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INTERNAL DEFECT DETECTION IN THE VICINITY OF SI WAFER SURFACE USING EVANESCENT WAVE

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Abstract − In order to reduce and control yield loss in the fabrication process of next generation ULSI devices, nano-defects inspection technique for polished Silicon (Si) wafer surface becomes more essential. This paper discusses the new optical nano-defects detection method, which is applicable to the silicon wafer surface inspection technique for next-generation semiconductors.

In our proposed method, the evanescent light is emerged on the wafer surface with total internal reflection (TIR) of infrared (IR) laser at the Si-air interface. And by scanning the surface where is evanescent light emerging with very shaped fibre probe, it enables to detect nanometre scale defects in the vicinity of Si wafer surface without diffraction limit to resolution. To verify the feasibility of this method, both of the computer simulations based on Maxwell's equations and the several fundamental experiments are performed. FDTD simulation shows that the proposed method is effective to detect nano-defects existing not only on Si surface but also in the subsurface with high sensitivity. And also the fundamental experiments show the validity of this method by demonstrating nano-defects detections of subsurface as well as surface.

Keywords: silicon wafer, internal defect, evanescent wave.

1. INTRODUCTION

In modern semiconductor manufacturing processes, the design rule will shrink to under 100nm scale. In order to realize high productivity and reliability of the semiconductor fabrication, defects inspection techniques for polished Si wafer surface become more essential. Defects of Si wafer surface are classified into two types that mean external defects on the surface (surface defects) and internal defects in the subsurface (subsurface defects) by the state of defect. The examples of surface defect are micro-scratch, COP (Crystal Originated Particle) [1] and so on. And the subsurface defect means void like defect existing in a few hundred nanometres deep. Reducing all of such defects is inevitable to reduce yield loss in the fabrication processes. The critical defect size, which is required to detect in the 100nm design rule processes, become several ten nanometres. But such small defects are undetectable by the conventional defects inspection techniques based on light scattering method, which reached physical limits imposed by the wavelength of its own incident laser beam. And there was no inspection technique to detect such a small subsurface defect. To overcome these serious problems, we propose the novel inspection technique that can detect such nano-defects in the vicinity of the polished Si wafer surface by applying IR evanescent light emerging on the surface. In this method, defects are evaluated not by using scattered light like conventional method, but by using evanescent light based on near-field optics. Therefore the resolution is independent of light wavelength. And it is possible to detect the nanometre scale defects. This method has a potential to sensitively detect subsurface defects as well as surface defects [2].

2. PRINCIPLE

Fig. 1 shows the concept of our proposed nano-defects inspection method. As shown in Fig. 1, IR laser light propagates in Si wafer that is transparent at IR wavelength. In the wafer, the laser light is reflected perfectly at the Si-air interface when the incident angle exceeds the critical angle. And the IR evanescent wave is generated onto the near field region over wafer surface where the total-internal reflection (TIR) occurs. This IR evanescent field is disturbed by the interaction between the light propagating in the wafer and nano-defects existing in the vicinity of the wafer surface. The scanning probe tip can detect the disturbed evanescent field when the tip is in near field on the wafer surface. In our method, we use a tip of Al coated tapered optical fibre as a probe. And the resolution isn't dependent on the light wavelength but on an aperture size of tip of the probe. Therefore this method makes it possible to sensitively detect the nano-defects, even if they exist in the subsurface [3].

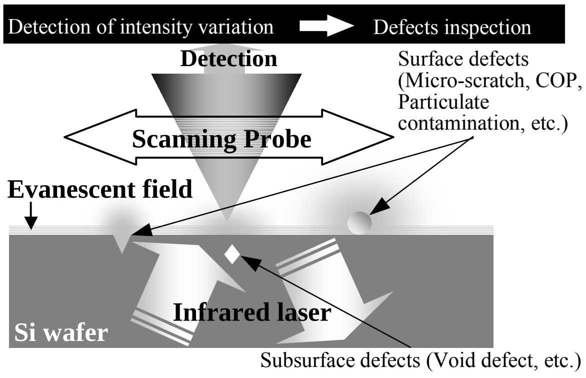


Fig. 1. Concept of defects detection by using evanescent wave

3. FDTD SIMULATION

In order to verify the feasibility of this proposed method, we have developed a computer simulation tool that can analyse the electromagnetic field in micro optical structure by solving Maxwell's equation directly. The tool is based on the 3-dimensional FDTD (Finite-Difference Time-Domain) method [4] that has proven to be one of the most prominent tools for numerical analysis of electromagnetic field. And we analysed the electromagnetic field of near field in the vicinity on the wafer surface using our developed FDTD simulator [5].

3.1. Computer model for simulation

To confirm the validity of our concept, we modelled the scanning fibre probe tip that closes with the Si wafer (N=3.55+0.00067i, N: complex refractive index) surface as shown in Fig. 1. The diagram of this simulation model is depicted in Fig. 2. The unit grid length is 10nm in the 296×218×300 unit simulation domain. The light source is located at the bottom of Si wafer (plane of z=0). And the light source emits the incident light that is p-polarized plane wave at 1064nm wavelength and the incident angle at 23.92° to be TIR condition. The fibre probe core is made of SiO_2 (N=1.55+0.0i) that is assumed to propagate the picked up light to detector. And its tip is formed cone shape with the semi-vertical angle of 45°. The probe tip is approached toward the surface with a gap of 100nm, and coated with aluminium (N=1.99+7.05i) of 100nm thick. To pick up the variation of evanescent signal, the tip has an aperture that is 300nm in diameter.

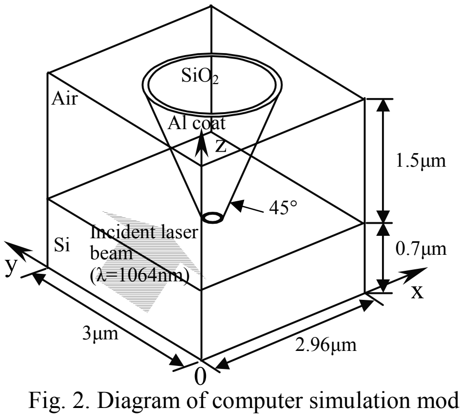


Fig. 2. Diagram of computer simulation model

3.2. Numerical results

Fig. 3 shows the computational results for the case of existing a surface defect. Here the pit like defect existing on the surface is assumed as COP on the surface, and the size has 50×50nm and the shape is concaved 30nm in depth. And the surface defect is allocated under the probe tip. Fig. 3 is a grey-scale representation of time-average electric field intensity distribution, which was obtained by subtracting the reference intensity distribution of the model without a defect in order to extract the disturbance of the defect. It can be seen that the aperture of the fibre probe picks up the disturbance of evanescent wave resulting from the surface defect. This result suggests that our proposed method enables the detection for a defect with tens of nanometre size.

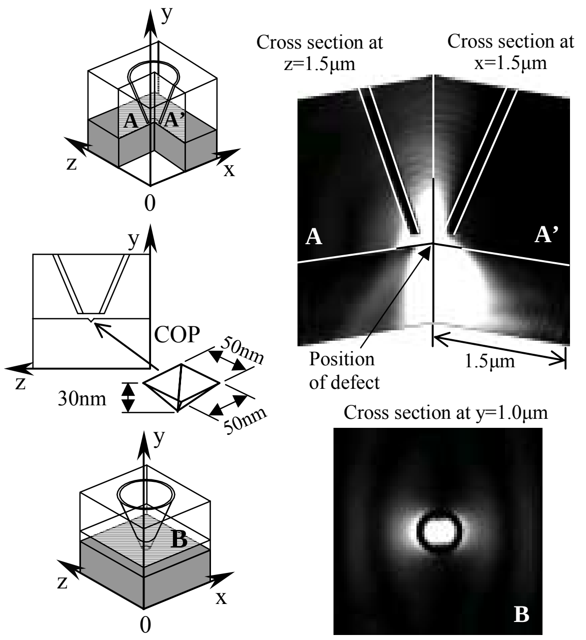


Fig. 3. Simulation result for the case of surface defect

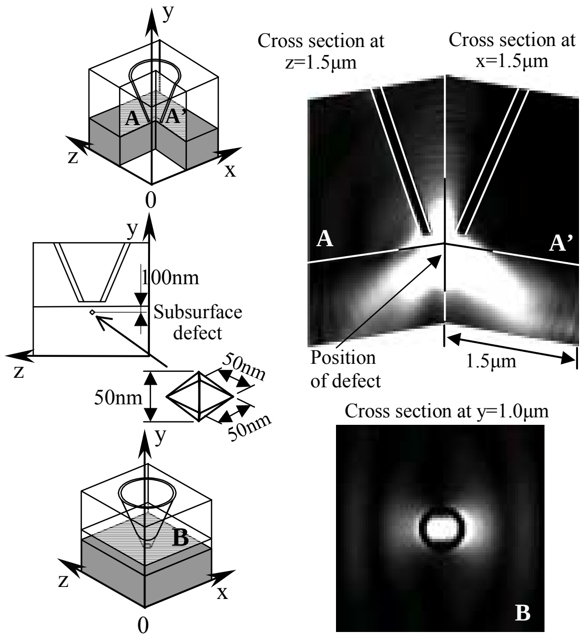


Fig. 4. Simulation result for the case of internal defect

Fig. 4 shows the results for the case of subsurface defects. The void defect existing in the subsurface is modelled as a subsurface octahedral defect (the size has 50×50×50nm; 100nm in depth). And the subsurface defect is assumed to be vacuum (N=1.0+0.0i) and also located under the probe tip. This figure shows that the distribution of scattering is different from that of surface defect. And the aperture of the probe tip picks up the disturbance of evanescent wave resulting from the subsurface defect. This result suggests that even if the defect exists in the subsurface at the depth of 100nm, our proposed method enables the high sensitive detection for a defect with the size of 100nm order.

4. EXPERIMENTS

4.1. Evanescent light measurement system

In order to verify the feasibility of our proposed method experimentally, we also developed the measurement system to detect evanescent light and performed the several fundamental experiments. Fig. 5 shows a schematic diagram of the experimental apparatus that is based on our proposed method. A p-polarized beam of Nd: YAG laser (λ=1064nm; 1W) is used to generate the evanescent field on the surface of sample Si wafer that is mounted on the trapeziform prism. And the incident laser beam illuminates the sample surface from its flip side with TIR condition by this prism. The prism is mounted on the xy-stage that enables probe scanning. To detect the intensity variation of the evanescent field, the fibre probe scans the near field of sample wafer surface. The probe tip, which altitude is controlled by z-piezoelectric translator, is coated with metal to effectively enhance the detected light with plasmon effect. The InGaAs photo diode connects with an optical fibre and detects the transmitted light from the fibre probe tip. To remove optical noise, the signal light can be lock-in detected by using light chopper and lock-in amplifier.

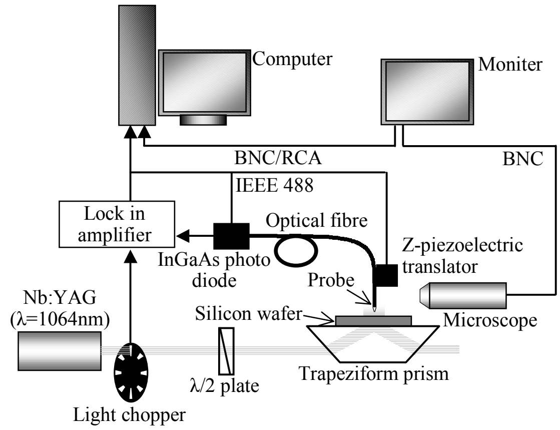
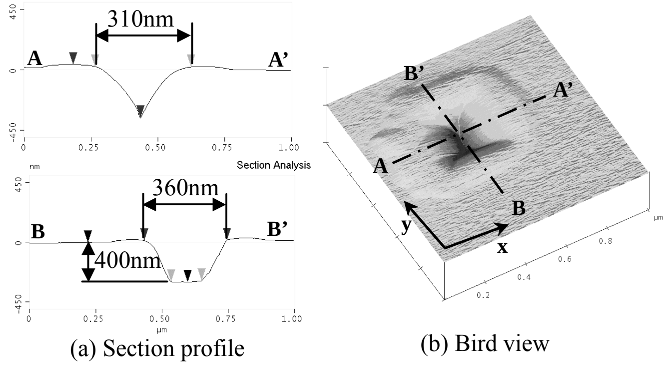


Fig. 5. Diagram of experimental apparatus

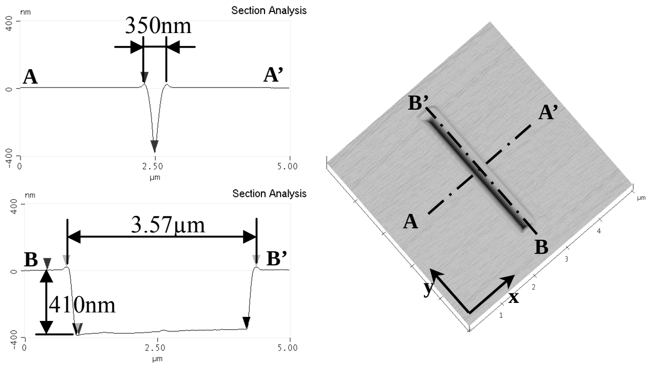
4.2. Detection of surface defects

At first, to confirm the capability of the above apparatus, we performed the experiment to detect surface defects. In this fundamental experiment, 2 types of surface defects that were fabricated on Si wafer using FIB (Focused Ion Beam) are used. One is assumed as COP, other one is assumed as micro-scratch. And the AFM images of these defects are shown in Fig. 7 and 8.



(a) Section profile (b) Bird view

Fig. 7. AFM image of pit like defect



(a) Section profile (b) Bird view

Fig. 8. AFM image of micro-scratch like defect

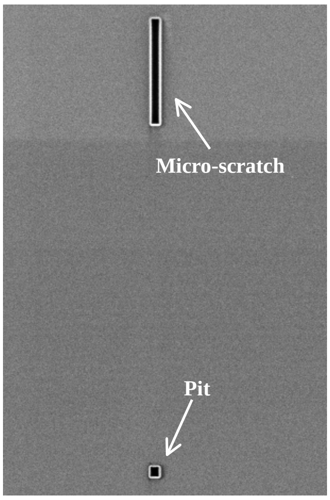


Fig. 9. SIM image of the surface defects

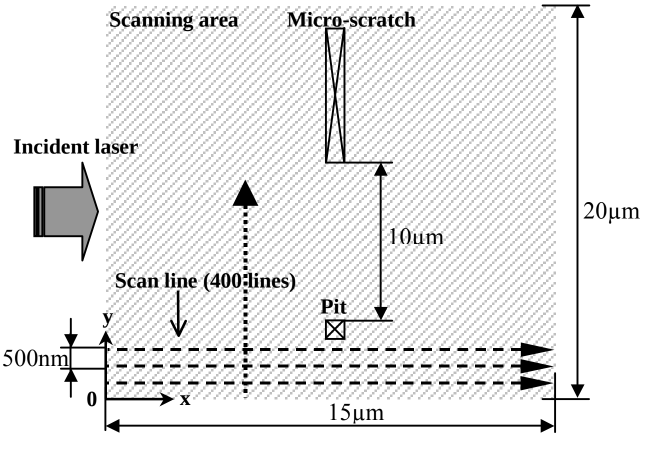


Fig. 10. Scan area and defects location

Fig. 7 shows the defect with 310nm×360nm in area and 400nm in depth, which imitates pit. And Fig. 8 shows the defect with 3.57μm in length, 350nm in width and 410nm in depth, which imitates micro-scratch. Fig. 9 is the SIM (Scanning Ion Microscopy) image of these surface defects. And Fig. 10 indicates the diagram of the experimental procedure that shows location of defects and scanning area of fibre probe. As shown in these figures, these two defects are separated for 10μm. And to detect them, the fibre probe has scanned for 15μm×20μm in area. The scanning of

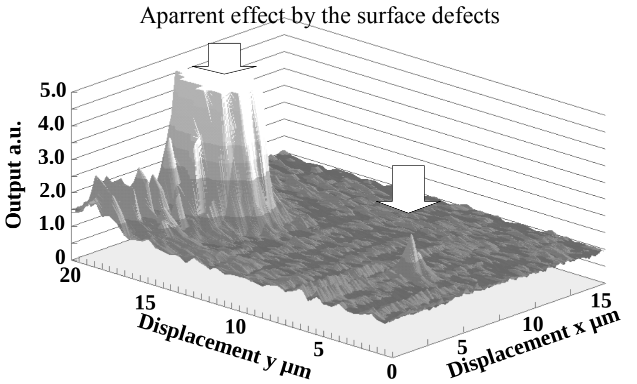


Fig. 11. Experimental result of surface defects detection

400 lines in x-direction is performed at intervals of 500nm. The samplings are executed 300 times at intervals of 50nm in each scan line. Fig. 11 indicates the light intensity variations detected from the surface defects by the scanning fibre probe.

This result shows these variations have an apparent peak (the arrows in Fig.11) corresponding to the position of both pit and micro-scratch. Characteristics of measured light intensity pattern reflect the orientation of the scratch. This result suggests that our proposed method enables inspection of surface defects with 100nm size.

4.3. Detection of internal defect

Second, to confirm the validity of our proposed method that enables to detect the internal defects, we performed the experiment to detect the internal defects. In this experiment, a defect was also fabricated using FIB in the vicinity of Si wafer surface from its side face. The schematic diagram of this internal defect is shown in Fig. 12. The tunnel like internal defect was etched at about 300 nm in depth. The shape of internal defect is tapered. This results from FIB process property that enabled to estimate the length of the tunnel at 5~6μm. The SIM image of the scanning area is shown in Fig. 13. And Fig. 14 shows the diagram of experimental procedure that shows the emplacement of internal defect and scanning area of fibre probe. As shown in these figures, there are 4 pit defects, which are same things in Fig. 7, as marker to indicate the emplacement of the internal defect. And these pit defects are allocated at intervals of 15μm in x-direction and 10μm in y-direction to enclose the internal defect.

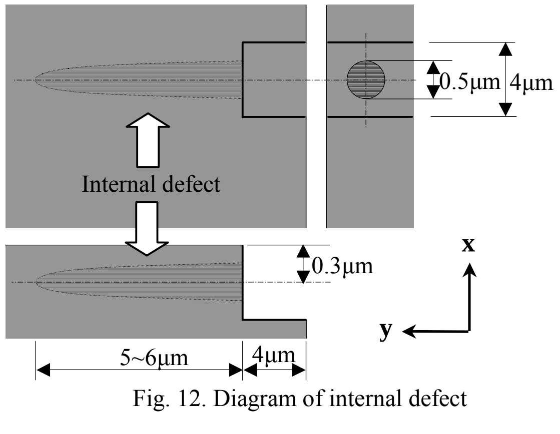


Fig. 12. Diagram of internal defect

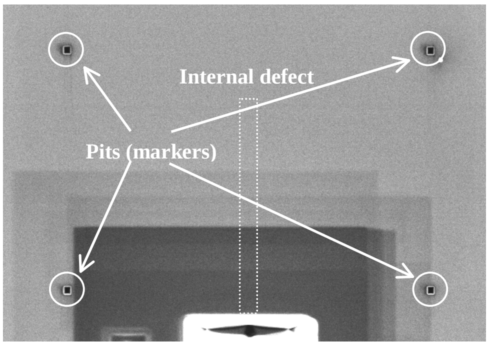


Fig. 13. SIM image of scan area

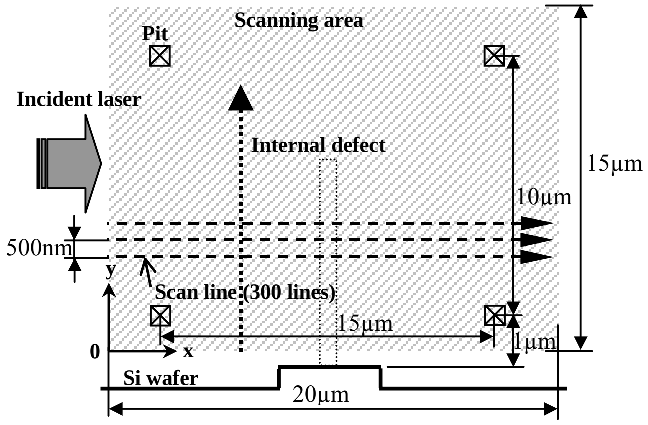


Fig. 14. Scan area and internal defect emplacement

To detect the internal defect with markers, the fibre probe has scanned for 20μm×15μm in area. The scanning of 300 lines in x-direction is performed at intervals of 500nm. The samplings are executed 400 times at intervals of 50nm in each scan line. And then, Fig. 15 shows the experimental result that shows the light intensity variations detected from the internal defects and the markers defects by the scanning fibre probe.

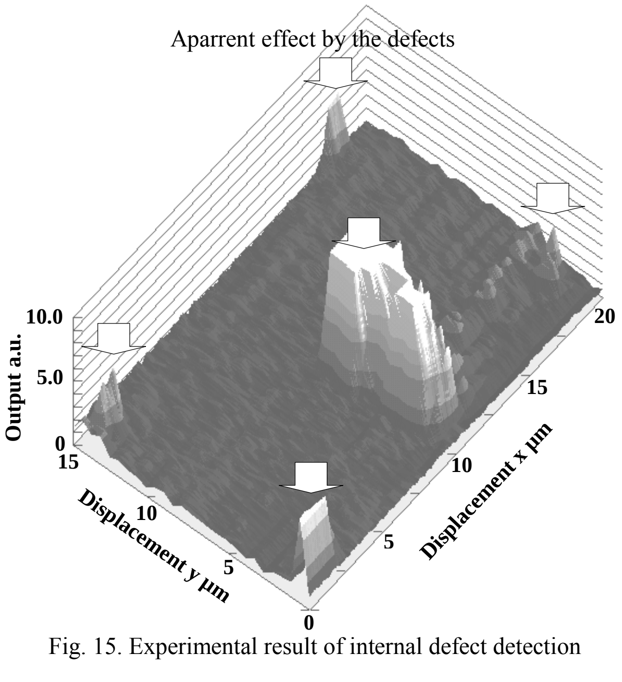


Fig. 15. Experimental result of internal defect detection

As shown in Fig. 15, these variations have an apparent peak (the arrow in Fig.15) corresponding to the position of markers and the internal defect.

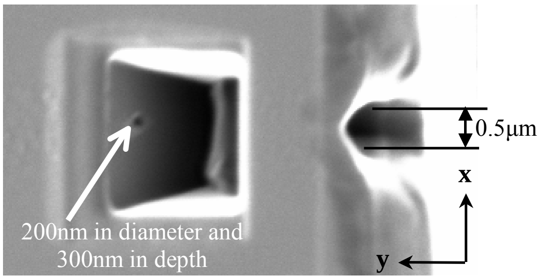


Fig. 16. SIM image of internal defect (opened by FIB machining)

In Fig. 16, the SIM image of internal defect shows the diameter of the tunnel tapers off from about 0.5µm to about 200nm. And the depth of the defect is about 300nm. This experimental fact suggests that our proposed wafer inspection technique enables to detect of internal defects with 100nm size.

5. CONCLUSION

We proposed a novel Si wafer surface inspection technique for nano-defects in the vicinity of Si wafer surface, not by using scattered light but by using evanescent light based on near-field optics. In order to confirm the validity of our proposed method, we developed a computer simulation tool that was based on the 3-dimensional FDTD method and the measurement system to detect evanescent light. The results of FDTD simulation showed our proposed method enables detection the defects with 10nm size not only on the Si wafer surface, but also in the subsurface. Several fundamental experiments are carried out to validate the capability of this developed system. And also the experimental results show that the detected light intensity variations indicate the defects position and configuration. Furthermore, the validity of this method is verified by demonstrating the detection of internal defect with 100nm size.

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