NEW OPTICAL MEASUREMENT TECHNIQUE FOR SI WAFER SURFACE DEFECTS USING ANNULAR ILLUMINATION WITH CROSSED NICOLS

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Abstract: This paper presents new optical measurement method for evaluating the microdefects on a silicon wafer surface using annular illumination based on the Fourier transform optics with crossed nicols. In order to verify a feasibility of this new measurement technique, the basic experiments are carried out by measuring the various types of Si wafer surface defects such as microscratches, particulate contaminations, COP (Crystal Originated Particle) [1], etc. All defects employed in this experiment are identified by making the use of AFM (Atomic Force Microscope) and SEM (Scanning Electron Microscope). Then it is found that microscratches induced in the CMP (Chemical Mechanical Polishing) processes with the depth of only 10nm can be detected by this method independent of their directions. And another result is also presented that the proposed method enables to clearly discriminate the defect types by combining with the normal illumination.

Key words: laser applied measurement, surface inspection, silicon wafer, surface defects

1. INTRODUCTION

In modern semiconductor technology, the reduction of the density of Si wafer surface defects that may decrease device yield has become an important issue. In order to fabricate the semiconductor device with high reliability, it is necessary to measure directly them during processing and control the fabrication process. The light scattering methods[2-4] based on the total integrated scatter (TIS) using oblique illumination are very often used for the inspection of Si wafer surface texture. However, these optical measurement methods have the following disadvantages:

1. It is difficult to sensitively detect the oriented defects such as microscratches due to oblique illumination from one direction, because the oriented defects preferentially scatter perpendicular to their long dimension. The microscratches will be more important in CMP (Chemical Mechanical Polishing) processes and may be main yield-limiting in the next VLSI generation.

2. It is hard to discriminate the different types of defects due to intensity detection of scattered light. Defect types for Si wafer surface are classified two types such as contaminant defects on the surface and pit defects at the surface. The contaminant defects mean particulate contaminants, film contaminants and so on, which are on the surface. And the pit defects do COP (Crystal Originated Particle) [1], microscratches, and so on, which are “surface-breaking” defects. And the wafer manufactures strongly need to classify into two types of contaminant defects and pit defects, because the strategy on management of yield is dependent on their defect types.

These disadvantages are great trouble to achieve the yield enhancement of VLSI in next generation. Therefore, the purpose of this study is to develop a new optical measurement technique resolving the above disadvantages, which can detect the microscratch with the depth of 10 nanometer scale and can discriminate the different types of Si wafer surface defects such as contaminant defects or...
pit defects.

2. **PRINCIPLE OF MEASUREMENT**

The normal configuration of optical microdefect detection widely used as commercial instruments is illustrated in Fig. 1. The laser beam is obliquely illuminated to the work surface from one direction. The incident angle is usually near to 70 degree. The several detectors are placed at arbitrary angle except specular direction to pick up the scattered light of the defect surface. In this optical configuration, when there exists no defect on the silicon wafer surface, the detectors do not get any output about the scattered light because the scatter is confined to a small angle around the specular direction. On the contrary, if there exists any defect on the surface, the scatter results from the defect at wide angle and the detectors pick up some of the scattered light as shown at the top of Fig. 1. The sizes and the types of the microdefects are estimated from the detected intensity value of $I_1$, $I_2$, and $I_3$, namely the sum of the ratio of $I_1$, $I_2$, and $I_3$, the difference between $I_1$, $I_2$, and $I_3$, the ratio of $I_2$ or $I_3$ to $I_1$, and so on. This optical arrangement is equivalent to dark field optical system based on far field optics, however, it is difficult to sensitively detect the oriented microdefects such scratches due to oblique illumination from one direction as shown at the bottom of Fig. 1. In order to overcome this major disadvantage, we proposed a new optical measurement method, which can be applied to the oriented microdefects independent of their directions with high sensitivity.

Fig. 2 shows the principle of our proposed measurement technique, which is based on the annular illumination and the Fourier transform optical system with crossed nicols. And this measurement technique is expected to have the following characteristics.

![Fig. 1 Normal configuration of optical microdefect detection](image1)

![Fig. 2 Principle of measurement based on annular illumination with crossed nicols](image2)
Fig. 3 Schematic diagram of silicon wafer surface defects measurement system

(1) The annular illumination generated by the high power objective, in which the Si wafer surface is obliquely illuminated from every direction, enables the oriented defects to be detected high sensitively independent of their directions (Fig. 2(A)). And the light polarizers arranged in the crossed nicols plays an extremely important role in enhancing sensitivity (Fig. 2(B)).

(2) As shown in Fig. 2(A)(B), since this optical measurement method detects scattering light intensity patterns of the defects (called “Laser Scattered Defect Pattern (LSDP)”[5,6]), which are generated based on the Fourier transform optics with crossed nicols, it is possible not only to detect the defects but also to discriminate the different types of ones such as contaminant defects or pit defects.

3. MEASUREMENT SYSTEM

Fig. 3 shows the schematic diagram of silicon wafer surface defects measurement system based on the measurement principle mentioned above. An Ar⁺ laser of wavelength 488.0nm is used as the light source. After passing through the single-mode optical fiber (mode field diameter = 4.0μm), the beam is collimated and polarized. This polarized Gaussian beam is converted into annular incident beam by passing the transparency filter made of the glass plate with the inside Cr coat (the diameter of Cr coat is taken 1200μm). The annular light beam focused by the high-power objective (with the numerical aperture of 0.95) is illuminated on the silicon wafer surface with the beam spot of about 1μm. These configurations enable the annular oblique illumination with the average incident angle of 68 degree (from 63 degree to 72 degree).

Fig. 4 Sample microgroove fabricated by FIB machining used in basic experiment

Fig. 5 Intensity pattern detected by Fourier transform optical system
(a) Reference pattern from smooth surface
(b) LSDP detecting the microgroove
The annular oblique beam spot is relatively scanned over the silicon wafer surface by the computer controlled xy-stage. The scattered light resulting from a microdefect within the annular oblique beam spot travels through the objective and the relay lens, and then forms LSDP corresponding to a Fourier transform image on the high sensitivity cooled CCD area sensor. The intensity distributions are converted to 12 bit digital image data and stored in the image memory.

4. EXPERIMENTAL RESULTS

4.1 Basic experiment for microgroove detection

In order to investigate the basic properties of this optical measurement method, primarily, experiments for detecting microgroove were carried out. Fig. 4 shows the optical and atomic force microscope image of the sample microgroove, whose size is 0.2µm wide, 50µm long and 0.05µm deep, which is fabricated as a typical oriented microdefect by FIB (Focused Ion Beam) machining. First, the intensity pattern of the smooth surface without any microdefects is detected as a reference one which is dark in the center part as seen in Fig. 5(a). Next, the defect pattern scattered from the microgroove is detected. Fig. 5(b) shows the defect pattern from the microgroove obtained as LSDP in Fourier transform optical system. As shown in LSDP of microgroove, a clear fringe image can be seen at the dark area in the intensity pattern. This fact means that a scattered light from the microdefect can be detect by this proposed optical system.

4.2 Scanning experiment for detection of microscratches induced in the CMP processes

Based on the basic experiment mentioned above, the scanning experiment for detecting the actual microscratches induced in the CMP (Chemical Mechanical Polishing) processes was performed by measuring the intensity variations of the scattering patterns. Fig. 6 shows the AFM image of the microscratches employed in this experiment, whose depth is only 9nm. Fig. 7 shows the intensity variations of the scattering pattern vs. the scanning distance of the annular oblique beam spot. In this experiment, the intensity of scattering pattern means the scattered light intensity monitored at the dark area of intensity pattern as shown at the top of this figure. This graph shows that the
intensity rapidly increases at the scanning distance of about 8µm and repeats up and down several times until about 12µm. The scanning range of about 4.5µm indicating the high intensity is equal to the horizontal size of microscratches area. This experimental results suggest that the proposed method can detect the oriented microdefects such as the microscratches induced in the CMP processes independent of their directions with the depth of 10 nanometer scale.

5. DISCUSSION OF DEFECT TYPE DISCRIMINATION IN COMBINATION WITH NORMAL ILLUMINATION

It is known that there is the difference between contaminant defects and pit defects coming from their responses to normal and oblique illumination. That is, in normal incidence, the scatter light from a pit defect is almost the same intensity as that from a contaminant defect, however, in oblique incidence, the scatter light from a pit defect becomes much smaller than that from a contaminant defect. Fig. 8 indicates the concept of defect type discrimination based on this characteristics using our proposed optical system. Here, in order to prevent the effect of absolute scattered intensity value dependent of defect sizes, normal illumination is combined with the annular oblique illumination mentioned before. And the ratio of scattered intensity at oblique illumination to one at normal illumination, Io/In, is employed as discrimination factor of the defect types.

In order to verify a feasibility of this concept, the defect type discrimination experiments were

### Table 1 Microdefects employed in the defect type discrimination experiment

<table>
<thead>
<tr>
<th>Type</th>
<th>Contaminant defects</th>
<th>Pit defects</th>
</tr>
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<tbody>
<tr>
<td>Microscope image</td>
<td>SEM image, AFM image</td>
<td>AFM image, AFM image, AFM image</td>
</tr>
<tr>
<td></td>
<td>Standard particle, Particulate contaminant, Film contaminant</td>
<td>FIB fabricating pit, COP defect, Microscratch</td>
</tr>
<tr>
<td>Horizontal size</td>
<td>0.21µm, 0.28 x 0.31µm, 0.66 x 0.90µm</td>
<td>0.8 x 1.0µm, 0.15 x 0.20µm, 4.5 x 3.0µm</td>
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<tr>
<td>Vertical size</td>
<td>0.21µm (Diameter), 91nm (Height), 110nm (Height)</td>
<td>65nm (Depth), 131nm (Depth), 5nm (Depth)</td>
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carried out by measuring the various kinds of Si wafer surface defects such as microscratches, particulate contaminants, film contaminants, COP, etc. All defects employed in this experiment are identified by making the use of AFM (Atomic Force Microscope) and SEM (Scanning Electron Microscope) as shown in Table 1. Fig. 9 shows the discrimination factor Io/In measured by each defect. The defect types, namely whether a contaminant defects or a pit defects, were clearly classified by the value Io/In in spite of various different kinds of defects.

6. CONCLUSIONS

In order to verify a feasibility of new optical Si surface defect measurement technique using annular illumination based on the Fourier transform optics with crossed nicols, the several basic experiments were carried. The results obtained in this paper are summarized as follows;
1. The microscratches induced in the CMP (Chemical Mechanical Polishing) process with the depth of only 10nm can be detected by the proposed method independent of their directions.
2. The proposed method enables to classify the various difference kinds of defects into two types of the contaminant defect and the pit defect by LSDP in combining with the normal illumination.

REFERENCES