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PRECISE VISUAL INSPECTION ALGORITHM FOR LSI WAFER PATTERNS USING GRAYSCALE IMAGE COMPARISON

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ABSTRACT

A sub-micron defect detection algorithm for LSI wafer patterns has been developed. This algorithm is based on a comparison of corresponding images of 2 chips or cells. Two grayscale images are aligned by their detected edge patterns and compared by the new algorithm called Local Perturbation Pattern Matching, by shifting one image in 8 plane-directions and in grayscale, and finding the best match in a local window between the shifted images and the other image. The resulting unmatched regions are recognized as defects. This method is performed so as to detect 0.3 μm defects of photoresist patterns without being influenced by small irregularities of the grayscale images.

INTRODUCTION

Considering that pattern density of LSIs has been remarkably increasing and the capacity of a memory chip has been growing four times in every three years, line width of LSIs will become less than 1 μm before long. To keep high yields of these LSI devices and to guarantee their reliability, visual inspection of in-process wafer patterns for monitoring the process conditions and preventing defect occurrence is indispensable.

Conventionally, the visual inspection of wafer patterns has been done by humans using a microscope, but they become less reliable and more time-consuming with the increase of the pattern density of LSIs. In consideration of this, automatization of the inspection process has been strongly indicated.

The visual inspections of wafer patterns are classified into two categories according to their purpose; one is multilayer pattern inspection for process monitoring and the other is single layer pattern inspection for preventing defect occurrence. In multilayer pattern inspection, the main objective is to extract only defects from the complex circuit patterns, so detectable defect size in the inspection counts for little, and small false alarm is important. On the other hand, in single layer pattern inspection, the detection of submicron-order defects, precisely, without false acceptance is strongly required.

Our objective is to develop a defect detection algorithm for single layer patterns that can reliably detect a 0.3 μm defect, as small as optical resolution limits.

As examples of multilayer pattern inspection, a method for detecting only fatal defects with the aid of original design data[1], and a method for inspecting aluminum patterns of the top layer using the comparison of two binary images detected by bright and dark field combined illumination[2] were presented.

As examples of single layer pattern inspection, a comparison method of design patterns with a detected binary image of single layer thin film patterns, obtained by using thin film interference color[3], and a comparison method of two extracted binary edge patterns[4] were presented. As both methods judge defects after thresholding the single layer patterns or their edge patterns, which are essentially delicate grayscale images, it is difficult to detect defects as small as the optical resolution limit. Besides these, some inspection systems for wafer patterns are already commercially available[5)~7)]. Although their inspection algorithm was not announced, according to their specifications they cannot detect 0.3 μm defects. For detecting defects as small as optical resolution limit reliably, it is necessary to use the delicate grayscale image itself.

Due to resolution characteristics of exposure optics, etc., patterns on a silicon wafer have different shapes from design patterns and there exist delicate differences in grayscale and also in shape even between neighboring like patterns. Therefore, only small defects must be detected in the inspection without being influenced by these error factors. Furthermore, high-speed processing is required for the inspection algorithm. We have developed a new high-speed inspection algorithm based on the comparison between two grayscale images of neighboring patterns, which reliably detects $0.3\mu m$ defects.

INSPECTION PRINCIPLE

INSPECTION OBJECTS : Fig.1 shows the appearrence of LSI photoresist patterns as an example of inspection objects. Because the defects are caused by the contaminants on a reticle or in a light path of a stepper, typical pattern defects in the case of positive photoresist are photoresist remainder which must essentially be removed i.e. convex, isorated defect, short, etc. as illustrated in Fig.2. There are also defects called "thin remnants" made by transparent or defocused contaminants which cause a shortage of exposure intensity. The thin remnant is so thin compared with normal patterns that occasionally it doesn't have an obvious edge. Inspite of this, it can be detected because of its interference color or grayscale difference from normal pattern edges.

AUTOMATIC INSPECTION : For defect detection of circuit patterns, there are 3 approaches ; (1) design-rule method, (2) comparison method with reference patterns generated from design data, (3) comparison method between two detected patterns. In general, the design-rule method is less reliable. As actual photoresist patterns differ much from the ideal binary patterns genarated from design data, it is difficult to implement method(2) in a practical system scale. We adopted the comparison method between two detected patterns, which is practical in both inspection reliability and machine scale. Fig.3 shows the principle of automatic inspection. Two chips or repeated patterns in a chip can be applied to the comparison. The comparison between the detected pattern and neighboring repeated pattern stored in memory was adopted for the automatic inspection. For detecting small defects reliably by using grayscale image comparison, stable image detection with high repeatability is required. For precise automatic focusing, a stripe pattern projected automatic focussing method [2] was applied. For preventing interference fringes caused by film thickness changes of normal portions, we used a xenon lamp as the light source which has an almost uniform light intensity distribution in the range of visible wave length.

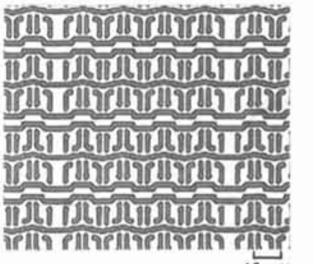


Fig.1 LSI photoresist pattern

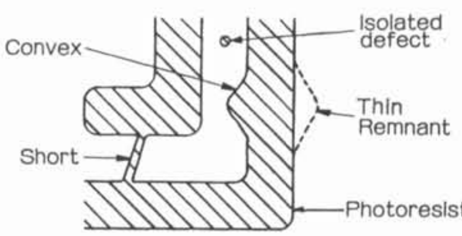


Fig.2 Typical defects of photoresist patterns

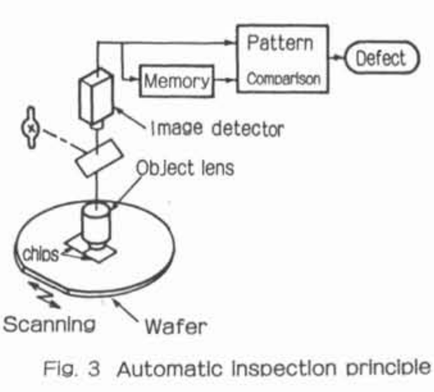


Fig. 3 Automatic inspection principle

DEFECT JUDGEMENT ALGORITHM

LOCAL PERTURBATION PATTERN MATCHING : It is impossible for two patterns, even if they are normal patterns which should be essentially same, to coincide perfectly, because of the following reasons :

(1) Delicate variation of the LSI manufacturing process conditions causes tiny shape differences.

(2) Variation of film thickness causes grayscale difference.

(3) Sampling position in image detection causes uneliminatable alignment errors between two images.

It is necessary for visual inspection to detect only small defects without being influenced by these allowable tiny differences in shape or grayscale.

To realize this requirement, we have developed a new algolithm named Local Perturbation Pattern Matching (LPPM for short), where two images are matched in a local window by shifting one image in the x-y plane and in grayscale, and the unmatched regions are regarded as defects.

Fig.4 illustrates the principle of the LPPM (shifting in grayscale is omitted). The concept of this algorithm is basically identical to the pattern matching algorithm which allows the geometrical distortion, the rotation of pattern, the variation in size etc.[8], it is characterized, however by the following two points.

(1) It utilizes sign changes of the subtracted images for allowing the error factor of normal patterns caused by the tiny shape difference or the difference of sampling position.

(2) It realizes real-time processing with pipelined architecture, as all processings are executed with local operators in one path.

The following are concrete procedures of LPPM. When there is a tiny shape difference or an uneliminatable alignment error less than 1 pixel between two patterns, they are not matched perfectly by shifting the stored image by ± 1 pixel. But, it is noticed that the sign of the subtracted image of the normal edge portion changes from positive to negative and vice versa by the ± 1 pixel shifting of the stored image, while the sign of the subtracted image of the defect does not change. Therefore, we can completely eliminate the unmatched regions of less than 1 pixel by outputting a zero for the part where the sign of the subtracted image changes by a ± 1 pixel shift.

When there are allowable differences in grayscale between two patterns, the differences can not be eliminated by shifting the stored image in x-y plane. Then, shifting of $\pm\alpha$ level in grayscale and the subtraction are also done in addition to the x-y plane shifting and subtraction operations.

From the 10 subtracted images obtained, a value of zero is output if the values of the corresponding pixels of the 10 subtracted images include both positive and negative values, or else, the absolute minimum value of the corresponding pixels is output as a defect signal.

Finally, the defect is detected by thresholding the output grayscale image with a suitable Th.

PIXEL RESAMPLING FOR SHORTENING THE INSPECTION TIME : In the conventional visual inspection technique, it is recommended to sample the images at 1/2~1/3 the size of the minimum detectable defects. However, optical resolution is limited, therefore sampling images with extremely small pixels does not improve the resolution and requires a longer inspection time.

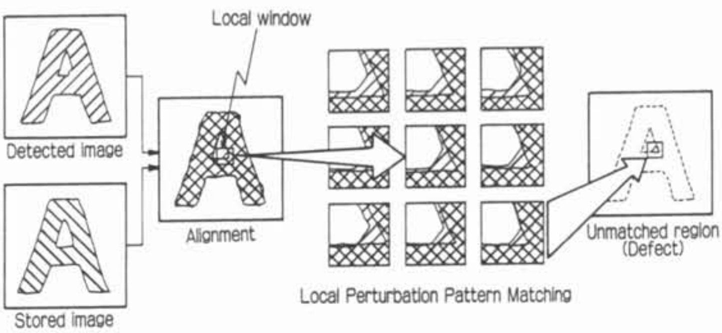


Fig.4 Principle of Local Perturbation Pattern Matching (LPPM)

To shorten the inspection time, we applied LPPM to images which are created by resampling the detected images with half-size pixels. Using this resampling technique, we can detect defects as small as the initial sampling pixel and have achieved an inspection speed four times faster than the conventional method.

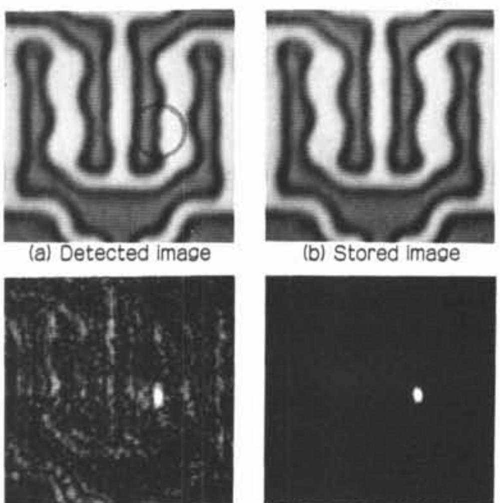
As all processings are executed with local operators, the real-time processing can be achieved by a pipelined architecture.

EXPERIMENTAL RESULTS

To confirm the validity of the developed algorithm, we experimented the defect judgement of LSI photoresist patterns.
Fig.5 shows examples of the defect detection. The images were detected at 0.24 μm/pixel and resampled at 0.12 μm/pixel. The detected image (Fig.5(a)) includes the 0.3 μm convex defect. There are many unmatched regions in the simply subtracted image (Fig.5(c)), however, only the defect is clearly detected by LPPM as shown in Fig.5(d)

CONCLUSIONS

In order to detect submicron-order defects of single layer patterns, we have newly developed an automatic visual inspection algorithm based on the comparison of grayscale images, named Local Perturbation Pattern Matching. This algorithm eliminates differences of normal patterns and correctly detects defects only, by aligning two images by shifting one image in the x-y plane and in grayscale locally, and regarding the unmatched region as a defect.
The application of the developed algorithm to the inspection of photoresist patterns on a silicon wafer, confirmed the detection of 0.3 μm defects with a 0.24 μm pixel size.



(a) Detected image (b) Stored image

(c) Subtracted image (d) Detected defect (by the LPPM method)

Fig.5 Examples of defect detection (0.3 μm convex defect as shown by the circle)

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