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Advanced Analytical Tools in KUKUM's Microelectronics Laboratory

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ABSTRACT

Advanced analytical tools that have been primarily used for research and development application in the past are now being used extensively to understand semiconductor failure analysis and reliability problems. In this paper, we will discuss an application and technique in the use of Atomic Force Microscopy (AFM), Mini Secondary Ion Mass Spectroscopy (MiniSIMS), and Scanning Electron Microscopy (SEM) for teaching and learning purposes. These tools have been extensively used in identifying semiconductor characterization which contributes to enhancing the fabrication processes in Microelectronic labs specifically.

Keywords: *Failure analysis, characterization, AFM, SEM, and MiniSIMS*

Introduction

Microelectronic Laboratory in KUKUM is equipped with several advanced analytical equipment such as Atomic Force Microscopy (AFM), Mini Secondary Ion Mass Spectroscopy (MiniSIMS), Scanning Electron Microscopy (SEM), and Energy Dispersive X-Ray (EDX). These tools are extensively used not only by undergraduate students but also by post-graduate students in their learning purposes and research activities respectively.

This laboratory has been designed for the students who enroll in courses like Reliability & Failure Analysis (EMT361) and Semiconductor Packaging (EMT453). The students are exposed to these advanced equipment during analyzing the characterization of semiconductor samples.

Failure Analysis techniques commonly used in the semiconductor industry can be divided into two categories: destructive and non-destructive.

This paper is organized as follows. In the second section, we provide several applications of AFM, MiniSIMS, and SEM. In the third section, we describe procedures in preparing the samples and results of analysis using these advanced equipment. The conclusions of this paper are stated in last section.

Applications of Advanced Analytical Tools

Atomic Force Microscopy (AFM)

Atomic Force Microscopy (AFM) which is also known as Scanning Probe Microscope (SPM) is one example of non-destructive techniques tool. It is a type of surface topography imaging SPM that touches the sample surface with the tip of the cantilever using a microscopic force and scans the sample while controlling the distance between the probe tip and the sample so that the bend amount of the cantilever is constant. AFM is widely used as an application for evaluating a variety of surface characteristics, such as friction force, viscoelasticity, and surface potential. In this paper, we will describe the use of AFM in analyzing the profile of corning glass (Morris 2001).

Secondary Ion Mass Spectroscopy (SIMS)

Another type of non-destructive techniques is Secondary Ion Mass Spectroscopy (SIMS). In this paper, we will discuss the use of Millbrook MiniSIMS. KUKUM recently purchased a miniSIMS unit (Morris 2001) and at the moment, it is the only unit available in this region. The unit uses gallium ions (Ga+) with energy of approximately 6 keV as the primary ion beam (MiniSIMS *INSTRUMENT MANUAL* 2004). The correct generic term for the MiniSIMS is actually a secondary ion microprobe. Its operation is based on the phenomenon of secondary ion emission and the mass analysis of charged particles from solid surfaces, i.e. secondary ion mass spectrometry (SIMS). It is a desktop SIMS analysis instrument.

Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is another non-destructive techniques used in semiconductor industry. It is used for inspecting topographies of specimens at very high magnifications which can go to more than 300,000 X. The inspection involves the analysis of die/package cracks and fracture surfaces, bond failures, and physical defects on the die or package surface. It employs electron beam while the optical microscope uses natural light as illuminating source. SEM images include secondary electron and backscattered electron images and the resolution down to 5nm. Though SEM is restricted in operation and application due to its illuminating beam and operating medium (vacuum), SEM are effective for obtaining a variety of information from sample specimens by utilizing many available attachments such as backscattered electron detector and X-ray spectrometer. SEM permits not only observation of very fine details and high resolution but also good in focusing a wide range of sample surfaces.

Experimental Results

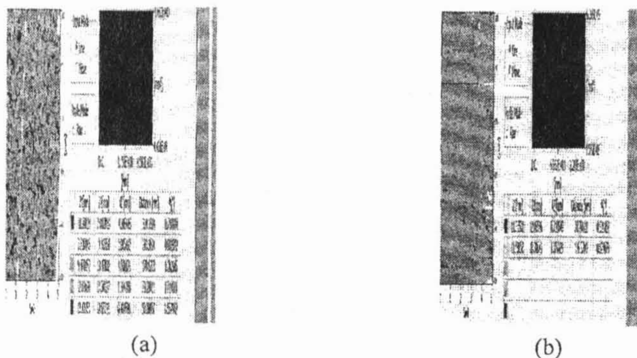
Analysing Corning glass profile using AFM

Before using AFM, certain procedures have to be followed. They involve sample preparation and scanning the surface. In this experiment, we use sample of Transparent Conductive Oxide (TCO) which is made of from tin oxide.

During surface scanning, a small vertical displacement of the specimen surface will cause a deflection of the laser beam as it reflects off the cantilever surface. Displacements less than 1nm can be detected and if negative feedback is used to couple the detector signal to the z displacement of the piezo-scanner, then a greater range in specimen height can be measured.

Scanning procedure is started with specimen placement on the sample stage which is set on the mount on top of scanner. Then cantilever is prepared on the cantilever mount and the software using for this AFM operation is SPISEL32. A critical procedure in actual operation is the approach of the tip to the specimen. With the aid of a light microscope, the tip-specimen separation is mechanically reduced to a few micrometers and the specimen is then advanced using the piezo-actuator z motion until contact is made. The camera light then must be minimized to ease laser adjustment. Laser X and laser Y knob is adjusted to maximize ADD output (8~13 V). Using laser position window, DIF and FFM knob is rotated to the center of laser position to ensure the spot moves smoothly across the range. After all the procedures, parameters such as Force Reference, I Gain, P Gain and A Gain must be set up. Finally, the range between the cantilever and the sample is brought into the force area and now the specimen can be scanned and monitored using two scan canvases. The first scan canvas data type is set to "Deflection" and another one is set to "topo (Servo)" data type (*Manual* SPA400 AFM).

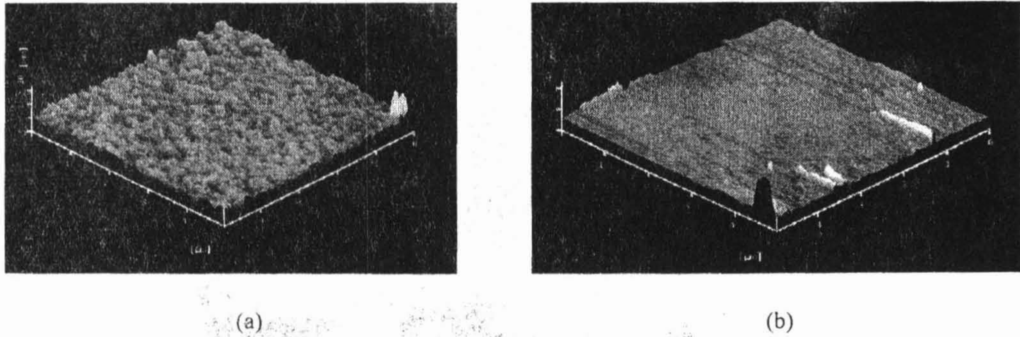
The top view, or gray-scale image, is analogous to a topographic map, with a view looking directly down onto the surface. Figure 1(a) show the surface topography for Corning Glass deposited with Transparent Conductive Oxide (TCO) thin film while Figure 1(b) shows non-deposited Corning Glass. The scanned area for both figures is 5000 nm x 5000 nm. Higher points are brighter and lower points are darker.



(a) (b)

Fig. 1: The surface topography for Corning Glass (a) deposited with TCO thin film (b) non-deposited.

Since the image data are inherently three-dimensional, display can be as a three-dimensional rendition or perspective view. Figure 2(a) and (b) shows an example of 3D view for TCO deposited and non-deposited Corning Glass. Computer processing can display the rendered image from any angle and the height scale is frequently expanded with respect to the lateral scales. Coloring can be added which maps colors to different elevations.



(a) (b)

Fig. 2: 3D Image for Corning Glass (a) deposited with TCO film (b) non-deposited.

Performing Mass spectrum analysis on phosphorus doped silicon Using MiniSIMS

In this experiment, the mass spectrum analysis is performed on 5mm X 5mm phosphorus doped silicon sample. The sample is fabricated in the school of microelectronic engineering microfabrication laboratory via the thermal diffusion process (Mathiot et al. 1998). The steps involved in mass spectrum analysis are as followed. The analysis starts with the sample preparation. The sample is cut into 5mm X 5mm shape and mounted on a metal stub (metal supporter to place the sample properly when loading into the MiniSIMS). It is also necessary to ground the sample and this is achieved using aluminum foil. The stub with the attached grounded sample is then placed in the MiniSIMS chamber of which vacuum level of approximately 10^{-7} mbar is pumped down before starting with the data acquisition. All the procedures used in the study follow closely the User Manual of MiniSIMS (MiniSIMS *USER MANUAL* 2004).

The second step is to obtain the Secondary Electron Detection (SED) image. This is to show the orientation of the sample in the MiniSIMS. For a clear view of the SED image, the ion source is set to focus beam and the magnification to minimum.

The final step of this experiment is to perform the mass spectrum analysis on the sample. This is to investigate the existence of the interested peak of the secondary sputtered ions (i.e. either phosphorus ions, P^+ and or silicon ions, Si^+). A point/area on the SED image, preferably at the centre area is chosen as the analysis point/area. The magnification is set to a high value (>30) and a broad beam is utilised in order to obtain good intensity of the ions. Table 1 gives the analysis parameters that have been set to obtain the mass spectrum. This technique is also known as static SIMS since the analysis will not alter or damage the surface of the sample.

Table 1: The setting parameters to acquire the mass spectrum analysis

Parameter	Setting
Start Mass	2
End Mass	200
Step Size	0.2
No. of Scan/Spectrum	2
Dwell Time/Point (s)	0.05
Ion Mode	Positive Ion

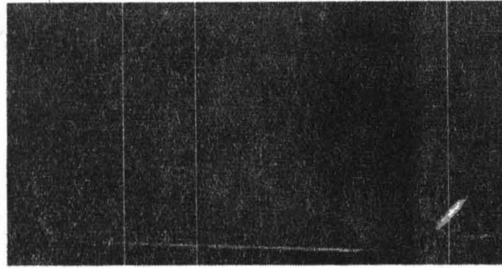


Fig. 3: SED Image of the phosphorus doped silicon sample (Magnification = 1)

Figure 3 shows the SED image obtained. The image provides useful information about the topographical map of the surface which facilitates in selecting a spot area for the analysis.

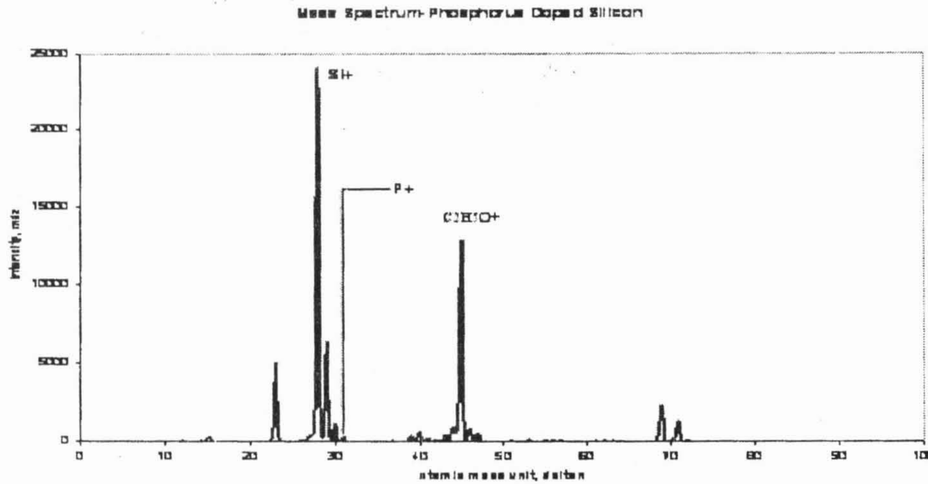


Fig. 4: Mass Spectrum of phosphorus doped silicon sample. Notice that Si^+ and P^+ exist in the sample

Figure 4 shows the positive ion spectrum (mass spectrum) obtained. Silicon can be detected at relative mass of 28 and phosphorus can be detected at relative mass of 31. Apart from these, peak near the mass value of ~ 45 is also observed. This peak corresponds to $C_2H_5O^-$ ions. Since the surface layer should only contain silicon and phosphorus, the $C_2H_5O^+$ ions are contaminants which probably originate during the fabrication process of the sample. From the spectra, we can see that the intensity of silicon mass (approximately 24000 cps) is very high compared to phosphorus mass (approximately 9350 cps). The huge difference between these two masses is related to the amount of phosphorus doped into the silicon wafer.

Imaging a sample of Poly Methyl Metacrylite (PMMA) on silicon using SEM

There are two types of scanning image of SEM which are Secondary Electron Image (SEI) and Backscattered Electron Image (BEI). SEI produces image of surface structure, magnetic domain and potential distribution. On the other hand, BEI gives information on composition, topography, magnetic domain and crystalline state (JEOL Ltd). In this paper, we will use a sample of PMMA on silicon. Before capturing the image of the surface of sample, the following procedures are to be pursued by SEM user. First step is to start up the SEM. Then, prepare a sample. Sample is loaded into the chamber in a vacuum mode. Table 2 summarizes the setting parameters of SEM.

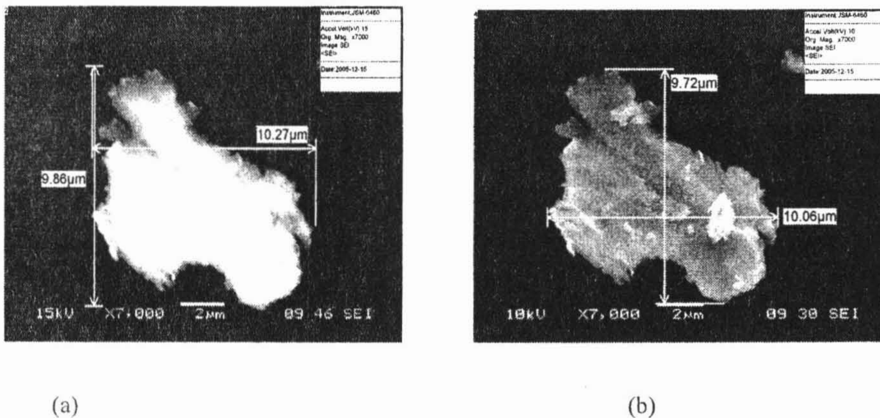
Table 2: Setting Parameters of SEM

Parameter	Setting
Accelerating Voltage	3 ~ 30 kV
Working Distance	Up to 5 mm from the detector
Signal	SEI/BEI
Vacuum	Low/High
Spot size	0 ~ 50
Objective Lens Aperture	1,2,3

After setting all the parameters value according to the Table 2, the image of the sample can be observed. For clearer view image of the samples, one can adjust the following menu:

i. Gun Alignment, OL Aperture Alignment
ii. Focus, Astigmatism, Brightness and Contrast Adjustment

Figure 5 shows the difference between the brightness of the sample. In (a) the accelerating voltage is set to 10 kV while in (b) the accelerating voltage is set to 15 kV. The lesser the value of accelerating voltage, the image that we captured will become clearer.



(a) (b)

Fig. 5: Image of PMMA using SEM. (a) 10 kV, (b) 15 kV

Conclusion

In this paper we described the implementation of three types of experiments using AFM, MiniSIMS, and SEM. These have been carried out during teaching and learning activities in KUKUM's Microelectronic Laboratory. Through these experiments, students have learned the basic techniques and applications of these advanced analytical tools. In the future, we are planned to further increase the usage of the advanced analytical tools in our learning, teaching and research activities.

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