The Systems of TOF-low Energy Ne Scattering Spectroscopy for Insulator

Kenji Umezawa
Department of Physics, Graduate School of Science,
College of Integrated Arts & Sciences, Osaka Prefecture University,
1-1 Gakuen-Cho, Naka-Ku, Sakai, Osaka 599-8531, Japan
(Received 10 January 2010; Accepted 15 February 2010; Published 1 May 2010)

We have developed a home-made low-energy Ne scattering system combined with a time-of-flight spectrometer for insulator surface structural analysis. Insulator surface structure is difficult to study because of charging effects during electron or ion beam bombardment. To avoid the charging effects, low energy atom particle beams (2 keV-20Ne+) were projected onto the sample surfaces. As an example of data measured by the developed system, a time of flight spectrum obtained from MgO (001) crystal is presented.

[DOI: 10.1380/ejssnt.2010.194]

Keywords: Ion scattering spectroscopy; Ne; MgO; Surface structure; Ion-solid interactions

I. INTRODUCTION

The physical properties of insulators are becoming more and more important. Also, surface structural analysis of insulators requires detailed knowledge of microscopic process for both fundamental and technological reasons. Generally speaking, measurements of insulator surfaces are difficult to study because of charging effects during electron or ion beam bombardment which are mostly employed in surface analysis methods. Sometimes, electron-shower failure causes sample damage, as well. For example, the surface structural analysis of CsCl were carried out [1].

An array of surface analysis techniques has provided a wealth of valuable surface information. Among these, low keV energy ion scattering has been established for determining the composition and structure of the surface layers of materials. Low energy ion scattering is a simple and extremely surface sensitive technique because of attributes of low keV energy [2-5]. Especially co-axial impact collision ion scattering spectroscopy using He+ ion beams has been popular [3, 4]. That is to say that low keV ions have short de Broglie wavelength (∼10−14 m), which constrain them to classical behavior, and large collision cross sections. In the energy region between 1 and 5 keV of Ne+ beams the Thomas-Fermi-Moliere (TFM) potential or Ziegler-Biersack-Littmark (ZBL) has been used for the analysis [6, 7].

In this study, low energy Ne+ ion scattering spectroscopy has been modified for analysis of insulator surfaces. This technique is quite useful for the analysis of semiconductor as well as metal surfaces. Low energy atom particle beams (2 keV-20Ne0) were projected onto the sample surfaces to avoid charging effects. Measurements were carried out by the time-of-flight technique.

II. EXPERIMENTAL SYSTEMS

Low energy Ne scattering spectrometer instrument developed for insulator surfaces. The spectrometer system is constructed from both custom made and commercially available components. Figure 1 shows the equipment of low energy Ne scattering spectroscopy system, as described below. It consists of an ultrahigh vacuum (UHV) chamber with the following components: (1) ion source (custom made), (2) MCP detector, (3) pulse generator (custom made), (4) pre-amplifier (custom made), (5) amplifier (custom made), (6) 4ch multiple-stop time-to-digital converter (custom made), (7) pulse generator (custom made), (8) low-energy electron diffraction (LEED) optics and electric power supplier (custom made), and (9) soft wares to collect data and control stepping motor. It has taken for around four years. These components will be described in detail. A 2 keV-Ne+ ion beam is typically produced by an ion source with an electron impact type and research grade Ne gas. The energy of ions ranges between 0.5 through 3 keV. An ion beam is collimated to a diameter of 1.5 mm by an aperture. The position of the collimated ion beam is adjusted by an electrostatic shifter to pass the right middle of a deflector. The chopping of the ion beam is carried out when ion beam passes the deflector to produce a pulse beam. The voltage applied to the chopping plates is 20 V with a pulse width less than 10 ns. The chopping frequency is typically 100 kHz. A pulse beam is neutralized in the a small charge exchange cell where Ne gas was introduced through a variable leak valve up to a pressure of 1 × 10−2 Pa. The shape of this cell is a cylinder; length 12 cm, an outside diameter 12 mm, an inside diameter 10 mm, thickness 1 mm. This cell has two center halls (aperture) with a diameter of 1 mm to collimate a pulsed beam. The conversion efficiency from Ne+ to Ne0 beam was about 34%. A neutralized beam pass through an MCP (micro channel plate) which has a center hole with a diameter of 5 mm. An aluminum pipe with a length of 4 cm, a inside diameter of 1.0 mm, and an outside diameter of 3.0 mm is located at a center of φ = 5 mm hall of an MCP. The front of the first MCP is at a negative potential of −15 V with reference to the ground. Because secondary electrons are emitted.

This paper was presented at 7th International Symposium on Atomic Level Characterizations for New Materials and Devices, The Westin Maui Resort & Spa, Hawaii, U.S.A., 6-11 December, 2009.

Corresponding author: uemezawa@las.osakafu-u.ac.jp
FIG. 1: Experimental equipment of low energy Ne scattering spectoscoy.

FIG. 2: Back scattered spectrum obtained from MgO(001) sample. Incidental particles were 2 keV-Ne.

from an aluminum pipe when primary $^{20}\text{Ne}^{0}$ beam passes through it, and hit its edge. An aluminum pipe is connected to ground level. These secondary electrons are detected by an MCP, unless a negative potential applies to the front of the first MCP. An MCP detector (assembly outer diameter = 34 mm, effective diameter = 20 mm) is coaxially mounted along the primary drift tube. The residual $^{20}\text{Ne}^{+}$ ions were removed by the deflector at the entrance of UHV chamber. Thus, $^{20}\text{Ne}^{0}$ particles impinge on a sample and the scattered particles are detected by an MCP which is located at 180°. A UHV chamber is kept a base pressure of $\sim 10^{-8}$ Pa. A differential pumping system is carried out between a UHV chamber and the ion source. A distance between a sample and an MCP is about 43 cm. The time of flight measurements are carried out using a trigger circuit and a time-to-digital converter (TDC) which has four independent channels. Each channels independently measures the time between a trigger and stop signals at a time resolution of 10 ns. A PC has installed two I/O boards (16 bit each). One is for control a manipulator to rotate a sample at an adequate azimuth and polar angles using two stepping motors. Another is for control a pulse generator and a TDC to carry out measurements. Data acquisition mode (polar scan and azimuth scan) has been automated, and collected in 2° steps. For measurements, an acquisition time of 40 s is typically employed at each step.

Figure 2 shows the typical time of flight spectra obtained from one of insulator samples of MgO (001) crystal. The energy and momentum conservation conditions entirely determine the kinematical relationships for an elastic collision between incidental atom and sample atom. Equation (1) below shows the energies of projectile ($E_p$) after the scattering event as a function of $\theta_p$ [8]. The incident kinetic energy is represented by $E_{\text{inc}}$.

$$E_p = E_{\text{inc}} \times \gamma^2 \left( \cos \theta_p \pm \sqrt{\gamma^2 - \sin^2 \theta_p} \right)^2, \quad (1)$$

where $\gamma = M_p/M_T$ is the ratio of the masses of the projectile $M_p$ ($^{20}\text{Ne}$) and target $M_T$. The projectile mass is smaller than the target mass ($\gamma < 1$), the plus sign is take in Eq. (1), and the range over which $\theta_p$ can vary is 0 to $\pi$. In this experimental system, the scattering angle $\theta_p$ was fixed at $\pi$. The flight time depends on the $E_p$ based on $M_T$. Thus, component atoms on material surfaces can be distinguished. In Fig. 2 strong peaks at 16.2 $\mu$s shows Mg signals. The signal coming from oxygen is hard to see, because $M_T$ is lower than $M_p$. However, the presence of the oxygen atoms is quite evident for the azimuth and polar scans depending on the crystal axis with $^{20}\text{Ne}$ particles. The scattering intensity of Mg signals depends on
azimuth and polar angles based on the crystal geometry.

III. CONCLUSIONS

We have developed a home-made low-energy Ne scattering system combined with a time-of-flight spectrometer for insulator surface structural analysis. Insulator surface structure is difficult to study because of charging effects during electron or ion beam bombardment. To avoid the charging effects, low energy atom particle beams (2keV-20\textsuperscript{Ne}\textsuperscript{0}) were projected onto the sample surfaces. As an example of data measured by the developed system, a time of flight spectrum obtained from MgO (001) crystal is presented.

Acknowledgments

This research has been supported by JST (Japan Science and Technology Agency) and Grant-in-Aid for Scientific Research (Kakenhi). Also, this was financially supported by the Mitsubishi Foundation and the Murata Science Foundation. The author appreciates these financial supports.

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