	20 W	4 W	25 W	20 W
– / –	– / –	10 - 80% / 10 - 40 °C	10 - 80% / 10 - 40 °C	10 - 80% / 10 - 40 °C	10 - 80% / 10 - 40 °C
PC	PC	PC	PC	PC	PC
CameraLink	CameraLink	FireWire	FireWire	GigE, USB, FireWire*4	CameraLink
–	–	16 bit raw data, tiff, bmp	16 bit raw data, tiff, bmp	16 bit raw data, tiff, bmp	16 bit raw data, tiff, bmp
Hamamatsu DCAM driver*2	Hamamatsu DCAM driver*2	Windows 2000, Linux	Windows 2000, Linux	Windows 2000, Linux	Windows 2000, Linux
2 years	2 years	1 year	1 year	1 year	1 year
~ 4 weeks	~ 4 weeks	2 weeks	2 weeks	2 weeks	2 weeks
worldwide	worldwide	worldwide	worldwide	worldwide	worldwide
~ €12,000 ($16,000)	~ €22,000 ($29,400)	€9,500 ($12,700)	€6,500 ($8,700)	> €22,400*5 ($29,900)	€13,000 - €15,000*4 ($17,400 - $20,000)
*1 50 kHz line rate *2 SDK available	*1 100 kHz line rate *2 SDK available *3 M72, P=0.75	*1 1.4 megapixels *2 single-stage Peltier element *3 versus ambient *4 at full resolution	*1 1.4 megapixels *2 at full resolution	*1 11 megapixels *2 double-stage Peltier element *3 at full resolution *4 CameraLink *5 depend. on memory and cooling	*1 5.5 megapixels *2 double-stage Peltier element *3 at full resolution *4 depend. on shutter mode

this device is also capable of detecting shunts and inactive areas, in addition to thin-film-specific flaws such as defects in laser scribing. It employs a 1.4 megapixel camera and tests up to 80 thin-film modules per hour. Komax is selling this new system for a price range of €70,000 to €170,000 ($93,500 to $227,100). Another two models dealing with crystalline modules are planned to be launched in 2012. Its **X4800i thermo module tester** will be integrated with thermography mapping capabilities to detect hot spots, in addition to EL mapping. The **X6000i EL tower flasher** will be integrated into a module flasher.

Except for the **X1000s EL string tester** and the **X2000s EL module tester**, all of Komax's products are offered with an automatic fault-detection algorithm, as well as backlight and front optical inspection options for measuring dimensional accuracy, bus bar alignment, contamination detection and cell-edge inspection.

Berger – solution for modules: While Berger Lichttechnik GmbH is still offering its PSL EL 2 as a subsystem for its tools related to cell characterization, the German company has expanded into module characterization with its **PSL MEL**. Although introduced in 2010, Berger has only provided the data now. Most of the parameters for this tool resemble the PSL EL 2, except for the fact that it has a larger field view of up to 1,800 × 1,200 mm to accommodate module testing. The other major difference is price. While the PSL EL 2 is sold for €66,000 ($88,200), the new launch is shipped for €45,000 ($60,100). Both of these EL systems are offered as subsystems for IV measurement and additionally perform IR substrate scans.

Manz – shorter exposure time: Manz has been integrating its **Manz EL 2400** system for EL cell characterization as a subsystem in its ICT 2400 cell sorter since 2008. The only change the system has undergone since our previous listing is that the exposure time has been reduced to 0.3 seconds from 0.4 seconds. The product is still featured with a 1,024 × 1,024 pixel resolution camera and supports the measurement of 2,400 cells per hour. It is sold for €103,000 ($137,600), but only to users of the ICT 2400 cell sorter.

Vitronic – on- and offline detection like before: Germany-based Vitronic Dr.-Ing. Stein Bildverarbeitungssysteme GmbH introduced its **VINSPECsolar** in 2009. It is capable of characterizing cells, strings and modules, mapping contour defects, grid-line defects, cracks with electrical effects and inactive

Cameras for luminescence imaging

Company	Princeton	Princeton	Princeton	Princeton
model	PIXIS: 1024BR, BR_eXcelon*1	PIXIS: 2048BR	ProEM: 1024B, B_eXcelon	Rolera EMC²*1
market introduction	2006, 2010*1	2010	2009	2010
Application				
electro- or photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence
Camera				
type of camera	cooled scientific CCD	cooled scientific CCD	cooled scientific EMCCD	cooled scientific EMCCD
type of sensor	deep-depletion CCD	deep-depletion CCD	EMCCD	EMCCD
resolution	1,024 × 1,024 pixels	2,048 × 2,048 pixels	1,024 × 1,024 pixels	1,004 × 1,002 pixels
pixel size	13 × 13 µm	13.5 × 13.5 µm	13 × 13 µm	8 × 8 µm
quantum efficiency at 1,000 nm	40, 43%	40%	10, 11%	7%
full well capacity	100,000 e-	100,000 e-	80,000 e-	34,700 e-
dark current	0.01 e-/pix.s at -80 °C	0.02 e-/pix.s at -60 °C	0.002 e-/pix.s at -55 °C	0.06 e-/pix.s at -50 °C
readout noise	3 e- (rms)	3 e- (rms)	< 1*1, 2.5*2 e- (rms)	< 1 e- (rms)*2
cooling method / attainable temperature	thermoelectric / -90 °C	thermoelectric / -70 °C	thermoelectric / -75 °C	thermoelectric / -50 °C
readout rate	1.7 fps	0.5 fps	9 fps	34 fps
dynamic range (A/D converter)	16 bit	16 bit	16 bit	14 bit
min. & max. field view of camera in standard config.	13.3 × 13.3 mm*2	27.6 × 27.6 mm*1	13.3 × 13.3 mm*3	8 × 8 mm*3
possibility to enhance field view / range	yes / –	yes / –	yes / –	yes / –
typical exposure time	100 ms	100 ms	100 ms	100 - 1,000 ms
System				
optical interface for lenses	C-mount, F-mount*3	F-mount, C-mount	C-mount, F-mount*4	C-mount
dimensions (length × width × height)	166 × 118 × 113 mm	188 × 118 × 113 mm	200 × 147 × 147 mm	150 × 76 × 64 mm
certification	CE	CE	CE	CE
Utilities				
power supply	12 V	12 V	24 V	12 V
max. power	50 W	50 W	50 W	40 W
ambience (humidity / temperature)	50% / 5 - 30 °C	50% / 5 - 30 °C	50% / 5 - 30 °C	50% / 5 - 30 °C
System control & software				
computer hardware	PC	PC	PC	PC
PC interface	USB2.0	USB2.0	GigE	FireWire (1394b)
compatible data formats	16 bit tiff, bmp, fits	16 bit tiff, bmp, fits	16 bit tiff, bmp, fits	16 bit tiff, bmp, fits
software compatibility	Windows, Linux	Windows, Linux	Windows, Linux	Windows, Linux
Warranty, delivery, distribution, price				
warranty	1 year*4	1 year*2	1 year*5	2 years
time of delivery	4 weeks	8 weeks	4 weeks	4 weeks
distribution area	worldwide	worldwide	worldwide	worldwide
price	$37,000 - $45,000	$75,000 - $80,000	$57,000 - $65,000	$22,950
Notes	*1 proprietary technology *2 sensor image area *3 C-mount *4 lifetime on vacuum	*1 sensor image area *2 lifetime on vacuum	*1 EM mode, *2 non-EM mode *3 sensor image area *4 C-mount *5 lifetime on vacuum	*1 manufactured by Qimaging *2 EM mode *3 sensor image area



▲ Tailored for PL: Princeton Instruments has introduced a new camera, the PloNIR: 640 (pictured on the left), with a response bandwidth via an InGaAs sensor that makes it a better option for PL-related applications than the company's silicon CCD sensor-based PIXIS: 1024BR (shown on the right).

cells. For modules, the tool also inspects the spacing between cells, as well as the ribbons between cells. This EL inspection system, which can be installed at various process stations, is offered in both inline and stand-alone configurations. Vitronic, which is also promoting the tool for thin-film module characterization, has not made any major changes since last year. The device can support a testing speed of up to 3,600 cells, and 900 strings and modules per hour. The company is selling the tool for €40,000 ($53,400).

Zenith Solar – same product for many configurations: China-based Zenith Solar Technological Co. Ltd. is still offering its **EL-4P** system, first introduced in 2007. The company claims that in addition to characterizing the PV substrate at various stages in crystalline silicon (c-Si) solar cell

Princeton	Sensovation	Sensovation	Sensovation	Sensovation	Vision Components
PloNIR: 640	coolSamBa HR-830	coolSamBa HR-400	coolSamBa HR-320	SamBa Ci	VC4067/NIR
2011	2007	2007	2005	2009	2009
electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electro-, photoluminescence	electroluminescence
cooled scientific InGaAs	cooled scientific CCD	cooled scientific CCD	cooled scientific CCD	scientific CCD	CCD
InGaAs	CCD	CCD	CCD	CCD	Sony EXview HAD CCD
640 × 512 pixels	3,326 × 2,504 pixels	2,048 × 2,048 pixels	2,184 × 1,471 pixels	3,326 × 2,504 pixels	1,280 × 1,024 pixels
20 × 20 µm	5.4 × 5.4 µm	5.4 × 5.4 µm	6.8 × 6.8 µm	5.4 × 5.4 µm	6.5 × 6.5 µm
80%	8%	8%	10%	8%	~ 6%
> 45,000 e-*1	25,000 e-	25,000 e-	55,000 e-	25,000 e-	16,000 e-
450 e-/pix.s at -80 °C	0.03 e-/pix.s at -20 °C	0.03 e-/pix.s at -20 °C	0.01 e-/pix.s at -35 °C	–	–
< 65 e- (rms)*1	< 10 e- (rms)	< 10 e- (rms)	< 10 e- (rms)	< 20 e- (rms)	–
thermoelectric / -80 °C	thermoelectric / -30 °C	thermoelectric / -30 °C	4-stage thermoelectric / -40 °C	passive / –	no cooling / –
110 fps	max. 1.5 fps*1	max. 1.5 fps*1	max. 5 fps*1	3 fps	max. 14 fps
16 bit	16 bit	16 bit	16 bit	8, 12 bit	10 bit
12.8 × 10.24 mm*2	1,200 × 1,200 - 500 × 500 mm*2	600 × 600 - 100 × 100 mm*2	800 × 800 - 300 × 300 mm	300 × 300 - 100 × 100 mm*1	depend. on lens
yes / –	yes / –	yes / –	yes / –	yes / –	– / –
100 - 1,000 ms	(6 - 100) × 10^4 ms	(6 - 100) × 10^4 ms	(6 - 100) × 10^5 ms	50 - 5,000 ms	0.005 - 17,590 ms
C-mount	F-mount, combi-mount	C-mount, combi-mount	C-mount	C-mount	C-mount
200 × 147 × 147 mm	100 × 130 × 170 mm	100 × 130 × 170 mm	100 × 130 × 170 mm	110 × 110 × 35 mm	110 × 50 × 35 mm
CE	CE, ISO9001, ISO13485	CE, ISO9001, ISO13485	CE, ISO9001, ISO13485	CE, ISO9001, ISO13485	CE
24 V	12 V	12 V	12 V	12 V	24 V
150 W	–	–	–	–	5 W
50% / 5 - 30 °C	– / 15 - 40 °C	– / 15 - 40 °C	– / 15 - 40 °C	– / 15 - 40 °C	10 - 80% / 0 - 40 °C
PC	PC	PC	PC	PC	DSP
GigE	USB2, CameraLink	USB2, CameraLink	Ethernet	GigE, USB2.0	Ethernet, RS232
16 bit tiff, bmp, fits	16 bit tiff	16 bit tiff	16 bit tiff	8, 12 bit tiff, bmp, jpg	bmp, jpg*1
Windows, Linux	SDK for Windows XP, Vista	SDK for Windows XP, Vista	SDK for Windows XP, Vista	SDK for Windows XP, Vista	Windows, Linux
1 year*4	1 year	1 year	1 year	1 year	2, 3 years
4 weeks	4 weeks	4 weeks	4 weeks	4 weeks	2 weeks
worldwide*5	worldwide	worldwide	worldwide	worldwide	worldwide
$110,000	€8,370 ($11,200)	€8,250 ($11,000)	€11,875 ($15,900)	€5,800 ($7,700)	€4,285*2 ($5,700)
*1 high gain output, *2 @ 2 MHz *3 sensor image area *4 lifetime on vacuum *5 export controlled	*1 at full resolution *2 for modules	*1 at full resolution *2 for modules and cells	*1 at full resolution	*1 for cells	*1 for storage *2 unit price

manufacturing, such as cells, strings and modules, the tool is also capable of testing thin-film modules at a number of processing steps. Zenith has not made any major changes to the system since last year. The system is again offered with the option to choose either a 1,360 × 1,024 pixel or 3,326 × 2,504 pixel resolution. It is configured to inspect up to 150 cells, and 15 to 120 strings or modules per hour. The EL-4P has an unchanged price range of $35,000 to $60,000.

Luminescence cameras

Excluding the automatic defect-detection software, EL and PL systems are not worth much without a decent camera. For cell and module manufacturers that do not require high-end algorithms and simply need to generate images, then buying a luminescence camera and building their own peripherals is a much more cost-effective solution.

The most important parameter of the camera is its sensitivity governed by the sensor technology. The luminescence signals from the solar substrate under investigation are near the IR wavelength. Thus, the cameras must be sensitive enough to capture this low-level light. The cameras are also expected to produce accurate images with a sufficient resolution. Following this lead, other camera terminology parameters come into play, such as quantum efficiency, readout noise, dark current, resolution, pixel size and readout rate.

Princeton – tailored for PL: US-based Princeton Instruments is the only company from last year's participants to come out with a new product. Its **PloNIR: 640** is well-suited for PL imaging of PV wafers and cells in low-light conditions, according to product manager Ravi Guntupalli. The camera, with its high sensitivity in the near-infrared (NIR) band, he says, is built on an InGaAs focal-plane array (FPA) sensor. The response bandwidth wavelength of the sensor is 900 to 1,700 nm, with a quantum efficiency at 1,000 nm of up to 80 percent.

For PL, Guntupalli says that the new camera is better at capturing images than Princeton's silicon CCD sensor-based **PIXIS: 1024BR** camera with a silicon response that »is not ideal at the peak PL wavelength of 1,150 nm.« The other advantage of the PIoNIR: 640, he says, is that due to the higher sensitivity, the camera has a high image-

Cameras for luminescence imaging

Company	Vitronic	Zenith Solar
model	VICAM EL	EL-4C
market introduction	2011	2007
Application		
electro- or photoluminescence	electroluminescence	electroluminescence
Camera		
type of camera	uncooled CMOS	cooled scientific CCD
type of sensor	CMOS	CCD
resolution	2,000 × 2,000 pixels	1,360 × 1,024 pixels
pixel size	–	6.8 × 6.8 µm
quantum efficiency at 1,000 nm	–	5%
full well capacity	–	50,000 e-
dark current	–	0.01 e-/pix.s at -50 °C
readout noise	–	< 10 e- (rms)
cooling method / attainable temperature	– / –	forced air*1 / -50 °C
readout rate	3 fps	11.7 fps*2
dynamic range (A/D converter)	12 bit	16 bit
min. & max. field view of camera in standard config.	170 × 170 - 1,300 × 2,000 mm	depend. on lens
possibility to enhance field view / range	yes / yes	– / –
typical exposure time	–	(100 - 6) × 10^6 ms
System		
optical interface for lenses	–	C-mount
dimensions (length × width × height)	60 × 70 × 110 mm	500 × 500 × 700 mm
certification	CE	CE*1
Utilities		
power supply	–	50 V
max. power	–	50 W
ambience (humidity / temperature)	– / –	10 - 80% / 10 - 40 °C
System control & software		
computer hardware	PC	PC
PC interface	Ethernet	USB, RS232
compatible data formats	txt, jpg, tiff	bmp, jpg*2
software compatibility	Windows XP	Windows XP
Warranty, delivery, distribution, price		
warranty	2 years	1 year
time of delivery	16 weeks	2 - 4 weeks
distribution area	worldwide	worldwide
price	€40,000*1 ($53,400)	$30,000 - $48,000
Notes	*1 system price	*1 in progress *2 16 bit *3 up to 3,032 × 2,016 pixels

capturing speed. Indeed, at 110 frames per second at 10 MHz, it is the highest in the survey. The camera comes with a complete software acquisition package for R&D or for use by original equipment manufacturers (OEM) of PL inspection systems. At $110,000, Princeton's PIoNIR: 640 is the second most expensive camera in the survey. Princeton's other camera models, all featured in our previous overview, have not undergone any changes.

Vitronic – not for separate sale: While Vitronic is new to the segment on cameras, it has actually been designing and producing special line-scan and area cameras since 1995. According to deputy sales director Richard Moreth, the German company has integrated »thousands« of inspection systems with Vitronic's cameras.

Vitronic, however, does not sell its **VICAM EL** camera separately, but only as an integral part of its EL inspection system. That could be the reason for its incomplete spec sheet. The only valuable information available for this CMOS sensor-based camera is its resolution, given as 2,000 × 2,000 pixels. The price listed in the camera table is misleading: Vitronic has not entered the camera price, but rather the cost of the complete inspection system.

Boostsolar– sparse specs: China's Boostsolar Photovoltaic Equipment Co. Ltd. is another new entrant to the camera segment. Like Vitronic, Boostsolar is also promoting one camera, for which it has provided very few details, even though it hasn't sent any information for a system. According to the available data, the **LMEL01** employs a Sony-branded interline transfer CCD sensor with a resolution of 1,392 × 1,040 pixels. The pixel size is given as 6.45 × 6.45 µm. Boostsolar sells the camera for 180,000 CNY ($28,300).

Hamamatsu – simply adding models: Except for reduced prices, Hamamatsu has not reported any major changes to its wide product range of seven cameras. But it has provided some details on a »new« camera model introduced in 2009. The **C10000-701**, like Hamamatsu's **C10000-401**, is based on a back-illuminated time-delayed integration (TDI) sensor. However, the 4,096 × 128 pixel resolution of the C10000-701 is twice as high. The camera is rated with a quantum efficiency of 20 percent at 1,000 nm. While Hamamatsu has not filled in the dark current data (also the case for its other models), the C10000-701 readout noise is put at 100 e⁻ (rms). As with most of its other products, this camera is suitable for both EL

Quasi-mono or Quasimodo?

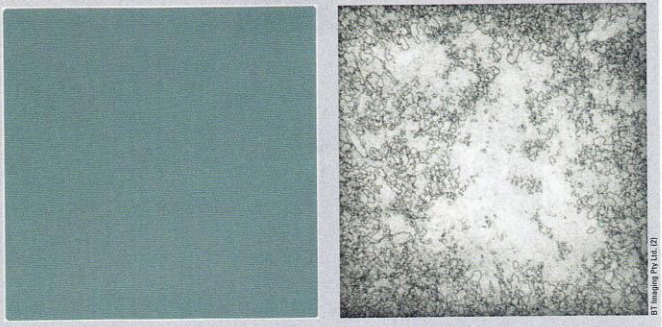
The problem with beauty is that sometimes it is only skin-deep. As for quasi-monocrystalline silicon, the sexiest PV development to emerge in a long time, the jury is still out.

On the surface, this new class of substrate material appears to be a dream come true with a cost-reducing allure that has increasingly been setting the hearts of wafer manufacturers aflutter. They are swooning to the promise that this novel process will marry the higher performance of monocrystalline with the less costly manufacturing process of multicrystalline silicon (see PI 6/2011, p. 260).

But what looks like a PV marriage made in heaven could turn out to be trouble in paradise. The optically perfect monocrystalline-like wafers, produced via the so-called mono-casting process, look no different from the silicon substrates sliced from cylindrical ingots grown in traditional Czochralski furnaces. But what lurks just below the wafer surface could leave the eventual efficiency of processed cells wanting – and many experts full of questions.

The answer to at least part of the uncertainty has come from revealing analysis made possible by photoluminescence (PL). Unlike its cousin, electroluminescence (EL), PL can peer into silicon bulk and as-cut wafers.

And what PL imaging has exposed so far is something ingot and wafer manufacturers do not like to see – a high density of electron-trapping and efficiency-lowering dislocations in the bulk. The culprit is stress, says Thorsten Trupke, the CTO at Australia-based BT Imaging Pty Ltd., one of the leading luminescence companies around. Stress builds up during the casting process. He notes that this is equally true for conventional multicrystalline-ingot making.



BT Imaging Pty Ltd. (2)

▲ Beauty and the beast: Using a PL tool, BT Imaging has exposed this optically perfect monocrystalline wafer derived from mono-cast quasi-monocrystalline silicon (on the left) as containing a high density of dislocations (shown on the right), an indication of poor wafer quality.

However, that process offers a defense mechanism to release stress – the formation of grain boundaries. While grain boundaries are also an unwanted defect, at least they help lower the crystal-dislocation density in the casting process. But in quasi-monocrystalline silicon, there is a considerably reduced density – or even a total absence – of grain boundaries. That leads to extra stress and, hence, a high density of dislocations.

In the case of traditionally processed multicrystalline silicon, dislocations have long been a major concern that has kept PV researchers busy. While a complete remedy has not yet been found, the top-tier luminescence imaging system suppliers have developed algorithms to help gauge the eventual cell efficiency of traditional silicon substrates, taking into account the adverse effect of many defects, including grain boundaries.

However, the situation seems to be much more challenging for quasi-monocrystalline silicon, says Trupke. »We are maybe one or two steps behind conventional multi.« Currently, BT Imaging is cooperating with wafer and cell manufacturers to develop quasi-mono software, but Trupke would not reveal the names of the company's partners. Several other companies, including Op-tection GmbH and 3i Systems Corp., are also working on the development of such an algorithm.

For now, a credible set of rules to forecast the influence of dislocations on the potential electrical performance of as-cut quasi-monocrystalline silicon wafers has not yet been formulated. Until then, the answer to the question of whether the external beauty of such substrates is more than skin-deep will have to wait. ● skc

and PL imaging. The price for the C10000-701 is given as about €22,000 ($29,400).

Companies unchanged: The cameras from the other companies listed have not undergone any significant changes. UK-based **Andor Technology Ltd.** is still promoting the same five cameras. The four products from **PCO AG** have also not undergone any upgrades. **Greateyes**, though it updated its integrated systems considerably, has left its two cameras unaltered since last year. **Sensovation AG** from Germany is again promoting four models with unchanged specs. Another German company, **Vision Components**, is again listing its solo model with no alterations. As for the only model from **Zenith Solar**, it specified that the cooling method has been adapted to »forced air,« noting no other changes.

Summary

Overall, looking at all these developments, camera suppliers appear to be taking the PV segment more seriously than in the past. They are churning out new models that are especially suited to EL and PL applications for solar cells. This may be the result of more competition, as the number of camera suppliers has also increased. This may result in better designs at lower prices, as has been seen in the system segment. On the systems front, there is no doubt that luminescence imaging systems have landed a permanent position in PV production as reliable characterization tools.

So which is the better choice? Despite the apparent rivalry, EL and PL imaging actually complement each other. While the former is well established at the bottom end of the value chain (for finished modules), PL applications are beginning to prove their worth at the early stages of PV wafer manufacturing. In the next few years, it is quite probable that every PV substrate leaving a wafer, cell or module factory will be labeled with the inspection results of both EL and PL imaging. ●

Further information

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