AES Depth Profiling
of a P Doped Si Nanowire

Overview: The rapidly growing interest in novel nanostructure based applications requires the optimization of new fabrication processes as well as nanometer scale analytical techniques to quantify compositional information from these new structures. For example, doped silicon nanowire (SiNW) based FET devices are being evaluated as promising candidates for replacing traditional MOSFETs, creating the requirement to understanding their unique electronic properties. In this study, the elemental depth compositions of individual P doped SiNWs were analyzed with a PHI *700Xi* Scanning Auger Nanoprobe using low voltage Ar ion sputter depth profiling. The resulting quantitative elemental information provides a unique understanding of the outermost composition of the P distribution with a surface sensitivity and depth resolution that is not available with other imaging techniques such as TEM/EELS or Atom Probe Tomography.

Experimental: The phosphorus doped SiNWs were grown by the Vapor Liquid Solid (VLS) technique in a hot-wall CVD chamber. 20 nm gold nanoparticles dispersed on a cleaned silicon substrate were the catalysts for the growth of the SiNWs. The SiNWs were grown with high-purity silane (SiH_4) and phosphine at a ratio of 1/2000 in a H_2 carrier gas at 350° C. The resulting phosphorus doped SiNWs, about 30 µm in length, were then removed from the silicon substrate and placed on a highly ordered pyrolytic graphite (HOPG) substrate for Auger analysis. The selected SiNWs had a diameter of approximately 60 nm. The HOPG substrate was selected to minimize backscattered electron beam induced Auger electrons.

The Auger data was acquired with a PHI *700Xi* Scanning Auger Nanoprobe equipped with a 25 kV Schottky field emission electron gun and a coaxial Cylindrical Mirror Analyzer (CMA). All secondary electron images, Auger spectra and Auger depth profiles were acquired with a 20 kV electron beam that provided a 5 nA incident beam current and a probe diameter of 9.5 nm. Image registration, using an interleaved acquisition of secondary electron images and Auger spectra, maintained the registration of the incident beam to the selected area of analysis on the SiNW to ± 5 nm. Auger spectra were acquired at 0.5% ΔE/E energy resolution with quantification performed using standard PHI Auger sensitivity factors for a 20 kV electron beam. Depth profiling of the phosphorous doped SiNWs was performed using an alternating Auger data acquisition with 500 eV Argon ion sputtering. The sputter rate and reported sputter depths were calibrated using a standard SiO_2 thin film.

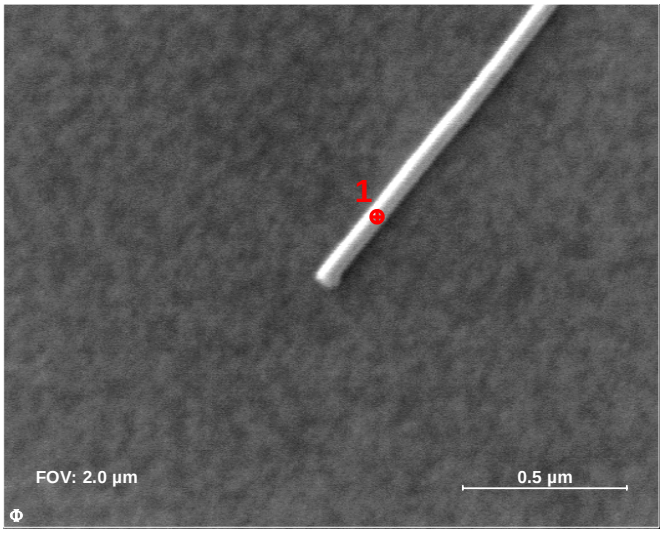

Figure 1. SE image of a 60 nm diameter Si nanowire

Results: Figure 1 shows the Secondary Electron Image (SEI) of a SiNW on the HOPG substrate at a 2 µm Field of View (FOV). The gold catalyst can be observed on the end of the SiNW. The selected point for the Auger elemental survey spectrum shown in Figure 2 is labeled as point 1. The Auger spectrum shows the presence of the phosphorous dopant on the outer surface of the SiNW.

Figure 3 shows an overlay of several Auger spectra for P: from the HOPG substrate, from the near surface of the SiNW, and from below the surface of the SiNW, to illustrate the ultimate detection limit of 0.1% P. A depth profile from one of several points along the longitudinal axis of the SiNW is shown in Figure 4. The rate of decrease in the P as a function of sputter depth was similar for all points along the length of the SiNW. The initial P concentration was highest at the end of the SiNW away from the Au catalyst and decreases for depth profiling points approaching the Au catalyst end of the SiNW.

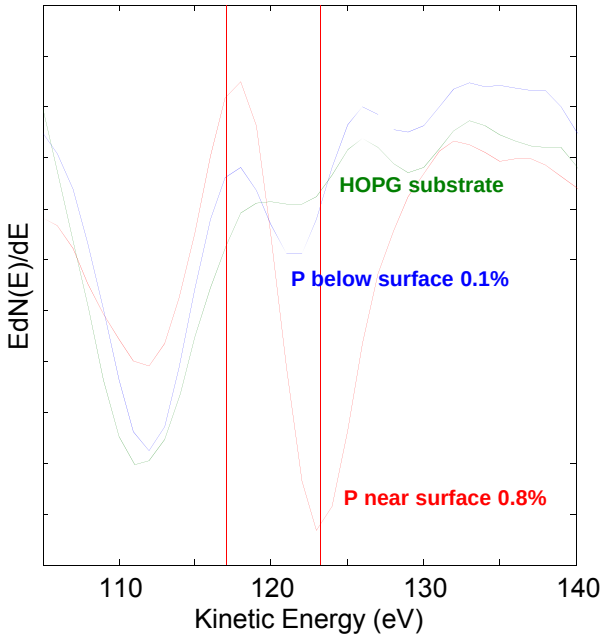

Figure 3. P Auger spectra from near-surface of SiNW (red), from adjacent HOPG substrate (green), and the ultimate detection limit of 0.1% P below the surface of the SiNW (blue).

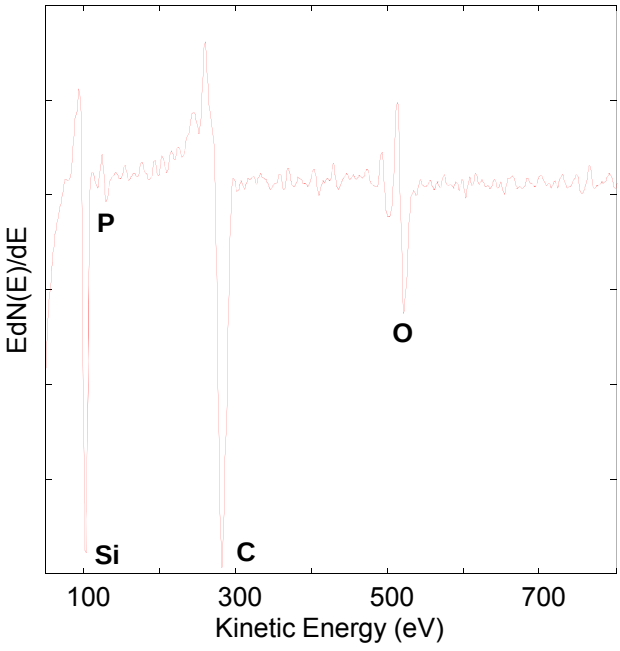

Figure 2. Auger spectrum showing the presence of a P dopant on the surface of the silicon nanowire.

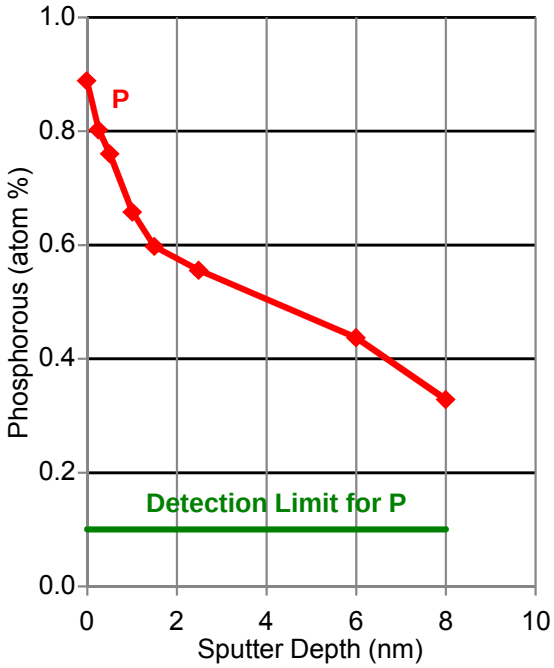

Figure 4. Auger sputter depth profile of P on the surface of the SiNW.

Conclusion: The PHI *700Xi* Scanning Auger Nanoprobe provides a valuable tool for the quantitative elemental characterization of new nanomaterials such as SiNWs. The PHI *700Xi* provides important capabilities needed to characterize these materials: nanometer surface sensitivity, 8 nm Auger spatial resolution, high sensitivity from samples with flat or curved surfaces, high sensitivity for all elements (except H and He), and a high stability sample platform and image registration software that provides the ability to perform a detailed set of measurements from a nanoscale sample feature. Special sample preparations such as applying coatings or preparing a FIB cross-section are not required.

The results of the analysis discussed in this application note and additional research now being published supports the conclusion that the SiNWs produced using the discussed growth process is based on a Vapor/ Liquid/ Solid growth mechanism. The doping of phosphorous in the surface of the SiNW is based on a Vapor/ Solid growth mechanism. The quantitative P depth profiles provide complimentary information to electrical measurements, making it possible to identify sample compositions that provide desired electrical properties.

Acknowledgement

Dr. Uri Given, Northwestern University, Illinois, for providing the SiNWs.

Physical Electronics USA, 18725 Lake Drive East, Chanhassen, MN 55317
Telephone: 952-828-6200, Website: www.phi.com

ULVAC-PHI, 370 Enzo, Chigasaki City, Kanagawa 253-8522, Japan
Telephone 81-467-85-4220, Website: www.ulvac-phi.co.jp