Photolithographic solutions for image sensors with high pixel density

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Abstract

An increasing number of technical challenges have arisen in the image sensor manufacturing process, such as wafer distortion in backside illumination (BSI) processes and reticle distortion in colour filter (CF) processes. In this paper, Canon lithographic solutions that optimise both alignment and exposure performance are explained in detail. Exposure results with these solutions applied are also presented.

Introduction

The increase in the number of pixels in image sensors has been accelerating pixel shrink. To establish a manufacturing process for smaller pixels, overlay accuracy improvement of photolithography equipment is the key technical challenge, because each pixel must be precisely overlaid to various layers, colour filters and micro-lenses.

BSI image sensors, the current mainstream of CMOS sensors, enhance light sensitivity by applying a structure that receives light from the backside of circuit patterns, eliminating the vignetting of light from the circuit. In the manufacturing process, the back side of a patterned wafer is ground to a thickness of a few microns (μm) after being bonded to a supported wafer. This bonding and thinning process causes large distortion to the wafer, resulting in the deformation of shot shape that are pre-exposed by exposure equipment during the circuit pattern process.

In the next process, the colour filter process, CF patterns need to be exposed on the distorted shots with high accuracy, which is one of the main technical challenges for high productivity. Semiconductor exposure equipment generally adopt a global alignment system, which measures four or eight sample shots on a wafer and linearly calculates overlay information such as shift, rotation and magnification of shots. However, non-linear errors caused by wafer distortion in BSI processes have become an enormous technical challenge in mass production. Moreover, it is necessary to detect alignment marks from the back side of Si wafers since alignment marks are located on the circuit pattern side.

In addition, high exposure dose required in CF processes must be carefully considered to improve overlay accuracy. Negative resists, generally used in CF processes, are widely known for inhibition of polymerization due to oxygen in the air. This effect requires larger exposure dose in CF processes, resulting in the deterioration of overlay accuracy.

Lithographic solutions to technical challenges in manufacturing process of image sensors

1) Introduction of the FPA-5510iZ

The FPA-5510iZ has been developed as an exposure system to solve the above mentioned issues. A list of major specifications of the FPA-5510iZ is shown in Table 1.

The FPA-5510iZ, equipped with functions on the table, is an ideal exposure system for BSI and CF exposure processes.

Item		Specification
Projection Lens	Magnification	4:1
	NA	0.45～0.57
	Field Size	26 x 33mm
	Resolution	≤0.35mm
Illumination	Wavelength	365nm
	σ Aperture	0.40～0.75 (@NA0.57)
	Intensity	≥34,500W/m2 (@ NA0.57 / σ0.70)
Overlay Accuracy		≤ 18nm
Oxygen Concentration		8～21%

Table.1: Major specifications of FPA-5510iZ

2) Solutions for BSI process

2-1) Alignment solution to distorted wafers caused in bonding process： EAGA function

The EAGA (Extended Advanced Global Alignment) function of the FPA-5510iZ is one lithographic solution to improve overlay accuracy in a BSI process. The EAGA function calculates alignment information of all shots, such as shift, rotation and magnification, after measuring alignment marks in every shot on a wafer. Unlike the conventional AGA (Advanced Global Alignment) function, EAGA can measure and correct for non-linear shot errors such as non-linear shift, rotation and magnification. The shot information is used to control the position and rotation of wafer stage and the magnification of projection optics during the wafer exposure sequence.

Fig.1 and Fig.2 show simulation results of overlay accuracy using the AGA and EAGA functions. The functions are applied to a typical example of a bonded wafer with distortion caused by bonding in the BSI process. The conventional AGA function, which measures and corrects for linear shot information, can only obtain the overlay result of X = 114 nm & Y = 129 nm because of large shot distortion. On the other hand, the EAGA function, which measures and corrects shot information of all shots on a wafer, can improve overlay accuracy to X = 85 nm & Y = 85 nm.

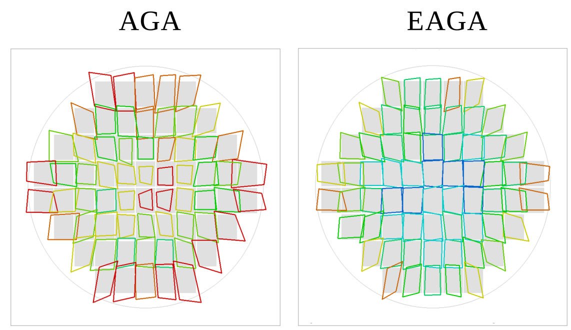

Fig.1: Overlay results with AGA and EAGA functions

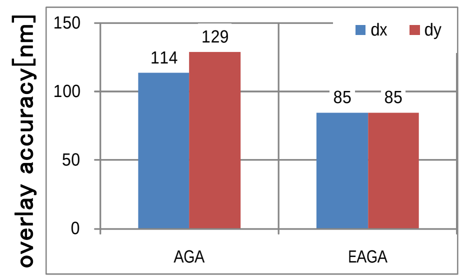

Fig.2: Comparison of overlay results with AGA and EAGA functions

2-2) Exposure solution to distorted wafers caused in bonding process： SSC function

The SSC (Shot Shape Compensator) function of the FPA-5510iZ is a newly designed and developed function that enables high overlay accuracy in BSI process. (In this paper, simulation results are displayed only because the SSC function is still under development.) SSC is a function to control the magnification of projection optics in step and repeat exposure equipment. The special feature of the SSC function is that it can independently control magnification in X and Y directions.

Fig.3 and Fig.4 show simulation results of overlay accuracy using the AGA and SSC functions. Unlike the conventional AGA function, SSC can improve overlay accuracy to X = 25 nm & Y = 32 nm, which is equivalent to that of scanning exposure equipments.

The above mentioned two unique lithographic solutions; EAGA and SSC, can lead to high productivity in BSI process by improving overlay accuracy in spite of large shot distortion caused by bonding and thinning process.

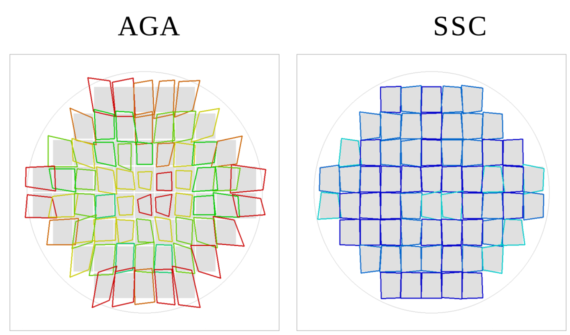

Fig.3: Overlay results with AGA and SSC functions

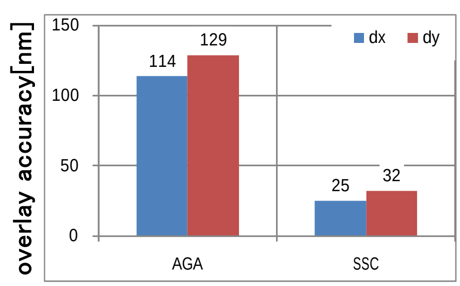

Fig.4: Comparison of overlay results with AGA and SSC functions

2-3) Backside Alignment solution： IR-alignment function

In the BSI process, it is essential to detect alignment marks on the backside of Si wafer, since CF patterns and micro lens patterns need to be aligned to the circuit patterns that are pre-exposed on the backside of the wafer. However, image quality of alignment marks detected by conventional visible alignment systems deteriorates because of low transmittance of visible light through Si. The improvement of measurement accuracy has been one of the main technical challenges in BSI process, and to addresses this critical challenge, Canon has developed an IR-alignment system as one of solution.

Fig.5 shows a simulation result of the internal transmittance of Si to visible and infrared light, which is calculated from extinction coefficient of Si. With visible light of 600 nm, it is difficult to obtain clear images of alignment marks on the backside of a wafer because the internal transmittance through Si is less than 30% through a thickness of a few μm.

On the other hand, since infrared light penetrates Si with high transmittance, infrared light of 1100 nm can achieve more than 70% of internal transmittance through a Si wafer with thickness of even 775 μm. Fig. 6 shows a measurement result of an alignment mark on the back side of Si wafer with thickness of 775μm. The IR-alignment system with the wavelength of 1100 nm enables the stepper to detect alignment marks on the backside of Si wafer with high contrast.

Canon's IR-alignment system can simplify the BSI process and lead to greater productivity by eliminating the additional manufacturing process required for the conventional visible alignment systems.

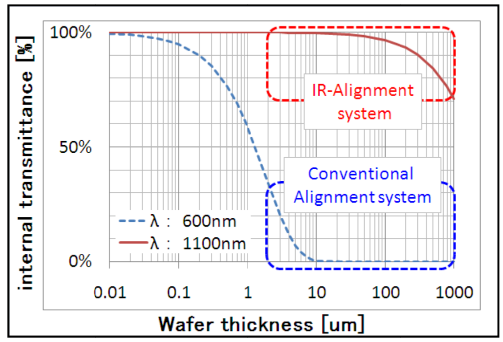

Fig.5: internal transmittance of Si

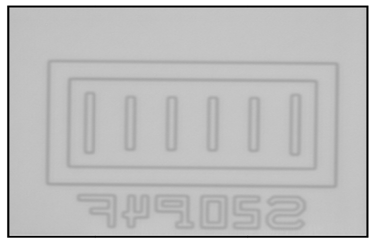

Fig.6: measurement image of alignment mark

3) Solutions for colour filter process

3-1) Solution to exposure distortion caused by high dose： Low oxygen exposure function

Due to inhibition of polymerization caused by oxygen in the air, a high dose of exposure is generally applied to CF exposure processes. Exposure light is absorbed and induces thermal expansion of a reticle, which poses another technical challenge of overlay accuracy. To tackle this challenge, Canon developed the low oxygen exposure (LOX) function that can lower the oxygen level in the air. Under a lower level of oxygen, required exposure dose may be decreased by more than 50%, which can suppress thermal expansion of reticles and improve overlay accuracy.

Fig.7-1〜7-3 and Fig.8-1〜8-2 show experimental results of shot shape deformation given different exposure doses, such as 1,600, 4,000 and 8,000 J/m². Shot shape deformation decreases by 1.3 nm in x direction and 2.4 nm in y direction when exposure dose are decreased from 8,000 J/m² to 4,000 J/m², because of low thermal expansion of the reticle. If exposure dose are reduced from 8,000 J/m² to 1,600 J/m², shot shape deformation can be more improved to 2.0 nm in x direction and 2.1 nm in y direction.

The Canon LOX function enables control of the concentration of oxygen in the air to improve overlay accuracy in CF process and to realise the high pixel density of sensors.

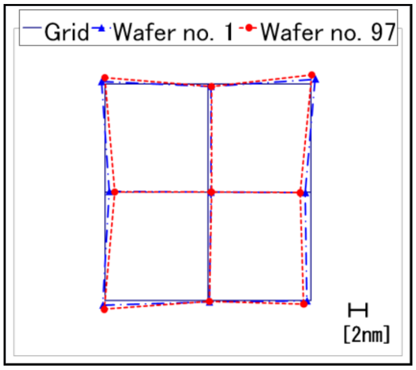

Fig.7-1: Shot distortion at 1,600 [J/㎡]

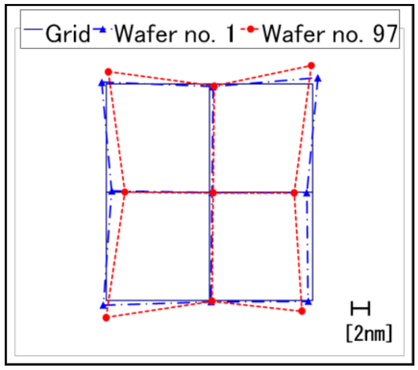

Fig.7-2: Shot distortion at 4,000 [J/㎡]

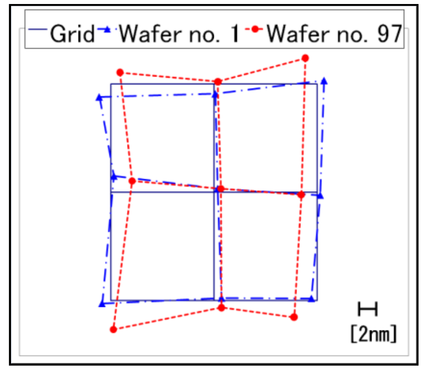

Fig.7-3: Shot distortion at 8,000 [J/㎡]

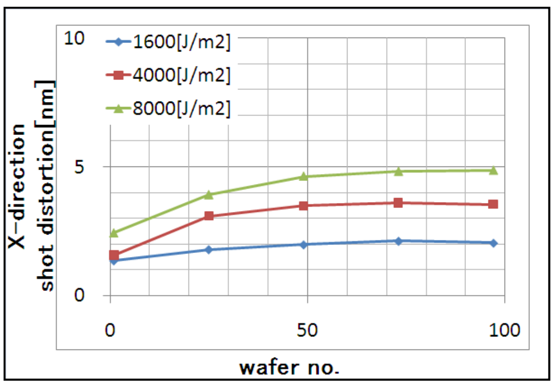

Fig.8-1: Shot distortion in X direction

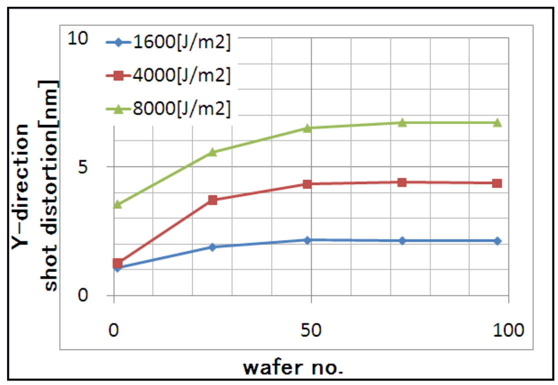

Fig.8-2: Shot distortion in Y direction

Summary

Canon has contributed to improving yields and productivity by proposing various lithographic solutions to technical challenges in the manufacturing process of image sensors.

To improve overlay accuracy in BSI process, Canon offers the following solutions;

1) Non-linearity correction by EAGA function
2) Exposure shot shape correction by SSC function
3) Backside alignment by IR-alignment function
4) Controlling the oxygen level by LOX function

The pixel size of image sensors will continue to shrink, and further technical challenges are expected to arise in the future. Canon is committed to contribute to increase the pixel density of image sensors by clarifying technical challenges in the manufacturing process and proposing lithographic solutions.

References

1. H. Rhodes et al, 2011 Int. image Sensor Workshop, 2011
2. Dr. Howard Rhodes, Int. image Sensor Workshop 2009 Backside Illumination Symposium, 2009