New Approach for Defect Inspection on Large Area Masks

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Abstract

Besides the mask market for IC manufacturing, which mainly uses 6 inch sized masks, the market for the so called large area masks is growing very rapidly. Typical applications of these masks are mainly wafer bumping for current packaging processes, color filters on TFTs, and Flip Chip manufacturing. To expose e.g. bumps and similar features on 200 mm wafers under proximity exposure conditions 9 inch masks are used, while in 300 mm wafer bumping processes (Fig. 1) 14 inch masks are handled. Flip Chip manufacturing needs masks up to 28 by 32 inch. This current maximum mask dimension is expected to hold for the next 5 years in industrial production. On the other hand shrinking feature sizes, just as in case of the IC masks, demand enhanced sensitivity of the inspection tools.

A defect inspection tool for those masks is valuable for both the mask maker, who has to deliver a defect free mask to his customer, and for the mask user to supervise the mask behavior conditions during its lifetime. This is necessary because large area masks are mainly used for proximity exposures. During this process itself the mask is vulnerable by contacting the resist on top of the wafers. Therefore a regular inspection of the mask after 25, 50, or 100 exposures has to be done during its whole lifetime. Thus critical resist contamination and other defects, which lead to yield losses, can be recognized early.

In the future shrinking feature dimensions will require even more sensitive and reliable defect inspection methods than they do presently. Besides the sole inspection capability the tools should also provide highly precise measurement capabilities and extended review options.

Keywords: large are mask, defect inspection, *Mue***Tec** DefectCheck, golden image, smart defect inspection, defect classification, defect review, CD measurement, line width measurement, line edge roughness measurement, dots and holes measurement.

1. Introduction

This paper describes a new kind of inspection tool built up from a flexible construction kit and equipped with new defect inspection algorithms. This enables customized systems and provides appropriate solutions to individual customer specifications concerning the sample-size, defect sensitivity, throughput and wavelengths of illumination.

Besides sole inspection capability the tool offers also highly precise and field proven measurement methods for line widths with sub 4 nanometer repeatability. Measurements of the line edge roughness can be undertaken, and comprehensive measurement methods especially developed for dots and holes (contacts) metrology, including corner rounding, are also available. *Mue***Tec** Defect Check enables also thickness measurements on transparent films. These superior software potentials are transferred from the famous Leica LWM mask CD measurement tools as virtual industry standard for optical mask CD metrology. It is used in nearly all worldwide existing IC mask making facilities.

The tool is equipped with a full set of microscope objectives (Vistec Semiconductor Equipment) and software to execute defect review with the best possible optical resolution. Its optical concept allows one to use the tool also as a stand alone defect review tool, too, accepting defect coordinates and defect classification data from user-defined sources.

In contrast to the concepts of other products the described software package makes it possible to develop customized software applications.

2. *Mue*Tec DefectCheck Concept

The newly introduced *Mue***Tec** SDI (Smart Defect Inspection) inspection method includes a new approach to check large area and IC masks rapidly and with high defect sensitivity. SDI and other inspection methods are implemented on the *Mue***Tec** DefectCheck 2030 tool, which accommodates masks up to a size of 14 inch and is also qualified for the inspection of wafers of a size up to 300mm. The further development of *Mue***Tec** 2030 is *Mue***Tec** DefectCheck 5500, which is designed for substrates up to 550 x 550 mm^2 and runs with about the same software like *Mue***Tec** 2030.

All *Mue***Tec** DefectCheck systems operate either with transmitted or incident light illumination (bright- and darkfield) or a combination of both illumination types, allowing the often difficult inspection of ADI (after-development inspection) masks too. As illumination wavelengths visible light sources as well as UV @365 nm light sources are available.
*Mue***Tec** DefectCheck as stand-alone review tool enables to apply even DUV @248 nm optics. In this case 50x, 150x and 200x objectives are available. The 200x objective is a water immersion type with a numerical aperture of 1.25 and provides an excellent optical resolution on structures down to 60 nm.

SDI uses the multiple advantages of 'Golden Image' processing and at the same time avoids its typical drawbacks. It creates a new 'Golden Image' calculation at each run from scratch. Any reteaching of golden images or threshold settings after process changes is not necessary. Especially in mask making this is a valuable advantage of the SDI method. For day-to-day examination an inspection recipe, if required at all, is set up within very short time. In any case the operator does not need any special knowledge of the tool and its usage, since the 'Golden Image' is created by the system itself.

*Mue***Tec** DefectCheck is working with a cluster PC concept (Fig. 2) and, in accordance to the complexity of its tasks, it will be equipped with an individually customized number of satellite workstations.

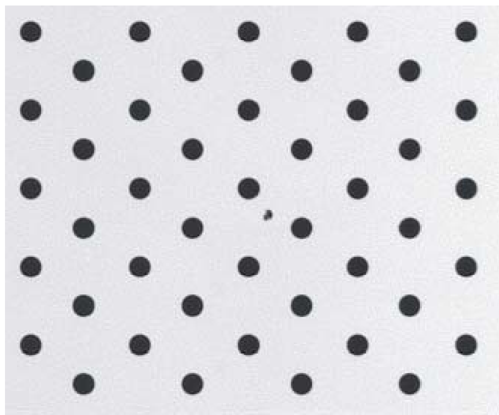


Fig 1: Chrome spot on 14 inch bumping mask

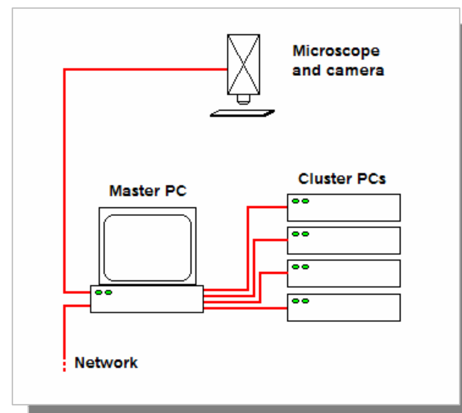


Fig. 2: DefectCheck hardware concept

The analysis of the images is performed almost exclusively by software. Thus there are solutions even in cases which deviate from usual inspection tasks.
Image acquisition and storage operates on the fly (Fig. 3). Each individual image is stored with 16-bit resolution due to a high resolution camera system. Dependant on the individual application mostly stroboscopes are used for the sample illumination.For the image alignment procedure of the taken pictures a comprehensive set of alignment procedures with sub-pixel resolution and precision is available.

After image alignment statistical methods are applied (Fig. 4), to extract the defects and classify them. The result is a software configurable list of defects with their micron precise x and y coordinates (Fig. 5) and other related parameters, which can be used for further processing. All captured images remain stored on the harddisks for a following defect review until they are deleted.

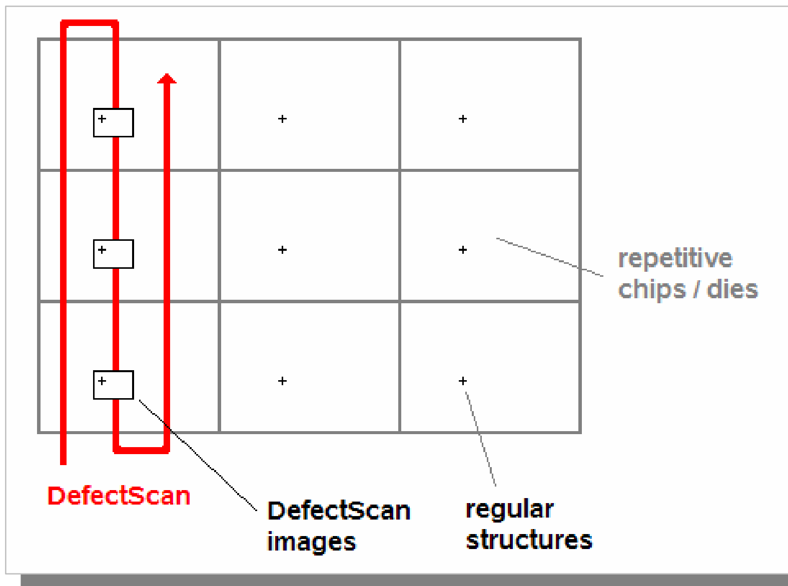


Fig. 3: Scanning on the fly

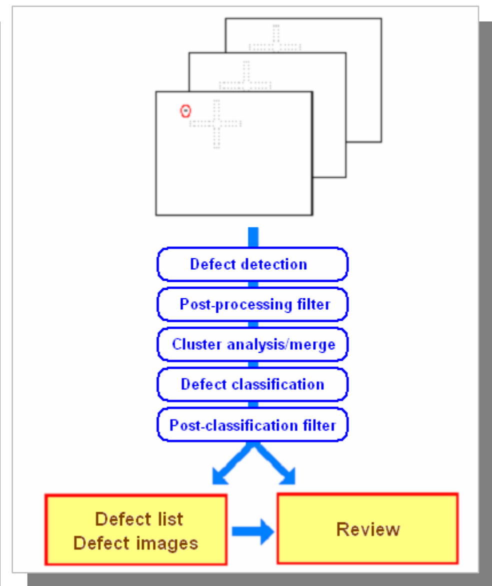


Fig. 4: Schematic of image processing

InspReview

Evaluation Defect Filter

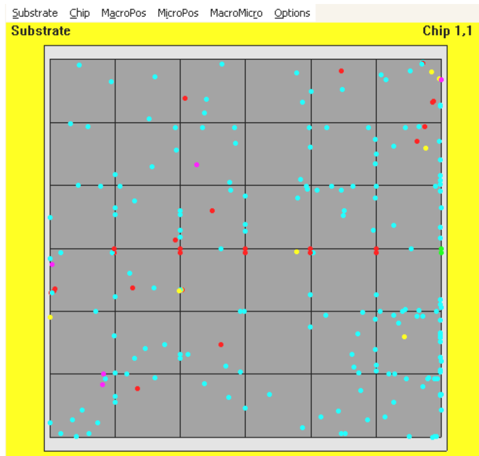
Index	Code	Class	Chip	X [µm]	Y [µm]	Size	Area	FillF	FormF	GreyV
513	104	1	9,30	18963.3	45978.1	22.8	0.0	0	0	0
514	104	1	10,2	21616.5	2361.6	1.4	0.8	100	0	36
515	104	1	10,4	20701.9	5677.1	19.2	0.0	0	0	0
516	104	1	10,4	20704.2	5664.5	24.7	0.0	0	0	0
517	104	1	10,6	20941.6	8188.0	7.2	5.0	55	0	28
518	104	1	10,8	21512.7	11356.8	17.3	0.0	0	0	0
519	104	1	10,8	21498.8	11358.1	20.8	0.0	0	0	0
520	104	1	10,9	20765.3	13426.8	19.2	0.0	0	0	0
521	104	1	10,17	20873.0	25750.8	1.4	0.8	100	0	40
522	104	1	10,17	21343.6	25903.1	16.4	0.0	0	0	0
523	104	1	10,18	21428.9	26471.1	1.8	1.6	100	0	41
524	104	1	10,20	20765.3	30479.1	19.2	0.0	0	0	0
525	104	1	10,23	21196.4	34878.6	1.8	1.6	100	0	35
526	104	1	10,25	20764.7	38230.0	19.2	0.0	0	0	0
527	104	1	10,27	21530.1	41315.7	19.9	0.0	0	0	0
528	104	1	10,27	21523.7	41323.8	24.9	0.0	0	0	0
529	104	1	10,28	21575.1	42457.3	1.4	0.8	100	0	35

Fig. 5: Configurable defect coordinate list

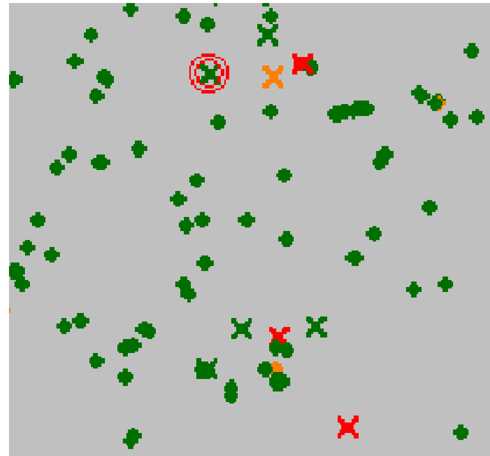
Besides the defect inspection capability *Mue***Tec** DefectCheck enables one to perform also defect review. The software is integral part of the *Mue***Tec** DefectCheck software package. A special review tool or data server is not needed for review. The software concept allows to execute online review as well as offline review by PCs outside the cleanroom.

Online review is the process where the mask is on stage of the inspection system and the defects can be assessed directly in the microscope using the full power of the tools microscope objectives with different magnification and different NA (numerical aperture). For offline review only the stored digital images are accessible. In both cases a graphical user interface (GUI) gives an easy and convenient way to review the defects by showing them on a defect map (Fig. 6 a). As a special feature the review software labels the already visited defects and the effective review position (Fig. 6 b). Different defect types are marked in different colors. In the case of online review the defect is positioned exactly in centre of the microscopes field of view by selecting it with the mouse. The defects can also be shown using a time controlled automatic course.

During offline review the digital original defect image (Fig. 7 and 8) is displayed in the centre on the PC screen as well as optionally the 'Golden Image' and the extracted defect image. All images can be digitally zoomed.

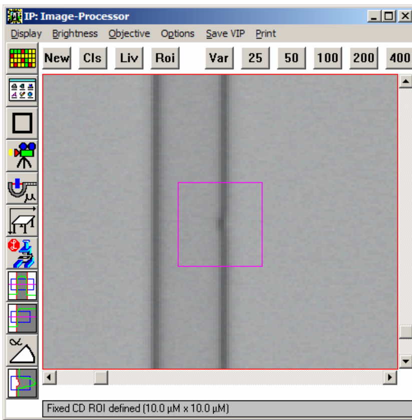


a. Defect Map

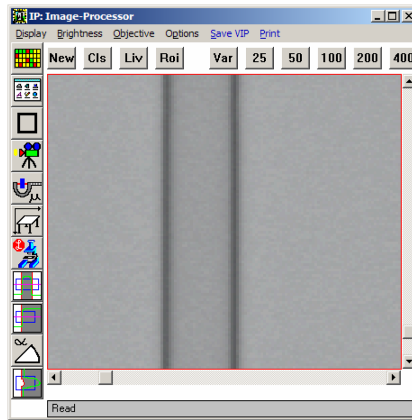


b: Cutout of defect map

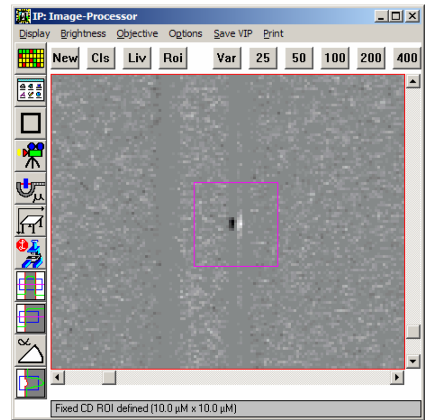
Fig. 6 a, b: Parts of the GUI



a: Original defect image

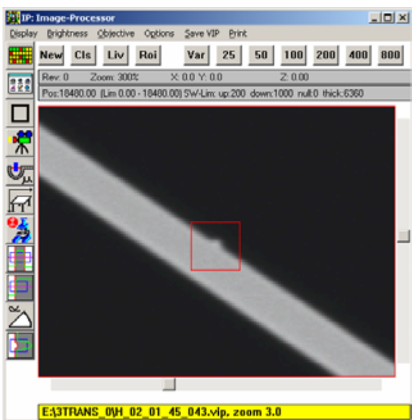


b: Golden image

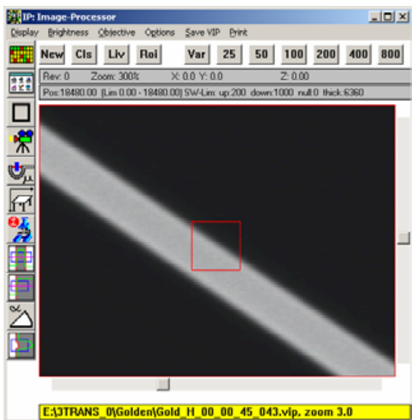


c: Extrated defect

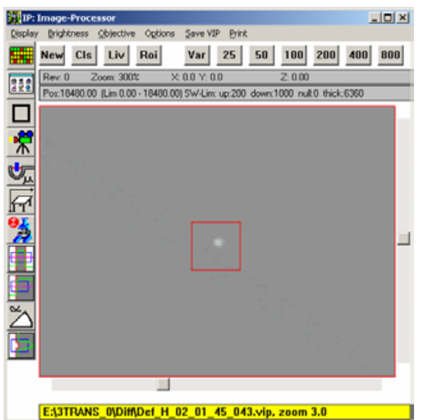
Fig. 7 a, b, c: Preprogrammed defect on ADI (after-development inspection) mask; defect size < 0.8 micron



a: Original defect image



b: Golden image



c: Extrated defect

Fig. 8 a, b,c: Preprogrammed defect on final chrome mask; defect size < 0.8 micron

Defect inspection on resist masks is mostly critical and difficult because of photoresist structures. These can have significant variation depending on the maskwriting process. Therefore the background in the defect image (7 c) appears a little "noisy". But the SDI method is able to detect sub-micron defects without major problems.

The measurement tools for masks, implemented in the *Mue***Tec** DefectCheck were fully and without limitations transferred from the LWM system for CD measurements on masks. Thus the Software, which was originally developed only for optical measurements of structural widths on high-end masks in IC manufacturing, is now even available for DefectCheck. In fact from today's view one can hardly forecast when the structural dimensions of large area masks will draw level with current dimensions in IC production. But so every future aspect of measurements on large area masks is covered. Therefore DefectCheck offers both the ability of inspection and a future-proof top-class measurement system for large area masks.

The most frequently undertaken measurements on masks are CD measurements (Critical Dimension) concerning the line width. They proceed automatically after a recipe set-up, which can be created with fast and easy to use tools. The structures to measure can even be imported from the dataset of the mask itself.

The linearity of CD measurements is clearly below 1 µm. With visible and UV light @365 nm line widths down to 0.8 µm and 0.3 µm, respectively, can be recorded linearly. With DUV illumination @248 nm it is even possible to extend the linear range down to 220 nm.

The existing calibration procedures of the software offer a tolerance of +/- 2nm referring to a calibration standard.

The sub-4 nm repeatability mentioned before refers to the results of dynamic measurements. In this mode the substrate is gauged and re-positions for at least 10 times. The values in table 1 give 3-sigma standard deviation.

	3-sigma repeatability for structures < 1 µm	**Measurement linearity down to:**
Visible light illumination	<< 4 nm	0.50 µm
UV @ 365 nm	< 2 nm	0.30 µm
DUV @ 248 nm	< 1 nm	0.22 µm

Table 1: 3-sigma repeatability and measurement linearity versus illumination wavelength

The excellent repeatability originates from a measurement mode called "Through Focus". In this mode a series of images is taken while the object is moved through the focus position in nm-size steps. The stack of pictures is used to calculate the sharpest image (Fig.: 9), which is consecutively used for the line width measurement. This leads to the 3-sigma repeatability values given in table 1.

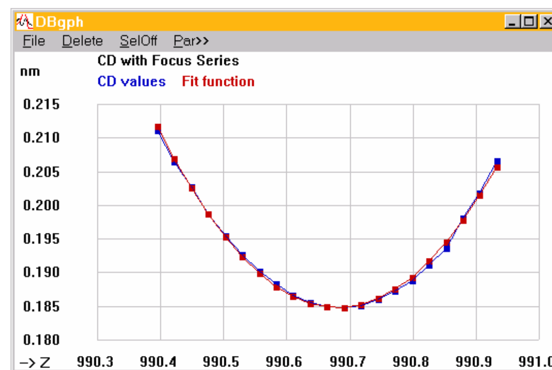


Fig. 9: "Through Focus" measurement results, from which the sharpest image is calculated

For the measurement of contact-holes (dots and holes) and bumps a wide-ranging software is allocated.
This software measures the contacts depending on their size and appearance on the mask with different sets of parameters in x and y direction. Furthermore the software is able to give information about the corner rounding and the area loss.

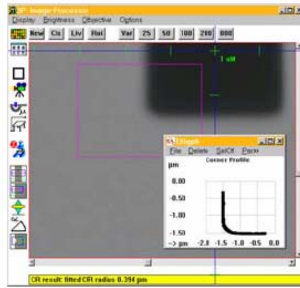


Fig. 10: Corner rounding measurement

The 3-sigma repeatability values achieved are given in table 2. They exceed the present requirements of measurements on large area masks by far.

Contact-holes Bumps	**3-sigma repeatability for structures <= 20 µm**
Visible light illumination	<< 10 nm
UV @ 365 nm	< 6 nm

Table 2: Repeatabilty values for contact-hole measurements

A very valuable option given by the software also is the line edge roughness (LER). This can give some important information during process optimisation.

LER measures within a region of interest (ROI) the position of the edge of a structure with a sub-pixel accuracy. To do this, a linear fit over the edge positions is calculated to estimate the mean border line and the residuum of the fit is used to calculate the edge roughness.

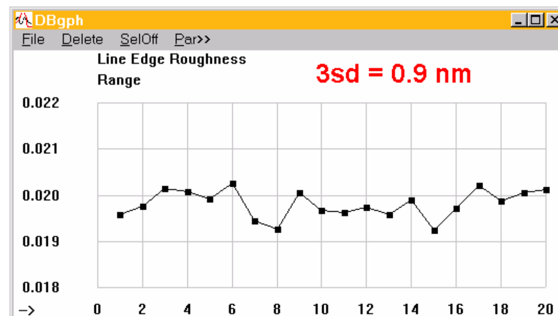


Fig. 11: Graphical representation of line edge roughness (LER) measurement result

The repeatability of the LER software usually shows up with values of 1-2 nm using UV illumination, while visible light results in a repeatability of 3-4 nm.

During the fabrication of a mask the stability of the mask writer is an essential topic. Especially after long lasting usage it is often interesting to gain some information about the writers stability and thus draw a conclusion of the quality of the mask. For this *Mue***Tec** DefectCheck possesses a butting error software tool, which measures the misalignment of parts of the structure relative to each other. Both the comparison with special test-structures and the comparison of structures within the active field is possible.

Fig. 12: Typical test structure of a mask writer (ALTA)

As a general rule the dynamic 3-signma repeatability of these measurements is smaller than the repeatability of line width measurements, because one has to metrological scan only one edge.

Last but not least it has to be mentioned, that *Mue***Tec** DefectCheck can also be equipped with an option to measure the thickness of a transparent films. The system uses a spectroscopic analysis and is especially useful to gain results on resist coatings. The dynamic long time repeatability (3-sigma) of a resist layer on a mask blank is typically one per mill of the film thickness or even less.

3. Summary and Conclusion

Featured with inspection, review, and mask measurement capabilities the *Mue***Tec** DefectCheck tool series represents a unique multi-purpose system for individual and standard applications on large area and smaller masks.

The newly introduced SDI software provides outstanding and unique inspection features by generating a 'Golden Image' for each particular substrate during each inspection run. Thus a secure defect identification with sparse false defects is enabled in standard applications as well as during critical evaluations.

The discussed construction kit enables to build up customized tools regarding substrate size, defect sensitivity, throughput, and the required tools application. Furthermore recipe setups require only a short time, and operators can easily handle the system enabled by the SDI software package.

*Mue***Te**c DefectCheck software includes a package to serve also as review station with high optical resolution.

The ability to gauge typical structures on masks, such as line-width, x- and y-measurements on contact-holes, line edge roughness, butting error measurements, and others is state-of-the-art for high-end masks in semiconductor industries.

With all its prospects *Mue***Tec** DefectCheck offers guaranteed future in the field of large area masks, because it outranges the less crucial requirements compared to IC technology by far.