Weeding out wafers with defects is necessary to prevent unnecessary costs from incurring. Above is GP Solar's illumination concept of an in-line microcrack scanner.

Not falling through the cracks

Optical wafer inspection: Metrology systems are available in the market for the tedious task of detecting errors in wafers before they get forwarded onwards in the manufacturing line.

Within the scope of solar module manufacturing, the wafer segment accounts for about 60 percent of the total costs incurred. Given such a significantly large portion of the cost-pie, it is pertinent for these wafers to be substantially error-free. Having said that, the efficient handling of these ultra thin elements in the production process of solar cells is an important challenge for solar cell manufacturing. As stated before, the ultra-thin characteristic of the wafers, apart from their value, makes them extremely fragile, with typical thicknesses being 0.18 to 0.20 millimeters (mm). This, thereby, translates into potential further cost penalties. Wafers have the tendency to break very easily should they be not treated in a gentle manner. The problem with that (apart from the fact that the manufacturer has broken wafers that become redundant) is that this may result in the decreased optimal utilisation of the production line significantly and furthermore lead on to the waste of costly production material. When examining current production costs and wafer prices, the increase of wafer breakage by one percent (e.g. from three to four percent) leads to costs about 500,000 euros per year for a 80 megawatt per year production line. These are the typical figures existent. That is already a hefty figure for a manufacturer to take into account.

Handling

Cell factories are equipped with handling and processing equipment, which is designed to handle wafers that remain within certain parameters with respect to geometry and surface properties, and most importantly rigidity. Any wafer unable to comply with these specifications has then the increased likelihood of breakage. Even if such a wafer with non-complied parameters survives the cell production process and becomes a solar cell, it has the potential to break in the module assembly segment, thereby causing even greater damages. Electrical properties of wafers can be checked with statistical methods. The parameters that are linked to breakage or shunts, on the other hand, need to be inspected 100 percent. At the same time, this needs to be undertaken without increasing the likelihood of breakage through the inspection process itself. Being non-tactile, fast and flexible, optical in-line wafer inspection is the established method for the incoming inspection of wafers in a solar cell factory.

Defects

There are a smorgasbord of defects that can come into play, and in order to match that, a wide array of tools within the equipment. These include geometry, box-warp, waviness, thickness, edge defect, saw mark and non-visible crack detection tools, to name the main ones. Wafer size and thickness (TTV = Total Thickness Variation) must stay within tolerance boundaries that are in the order of 0.1mm, usually not a big challenge for an optical in-line inspection system. Defects that occur at the outer contours, surface chips or the so-called saw-marks have to be detected as of 0.01mm. These are already a bit of a challenge. Saw-marks are usually caused by a sawing wire's temporary deviation from its position. This thereby exhibits itself as steps in the wafer's surface profile. The biggest challenge, however, is the detection of defects hidden within the bulk of the wafer. These are the so-called microcracks and inclusions of contaminations. Microcracks cannot be detected with visible light and may not even necessarily penetrate into the surface of the wafer. It is not entirely clear how these microcracks occur. Their occurrence seems to be related to thermal stress in the production process or physical stress during transportation and is directly related to the breakage rate in the cell production process. Given the wide variety of different inspection requirements, it is virtually impossible to combine all of them into one inspection system. In a typical system, the focus is normally on a sub-set of the inspection criteria. Some equipment even specialize specifically in microcrack inspection only.

Main requirements of systems

With the purchase of optical inspection systems, there is the expectation that these systems will make reliable statements with respect to the occurrence of defects, their size and type. Over-

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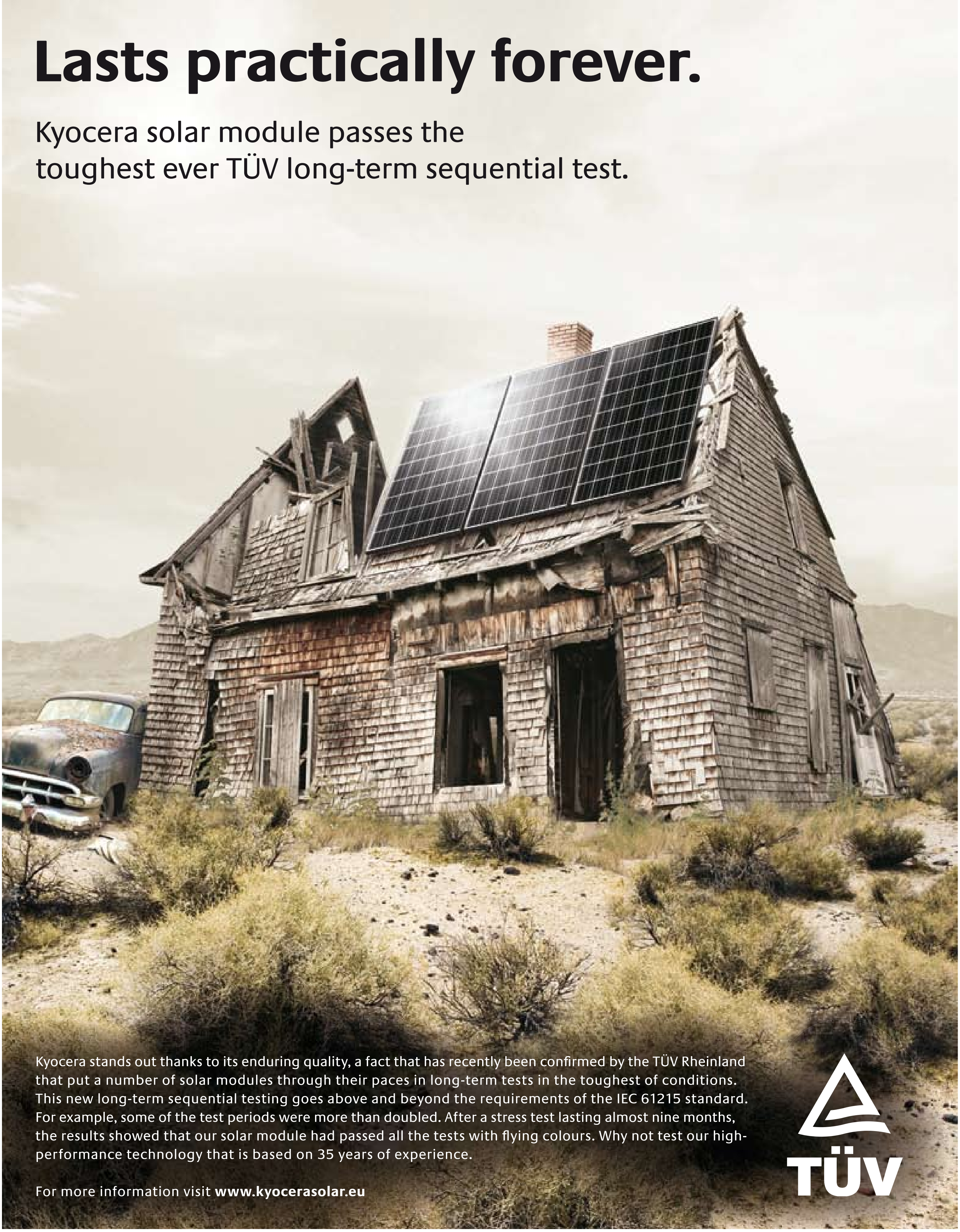

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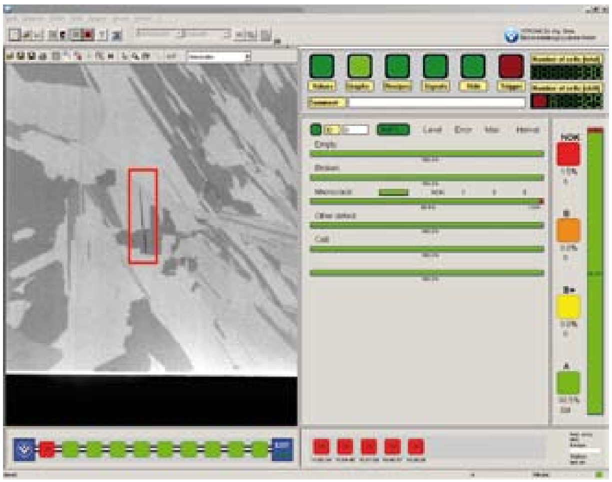
A microcrack that is detected and highlighted.

Photo: ISRA Vision



A screenshot of a microcrack that is generated by the system.

Photo: Vitronic

rejects, which means the system classifies acceptable wafers as rejects, should be minimal. Under-rejects, meaning the system lets non-acceptable wafers slip through, should not occur at all. In microcracked wafers, however, users prefer a low over-reject rate to avoiding under-reject by all means. Over-rejects cannot be sorted manually as the cracks are not visible to the naked eye. Trashing wafers, where there is uncertainty whether they are microcracked or not, is very painful. On the other hand, under-rejects would increase the breakage rate slightly but not influence the average cell quality significantly. Optical inspection systems are composed of a camera, illumination, and a system that presents the wafer to illumination and a handling system. The illumination is usually designed in a manner that the features that are to be inspected appear enhanced while those that are of no interest are at best not visible at all. This can be further elaborated as such. The wafer's outer circumference, for one, is best inspected with the wafer being illuminated from the back. Surface defects are typically seen in a structured light (line projectors). Microcracks can appear as contaminations when the wafer is transparent and the light is penetrating the wafer in a direction parallel to the surface. Light sources for microcrack inspections operate therefore typically at a wavelength of 1.5 µm (microns) and above. (That implies that cracks smaller than 1.5 µm cannot be seen). In order to meet and deliver the reliability criteria as stated above, the wafers must be presented in the most predictable and controlled way to both light and camera. Transferring a measurement principle which works fine in the laboratory to the shop-floor is the most critical part of the system design. In order to control this step 100 percent, some system manufacturers supply a complete unit which includes the handling system. Others supply a tool kit which allows integration into the most popular process equipment. Solar cell manufacturers often contemplate retrofitting optical inspection systems into their existing production lines. Thus, with a special focus, the integration aspects have been covered in the survey.

It is also important to keep in mind that wafer manufacturers and cell manufacturers may have different requirements pertaining to the systems. Solar cell manufacturers are not satisfied with a system that aids in the removal of wafers with defects out of the production process only. Since a production process is optimized by carefully balancing the recipes of all production steps with respect to one other, it is crucial to export data from each process step into an off-line computer for analysis by the process technology engineers. The inspection system is used for "in-line characterisation". Thus, inspection systems are expected to provide measurement data in a non-proprietary but standardised format (MS excel, MS Access, Oracle, SQL) using a standard data interface such as OPC or SEGS/GEM. Some systems even offer the option to define the classification criteria in database query formats. This thereby, allows the definition of the classification criteria following a careful off-line analysis of the measurement data.

Innovations and expectations

The industry has seen the introduction of some microcrack inspection systems into the market in the last two years. These systems are gaining a reputation for reliability and are about to be widely accepted. With the difficulty of microcrack inspection on wafers being overcome, the industry is anxiously waiting for reliable inspection systems with the ability to find microcracks in processed solar cells. Only such systems can potentially save the module manufacturers from the issues of breakage brought on by microcracks. ◆

Stephanus Wansleben, Solsol

THE AUTHOR

Stephanus Wansleben is the Managing Director of Solsol. Dr. Wansleben founded the machine vision company Qtec in 1994. Qtec supplied the vision inspection technology to the first production line of Schott Solar in Alzenau, Germany – ASE GmbH at that time – in 1998, and was selected as the general supplier of vision inspection technology for centrotherm's first turnkey project in 2001 for Deutsche Cell. After Qtec merged with ICOS Dr. Wansleben remained Managing Director of ICOS Vision Systems GmbH until 2008. Under his management, ICOS launched its series of solar cell/wafer inspection systems, one still very popular among solar cell manufacturers world-wide. Dr. Wansleben co-founded GPinspect, Munich, in 2008, which has developed into a dominant supplier of inspection technology for the PV industry. His active involvement at GPinspect ended in 2009.

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Photo: GP Solar

Rectifying issues

Interview: GP Solar's Managing Director Eric Rüland explains innovations and the complex process of weeding out the good from the bad.

How does GP Solar differentiate its systems from the others in the market?

Usually optical inspection means you check the image and see if you find something somewhere and you have a routine where you categorize these findings into a defect category. And then, you have prioritization within the different defects. Thereafter, the wafer gets a category, according to which the sorting is done. GP Solar's software structure operates in a different manner. Measurement and defect data are written into a database, an online MES (Manufacturing Execution Systems) in a way. These are measurement data like geometry, sizes, angles and so on as well as defects, not just size and color, but also special process defects. These can be saw marks, microcracks, edge cracks, of which it can be parallel to the edge or a V-shape and so on. With this information, we can define the overall quality. It is not just about image checking and stating if the wafer has to be sorted out. It is the total set of information that is used to define and determine the further processing of the wafer. If it is a process-related problem, then the process can be changed. That is the real benefit for the user.

The database that I am talking about is an internal procedure. We classify based on database records. Separately, we have an interface to an outside (external) MES. The database that we use for classification is more detailed. The internal database has roughly one day of production, as it is online and not stored in the hard disk. With one second cycle-time, this database check is made and we get the wafer categorization results. So, we do not classify on image but database information. The big benefit is that you can sum up information from 100 wafers in a row for example and track process changes as additional information to the single image information.

There is this issue of over and under rejects. How does GP Solar rectify this?

Microcrack detection is one aspect where over and under rejects detection is essential. Five to six years ago, it was discovered that it is relatively simple to do with some kind of cameras, with infrared light-through technique to see a sort of an X-ray picture of the wafer. But with this X-ray picture, at least for multi-crystalline wafers, you see all the crystalline information. And quite often, the crystals themselves look dented, just like microcracks. Therefore, there is almost no chance to differentiate between them. Most of the systems in the market, I would say, almost all, developed special software techniques to find categories to differentiate microcracks from the crystalline structures.

GP Solar has a patent-pending technique where the image itself shows a very low contrast, almost no crystallinity. We see only a kind of fingerprint-structure where we can define between the two, making the entire process easier for us. The feedback that we had gotten from customers is that sometimes their microcrack systems sort out 50 percent of wafers that do not have microcracks. This means that the pseudo error rate is too high. With our technology for microcracks, the GP Nano-D technology, we had the chance to reduce the pseudo error rate to almost zero.

It seems microcracks are tricky to detect in this sense. Is it hard to pin-point the source of microcracks?

It can actually be defined with the system. There are mainly two sources. One, we call, a natural crack. This is a source that is combined with thermal stress. It can happen during the crystallization phase or later during the processing. But thermal stress means very limited energy and usually very small cracks, often just one line of cracks.

The other kind of cracks are artificial, mechanical cracks. Any mechanical stress to the wafer can cause these kinds of microcracks to happen. The thermal stress cracks are more complicated and cannot be easily detected back to the source. However, if you have an artificial crack, then you can utilise position information, together with statistical data combined in our system, to trace back the section that potentially caused the crack.

Why is integration of individual systems into one difficult?

Take the different tasks. One is to have a very accurate measurement of the wafer and the best way to do that is a matrix camera. You stop under a defined illumination and you take a picture. That is a defined procedure for accurate micrometer angles of the wafer and so on. On the other hand, microcrack and saw mark detection usually need an on-the-fly procedure for best results. If you think about attaining best measurement results, the procedures to move the wafer are different. And for one, you need illumination from bottom and top and the other, only from the top. You have different illumination wavelengths; microcracks usually use infrared. Whereas, for the other, optical light. That is the reason why. We discuss with our customers and ask them what their needs and main focuses are. We can then offer different kinds of set-ups. Perhaps the customer does not need very high accuracy on the geometry, so he can measure the geometry on-the-fly as well.

What are your innovation plans?

We are embarking on a saw-mark and waviness detection development. At the moment, the systems have a limited accuracy and some three dimensional defects are not measured as accurately as others. We are at the stage of having a product release later this year for a two dimensional topo scanner in a one second cycle-time which will be helpful for wafers and for cell inspection. ◆

Interview by Shamsiah Ali-Oettinger

GENERAL											DIMENSIONS OF THE COMPLETE UNIT				INTEGRATION EFFORT									
Manufacturer	Product name	Number of installed systems	Price range in Euros	Maximum wafer size	Pixel size in the object plane in µm x µm	Image acquisition		Laser classification (IEC 60825-1 standard)	Wafer handling included?	Wafer handling with or without sorting	Length (in mm) (with handling in mm)	Width (in mm) (with handling in mm)	Height (in mm) (with handling in mm)	Weight (in kg) (with handling in kg)	Standstill time if not on-the-fly	Cycle time throughput per hour	Camera type			Spectral sensitivity greater than 1100 nm (SWIR)	Max conveyer speed if on-the-fly (in mm/sec)	Standards of machine interface		
				6"		On-the-fly	Stop-and-go	Class	Yes/No	With/without/optional					In msec		Laser sensor	Line scan camera	Area scan camera			SEGS/GEM	OPC	Parallel I/O
ATMvision AG	WIS	> 100	On request	x	13 x 13	x	x	n.a.	Yes	Op	6400	2000	2400	3500	700	4000		x	x		250	x	x	x
ATMvision AG	µCracks	> 250	On request	x	13 x 13	x	x	n.a.	No	n.a.	350	200	620	20	700	4000		x	x		250	x	x	x
ATMvision AG	OWI	> 500	On request	x	13 x 13	x	x	n.a.	No	n.a.	430	260	380	20	700	4000		x	x		250	x	x	x
ATMvision AG	TraceTTV	> 500	On request	x	1 x 18	x	x	n.a.	No	n.a.	380	110	310	20	700	4000		x	x		250	x	x	x
ESCAD	eWI-001 Topology	>15	22000 - 45000	x	0.02 x 0.02	x		3R	Yes (Op)	without	220 (400)	400	400	9 (20)	n.a.	3600	x	x (Op)			300	x	x	x
ESCAD	eWI-002 Optical Wafer	>10	35000 - 50000	x	40 x 40	x (Op)	x	n.a.	Yes (Op)	without	400 (440)	400	550	16 (25)	50	3600		x (Op)	x		300	x	x	x
ESCAD	eWI-003 Microcrack	>10	40000 - 60000	x	40 x 40	x		n.a.	Yes (Op)	without	400 (440)	300	550	15 (25)	n.a.	3600		x (Op)	x	x	300	x	x	x
GP Solar	GP CELL-Q FS 22MP	>100	120 000	x	40 x 40		x	n.a.	No	n.a.	340	344	844	30	180	3600			x		n.a.	x		x
GP Solar	GP CELL-Q FS 11MP	>100	90000	x	60 x 60		x	n.a.	No	n.a.	340	344	844	30	180	3600			x		n.a.	x		x
GP Solar	GP CELL-Q FS 4MP	>100	85000	x	80 x 80		x	n.a.	No	n.a.	340	344	844	30	100	3600			x		n.a.	x		x
GP Solar	GP CELL-Q RS 4MP	>100	50000	x	80 x 80		x	n.a.	No	n.a.	340	344	844	30	100	3600			x		n.a.	x		x
GP Solar	GP CELL-Q RS 1MP	>100	45000	x	160 x 160		x	n.a.	No	n.a.	340	344	844	30	50	3600			x		n.a.	x		x
GP Solar	GP PRINT-Q FS 22MP	>100	115 000	x	40 x 40		x	n.a.	No	n.a.	340	344	844	30	25	3600			x		n.a.	x		x
GP Solar	GP PRINT-Q FS 11MP	>100	85000	x	60 x 60		x	n.a.	No	n.a.	340	344	844	30	25	3600			x		n.a.	x		x
GP Solar	GP PRINT-Q FS 4MP	>100	80000	x	80 x 80		x	n.a.	No	n.a.	340	344	844	30	25	3600			x		n.a.	x		x
GP Solar	GP PRINT-Q RS 4MP	>100	45000	x	80 x 80		x	n.a.	No	n.a.	340	344	844	30	25	3600			x		n.a.	x		x
GP Solar	GP PRINT-Q RS 1MP	>100	40000	x	160 x 160		x	n.a.	No	n.a.	340	344	844	30	25	3600			x		n.a.	x		x
GP Solar	GP COL-Q .Cam	>100	35000	x	160 x 160		x	n.a.	No	n.a.	340	344	844	30	50	3600			x		n.a.	x		x
GP Solar	GP COL-Q .Scan	>20	45000	x	80 x 80	x		n.a.	No	n.a.	239	342	655	20	n.a.	3600		x			400	x		x

		INSPECTION CRITERIA																DATA PROCESSING			SET-UP/ USER INTERFACE				
		Saw-mark inspection minimum height in µm	Saw-mark inspection 3σ repeatability in µm (+/-)	Micro-cracks minimum length in mm	Micro-cracks 3σ repeatability in mm (+/-)	TTV/Thickness 3σ repeatability in µm (+/-)	SiC inclusions minimum area in mm²	SiC inclusions minimum area in mm² (+/-)	Outer wafer dimensions 3σ repeatability in µm (+/-)	V-shaped edge intrusion minimum depth in µm	V-shaped edge intrusion 3σ repeatability in µm (+/-)	Surface chipping minimum area in mm²	Surface chipping 3σ repeatability in mm² (+/-)	Surface contamination/stains minimum area in mm²	Surface contamination/stains 3σ repeatability in mm² (+/-)	Pin holes minimum area in mm²	Pin holes 3σ repeatability in mm² (+/-)	Crystallite classification (Poly-Si wafers only)	Data recording in database		Data export possible for offline analysis	Interface to external recipe management system	Time for change between two pre-defined recipes in sec.	Time for generating a new recipe in min.	Definable number of quality categories	Are quality categories customizable?
	Others																		SQL interface	Others						Yes/No
	ProfiBus, ProfiNet, XML, TCP/IP	3	3	3-4	3	1	0.1	0.05	25	75	25	0.25	0.1	1	0.25	0.01	0.003	x	x	CSV, XML, XSLX	x	x	1	5	1024	Yes
	ProfiBus, ProfiNet, XML, TCP/IP			3-4	3		0.1	0.05								0.01	0.003	x	x	CSV, XML, XSLX	x	x	1	5	256	Yes
	ProfiBus, ProfiNet, XML, TCP/IP								25	75	25	0.25	0.1	1	0.25			x	x	CSV, XML, XSLX	x	x	1	5	256	Yes
	ProfiBus, ProfiNet, XML, TCP/IP	3	3			1												x	x	CSV, XML, XSLX	x	x	1	5	256	Yes
	TCP/IP, ProfiBus, RS232	5	1			1													x	MES (OPC protocol via Ethernet TCP/IP.)	x	x	1	5	8	Yes
	TCP/IP, ProfiBus, RS232						0.08 x 0.08	0.001	20	15	3	0.08 x 0.08	0.001	0.12 x 0.12		0.08 x 0.08		x	x	MES (OPC protocol via Ethernet TCP/IP.)	x	x	1	5	8	Yes
	TCP/IP, ProfiBus, RS233			0.05 - 1	0.005														x	MES (OPC protocol via Ethernet TCP/IP.)	x	x	1	5	8	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								30	75	90			0.01	0.025	0.01	0.025		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								45	100	120			0.02	0.035	0.02	0.035		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								75	150	150			0.04	0.045	0.04	0.045		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								45	150	150			0.04	0.045	0.04	0.045		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								75	300	300			0.16	0.065	0.16	0.065		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								30	75	90			0.01	0.025	0.01	0.025		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								45	100	120			0.02	0.035	0.02	0.035		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								75	150	150			0.04	0.045	0.04	0.045		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								45	150	150			0.04	0.045	0.04	0.045		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								75	300	300			0.16	0.065	0.16	0.065		x	MS Excel, MES (AIS/Predictor)	x	x	10	10	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O								75	300	300			0.64	0.065	0.64	0.065		x	MS Excel, MES (AIS/Predictor)	x	x	10	3	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O													0.16	0.065	0.16	0.065		x	MS Excel, MES (AIS/Predictor)	x	x	10	3	∞	Yes

GENERAL											DIMENSIONS OF THE COMPLETE UNIT				INTEGRATION EFFORT									
Manufacturer	Product name	Number of installed systems	Price range in Euros	Maximum wafer size	Pixel size in the object plane in µm x µm	Image acquisition		Laser classification (IEC 60825-1 standard)	Wafer handling included?	Wafer handling with or without sorting	Length (in mm) (with handling in mm)	Width (in mm) (with handling in mm)	Height (in mm) (with handling in mm)	Weight (in kg) (with handling in kg)	Standstill time if not on-the-fly	Cycle time throughput per hour	Camera type			Spectral sensitivity greater than 1100 nm (SWIR)	Max conveyer speed if on-the-fly (in mm/sec)	Standards of machine interface		
				6"		On-the-fly	Stop-and-go	Class	Yes/No	With/without/optional					In msec		Laser sensor	Line scan camera	Area scan camera			SEGS/GEM	OPC	Parallel I/O
GP Solar	GP WAF-Q 11MP	>50	60000	x	60 x 60		x	n.a.	Op	Op	340 (1160)	344 (1670)	844 (2361)	*30	25	3600			x		n.a.	x		x
GP Solar	GP WAF-Q 4MP	>50	50000	x	80 x 80		x	n.a.	Op	Op	340 (1160)	344 (1670)	844 (2361)	*30	25	3600			x		n.a.	x		x
GP Solar	GP NANO-D .Scan	>30	75000	x	160 x 160	x		n.a.	Op	Op	239 (1160)	342 (1670)	655 (2361)	*20	n.a.	3600		x		x	500	x		x
GP Solar	GP MICRO-D .Cell	>5	135 000	x	160 x 160	x		n.a.	Op	Op	239	345	655	40	n.a.	3600		x		x	400	x		x
ISRA Solar Vision	Solarscan µCrack	On request	On request	x	85 x 85	x		n.a.	No	n.a.	420	420	1000	25	n.a.	3600		x		x	200	x		x
ISRA Solar Vision	Solarscan µCrack HiRes	On request	On request	x	45 x 45	x		n.a.	No	n.a.	420	420	1000	25	n.a.	2400		x		x	200	x		x
Intego	saw marks	On request	On request	x	10 x 10	x		n.a.	No	n.a.	300	300	600	15	n.a.	3600	x				320	x	x	x
Intego	u-crack ANTARES	On request	On request	x	150 x 150	x		1	No	n.a.	350	350	600	15	n.a.	3600		x		x	320	x	x	x
Intego	Topo	On request	On request	x	50 x 50	x		1	No	n.a.	300	300	900	15	n.a.	3600			x		320	x	x	x
Intego	TTV	On request	On request	x	50 x 50	x		1	No	n.a.	300	300	900	15	n.a.	3600			x		320	x	x	x
Intego	Geo	On request	On request	x	20 x 20	x		n.a.	No	n.a.	300	300	900	15	n.a.	3600		**x	***x		320	x	x	x
Intego	surface	On request	On request	x	80 x 80	x		n.a.	No	n.a.	350	350	900	15	n.a.	3600			x		320	x	x	x
Intego	Wafer ID	On request	On request	x	80 x 80	x		n.a.	No	n.a.	350	350	900	15	n.a.	3600			x		320	x	x	x
Intego	Grain statistics	On request	On request	x	80 x 80		x	n.a.	No	n.a.	600	600	900	15	2000	1200			x		n.a.	x	x	x
VITRONIC	VINSPECsolar for Micro Cracks	> 20	40000 - 70000	x	40 x 40	x		n.a.	Op	Op	300	435	1000	50	n.a.	2400-3600		x			300	x		x
VITRONIC	VINSPECsolar for Wafer	> 20	30000 - 40000	x	80 x 80		x	n.a.	Op	Op	350	475	1000	50	400	2400-3600			x		n.a.	x	x	x
														* An integrated system weighs approximately 5.5 tons or 4989 kg according to GP Solar.				** For edge defects and pinholes	*** For outer dimension					

Op - Optional | ∞ - Unlimited

		INSPECTION CRITERIA																	DATA PROCESSING			SET-UP/ USER INTERFACE				
		Saw-mark inspection minimum height in µm	Saw-mark inspection 3σ repeatability in µm (+/-)	Micro-cracks minimum length in mm	Micro-cracks 3σ repeatability in mm (+/-)	TTV/Thickness 3σ repeatability in µm (+/-)	SiC inclusions minimum area in mm²	SiC inclusions minimum area in mm² (+/-)	Outer wafer dimensions 3σ repeatability in µm (+/-)	V-shaped edge intrusion minimum depth in µm	V-shaped edge intrusion 3σ repeatability in µm (+/-)	Surface chipping minimum area in mm²	Surface chipping 3σ repeatability in mm² (+/-)	Surface contamination/stains minimum area in mm²	Surface contamination/stains 3σ repeatability in mm² (+/-)	Pin holes minimum area in mm²	Pin holes 3σ repeatability in mm² (+/-)	Crystallite classification (Poly-Si wafers only)	Data recording in database		Data export possible for offline analysis	Interface to external recipe management system	Time for change between two pre-defined recipes in sec.	Time for generating a new recipe in min.	Definable number of quality categories	Are quality categories customizable?
	Others																		SQL interface	Others						Yes/No
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O	100	300						30	100	120	0.02	0.1	0.02	0.035	0.02		Op	x	MS Excel, MES (AIS/Predictor)	x	x	10	5	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O	100	300						45	150	150	0.04	0.2	0.04	0.045	0.04		Op	x	MS Excel, MES (AIS/Predictor)	x	x	10	5	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O	100	300	0.5	0.45		1	2		300	900								x	MS Excel, MES (AIS/Predictor)	x	x	10	3	∞	Yes
	Profibus Datablock, UDP Datablock, RS232, combined RS232 with parallel I/O	100	300	1			1	2		300	900								x	MS Excel, MES (AIS/Predictor)	x	x	10	5	∞	Yes
	Profibus, Profinet, Ethercat, XML (AIS),			3	300		0.5	0.5	60	100	50	0.5	0.5			0.2	0.2		x		x		1	10	200	Yes
	Profibus, Profinet, Ethercat, XML (AIS),			1	200		0.1	0.2	30	60	30	0.3	0.3			0.1	0.1		x		x		1	10	200	Yes
	Profibus, Ethernet	10	8																x	csv-file for Excel-Import	x	x	<5	<15	∞	Yes
	Profibus, Ethernet			0.5	0.3		0.1	0.1											x	csv-file for Excel-Import	x	x	<5	<15	∞	Yes
	Profibus, Ethernet																		x	csv-file for Excel-Import	x	x	<5	<15	∞	Yes
	Profibus, Ethernet					10													x	csv-file for Excel-Import	x	x	<5	<15	∞	Yes
	Profibus, Ethernet								25	60	60					0.005	0.005		x	csv-file for Excel-Import	x	x	<5	<15	∞	Yes
	Profibus, Ethernet											1	1	1	1				x	csv-file for Excel-Import	x	x	<5	<15	∞	Yes
	Profibus, Ethernet																		x	csv-file for Excel-Import	x					No
	Profibus, Ethernet																	x	x	csv-file for Excel-Import	x					No
	Profibus, Ethernet, TCP/IP	20	#quali-tative	0.2	##		0.01			300		0.1		0.01		0.01		x	x		x	x	3-10	5-15	10	Yes
	Profibus, Ethernet, TCP/IP	10	#quali-tative		##				100	400		0.1		0.05		0.05		x	x		x	x	3-10	5-15	10	Yes
			#Qualitative detection, depends on depth and flanks steepness		##Depends on size of crack																					