Microscopic Chemical State Analysis by FE-SAM with Hemispherical Energy Analyzer

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Scanning Auger microprobe (SAM) equipped with a field emission (FE) gun and a hemispherical energy analyzer (HSA) has been developed for Auger analysis of micro-area with a high energy resolution. A FE-gun with a small source size and a high brightness is used for micro-area analysis. HSA has a property of high energy resolution and the energy resolution is controlled electrically. In this paper, the technical improvements on the new FE type electron optical column and the HSA with a multi-channel detector system are presented with the typical applications of Auger micro-area analyses.

Introduction
Auger electron microprobe has been used as an analytical tool for elemental distribution of thin or multi-layer materials and structures of micro-devices. These analyses need the enhanced spatial resolution for micro-area analysis and high energy resolution spectra for analysis of chemical bonding states. For requirement to improve the performance of Auger microprobe, FE-SAM (JAMP-7830F) was equipped with a newly designed optical system with a ZrO/W Schottky field emission (FE) gun, a new objective lens and an image drift compensation system. An advantage feature of the new electron optical system is ability to analyze micro-areas. Furthermore, the hemispherical energy analyzer (HSA) was installed as Auger detector in the ultrahigh vacuum scanning electron microscope. The new Auger system provides high image resolution and high beam stability. In general, HSA or concentric hemispherical analyzer (CHA) is usually used in X-ray photoelectron spectroscopy (XPS), because XPS for chemical state analysis needs high energy resolution spectra. By combination of HSA with the scanning electron microscope with FE gun, Auger chemical state analysis was possible in micro-area. In this paper, the technical improvements on the new FE type electron optical column and HSA with the multi-channel detector system are presented with applications of Auger micro-area analysis.

1. Features of FE type electron optical system
1) High spatial resolution
According to the trend of semiconductor devices towards down sizing less than several ten nm by the device rule, the performance of SAM is required to have a spatial resolution of 10nm for micro-area analysis. JAMP-7830F equipped with a FE-gun shown in Fig. 1 provides the capability of micro area analysis with 10 nm resolution. By using a Schottky field emitter, the source size is smaller than 10nm diameter. It is about 1/100 of the LaB$_6$ source size and the current stability is several % per hour as with a LaB$_6$ cathode. Furthermore, a position compensation system for specimen drift during analysis is attached to a controller system of the electron optical column and is very useful for high magnification analysis [1].

2. Largest beam current
The electron optical system of SAM needs a largest beam current with smaller beam size for Auger analysis, especially, the FE-gun is effective when the probe current exceeds several ten nA for Auger analysis. The demagnification by the electron optical system for the field emitter is within one order of magnitude, so the aberration term of the first condenser lens is no more ignored. One of methods to reduce the aberration coefficients is to shorten the working distance between the emitter and the first condenser lens. The first condenser lens is newly designed to reduce the aberrations. The polepiece of the first condenser lens is located beneath the anode, the resulting principal focal plane of the first condenser lens is between the anode and the extractor as shown in Fig. 1. In the arrangement shown in Fig. 1, the magnetic field (B) of the condenser lens is highest between the anode and the extractor, and the condenser lens is located within the acceleration field (E) of the electron beam. The design of the first condenser lens lead to reduction of lens aberrations and beam spread for FE gun. These electron optical systems provide a beam size of several nm and a probe current of several hundred nA.

2. Features of electron energy analyzer
1) High energy resolution and sensitivity
For the use of the HSA in Auger electron spectroscopy (AES) [2], a new HSA detection system was developed. This system consists of three functions, i.e., the input lens system, the HSA and the multi-channel detection system. The sensitivity of the Auger detection system depends on the design of the input lens system and the multi-channel detection system installed with the HSA. The input lens system is designed to effectively detect the signal from a point source on the specimen. The design of input lens system has been carried out by computer simulation. The aberration of the input lens system affects the beam shape inside the HSA, and lowers the detection efficiency for the HSA. The spherical aberration coefficient of new input lens was decreased to 1/3 of that of the previous one. This makes the increase of the sensitivity [3].

HSA is an energy dispersive spectrometer and the electrons passed through between electrostatic deflectors focus at the output plane of HSA by separating the electron energy. The multi-channel detectors placed at the dispersion position on the output plane detect all available signals of a spectrum. The sensitivity increases proportionally to the number of detectors introduced. The constant retarding
A sufficient number of Au, and (b) Auger microprobe with FE electron optical system.

Fig.1. Auger microprobe with FE electron optical system.

100nm Au and (b) Auger microprobe with FE electron optical system.

Fig.2. SEM image of Au on the graphite is measured at 25 kV primary electron beam energy and 2 nA beam current.

Fig.3. Au Auger line profile at showing Auger line analysis position in Fig2. P is the intensity of Au-NOO at 86 eV and B is the background at 80 eV.

Fig.4. Au (a) and C (b) Auger images are measured at the same beam condition of the line analysis and the different position on the same specimen.

2) Reliability for HSA

The measurement of the spectra in a low energy range from 0 to 100 eV is very difficult and requires the reliability of HSA and the less magnetic flux of the objective lens or the stray filed. The special magnetic shield case is equipped inside the analyzing chamber to reduce the magnetic flux. Still more, the unique objective lens is designed to prevent the spreading of magnetic flux on the specimen. This magnetic shield technique is capable of the measurement of the low energy electron spectra with sufficient reliability. A typical example of the low energy electron spectra is the measurement of the true secondary electron spectra. The work function is obtained by the onset energies of the secondary electron spectra [4]. These capabilities will provide new applications of the work function for micro-areas.

3. Applications

1) High spatial resolution analysis

To check the Auger spatial resolution, the Auger line profile was analyzed for a gold particle evaporated on a graphite substrate. A primary electron beam with an energy of 25 kV and 2 nA was measured by a Faraday cage built in the electron optical column was used to take a scanning electron image shown in Fig. 2. The line scan of the Au-NOO Auger signal is shown in Fig. 3. The spatial resolution is about 10 nm estimated by a distance corresponding to the change of the Au intensity at the sharp edge from 20% to 80% of the value. The Auger images of Au and C taken by the same condition of the primary beam and the same area of specimen are shown in Fig. 4 (a) and (b). The image drifts of these images were compensated by the probe tracking software. The Au Auger image of the Au particle with a 20 nm diameter (arrows) is clearly observed in Auger image.

2) High energy resolution spectra

The energy resolution of HSA is changed by controlling the retarding ratio electrically. The
3) Auger chemical depth analysis

The Auger spectra of Si-KLL for Si, SiO₂ and SiON₅, and the chemical state mapping for each chemical state were shown in the paper [3]. In this experiment, the chemical depth analysis for multilayers of SiO₂ and SiON₅ on Si substrate were measured. Fig. 6 shows the Auger spectra as a function of depth which is used to analyze the change of spectrum shape. The number of each spectrum shows the depth level from the surface to the substrate. No.1 spectrum corresponds to the top surface. The spectra of number 9 and 23 depth levels were taken out from the depth profile data. The number 9 spectrum shows the interface including two states of SiO₂ and SiON₅, and the number 23 spectrum including two states of SiON₅ and Si. These spectra were analyzed by the curve fitting method using the synthesized spectra of Gaussian-Lorentzian function. Fig. 7 and Table 1 show the analyzed data for spectra of number 9 and 23. Each Si-KLL spectrum is separated into 4 peaks of SiO₂ and SiON₅, and 5 peaks of SiON₅, and Si-loss. The calculation were carried out by using the most rapid of the non-linear least means square techniques to obtain the best fitting between measured spectra and synthesized spectra. An Auger line shape consists of asymmetric peaks and includes a large background. Therefore the best ways is to use the measured standard spectra instead of the Gaussian-Lorentzian functions. The curve fitting by using the measured standard spectra will be expected to provide more exact analytical values for mixtures of different chemical state.

4. Summary

FE-SAM with the new FE optical system was designed to get the minimum probe size and the largest beam current. The HSA is applied in Auger electron spectroscopy in order to decrease the input lens aberrations and improve the detection sensitivity. By this technique, the FE-SAM with HSA allows Auger chemical state analysis in a nanometer dimension. The applications of depth analysis show the capability of Auger chemical analysis in the depth direction as well as XPS. Moreover, by improving the reliability of HSA, the work functions are measured from the onset energy of the secondary electron spectrum and the measurement of barrier height of the p-n junction is possible.

References

Table 1: Chemical analysis by the curve fitting method for SiO₂, SiON₅ and Si interface.

<table>
<thead>
<tr>
<th>Peak No</th>
<th>Peak position(eV)</th>
<th>Peak Intensity (arbitrary)</th>
<th>Half width HWHM(eV)</th>
<th>S-KLL peak assignment</th>
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</thead>
<tbody>
<tr>
<td>The spectra of number 9 depth level.</td>
<td></td>
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<tr>
<td>1</td>
<td>1597.3</td>
<td>0.054</td>
<td>1.588</td>
<td>SiO₂</td>
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<tr>
<td>2</td>
<td>1600.2</td>
<td>0.017</td>
<td>1.179</td>
<td>SiON₅</td>
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<tr>
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<tr>
<td>4</td>
<td>1607.3</td>
<td>0.393</td>
<td>1.859</td>
<td>SiON₅</td>
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<tr>
<td>The spectra of number 23 depth level.</td>
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<td></td>
</tr>
<tr>
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<tr>
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<td>1.408</td>
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</tbody>
</table>

Fig.5. Si-KLL Auger spectra with 0.15%, 0.35% and 0.5% of energy resolution.

Fig.6. Depth analysis for SiO₂ and SiON₅ on the Si substrate.

Fig.7 (a). Chemical analysis for the spectra of number 9 depth level.

Fig.7 (b). Chemical analysis for the spectra of number 23 depth level.