Angle-Dependent Analysis of a Silicon Wafer with a Native Oxide

Introduction

Angle-dependent X-ray Photoelectron Spectroscopy (XPS) is a method for non-destructively probing thin (<100Å) surface layers and extracting chemical state information. The effective analysis depth in an angle-dependent experiment is defined by the equation: $d = 3\lambda\sin\theta$ where d is the effective analysis depth, λ is the mean free path of the escaping photoelectron and θ is the angle between the analyzer input lens axis and the surface of the sample.

The angular resolution of an angle-dependent experiment is determined primarily by the topography of the sample and the acceptance angle of the analyzer input lens. The Quantum 2000 Scanning ESCA Microprobe™ input lens operates in two modes. In the "normal" high sensitivity mode, the acceptance angle is ±20°. In the high angular resolution mode, the acceptance angle is reduced to ±4° by placing a slot-shaped aperture in front of the input lens. Useful angle-dependent information can be obtained with either mode. The Quantum 2000 provides eucentric tilt at the analysis point, which simplifies the automation of angle-dependent experiments by keeping the analysis area at the focal point of the X-ray source and analyzer at all takeoff angles.

Angle-Dependent XPS Profiling

To acquire an angle-dependent profile, spectra for the elements of interest were collected from a silicon wafer at 10°, 15°, 20°, 30°, 60° and 90° with a ±4° acceptance angle. The plot of atomic concentration versus sin(θ) in Figure 2 shows that

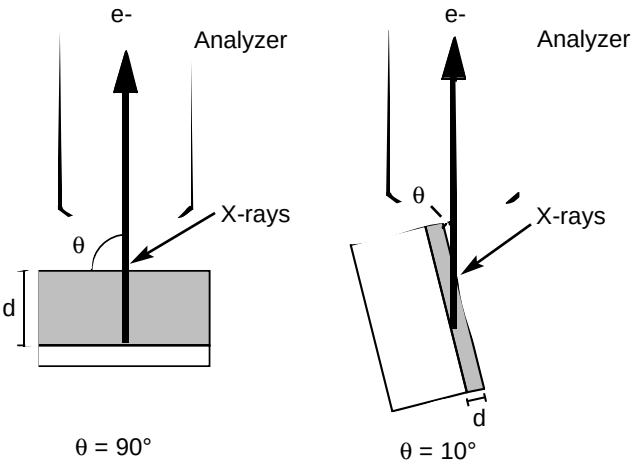

Figure 1. Schematic diagram showing the effect of θ on analysis depth.

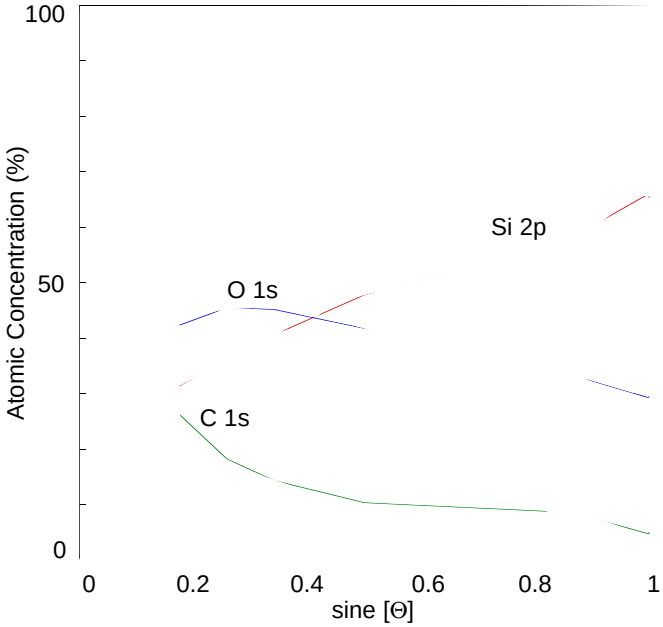

Figure 2. Angle-dependent profile from a Si wafer with a native oxide.

there is a thin oxide on the surface of the silicon wafer and a thin carbon contamination covering the thin oxide layer.

Chemical State Information

The chemistry at the surface of a silicon wafer is of great interest to the microelectronics industry. The high resolution spectra from the angle-dependent profile in Figure 3 indicate significant chemical changes are taking place as a function of sampling depth. The spectrum taken at 90° consists primarily of metallic Si with a low intensity oxide peak. In contrast, the spectrum taken at 10° shows a dominant Si oxide peak with a smaller metallic Si peak. To more accurately determine the number of chemical states present and to quantify the chemical information, curve fitting was performed. PHI MultiPak™ software can simplify this task by automatically performing curve fits on a group of spectra. Figure 4 shows the curve fit from the Si 2p spectrum that was collected at 15°. In addition to the SiO_2 and elemental species of Si, a sub-oxide species Si_2O_3 is observed.[1] PHI MultiPak allows the analyst to merge the curve fit results into the angle-dependent profile display to generate a chemical state angle-dependent profile, as shown in Figure 5.

Summary

The PHI Quantum 2000 was able to efficiently collect and facilitate the interpretation of the angle-dependent XPS depth profile by providing:

- A narrow acceptance angle (±4°)
- Eucentric tilt about the analysis point
- Spectral fitting tools including: curve-fitting, Linear Least Squares (LLS) fitting, and Target Factor Analysis (TFA) to increase the chemical interpretation of angle-dependent XPS profiles.

1. John F. Moulder and John S. Hammond, *Research and Development*, February 1985.

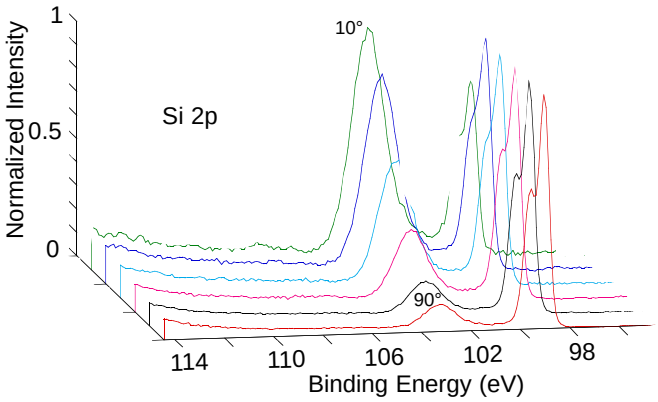

Figure 3. Si 2p spectra from angle-dependent profile, displayed in a montage plot from 90° to 10°.

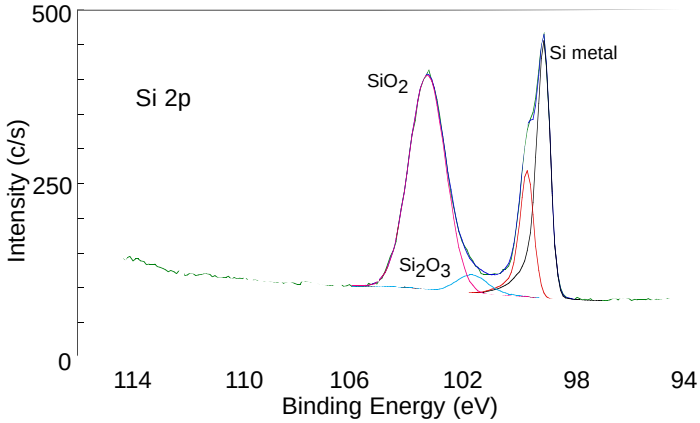

Figure 4. Curve fit of Si 2p spectrum at 15°.

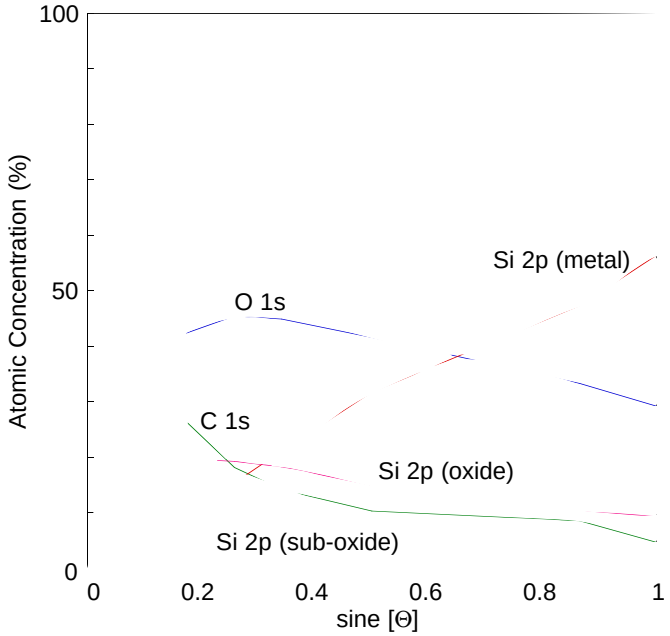

Figure 5. Chemical state angle-dependent profile obtained using PHI MultiPak.