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CHARACTERIZATION OF METALLIC CONTAMINATION OF SILICON WAFER SURFACES FOR 1G DRAM USING SYNCHROTRON ACCELERATOR

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Abstract

At Present, 200㎜ wafer technology is being applied for commercial fabrications of 64, 128, and 256 M DRAM devices, and 300㎜ technology will be evolved for 1G DRAM devices in the early 21th century, recognizing limitations of several process technologies. In particular, recognition has been realized in harmful effects of surface contamination of trace metals introduced during devicing processes. Such a guide line for surface metal contamination has been proposed as 1E9 and 1E10 atoms/cm^2 of individual metal contamination for wafering and devicing of 1G DRAM, respectively, and so its measurement limit should be at least 1E8 atoms/cm^2. The detection limit of present measurement systems is 2E9 atoms/cm^2 obtainable with TRXFA(Total Reflection X-Ray Fluorescence Analysis). TRXFA is nondestructive and the simplest in terms of operation, and it maps the whole wafer surfaces but needs detection improvement.

X-Ray intensity produced with synchrotron accelerator is much higher than that of conventional X-ray sources by order of 4-5 magnitudes. Hence theoretically its reactivity with silicon surfaces is expected to be much higher than the conventional one, realizing improvement of detection limit. X-ray produced with synchrotron accelerator is illuminated at a very low angle with silicon wafer surfaces such as 0.1 degree and reflects totally. Hence informations only from surface can be collected and utilized without overlapping with bulk informations. This study shows the total reflection phenomenon and quantitative improvement of detection limit for metallic contamination. It is confirmed that synchrotron X-ray can be a very promising alternative for realizing improvement of detection limit for the next generation devices.

Key words : *Synchrotron, Total reflection, X-ray, Semiconductor, Cleaning*

1. Introduction

ULSI (Ultra Large Scale Integration) devicing technologies for the next generation DRAM (Dynamic Random Access Memory) saturate to mature stages and require some kinds of breakthrough. Contamination control by cleaning as well as measurements is one of important aspects for realizing the next generation devices. Contamination measurement backs up cleaning process and hence needs better detection limit such as 1E8 atoms/cm^2 for metallic contamina tion measurement. The present measurement technology realizes 2E9 atoms/cm^2 with TRXFA, which requires at least one order improvement. Total reflection of X-ray takes place when X-ray is incident on silicon wafer surface with very low angle of such as 0.1 degree. Hence only surface information can be selected eliminating bulk ones since the incident X-ray does not penetrate into the bulk. X-ray hitting metallic contaminants on silicon wafers induces characteristic secondary X-rays from them. The characteristic X-rays are collected and quantified for metallic concentration measurement. If intensity of incident X-ray is higher, its reaction with surface contaminants is to be stronger generating more characteristic X-rays from contaminants and improving detection limits of surface contaminants. Synchrotron is nothing but a plant generating higher density X-ray than the conventional X-ray generators by order of 4-5 magnitudes.[1, 2] Hence synchrotron X-ray is expected to yield much better detection limit than the conventional ones. This detection limit improvement will fulfill one of the next generation device process requirements. Photon factory of Japan and SSRL of Stanford, USA are representatives for studying of synchrotron X-ray total reflection.[3, 4] In Korea, Pohang Light Source(PLS) is optimally built for realizing Total Reflection of Synchrotron X-Ray Analysis (TRSFA) on silicon wafer surface in terms of energy and intensity of generated X-ray. In this study, total reflection of synchrotron X-ray is demonstrated for the first time in Korea and utilization of TRSFA technology for the next generation devicing is confirmed to be satisfied with the requirement and inevitable.

2. Experimental

The measurement system is designed to be separated in three sections as shown in Fig. 1. The first section is attached to the X-ray beamline which is for guiding X-ray generated from synchrotron to experimental systems. In this section, X-ray monochromater is installed

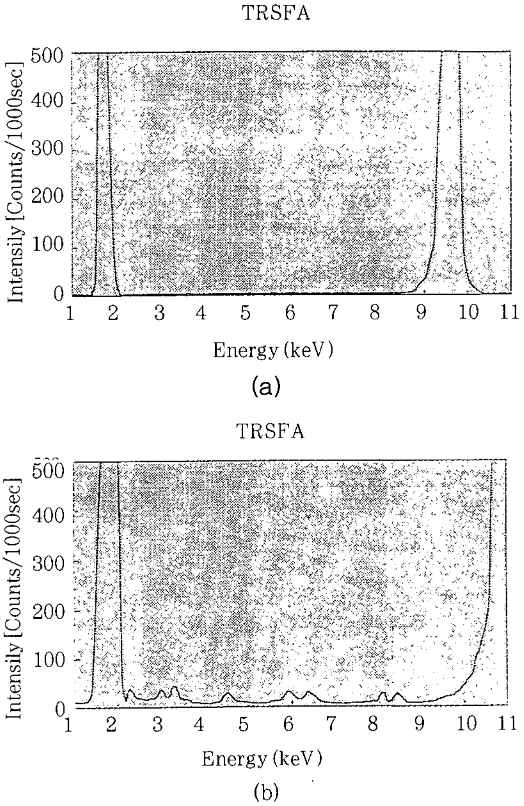


Fig. 1 Comparison of TRXFA with TRSFA spectra of RCA cleaned wafers, acquired for 100 seconds

to filter a monochromatic X-ray out of white synchrotron X-ray. Several W and B4C superlattice layers of 29.7 angstrom thick are stacked on a (111) silicon wafer for filter. When one of white X-ray entering the filter meets Bragg's condition, it only diffracts to a given angle and other X-rays are out of phase and eliminated. Hence monochromatic X-ray energy can be selected for detecting contaminants and can be varied depending on contaminant species, which is not possible in TRXFA. The other side of the first section is connected to the second section where the selected monochromatic X-ray is shaped with slits. Finally the X-ray is illuminated on silicon wafer surface with very low incident angle such as 0.1 degree in the third section. The incident angle control is the key in this experiment and angle is managed with three axis goniometers to the accuracy of 0.001 degree. Two methods are applied to obtain and confirm the total reflection condition. One is to observe the X-ray beam passing the wafer surface and reflected beam, by observing excited fluorescent plate placed after silicon wafer. Another is to observe the theoretically selected X-ray energy by a Bragg's condition on EDX (Energy Dispersive X-ray) spectrum, since a part of the incident beam is scattered on silicon wafer surface to EDX detector.

200㎜ silicon wafers were RCA-cleaned. RCA-clean is two step cleaning process developed in RCA. The first step is to clean particles and organics using ammonium hydroperoxide solution and the second step is to remove metallic contamination using hydrochloric hydyoperoxide solution. RCA-clean satisfies the present requirement for surface cleanness of silicon wafers so far.$^{5)}$ Wafers were separated to two groups. One group was for reference and the other was for contamination of Fe up to 1E14 atoms/cm^2. Each group wafers were measured with TRXFA as well as TRSFA to compare their detectabilities. Data aquisition time of EDX system was usually 100 seconds and varied up to 1,000 seconds to compare time dependence of detectabilities of TRXFA and TRSFA.

3. Results and Discussion

Total reflection of synchrotron X-ray was attempted. X-ray was introduced on a silicon wafer with angle as low as possible. After wafer, a fluorescent plate was placed so that X-ray passed, penetrated, or reflected could excite the fluorescent plate. When X-ray passed or penetrated the wafer, it generated only a fluorescent spot. However, when it reflected, it generated another spot near the passed beam spot. As incident angle of X-ray increased, the passed beam spot was getting darker and a new spot generated nearby was getting brighter. When the incident angle increased further only the new spot remained while the original spot was disappearing. This proves the occurrence of total reflection phenomenon. Also a part of monochromated X-ray was observed on EDX spectrum. This was due to partial scattering of monochromated X-ray from silicon wafer surface to X-ray detector. Hence the total reflection of synchrotron X-ray was confirmed to be realized in this study.

Contaminated wafer surfaces were investigated, comparing two data obtained with TRXFA and TRSFA. Table 1 shows data obtained from

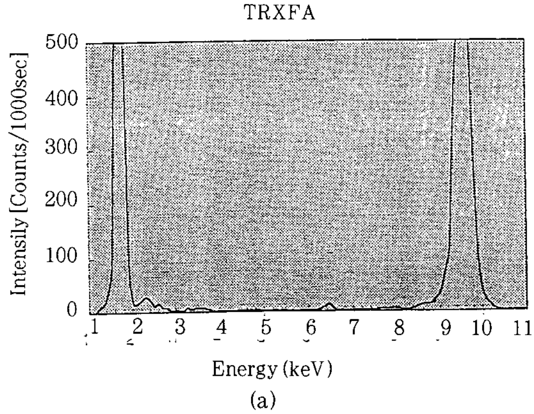
Table 1. Summary of comparison of TRXFA with TRSFA detections for comtaminated wafers

samples / methods	1	2	3	4	5	6	7	8
Fe Concentrn. (1E10 atoms/cm^2)	10.3	19.4	15.1	23.2	31.8	8366	9590	10508
TRXFA (Counts)	3	4	4	5	7	2169	2136	2835
TRSFA (Counts)	28	18	45	49	73	8329	12846	19200

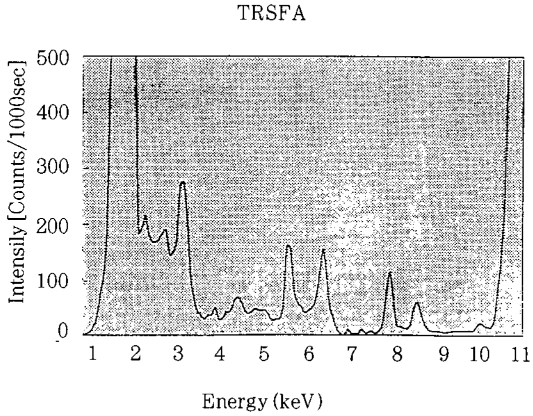
intentionally contaminated wafers of up to 1E14 atoms/cm^2 Fe, varying its concentrations. As shown in Table 1, TRSFA data of characteristic X-ray counts give clearly that detection limit improvement of down to 1E10 atoms/cm^2 level contamination.

Fig. 1 and Fig. 2 compare the dependence of relative data aquisition times. To obtain clear comparison, RCA cleaned wafers were used instead of intentionally contaminated wafers. With same scale of counts, it is clear that TRSFA is confirmed to be superior to TRXFA for given acquisition time as shown in Table 1, and detection limit improves for TRSFA as the data aquisition time increases as well.

Synchrotron X-ray photons of higher intensity react with more metallic impurities on silicon wafer surfaces, generating more characteristic X-ray from them. Counts of all characteristic X-rays for TRSFA are almost ten times as high as those of TRXFA. This fact tells approximately one order improvement of detection limit, which is the most important aspect of TRSFA evaluation. Hence it can be said that detection limit of TRSFA reaches to below 1E9 atoms/cm^2, while that of TRXFA utilized in this study is 5E9 atoms/cm^2. There are many experimental crudenesses left to be improved. For example, this study was carried out using X-ray slitted to one tenth of the original beam. Instead of slit-



(a)



(b)

Fig. 2 Comparison of TRXFA with TRSFA spectra of RCA cleaned wafers, acquired for 1,000 seconds ting monochromated beam by diffraction, focusing the beam to a given size will improve the detection limit up to one order since all synchrotron X-ray intensity is utilized. Therefore, if automation, carefulness, and hardware improvement for TRSFA measurement are involved in commercial system, detection limit of TRSFA will enter below 1E8 atoms/cm^2. This achievement will naturally meet the requirements of 1G DRAM or higher level device fabrication.

4. Conclusions

Total reflection study using synchrotron was carried out and total reflection phenomenon was realized for the first time in Korea. Synchrotron X-ray gives improvement of detection limit of almost one order, which needs further refined quantification. Improvement of details supporting measurement is expected to meet the requirement of 1GDRAM or higher level device fabrication.

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