An Automatic Vision System using Optical Scanning Mechanism with Near-infrared Optics for Solar Cell Wafer

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Abstract: In this paper, an automatic vision system based on optical scanning mechanism is developed for solar cell wafer. It consists of optical scanning mechanism with near-infrared(NIR) camera optics, machinery and control system, algorithm of defect detection and software. Optical scanning mechanism is composed of geometrical camera optics and structured hybrid illumination system(SHIS). It is used to inspection of surface defects. Also, NIR camera optics is used for inspection of defects inside solar cell wafer. It is shown that the automatic inspection system give satisfactory performance for micro defects in solar cell wafer.

1 INTRODUCTION

Solar energy using solar cell wafer is considered as renewable green energy. The silicon wafer is an inevitable part in solar cell. Its thickness has been slim so far due to competition of cost. It is because the cost of silicon wafer manufacturing is involved more than 60% in solar cell manufacturing. A lot of defects such as topology defects, surface defects and internal micro defects, are generated in silicon wafer manufacturing. They highly result from slimmer thickness of silicon wafer. They result in high manufacturing cost and lack of efficiency. Therefore, the automatic inspection of defects in solar cell wafer is urgently required.(Li, 2011)

In this paper, an automatic inspection system is developed for solar cell wafer. It is composed of optical scanning mechanism, NIR camera optics, machinery and control system, defect detection algorithm and software.

2 OPTICAL SCANNING MECHANISM

2.1 Geometric Camera Optics

The optical scanning mechanism in Figure 1 is designed for solar cell wafer. It is composed of geometric camera optics, structured hybrid illumination system(SHIS). High-speed machine vision must be applied to manufacturing process of solar cell wafer due to fast production line.(Golnabi, 2007) To implement the fast inspection, TDI(time delay & integration) line scan camera is used. It has high sensitivity and is used as inspection camera in geometric camera optics. Also, an area camera with high resolution is used as monitoring. The detail specifications of optical scanning mechanism is in Table 1.

Table 1: Specification of geometrical camera optics.

Lists		Specification
Line scan camera		Resolution: 8192×32TDI Pixel size: 7×7 ㎛ Line rate: up to 34kHz
Area camera		Image sensor: SONY CCD Resolution: 1280×1024 Frame rate: 15fp
Lens	Macro-symmar 5.6/102	Focal length: 120mm Mag.: 0.38 ~ 0.63x Max aperture: F5.9
	Zoom 70XL	Zoom range: 7:1 Mag.: 0.75 ~5.25x Work distance: 89mm
Frame grabber		SOL 2M EV CLF Data acquisition: Camera link
Image library		MIL 9.0

The best focused position of camera can be found

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automatically. To solve this problem, the hill climbing algorithm(Cho, 2006) is used as auto focusing method. It determines the direction of the lens and camera movement in order to search for the maximum value of the focus measure in Figure 2. Also, lens magnification can be automatically adjusted. the length between solar cell wafer and lens is 'a' and length between lens and camera sensor is 'b', the lens formula is formed by Gaussian lens principle. Here, focal length of lens is f. Once f, a and b are changed, magnification M is varied. The optical scanning mechanism can change lens magnification through controlling the interval of 'b'.,

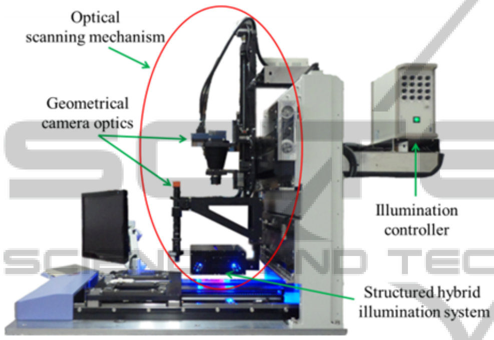

Figure 1: Optical scanning mechanism.

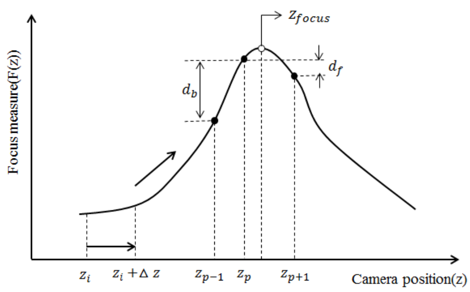

Figure 2: Distribution of focus measure for autofocusing.

2.2 Structured Hybrid Illumination System

An illumination system is used to keep uniformly good contrast between object and background in machine vision. Illumination conditions for high-quality and reliable images are very important, because suitable illumination conditions result in the extraction of useful features.(Sunil, 2006) There are a lot of illumination methods exclusive of illumination sources such as bright field, dark field, dome light, oblique front light, directional front light, diffusion front light, back light, co-axial light and structured light etc..

In this paper, SHIS(Kim, 2012) are designed to optionally use bright field, dark field, oblique front light, directional front light and diffusion front light, in accordance with inspection environment. SHIS consists of upper illumination in Fig. 3 ① and under illumination in Fig 3 ②. SHIS is symmetry structure against optical axis. The upper illumination is mainly the bright field method and can use directional front light because illumination channels are separately controlled. The channel 1 and 4 are Blue LED, channel 2 and 5 are Green LED and channel 3 and 6 are Red LED. The under illumination is usually used for dark field method and oblique front light. The channel 7~15 consist of Blue-Green-Red LED in order. Each channel row is separately controlled but it is symmetrically controlled in the same time. Also, angle of under illumination can be adjusted in a certain range θ. Illumination source is LED. The advantages of LED are high efficiency, uniformity of luminance, no flicker, long lifetime and requirement of low current. All illumination channels are directed to one point. The used LED specifications are in Table 2. Diffusion filter is utilized in order to uniform and get a smooth image. SHIS makes an efficient combination of upper and under illumination. When all upper and under illumination are used, SHIS can be used as diffusion front light.

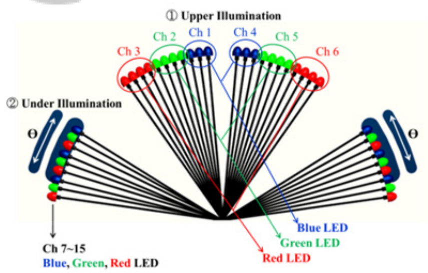

Figure 3: Structured hybrid illumination system.

Table 2: Specification of LED.

List	Blue	Green	Red
Forward Current	35mA	35mA	30mA
Forward voltage	3.2V	3.2V	2.1V
Wavelength	471nm	525nm	628nm
Operation temperature	-30 ~ 85	-30 ~ 85	-30 ~ 85
Luminous intensity	8200mcd	9600mcd	12000mcd

2.3 NIR Camera Optics

Infrared ray is used as heat source. Solar cell wafer can be damaged by its longtime incidence. Accordingly, The infrared spectrum band that has a little transmittance as well as weak heat source needs to be selected for solar cell wafer. It is regarded as the spectrum of near-infrared ray. In case NIR is incident to solar cell wafer, full reflectance ray is represented from surface. Also, while the phenomenon of transmittance and reflectance is represented in repetition by optical scattering inside wafer, the ray of absorption, body reflectance and transmittance resulting in solar cell wafer is dispersed in all direction.(Choi, 2006)

Inspection of internal micro defect uses transmission characteristic of NIR because it is not inspected in general illumination like LED and halogen. NIR camera optics is known as temperature detection of object because it is mainly affected by heat source. But, NIR camera optics is not detection of heat source. NIR camera optics acquires wavelength that is not transmitted by visible ray. Solar cell wafer has a relatively high transmission characteristics about wavelength of 1 micron level. Using this principle, images of internal defects can be acquired in NIR camera when NIR light is incident to solar cell wafer by back light method. NIR camera optics in Fig. 4 is designed for internal micro defect inspection of solar cell wafer. Its detail specifications are in Table 3.

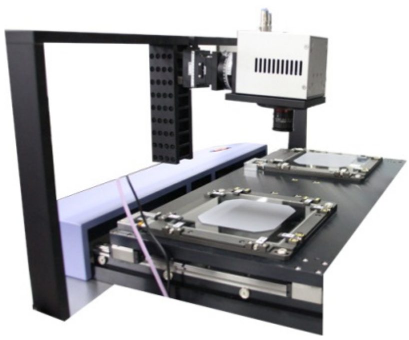

Figure 4: NIR camera optics.

3 AUTOMATIC INSPECTION SYSTEM

The automatic inspection system for solar cell wafer is described in Figure 5. It consists of optical scanning mechanism with NIR camera optics, machinery and control system, algorithm of defect detection and software.

The inspection software is described in Figure 6, and includes 15 software modules. They are as follows; (1) Geometry: Translation and rotation of

Table 3: Specification of NIR camera optics.

Lists	Specifications
NIR camera	Array type: InGaAs Spectral band: 900~1700nm Pixels: 320×256 ㎛ Pixel operability: >99% Frame rate: 100Hz, 12bit Camera control: USB 2.0
Lens	Compact VIS-NIR lens
Illumination	Infrared halogen light source: 1127nm IR back light source: 850~940nm

inspected image (2) Configuration: confirmation and modification and of inspected image information from teaching reference image (3) Anisotropic diffusion: Image filtering option (4) Model selection: information save in specified region of reference image (5) Teaching: Save of wafer information (6) Image alignment: alignment of inspected image based on reference image (7) Inspection: defect detection of inspected wafer based on reference image (8) Auto inspection: automatic execution of detection and inspection process using Figure 7 (9) Image open (10) Image save (11) Zoom in/out (12) Inspection result: information of detection defect (13) Number of defects.

Its inspection performance has been evaluated for various defects such as pinhole, scratch, edge defect, stain and sawmark, in terms of accuracy, repeatability and undetected error rate. Inspected wafers with no defect, pinhole, scratch, edge defect, stain and sawmark, are prepared for the simulation of real inspection. Their number is 50 sheets, respectively. So, the total wafer number is 300. The inspection results is shown in Table 4. The developed algorithm results in 100% accuracy for defects such as pinhole, stain and sawmark. It gives excellent results. Also, its accuracy is 96% for edge defect and 92% for edge defect. Its undetected error rate is 4% and 8% for scratc and edge defect,

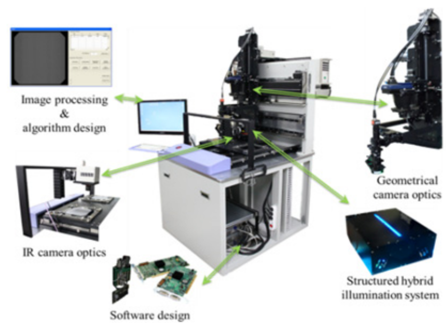

Figure 5: Automatic inspection system.

respectively. The developed algorithm gives 100% detection repeatability. In case the inspected image, relative to the reference image, two defects such as edge defect and scratch can not be detected. This result from non-uniformity of wafer edge and internal wafer. As a result, the useful performance of our algorithm is verified through detection experiments using 5 types of defects.

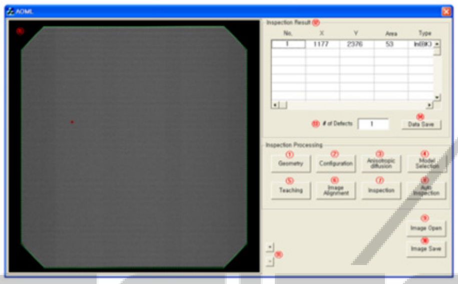

Figure 6: The inspection software.

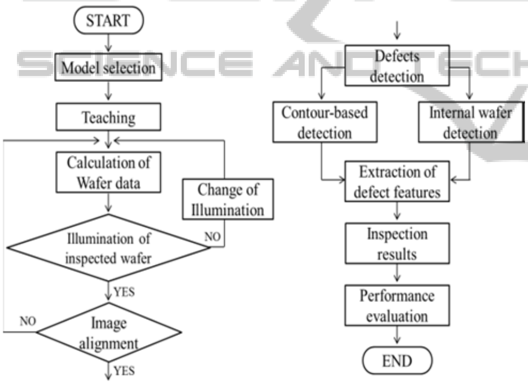

Figure 7: Flow chart of defect detection algorithm.

4 CONCLUSIONS

In this paper, an automatic vision inspection system based on optical scanning mechanism with NIR optics is developed for solar cell wafer. It consists of optical scanning mechanism with NIR camera optics, machinery and control system, algorithm of defect detection and software. It is shown that the developed inspection system gives useful and excellent results in performance evaluation and is applied to measurement and inspection processes related with surface quality control as well as solar cell manufacturing.

Table 4: Results of performance evaluation.

Lists	Accuracy	Repeatability	Undetected error rate
Pinhole	100%	100%	-
Scratch	96%	100%	4%
Edge defect	92%	100%	8%
Stain	100%	100%	-
Sawmark	100%	100%	-

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